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Economic valuation of climate induced losses to aquaculture for evaluating climate information services in Bangladesh

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ABSTRACT

Very little research has focused on climate impacts on aquaculture and the potential of climate information services (CIS) for aquaculture to support sustainable development goals 2030 (SDGs).[1] This study represents an effort to bridge this gap by conducting a first *ex-ante* economic evaluation of CIS for aquaculture in Bangladesh by semi-automating the extraction of data on climate-induced fish losses during 2011 to 2021 from popular online newspaper articles and corroborating them with available government and satellite datasets. During this period, Bangladesh faced an estimated loss of around 140 million USD for hatcheries, open water fish and shrimp. When validated with a year of country-wide official data on climate-induced economic losses to aquaculture, the damage reported from these media sources is approximately 10 percent of actual losses. Given this rule of thumb, the potential economic value of aquacultural CIS could be up to USD14 million a year, if 10 percent of the damage can be offset by appropriate services through a range of multi-sector efforts to establish and extend these services to farmers at scale.

1. Introduction

Globally aquaculture (farming of aquatic animal and plants) continues to dominate aquatic food production systems and fish along with other aquatic foods are among the most traded food commodities (Watkiss,Ventura & Poulain, 2019). The value of aquatic food production through aquaculture alone was $264 billion (Barrange et al. 2018). In 2020, total fisheries and aquaculture production was at an all-time of 214 million tonnes while per-capita aquatic food consumption was 20.2 kg which was double the consumption rate 50 years ago (FAO, 2022). Over 91 % of global aquaculture production (102.9 million tonnes in 2017) is currently produced within the

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[1] Resilient aquatic food systems can substantially contribute to SDG 1 to end poverty in all its forms, SDG 2 to end all forms of hunger through food and nutrition security, SDG 3 to ensure healthy lives and promote well-being for all at all ages, SDG 8 to promote inclusive economic growth, employment and decent work for all, SDG 12 to ensure responsible consumption and production patterns, SDG 13 to combat climate change and its impacts, SDG 14 to conserve the oceans, seas and marine resources and SDG 17 to strengthen the means of implementation and revitalize the global partnership.

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Asian region (Tacon, 2020). Bangladesh has been playing a dominant role in fish production and consumption, reflected by its fifth ranking in terms of aquaculture production (Barrange et al. 2018). Fish and fish-based foods supply 60 percent of the total daily animal protein intake for its population (with a per capita intake of 62.58 gm/day against a targeted 60 gm/day) (Rashid & Zhang, 2019; BBS, 2017), significantly contributing to ensuring nutrition and food security for the vulnerable and marginalized people of the country. Aquaculture and fisheries contribute 25.72 percent to the agricultural gross domestic product (GDP) of Bangladesh (3.50 percent to national GDP), support the livelihoods of more than 12 percent of the population (MoF, 2020, Shamsuzzaman et al., 2020, FRSS, 2017), and provide large export earnings (MoF, 2020). Despite the importance of aquaculture to livelihoods, nutrition, and the economy, very limited importance is attributed to climate challenges in aquaculture compared to crop agriculture.

Freshwater aquaculture in Bangladesh is highly vulnerable to climate change, ranking second globally in terms of climate vulnerability (Field et al., 2014, Barange et al., 2018). Both extreme temperature and erratic rainfall events pose substantial risk to aquaculture operations and thus, fish production (Hossain et al., 2021). The frequency and intensity of these climate crises are predicted to increase in the near and distant future due to climate change (EPA, 2021). This scenario calls for mechanisms able to offset the increasing climate risks for aquaculture farmers. Climate information services (CIS) are a potential climate-risk reduction approach that could de-risk the aquaculture sector by supporting fish farmers' climate resilient decision-making and production management processes.

The optimum water temperature for fish production in Bangladesh ranges from 26 °C to 32 °C (Hossain et al., 2021). However, current maximum (>34 °C on average during April to June) and minimum temperature (<20 °C during December to February) variations, increasing high temperature (32 °C ~ 36 °C) and extreme hot (~40 °C) days is predicted to vary between 3.24 °C and 5.77 °C by the end of the century (Fahad et al., 2017), a rise that will likely push the maximum water temperature to exceed the physiological tolerance level of multiple fish types and increase fish mortality. Besides, a 2 °C temperature increase is expected to decrease freshwater availability (Cisneros et al. 2014), putting further pressure on freshwater fish production. Furthermore, an already-increasing trend of dry spells, erratic rainfall patterns (Khatun et al., 2016; Hossain, 2018) along with future projections reflect continued increase in rainfall variability as well (Caesar et al., 2015; Nowreen et al., 2015; Raihan et al., 2015). A recent study (Fahad et. al., 2023) has indicated that climate change may lead to a fourfold increase in extreme rainfall events. Such a significant escalation could have detrimental effects on aquaculture.

Variations in both temperature and rainfall could be substantially detrimental to aquaculture production and infrastructure (Islam et al., 2014, Montes et al., 2021, Montes et al., 2022) and inflict heavy losses to aquaculture (Islam, et. al., 2018; Montes et al., 2022). For instance, in 2020 a single flood event in Bangladesh alone caused a loss of around USD 5 million to the aquaculture sector (Saha, 2020; Hossain et al., 2021), while Cyclone Amphan resulted in a loss of approximately USD 30 million to the sector by inundating 180,500 enclosure (TBS, 2020; Hossain et al., 2021). These loss data reflect the consequences of only extreme events like cyclones and/or severe floods and refer to existing adaptation options (like early warning systems) for reducing the associated risks. However, data on losses induced by climate variability (such as erratic rain, heatwaves, cold spells, etc.) in aquaculture are scarce in the country, making it challenging to economically evaluate climate risk management interventions like CIS for enhanced uptake and scaling.

Cognizant of the importance of aquaculture in Bangladesh and the risks posed to daily operations by climate variability and extremes, CIS can play a substantial role in facilitating climate-informed operational and/or strategic management decisions. This can help manage the associated risks and consequently reduce correlated losses. For instance, if there is an authentically generated forecast information of very heavy rain during next week and if this information along with actionable advisory services (like protecting the ponds with nets or heightening the pond dikes or harvesting the table size fish early) can be communicated with the fish-farmers with a 5–7 days lead time, they will be able to manage the risks of fish loss and/or pond damage by making management decisions in advance of that specific climatic event.

The National Adaptation Plan of Bangladesh (NAP) 2022 has recognized the need to protect aquaculture from risks posed by both extreme climate and climate variability. Besides, the 2021 IPCC report on climate change stressed the increased likelihood of climate variabilities and extreme events in the South Asian region. Both NAP 2022 and IPCC 2021 highlight the urgency to enhance CIS for risk assessment at scale. CIS has evolved and expanded over the last few decades in Europe and North America, while countries in the global south have tended to be slower to develop and use climate information decision support frameworks and tools (Clements, Ray & Anderson 2013). Lack of awareness of the opportunities along with highlighted economic benefits of CIS is one of the key reasons for their low uptake in the developing world. In addition, a large number of CIS efforts around the world have focused on crop agriculture, and only a limited number of efforts (Hossain et al., 2021; Carlo et al. 2022) have focused on CIS for aquaculture. Consequently, the lack of knowledge about the economic benefits of aquaculture CIS has limited its awareness and uptake in both the public and private sectors. An improved understanding of the economic benefits of aquaculture climate services, therefore, is important for several reasons, including fostering awareness and increasing the use of CIS, enhancing the value and the efficiency of CIS, assessing pricing and charging mechanisms for CIS, justifying investments and/or financing, and helping to form public policy in relation to CIS (WMO 2007; Zillman 2007). Therefore, the specific objective of this study is to assess the climate-induced economic losses in the aquaculture sector, thereby unraveling the potential of CIS in de-risking aquaculture value chains.

Evaluating any CIS for aquaculture requires data that indicates economic loss resulting from climatic stress events. Unfortunately, Bangladesh doesn't have historical data on aquaculture loss and damage due to climate variability and extreme climate events. Only recently, starting from 2019, has the Department of Fisheries begun recording aquaculture losses caused by climatic stresses. This poses a significant hurdle in estimating the economic valuation of climate services. To address this issue, the study explored aquaculture losses in line with climate variabilities as reported in leading national newspapers since 2011, focusing on news about climate-

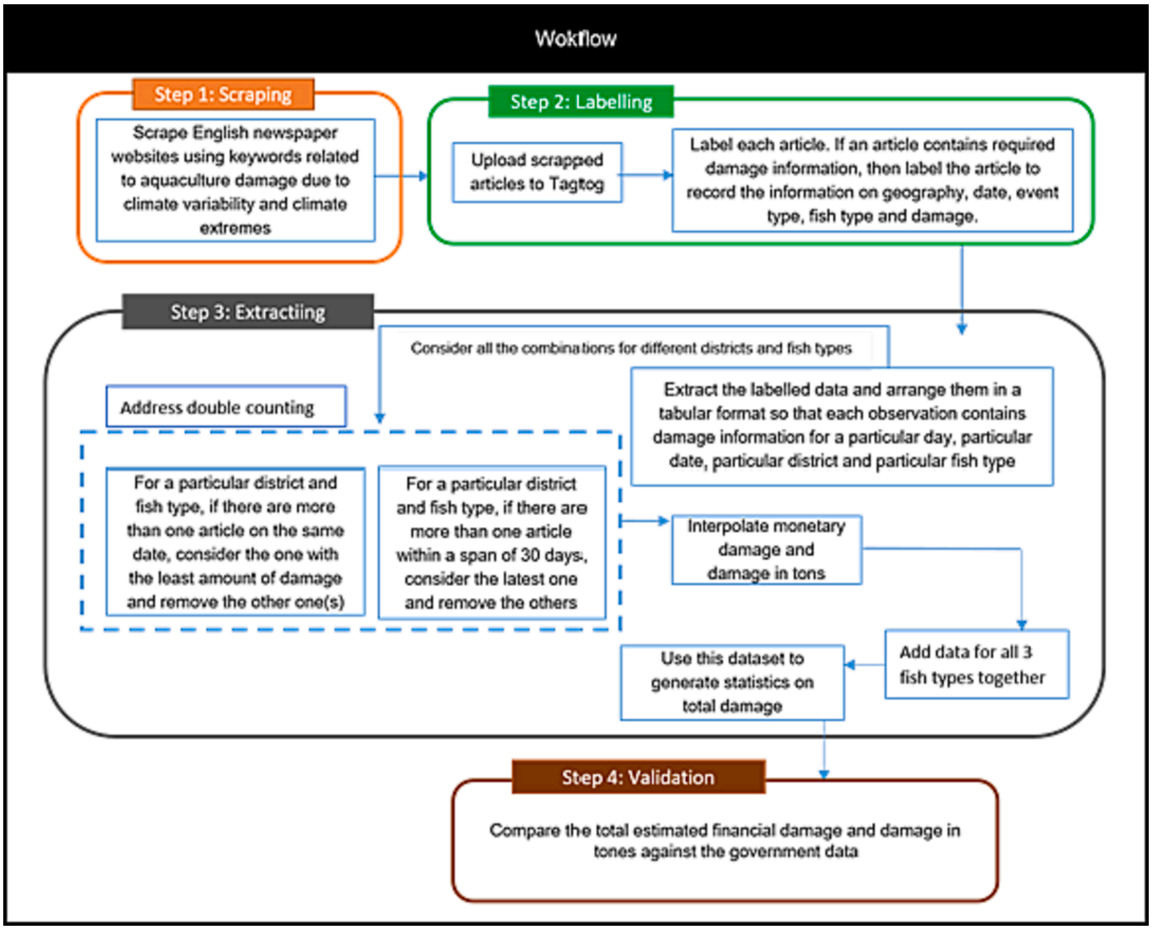

Fig. 1. Workflow.

induced loss and damage. Therefore, by using the approach of data scraping from newspaper reports on climate-induced aquaculture loss, this study responds to the need for generating relevant economic loss data and offers the very first endeavor to conduct an economic valuation of the potential benefits of aquaculture CIS in a data-poor environment.

2. Materials and methods

Time series data on climate-induced aquaculture losses (in monetary terms) was extracted from four major English dailies in Bangladesh: The Daily Star, Dhaka Tribune, The Independent, and New Age in order to determine the economic value of CIS. The newspapers were chosen based on several factors, including circulation, a decade-long online presence, regular coverage of aquaculture losses due to climatic events, and credible, evidence-based reporting. As shown in Fig. 1, we used a four-tier methodology: scraping, labeling, extraction, and validation. The method of newspaper scraping for generating data has been already used in previous researches (Sarr et al., 2018; Schnell and Redlich, 2019; O'Halloran et al., 2021).

In Tagtog, a framework was developed to extract economic losses from articles, categorizing them into "shrimp," "open water fish and hatcheries," or a combined fish category. These articles conveyed losses through metrics such as monetary value, damaged ponds, hectares, and fish tonnage. To get monetary loss when non-monetary terms were reported, an average monetary loss was calculated for particular metrics, such as per pond/enclosure. The articles that only listed non-monetary metrics were then subjected to this average. Estimates based on tons and hectares were also used in monetary conversions. The lowest value was used to avoid double counting for overlapping reports, and only the latest monthly report was retained. Monetary losses were converted to tons employing a specific formula. After determining fish loss, it was aggregated by damage type. If different losses in terms of fish types were reported in multiple articles within a 30-day period for any district, only the most recent report on 'shrimp, open water fish, and hatcheries' was taken into account. The other reports were discarded, presuming that the loss estimate for this aggregated category would sufficiently cover them. Finally, the loss data was validated using the Department of Fisheries' 2019 data, ENACTS-BMD (a composite dataset of satellite and observation) rainfall Data, and maps of floods generated from Sentinel-1 satellite data for specific events.

Table 1
Distribution of scraped articles under different query sets.

Keywords	The Daily Star	New Age	Dhaka Tribune	The Independent	Total
Query 1 (fish loss OR shrimp loss)	114 (23)	54 (9)	72 (32)	32 (7)	240
Query 2 (aquaculture OR washed away)	71 (8)	57 (4)	40 (4)	6 (3)	168
Query 3 (fish OR shrimp OR washed away)	39 (2)	0 (0)	0 (0)	81 (3)	39
Total	224 (33)	111 (13)	112 (36)	119 (13)	447 (95)

Note. the number of newspapers scraped and values within parentheses show articles among these which actually contained data about aquaculture loss resulting from climatic events.

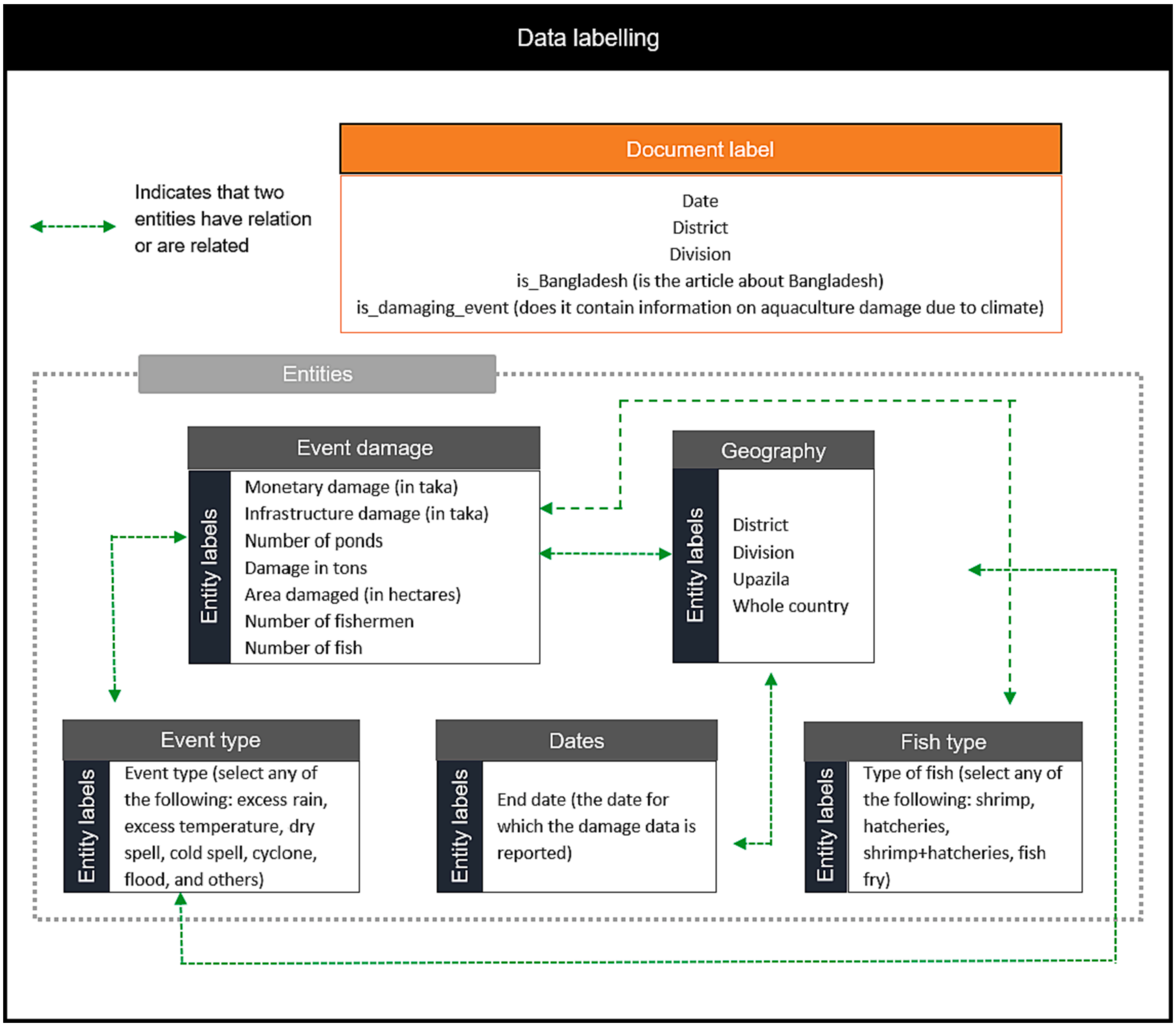

Fig. 2. Data labeling framework.

2.1. *Scraping data on climate-induced aquaculture loss*

Using keywords relating to climatic variability and extremes, such as heat, cold spells, dry spells, heavy rain, cyclones, floods, and fish loss, we scraped online versions of a selection of English dailies from July 2011 to June 2021. A previous study on CIS for aquaculture in Bangladesh (Hossain et al., 2021) provided the basis for these keywords. The relevant articles were extracted with Python 3.6 and SerpAPI[2] (Goldfarb-Tarrant et. al., 2020; Luo et. al., 2020). Utilizing SerpAPI with the specified keywords, a list of

[2] https://serpapi.com.

articles along with their publication dates was generated. However, many were not pertinent to our study. Through iterative keyword refinement, we eventually arrived at three sets (Table 1) that yielded a greater percentage of pertinent articles. Out of 447 articles in total, 95 articles contained physical or economic (or both) loss information. This data was subsequently uploaded to Tagtog[3] for additional processing, namely labeling.

2.2. Labeling the scrapped economic loss data

A labelling framework in Tagtog was created (Fig. 2) to capture data on economic loss from the articles. The types of events (e.g., floods and high temperatures), location details, loss metrics (e.g., physical loss in tons and economic value in Bangladeshi taka), and fish types were carefully examined in the articles. The three main categories of loss identified were 'Loss to open water fish and hatcheries,' 'Loss to shrimp,' and 'Aggregate loss for all fish types: shrimp, open water fish, and hatcheries. There was also some loss data on fish fry, but it was excluded due to its infrequent mention (fewer than 10 instances) in the articles.

2.3. Data extraction

After labelling was completed in Tagtog, the data were organized so that each row corresponded to a distinct location, date, and one of the three damage types. If a single article was reported for multiple locations, the losses were divided into separate rows. For validation against the Government of Bangladesh's fiscal year statistics (July to June), the labelled data were aggregated annually, covering the fiscal years from 2011 to 2020, starting in July 2011 and ending in June 2021.

2.3.1. Approach to avoid double counting

Events were occasionally repeated in multiple articles or during protracted events. To construct fisheries loss time series, avoiding duplication in reported data was prioritized to avoid double counting. In cases of overlapping loss reports on the same date, in the same district, and for the same fish type, the report with the least loss was retained and the others were discarded. Additionally, within a 30-day period, only the most recent report, excluding the others, was utilized for a given district and fish type. This ensured that our loss estimates were on the conservative side, rather than being an overestimation.

2.3.2. Valuing fish loss

Articles on fish loss caused by climate were reported in a variety of ways, including monetary value, the number of ponds or enclosures damaged, the affected area (hectare), and the actual amount of fish (ton) lost. To convert non-monetary losses to monetary terms, estimated values per pond/enclosure, per hectare, or per ton were used. For example, if an article reported the total number of impacted ponds as well as the monetary loss for a specific fish type in a given area, the monetary loss per pond/enclosure for that area and fish type was calculated. When multiple articles offered this data, average monetary loss per pond/enclosure for that fish type and that area was calculated. In articles that only listed the number of impacted ponds for that particular area and fish type, this average was then used to calculate financial loss for those articles. Similarly, loss per unit area (hectare) and per ton metrics were employed for monetary conversions. For consistency, data on infrastructure damage, which was present in only four publications, was omitted. The exchange rate used to convert all losses from taka to US dollars was 1 dollar to 94.59 taka (as of October 2022). The steps described here were implemented using R (R Core Team 4.2.1). Refer to Appendix 1′s Fig. A1 for a comprehensive illustration.

2.3.3. Estimating the quantity of fish loss

Fish loss is reported in physical quantities (tons) in some articles; in the rest, it is either not reported or reported in terms of monetary value or by using other yardsticks. To estimate fish loss in tons for a particular district and damage type reported in monetary terms, the following formula was utilized:

Loss in tons of i^{th} event = monetary loss as reported for i^{th} observation / average monetary loss per ton for the particular district and the damage type — (1)

If, for the considered district and damage type, there were no data on loss in tons (because no other articles contained information on these), in order to calculate average loss per ton, the average loss per ton for that fish type was used across all districts and then used to calculate an estimate for loss in tons (Please see Appendix A, Fig. A2 for the interpolation method). The figures shown here are thus in no way a very accurate measurement of the loss, but rather an educated, conservative estimate based on interpolation.

2.3.4. Combining loss data from different types of hazards

After estimating and/or interpolating the fish loss information, the total fish loss was aggregated over the types of damage identified in the media. In some articles, loss information was reported for a particular district for the combined category of 'shrimp, open water fish, and hatcheries,' rather than for 'shrimp' or 'open water fish and hatcheries' individually. For a single district, if one article contained loss information for shrimp, open water fish and hatcheries together and another article or multiple articles contained loss information on 'shrimp' and/or 'hatcheries and open water fish' within a span of 30 days, then the latest observation was considered

[3] https://www.tagtog.com.

Table 2
Five pond locations in Bagerhat district.

Upazila/district	Pond location				
	Pond 1	Pond 2	Pond 3	Pond 4	Pond 5
Fakirhat *upazila*, Bagerhat district	N 22.75968 E 89.694366	N 22.773685 E 89.719440	N 22.799685 E 89.734670	N 22.683061 E 89.721744	N 22.672330 E 89.744559

Table 3
Total monetary loss estimates for hatcheries and open water fish (in BDT million) and loss in quantity in tons between 2011 and 2020.

District	Monetary loss (in million USD)	Loss in quantity (in tons)
Sunamganj	19.4	14644.0
Tangail	6.3	10369.4
Gopalganj	5.3	3212
Jamalpur	5.2	3052.3
Satkhira	3.9	2907.6
Naogaon	2.6	1983.1
Gaibandha	2.6	2622.4
Netrakona	2.5	1181.0
Lalmonirhat	1.1	793.2
Munshiganj	0.9	713.9
Sylhet	0.7	3518.0
Sirajganj	0.3	155.0
Habiganj	0.2	257.4
Rangpur	0.2	88.0
Rajshahi	0.1	53.2
Maulvibazar	0.1	78.5
Kurigram	0.1	100.3
Khulna	0.0004	0.3

and all other observations were removed. This was based on the assumption that for an event lasting around a month or less, the last article would give the final aggregated loss estimate. Again, if loss information for a single district on a particular date was reported for both “shrimp, open water fish and hatcheries” type and either or both of the shrimp and hatcheries types, only the information for “shrimp, open water fish and hatcheries” category was considered and the information for the others was discarded. We, therefore, assumed that the loss reported for “shrimp, open water fish and hatcheries” together would contain or cover individual loss information for shrimp, open water fish and hatcheries for that day.

2.4. Validation of media derived estimates

A thorough three-step validation process was applied to the estimated data for the open water fisheries/aquacultures loss.

2.4.1. Comparison with government statistics

The Department of Fisheries’ official statistics were compared with the scraped 2019 loss data. Since the government did not have a consistent time series available, the authors used the data from 2019 as a benchmark to assess how reliable newspaper reports were as proxies for the losses.

2.4.2. Verification using ENACTS-BMD Rainfall data

The ENACTS-BMD dataset, a composite of satellite and observational data covering Bangladesh with a 0.5° x 0.5° spatial resolution, was used to verify events of reported floods and heavy rainfall. This dataset, which combines observational data with data from the Climate Hazard Group InfraRed Precipitation (CHIRP) (Acharya, N. et al., 2020), focuses on rainfall in Bangladesh. Floods brought on by outside rainfall or external riverine flows are not taken into consideration in this dataset. To address this limitation, flood maps for particular areas were created. To verify the alignment between reported and recorded rainfall, specific events in two districts, Barishal and Sunamganj, were cross-checked with this dataset.

2.4.3. Satellite data validation

Sentinel-1 satellite data were utilized to validate the correspondence between flood maps and reported occurrences. Since Sentinel-1′s data for Bangladesh begins in 2017, for mapping only 2019 and 2020 were considered. The algorithm proposed by Thomas et al. (2023) was used to create the flood maps. Two randomly chosen events were investigated: a heavy rainfall event on 26 September 2019 in Fakirhat Upazila, Bagerhat district, and tidal floods in Shyamnagar and Assasuni Upazila of Satkhira due to Cyclone Amphan on 24 May 2020. For the former, flood conditions at five pond locations in Fakirhat Upazila were examined/mapped (Table 2). For the second event, a flood map covering Shyamnagar and Assasuni *upazila* of Satkhira was generated and investigated. It was reported in

The Independent newspaper that in Satkhira, "12,257 fish enclosures and ponds have been washed away." Consequently, we generated a flood map of this area on the 25th of May 2020 to determine if these areas were actually inundated.

3. Results

3.1. Loss for open water fish and hatcheries

3.1.1. Physical and monetary loss for hatcheries and open water fish

The top five districts that experienced greatest loss for hatcheries and open water fish between 2011 and 2020 are Sunamganj, Tangail, Gopalganj, Jamalpur and Satkhira (Table 3). Sunamganj alone faced a total loss of around USD 19.4 million and a quantity of around 14,644 million tons. The second most affected was Tangail with losses valued at around USD 6.3 million, almost three times less than the amount lost for Sunamganj. Gopalganj, Jamalpur and Satkhira incurred losses of around USD 5.3, USD 5.2 and USD 3.9 million, respectively. District-wise yearly loss of fisheries is provided in Appendix B, Table A1.

3.1.2. Country-wide open water fish and hatcheries loss

In 2011, our data suggest that the total loss for open water fisheries and hatcheries in Bangladesh was around USD 3.9 million and 2908 tons. In 2016, this rose to around USD 13.7 million, with fish loss of 9,603 tons. In 2020, the monetary loss increased almost twofold to USD 23.9 million, while the quantity of fish lost rose to 24,892 tons (Fig. 3). It appears that 2020 was a really challenging year for fish losses as the highest amount of recorded loss was found for this year.

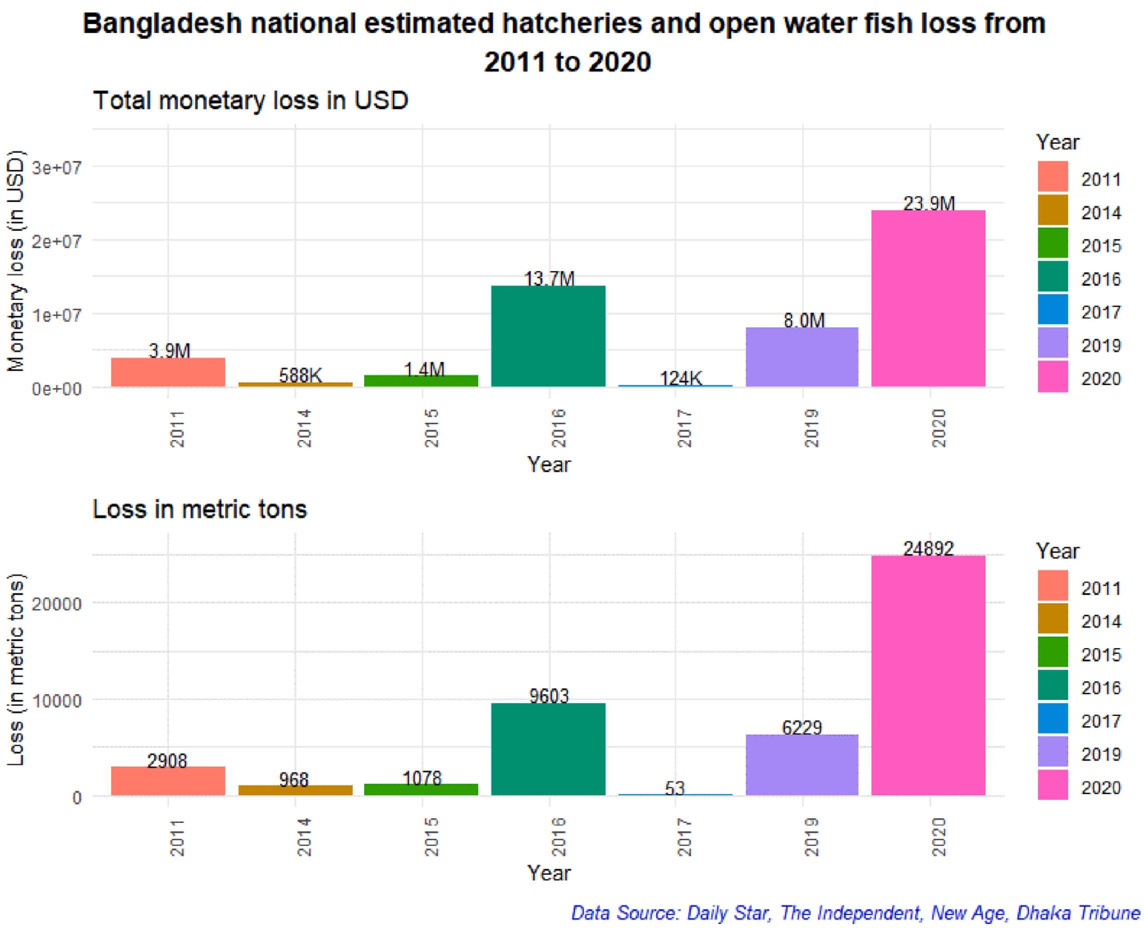

Fig. 3. Aggregated estimated monetary and physical losses for the hatchery and open water fish sector in Bangladesh.

Table 4
Total monetary loss for shrimp (in BDT million) and loss in quantity in tons between 2011 and 2020.

District	Monetary loss (in million USD)	Loss in quantity (in tons)
Satkhira	15.7	5,649.3
Bagerhat	11.9	4,294.8
Khulna	0.5	185.4

3.2. Loss for shrimp

3.2.1. Monetary loss and loss in tons for shrimp

Shrimp loss was reported for just three districts where production is most common: Satkhira, Bagerhat and Khulna. Similar to the figures for aquaculture and open water fish loss, data for shrimp loss for 2011 to 2020 were sparse. Satkhira faced the highest loss among all districts for shrimp, with a total loss valued at more than USD 15.7 million and amounting to around 5649 tons of shrimp. After Satkhira, Bagerhat faced the most shrimp loss with around 4,295 tons of shrimp worth around USD 11.9 million. For Khulna, the loss was much less than both Bagerhat and Satkhira, at around 185.4 tons of shrimp worth around USD 0.5 million Table 4.

3.2.2. National shrimp loss

Considering the nation-wide aggregate estimate generated for shrimp loss, 2011 was the worst year, with around 5,488 tons of shrimp worth around USD 15.3 million lost (Fig. 4). In the following years up to 2018, yearly losses dropped sharply to less than 170 tons, worth less than USD 500 thousands. However, from 2018 to 2019, monetary losses jumped around eight-fold, from around USD 468 thousands (168 tons) to around USD 3.7 million (1315 tons). As observed above, losses were considerably higher in 2020, with more than 3000 tons of fish lost worth around USD 8.4 million.

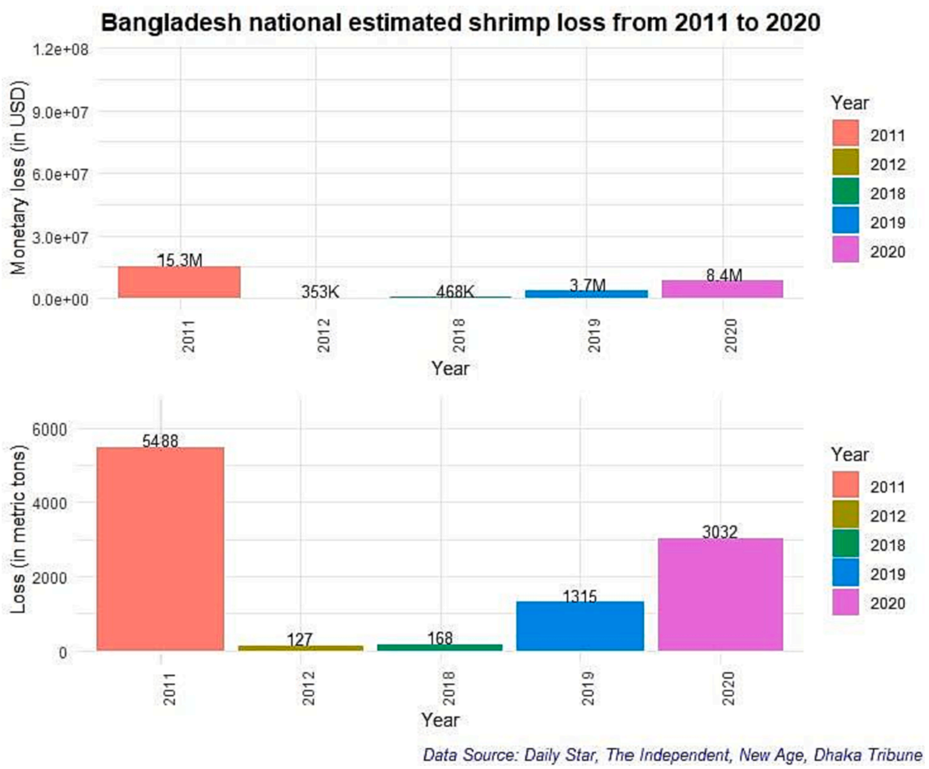

Fig. 4. Country-wide monetary loss for shrimp.

Table 5
Monetary loss (in USD million) for all fish types (hatcheries, open water fish, shrimp) and loss in quantity in tons.

District	Monetary loss (in million USD)	Loss in quantity (in tons)
Satkhira	25.9	11,928
Sunamganj	19.4	14,645
Bagerhat	19.2	6906
Patuakhali	12.0	2136
Khulna	11.2	7576
Jessore	9.5	3422
Lalmonirhat	7.6	2718
Tangail	6.4	10,505
Jamalpur	6.1	3233
Gopalganj	5.3	3212
Naogaon	4.7	2743
Gaibandha	2.7	2668
Netrakona	2.5	1181
Natore	2.2	798
Madaripur	2.0	1000
Munshiganj	0.9	714
Kurigram	0.8	366
Sylhet	0.7	3518
Sirajganj	0.3	155
Habiganj	0.2	257
Rangpur	0.2	88
Rajshahi	0.1	53
Barisal	0.1	40
Joypurhat	0.1	38
Maulvibazar	0.1	79

3.3. Aggregate loss estimates for all fish types (hatcheries, open water fish and

3.3.1. Monetary loss and loss in tons for all fish types

We calculated the total loss (monetary loss in USD million and fish loss in tons, within parentheses) is tabulated for hatcheries, open water fish and shrimp for different districts from 2011 to 2020 (Table 5). Satkhira appears to have experienced the greatest amount of loss from 2011 to 2020, with a fish loss of around 11,928 tons worth around USD 25.9 million. Next, Sunamganj and Bagerhat experienced monetary losses of USD 19.4 million and around USD 19.2 million respectively. Maulvibazar faced the least amount of loss among all the reported districts, at around 79 tons of fish worth USD 0.1 million.

Our data suggest that the top five districts (Satkhira, Sunamganj, Bagerhat, Patuakhali, and Khulna), which suffered the most from climate-induced financial losses in the fisheries sector, incurred estimated losses of around USD 25.9 million, USD 19.4 million, USD 19.2 million, USD 12.0 million, and USD 11.2 million, respectively, between 2011 and 2020 (Fig. 5). However, these data should be interpreted carefully, as prior to 2019, few loss data were available for most of the districts. For example, in 2011, loss data were available for only one district, while in 2012, data were available for only two districts, and for 2013, no data were available for any district. In 2020, fish loss was reported in at least 18 districts, indicating more coverage of or focus on the fisheries sector by the print media outlets.

3.3.2. Country-wide estimate of all damage types

In 2011, the total estimated hatcheries, open water fish and shrimp loss was 10,755 tons and around USD 24.9 million (Fig. 6). In the following years up to 2019, the yearly loss fluctuated between USD 353 thousands (corresponding to 127 tons) and USD 15.8 million (corresponding to around 11,235 tons). In 2020, total fish loss increased sharply from a value of around USD 15.8 million (11,235 tons) in 2019 to around USD 56.2 million (336,826 tons).

3.4. Aquaculture loss by climatic events

Among cyclones, excess rain, floods and tidal surges, flooding appears to have been the most monetarily damaging and regularly occurring event type (at least in terms of being reported in the popular English media) for hatcheries, open water fish and shrimp (Table 5). Between 2011 and 2020, floods inflicted an estimated losses of around USD 93.0 million with a quantity of around 53,604 tons of aquaculture production lost. In 2020 alone, flooding alone caused fish loss of around 21,156 tons with a monetary value of around USD 28.5 million. Cyclones were the second most damaging event, with an accumulated fish value loss of around USD 24.8 million and around 12,480 tons of fish products lost. Tidal events were the least damaging of these events and is reported, causing

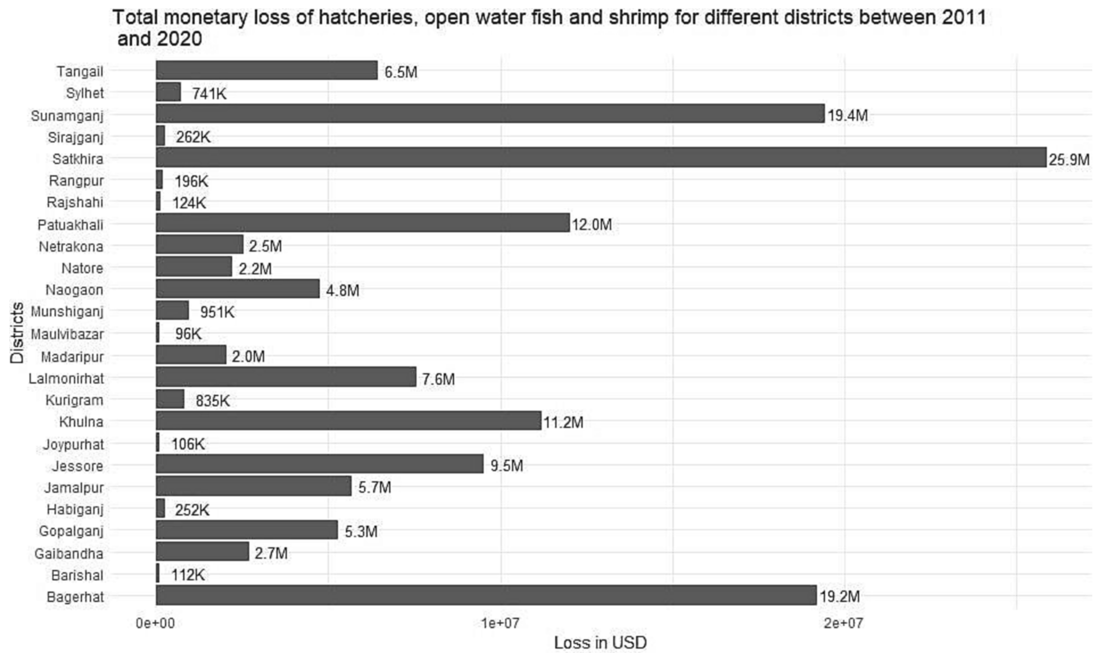

Fig. 5. Total monetary loss of hatcheries, open water fish and shrimp for different districts from 2011 to 2020.

estimated fish losses of 51.6 tons worth around USD 0.1 thousands (further specification of monetary losses due to different events are provided in Appendix B, Tables A2-A6).

3.5. Validating scraped data

3.5.1. Validating scraped data using Department of fisheries (DoF) dataset

Data collected by DoF for hatcheries, open water fish and shrimp from July 2019 to June 2020 shows that the value of loss was USD 166.7 million. The total monetary loss of just shrimp and hatcheries computed for 2019 using scraped newspaper data was USD 15.8 million. As such, these figures estimate that media reports captured only around 9.5 percent of the total monetary loss calculated by DoF.

3.5.2. Validating scraped data using ENACTS-BMD dataset

3.5.2.1. Barishal (for articles published between August 20 and August 28, 2020). Newspapers published on August 28, 2020 (Hossain, 2020) reported flood loss for Barishal. Monthly rainfall anomalies from 2019 to 2021 were plotted to see if the period under investigation was wetter than average. August 2020 appears as a positive anomaly in rainfall, indicating more rainfall than the average August rainfall amount in this location, at the time and in the place when the newspapers indicated flood-induced losses (Fig. 7a). However, May–June 2020 also appears to be above average, as does November 2019. The newspaper article related to this date and district published in New Age on August 28, 2020 was therefore checked. It stated that flooding started on 27 June 2020 and lasted for two months. An excerpt reported, "*Over 72,000 fish farmers have suffered nearly* [BDT] *500 crore loss during the flood that continued to wreak havoc in parts of Bangladesh until Thursday, two months after it began in the north on June 27*" (Hossain, E, 2020). To understand whether the loss is due to (1) the timing of the extreme event, (2) the level of precipitation, or (3) a combination of several events, a longer time series from 2011 to 2021 was considered to understand these phenomena (Fig. 7b). These data show more severe monthly anomalies in 2013 and 2015, and more moderate but repeated anomalies in 2016 and 2017. Unfortunately, no articles were found to report on weather-induced aquaculture or fisheries losses for Barishal for 2016 and 2017; however, articles mentioned high rainfall in Bagerhat, close (approximately 40 km distance) to Barishal. If loss was due to the timing of the extreme event, this may indicate that rainfall in August may lead to more loss than rainfall in other months. A positive anomaly in August 2020 (Fig. 7c) might corroborate what newspaper articles indicate. However, this is one of four positive anomalies in August in the past 10 years, with a similar anomaly observed in August 2011 and more severe one in 2016. The scraped articles provide references to flood events in August 2016 and August 2011, supporting the research's newspaper data of flooding in August 2020. Tidal movement can also cause flood in Bangladesh irrespective of rainfall. To ascertain whether this was due to a combination of several events, anomalies from April to August for the years 2011–2021 were also analyzed. Here, 2020 does not appear as one of the worst years, compared with 2013 and 2015. There were no article with fisheries loss data for these two years (2013 and 2015) in August which could be due to the fact that

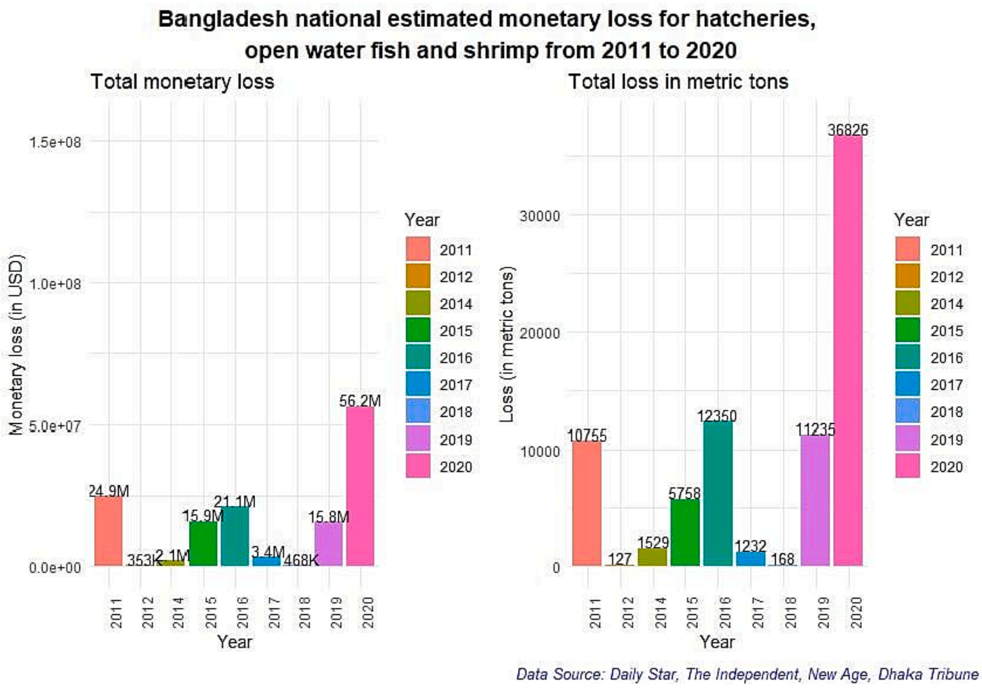

Fig. 6. Bangladesh national estimated monetary and physical loss for hatcheries, open water fish and shrimp.

aquaculture loss data was not much reported in newspapers at that time. Thus, it could still be possible that although August 2020 was not one of the worst years, the flood event did occur in the 2020.

3.5.2.2. Sunamganj (for articles published during 20–31 July 2019). Sunamganj is located in the the north-east part of Bangladesh. We verified whether the flood event mentioned in an article of The Daily Star (Floods wash away Tk 9 crore fish in Sylhet division, 2019) was detectable using ENACTS-BMD rainfall data. For Sunamganj, the coordinates (longitude 91.4072° E and latitude 26.0667° N) were used to examine the monthly ENACTS-BMD rainfall from May to November 2019 (Fig. 8a). Surprisingly, a negative anomaly (Fig. 8b) occurred in July 2019, with a slight positive anomaly taking place in the immediately preceding months. Sunamganj faces monsoon floods, heavy prcipitation events and flash flooding, the latter being caused by heavy rainfall events in the upstream regions of the Indian state of Meghalaya (Collier, 2007).

3.5.3. Valildating scraped data using flood maps

A flood inundation map of Bagerhat (Fig. 9) shows the base period for flood mapping (20th of December in 2018, which corresponds to the dry period in Bangladesh). The blue patches on the right-hand map shows inundated areas which were without water during the base period. Although not all the ponds were inundated on 29 September 2019, the map shows that many of the surrounding places were in fact inundated. This supports the media observation that “A sudden drop in the oxygen level has led to the deaths of shrimps in 8,000 enclosures at …” from the article published in The Daily Star (Low oxygen level killing shrimps, 2019). The flood inundation map for Shyamnagar and Assasuni *upazilas* of Satkhira map (Fig. 10) shows that areas adjacent to the river boundaries were inundated. This map corroborates the newspaper report of tidal flooding on this day for these areas. From the map, it can be seen that the east part of Shyamnagar and the south part of Assasuni were inundated. The report reads as “a 40-km of embankment has been damaged while a 10-km stretch has completely been destroyed in Koyra upazila” and it can also be seen that south-west part of Koyra adjacent to river is submerged corroborating the report.

4. Discussion and conclusions

Gathering data for different fish types was a challenging task as different newspapers reported loss information for different fish types and it became more challenging as the data was not available for all the years between 2011 and 2020 (from July of 2011 to the June of 2021). However, the novel methodological framework (i.e., scrapping, labelling, extracting and validation) adopted for the study has helped to close this data gap to a certain extent. Results showing flood to be the most damaging risk for the aquaculture sector, followed by cyclones and excessive rain events reflects that the heat wave events relevant news were not reported sufficiently. This may be due to the absence of immediate impacts of heat waves on aquaculture operations unlike heavy rain impacts causing flood and washing away fish enclosures along with fish. It is noteworthy that the fish loss data before 2017 was not regularly available for

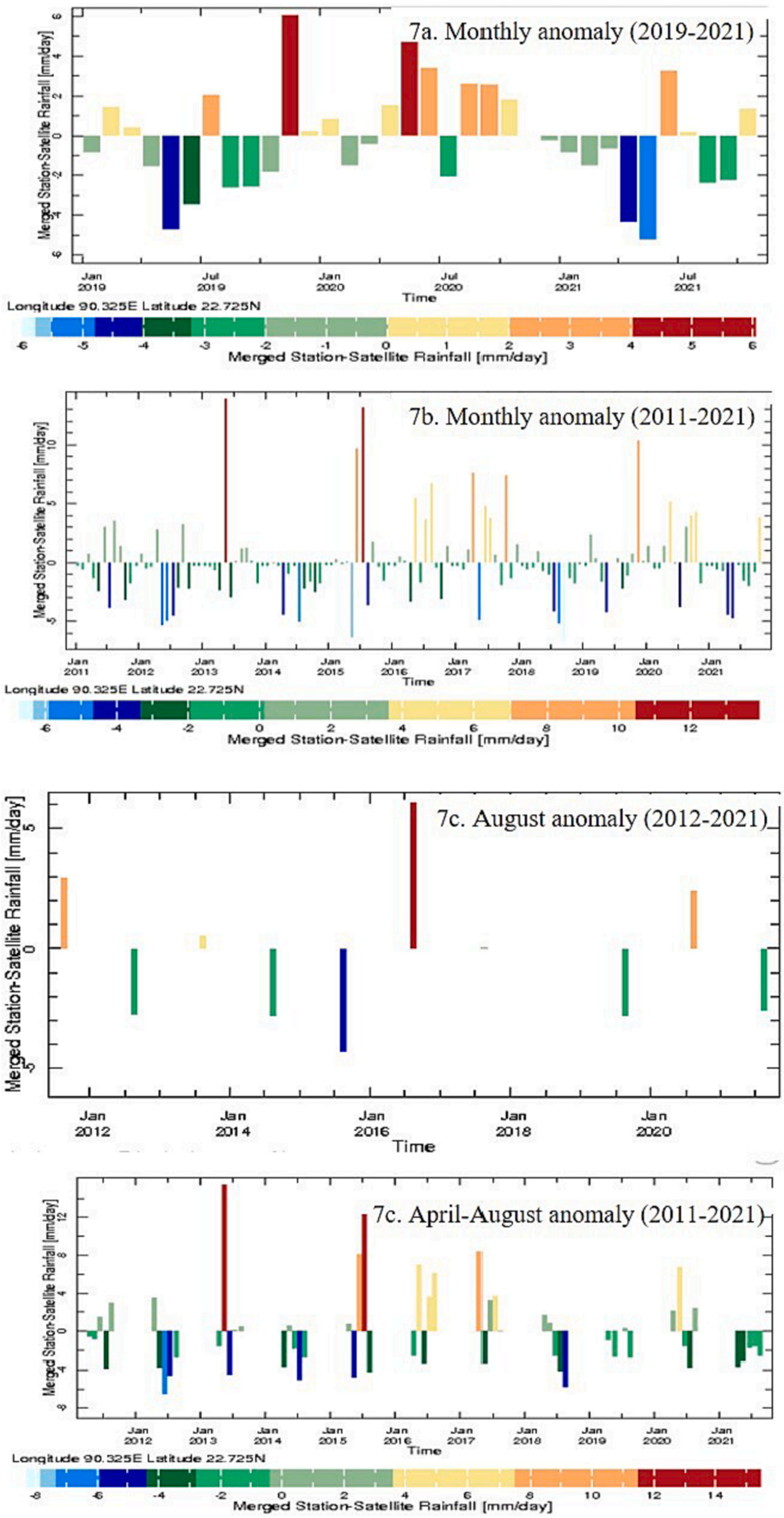

Fig. 7. Rainfall anomalies in Barisal.

almost all the districts. There were also very few articles in 2011 that reported on aquaculture losses, which could be due to the lack of coverage of the issue by newspapers at that time. The data from Bengali newspapers also could have been used but this was not considered to avoid further time requirement regarding Bengali data labelling and data analysis. As the data here represent extracted

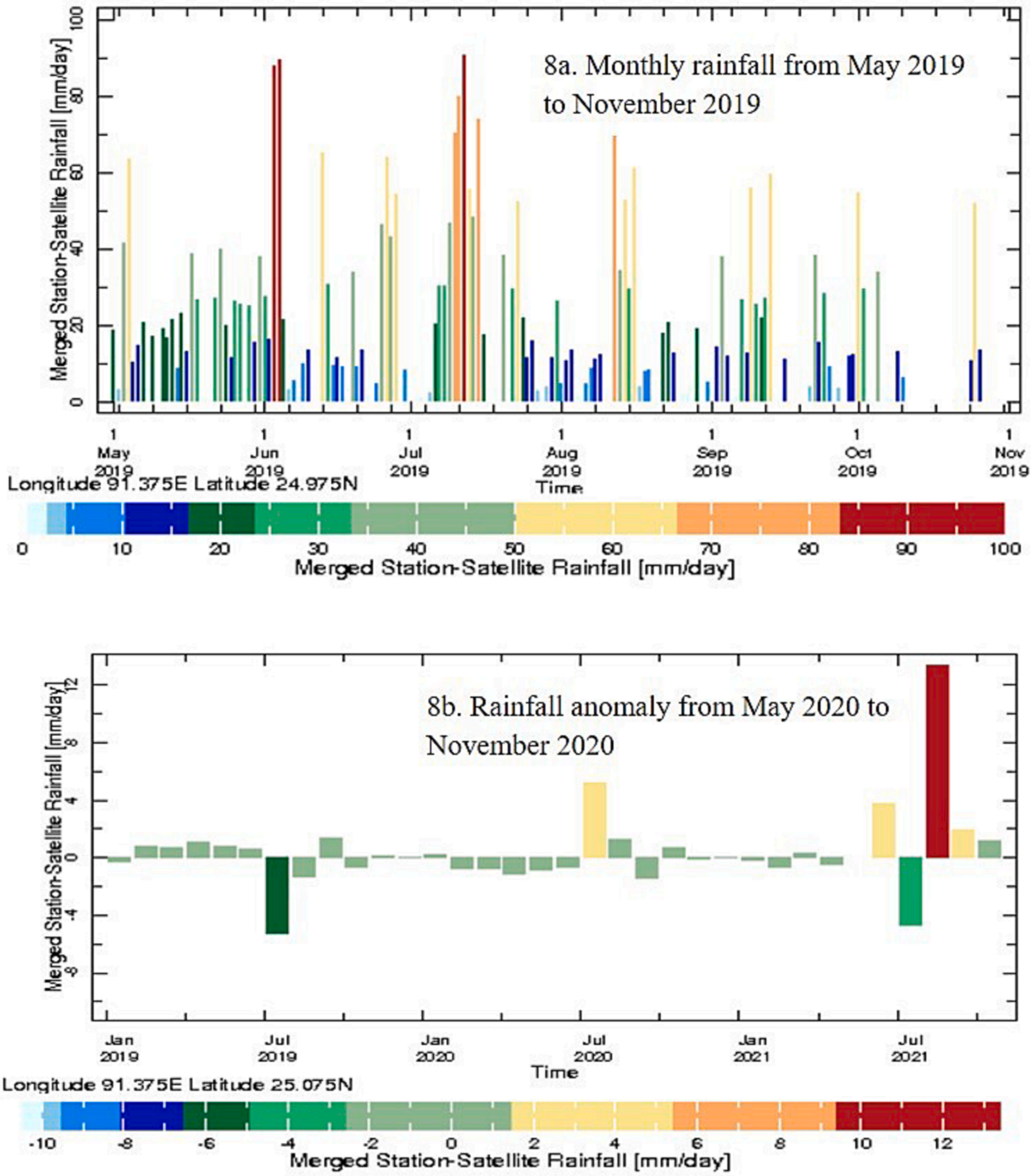

Fig. 8. Rainfall anomalies for a point location in Sunamganj.

newspaper data from only 4 newspapers, the newspaper data might have missed many real events, which is also evident from our estimate being significantly lower than the national statistics as discussed below.

Using the scraped newspaper data, we estimated that Bangladesh lost at least 7,9981 million tons of fish with a value of around USD 140.1 million between 2011 and 2020. In 2019 alone, the scraped data suggest that monetary loss for hatcheries, open water fish and shrimp was around USD 15.8 million while the actual loss reported by government sources was USD 166.7 million. Using the rule of thumb of 10 times the scraped damage value representing true damage, the total monetary loss between 2011 and 2020 is at least USD 1.4 billion. Floods and cyclones have been the most devastating climate events for aqutic food systems, with accumulated estimated damage of around USD 93.0 million and USD 24.8 million respectively between 2011 and 2020. Flood was the most damaging for hatcheries, while cyclone was the most damaging for shrimp.

In recent years, loss in the fisheries sector has increased significantly. In 2019, the monetary loss (according to scraped data) was around USD 15.8 million, which increased more than three-fold to USD 56.2 million in 2020. This sudden sharp increase in loss could be due either to less coverage of fish loss information in the newspapers in 2019, an increase in fish prices, increased loss in recent years, or a combination of all these potential facts. The argument for less coverage is partially supported by the avaiabiltiy of a few

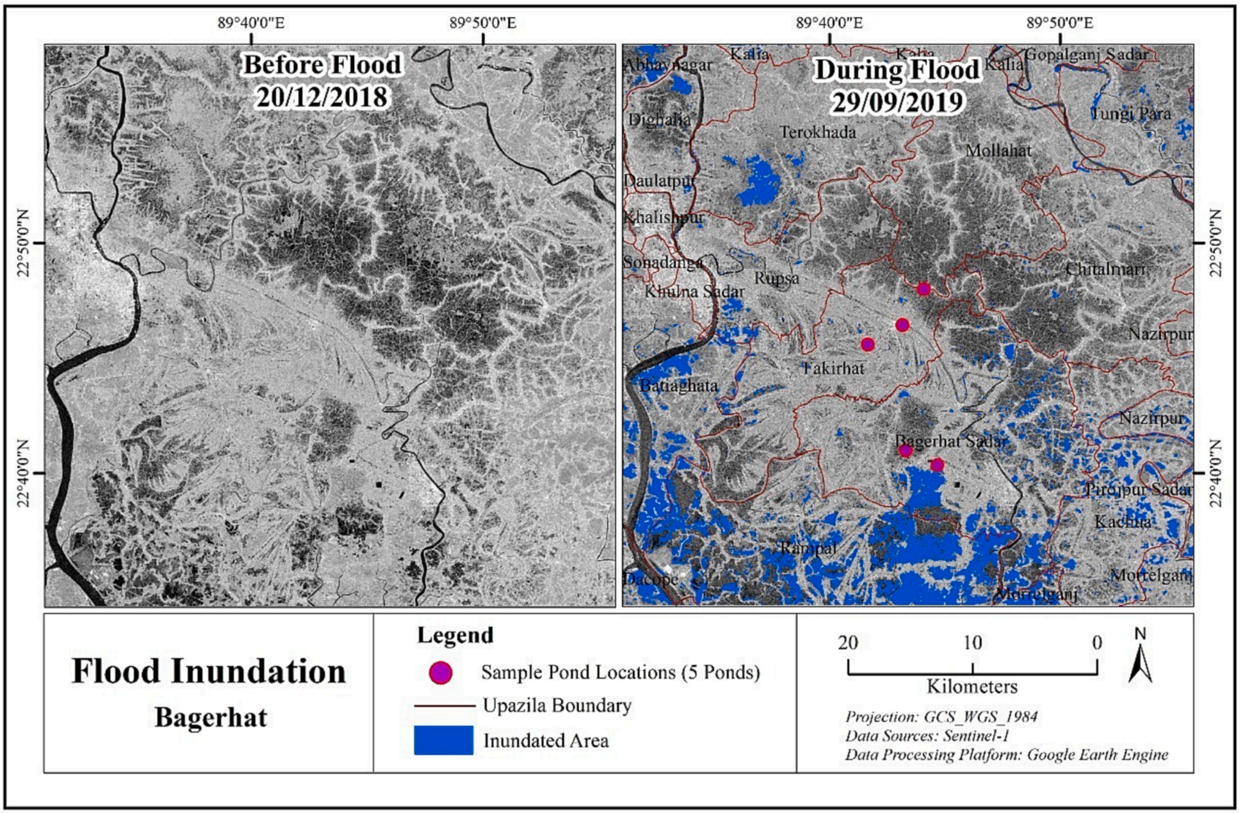

Fig. 9. Flood inundation map for five pond locations in Bagerhat.

articles before 2017 which resulted little information on loss data. In 2020, a sharp increase in loss was witnessed as the southern or coastal districts were hit by Cyclone Amphan. Besides, the Haor region (large, round-shaped floodplain depressions located in the North-Eastern region of Bangladesh) was also the victim of heavy rainfall induced flash floods during 2020 (Bhodra and Islam, 2020). Flooding in July 2019 could have been a flash flood that actually originated from India and was not due to the rainfall event in Sunamganj. This is further corroborated by the fact that there was heavy rainfall and a positive anomaly in June, which might also have had a role in the flooding occuring in July.

Low adaptive capacity of aquatic food systems to cope with this climate risks ultimately induce loss. The shrimp sector was found to be impacted more adversely than hatcheries and open water fisheries. Taking all damage types into consideration, Satkhira, Sunamganj and Bagerhat appear to have suffered the most fish loss. For hatcheries and open water fish alone, Sunamganj, Tangail and Gopalganj hae encountered the highest amount of financial loss, while Satkhira, Bagerhat and Khulna faced the highest loss for shrimp. Comparing monetary loss data for three damage types in 2019 against DoF data for 2019 indicated a large margin of under-reporting by the media; it thus can be said with high confidence that the real historical monetary loss is much higher than the estimated amount, with the alternative interpretation being that the actual losses could be around 10 times that reported in the newspapers. Verification of this rule of thumb would be possible by validating multiple years of loss data. This is left to future studies. For 2019, our estimated loss of USD 15.8 million was only 10.5 percent of the official reported data of around USD 166.7 million.

This study shows how newspaper scraping can be used as a potential source of information for generating data on the historical economic impact of climate on aquatic food systems, in a data-poor environment, although given the poor match between governmental and media reports, it should not be relied upon as an exclusive data source. This method can be replicated in other countries to generate estimated financial loss data for aquaculture where official data or statistics for aquaculture loss are not available or are sparce, although efforts may be required to educate the media as to how to report on and interpret the effects of climatic events on aquatic food systems. The reported economic damage can be considered as potential cost avoided by using CIS for a short lead time (i.e., 5 or 7 days) to deal with varaibiltiy induced risks (Hossain et al., 2021) as well as for a moderate lead time (seasonal) to deal with the extreme events' induces risks. This estimate can be an upper limit of economic value of aquaculture CIS and potentially provide a range of values for different sectors.

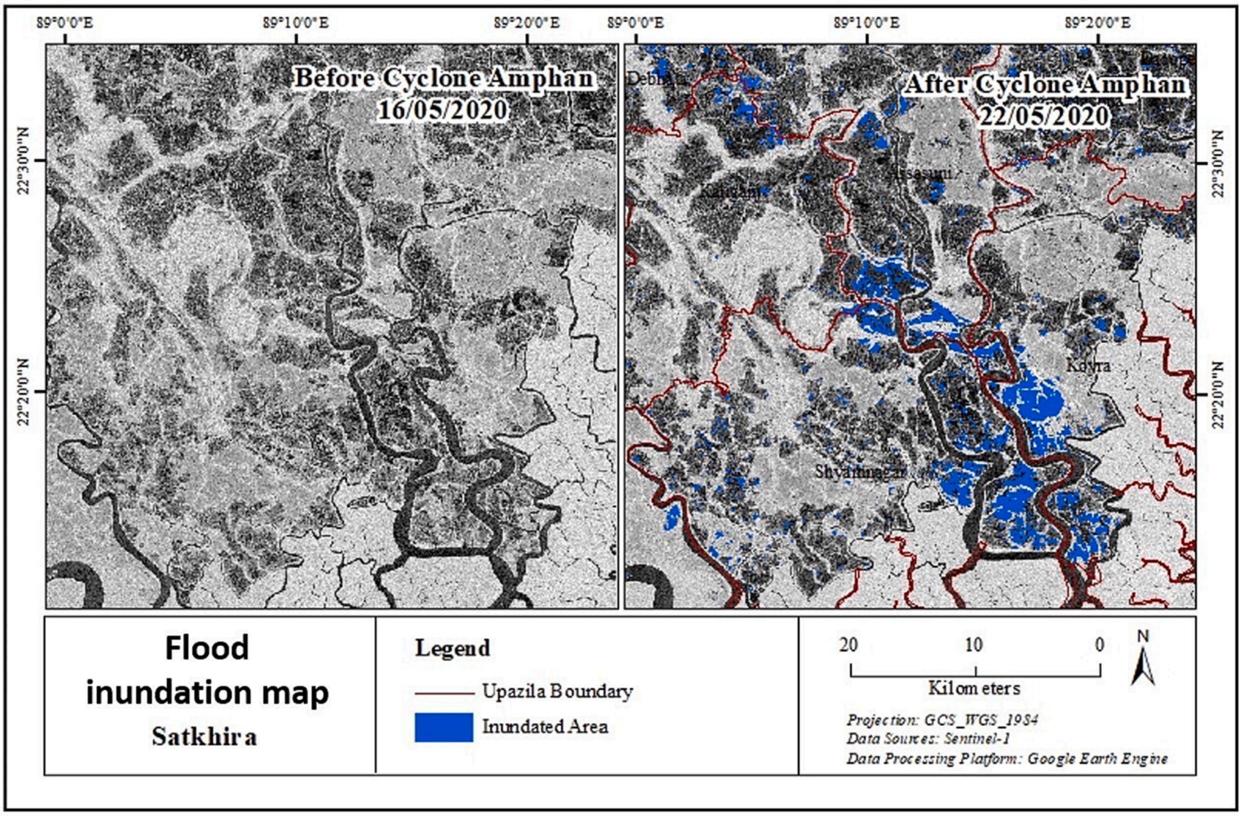

Fig. 10. Flood inundation map for Shyamnagar and Assasuni *upazilas* of Satkhira.

To underscore the importance of aquaculture CIS, a decision framework (Hossain et al., 2021) for managing temperature and rainfall varaibility induced risks in aquaculture of Bangladesh can be given, This framework is integrated into the existing digital platform (https://www.agvisely.com/about) initiated by CIMMYT for providing climate information services for a range of food systems. This aquaculture decsion framework is able to trigger advisories if the weather forcast exceeds the temeprature and/or rainfall thresholds identified for the selcted fish spcies. This is a live example from south-west and north-east part of the country for managing cliamte idnuced loss and/or damge of fish-farmers by taking pond water quality and/or feed management relevant decsions like feed convertion ratio, application of lime, use of aerator, adding ground water to balance pH, dissolved O2 and water temperature along with reduced disease outbreak and mortality rate, and optimal growth of fish stock.

If the CIS can offset at least 10 percent of climate-induced damage to aquaculture, and the scraping reports 10 percent of the actual damage, the value of CIS is approximately the same as the scraped monetary value (that is, around USD140 million) in Bangladesh between 2011 and 2020 (USD14 million per year). This demonstrates the potential of CIS in targeting aquatic food systems, indicating that for every additional 10 percent of damage offset, the estimated value of CIS increases by approximately USD 14 million annually. The study shows that investing in CIS and enabling offsetting actions by different supply chain actors like farmers and hatchery owners can create substantial benefits for the country, catalysing aquaculture growth, enhancing nutritional security and contributing to poverty allevaiation. There is a need for public and private sector attention in utilizing this opportunity. Furthermore, considering the earlier mentioned challenges regarding the availability of climate-induced loss and damage data, this study recommends implementing a broad range of climate literacy programs at the national level. These programs should target not only journalists for better capture and reporting but also extension officers, local service providers, and fish-farmers. This would enable them to identify climate-induced direct and indirect issues, assess associated losses, and report to relevant authorities to receive more appropriate climate advisories for specific risk management.

CRediT authorship contribution statement

Shammunul Islam: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Peerzadi Rumana Hossain:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing. **Melody Braun:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft. **T.S. Amjath-Babu:** Conceptualization, Funding acquisition, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Essam Yassin Mohammed:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision. **Timothy J. Krupnik:** Conceptualization, Writing – original draft, Writing – review & editing. **Anwar Hossain Chowdhury:** Data curation. **Mitchell Thomas:** Resources. **Max Mauerman:** Resources.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A

Interpolating monetary damage.

We used this algorithm to interpolate fish damage value in monetary terms for the observations where the damage is reported either in terms of area affected or in terms of the amount of fish affected. We also ran the above algorithm for every district and every different fish type separately in order to obtain all the different combinations of district and fish type. We could then interpolate fish damage separately for each of these different combinations.Fig. A1

The algorithm described above was run for all possible combinations of districts and fish types. To get monetary estimate of damage for district x and fish type y, the algorithm can be described as follows:Tables A2-A6

Filter the data to have data for district x and fish type y only.

Calculate average damage per pond/enclosure, average damage per ton and average damage per hectare for this filtered data.

Initialize an empty variable (say, row_indicator) which will keep a record of the row number in which monetary damage cannot be calculated using existing data.

Now loop through all the observations one by one to calculate monetary damage.

If an observation already has monetary damage data in it.

Monetary damage for this record = Monetary damage mentioned in the data.

Else if an observation does not have value for monetary damage.

Check if this observation has value for number of ponds and if it does then:

*Monetary damage for this record = number of ponds for this record * average damage per pond/enclosure.*

Otherwise, check if this observation has value for tons of lost fish and if it does then:

*Monetary damage for this record = tons of fish lost * average damage per ton*

Otherwise, if this observation has value for areas affected.

*Monetary damage for this record = hectares of areas affected * average damage per hectare.*

If the monetary damage value for this row is still empty or any of the previous damage information can't be calculated:

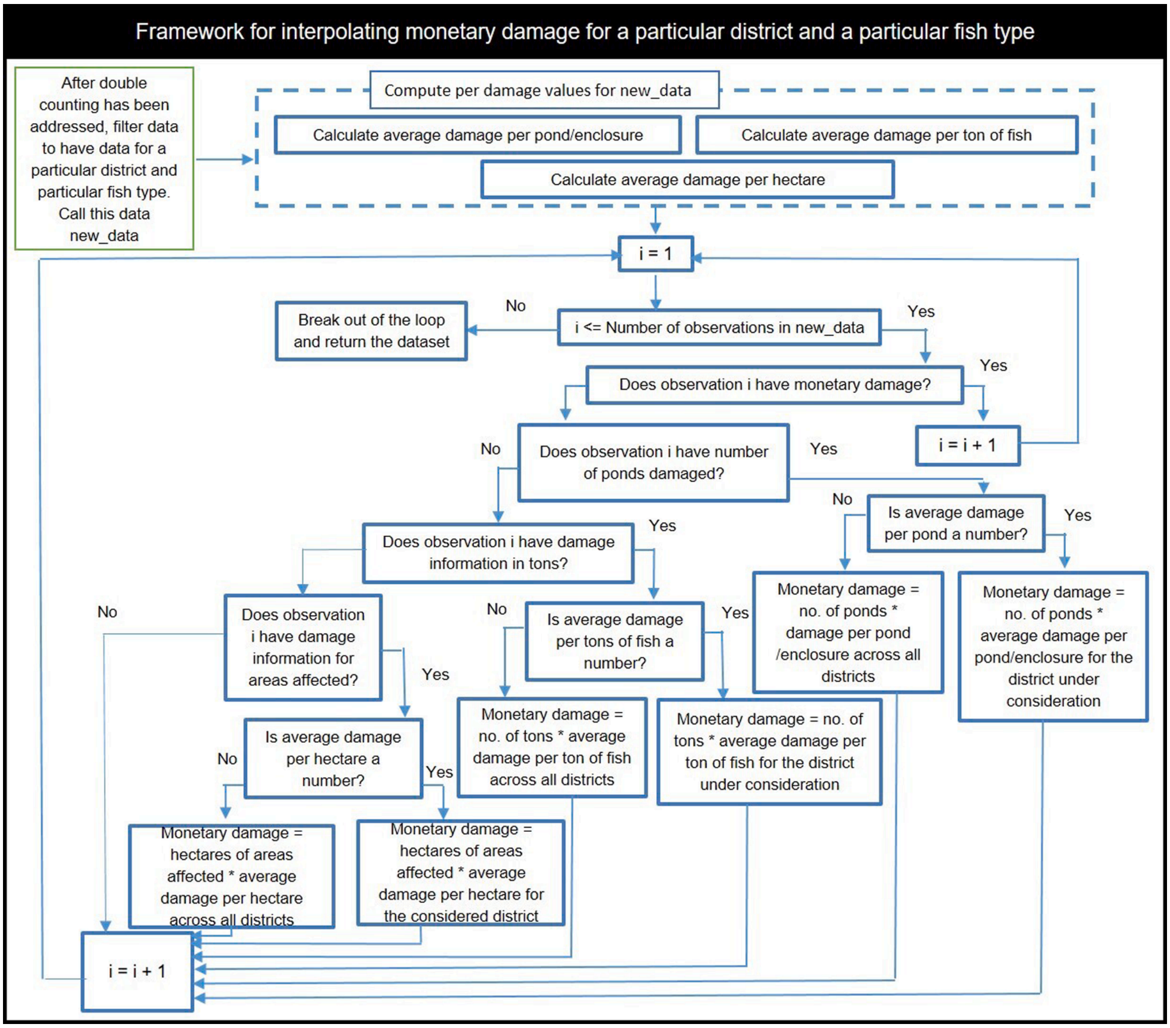

Fig. A1. Interpolating monetary damage for a district for any particular fish type.

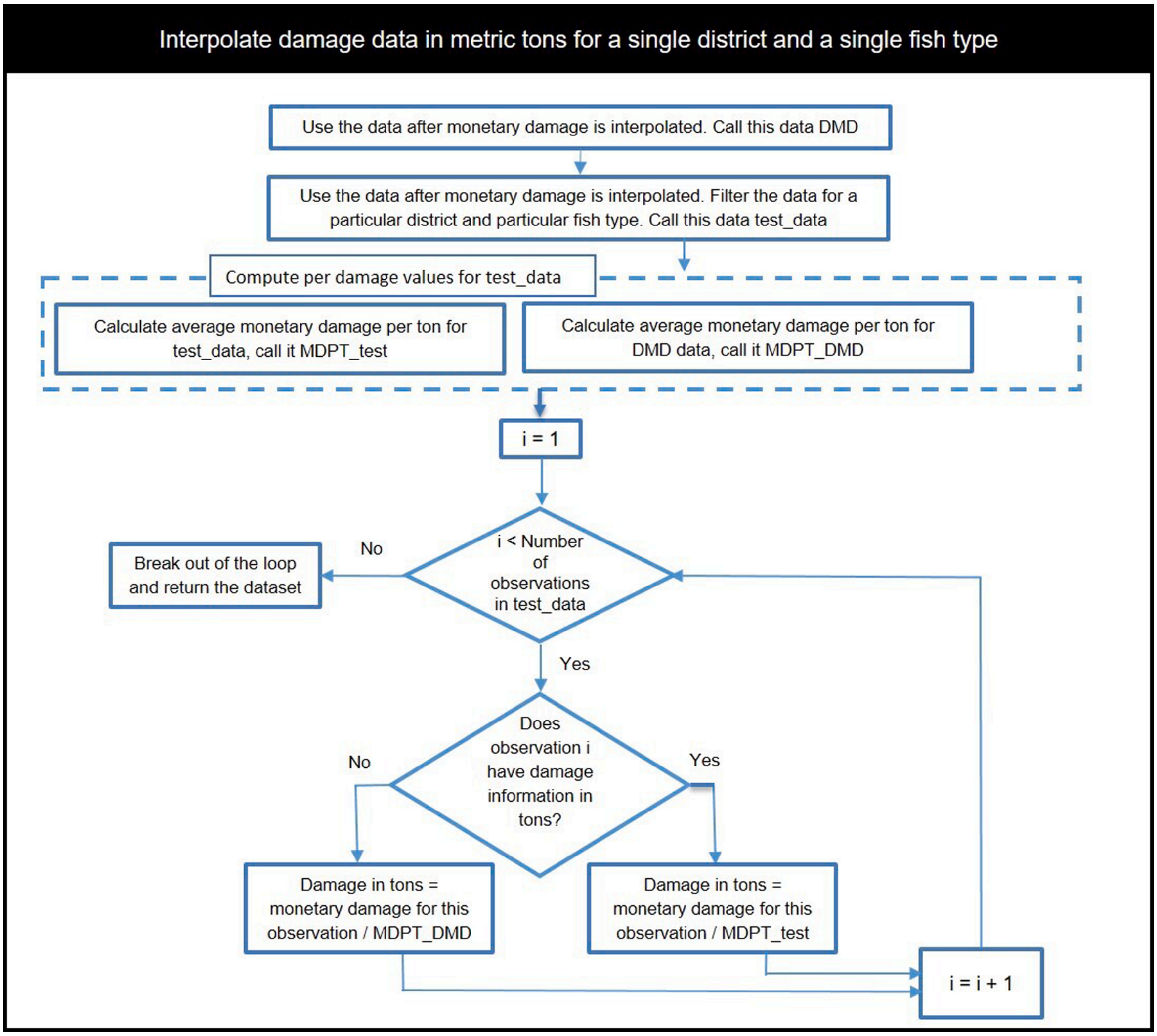

Fig. A2. Interpolating damage data in metric tons for a single district and for a single fish type.

Table A1
Monetary loss (in USD million) for all fish types (hatcheries, open water fish, shrimp) and loss in quantity (in tons, within parentheses).

District	2011	2012	2014	2015	2016	2017	2018	2019	2020	Total
Satkhira	20.5 (7755)	–	–	–	–	–	0.4 (161)	4.1 (3692)	0.8 (320)	25.9 (11928)
Sunamganj	–	–	–	–	11.1 (8414)	–	–	0.5 (400)	7.8 (5831)	19.4 (14645)
Bagerhat	–	–	–	–	7.3 (2611)	–	–	3.6 (1315)	8.3 (2980)	19.2 (6906)
Patuakhali	–	–	–	0.5 (94)	–	–	–	–	11.5 (2042)	12.0 (2136)
Khulna	4.3 (3000)	0.3 (127)	–	–	–	–	0.02 (7)	–	6.5 (4442)	11.2 (7576)
Jessore	–	–	–	8.5 (3041)	–	1.1 (381)	–	–	–	9.5 (3422)
Lalmonirhat	–	–	1.1 (380)	6.5 (2338)	–	–	–	–	–	7.6 (2718)
Tangail	–	–	0.6 (968)	–	0.1 (136)	–	–	0.4 (696)	5.3 (8705)	6.45 (10505)
Jamalpur	–	–	0.5 (181)	–	–	–	–	5.1 (2984)	0.1 (68)	5.7 (3233)
Gopalganj	–	–	–	–	–	–	–	–	5.3 (3212)	5.3 (3212)
Naogaon	–	–	–	–	–	2.1 (760)	–	–	2.6 (1983)	4.8 (2743)
Gaibandha	–	–	–	0.3 (214)	–	–	–	1.8 (2060)	0.6 (394)	2.7 (2668)
Netrakona	–	–	–	–	2.5 (1181)	–	–	–	–	2.5 (1181)
Natore	–	–	–	–	–	–	–	–	2.2 (798)	2.2 (798)
Madaripur	–	–	–	–	–	–	–	–	2.0 (1000)	2.0 (1000)
Munshiganj	–	–	–	–	–	–	–	–	0.9 (714)	0.9 (714)
Kurigram	–	–	–	–	–	–	–	–	0.8 (366)	0.8 (366)
Sylhet	–	–	–	–	–	–	–	–	0.7 (3518)	0.7 (3518)
Sirajganj	–	–	–	–	–	–	–	–	0.3 (155)	0.3 (155)
Habiganj	–	–	–	–	–	–	–	–	0.2 (257)	0.2 (257)
Rangpur	–	–	–	–	–	–	–	0.2 (88)	–	0.2 (88)
Rajshahi	–	–	–	–	–	0.1 (53)	–	–	–	0.1 (53)
Barisal	–	–	–	–	–	–	–	–	0.1 (40)	0.1 (40)
Joypurhat	–	–	–	–	–	0.1 (38)	–	–	–	0.1 (38)
Maulvibazar	–	–	–	0.1 (71)	0.002 (8)	–	–	–	–	0.1 (79)
Total	24.9 (10755)	0.3 (127)	2.1 (1529)	15.9 (5758)	21.1 (12350)	3.4 (1232)	0.5 (168)	15.8 (11235)	56.2 (36826)	140.2 (79980.9)

Table A2
Monetary loss in USD million and loss in tons by event for hatcheries, open water fish and shrimp (loss in quantity in tons, within parentheses).

From 2011 to 2020	Cyclone	Excess rain	Flood	Tidal surge
Total loss	24.8 (12479.7)	22.2 (13843.9)	93.0 (53605.7)	0.1 (51.6)

Table A3
Monetary loss in USD million due to flood in different years for hatcheries, open water fish and shrimp (loss in quantity in tons, within parentheses).

Fish type	2011	2014	2015	2016	2017	2018	2019	2020	Total
Hatcheries and open water fish	3.9 (2908)	0.6 (968)	1.4 (1078)	13.7 (9603)	0.1 (53)	NA	8.0 (6299)	17.3 (18132)	45.1 (38970)
Shrimp	15.3 (5488)	NA	NA	NA	NA	0.5 (168)	0.1 (39)	2.4 (874)	18.3 (6570)

Table A4
Monetary loss in USD million due to cyclone in different years for hatcheries, open water fish and shrimp (loss in quantity in tons, within parentheses).

Fish type	2019	2020	Total
Hatcheries and open water fish	NA	0.0004 (0.32)	0.0004 (0.32)
Shrimp	0.4 (134.94)	5.3 (1900.66)	5.7 (2035.6)

Monetary damage for this record = Empty or Not a Number (NA).
Add this observation number to row_indicator.
If there are still some observations with empty value for monetary damage:
Remove the list of rows with no values for monetary damage as indicated by row_indicator from the original dataset.
Return the modified dataset which now have estimated monetary damage for all the records contained in it.

Table A5
Monetary loss in USD million due to rain in different years for hatcheries, open water fish and shrimp (loss in quantity in tons, within parentheses).

Fish type	2012	2019	2020	Total
Hatcheries and open water fish	NA	NA	6.5 (6760.62)	6.5 (6760.02)
Shrimp	0.3 (126.926)	3.2 (1140.396)	0.6 (205.2712)	4.1 (1472.593)

Table A6
Loss due to tidal flood in different years for hatcheries, open water fish and shrimp.

Fish type	2020	Total
Shrimp	0.1 (51.58)	0.1 (51.58)

Appendix B

Interpolating fish damage in tons.

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