PLOS CLIMATE

RESEARCH ARTICLE

Local social-ecological context explains seasonal rural-rural migration of the poorest in south-west Bangladesh

Lucie Clech[1,2]*, Juan Pablo Sierra[3], Muhammad Abdul Mannan[4], Mollah M. Shamsul Kabir[4], Mrittika Barua[4], Jhan-Carlo Espinoza[5,6], Valery Ridde[1]

1 Université de Paris, IRD, INSERM, Ceped, Paris, France, **2** Department of Anthropology and Archaeology, University of Bristol, Bristol, United Kingdom, **3** Laboratoire de Météorologie Dynamique (LMD), IPSL, CNRS, École Polytechnique, Palaisseau, France, **4** BRAC James P Grant School of Public Health, BRAC University, Dhaka, Bangladesh, **5** Institut des Géosciences de l'Environnement (IGE, UMR 5001), Université Grenoble Alpes, IRD, CNRS, Grenoble INP, Grenoble, France, **6** Instituto de Investigación sobre la Enseñanza de las Matemáticas, Pontificia Universidad Católica del Perú, (PUCP), Lima, Peru

* lucieclech@gmail.com

Citation: Clech L, Sierra JP, Mannan MA, Kabir MMS, Barua M, Espinoza J-C, et al. (2024) Local social-ecological context explains seasonal rural-rural migration of the poorest in south-west Bangladesh. PLOS Clim 3(3): e0000239. https://doi.org/10.1371/journal.pclm.0000239

Editor: Ferdous Ahmed, IUBAT: International University of Business Agriculture and Technology, MALAYSIA

Received: May 30, 2023

Accepted: February 13, 2024

Published: March 26, 2024

Peer Review History: PLOS recognizes the benefits of transparency in the peer review process; therefore, we enable the publication of all of the content of peer review and author responses alongside final, published articles. The editorial history of this article is available here: https://doi.org/10.1371/journal.pclm.0000239

Data Availability Statement: This study involves human research participant data. Our qualitative data set will be available upon request. Quantitative

Abstract

Bangladesh is one of the countries most affected by climate change. Internal migration is often presented as a response to environmental degradation. Here, using a people-centred perspective, we explore the complexity of the links between climate-induced change, environmental degradation caused by waterlogging and seasonal rural migration. We used an inductive qualitative approach in social sciences, conducting fourteen semi-directed interviews and six focus group discussions in March-April 2022. We related those results to a rainfall analysis on CHIRPS data for 1981-2021and we represented interactions and feedback between changes and livelihoods in a model. A complex picture of the situation is emerging, showing the interweaving effects of non-climatic and climatic changes, their interplay at different scales, their cumulative effects, the interactions between livelihood types and feedback between social and natural systems. Most of the climate-induced changes gradually become noticeable over the past 25 years. Climate data confirm these changes in recent decades, with July being wetter and January being dryer. Villagers reported waterlogging as the most significant change in their community, pointing to its multiple causes, originating in non-local and local, non-climatic anthropic changes, exacerbated by shrimp farm enclosures and worsened by climate-induced changes such as heavier rains, wetter monsoons and cyclones. Tiger prawn farms, reported as a lucrative and local adaptation to waterlogging and salinisation for the ones who can afford it, worsen the situation for the less wealthy, causing waterlogging and salinisation of the adjacent agricultural lands and buildings, the disappearance of traditional fishing and a reduction of the local job market. In addition, erratic rain patterns, droughts and cyclones affect local production and labour markets. COVID-19 lockdowns, by impacting markets and mobilities, further aggravated the situation. Inequality has increased as the range of adaptations of the less wealthy appears limited in this context of multiple crises.

secondary data (rainfall data) is freely available here :https://www.chc.ucsb.edu/data/chirps.

Funding: This study is funded by the French National Research Agency (ANR) as part of the French presidential call "Make Our Planet Great Again" (MOPGA), ANR-18-MPGA-0010. The funders had no role in study design, data collection and analysis, publication decision, or manuscript preparation. The Grant recipient was VR.

Competing interests: The authors have declared that no competing interests exist.

Introduction

Bangladesh is among the fastest-growing economies in the world and is improving on numerous development indicators [1], but it is also one of the vulnerable countries most affected by climate change [2]. There, rural livelihoods are undergoing many, often interrelated changes, from socio-economic and demographic changes to environmental changes and climate-induced changes, which are exacerbating the situation. For example, cyclones, droughts, heavy rainfall, and consequences from land and water use changes are among the challenges experienced by the coastal population [3–7]. Changes in land use and water management associated with the development of brackish shrimp production cause important environmental degradations, due to the influx of salt water and water congestion, resulting in waterlogging and salinisation of soil and water [4]. Heavy rains, intensifying monsoons and cyclones are additional factors that aggravate waterlogging [8], highlighting the importance of identifying feedback and interactions between and within natural and social systems Finally, economic, political and social dimensions are significant: the first fish and shrimp processing plants were set up in the late 50s and early 60s [9] and the start of shrimp farming is mentioned in the 70s [10, 11]; since then, freshwater and brackish water shrimp farming have depended on international demand and market. Shrimp production is an important source of income for the country and leads to local power dynamics over access to natural resources to the disadvantage of the less wealthy [4, 5, 12]. Other global changes, such as the COVID-19 pandemic crisis, have added to the burden of this population [13] and should not be ignored.

Several studies have pointed out the role of internal migration in supporting rural livelihoods in southwestern Bangladesh, with migration being cited as a response to environmental degradation [7, 6, 14, 15]. The phenomenon is expected to increase with pessimistic climate change scenarios, amplifying environmental degradation and projecting the number of 13,3 million climate migrants by 2050.

The climate change-migration nexus is increasingly covered in academic research while still being debated [16]. Migration is complex in form, origin and destination, temporality, investment and outcome [17] and pathways connecting climate to migration are multiple and non-linear [18]. In short, climate-induced migration decisions and pathways are embedded in a complex socio-economic, behavioural, and environmental context [19, 20], and ignoring this complexity might lead to overlooking other important non-climate induced changes, thus hampering long term solutions [4, 21] by misreading the evolution of the Bangladesh delta and the associated livelihoods.

Past studies in southwestern Bangladesh have shown various migration strategies depending on contexts, sectors or social-ecological systems [7, 14]. Our study aims to explore villagers' responses to what they perceive as important events impacting their community and livelihoods. In other words, using an inductive, people-centred approach, we examine how villagers perceive and experience changes to contextualise climate changes and explore the mechanisms by which changes interact and impact local production, power dynamics and labour markets, pushing out unskilled workers seasonally. We argue that local heterogeneity of livelihood at the village level is essential to consider because socio-political and institutional contexts, including local power dynamics, values and interests, interact with the environmental context and limit the possible choice of responses to changes for households and individuals [5, 22–24].

Most recent multi-site studies encompassing various villages in regions or districts on the exposed coast, thus providing a sub-regional perspective. While the effects of climate change are intensifying, waterlogging and salinisation are also increasing on the interior coast [8, 25], showing the need to focus further inland. We propose a qualitative approach combined with rainfall analysis on one village of the most rural Unions in Tala Upazila, located on the south side of the interior coast (see the map in Fig 1) that has been increasingly embracing brackish shrimp farming in the last decade and where waterlogging is intensifying [8].

Based on empirical data, this research aims to fill the gap about the complexity of the links between climate change and migration. This work contributes to the growth of the limited research based on a people-centred perspective necessary for a better understanding of local experiences. In addition, this research aims to reflect on the dialogue between natural sciences and social sciences by combining the experiences of climate, and climate data analysis, and by identifying the interactions and feedback between and within natural and social systems to understand better the effect this has on the most vulnerable and poorest people. Finally, this paper focuses on rural-to-rural migration, less explored than rural-to-urban migration in Bangladesh.

This article tries to answer these questions:

1. What significant changes do villagers believe have impacted their village and livelihoods over the past five years, and are these changes reflected in rainfall data analysis?
2. In what ways are different livelihoods impacted and responding to these changes in this village?
3. What are the connections between environmental changes (climate and non-climate-related), other changes and unskilled seasonal migration of the poorest in this village?
4. What recommendations can be made from our study to inform future policies?

Methodology

This study is part of the second phase of a mixed-method sequential exploratory project on climate change, migration and health system resilience. In phase I, when compiling the site monographs, we identified waterlogging as an environmental threat at Tala. In addition, six months in the earlier stages of phase II, focus group discussions and interviews were conducted in various communities in the Tala Upazila, and waterlogging was identified as the most important local environmental challenge in this area, which is also confirmed in the literature [8]. This study extends this qualitative data collection (Phase II) to focus on one rural community experiencing waterlogging to explore the most environmentally challenging context and the interactions between different local issues. In the ClimHB conceptual framework [26], this study encompasses the changes (shock, events, stress), the (im)mobility and adaptative capacities of the population. Here, for this study, we use an inductive social-ecological approach drawing on previous studies using ecosystem services (i.e. ecosystem providing food, water and income) as resources for rural livelihoods in Bangladesh [27, 28] but at the level of a village and with a qualitative focus on local perceptions and experiences. In question (1), we used a convergent parallel mixed method design [29] relying on a combination of natural (quantitative) and social sciences (qualitative) to compare emic perception with climate data, and in questions (2) (3) (4) we used a qualitative methodology.

Study site

We focus on one inland rural community in Tala Upazila, which is not experiencing the environmental deterioration of southern territories but might be next in line [8, 30]. Tala Upazila is located in the Satkhira District in the Khulna Division of Bangladesh. The chosen location in Khalilnagar Union was selected after an extensive prior visit to the Tala Upazila and with practical and logistical considerations. It is located between Khalilnagar bazaar and the Shalta river.

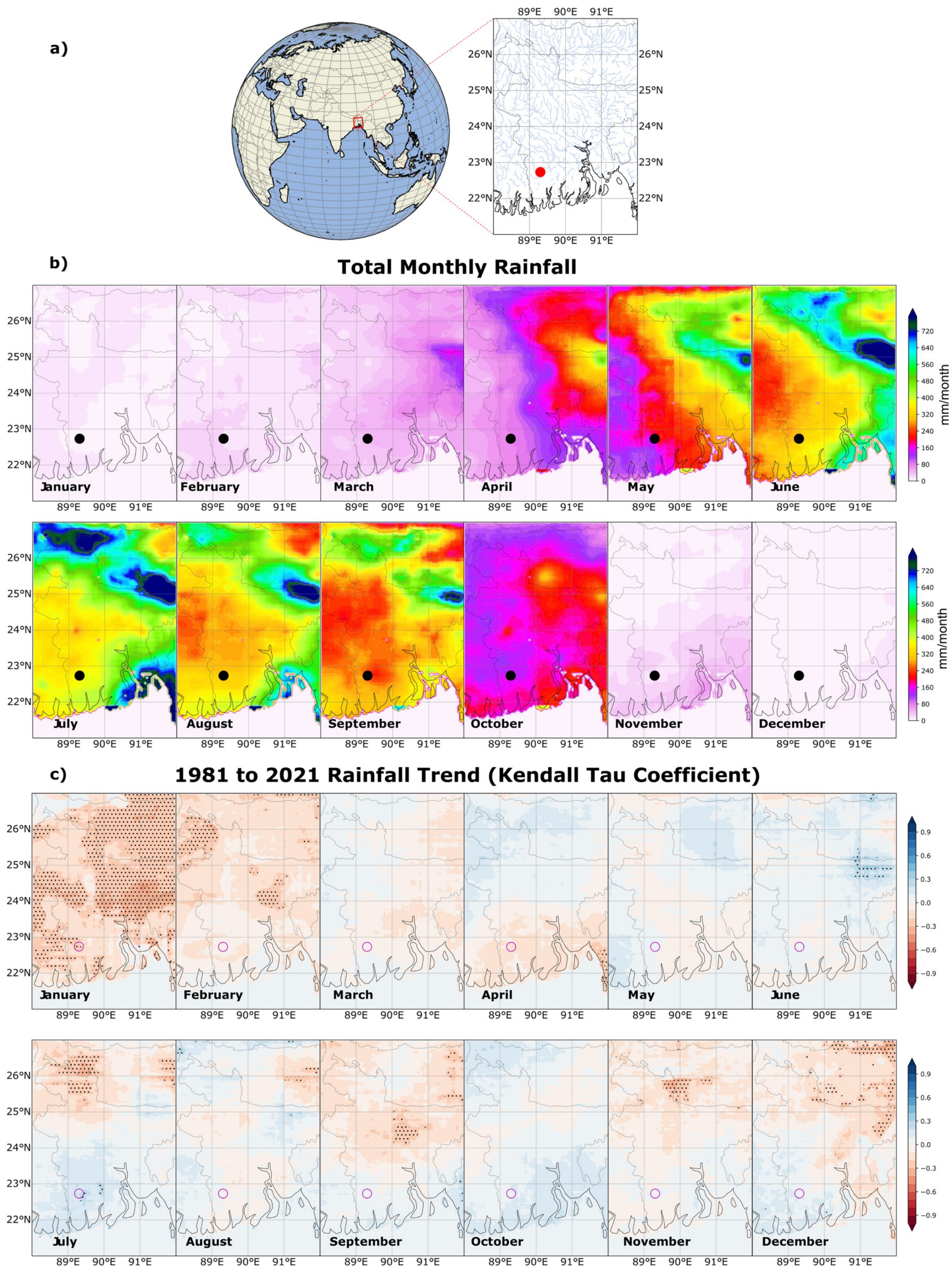

Fig 1. (a) Location of the interest region and river network from the vectorised information HydroRIVERS derived from the World Wildlife Fund's (WWF) HydroSHEDS. (b) Monthly accumulated rainfall mean for the period 1981–2021 from the CHIRPS database. Data in mm/month. (c) Rainfall trend measurement through the Kendall coefficient. Small black dots highlight places with significant trends at 95% confidence. Blue indicates an increasing rainfall trend, while red indicates a decreasing trend. The location of Tala (89.30567 W˚–22.73222˚ N) is represented with a dot in all subplots. HydroSHEDS database is freely available for scientific, educational and commercial use and is available at https://www.hydrosheds.org/products/hydrorivers. CHIRPS dataset is in the public domain as registered with

Creative Commons and is available at https://www.chc.ucsb.edu/data/chirps. The figures of all the subpanels have been created with the free software Python version 3.8.5 (Van Rossum and Drake 2009). Geographic information such as country and continent boundaries comes from Python's Cartophy library. Cartophy uses geographic information from freely available databases such as Natural Earth (available at http://www.naturalearthdata.com/) in the public domain.

https://doi.org/10.1371/journal.pclm.0000239.g001

The study site is approximately 20km from Khulna and Satkhira and 25-30km from Jessore, three regional cities with meteorological stations. Analysis of regional data from those forecast stations has already been covered in the literature for 1995–2015 [3]. This Union is one of the most rural and poorest of Tala.

Qualitative data collection and analysis

We use the local perceptions, changes and impacts experienced by villagers over the past five years to understand the complexity of a changing context. We collected the data from March to April 2022 with an inductive qualitative approach focusing on livelihoods. Interview and FGD guides were designed to collect emic perspectives on (a) the external changes impacting their household since 2017 (b) the impacts of these changes on the livelihood of the respondents and their household's members (c) their strategies to overcome these impacts (d) the impacts of these strategies for the respondent and their household's members (d) the type of projects or programs that impacted directly or indirectly their livelihood or the community life (e) respondent experience, knowledge, and views on climate change. This people-centred perspective facilitates the identification of interaction effects between events/changes that could accumulate in a context(s) of multiple stresses, multi-crises and interactions between livelihood pathways.

We carried out six focus group discussions (FGDs) and 14 semi-structured interviews (SSIs) (Tables 1 and 2) [31] for a total of 50 persons, including crop farmers (vegetable, fruits, rice, and other cereals), shrimp/ fish farmers (cultivators), independent fishermen, wage

Table 1. Respondents' characteristics (FGD).

FGD#	Number of participants	Gender	Age class	Religion	Main Occupation	Wealth status	Connection between participants	Presence of other person
FGD.1	4	Males	35–55	Muslims and Hindus	Shrimp farmers and shrimp business	Wealthy	Business and training	None
FGD.2	8	Females	18–30 and one elder 50 +	Muslims	Housewives (husbands are farmers cultivating crops and having shrimp farms)	Middle class	Husbands are related and they are neighbours	Children
FGD.3	7	Females	35–50	Hindus	Housewives, (husbands are goldworkers)	Lower middle class	Husbands are related and they are neighbours	Children
FGD.4	7	Males	50–70	Muslims	Independant fishermen	Very poor/ poor	All related and neighbours	Kin and neighbours
FGD.5	6	Males	20–50	Muslims	Independent fishermen	Very poor/ poor	All related and neighbours	Kin and neighbours
FGD.6	4	Males	<40 and one elder 60 +	Muslims	Paddy farmers	Lower middle class	They are related and neighbours (father and sons)	Wife of the elder

Notes: All were married with children. Shrimp farmer (or shrimp cultivator) is a generic name for farmers cultivating mostly crustaceans such as freshwater prawns (Golda), brackish prawns (Bagda or Tiger prawns), and also some fish like Tilapia, and Rui among others in artificial freshwater or brackish ponds (enclosure or gher). They might focus on one variety of shrimps/prawns and mix multiple species simultaneously or consecutively. Brackish shrimps (Bagda) are becoming more commonly used, due to the cheaper costs of immatures, their resistance, the higher production and the price on the market at maturity. Numbers of the FGDs (first column) were attributed chronologically, starting from the first one. Wealth categories are relative to the community.

https://doi.org/10.1371/journal.pclm.0000239.t001

Table 2. Respondents' characteristics (Interviews).

Semi-structured Interview #	Gender	Age	Religion	Main Occupation	Wealth status	Other participant presence if any
SSI.1	F	34	Muslim	Wife of daily worker-farmwork	Poor	Husband
SSI.2	F	36	Muslim	Wife of migrant -farmwork	Poor	Mother-in -law
SSI.3	M	36	Muslim	Daily-worker, brickfield, independent fishing	Poor	Wife
SSI.4	M	50	Muslim	Daily-worker, farmwork, brickfield	Poor	Wife
SSI.5	M	38	Muslim	Shrimp farmer	Wealthy	Wife, nefew
SSI.6	M	52	Muslim	Farmers -paddy/crop and shrimp farming	Wealthy	Nefew
SSI.7	M	55	Muslim	Shrimp farmer, paddy and crop farmer	Wealthy	None
SSI.8	M	70	Muslim	Shrimp farmer on khasland	Lower middle class	Neighbours, family
SSI.9	M	45	Muslim	Crop farmers	Lower middle class	None
SSI.10	M	45	Muslim	Daily worker -brickfield, farmwork in the community	Poor	None
SSI.11	M	45	Muslim	Brickfield worker	Poor	Wife and neighbours
SSI.12	M	52	Hindu	Service job-barber	Poor	Wife
SSI.13	F	55	Muslim	Wife of Small cattle farmer	Lower middle class	Husband
SSI.14	M	50	Muslim	Shrimp farmer, mango farmer and paddy farmer	Upper middle class/ wealthy	His father

Notes: All were married with children. Numbers of the SSIs (first column) were attributed chronologically, starting from the first one. Wealth categories are relative to the community.

https://doi.org/10.1371/journal.pclm.0000239.t002

labourers, housewives, and/or people who lived in flood-prone locations. We use the term of shrimp farmers, and shrimp farming, as previous literature in Bangladesh use this term. In our site, the shrimp farmers grow shrimps and fish (finfish). Farmers call themselves *gher malik*, use fresh and brackish water in different types of enclosures (*gher)*. They are mostly *chingri chashi* (shrimp farmers), but they also produce various types of fish (they are also *mach chashi*), alongside other agricultural activities as explained in the result section. Independent fishermen (*jélé*) are landless villagers fishing wild fish and shrimps in streams, ponds, and wetlands originally. They are now paying for access to the enclosures to fish.

For citation purposes, each FGD and SSI received an individual number as reported in Tables 1 and 2 (i.e: ISS.3 for semi-structured interview number 3). Participants were recruited using a snowball approach, starting with people attending a meeting about a program for shrimp farmers that was brought to our attention by a local official. We tried to vary the profile of the respondents according to the categories suggested by the respondents to capture diverse categories of livelihood and living conditions.

External changes were defined as all changes or events impacting their community and household since 2017, the year of a widespread destructive flood in the region [32] to allow for a decent recall time for the interviewees' memories, and to identify the recent events and changes impacting their community. While describing those changes, informants compared past time (prior to 2017) to current time (2017–2022), providing information about their occurrence or severity prior to 2017. We wanted to include all types of recent or ongoing external events or changes perceived as important by the community members to understand how crucial climate-induced changes have been for this community and how changes or events of all types related to each other. Rather than an exclusive criterion, the external changes provide an entry point into the discussion of the issues faced by community members and allow us to be more open to other changes perceived possibly as more important to the community than climate change.

Inductive content analysis [33] was performed to understand how the social-ecological context impacts different types of livelihoods that emerged during analysis (land-right owners: shrimp farmers, agricultural farmers, landless: independent fishermen and daily/contract workers) and how this shapes the context for the poorest and landless and their migration strategies.

In the final section of the results, we used a social-ecological system approach to illustrate the complexity of the local context. This work builds conceptually on the ClimHB conceptual framework [26], and most specifically on the dimensions based on the FCDO (formerly DFID) framework, which includes context, disturbance, capacity to deal with, and action-reactions [34]. We based this representation on the analysis of qualitative data to reconstruct changes in livelihoods, following the path (changes>impacts on livelihoods>responses>impacts). To do this, we developed a model based on previously described people's perspective, in the form of a diagram, showing the influence of changes on livelihoods, as well as interactions and feedback inside the system (Fig 3) based on a "common sense approach" [18], converging with to the conceptualised system dynamics model presented by Hossain et *al*. [27] and the complex adaptative system [35] produced by Talukder et *al*. [36] of social ecological system in Bangladesh. The three field researchers validated the final version by consensus. Separate diagrams for the different livelihood types are presented in supportive information (S1–S4 Figs). Such approach is advantageous regarding interdisciplinary communication and knowledge transfer to the population and decision makers.

Quantitative climate data and analysis

To support the qualitative information from local's perceptions, we use secondary data from the Climate Hazards group Infrared Precipitation with Stations (CHIRPS; [37]). This dataset combines satellite and *in-situ* rainfall stations to produce rainfall-gridded estimations at a high spatial resolution (5.5km x 5.5km). CHIRPS spans from 50˚S to 50˚N and ranges from 1981 to the near present. Its long-time record and high spatial resolution make this database useful for analysing rainfall trends at regional and local scales. CHIRPS dataset is freely available here: https://www.chc.ucsb.edu/data/chirps.

The annual cycle of precipitation is computed with CHIRPS estimations. For this, we averaged the accumulated rainfall falling each month over the period 1981–2021. Temporal rainfall trends for 1981–2021 were identified in each map grid cell using the rank-based non-parametric Kendall test [38]. Rainfall analysis needs to cover several decades to identify changing patterns [39]. Since local climate depends on the regional climatic context, a regional approach is necessary [40]. This statistical test is widely implemented in hydrology and climatology studies in the region [41, 42]. The statistical analysis of rainfall trends was performed using the Python package pyMannKendall developed by Hussain and Mahmud [43].

Figures for climatological data were designed with the Python library Cartopy [44] created by the MetOffice. We used the free software Python version 3.8.5 [45]. All Python libraries used in this study are open source initiatives. The geographic information used to create the maps is based on public domain databases such as Natural Earth (available at). Finally, a freely available database for the Asian stream and river network produced by the World Wildlife Fund's (WWF) HydroSHEDS was used [46]. In addition, we analysed the time evolution of July rainfall for our exact study site, located at 89.30567 W˚– 22.73222˚ N for the same period, because it was the month showing a significant increase in rainfall.

Ethics approval and inclusivity in global research

Ethics approvals have been granted from the Institutional Review Board (IRB) of the BRAC James P Grant School of Public Health, BRAC University (ref: IRB-19 November'20–050) in

Bangladesh. The usual ethical criteria for qualitative health research was respected, [26]. Information about the study was provided before data collection, verbal consent was collected, respondents were informed of their right to withdraw at any moment, a debrief with respondents was conducted at the end, and written consent were collected before leaving. Additional information regarding the ethical, cultural, and scientific considerations specific to inclusivity in global research is included in S1 Checklist.

Results

Southwestern Bangladesh lies in the arms of a delta, crisscrossed by a network of multiple rivers and canals leading down to the sea (Fig 1a). While this green land was once compared to a fertile Eden by Bangladeshi poets, livelihoods have become more problematic even in this community, more than 50 km inland. Once, floods used to bring fertile sediments; nowadays, sedimentation issue and waterlogging affect communities near riverbeds and shrimp farms, and climate-induced changes are exacerbating the issue with heavy rainfalls, wetter monsoons and cyclones. While most of villagers reported a religious interpretation of climate change causes resulting from God's doing or God(s) punishment, climate-induced changes have a growing impact on their lives, as presented in the following sections.

This section is based solely on the analysis of field data and secondary climate data. Discussion of these results in relation to the literature is presented later in the discussion section. During analysis of the interviews and FGDs with the 50 respondents, we categorised the information collected into four categories of livelihoods that reflect self-identification and land-right status locally: land-right owners with agricultural farmers and shrimp farmers (part 1 of results) and landless with independent fishermen and wage labourers (part 2 of results). The identification of these categories reflects livelihood pathways and actions/responses to changes (Results: parts 1 and 2). It enables the identification of intra- and inter-pathway interactions and feedbacks (Results: part 3), thus facilitating the identification of social and ecological stressors for the poorest and landless. This categorisation also facilitates the representation of the dynamics in the social-ecological system, leading to the migration of the poorest and landless (Results: part 3, Fig 3). Those categories do not represent some strict employment categories but rather a connection of their livelihood to natural resources and are not exclusive. Many crop farmers have become shrimp farmers. Some mix crop and shrimp farming, the young generation of open-water fishermen resort to unskilled jobs, and many villagers are fishing punctually. In addition, those categories reflect two wealth categories based on land access: fish and crop farmers have "land" access, while fishermen and wage labourers are landless, unskilled and among the poorest.

Apart from the COVID-19 lockdowns, all changes cited were directly or indirectly climate-induced, and waterlogging was said to be exacerbated by heavy rainfall and cyclones. Lockdowns imposed during the COVID-19 crisis in 2020 aggravated the economic situation of all, creating a context of multiple crises. Fish and crop farmers had to sell their products locally at a much lower cost, and often on the black market. Local workers had to work illegally to survive, and migrants had to move before or illegally during the lockdown, thus experiencing police violence. NGOs and authorities provided some support, but not all disadvantaged families received it. Most relied on formal and informal loan and debt systems.

1. Farming is experiencing difficulties because of climate-induced and environmental changes

1.1 Crop farmers perception and experiences. Many farmers practice mixed farming, sometimes having farmland on lowlands and uplands, which are only a few meters above lowlands. Farmers often have multiple sources of income from various crops, from rice to vegetables, fruits and other cereals, poultry and small-scale livestock, milk production and small-scale shrimp farming. In addition, they are often engaged in other activities ancillary to the household, such as small store, sewing/tailoring, handicraft.

The changes reported in the past five years have been perceived to happen gradually in the last 20–25 years. As the country's economy improved, farmers faced new challenges that negatively impacted their livelihoods. When speaking about the past, farmers picture a land of milk and honey: "*Harvests were so plentiful; the stocks were rotting*" [FGD6]. They remember an idealised past and depict an infertile present: "*We had cowsheds filled with cows, rice storages filled with rice, ponds filled with fish. But now we have problems everywhere.*" [FGD.6].

All reported a negative perception of the changes affecting their environment. However, the impacts do not affect everyone equally and coping capacities vary according to resources, with less affluent farmers reporting a deterioration in their livelihoods, suggesting an increase in local inequalities. COVID-19 lockdowns have worsened the situation as farmers have had to sell their production locally, losing money, and some production networks have been suspended for some time, such as for milk. Most of them had to take out loans they were finishing paying back during the fieldwork.

> *[SSI.6] During the COVID period, I lost 10 lakh tk (1000000tk), because 2,5 biga of brinjal were destroyed by [the cyclone] Amphan. The loss was 8lakh tk. We couldn't sell milk to the market. I lost 2 lakhs from that. So I sold 6 cows during COVID, for 8lakhs tk (in total) and I took loans from Brac for 6 lakh 50000 tk (650000tk) and 4 lakh tk (400000). I almost paid back all. Only 1lak20000 (120000) need to be paid back.*

> *[SSI.9] 2 years ago, due to [the cyclone] Amphan, I almost lost 4 bigas of papaya trees, about 4 lakh taka (400 000). He took a loan from Brac (50000 tk) and U. Protestaat (80000tk). During the COVID, we had many problems in selling products due to governmental restrictions, we sold for half price or below.*

> *[SSI.14] During the COVID, I had to sell shrimp, milk, mangoes, at half price. Because the government prohibited the movement of the population, there was less transport. It was possible to sell things locally only once a week at the market so we sold it in the community instead of nationally. The milk collector network didn't take their milk. I produce different kinds of fish in the pound, but we had to sell fish under cover during the COVID time, on the informal market. [Because I lost money], I took many loans from different organisations, 50000tk from Brac, 100000tk from U.Protestaat, 20000tk from SPF, we used it to repair the enclosure and to make the barn and we sold 2 cows (150000tk for the two).*

Depending on the farmland elevation and location and individual resources, farmers are not impacted equally. Farmers on lowlands, with land close to canals or fish farms, report suffering first because of waterlogging, changes to their land quality due to flooding and salinisation, and new crop diseases. Farmers with higher land are less often exposed to waterlogging. They suffer first because of changes in seasonal climate patterns. They specifically reported destructive heavy rains during Monsoon, off-season unpredictable rains, cyclones and droughts in addition to the loss of land productivity due to land exhaustion, lower levels of underground water due to irrigation and overexploitation and its contamination with minerals that impedes cultures. Lowland farmers also experience most of these changes.

In addition, the capacities to adapt to changes depends on material resources. Farmers report the use of new variants, new crops, diversification of crops, change in the cultivation calendar, more intensive practices with more fertilisers, supplements chemicals to offset iron in water, plastic sheets (in polythene and tripal) to protect their crops, deeper water pumping, rent of water truck, and/or the shift to other activities, such as shrimp farming. Farmers living in the flooded area raise the land of their compound or buildings. Most of those techniques imply extra monetary costs, and for those who can afford the costs, those strategies might be economically profitable. Non-monetary costs, for example, in the case of land salinisation due to shrimp farming and waterlogging. For less wealthy farmers, those monetary and non-monetary costs add to their burden, and the feeling of socio-economic downgrading, which might result from environmental deterioration but also from other global changes such as a system relying more and more on the market economy and wage jobs, creating new social recognition of livelihoods, might also play a role in the perception of the negative evolution of their livelihood:

> [FGD.6] *"Those who used to do agriculture before, were in a good position. Now, it has been taken over by jobs [wage jobs]. The best ones were farmers, the mediums were the businessmen, and the lower ones were wage-jobs. Now the wage-jobs are the best, business is still medium, and agriculture is at the lowest."*

1.2 Rainfall data are corroborating farmers' perception on climate. Rainfall measurements from the CHIRPS database point in the same direction as local perceived regional climate changes. Seasonality of precipitation in the region is characterised by a dry winter from December to February with a total rainfall of less than 40mm/month, followed by a pre-monsoon hot season between March to May, with moderate cumulated rainfall in the south and western parts and higher total rainfall values over the east (Fig 1b). The rainy season extends from June to September, July being the wettest month for the entire region. The end of the monsoon coincides with autumn in the northern hemisphere and is caused by an abrupt decrease in precipitation from October to November [47].

Analysing rainfall trends at regional level allowed us to identify a rainfall reduction (red colours in Fig 1c) during the dry months, particularly during January over the interest region. A similar result was previously reported by Nashwan et al. [48] with different observational datasets. During the wet season, especially during the rainy month of July, an increase in precipitation is observed in CHIRPS data along southwest Bangladesh. Analysis at the local scale confirms these regional findings (Fig 2): it is about +36.07mm of rainfall per decade when plotting the calculated linear trend over the interest site. Before 2003, the trend was weaker than after 2003, which is more or less the recall time reported by villagers about ongoing seasonal alterations in climate patterns. Villagers also said having experienced destructive heavy rainfall during monsoon that could be related to the wetter conditions for the humid month of July. Previous works have reported more frequent heavy rainfall events in Bangladesh on the southwestern side [41].

Rainfall during the pre-monsoon period is significant for Bangladeshis since most grain crops are grown during this season [41]. Therefore, dry events between March and May can cause crop stress and productivity loss and exacerbate agricultural production dependency on groundwater [42]. We found a precipitation decrease during the months prior to the monsoon over southern Bangladesh, which can be related to the feeling of more frequent droughts experienced by Khalilnagar's local population (Fig 1c). Finally, the local population are affected by unpredictable off-season rains. According to the satellite rainfall data, there is a slight positive precipitation trend during the beginning of the wet-to-dry transition period (October) and the beginning of the dry period (December) over the southern and southwestern parts of the country in agreement with villagers and previous studies [49].

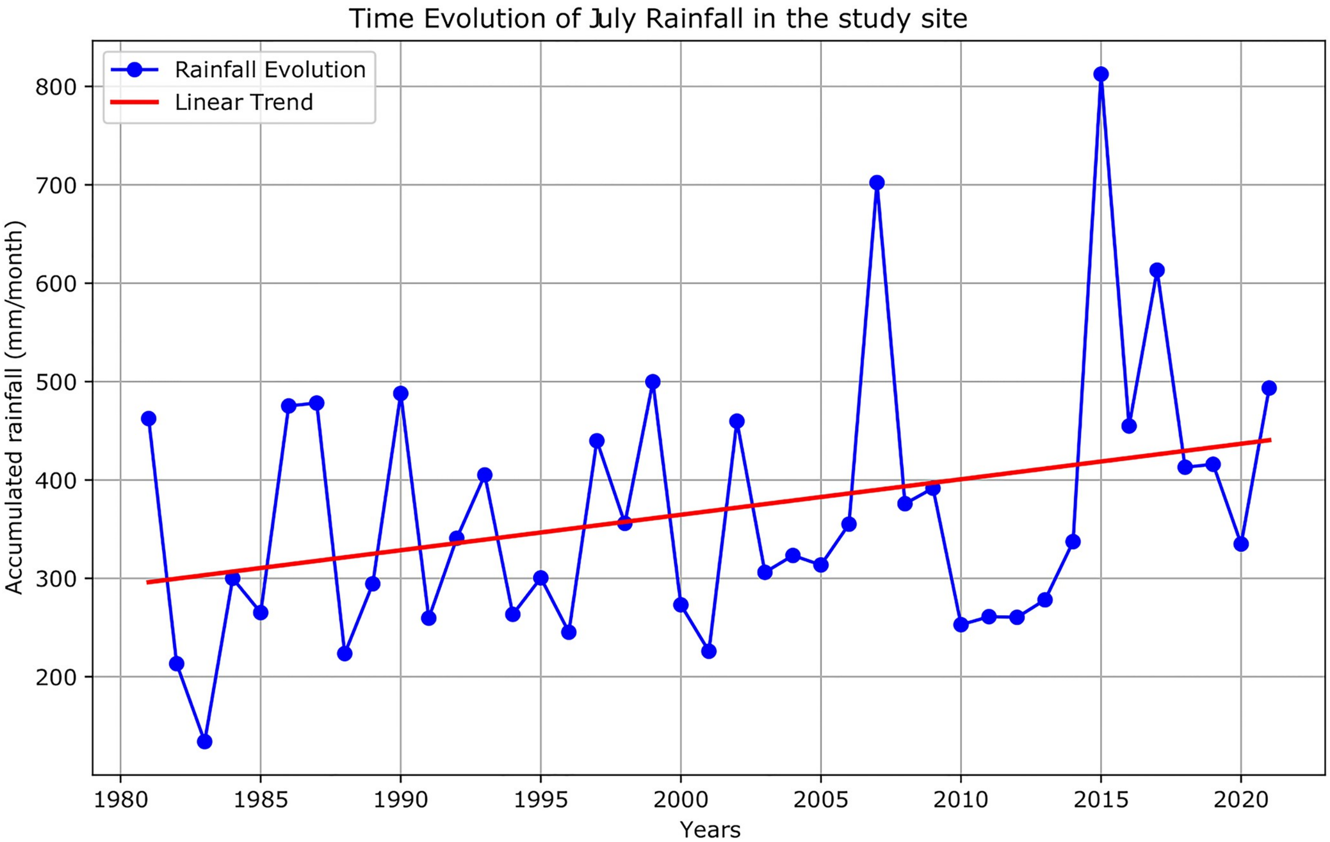

Fig 2. Time evolution of July rainfall in the study site (located at 89.30567 W˚– 22.73222˚ N; blue line). The red line shows the rainfall linear trend. This figure has been created with the free software Python version 3.8.5 (Van Rossum and Drake 2009), and using rainfall information from the CHIRPS dataset, which is in the public domain as registered with Creative Commons and is available at https://www.chc.ucsb.edu/data/chirps.

https://doi.org/10.1371/journal.pclm.0000239.g002

1.3 Switching to shrimp farming: A solution with ambivalent sustainability consequences. Farmers explain their switch from agriculture to shrimp farming (a term used here for shrimp and fish cultures dominated by shrimp production) by a combination of motivations stemming from the vulnerability of their land to waterlogging, an economic motive, the common good because they are feeding the growing population and following government recommendations and because shrimp farming is less physically demanding work compared to agricultural farming.

[SSI.5]: *"20 years ago, the price of rice was low (400 tk for 40kg). The price of shrimp was better. So, they choose the shrimp farming. "In this area, in 2000, there were 100 bigas of land for shrimps. Now, in 2022, it's 500 bigas of land. The land for shrimp farming is increasing. The price of shrimp is increasing. It's sold in Bangladesh and abroad now. The government is encouraging the business".*

[FGD.1] "This is not only for my profit. There are many reasons behind the production of shrimp. Do I do it only for myself? Everyone has the duty to fulfill the nutritional need of the normal people. We don't eat the whole product, we also supply abroad. We are trying to earn money and also we are trying to reduce the deficiency of protein".

> [SSI.17] *[People are switching] "because they are on lower land or close to the river, so already vulnerable to waterlogging. It's both because of waterlogging and higher profits in shrimp farming".*
>
> *[I started shrimp farming] "because it was profitable, six months paddy farming, six months shrimp on the same land. But in the last 10 years, there was an increase. Waterlogging problem is increasing, and government encourages shrimp farming. Due to the export of shrimp, the price is increasing".*
>
> "*paddy farming involves physical labour force repetitively. Shrimp farming, is less difficult, you build ghers [enclosures] only once a year".*

In the past decades, areas near canals have been increasingly covered with enclosures for different varieties of shrimps, and fish cultures (such as *golda* freshwater prawn -a giant freshwater prawn: *Macrobrachium rosenbergii*) and *bagda* brackish water prawn (*Penaeus monodon*, also called tiger prawn), tilapia fish, ruhi fish etc.). The landscape is changing with the evolution of practices from seasonal fresh-water fish and shrimp farming *(golda* prawn) to permanent "modern" saltwater resistant shrimp farming (*bagda* prawn), which requires brackish water and higher enclosures by larger and higher dikes and deeper ponds.

For brackish shrimp production, farmers divert the saltwater, which arrives from downstream with the river tide, to the fish farms. There, saltwater penetrates the soil, making the land unsuitable for agriculture. The water overflowing from the fish farms contaminates the adjacent lands with salt and causes neighbouring farmers, in a domino effect, to abandon agriculture and adopt brackish shrimp farming. During/after the rainy season, heavy rains or during cyclones, the combination of river tides and rains creates waterlogging, the high enclosures prevent the proper evacuation of the water flow, enclosures are overflowed, shrimps and fish production is damaged or lost, and neighbouring lands and buildings are waterlogged. The monetary benefit of shrimps and fish farming is still advantageous, but less than before when there were only a few shrimp farmers. Increased competition, increasing land and lease prices, increasing prices of shrimplets, lower production and loss of production due to a virus are other costs and losses impacting shrimp farmers.

Large shrimp farms owned by affluent people are especially pointed as responsible for waterlogging, as they represent the largest risk and influential people regarding social and economic status. They refuse to open their enclosures to let waterlogged water evacuate to the canals and the Shalta River, as this means losing their production. They control the sluice gate bringing saltwater in. [SSI.11]: "*Rich shrimp farms have an impact on water flow, the water does not flow properly. These farmers are political people or upper class or have important connections*". The enclosures built on *Khasland*, land bordering the canal leased by the government, are also pointed, as they are the last physical obstacle to the water flow.

At the time of the data collection, a local NGO was involved by the local authorities to help shrimp farmers to "modernise" their practices and to work in cooperation with each other, which is expected to help reduce some of the problems encountered by the shrimp farmers.

The Bangladesh Water Development Board (BWDB) have been called upon several times by the local authorities to send support but have yet to be successful. Villagers have tried to dig the canals themselves, but the magnitude of the task is such that without motorised machines and done by hand, the result is minimal and not sustainable.

2. Responses to changes are limited for the landless and insolvents

2.1 The disappearance of water bodies is a cause of livelihood degradation for fishermen. For the past 20–25 years, sediments brought by the river tides, filled up water bodies, creating new land, which is now used for shrimp farming, leaving independent fishermen with very little access to water bodies. *[FGD.4]*: *"There is nowhere left to fish to feed our children. Every piece of land has been bought up by wealthy people* (. . .). *Where will everybody go if there is no river*?*"*

Once, fishing supported entire families and was part of the identity of many. Nowadays, fishermen have to pay shrimp farmers an increasing price for fish pond access, making families struggle to support themselves. They try to diversify their activities but have no land are not solvent, so their options are limited. Before, they were going to the Sundarbans forest to harvest honey. Since 2018, they stopped for fear of kidnapping, robbery, and beatings, which happened to several of them. Today, when they can, they travel outside the upazila by boat for weeks at a time with several male members of the same family, paying for access to portions of rivers and sharing the profits of the fishery equally. Men of the younger generation [FGD.5] are changing occupations; they work in agriculture or brick factories as contract or daily workers, often joining the crowd of seasonal migrants (see next section). Some families have migrated out permanently to other rural areas.

All are now hoping for a better future for their children and a change of profession for the next generation. Education was cited as a possible way to improve their situation: most of the older generation [FGD.4] was not schooled, while most of the younger generation [FGD.5] received secondary education. However, (in)solvency was cited multiple times as a barrier to getting a loan, a job or diversifying activities. [FGD.4]: "*We want them to be happy and solvent. We want them to have jobs* [wage jobs]. *But nowadays people have to pay 10 lakhs Taka for bribing to have a job*, [when] *we can manage 10 Taka. How would we manage that much money*? *But we will try*, *if god wishes*, *they might get a job*."

Most rely on their support networks. They reported "*trying to maintain solidarity and equality*". They try to work collectively, live on a relative's land, help each other, rely on an extensive network of contacts in Bangladesh, and marry their children throughout the country. When they need to make a demand to the local authority, they organise themselves and sometimes cooperate with other settlements to have more political weight. For daily expenses, they, as many households in the community that struggle to make ends meet, rely on credits in local stores and pay back when they can, and at least all their debts once a year, for Bengali New Year (*Pohela Boishakh*).

Waterlogging is an important issue. Fishermen's houses are submerged for 4–5 months per year. The water is stuck and cannot be drained out because of the nearby enclosures that impact water flow. When everything is underwater, and because of the rains, they cannot fish properly and cannot find other jobs locally. Villagers are trying to escape the water by building higher houses, but some houses are still filled with water.

2.2 Unskilled seasonal migration, a temporary solution in a changing environment?. Before the changes, the region was perceived as rich in seasonal agricultural jobs, providing a local livelihood for the landless. The population has increased, shrimp farming is less labour-intensive than agricultural farming, there are fewer agricultural jobs in the community due to waterlogging, and wages are lower in Tala Upazila, possibly because women work in agriculture. For the unskilled and landless, local job opportunities are too few and poorly paid. Many move out of the community to other districts seasonally to secure a better income. [SSI.11]: *"We suffer a lot. When it's flooding*, *we don't have any work*, *our crops go underwater. Our crops get destroyed. If the crops of the land where I work get destroyed then I can't work there"*. "*People* *are going to the brickfields, because there is not enough work in the community*". [SSI.1]: *"it is not the same inside the community and outside. He [her husband, an agricultural daily labourer] is paid 250–300 tk inside the community and 500* outside"

Push and pull factors are intertwined. These movements also coincide with the development of brick factories 20–25 years ago, where jobs allow for steady income for several months. Choice destination varies depending on opportunities. They have an extended network of acquaintances and they agree with the manager by phone before leaving. [SSI.11]:*"I work everywhere because in the district there is too much competition, I prefer to go out of the district. I have been working in the 60 districts"*. Most of the time, migration is collective. They try to form a group of friends and relatives. [SSI.1]: "*If they don't manage to make a group, they don't go and stay to find daily work here*". Older workers feel too weak to sustain this type of work stay in the community and work locally.

The livelihoods of the unskilled workers are precarious, physically difficult and temporary. In agriculture, as in brick fields, they work in the open air. Their employment depends on weather conditions and waterlogging from October to April. In the remaining months, because most of the agricultural fields and brick factories are underwater, they return to the village and survive the monsoon by working in the jute fields, fishing, or taking loans from their manager, which leads them into a spiral of debt by mortgaging their future wages.

Some agricultural workers migrate only for a few weeks at a time and come back frequently between contracts because they worry about the security of the left behind or cannot cope too long with the living conditions. Brickfield work is tedious and some workers wish for better occupations for their children: [SSI.4] "*Our son, went to the brickfield this year for 6 months, but stayed for 3 months and came back. The situation was bad, there was rain. So, he came back. He joined his uncle to do construction work in Dumuri Thana* [another upazila]. *He will do that in the future, as a profession. It's easier, and more profitable and more respectable. He will have independence. In the brickfield, there is no independence, the manager is the one taking decisions."*

Many reported combining different activities depending on the season or year: farm work, brick making, shrimp farming work, and independent fishing. Most do not go to urban areas, as many are not literate and do not have contact there [SSI.4]: *"We don't go to the city because I don't know other activities/jobs than what I already do, I am an illiterate person, so it's impossible to go to a city and get a job; I don't have any connection in the city and don't feel safe going there."*

3. Interactions and feedback in changes and livelihood pathways

Fig 3 shows the interactions and feedback between the reported changes and the livelihoods of farmers, shrimp farmers, fishermen and day labourers based on their reported experiences described earlier (see in supplementary material for separated diagrams). The most reported changes were the most detrimental: waterlogging and salinisation, cyclones, and heavy rains, which impacts all, by damaging infrastructures (for all), agricultural and fish production (land-right owners: 1.1 and 1.3 in the result section) and thus local labour market for the landless (2.1 and 2.2 in the result section). The COVID lockdowns added to the burden of all, specifically to the poorest (2.1 and 2.2). Underground water level and contamination were perceived as still manageable (1.1). Erratic and lack of rain were also cited for the crop farmers (1.1). Waterlogging, which results from excess water and a lack of drainage, is worsening with the development of fish farms and other artificial structures, as well as with changes in rainfall patterns, more abundant rainfall and wetter monsoons at the local level and in the broader hydrological system. An important feedback loop here concerns waterlogging; it is described

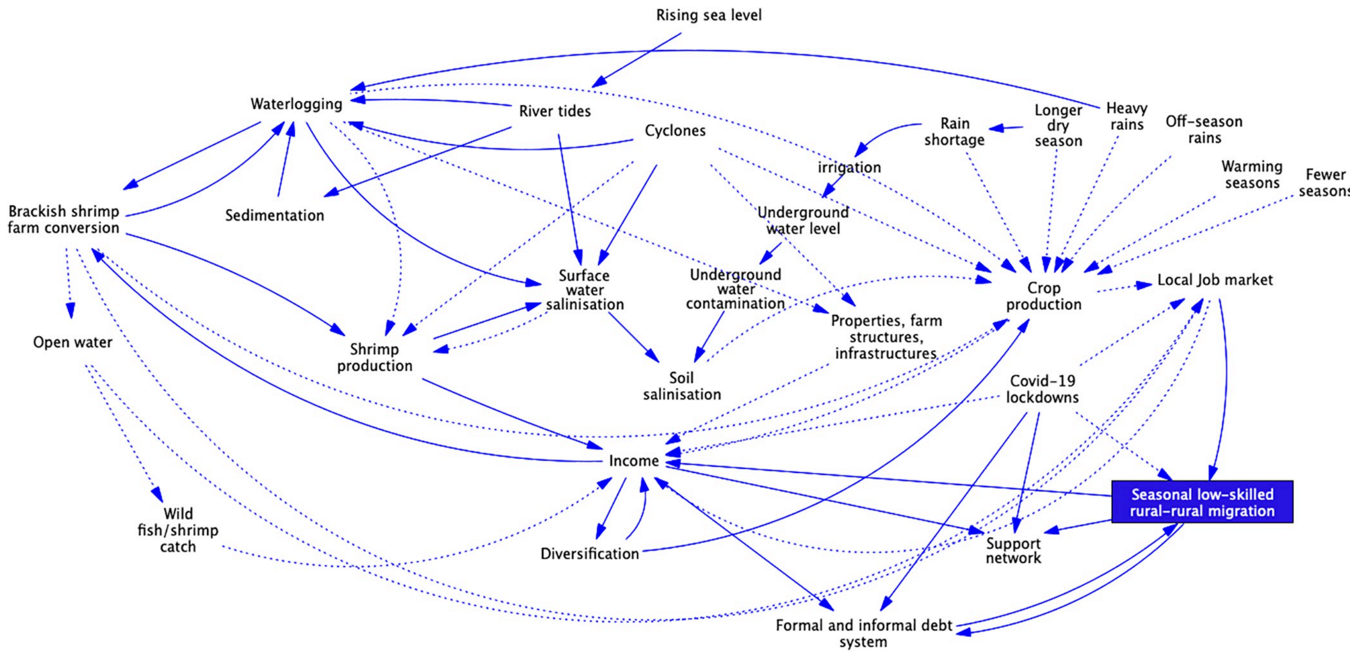

Fig 3. Local social-ecological context explains seasonal migration of the poorest. Influence of changes on livelihoods based on FGDs and semi-structured interviews with villagers in Khalilnaar, Tala. The solid lines represent positive relationships, while the dots represent negative ones. Separate diagrams for land right owners versus landess are presented in supplementary material. External factors such as government policies, international demand and market price for shrimps, and pull factors for migration such as labour market in destination areas were not presented in this diagram.

https://doi.org/10.1371/journal.pclm.0000239.g003

as both a cause and a consequence of (brackish) shrimp farming conversion. Not surprisingly, while shrimp farmers are mostly pointing to the change in rainfall patterns, the cyclones, the monsoon and the problem of sedimentation, the rest of the community accuses the fish farm enclosures of the lack of drainage. Factors external (not represented in Fig 3) to the local context, such as government policies, international demand and international market are also important incentives to shrimp farming.

Livelihood strategies interact around resource access, creating unbalanced power dynamics disadvantaging the landless. When landowners turn to shrimp farming, they compromise the availability of freely accessible lands and fishing grounds and the associated income for the landless and local agricultural production, as shrimp farming is less labour-intensive than crop production. In addition, seasonal waterlogging caused by shrimp farms is detrimental to local production and, therefore, to the local labour market, pushing out the unskilled and landless. Thus, seasonal migration of unskilled workers results from a complex interaction between climate-induced changes, which exacerbate environmental degradation, and local power dynamics over access to natural resources. A form of system of indebtedness to the employer keeps the migration cycles going, with people living on credit in their community before migrating to pay off their debts. Migration also interacts with external factors, such as labour market in the destination area.

In this rural setting, one of the poorest and most rural areas of Tala, seasonal rural-rural labour migration was cited as being more widespread than rural-urban migration, which might not be the case on other communities. Permanent rural-rural migration was also cited, and some villagers were said to have moved to urban centres. Simplified versions for land right owners and landless are presented in supplementary materials.

Discussion

In deltas, water, sediment and people have always been in movement. Historically, the Bengal delta population has always been highly adaptable to the fluctuation of water and sediments, both being a threat and a resource [4]. In the contemporary context of the Anthropocene [50], the increasing speed of local and global changes, never met in History, question sustainability [51, 52].

1-A context of multiple changes and crises

Villagers reported a complex context of multiple crises with changes or events directly, indirectly or non-related to climate. Environmental deterioration started gradually to be noticeable 20–25 years ago, affecting production, the local job market, livelihood activities, and everyday lives. The increase in waterlogging, shrimp farming and climate change were reported during the same period, suggesting some complex interactions. This is consistent with the analysis of satellite rainfall data that reveal a change in seasonal rainfall patterns for 1981–2021, with longer, drier seasons and wetter rainy seasons, particularly in July. Our results confirm those of Akter and Amed [3] based on data from 11 meteorological stations, between 1995 and 2015, located the closest to 20km from our study site.

Combined effects of multiple environmental changes are reported, confirming previous work [3, 5–7]. Reports of increasing waterlogging problems and salinisation are aligned with the findings of Tareq et *al*. [8], showing an increase in waterlogging hazards in Tala between 1989 and 2011, with tidal saline water intrusion and trapped rain water. Villagers point to multiple interacting causes for waterlogging: heavy rains, wetter rainy season, the problem of sedimentation/siltation caused by the lack of proper management of the river and canal, changes in land use for shrimp farming and an issue of power dynamics, favouring wealthy fish farmers, in the community for land and water management. Previous studies have shown that embankments, initially created to protect from saltwater, are repurposed to bring in salinity, protecting shrimp farms [4, 53]. Here, embankments (polder 16 in [54] were not cited by villagers. However, the retention of saltwater by the network of shrimp-farm dikes and the use of a sluice gate to introduce tidal salted water to the brackish shrimp farms were cited, confirming a problem of water grabbing by the powerful [4] and failed attempt of community-based management of water resource [55].

The literature provides additional information about waterlogging causes, such as the low flow on the upstream side due to the Farraka barrage on the Ganges [56, 57] combined with other factors impacting the delta geomorphology or the river flow downstream, such as the sea level rise, polderisation, land subsidence, coastal and river erosion, channel modifications, land use changes, and ongoing change in the mangrove system in the South [58, 59]. Waterlogging is a local and regional problem with a historical context. Dewan's meticulous work [4] has shown in detail that waterlogging results from a long history of a top-down oversimplification of the ecological and social landscape that increased in the context of capitalism and globalisation. Direct and indirect effects of climate change are worsening the waterlogging problem and adding additional constraints to local livelihoods.

In addition to waterlogging, farmers reported crop production suffering from drought, off-season rains or heavy rains. Cyclones are damaging housing, infrastructures and production. Underground water level and water quality are affected. The COVID-19 lockdowns were cited as aggravating events impacting incomes, market and labour mobilities. Those results are similar to those observed in multiple crises, aggravating community and individual vulnerability and exposing inequalities and inequities [13, 60, 61].

2-Responses to changes are limited by resources

In this rural community, relying on vegetables, fruits, rice, fish, freshwater and brackish water shrimp productions, responses to change vary according to livelihoods, resources and exposure to waterlogging. The less affluent find it more difficult to bear the monetary or non-monetary costs of environmental change and the costs of adaptation, revealing an increase in local socio-economic inequalities.

Local collective action to address waterlogging failed, confirming previous work on the risks of depoliticising community-based water management in Bangladesh [53, 55]. Confronted to their lack of effectiveness, local leaders sought (unsuccessfully) the support of the Bangladesh Water Development Board (BWDB) as a last resort. Farmer's strategies to overcome their environmental degradations are mainly based on innovations and diversification: new variants of rice, tests of new crops, use of fertilisers, use of materials to protect from the rains, attempts of different timing for cultures, diversification in crops and economic activities, switch to intensive shrimp farming and use of financial credits to afford those costs. Most of those adaptations are already well-covered in the literature [3, 5, 6, 62].

Financial debt is widespread, from NGO loans, mortgages of goods, lands or future wages to informal debts with kin, neighbours or local shops. Insolvency is a barrier to formal loans for the poorest, who can only rely on an extensive support network but with limited resources. For example, fishermen reported marrying off their children all around Bangladesh, which could help spread their support network to less risky regions [63].

3-Seasonal rural to rural migration of the poorest

Seasonal unskilled migration was cited as the most common strategy for the poorest households as in previous work in Southwestern Bangladesh [5, 7, 14]. The rural mobility of unskilled, landless people, depending on the availability of agricultural jobs, has been a constant for centuries in many cultures around the world among the peasantry. For this site, it has been reported to increase in parallel with environmental degradation and the development of new industries (here were cited brick manufacturing in rural areas and in other studies, garment factories in cities). While urban destinations are more frequent in previous studies, here, migrants reported rural destinations. Our site is one of the most rural of Tala and less exposed to peri-urban or urban activities, suggesting fewer contacts in cities, which was confirmed by interviews. Interactions and feedback between change, impacts and responses, such as the switch to shrimp farming and the disappearance of water bodies, combined with power dynamics and further (non)-climate-induced change, such as waterlogging and rainfall variability, associated with local norms (female rural work) are limiting the options in the local labour market for the poorest and landless, making other rural destinations more attractive. As [15] pointed out, climate migration is first"economic-induced". Rural-rural migrants earn a better living than if they stayed in their community. When several household members migrate and earn a wage, the households may experience relative (still modest) prosperity compared to their initial economic status in their community. Studying the life trajectories and social mobilities of these migrants and households would be interesting in understanding the resilience of this livelihood strategy, concerning ageing and gender, for example, and the impact of this strategy on the socioeconomic and health status of the next generation.

Seasonal migration might be a temporary alternative to permanent migration "as a way to sustain long-term non-migration in the place of origin" [64]. However, risks and hazards are still part of this strategy [7, 65], and migrants encounter hazards far from home and their support network. Their left behinds are also exposed to hazards in their absence. Seasonal migrants might make the best of a bad job, which brings additional nuance to the debate about framing migration as a failure to adapt to environmental risks or as an adaptation [66]. They have agency but within a minimal range of choices with negative and positive outcomes, the balance of which may vary depending on the exposure to hazards that impact their trajectories. Finally, the sustainability of the debt-and-migration association can be questioned at the scale of the individuals and households.

All migrants interviewed came from poor and landless households; no information was collected on other types of unskilled migrants locally, which does not mean there are none. Traditionally, farmers' sons inherit their land upon their father's death and on an equal basis among the sons; daughters can claim up to half of a brother's portion. In other words, sons compete with their fathers for land access during their father's lifetime and compete with their brothers for the inheritance. Moreover, according to an informal interview with a police officer, the most frequent conflicts in this community involve land disputes and inheritance issues, suggesting that land is a crucial resource here. Intrahousehold and interhousehold mechanisms leading to inequality must be considered potential push factors [66–68]. Such considerations will require another level of downscaling in the social-ecological system, including households, kin and non-kin networks and individual levels.

4-The temporality of changes questions the sustainability of the system

The individual knowledge needed to farm or fish in a given ecosystem results from cumulative knowledge about a complex system that balances climate, soil, water access, biodiversity, crops and associated practices such as calendars and technologies. Temporality is an essential dimension in skill and knowledge acquisition. Here, the speed of environmental changes is so fast that those under 40 have not farmed the same land or fished in the same water as those above 40, and the youngest in the community have never known the lush nature described by the elders. Even worse, on a lifetime scale, farmers living by their climate and production predictions must think about a constantly changing and unpredictable system. The baseline state of the system is changing so rapidly that these changes induce a sliding referential of the ecosystem for the villagers. If work is not done on what can be improved, i.e. in terms of waterlogging management or control of strategies with ambivalent socio-economic outcomes such as brackish shrimp farming [5], waterlogging and salinisation will gain more territories in Tala [8]. With salinisation increasing, a salt concentration threshold will be met, and crop diversification will no longer be possible at the current production [69], or only after several years of difficult back-transition [4]. Finally, the disappearance of wetlands could make droughts even more critical.

This context is a local example of the environmentalist's paradox [70]. While Bangladesh is rapidly progressing on several socio-economic indicators [1], all interviewees, rich and poor, reported having a pessimistic perspective depicting a degradation of their environment and livelihoods. However, the wealthy farmers (including rice farmers, other agricultural farmers and shrimp farmers) in the community "are not doing that bad; they are still making good profits", according to less-wealthy villagers. This attitude could be a by-product of the risk-averse tendencies of farmers, who are highly dependent on climate, more than a result of resource status, where wealthy people are expected to have a more tolerant attitude to risks, or it could be an internalisation of official discourse on climate change.

Southwest Bangladesh's environmental condition results from the thinking and planning of the territory over the last two centuries from technological and "development" thinking of the colonial and post-colonial eras [4, 53]. In other words, the current landscape is the product of power dynamics between cultures that have disrupted the Bengal Delta's natural and self-regulating fluidity, from the past centuries' mangrove deforestation to the more recent permanent and protective embankment [4]. In addition, the transformation of the landscape into vast expanses of fish farms, turning wetlands, swamps and water bodies into artificial mud mounds and fish pounds, in this location but also across many areas in the South of Bangladesh [69] question the future natural ability of the deltaic system to cope with flood, riverbed fluctuations and sedimentation issues, shrimp farming and other anthropic pollution, groundwater aquifer decreasing level and loss of biodiversity among others [71–73] and thus the future of environmentally dependent populations.

In short, as development project after development project is implemented, the relative importance of the long-term detrimental impacts of these projects compared to the climate-induced change is unclear in the multiple environmental crises that result from their combination. An important part of the rural population is left out, or worse, is suffering from it [12, 74].

Multi-site studies have shown that the sustainability of the socio-ecological system is deteriorating at a regional/sub-regional level [27, 28, 75, 76]. Those multi-site studies often associate one socio-ecological system per site (i.e. rice-based, shrimp-based, forestry), thus highlighting the heterogeneity of the deltaic system at the sub-regional level but ignoring the local heterogeneity specific to each community. Here, we highlight the local complexity by focusing on the heterogeneity of livelihoods and associated power dynamics that affect the poorest at a micro level: their village.

Concerning sustainability, our work suggests a similar conclusion at the community level, with a nuance of optimism: collective and political action for 1-tidal river management 2-controlling power dynamics, for example, through land access management [5] to limit the expansion of brackish shrimp farming for example, could improve the situation locally, but should also be considered in coordination with neighbouring territories. Thus, as Dewan et *al*. suggested in 2014, a bottom-up approach is needed and local government should be formally involved in water management [55].

The use of a mixed methodology with qualitative social sciences and quantitative climate sciences is also a challenge, as the literature on this topic is virtually non-existent, suggesting a gap in practice and a lack of resources to guide interdisciplinary research away from silo approaches. In our study site, the perception and experience of climate change reflect rainfall patterns, and people have a clear understanding of how their environment is changing, reinforcing the idea that a bottom-up approach to ecosystem management, including local people's perspective should be decided upon [55, 77].

It is the combination of climate-induced changes with non-climate-induced changes that impact livelihoods, and we might even say it imprints, directly and indirectly, the lives, flesh, and souls of people through livelihoods, health and well-being on many generations to come through societal and political choices. Political and societal choices are specifically in question because there is no climate justice without social justice, and inequities need to be addressed to leave nobody behind [4, 12, 60, 78].

Conclusion

The seasonal rural-to-rural migration of unskilled workers is rooted in the changing social-ecological context of this community. Attributing local environmental changes solely to climate change is a misinterpretation and an oversimplification of this social-ecological system [4] and climate migration [21] and obliterates other changes at different scales. The resulting complexity of this "polycrisis" [79, 80] lies in the interconnected effects of direct and indirect climate-induced and other global and local changes, which increase local inequalities and vulnerabilities [4, 12, 13]. In the current context of brackish shrimp farming development, intensifying climate-induced changes, such as changes in rainfall pattern and intensity, is likely to increase environmental stress locally and in the country, impacting local livelihood, wellbeing and health [36, 81] and pushing this rural population out of their community. Due to the disruption that migration brings to migrants' lives and the exchange of risks they experience [82], their health is also affected, making them even more vulnerable.

While climate-induced change is expected to increase and worsen the situation further, local actions regarding land and water management, to solve the waterlogging problem and improve the water retention capacity of the hydrological system, i.e. restoring wetlands rather than converting them into land or shrimp farms, could provide relief to the community and, thus, slow down the threat of waterlogging and salinisation, but also drought, as having an effect on local inequalities and strengthening local resilience to climate-induced changes.

Supporting information

S1 Fig. Local social-ecological context for agricultural farmers, without the context of waterlogging. The solid lines represent positive relationships, while the dots represent negative ones.
(TIF)

S2 Fig. Local social-ecological context in the context of waterlogging for shrimp farmers and agricultural farmers. The solid lines represent positive relationships, while the dots represent negative ones. External factors such as government policies, international demand and market price for shrimps were not presented in this diagram.
(TIF)

S3 Fig. Local social-ecological context for unskilled workers, in the context of shrimp farming and waterlogging. External factors such as government policies, international demand and market price for shrimps, and pull factors for migration such as labour market in destination areas were not presented in this diagram.
(TIF)

S4 Fig. Local social-ecological context for independent fishermen, in the context of shrimp farming and waterlogging. External factors such as government policies, international demand and market price for shrimps, and pull factors for migration such as labour market in destination areas were not presented in this diagram.
(TIF)

S1 Checklist. Inclusivity in global research.
(DOCX)

Acknowledgments

The co-authors of this manuscript would like to thank the people of Khalilnagar union, Tala Upazila, for their warm welcome and their openness to share their experiences with us. In addition, we would like to thank the reviewers for their feedback and interest.

Author Contributions

Conceptualization: Lucie Clech, Juan Pablo Sierra, Jhan-Carlo Espinoza, Valery Ridde.

Data curation: Lucie Clech, Juan Pablo Sierra, Muhammad Abdul Mannan, Mollah M. Shamsul Kabir.

Formal analysis: Lucie Clech, Juan Pablo Sierra.

Funding acquisition: Valery Ridde.

Investigation: Lucie Clech, Juan Pablo Sierra, Muhammad Abdul Mannan, Mollah M. Shamsul Kabir.

Methodology: Lucie Clech, Juan Pablo Sierra, Jhan-Carlo Espinoza.

Project administration: Lucie Clech.

Resources: Lucie Clech, Mrittika Barua.

Software: Juan Pablo Sierra.

Supervision: Lucie Clech, Mrittika Barua, Jhan-Carlo Espinoza, Valery Ridde.

Validation: Lucie Clech, Juan Pablo Sierra, Muhammad Abdul Mannan, Mollah M. Shamsul Kabir, Mrittika Barua, Jhan-Carlo Espinoza, Valery Ridde.

Visualization: Lucie Clech, Juan Pablo Sierra.

Writing – original draft: Lucie Clech, Juan Pablo Sierra.

Writing – review & editing: Lucie Clech, Juan Pablo Sierra, Muhammad Abdul Mannan, Mollah M. Shamsul Kabir, Mrittika Barua, Jhan-Carlo Espinoza, Valery Ridde.

References

1. World Bank. Bangladesh Country Climate and Development Report. Washington, DC: World Bank Group; 2022.
2. Kreft S, Eckstein D, Dorsch L, Fischer L, Germanwatch. Global Climate Risk Index 2016 Who Suffers Most From Extreme Weather Events? Weather-related Loss Events in 2014 and 1995 to 2014. 2015.
3. Akter S, Ahmed KR. Insight and explore farming adaptation measures to support sustainable development goal 2 in the southwest coastal region of Bangladesh. Environ Dev Sustain 2021; 23:4358–84. https://doi.org/10.1007/s10668-020-00778-y
4. Dewan C. Misreading the Bengal Delta: climate change, development, and livelihoods in coastal Bangladesh. Seattle: University of Washington Press; 2021.
5. Hoque SF, Quinn C, Sallu S. Differential livelihood adaptation to social-ecological change in coastal Bangladesh. Reg Environ Change 2018; 18:451–63. https://doi.org/10.1007/s10113-017-1213-6
6. Alam GMM, Alam K, Mushtaq S. Climate change perceptions and local adaptation strategies of hazard-prone rural households in Bangladesh. Climate Risk Management 2017; 17:52–63. https://doi.org/10.1016/j.crm.2017.06.006
7. Ayeb-Karlsson S, van der Geest K, Ahmed I, Huq S, Warner K. A people-centred perspective on climate change, environmental stress, and livelihood resilience in Bangladesh. Sustain Sci 2016; 11:679–94. https://doi.org/10.1007/s11625-016-0379-z PMID: 30174739
8. Tareq SM, Tauhid Ur Rahman M, Zahedul Islam AZM, Baddruzzaman ABM, Ashraf Ali M. Evaluation of climate-induced waterlogging hazards in the south-west coast of Bangladesh using Geoinformatics. Environ Monit Assess 2018; 190:230. https://doi.org/10.1007/s10661-018-6591-9 PMID: 29556796
9. Udding MH, Das TK. Status of seafood quality management in the country and improvement needed. FISHERIES RESEARCH INSTITUTE, MYMENSINGH GOVERNMENT OF THE PEOPLE'S REPUBLIC OF BANGLADESH/ UN/FAO; 1994.
10. Deb AK. Fake blue revolution: environmental and socio-economic impacts of shrimp culture in the coastal areas of Bangladesh. Ocean & Coastal Management 1998; 41:63–88. https://doi.org/10.1016/S0964-5691(98)00074-X
11. Mazid MA. Evaluation of Prawn Farming on Socio- Economic Aspects. Fisheries Research Institute,. Mymen- Singh, Bangladesh.: Fisheries Research Institute; 1994.
12. Paprocki K. Threatening Dystopias: The Global Politics of Climate Change Adaptation in Bangladesh. Cornell University Press; 2021. https://doi.org/10.7591/cornell/9781501759154.003.0001
13. Priodarshini R, Biswas B, Sánchez Higuera AM, Mallick B. Livelihood challenges of 'double strike' disasters: Evidence from rural communities of southwest coastal Bangladesh during the Covid-19

pandemic and cyclone Amphan. Current Research in Environmental Sustainability 2021; 3:100100. https://doi.org/10.1016/j.crsust.2021.100100 PMID: 36570858

14. Mallick B, Sultana Z, Bennett CM. How do sustainable livelihoods influence environmental (non-)migration aspirations? Applied Geography 2020; 124:102328. https://doi.org/10.1016/j.apgeog.2020.102328
15. Bernzen A, Jenkins J, Braun B. Climate Change-Induced Migration in Coastal Bangladesh? A Critical Assessment of Migration Drivers in Rural Households under Economic and Environmental Stress. Geosciences 2019; 9:51. https://doi.org/10.3390/geosciences9010051
16. Boas I, Farbotko C, Adams H, Sterly H, Bush S, van der Geest K, et al. Climate migration myths. Nat Clim Chang 2019; 9:901–3. https://doi.org/10.1038/s41558-019-0633-3
17. de Haas H, Castles S, Miller MJ. The age of migration: international population movements in the modern world. 6. Auflage, Reprinted by Bloomsbury Academic. London: Bloomsbury Academic; 2020.
18. Perch-Nielsen SL, Bättig MB, Imboden D. Exploring the link between climate change and migration. Climatic Change 2008; 91:375–93. https://doi.org/10.1007/s10584-008-9416-y
19. Curran S. Migration, Social Capital, and the Environment: Considering Migrant Selectivity and Networks in Relation to Coastal Ecosystems. Population and Development Review 2002;Supplement: Population and Environment: Methods of Analysis: 89_125.
20. Martin M, Billah M, Siddiqui T, Abrar C, Black R, Kniveton D. Climate-related migration in rural Bangladesh: a behavioural model. Popul Environ 2014; 36:85–110. https://doi.org/10.1007/s11111-014-0207-2
21. Dewan C. Climate refugees or labour migrants? Climate reductive translations of women's migration from coastal Bangladesh. The Journal of Peasant Studies 2023:1–22. https://doi.org/10.1080/03066150.2023.2195555
22. Snorek J, Renaud FG, Kloos J. Divergent adaptation to climate variability: A case study of pastoral and agricultural societies in Niger. Global Environmental Change 2014; 29:371–86. https://doi.org/10.1016/j.gloenvcha.2014.06.014
23. Wise RM, Fazey I, Stafford Smith M, Park SE, Eakin HC, Archer Van Garderen ERM, et al. Reconceptualising adaptation to climate change as part of pathways of change and response. Global Environmental Change 2014; 28:325–36. https://doi.org/10.1016/j.gloenvcha.2013.12.002
24. Haasnoot M, Kwakkel JH, Walker WE, ter Maat J. Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. Global Environmental Change 2013; 23:485–98. https://doi.org/10.1016/j.gloenvcha.2012.12.006
25. Akter R, Asik TZ, Sakib M, Akter M, Sakib MN, Al Azad ASMA, et al. The Dominant Climate Change Event for Salinity Intrusion in the GBM Delta. Climate 2019; 7:69. https://doi.org/10.3390/cli7050069
26. Clech L, Meister S, Belloiseau M, Benmarhnia T, Bonnet E, Casseus A, et al. Healthcare system resilience in Bangladesh and Haiti in times of global changes (climate-related events, migration and Covid-19): an interdisciplinary mixed method research protocol. BMC Health Services Research 2022; 22. https://doi.org/10.1186/s12913-021-07294-3 PMID: 35291985
27. Hossain MS, Ramirez J, Szabo S, Eigenbrod F, Johnson FA, Speranza CI, et al. Participatory modelling for conceptualizing social-ecological system dynamics in the Bangladesh delta. Reg Environ Change 2020; 20:28. https://doi.org/10.1007/s10113-020-01599-5
28. Nicholls RJ, Hutton CW, Adger WN, Hanson SE, Rahman MdM, Salehin M, editors. Ecosystem Services for Well-Being in Deltas: Integrated Assessment for Policy Analysis. Cham: Springer International Publishing; 2018. https://doi.org/10.1007/978-3-319-71093-8
29. Creswell JW, Plano Clark VL. Designing and conducting mixed methods research. Third edition, international student edition. Los Angeles London New Delhi Singapore Washington DC Melbourne: Sage; 2018.
30. Rahman MTU, Tabassum F, Rasheduzzaman Md, Saba H, Sarkar L, Ferdous J, et al. Temporal dynamics of land use/land cover change and its prediction using CA-ANN model for southwestern coastal Bangladesh. Environ Monit Assess 2017; 189:565. https://doi.org/10.1007/s10661-017-6272-0 PMID: 29039035
31. Tong A, Sainsbury P, Craig J. Consolidated criteria for reporting qualitative research (COREQ): a 32-item checklist for interviews and focus groups. International Journal for Quality in Health Care 2007; 19:349–57. https://doi.org/10.1093/intqhc/mzm042 PMID: 17872937
32. Philip S, Sparrow S, Kew SF, van der Wiel K, Wanders N, Singh R, et al. Attributing the 2017 Bangladesh floods from meteorological and hydrological perspectives. Hydrol Earth Syst Sci 2019; 23:1409–29. https://doi.org/10.5194/hess-23-1409-2019
33. Bhattacherjee A, Toleman M, Rowling S, Frederiks A, Andersen N. Chapter 13: Qualitative analysis. Social Science Research: Principles, Methods and Practices (Revised edition), 2019.
34. DFID. Defining Disaster Resilience: A DFID Approach Paper. 2011.

35. Carmichael T, Collins AJ, Hadžikadić M, editors. Complex adaptive systems: views from the physical, natural, and social sciences. Cham: Springer; 2019.
36. Talukder B, Schubert JE, Tofighi M, Likongwe PJ, Choi EY, Mphepo GY, et al. Complex adaptive systems-based framework for modeling the health impacts of climate change. The Journal of Climate Change and Health 2024; 15:100292. https://doi.org/10.1016/j.joclim.2023.100292 PMID: 38425789
37. Funk C, Peterson P, Landsfeld M, Pedreros D, Verdin J, Shukla S, et al. The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. Sci Data 2015; 2:150066. https://doi.org/10.1038/sdata.2015.66 PMID: 26646728
38. Kendall M. Rank correlation methods. Grifin, London. Grifin. London: 1975.
39. Hegerl GC, Zwiers FW, Braconnot P, Gillett NP, Luo Y, Orsini JAM, et al. Understanding and Attributing Climate Change. Climate Change: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon S., Qin D., Manning M., Chen Z., Marquis M., Averyt K.B., Tignor M. and Miller H.L., Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press; 2007.
40. Meehl GA, Lukas R, Kiladis GN, Weickmann KM, Matthews AJ, Wheeler M. A conceptual framework for time and space scale interactions in the climate system. Climate Dynamics 2001; 17:753–75. https://doi.org/10.1007/s003820000143
41. Shahid S. Trends in extreme rainfall events of Bangladesh. Theor Appl Climatol 2011; 104:489–99. https://doi.org/10.1007/s00704-010-0363-y
42. Shahid S. Rainfall variability and the trends of wet and dry periods in Bangladesh. Int J Climatol 2010; 30:2299–313. https://doi.org/10.1002/joc.2053
43. Md Hussain, Mahmud I. pyMannKendall: a python package for non parametric Mann Kendall family of trend tests. JOSS 2019; 4:1556. https://doi.org/10.21105/joss.01556
44. MetOffice. Cartopy: a cartographic python library with a Matplotlib interface. Exeter, Devon: 2010.
45. Van Rossum G, Drake FL. Python 3 Reference Manual. Scotts Valley, CA: CreateSpace. Scotts Valley. CA: CreateSpace; 2009.
46. Lehner B, Grill G. Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems: GLOBAL RIVER HYDROGRAPHY AND NETWORK ROUTING. Hydrol Process 2013; 27:2171–86. https://doi.org/10.1002/hyp.9740
47. Rashid H. Geography of Bangladesh. Dhaka: University Press Ltd; 1991.
48. Nashwan MS, Shahid S, Wang X. Uncertainty in Estimated Trends Using Gridded Rainfall Data: A Case Study of Bangladesh. Water 2019; 11:349. https://doi.org/10.3390/w11020349
49. Md Hossain, Roy K, Datta D. Spatial and Temporal Variability of Rainfall over the South-West Coast of Bangladesh. Climate 2014; 2:28–46. https://doi.org/10.3390/cli2020028
50. Nicholls RJ, Adger WN, Hutton CW, Hanson SE, editors. Deltas in the Anthropocene. Cham: Springer International Publishing; 2020. https://doi.org/10.1007/978-3-030-23517-8
51. Søgaard Jørgensen P, Weinberger VP, Waring TM. Evolution and sustainability: gathering the strands for an Anthropocene synthesis. Phil Trans R Soc B 2024; 379:20220251. https://doi.org/10.1098/rstb.2022.0251 PMID: 37952619
52. Ellis EC. The Anthropocene condition: evolving through social–ecological transformations. Phil Trans R Soc B 2024; 379:20220255. https://doi.org/10.1098/rstb.2022.0255 PMID: 37952626
53. Dewan C, Mukherji A, Buisson M-C. Evolution of water management in coastal Bangladesh: from temporary earthen embankments to depoliticized community-managed polders. Water International 2015; 40:401–16. https://doi.org/10.1080/02508060.2015.1025196
54. Bangladesh Water Development Board, Ministry of Water Resources, Government of the People's Republic of Bangladesh. COASTAL EMBANKMENT IMPROVEMENT PROJECT, PHASE-I (CEIP-I). 2012.
55. Dewan C, Buisson M-C, Mukherji A. The Imposition of Participation? The Case of Participatory Water Management in Coastal Bangladesh 2014; 7.
56. Kawser MA, Samad Abdus Md. Political history of Farakka Barrage and its effects on environment in Bangladesh. Bandung: Journal of the Global South 2016; 3:1–14. https://doi.org/10.1186/s40728-015-0027-5
57. Swain A. Displacing the Conflict: Environmental Destruction in Bangladesh and Ethnic Conflict in India. Journal of Peace Research 1996; 33:189–204. https://doi.org/10.1177/0022343396033002005
58. Islam T. Vegetation changes of Sundarbans based on Landsat imagery analysis between 1975 and 2006. Landscape & Environment 2014; 8:1–9.
59. Islam MD, Di L, Mia MdR, Sithi MS. Deforestation Mapping of Sundarbans Using Multi-Temporal Sentinel-2 Data & Transfer Learning. 2022 10th International Conference on Agro-geoinformatics (Agro-

Geoinformatics), Quebec City, QC, Canada: IEEE; 2022, p. 1–4. https://doi.org/10.1109/Agro-Geoinformatics55649.2022.9858968.

60. Sultana F. Climate change, COVID-19, and the co-production of injustices: a feminist reading of overlapping crises. Social & Cultural Geography 2021; 22:447–60. https://doi.org/10.1080/14649365.2021.1910994

61. Rahman MM, Bodrud-Doza M, Shammi M, Md Towfiqul Islam AR, Moniruzzaman Khan AS. COVID-19 pandemic, dengue epidemic, and climate change vulnerability in Bangladesh: Scenario assessment for strategic management and policy implications. Environmental Research 2021; 192:110303. https://doi.org/10.1016/j.envres.2020.110303 PMID: 33069704

62. Islam Monirul Md, Sallu S, Hubacek K, Paavola J. Limits and barriers to adaptation to climate variability and change in Bangladeshi coastal fishing communities. Marine Policy 2014; 43:208–16. https://doi.org/10.1016/j.marpol.2013.06.007

63. Rosenzweig MR, Stark O. Consumption Smoothing, Migration, and Marriage: Evidence from Rural India. Journal of Political Economy 1989; 97:905–26.

64. Etzold B, Mallick B. Moving Beyond the Focus on Environmental Migration Towards Recognizing the Normality of Translocal Lives: Insights from Bangladesh. In: Milan A, Schraven B, Warner K, Cascone N, editors. Migration, Risk Management and Climate Change: Evidence and Policy Responses, vol. 6, Cham: Springer International Publishing; 2016, p. 105–28. https://doi.org/10.1007/978-3-319-42922-9_6

65. Ahmed AU, Hassan SR, Etzold B, Neelormi S. Rainfall, food security, and human mobility: case study Bangladesh. UNU- EHS; 2012.

66. Clech L, Jones JH, Gibson M. Inequality in the household and rural–urban migration in Ethiopian farmers. Evolut Hum Sci 2020; 2:e9. https://doi.org/10.1017/ehs.2020.10 PMID: 37588363

67. Templon AR, Kirsch DR, Towner MC. Contributions of evolutionary anthropology to understanding climate-induced human migration. Am J Hum Biol 2021; 33. https://doi.org/10.1002/ajhb.23635 PMID: 34212453

68. Jones JH, Ready E, Pisor AC. Want climate-change adaptation? Evolutionary theory can help. Am J Hum Biol 2020. https://doi.org/10.1002/ajhb.23539 PMID: 33247621

69. Faruque G, Sarwer RH, Karim M, Phillips M, Collis WJ, Belton B, et al. The evolution of aquatic agricultural systems in Southwest Bangladesh in response to salinity and other drivers of change. International Journal of Agricultural Sustainability 2017; 15:185–207. https://doi.org/10.1080/14735903.2016.1193424

70. Raudsepp-Hearne C, Peterson GD, Tengö M, Bennett EM, Holland T, Benessaiah K, et al. Untangling the Environmentalist's Paradox: Why Is Human Well-being Increasing as Ecosystem Services Degrade? BioScience 2010; 60:576–89. https://doi.org/10.1525/bio.2010.60.8.4

71. Tareq SM, Rahman MTU, Uddin SZ, Uddin AFMJ. Waterlogging Threaten Biodiversity along the South-West Coastal Region of Bangladesh. Int J Bus Soc Sci Res 2016; 4:203–10.

72. Mitsch WJ, Bernal B, Hernandez ME. Ecosystem services of wetlands. International Journal of Biodiversity Science, Ecosystem Services & Management 2015; 11:1–4. https://doi.org/10.1080/21513732.2015.1006250

73. Mitsch WJ, Gosselink JG. Wetlands. Fifth edition. Hoboken, NJ: John Wiley and Sons, Inc; 2015.

74. Paprocki K. On viability: Climate change and the science of possible futures. Global Environmental Change 2022; 73:102487. https://doi.org/10.1016/j.gloenvcha.2022.102487

75. Mallick B. The Nexus between Socio-Ecological System, Livelihood Resilience, and Migration Decisions: Empirical Evidence from Bangladesh. Sustainability 2019; 11:3332. https://doi.org/10.3390/su11123332

76. Hossain MS, Eigenbrod F, Amoako Johnson F, Dearing JA. Unravelling the interrelationships between ecosystem services and human wellbeing in the Bangladesh delta. International Journal of Sustainable Development & World Ecology 2017; 24:120–34. https://doi.org/10.1080/13504509.2016.1182087

77. Waltner-Toews D, Kay JJ, Neudoerffer C, Gitau T. Perspective changes everything: managing ecosystems from the inside out. Frontiers in Ecology and the Environment 2003; 1:23–30. https://doi.org/10.1890/1540-9295(2003)0010023:PCEMEF.2.0.CO;2

78. Ridde V, Hane F. Universal health coverage: the roof has been leaking for far too long. BMJ Glob Health 2021; 6:e008152. https://doi.org/10.1136/bmjgh-2021-008152 PMID: 34896981

79. Lawrence M, Homer-Dixon T, Janzwood S, Rockstöm J, Renn O, Donges JF. Global polycrisis: the causal mechanisms of crisis entanglement. Glob Sustain 2024; 7:e6. https://doi.org/10.1017/sus.2024.1

80. Lawrence M, Janzwood S, Homer-Dixon T. What Is a Global Polycrisis? And how is it different from a systemic risk? Cascade Institute; 2022.

81. Talukder B, Van Loon GW, Hipel KW, Chiotha S, Orbinski J. Health impacts of climate change on small-holder farmers. One Health 2021; 13:100258. https://doi.org/10.1016/j.onehlt.2021.100258 PMID: 34027006

82. Schwerdtle PN, Baernighausen K, Karim S, Raihan TS, Selim S, Baernighausen T, et al. A Risk Exchange: Health and Mobility in the Context of Climate and Environmental Change in Bangladesh—A Qualitative Study. IJERPH 2021; 18:2629. https://doi.org/10.3390/ijerph18052629 PMID: 33807919