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Climate Perceptions and Adaptation Practices of Traditional Marine Fishermen in Coastal Bengal, India: Toward Participatory Policy Recommendations

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Traditional marine fishing communities in the global south heavily rely on fisheries for survival, facing threats from climate change and associated coastal challenges. Effective adaptation hinges on understanding fishermen's perceptions of these changes. The present study investigates fishermen's perceptions of fish catches and adaptation practices to climate change, proposing a

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participatory adaptation strategy to guide policy in Bengal's coastal region. For strategy development, two field surveys collected climate perception data from households, focus group discussions and community engagement meetings on fishing activities and adaptation measures. Further, the CRU, PSMSL, and IMD data assessed scientific climate evidence. The study employed a mixed-method approach encompassing general descriptive statistical techniques and Garrett ranking techniques to determine climate perceptions. Furthermore, climatic trend analysis was conducted using the Mann-Kendall (MK) test and Sen's slope estimator, while a modified catch variation empirical model was utilized to evaluate variations in fish catches and their socio-environmental perceptions among fishermen. Additionally, a participatory approach was employed to develop an adaptation strategy for the study area. The analysis of climate perception and evidence data revealed that climate variability and change are the primary drivers behind disruptions in traditional fish catches and adaptive practices. Notably, nearly 45.63% of respondents had not embraced any adaptation measures, primarily due to limited knowledge and education. Furthermore, this study integrates community engagement perspectives to identify opportunities and potential for a participatory adaptation strategy. This approach, which emphasizes spatial considerations and active community involvement, assists policymakers in safeguarding the living conditions and livelihoods of fishing communities.

Keywords: Participatory adaptation strategy; climate perceptions; marine lives and global south; traditional marine fishermen: policy initiative.

ABBREVIATIONS

CRU : Climatic Research Unit
PSMSL : Permanent Service for Mean Sea Level
IMD : India Meteorological Department
TMF : Traditional Marine Fishermen

1. INTRODUCTION

Traditional marine fishermen (TMF) play a crucial role in marine socio-ecological systems by bolstering food security, alleviating poverty, fostering employment, and promoting socio-environmental conservation [1,2], thereby contributing to the attainment of sustainable development goals [3]. Marine fishing is a primary source of income for millions of people in several developing nations [4]. TMF communities face increasing uncertainty and vulnerability as a result of overfishing and climate change impacts [5]. The growing concern about climate change, sea-level rise, erosion, cyclones, pollution, overfishing, and unsustainable fishing techniques in coastal areas has contributed to the overexploitation of marine resources. This tendency exacerbates stresses on coastal socio-ecological systems, threatening fishing communities' everyday lives and livelihoods [6-8].

In recent years, the rising variations of climate concern have had a variety of effects on fisheries, including ecological, socioeconomic, and oceanographic. Some socio-ecological effects include loss of marine biodiversity, income uncertainty, and loss of livelihoods [9-11]. At the same time, the effects of oceanic variability include sea-level rise, sea-surface temperature, salinity, changes in fishing grounds, and higher risks of severe winds and huge waves [12]. Climate and oceanographic variability, in particular, have a significant impact on marine biota, ecosystems, and fish alteration [13,14]. Moreover, alterations in precipitation, storms, cyclones, and drought patterns impact species movement in coastal regions [15], thereby affecting fishing productivity and leading to socioeconomic consequences for fishermen in terms of income and livelihood practices. Consequently, addressing climate change necessitates comprehensive and forward-looking efforts, including the development of mitigation and adaptation strategies [8].

Traditional marine fishermen (*Jalia Kaibarta*) in India's Bengal coastal region have reported enduring everyday challenges and pressures due to climate change. Very specifically, most of the researchers studied Bengal coastal area's climate change/variability conditions [16,17], and highlights the various climate-induce challenges like cyclone hazards, floods [18], loss of livelihoods [19], ecological stress [20], coastal vulnerability [21], socio-economic vulnerability [17, 22-23], ecological vulnerability [24], various potential threats [25], social, economic, and environmental change [26], local sea level change [27], morphological coastal vulnerability [28], coastal erosion [29], shoreline change [30], coastal land-use dynamics [31], tourism and coastal ecology [32], loss of fishing ecosystem and their particular species [33], lack of technologies used for fisheries [34, 35], fish diversity [36], poor socio-economic conditions of fishing community [37], challenges faced by fisherwomen [38], decline of traditional fishing species [39], marine fisheries and management of fisheries [40, 41], lack of fundamental fishing amenities [42], other anthropological challenges to climate change [30]. In this regard, the present study looked further into the literature to assess ways and strategies for mitigating climate change and sustaining coastal socio-ecological systems in the TMF. Shaana et al. [43] investigated climate variability and its effects in the Sundarban Biosphere, making policy recommendations for early warning systems, disaster management training, and management strategies for coastal flood and salinity intrusion. Ghosh and Mistri [18] provide appropriate cyclone management measures and address the need for coping mechanisms in the studied area. Dutta et al. [33] recommends taking remedial actions to manage sustainability in West Bengal's marine fishery sector. Therefore, the presence of significant gaps in the management of climate challenges and sustainable fishing in coastal Bengal has been observed, indicating a lack of appropriate strategies.

The present study introduces a participatory adaptation strategy in the fishing community to address climate concerns and promote sustainable fishing. Multiple studies have proposed participatory approaches to address the effects of climate change and incorporate the perspectives of local stakeholders in the process of policy development [44,45]. Participatory adaptation strategies attempt to tackle the immediate issues of climate change and promote sustainable fishing practices [46]. Prior to implementing the participatory adaptation method, it is essential to comprehend certain critical factors in order to evaluate the spatial connectedness of the area. The spatial comprehension of climate perceptions, existing adaptation techniques, and the related issues faced by fishermen are of utmost importance for management efforts [47-49]. This understanding facilitates the development of strategies for when and how stakeholders will be involved and fulfill their roles in policy development and execution. It also helps identify the specific actions required to address the difficulties at hand. This study aims to analyze the climatic perceptions of fish catches and adaptation techniques of traditional marine fishermen in coastal Bengal, with a focus on the aforementioned concern. The present study's findings are intended to offer participatory adaptation strategy suggestions for developing sustainable policy implications. This will contribute to fisheries management efforts and sustainable livelihood development in the study area and other similar regions worldwide.

2. LOCATION OF THE STUDY AREA

The coastal region of Bengal (also known as the West Bengal coast) was the primary focus of our study. West Bengal is the sole Indian state that extends from the Himalayas to the Indian Ocean. A population of 7 million individuals resides in the coastal region of West Bengal, which boasts a coastline spanning 220 kilometers [25, 30]. The present study focuses primarily on the TMF linked to the Bengal seacoast. Three coastal districts, namely Medinipur East, 24 Parganas South, and 24 Parganas North, comprise the study area (Fig. 1), which consists of 25 coastal community development blocks (C.D. Blocks). It is located in the Gangetic Plain and has close proximity to the Bay of Bengal (Indian Ocean). The research region, consisting of Medinipur and 24 Parganas coastal areas, is home to 574 marine fishing villages [50].

The coastal area of Medinipur lies to the southwest of the Hooghly estuary, spanning from the northeast of the Hooghly estuary to the southwest border of Digha, which is affiliated with the eight coastal C.D. blocks, namely Sutahata, Haldia, Nandigram-1, Khejuri-2, Deshopran, Contai-1, Ramnagar-2, and Ramnagar-1 C.D. blocks. Approximately 191 marine fishing villages are located in this region [50]. The Medinipur coast is characterized by coastal sand dunes, elevated soil salinity, limited river discharges, low turbidity, and sparse vegetative cover influenced by shore currents, all of which contribute to a rich ecological diversity. The majority of the population in this coastal area consists of fishing communities engaged in traditional marine fisheries [51,52]. The Hooghly estuary situates South 24 Parganas and North 24 Parganas districts to the east and southeast, respectively, with the international border of Bangladesh marking the easternmost boundary. While the coastal features of the Bay of Bengal dominate South 24 Parganas, the southern part of North 24 Parganas is characterized by the river bay features of the Sundarbans. The Indian Sundarbans (covering 4200 sq. km of the total Sundarbans) are located in South 24 Parganas district and are renowned for their dense mangroves, intricate network of tidal rivers, abundant flora and fauna, and human settlements, making them globally acclaimed and listed as a World Heritage Site [53] and Ramsar Site [54]. It also acts as a natural shield for the millions residing in the district's southern region. The study focused on C.D. Blocks Gosaba, Basanti, Canning-1, Kultali, Jaynagar-2, Mathurapur-2, Patharpratima, Namkhana, Sagar, Kakdwip, Kulpi, Diamond Harbour-1, and Diamond Harbour-2, as well as Sandeshkhali-1, Sandeshkhali-2, Hingalganja, and Hasnabad from the North 24 Parganas. According to the Marine Fisheries Census [50], South 24 Parganas has approximately 296 marine fishing villages, while North 24 Parganas has around 87. Both coastal fishing communities are vulnerable to climate change and have to deal with a range of socio-ecological issues, including their traditional way of life and livelihoods [5, 21].

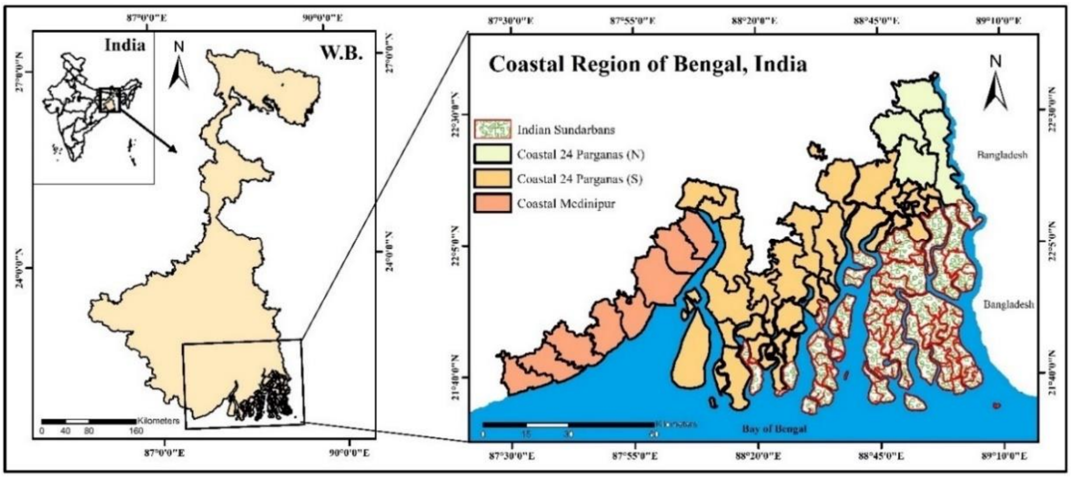


Fig. 1. The geographical location of the study area

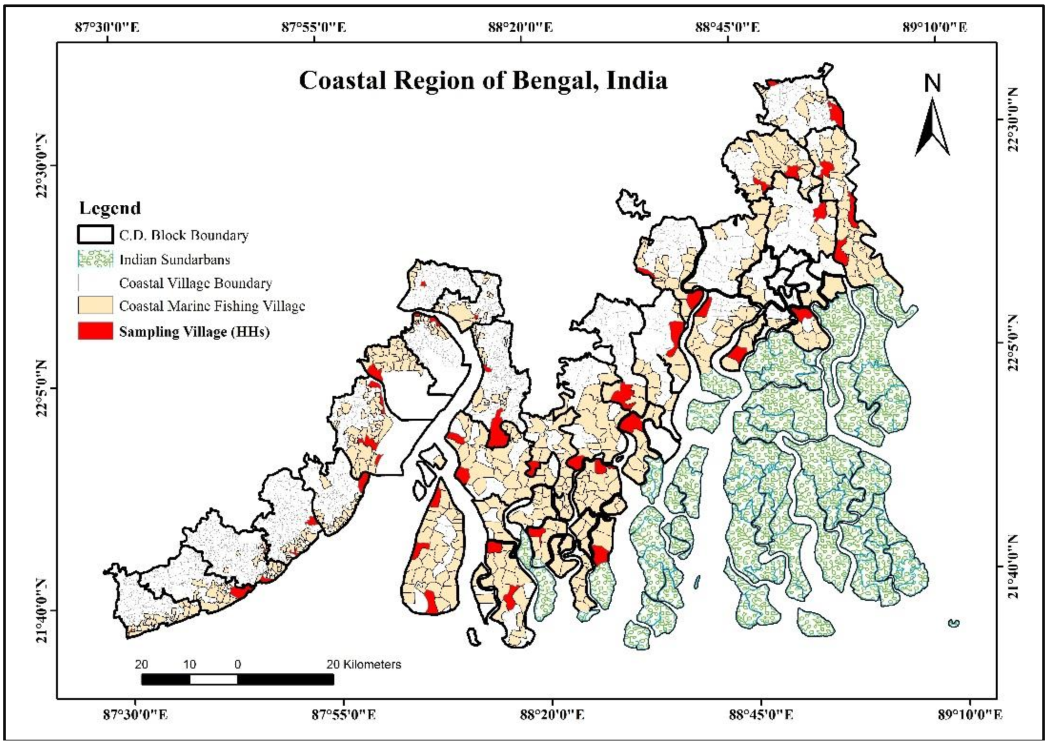


Fig. 2. Selected Households Village in the Study Area of Coastal Bengal

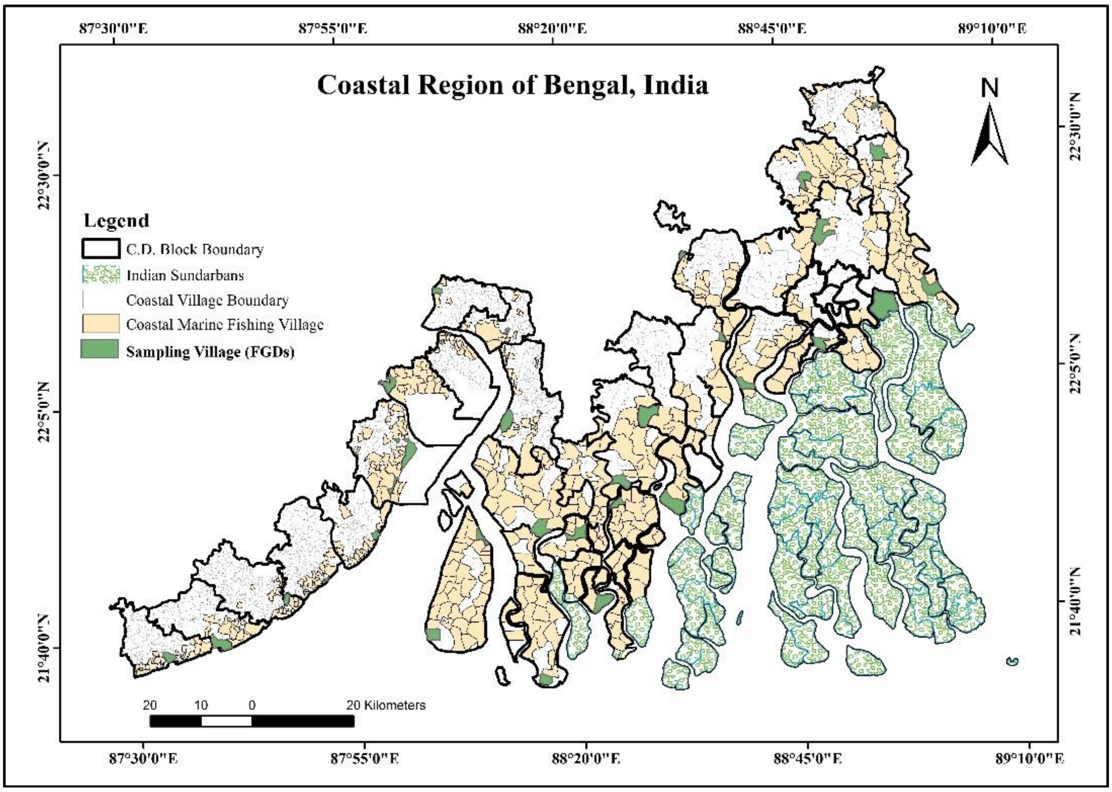


Fig. 3. Selected FGDs Village in the Study Area of Coastal Bengal

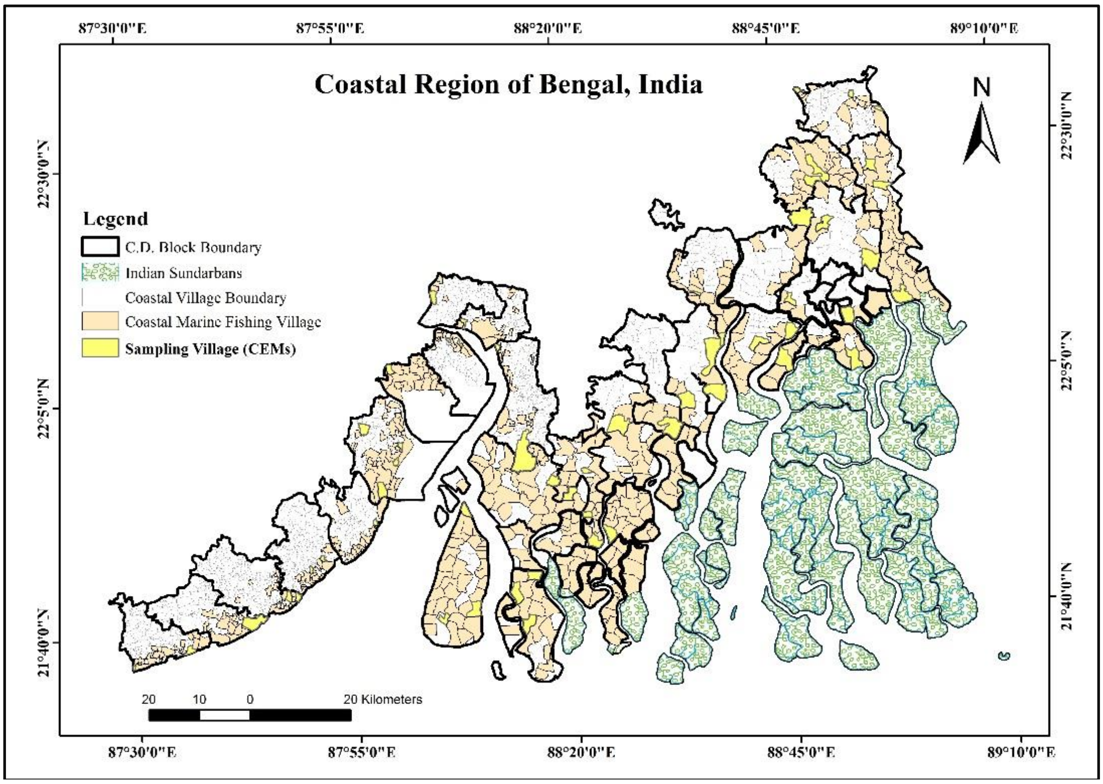


Fig. 4. Selected CEMs Village in the Study Area of Coastal Bengal

3. SURVEY DESIGN AND DATA COLLECTION

This study conducted two field surveys between March and May 2022 and March and April 2023. The first survey involved collecting climate perceptions through climate communication and field narratives, focusing on changing climate conditions, oceanographic data, fish catches, existing adaptation practices, and related challenges. Following the analysis of the first field survey's initial results, the study conducted a second field survey to incorporate the community's perspectives in the development of adaptation strategies. This second survey was based on discussions with community members about the primary findings and accounted for the study's spatial requirements. Both field surveys were carried out using a randomized sample methodology. The first survey involved face-to-face household interviews (N = 480) and focus group discussions (FGDs) (N = 33). The second survey included a larger number of community meetings and workshops (CEMs) (N = 55) to integrate community perspectives into policy recommendations. Figs. 2, 3, and 4 illustrate the selection of households visited, FGDs, and CEMs, respectively. Further, to assess scientific evidence of climate change, the study collected temperature and rainfall data from the Climatic Research Unit[1] for the period 1901–2022, sea-level data from the Permanent Service for Mean Sea Level[2] (Survey of India), and cyclone data from the Cyclone eAtlas [3] of the Indian Meteorological Department.

4. METHODOLOGY

The present research used a mixed method approach that included general descriptive statistical techniques, Garrett ranking techniques [55], the Mann-Kendall (MK) test, Sen's slope estimator [56, 57], a linear regression model, and a modified catch variation empirical model [58, 59]. In particular, general descriptive statistical approaches were utilized for examining the socio-demographic snapshot of fishermen, fishermen's perceptions on the causes of climate change, and the identification of changing climate and oceanographic elements. Furthermore, significant factors and evidences of climate change in the study area were identified using Garrett ranking techniques. This study also used the MK test, Sen's slope estimator, and a linear regression model to look at the trend and variability of climate parameters over the last 122 years, focusing on average temperature and rainfall. It then looked at data on sea level rise and the strength and frequency of cyclones in the study area to find out what effects climate change is having. The study then applied a modified catch variation empirical model to determine the variation in fish captures in the study area. Additionally, the existing adaptation procedures were investigated using descriptive statistical approaches and theme analysis. Finally, the current study used a participatory approach to develop policy recommendations for sustainable adaptation measures in the TMF. Appendix 1 provides a detailed explanation of the methodologies, equations, and model description.

5. RESULTS AND DISCUSSION

5.1 Climate Perceptions of Traditional Marine Fishermen

5.1.1 Socio-demographic snapshot

Table 1 presents a profile of the respondents. In all, 88.54% of the participants identified as fishermen, while 11.46% identified as fisherwomen. This survey encompassed a wide range of age groups. Specifically, 45.42% of the participants were between the ages of 45 and 65, 34.79% were between 35 and 45, 12.08% were between 25 and 35, and 7.71% were between 20 and 25, representing the younger generation. The largest proportion of the population, 40.21%, received education up to class IV. A significant portion, 32.92%, did not receive any formal education. However, a small percentage of the population pursued higher studies, with 12.50% reaching class XII and 2.50% attaining an undergraduate degree or higher. The data also showed that traditional fishing was the primary activity for 96.25% of the respondents. Additionally, 54.58% of them pursued alternative sources of income, such as agriculture, laborious work, and other activities, due to inadequate earnings from their fishing occupation. In addition, a significant majority of 90.42% confirmed their full-time engagement in fishing activities. Out of the observed population, 35.36% had more than 20 years of experience in the fish collection sector. Additionally, 25.42% had 15-20 years of experience, 17.92% had 10-

[1] *Climatic data (temperature and rainfall): Climatic Research Unit (https://crudata.uea.ac.uk/cru/data/hrg*

[2] *Sea-level data: PSMSL (https://psmsl.org/data)*

[3] *Cyclone data: Cyclone eAtlas of Indian Metrological Department (http://14.139.191.203)*

Table 1. Socio-demographic snapshot: Age distribution, education levels, and fishing practices of surveyed participants (TMFC)

Variables	Frequency	Of %	Variables	Frequency	Of %
Sex category			**Primary Occupation**		
Male	425	88.54	Fishing	462	96.25
Female	55	11.46	Non-fishing	18	3.75
Age Distribution (in years)			**Fishing Status**		
20-25	37	7.71	Full-time	434	90.42
25-35	58	12.08	Part-time	46	9.58
35-45	167	34.79	**Fishing experience (in years)**		
45-65	218	45.42	Below 5	34	7.08
Education Levels			05-10	67	13.96
No education	158	32.92	10-15	86	17.92
Class IV	193	40.21	15-20	122	25.42
Class X	57	11.88	Above 20	171	35.63
Class XII	60	12.50	**Alternative source of income**		
UG and above	12	2.50	Yes	262	54.58
Assess climate change or forecast information			No	218	45.42
Yes	271	56.46			
No	209	43.54			

Data source: TMFC perception of field survey (N: 480), 2022 (by the author)

15 years of experience, 13.96% had 5-10 years of experience, and 7.08% had less than 5 years of experience. Approximately 56.46% of respondents indicated that they considered climate change or forecasting information when evaluating their economic status and livelihoods.

5.1.2 Fishermen's perspectives on the causes of climate change

As the fishermen were surveyed on the causes of climatic parameters, 8.07% of the population stated that climate change is a natural process. However, a majority (71.55%) of respondents argued that anthropogenic activities are the primary factor responsible for climate change. In addition, 13.73% of the population acknowledged that both factors are responsible for climate change in the coastal area, whereas 6.65% were unaware of the real cause of climate change (Table ST 1). Moreover, the distribution of opinions by age group was recorded in Fig. 5. Interestingly, the present study aligns with the findings of N'Souvi et al. [60], which focused on small-scale fishermen in Togo, Africa, and Benansio et al. [61], who investigated similar issues in the Sudd Wetlands of South Sudan. Both studies underscored the crucial role that anthropogenic activities play in driving climate change.

5.1.3 Fishermen's perspectives on key parameters and evidence of climate change: A Garrett ranking approach

The Garrett ranking technique offers a systematic approach to identifying and prioritizing important parameters and evidence of climate change. For the present study, this technique entails gathering fishermen's opinions and performing a quantitative evaluation of the importance of several climate change signs. Within this context, this technique is especially valuable for determining the most crucial climatic parameters and evidence in the field by establishing a hierarchical ranking. Fishermen, invited to rank various climate parameters and evidence related to changing rainfall, changes in wind speed, increased air temperature, more frequent cyclones, rising sea levels, elevated sea surface temperature, and increased sea surface salinity, initiate the ranking process. These rankings were based on the perceived impact and reliability of each parameter.

This analysis conducted a statistical assessment of the scores obtained in different ranks (see Appendix 1) and then presents the average score of these particular parameters in Table 2. The most effective parameter and evidence, the air temperature (Garrett mean score: 70.17), ranked first. The frequency of cyclones (66.88) ranked second, followed by rainfall (62.95), sea-level rise (43.73), sea surface temperature (40.27), wing speed (31.98), and sea surface salinity (31.02) (Fig. 6). Thus, the fishermen's perception of ranking opinions has influenced their daily lives and livelihoods, as well as their ability to catch fish. Empirically, Geetha et al. [55] employed the Garrett ranking approach to identify the most significant climate and oceanographic parameters impacting the southeastern region of India. In this regard, the research further examines the following fish catch variation in the study area using a modified catch variation empirical model [60].

5.1.4 Fishermen's perspectives on the changing climate and oceanographic factors

The survey respondents, who are fishermen, have personal ideas and knowledge about climate change's causes and consequences. Following this, the fishermen shared their perspectives on climate and oceanographic elements, which aid in understanding the practical aspects of these concerns (Table ST 2). Approximately 92.87% of the respondents acknowledged that the air temperature in the coastal region of Bengal has risen over the past decade. Similarly, 83.76% voiced their belief in the changing pattern of rainfall conditions. Furthermore, 98.30% discussed the increase in tropical cyclone frequency, while 83.09% observed changes in wind speed during this time period. Regarding the oceanographic conditions within the study area, 90.31% of the fishing population reported that the sea level had increased during the past decade. The majority of respondents (91.48%) expressed concerns over the rise in sea surface temperature, while 89.39% reported concerns about the increase in sea surface salinity. In addition, the investigation organized this data according to different age groups to obtain detailed opinions on the perception of climate and oceanographic conditions in the study area over the past 10 years, based on assumptions made by local fishermen (Fig. 7). Thus, it has been determined that each of the chosen characteristics effectively emphasized the variations in climatic circumstances and oceanographic elements.

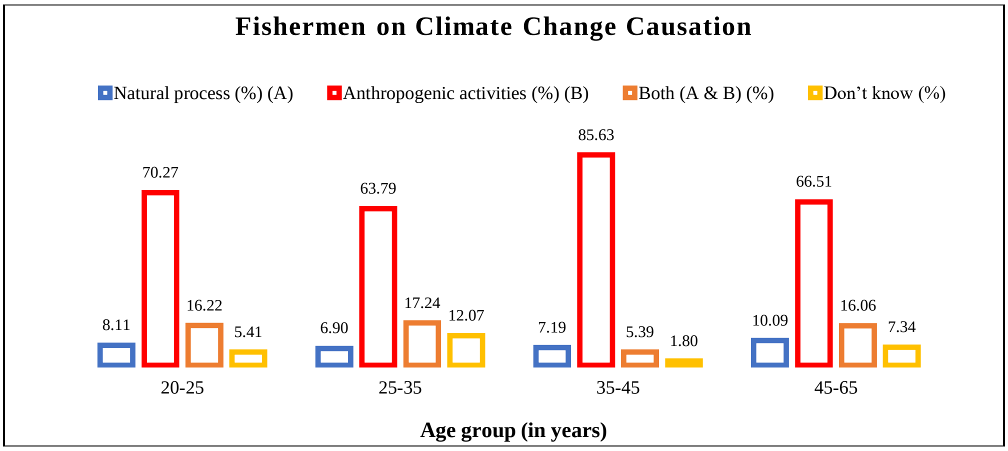


Fig. 5. Perceptions of respondents regarding the cause of climate change in the Bengal coastal region

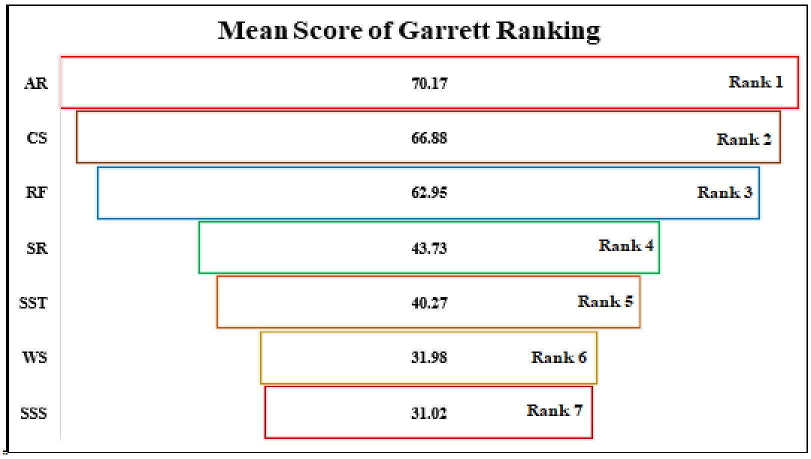


Fig. 6. Plotted the Garrett ranking scores for key parameters and evidence of climate change as identified by fishermen

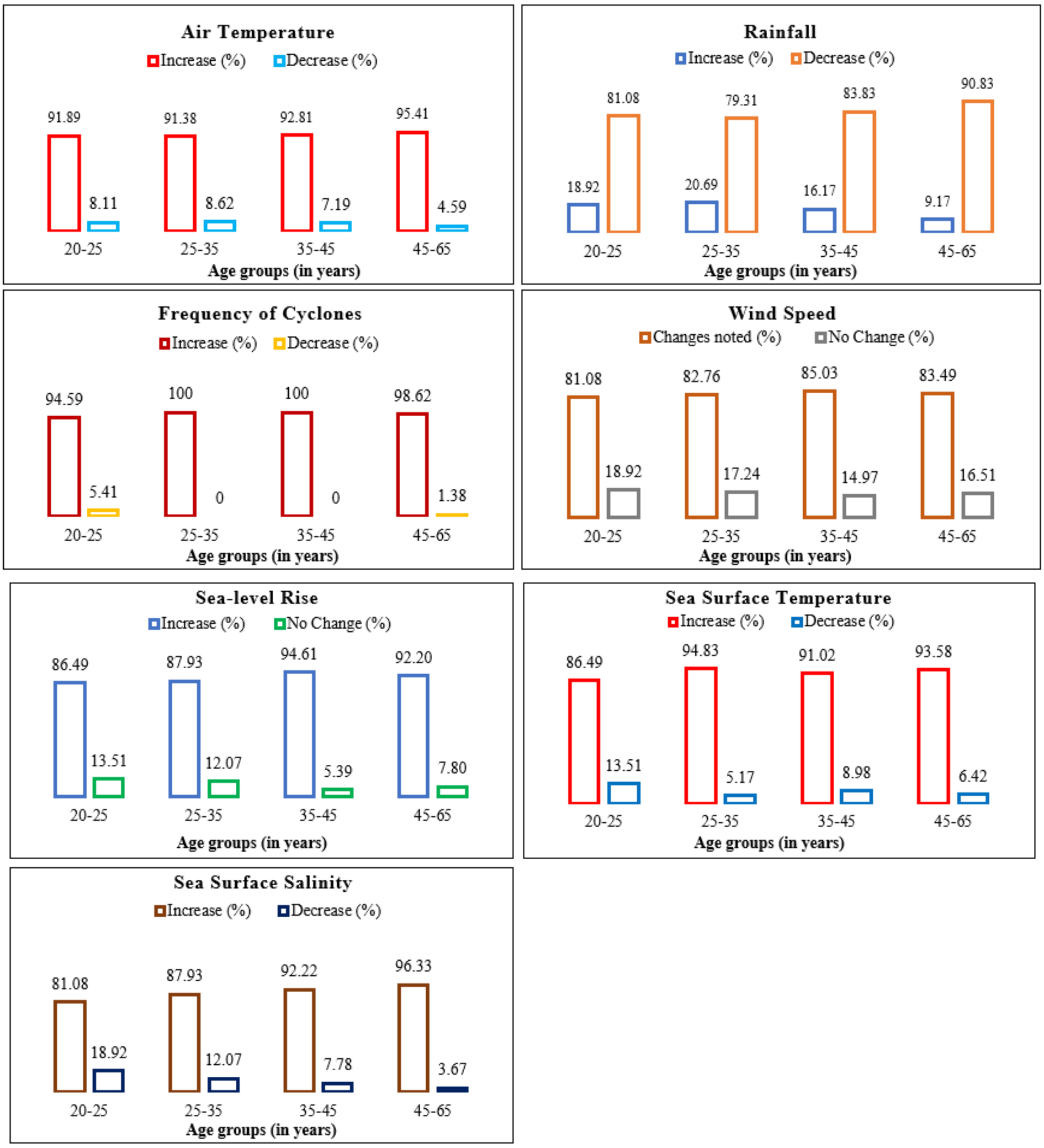
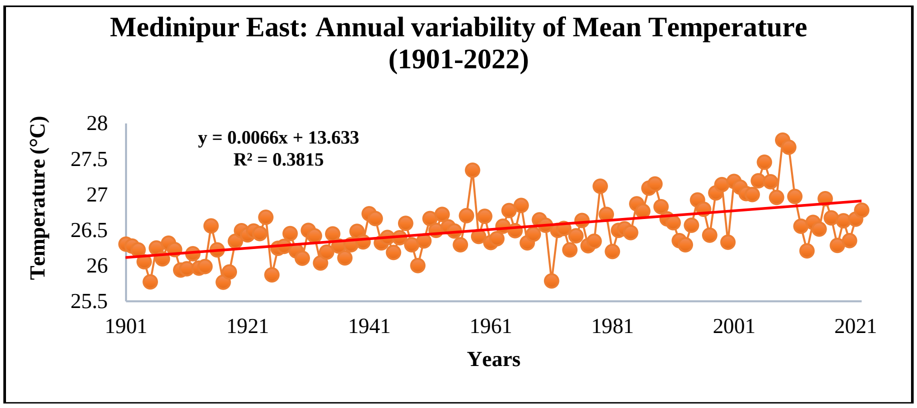
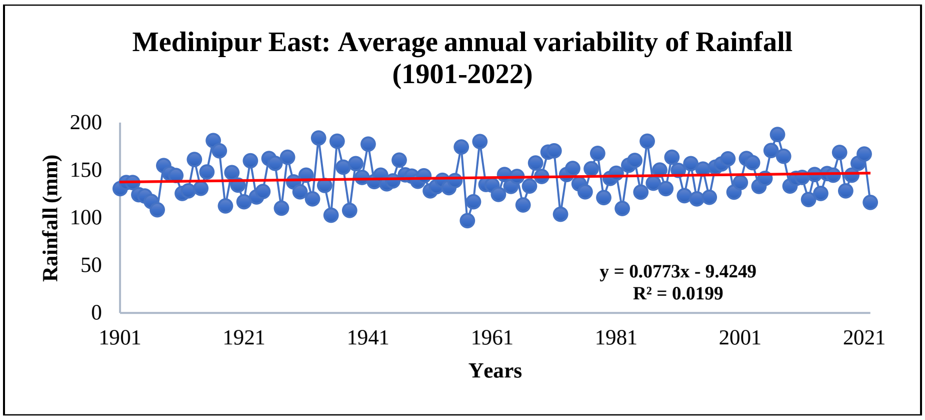
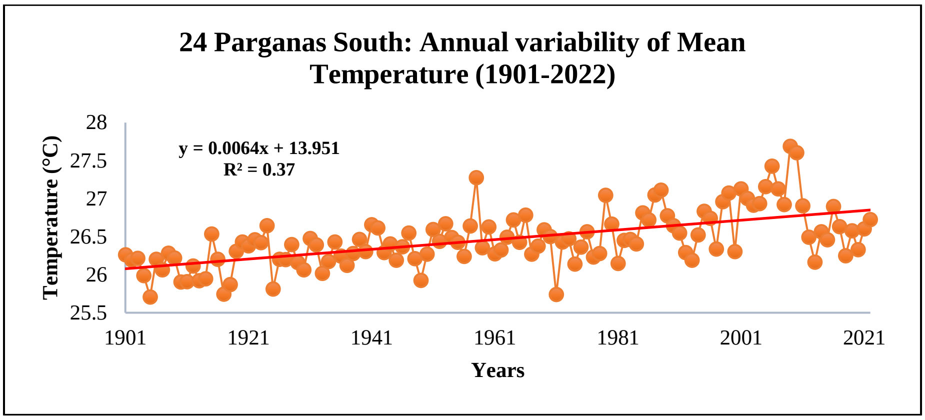
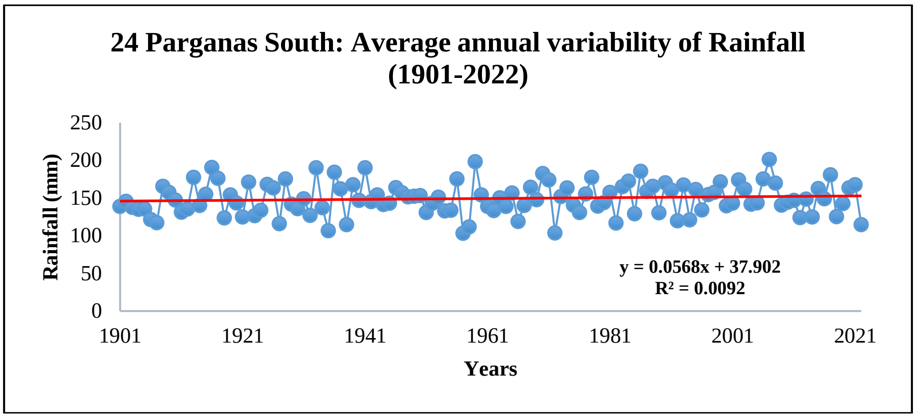


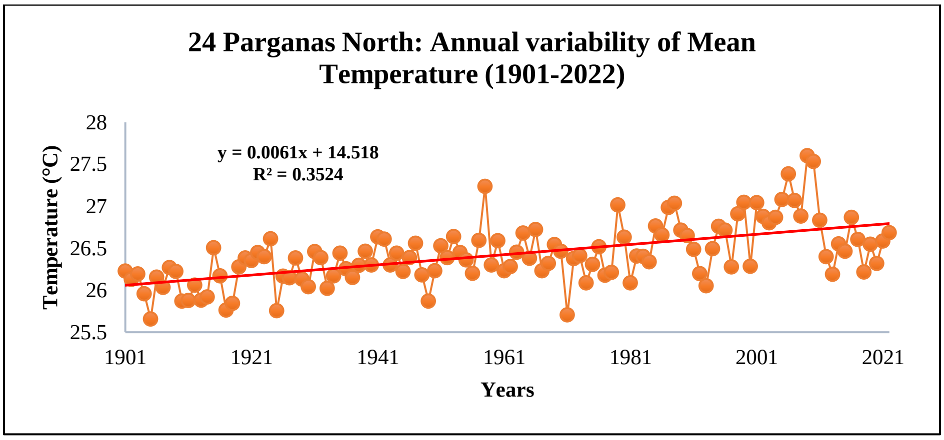
Fig. 7. Fishermen's (TMFC) perspectives on the changing climate and oceanographic factors




Medinipur East: Average annual variability of Rainfall (1901-2022)
Rainfall (mm)
200
150
100
50
0
1901
1921
1941
1961
1981
2001
2021
Years
y = 0.0773x - 9.4249
R² = 0.0199


24 Parganas South: Annual variability of Mean Temperature (1901-2022)
Temperature (°C)
28
27.5
27
26.5
26
25.5
1901
1921
1941
1961
1981
2001
2021
Years
y = 0.0064x + 13.951
R² = 0.37


24 Parganas South: Average annual variability of Rainfall (1901-2022)
Rainfall (mm)
250
200
150
100
50
0
1901
1921
1941
1961
1981
2001
2021
Years
y = 0.0568x + 37.902
R² = 0.0092


24 Parganas North: Annual variability of Mean Temperature (1901-2022)
Temperature (°C)
28
27.5
27
26.5
26
25.5
1901
1921
1941
1961
1981
2001
2021
Years
y = 0.0061x + 14.518
R² = 0.3524

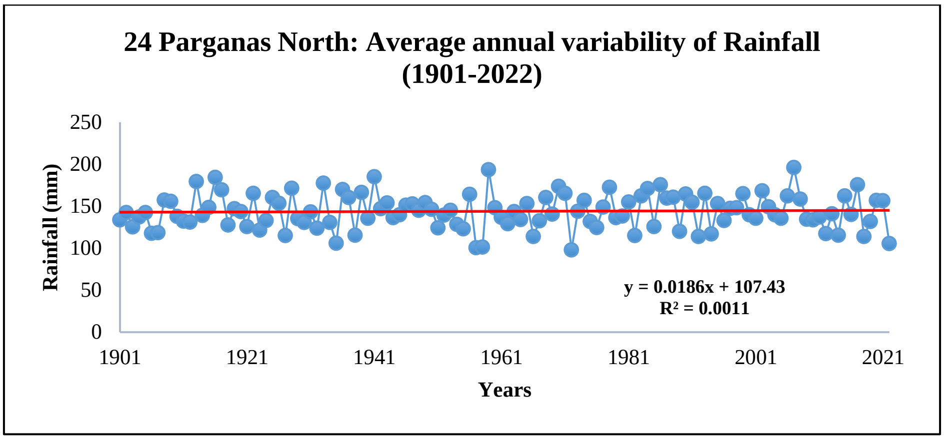


Fig. 8. Average annual variability of climatic parameters (Temperature and Rainfall) (1901-2022) in Medinipur East, 24 Parganas South and North, respectively

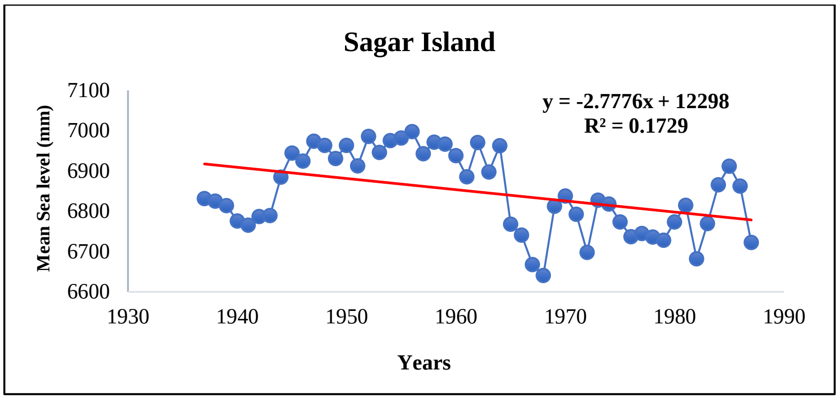
5.1.5 Scientific evidence of climate change

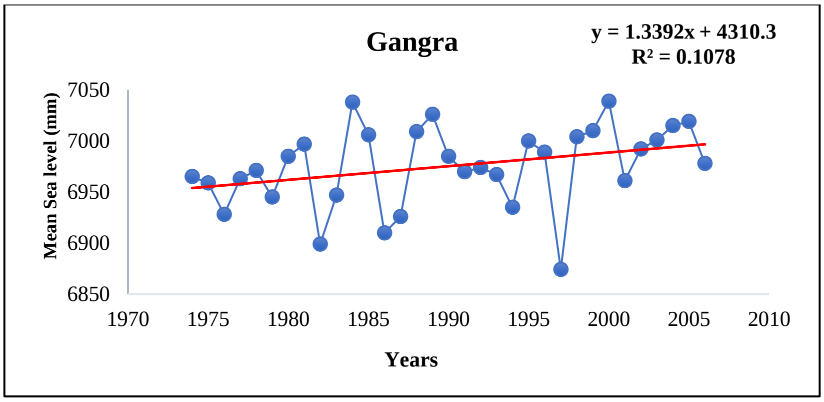
The scientific data on climate parameters, such as the yearly average temperature and rainfall, indicate a different trend in every coastal region within the study area. Table 3 provides a detailed statistical measurement of the Mann-Kendall and Sen slopes. Kendall's tau (0.451), S statistic (3331), and p-values (<0.0001), along with a slope of 0.00627 in coastal Medinipur, all showed that the average temperature rose from 1901 to 2022. In the yearly study, the significant Kendall's tau (0.441), S statistic (3257), p-values (<0.0001), and slope (0.00611) in coastal 24 Parganas South show that the average temperature is still going up. Apart from that, Kendall's tau (0.428), S statistic (3160), and p-values (<0.0001), along with a slope of 0.00576, support a significant rising trend in mean temperature in coastal 24 Parganas North from 1901 to 2022. Also, Kendall's tau (0.101, 0.078, and 0.031), S statistic (743, 573, and 231), p-values (0.1006, 0.2056, and 0.6108), and Sen's slope (0.089, 0.076, and 0.027) showed that there was no significant change in the amount of rain that fell each year on the coasts of Medinipur East, 24 Parganas South, and 24 Parganas North from 1901 to 2022.

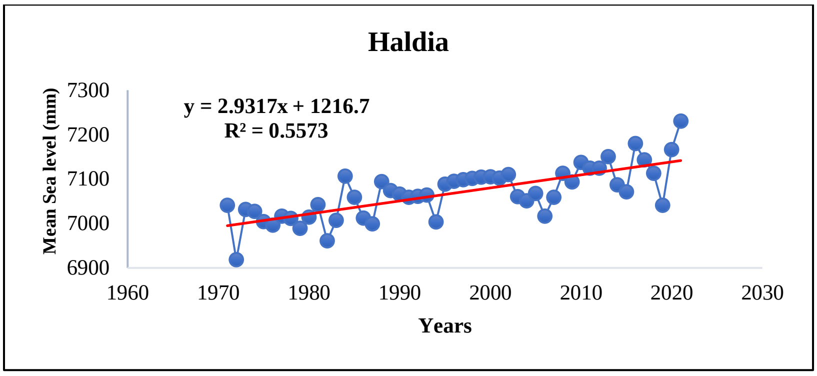
Further, the analysis of regression reveals significant changes in the study area (Fig. 8), and the present study also looked into the rate at which climate parameters in the study area changed throughout the same period. While rainfall in Coastal Medinipur has increased by 0.0773 mm per year, the annual average temperature has been rising at a rate of 0.0066 °C per year. In 24 Parganas South, too, the temperature has been rising at a rate of 0.0064 °C per year, and the amount of rainfall has similarly been rising at a rate of 0.0568 mm per year. Rainfall has been rising at a somewhat slower rate of 0.0186 mm per year, while the rate of temperature rise is a bit less at 0.0061 °C per year in 24 Parganas North. Therefore, the data indicates a persistent warming trend and rising rainfall in all three areas, with Coastal Medinipur experiencing the most noticeable changes and 24 Parganas North experiencing the least.

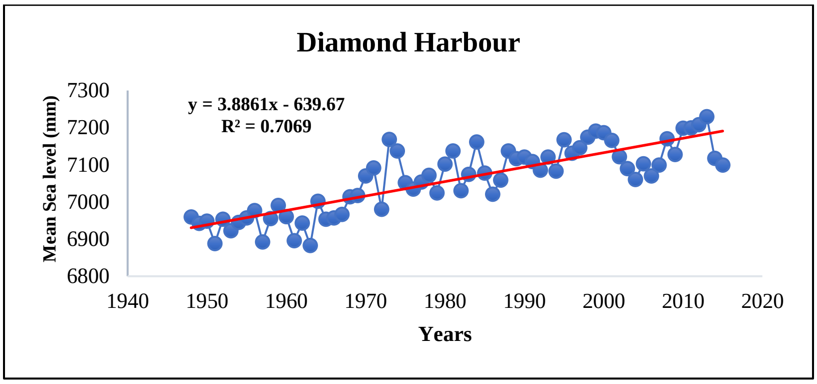
Sea level rise is another critical piece of evidence from the study area that must be considered. This significant consequence of climate change poses an immediate threat to coastal socio-ecological systems. The average height of the surrounding land, as well as the variations caused by waves and tides, affect the mean sea level. The study region's rate of sea level change was assessed using PSMSL data from coastal stations in Garden Reach, Diamond Harbour, Haldia, Gangra, and Sagar (Fig. 9).

The present study observed significant variability in sea level rise across all monitoring locations. The sea level change rates were determined to be ±6.1223 mm per year at Garden Reach, ±3.8861 mm per year at Diamond Harbour, ±2.9317 mm per year at Haldia, ±1.3392 mm per year at Gangra, and -2.7776 mm per year at Sagar Island. All stations, except for Sagar Island, experienced a rise in sea level. The stations at Garden Reach and Diamond Harbour experienced a particularly large rise in mean sea level. Furthermore, the decrease in sea level at Sagar Island can be attributed to the substantial accumulation of sediments by the Hooghly River.


Sagar Island
y = -2.7776x + 12298
R² = 0.1729
Mean Sea level (mm)
7100
7000
6900
6800
6700
6600
1930
1940
1950
1960
1970
1980
1990
Years


Gangra
y = 1.3392x + 4310.3
R² = 0.1078
Mean Sea level (mm)
7050
7000
6950
6900
6850
1970
1975
1980
1985
1990
1995
2000
2005
2010
Years


Haldia
y = 2.9317x + 1216.7
R² = 0.5573
Mean Sea level (mm)
7300
7200
7100
7000
6900
1960
1970
1980
1990
2000
2010
2020
2030
Years


Diamond Harbour
y = 3.8861x - 639.67
R² = 0.7069
Mean Sea level (mm)
7300
7200
7100
7000
6900
6800
1940
1950
1960
1970
1980
1990
2000
2010
2020
Years

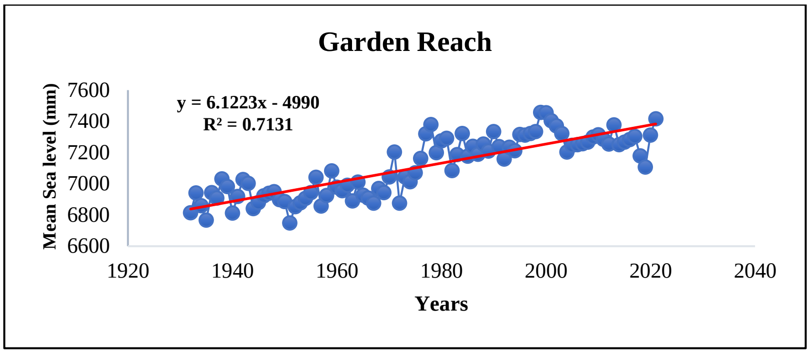


Fig. 9. Changes in Sea Level at Sagar, Gangra, Haldia, Diamond Harbour, and Garden Reach

In addition, the present study expanded on the existing data by examining cyclonic activities in the targeted study region. The coastal region of Bengal, situated in close proximity to the Bay of Bengal, experiences the effects of a variety of tropical cyclone magnitudes. Tropical cyclones can be categorized into two groups: cyclonic storms (CS), characterized by wind speeds between 60 and 90 km/h, and severe cyclonic storms (SCS), characterized by wind speeds between 90 and 120 km/h. The data (1891–2023) obtained from the IMD (Cyclone eAtlas) indicates that June to November experienced a high frequency of depression, cyclonic storms, and severe cyclonic storms in the Bay of Bengal, with more than 100 occurrences. Additionally, the months of May, July, September, October, November, and December recorded more than 40 instances of cyclonic storms and severe cyclonic storms. Furthermore, the months of May, October, November, and December exhibited a particularly high frequency of severe cyclonic storms, with more than 25 occurrences (Fig. 10). Climate change's increased frequency of cyclones in the Bay of Bengal has a significant impact on coastal socio-ecological systems. The cyclonic landfall sites in the study region include Ramnagar I, Ramnagar II, Sagar, Namkhana, Patharpratima, Kultali, Basanti, and Gosaba coastal blocks in coastal Medinipur and 24 Parganas South. Over the past 120 years (1891–2010), the region of 24 Parganas South experienced a 26% rise in tropical cyclones. According to a report by Sahana [43], the highest recorded surge height in the Sundarban coastline area over these 120-year period was 15.6 meters. In general, the growing occurrence of tropical cyclones has a detrimental effect on the socio-ecological systems in the coastal region of Bengal.

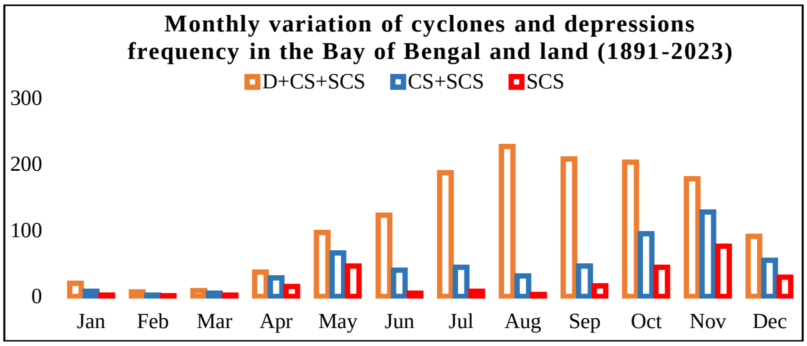


Fig. 10. Monthly variation of frequency of cyclones and depressions in the Bay of Bengal and land (1891-2023)

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
CTV	.202	25	.010	.907	25	.026

a. Lilliefors Significance Correction

Fig. 11. Outcome of the normality test for the CTV distribution

5.2 Modified Empirical Model for Fish Catch Variation

The study employed an empirical model to analyze variations in fish catch and examine the impact of climate change factors, including air temperature, rainfall, cyclone data, sea-level rise, and sea surface temperature. A multiple linear regression model was applied for this purpose. The analysis indicated that only two coefficients were statistically significant. The study specifically identified the independent variables of rainfall and cyclone data as significant predictors of the dependent variable, catch variation. In contrast, the variables air temperature, sea level rise, and sea surface temperature did not exhibit statistical significance in predicting the dependent variable, with p-values exceeding 0.05. The overall model demonstrates robust explanatory power, as evidenced by a high R-square value of 0.96326 and a statistically significant intercept. Table 4 and Table ST 3 detail the results of the descriptive and regression statistics, respectively. A comprehensive explanation of these findings will follow.

Intercept: The intercept term computes the value of the dependent variable when all independent variables are zero. The value of 4.489 and the p-value of 9.4853E-08 indicate a statistically significant result. The intercept's confidence intervals (CI) estimate its true value between 3.358 and 5.619 with 95% confidence and 2.943 and 6.034 with 99% confidence.

Variables: The rainfall coefficient was 0.174 with a p-value of 0.0081, showing statistical significance. A one-unit increase in rainfall raises catch variation by 0.174 units. The information about cyclone impact was likewise statistically significant, with a coefficient of -1.290 and an extremely low p-value (1.60716E-05). An increase in cyclone effects reduces catch variation by 1.290 units. Thus, decreased rainfall physiologically affected fishing habits, and increasing cyclones caused a regular interruption in fish catching in the study region, which may have caused this catch variation.

Regression Statistics: Multiple R: This is the relationship of dependent variable values as seen and predicted. It is about 0.981 in this analysis, suggesting a noteworthy positive linear connection between the dependent variable and the independent components.

R Square: The model's independent factors explain 96.33% of the dependent variable's variance. This shows that the model fits the data well and captures a lot of the dependent variable's variability.

Adjusted R Square: Adjusted R-square (0.95360) accounts for model predictors, estimating explained variance more conservatively. It is slightly lower than the R-square, suggesting the model may overstate the explained variance.

Standard Error: The standard error of 0.781 shows the mean difference between observed and anticipated dependent variable values. As the measure indicates model correctness, smaller numbers indicate a better match.

The reliability of the regression analysis was confirmed by post-estimation diagnostic tests. Figs 11 and 12 show that the normality test verified the CTV followed a normal distribution. Fig. 13 further confirmed the Durbin-Watson statistic, demonstrating a strong correspondence between the data and the employed linear model. Thus, it has been established that the climatic conditions, specifically the rising occurrence of cyclones and changing rainfall, predominantly influenced the fluctuations in fish harvest in the studied region. Similarly, the studies by Mbaye et al. [62], Mulyasari et al. [63], Chen et al. [64], and Harley et al. [65] identified patterns of rainfall, cyclonic activity, associated storm winds, and other spatial factors. Researchers found that these factors significantly impact fish catch activities and the availability of fish species on traditional fishing grounds.

5.3 Adaptation Practices by the Respondent

The present study also endeavoured to explore the capacity of fishermen to address the challenges posed by climate change and assess its potential ramifications. The results of this investigation suggest that fishermen demonstrate awareness of climate change and undertake adaptive measures in their practices, as evidenced by the data outlined in Table 5. The most common strategy, adopted by 77.68% of fishermen, is pursuing alternative occupations, indicating a significant shift away from traditional fishing activities, possibly due to declining fish stocks or adverse weather conditions. Changing fishing grounds is the second most common strategy, adopted by 35.20% of fishermen, suggesting a proactive approach to finding more sustainable or profitable fishing areas.

Membership in fishing cooperatives is also popular, with 44.26% of fishermen joining such groups to benefit from shared resources, collective bargaining, and better market access. 12.09% of fishermen use weather forecast information to plan their fishing activities, emphasizing their efforts to minimize risks and optimize their fishing efforts according to weather conditions. 10.33% of fishermen adopt seasonal fishing, which involves adjusting fishing activities based on seasonal variations, potentially targeting different species or avoiding adverse weather conditions. Lastly, 8.11% of fishermen have taken out life insurance policies, reflecting a focus on financial security and risk management for their families.

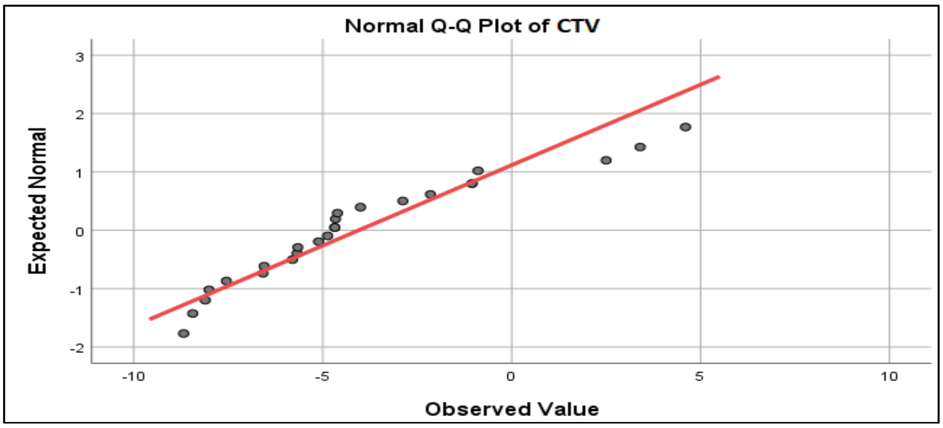


Fig. 12. Normal Q-Q plot of CTV distribution.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.981[a]	.963	.954	.78106	2.328

a. Predictors: (Constant), AR, SST, SR, FR, CS

b. Dependent Variable: CTV

Fig. 13. Result of the Durbin-Watson test (If 1.5< Durbin-Watson < 2.5, then autocorrelation (independence) not violated)

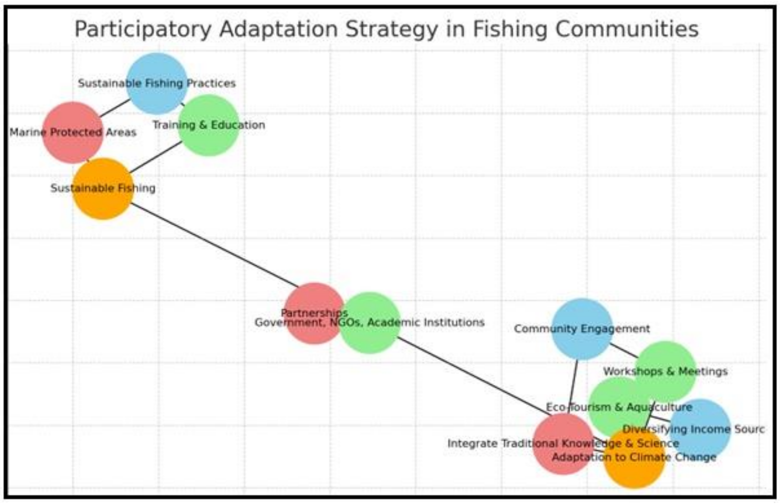


Fig. 14. Participatory approaches in implementing adaptation strategies by the fishing community.

Table 2. Fishermen's (TMFC) perspectives on key parameters and evidences of climate change in the coastal region of Bengal

Parameters	AR	RF	CS	WS	SR	SST	SSS
Garrett Mean Score	70.17	62.95	66.88	31.98	43.73	40.27	31.02
Garrett Rank	1	3	2	6	4	5	7

Note: AR: Air Temperature (increase); RF: Rainfall; CS: Frequency of Cyclones (increase); WS: Wind Speed (change); SR: Sea-LEVEL rise (increase); SST: Sea Surface Temperature (increase); and SSS: Sea Surface SALINITY (increase); Data source: TMFC perception of Field Survey (N: 480), 2022 (by the author)

Table 3. Statistical Measurement of the Mann-Kendall and Sen slopes

Annual Average: 1901-2022	Coastal Medinipur		24 Parganas South		24 Parganas North	
	Temperature	Rainfall	Temperature	Rainfall	Temperature	Rainfall
Maximum	27.764	187.701	27.691	201.24	27.604	196.229
Minimum	25.768	97.082	25.709	103.367	25.656	98.102
Mean	26.513	142.244	26.464	149.333	26.427	143.99
Standard Deviation	0.376	19.359	0.371	20.964	0.362	20.299
Kendall's tau	0.451	0.101	0.441	0.078	0.428	0.031
S statistic	3331	743	3257	573	3160	231
p-value (Two-tailed)	**<0.0001**	0.1006	**<0.0001**	0.2056	**<0.0001**	0.6108
Sen's slope	0.00627	0.089651	0.00611	0.07691	0.00576	0.02765

Data source: Climatic Research Unit (1901-2022)

Table 4. Descriptive statistics for both the independent and dependent variables

	CTV	AR	SST	SR	RF	CS
Max	4.60	5.90	4.80	6.80	4.80	5.61
Min	-8.68	1.00	0.56	0.40	-5.70	0.21
Mean	-3.64	3.80	3.22	3.73	-1.87	3.84
SD	4.12	1.36	1.27	2.12	3.28	1.92

Note: CTV: Catch Variation; AR: Air Temperature; RF: Rainfall; CS: Information about cyclones; SR: Sea-Level rise; SST: Sea Surface Temperature
Data source: TMFC perception of field survey (N: 480), 2022 (by the author)

Table 5. Adopted adaptation strategy by the Fishermen

Sr. No.	Adopted adaptation strategy	Adopted (%)
1	Alternative occupation	77.68
2	Fishing ground change	35.20
3	Weather forecast information and fishing	12.09
4	Seasonal fishing	10.33
5	Fishing cooperative membership	44.26
6	Life insurance policy	8.11

Source: TMF perception of field survey, 2022 (by the author).

Table 6. Level of education and adaptation strategies

Education	Coping Adaptation Strategies		
	Adopted (%)	Not Adopted (%)	Total
No education (32.92%)	22.14	77.86	100
Class IV (40.21%)	37.29	62.71	100
Class X (11.88%)	51.74	48.26	100
Class XII (12.50%)	61.88	38.12	100
UG and above (2.50%)	98.79	1.21	100
Total	**54.37**	**45.63**	**100**

Source: TMF perception of field survey, 2022 (by the author)

Furthermore, this study explores the relationship between fishermen's educational attainment and their adoption of coping adaptation strategies. The study conducts field investigations, as illustrated in Table 6. The data reveals that only 22.14% of fishermen with no education (32.92% of the total surveyed) have adopted adaptation strategies, while 77.86% have not. In contrast, fishermen with education up to Class IV (40.21% of the total) show a higher adoption rate of 37.29%, although a majority (62.71%) still have not adopted these strategies. Among those with Class X education (11.88% of the total), 51.74% have adopted adaptation measures, indicating a more balanced distribution between adopters and non-adopters. Fishermen with Class XII education (12.50% of the total) display a significant increase in adoption, with 61.88% implementing adaptation strategies. Fishermen with undergraduate education or higher (2.50% of the total) exhibit the most striking contrast, with 98.79% adopting adaptation strategies and only 1.21% not. Overall, 54.37% of the total fishermen surveyed have adopted coping adaptation strategies, while 45.63% have not. This data underscores a clear trend: higher education levels correlate with a greater likelihood of adopting adaptation measures. It stresses how important education is for making fishing communities more resilient and able to adapt. It suggests that educational interventions could greatly increase the use of effective adaptation strategies to deal with environmental and economic problems [60, 66-67].

The present study gathered opinions on adaptation in response to the growing impact of climate concerns on traditional fishing practices, livelihoods, and future adaptation strategies and capabilities through a comprehensive discussion at a 'Community Engagement Meeting' in the study area. It also examined their strategies and abilities to adapt to these changes in the future [68, 69]. Boxes 1–3 subsequently identified three discrete subjective local strategies.

BOX 1: Strategy 1: Restoring nature-based adaptation governance

We must use sustainable methods to protect the ecosystem and build resilience to restore fishing community governance for nature-based adaptation. To combat coastal erosion, habitat loss, and climate change, this technique blends traditional and modern methods. Restoring mangrove forests, promoting sustainable fishing, and diversifying revenue streams to reduce marine resource strain are the key goals. Effective governance requires all parties to work together to create comprehensive and flexible policies. This participatory technique helps the community preserve their livelihoods and natural heritage for future generations by managing resources, protecting biodiversity, and ensuring sustainability.

Source: Community Engagement Meeting (March to April 2023)

BOX 2: Strategy 2: Integrating science and technology into community members

Integrating science and technology into community life fosters innovation, improves quality of life, and addresses local issues. This can be done with instructional programs, interactive seminars, and technical tools. Scientific information and technical skills help community members engage in modern breakthroughs, make evidence-based decisions, and boost economic prospects. Digital literacy programs help residents use internet education, healthcare, and entrepreneurship opportunities. Technology-based community projects like environmental monitoring and smart agriculture promote sustainability.

Source: Community Engagement Meeting (March to April 2023)

BOX 3: Strategy 3: Educating and raising awareness about climate-coastal risks and participatory management

To build resilience, fishing communities must learn about climate-coastal hazards and participatory management. This requires expansive climate change education and fishermen's participation in decision-making. By understanding these risks and actively managing them, communities can ensure sustainable practices by taking adaptive actions. This technique builds resilience and helps communities address environmental issues.

Source: Community Engagement Meeting (March to April 2023)

6. PARTICIPATORY POLICY IMPLICATIONS

The study region has identified climate variability and change as the primary factors responsible for disrupting conventional fish catches and the adaptive techniques of traditional marine fishermen. Table 6 shows a significant proportion of fishermen who do not use any adaptation procedures due to a lack of education and knowledge. In addition, the summaries of the community engagement meetings highlight the advanced responses for the local plan of action in developing the adaptation strategy. The present investigation proposes a participatory adaptation strategy within the fishing community to tackle climate-coastal adaptation and enhance sustainable fishing practices (Fig. 14). The following are the primary key stages involved in this process: Firstly, it emphasizes the active involvement of the local community and the inclusion of local fishermen in the decision-making processes. This can be accomplished by organizing frequent workshops and meetings where fishermen can exchange their findings and experiences about climate impacts, such as alterations in fish populations and weather patterns. The integration of traditional knowledge with scientific research facilitates the development of adaptation methods that are tailored to specific contexts. Furthermore, the policy promotes sustainable fishing practices by providing training on methods that reduce environmental harm, such as the use of selective fishing gear and the implementation of seasonal fishing bans to protect breeding times. In addition, the establishment of marine protected zones can aid in the preservation of crucial ecosystems and enhance fish populations. Moreover, implementing alternative income streams for fishermen, such as eco-tourism or aquaculture, reduces reliance on fishing and strengthens the community's ability to adapt to climate change. Finally, establishing collaborations with government entities, non-governmental organizations (NGOs), and academic institutions can ensure the availability of resources, technical assistance, and financial support. This participatory strategy combines local knowledge, scientific insights, and policy support to empower fishing communities to effectively adapt to climate change issues. It also promotes the long-term viability of marine ecosystems.

7. CONCLUSION

The present study has analyzed both empirical perceptions and scientific evidence concerning climate change and its impact on the livelihoods of the traditional marine fishing community in the coastal region of Bengal. The analysis revealed that local empirical knowledge significantly contributes to understanding climate change impacts on fish catching and related factors. Notably, a majority (71.55%) of respondents identified anthropogenic activities as the primary drivers of climate change. Furthermore, Garrett’s ranking analysis highlighted key climate change parameters affecting fish catching, with air temperature ranked first, followed by rainfall patterns, sea-level rise, sea surface temperature, wind speed, and sea surface salinity. Additionally, an examination of fishermen's knowledge over the past ten years emphasized significant changes in climate-oceanographic factors, with over 90% of respondents acknowledging increased air temperature, more frequent tropical cyclones, rising sea levels, and higher sea surface temperatures as critical factors influencing fishing practices. Further analysis of scientific climate data revealed an increasing trend in climatic parameters such as annual mean temperature and rainfall, with coastal Medinipur experiencing the most noticeable changes and 24 Parganas North the least. Rising sea levels, except at Sagar Island, and the increasing occurrences of cyclones further underscore the scientific concern of a changing climate in the study area. The combined empirical and scientific investigations indicate that climate change has impacted fish catch variation. The results of a modified empirical model showed that the independent variables of rainfall and cyclone information were statistically significant predictors of catch variation. However, variables such as air temperature, sea level rise, and sea surface temperature did not demonstrate statistical significance in predicting catch variation, indicating a lesser impact on fish catching in the study area. Further, the present study also investigated the adaptation practices of fishermen, revealing a common strategy of adopting alternative occupations. This shift, however, has transformed traditional fishermen's identities and occupations. A significant finding was that many respondents had not adopted any adaptation practices due to a lack of knowledge and education.

Moreover, community engagement meetings inspired both youth and experienced fishermen to explore adaptive opportunities. The study identified three discrete local strategies for adaptation: Strategy 1: Restoring nature-based adaptation governance; Strategy 2: Integrating science and technology into community practices; and Strategy 3: Educating about and raising awareness of climate-coastal risks, as well as promoting participatory management. These strategies collectively aim to enhance the resilience and sustainability of the fishing community in the face of climate change. The input from local respondents in the study area was analyzed and regarded as advanced action in developing a participatory adaptation strategy. Consequently, the investigation proposes a participatory adaptation strategy within the fishing community to address climate-coastal adaptation and promote sustainable fishing practices. This strategy emphasizes spatial considerations and active community participation. Therefore, the present study advocates for participatory policy implications to safeguard the living conditions and livelihoods of the fishing community in the coastal region of Bengal, India.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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SUPPLEMENTARY MATERIAL (TABLE AND APPENDIX)

Supplementary Table (Table ST)

Table ST 1. Fishermen's (TMFC) perspectives on the causes of climate change

Age group (in years) of the TMFC\ Causes of climate change	Natural process (%) (A)	Anthropogenic activities (%) (B)	Both (A & B) (%)	Don't know (%)
20-25	8.11	70.27	16.22	5.41
25-35	6.90	63.79	17.24	12.07
35-45	7.19	85.63	5.39	1.80
45-65	10.09	66.51	16.06	7.34
Total	**8.07**	**71.55**	**13.73**	**6.65**

Data source: TMFC perception of field survey (N: 480), 2022 (by the author)

Table ST 2. Fishermen's (TMFC) perspectives on the changing climate and oceanographic factors

Perception on air temperature (changes in the last ten years)			
Age group (in years) of the TMFC	**Increase (%)**	**Decrease (%)**	**Total (%)**
20-25	91.89	8.11	100.00
25-35	91.38	8.62	100.00
35-45	92.81	7.19	100.00
45-65	95.41	4.59	100.00
Total	**92.87**	**7.13**	**100.00**
Perception on rainfall (changes in the last ten years)			
20-25	18.92	81.08	100.00
25-35	20.69	79.31	100.00
35-45	16.17	83.83	100.00
45-65	9.17	90.83	100.00
Total	**16.24**	**83.76**	**100.00**
Perception on the frequency of cyclones (changes in the last ten years)			
20-25	94.59	5.41	100.00
25-35	100.00	0	100.00
35-45	100.00	0	100.00
45-65	98.62	1.38	100.00
Total	**98.30**	**1.70**	**100.00**
Perception on wind speed (changes in the last ten years)			
	Changes noted (%)	**No Change (%)**	**Total (%)**
20-25	81.08	18.92	100.00
25-35	82.76	17.24	100.00
35-45	85.03	14.97	100.00
45-65	83.49	16.51	100.00
Total	**83.09**	**16.91**	**100.00**
Perception on sea-level rise (changes in the last ten years)			
	Increase (%)	**No Change (%)**	**Total (%)**
20-25	86.49	13.51	100.00
25-35	87.93	12.07	100.00
35-45	94.61	5.39	100.00
45-65	92.20	7.80	100.00
Total	**90.31**	**9.69**	**100.00**
Perception on sea surface temperature (changes in the last ten years)			
	Increase (%)	**Decrease (%)**	**Total (%)**
20-25	86.49	13.51	100.00
25-35	94.83	5.17	100.00
35-45	91.02	8.98	100.00
45-65	93.58	6.42	100.00
Total	**91.48**	**8.52**	**100.00**
Perception on sea surface salinity (changes in the last ten years)			
20-25	81.08	18.92	100.00

25-35	87.93	12.07	100.00
35-45	92.22	7.78	100.00
45-65	96.33	3.67	100.00
Total	**89.39**	**10.61**	**100.00**

Data source: TMFC perception of field survey (N: 480), 2022 (by the author)

Table ST 3. Results of estimating the impact of perceived climate change events on fishing catches

Regression Statistics								
Multiple R: 0.981462341				**R Square: 0.963268328**				
Adjusted R Square: 0.953602098				**Standard Error: 0.781055842**				
CTV	**Coefficients**	**Standard Error**	**t Stat**	**P-value**	**Lower 95%**	**Upper 95%**	**Lower 99.0%**	**Upper 99.0%**
Intercept	4.488823882	0.540172003	8.31	9.4853E-08	3.4	5.619	2.94	6.034221
AR	-0.01684227	0.491328045	-0.034	0.973012184	-1	1.012	-1.4	1.388815
SST	-0.87831297	0.543328325	-1.617	0.122459925	-2	0.259	-2.4	0.676114
SR	-0.1244837	0.177818298	-0.7	0.492372696	-0.5	0.248	-0.6	0.384243
RF	0.173566425	0.058706858	2.956	0.008104926	0.1	0.296	0.01	0.341523
CS	-1.29040302	0.225283241	-5.728	1.60716E-05	-1.8	-0.82	-1.9	-0.64588

Note: CTV: Catch Variation; AR: Air temperature; RF: Rainfall; CS: Information about cyclones; SR: Sea-level rise; SST: Sea surface temperature; Data source: TMFC perception of field survey (N: 480), 2022 (by the author)

APPENDIX 1

Detailed description of techniques/ equation/ model

Garrett ranking techniques: The Garrett ranking techniques (Eq. 1) were employed (Garrett, 1985) to identify the measurement of key parameters and evidence of climate change in the study area.

$$Percent\ position = \frac{100(R_{ij} - 0.5)}{N_j} \qquad Eq. 1$$

Here, R_{ij} is the rank given for the ith ith factors by the jth respondents, and N_j is the number of factors ranked by the jth respondents. The percentage position of each rank was converted into scores using the Garrett ranking conversion table.

Garrett Ranking Conversion Table

GARRET'S RANKING TABLE

PERCENTAGE	*SCORE*	*PERCENTAGE*	*SCORE*
0.09	99	52.02	49
0.20	98	54.03	48
0.32	97	56.03	47
0.45	96	58.03	46
0.61	95	59.99	45
0.78	94	61.94	44
0.97	93	63.85	43
1.18	92	65.75	42
1.42	91	67.48	41
1.68	90	69.39	40
1.96	89	71.14	39
2.28	88	72.85	38
2.63	87	74.52	37
3.01	86	76.12	36
3.43	85	77.68	35
3.89	84	79.12	34
4.38	83	80.61	33
4.92	82	81.99	32
5.51	81	83.31	31

6.14	80	84.56	30

PERCENTAGE	*SCORE*	*PERCENTAGE*	*SCORE*
6.81	79	85.75	29
7.55	78	86.89	28
8.33	77	87.96	27
9.17	76	88.97	26
10.16	75	89.94	25
11.03	74	90.83	24
12.04	73	91.67	23
13.11	72	92.45	22
14.25	71	93.19	21
15.44	70	93.86	20
16.69	69	94.49	19
18.01	68	95.08	18
19.39	67	95.62	17
20.93	66	96.11	16
22.32	65	96.57	15
23.88	64	96.99	14
25.48	63	97.37	13
27.15	62	98.72	12
28.86	61	98.04	11
30.61	60	98.32	10
32.42	59	98.58	9

34.25	58	99.82	8

PERCENTAGE	*SCORE*	*PERCENTAGE*	*SCORE*
36.15	57	99.03	7
38.06	56	99.22	6
40.01	55	99.39	5
41.97	54	99.55	4
43.97	53	99.68	3
45.97	52	99.80	2
47.98	51	99.91	1
50.00	50	100.00	0

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Mann-Kendall (MK) test and Sen's slope estimator: The Mann-Kendall (Eq. 5) and Sen's slope tests (Eq. 6) were used to investigate long-term trends in climatic variability (mainly temperature and rainfall) (Frimpong et al., 2022; Aditya et al., 2021). The MK test statistic was computed as follows (**Kendall, 1955; Mann, 1945**).

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\,(X_j - X_i) \qquad (Eq. 2)$$

Where,

n = The cumulative count of data points, where X_i and X_j represent data values in time series i and j (with j being greater than i), respectively, and $sgn(X_j - X_i)$ denotes the sign function.

$$sgn\,(X_j - X_i) = \begin{cases} +1, if\ Xj - Xi > 0 \\ 0, if\ Xj - Xi = 0 \\ -1, if\ Xj - Xi < 0 \end{cases} \qquad (Eq. 3)$$

The variance was calculated as follows:

$$Var\,(S) = \frac{n(n+1)(2n+5) - \sum_{i=1}^{m} t_i\,(t_1-1)(2t_1+5)}{18} \qquad (Eq. 4)$$

Where,

n = The quantity of data points,
m = The count of tied groups, where t_i represents the number of ties of magnitude i. A tied group refers to a collection of sample data sharing identical values.

In scenarios where the sample size exceeds 10 (n > 10), the standard normal test statistic Z_S was determined using the following equation:

$$Z_s = \begin{cases} \frac{S-1}{\sqrt{Var\,(S)}},\ if\ S > 0 \\ 0, \quad if\ S = 0 \\ \frac{S+1}{\sqrt{Var\,(S)}},\ if\ S > 0 \end{cases} \qquad (Eq. 5)$$

Positive values of Z_S indicate increasing trends, whereas negative Z_S values indicate decreasing trends.

Sen's slope estimator (Eq. 7): The non-parametric method for estimating the slope of a trend in a sample of N pairs of data was developed by Sen (**1968**):

$$Q_i = \frac{x_j + x_k}{j-k} \quad for\ i = 1,2,3 \ldots\ldots N \qquad (Eq.6)$$

Here, x_j and x_k represent the data values at times j and k, where j is greater than k.

If there is a single datum in each period, then the equation N = $\frac{n(n-1)}{2}$ is true, where n represents the number of periods. If there exist many observations within one or more time periods, the value of N can be expressed as N< $\frac{n(n-1)}{2}$, and n is the total number of observations.

The N values of Qi are arranged in ascending order, and the median slope, also known as Sen's slope estimator, was computed as:

$$Q_{med} = \begin{cases} Q\left[\frac{N+1}{2}\right], & if\ N\ is\ odd \\ \frac{Q\left[\frac{n}{2}\right] + Q\left[\frac{n+2}{2}\right]}{2}, & if\ N\ is\ even \end{cases} \qquad (Eq.7)$$

The Q_{med} sign represents the data trend, and its value denotes the steepness of the trend. To assess whether the median slope is statistically distinct from zero, the confidence interval of Q_{med} at a certain probability is calculated.

Therefore, the calculation of the confidence interval for the time slope was performed as:

$$C\alpha = Z_{1-\alpha/2}\sqrt{Var\ (S)} \qquad (Eq.8)$$

Here, Var (S) is defined in **Eq. 3.** and $Z_{1-\alpha/2}$ is obtained from the standard normal distribution table. The confidence interval was calculated in this investigation using a significance threshold of $\alpha = 0.05$.

So, $M_1 = \frac{N-C\alpha}{2}$ $\qquad (Eq.9)$

The positive numbers in the time series of analyzed temperature and rainfall indicate an upward trend, while the negative values show a downward trend.

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Linear Regression Model and Modified catch variation empirical model

Several studies have employed linear regression models (eq. 10) to establish the relationships between fish catch variables and dependent environmental factors (Rahman et al. 2022; Macusi et al. 2021; and Makwinja and M'balaka, 2017).

$$\gamma_i = \alpha_0 + \alpha_i X + \varepsilon_i \quad i = 1,2, \ldots. . N \qquad (eq. 10)$$

Where, Y: landing catches; X: predictors; α_0: intercept; α_1: coefficients to be estimated; N: sample size; and ε: error term.

In this study, the equation of the empirical model for predicting the values of fishermen's landing catches is formulated as follows (eq. 11):

$$\mathrm{CTV} = \alpha_0 + AR_i + RF_i + CS_i + SR_i + SST_i + \varepsilon_i \qquad (eq. 11)$$

Where, CTV: Catch Variation for fishermen i; AR: changes/variation in air temperature in fishermen i; RF: changes/variation in rainfall in fishermen i; CS: changes/variation in information about cyclones in fishermen i; SR: changes/variation in sea-level rise in fishermen i; and SST: changes/variation in sea surface temperature in fishermen i;

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