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Climate change and human security in coastal regions

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Abstract

Climate change has been recognised as a major concern in coastal hotspots exposed to multiple climate hazards under regionally specific characteristics of vulnerability. We review the emerging research and current trends in the academic literature on coastal climate risk and adaptation from a human security perspective. The ecological and socioeconomic developments are analysed for key risk areas, including coastal infrastructure; water, food and fisheries; health; human mobility; and conflict, taking the different geographical contexts of coastal areas in islands, megacities and deltas into consideration. Compounding and cascading interactions require integrative research and policy approaches to address the growing complexity. Governance mechanisms focus on coastal management and adaptation, nature-based solutions and community-based adaptation, considering their synergies and trade-offs. This perspective allows for a holistic view on climate risks to human security and vicious circles of societal instability in coastal systems and the interconnectedness of different risk dimensions and systems necessary for sustainable and transformative adaptation solutions for the most affected coastal hotspots.

Impact statement

Building on the growing body of literature on climate risk in coastal areas, this review provides a conceptual contribution and an integrated perspective through the lens of human security, examining multifaceted climate impacts and systemic risks to the vital core of human lives in different coastal contexts. Results are synthesised across coastal hotspots in islands, coastal megacities and river deltas exposed to local environmental and global climate hazards, threatening human life, health and infrastructure. In the underlying complex interconnections of coasts with land, sea and rivers, climate change acts as a threat multiplier in water, food and fishery, mobility and conflict, resulting in vicious circles of compounding and cascading impacts with severe risks to human security and societal stability, especially for marginalised communities. Contributing a deeper understanding of these interactions and trends, this research provides opportunities for understanding of emerging crises and solutions in adaptive governance and resilience across multiple scales, integrating coastal management, nature-based solutions and community-based adaptation adequate to the respective geographical coastal environments.

Introduction

Human populations in coastal areas are at increasing risk from climate change due to the interplay of coast-specific hazards and anthropogenic dynamics affecting their exposure and vulnerability (Magnan et al., 2019; Glavovic et al., 2022). Coastal climate risk results, on the one hand, from exposure to hazards such as sea level rise and tropical cyclones, causing erosion and flooding. According to current projections global mean sea level rises by 0.38 m to 0.77 m by 2100 (Fox-Kemper et al., 2021). The frequency of intense tropical cyclones is expected to increase in many regions (Seneviratne et al., 2021), with potentially severe consequences for different dimensions of human security (Ortiz et al., 2023a). On the other hand, exposure and vulnerability to these hazards are shaped by socioeconomic factors, infrastructure development, urbanisation, migration, demographic change and exploitation of coastal resources. Around 1 billion people already live in the so-called Low-Elevation Coastal Zone (LECZ), and the number is increasing, especially in urban areas (MacManus et al., 2021).

Climate risk is context-specific and heterogeneous across global coasts. Hotspots of coastal climate risk include small islands, river deltas and megacities (Magnan et al., 2019). These hotspots share a high exposure to climate hazards due to their topography and concentration of high-value assets and infrastructures, and a high vulnerability due to high rates of poverty, unequal income distribution, insecure livelihoods, reliance on natural resources and pressures to local cultures and traditions of living by the and with the sea (Gillis, 2012; Glaser et al., 2012; Spalding and Biedenweg, 2017).

Compared to the dominant conceptions of climate vulnerability and risk, human security perspectives found less attention in climate change scholarship over the past decades, particularly in coastal contexts. At the same time, there has been an increasing focus on coastal risk and adaptation, including a Special Report on the Ocean and Cryosphere in a Changing Climate by the Intergovernmental Panel on Climate Change (IPCC) with a dedicated focus on coastal systems (IPCC, 2019). Therefore, the main focus of this review is to translate the general human security perspective on livelihoods, culture, migration, conflict and geopolitics (Adger et al., 2014) to the coastal risk context (see Figure 1). Specifically, we focus on five dimensions of coastal human security risks which have been extensively discussed in the Sixth Assessment Report of the IPCC: Coastal critical infrastructure; water, food and fisheries; human wellbeing and health; human mobility and displacement; societal stability and conflict. We use this coastal human security lens to assess the main streams in recent academic literature with respect to three geographical units with particular vulnerability to climate change (islands; coastal settlements and megacities; river deltas and estuaries) and four interconnected realms of adaptation that combine a wide range of complementary response mechanisms affecting key natural and societal processes (coastal governance; management and protection; nature-based solutions; community-based adaptation). Moreover, this review aims at highlighting the value of a human security lens on future coastal climate risk.

Climate vulnerability and coastal risks in human security perspectives

Coastal risks to climate change can build on concepts of vulnerability, exposure, hazard, risk and adaptation defined by the IPCC (2022). Vulnerability is the "propensity or predisposition to be adversely affected, which encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt" (IPCC, 2022, p. 2927). This is relevant for exposure to hazards "that may cause loss of life, injury or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources" (IPCC, 2022, p. 2911). While impacts are the consequences of interactions between climate-related hazards, exposure and vulnerability, risk is the "potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems" (IPCC, 2022, p. 2921) which is subject to uncertainty in magnitude and likelihood of occurrence. Recently, also the term "severe" climate risk has been introduced, defined by "the physical and socio-ecological thresholds leading to transformational and possibly abrupt changes; the irreversibility of these changes; and the cascading effects within and across the affected systems" (Magnan et al., 2023b). Adaptation is

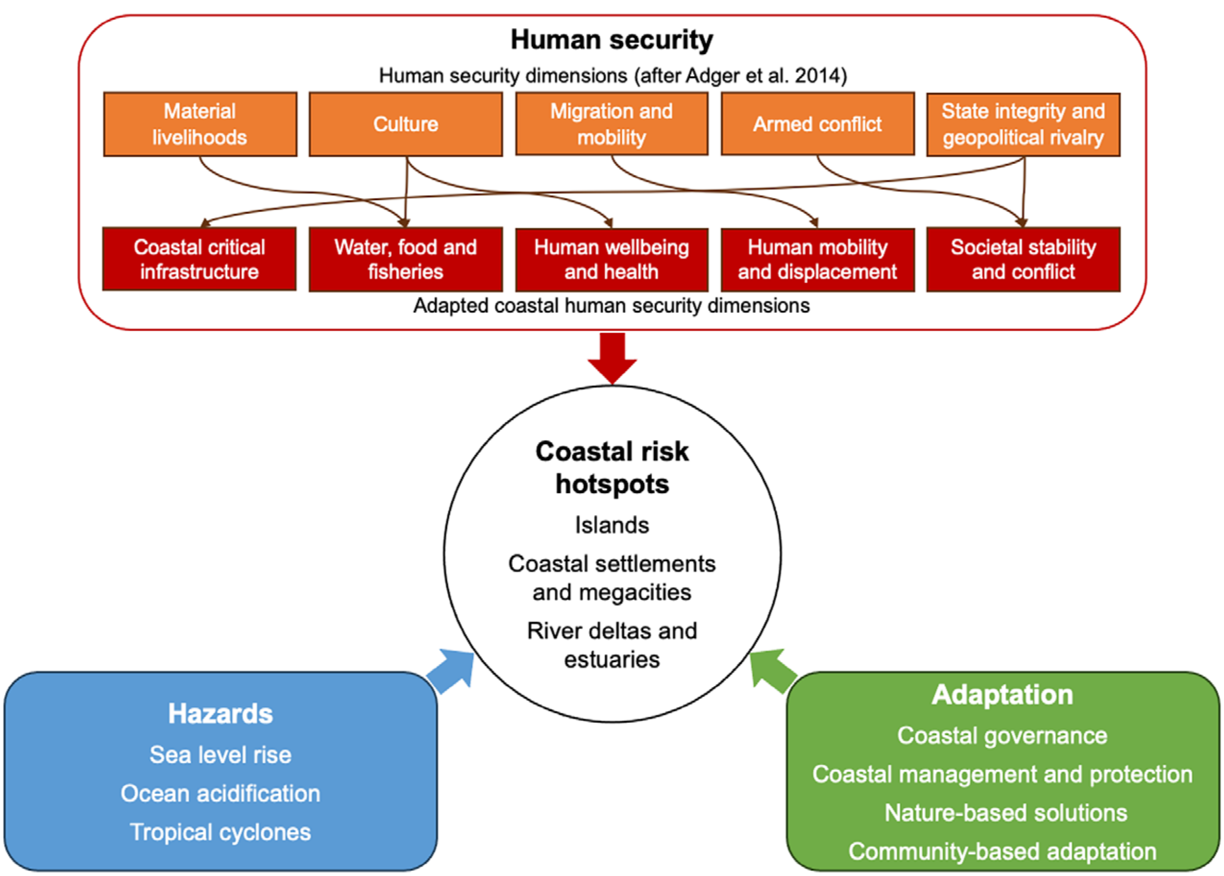

Figure 1. Framework for coastal human security assessments, building on translated general human security dimensions (Adger et al., 2014) into specific dimensions of human security for coastal hotspots in this review.

"the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities" (IPCC, 2022, p. 2898).

While these terms largely refer to a system perspective of causes and effects of climate change, human security is centred on the security and welfare of human beings as affected and responding agents, different from national and international security, which are the domain of governments and the military (for an overview, see Brauch and Scheffran, 2012). One approach to human security is based on "shielding people from acute threats and empowering people to take charge of their own lives" (CHS, 2003, p. iv). According to the IPCC (2022, p. 2911), human security is a "condition that is met when the vital core of human lives is protected, and when people have the freedom and capacity to live with dignity." In the context of climate change, the vital core of human lives includes "the universal and culturally specific, material and non-material elements necessary for people to act on behalf of their interests and to live with dignity." (IPCC, 2022, p. 2911).

Following this definition, protection against various adverse impacts, risks and threats to the "vital core of human lives" can be considered, from violent conflict, lack of human rights and development to environmental and climate risks for lives and livelihoods. Building on the concepts mentioned above, the following sections synthesise the current research trends on human security concerns considering diverse climate-related coastal hazards, security dimensions and coastal hotspots.

Human security risks in coastal regions

Coastal critical infrastructures

Climate-related hazards are projected to increase marine heatwaves, rising sea levels and extreme precipitation events that have high impacts in coastal zones (Collins et al., 2019). Coastal urban centres are agglomerations of dense settlements, high-value assets and real estate, as well as critical infrastructure that are highly exposed to coastal erosion, storm surges and pluvial flooding (Glavovic et al., 2022). Human security dimensions here deal, for example, with climate-related hazards and extreme events on coastal energy, transport and water infrastructures, as well as the associated effects on social infrastructures and systems, which are highly interconnected (Pal et al., 2023). While current research still focuses on physical infrastructure (Huddleston et al., 2022), there is an increasing understanding of the importance of analysing human security impacts through cascading events, including direct and indirect effects on social systems (Barquet et al., 2023) and compound risks that result from the combination of multiple climate hazards and interplay with anthropogenic drivers of coastal exposure and vulnerability (Cutter, 2018; Collins et al., 2019).

Water, food and fisheries

The nexus of water, food and human security is sensitive to environmental and climate change, including saltwater penetration by sea level rise, storms, floods and subsidence by groundwater loss. Risks to coastal ecosystem services affect freshwater provision, storage and regulation; groundwater flows; aquifer recharge and wetland flooding (Hérivaux et al., 2018).

Coastal waters can be overloaded with terrestrial nutrients and chemical, biological and physical pollutants, toxins and pathogens (Cooley et al., 2022). While the salinities of many estuaries, deltas, aquifers and soils are increasing, decreasing water quality is endangering human health, agricultural yields (Rakib et al., 2020; Mastrocicco and Colombani, 2021) and drinking water availability (Sithara et al., 2020; Wang and Hong, 2021) which depend heavily on regional variations in environment and human behaviour (Paldor and Michael, 2021). Water security is also threatened by various direct anthropogenic interventions that degrade coastal ecosystems, such as cutting mangroves, overexploitation of groundwater and pollution, resulting in poverty, tensions and instability (Babuna et al., 2023). With climate change, coastal water security is becoming intractable, requiring empowerment to avoid vicious circles (Powell et al., 2017).

Climate and environmental stress reduce coastal food security through decreasing crops, livestock and fishery, soil fertility and agricultural productivity, cultivable land and safe water, affecting livelihoods, especially for marginalised smallholder farmers (Shams and Shohel, 2016) with low investments in resilient infrastructure (Ismail et al., 2022). Regional studies show the effect of land fragmentation on farm efficiency and diversification in household food security in Vietnam (Tran and Van Vu, 2021) and climate challenges on Arctic food security, weakening food sovereignty and destabilising indigenous practices (Zimmermann et al., 2023). Coastal households of Bangladesh had a significantly lower Food Consumption Score than other areas (Rahman et al., 2023). Perceptions of small-scale fishers in Bangladesh show that wellbeing is more associated with fish yield than climatic stress (Alam and Mallick, 2022).

Linking ocean and land food supply chains across coasts, marine fisheries and aquaculture provide a significant fraction of human animal protein (Costello et al., 2020), dietary micronutrients (Vianna et al., 2020), livelihoods and income (Harper et al., 2020), in particular in Small Island Developing States and Indigenous Peoples (Cisneros-Montemayor et al., 2016). Temperature is a major driver of fishery changes, with other factors like acidification, deoxygenation and sea ice loss, placing many fisheries at risk of collapse, affecting fishery biomass, food web, catch and value (Olsen et al., 2018). Declining fish stocks are expected to have detrimental effects on marine life, ecosystems and services, harming dependent human communities, including Arctic Indigenous Peoples (Steiner et al., 2019). Global warming drives ocean and coastal fauna towards higher latitudes, challenging fishers to change habits and management (Smith et al., 2019).

Human wellbeing and health

Health security is closely linked to climate-related disasters and impacts on water, food and fishing. On the one hand, physical health concerns in coastal regions refer to malnutrition due to climate-related impacts, such as ocean warming and acidification, on fisheries, as well as direct and indirect health impacts from ocean warming, sea level rise and storm surges, including injuries and increasing exposure to waterborne diseases (Weatherdon et al., 2016; Banwell et al., 2018; Bindoff et al., 2019; Pugatch, 2019). On the other hand, there is increasing evidence and research attention to mental health impacts on coastal communities due to increased stress caused by climate-related hazards and pressure to adapt, as well as loss of local livelihoods and cultural heritage due to the impacts of climate change (i.e., ecological grief, solastalgia) (Cunsolo and Ellis, 2018; Kelman et al., 2021; Phillips and Murphy, 2021). Such impacts are especially critical and documented in indigenous coastal communities with strong ties to their local environment (Donatuto et al., 2014; Ford et al., 2014).

Human mobility and displacement

Several types of human mobility in coastal zones are related to climate change impacts, especially sea level rise, such as migration, displacement, relocation, retreat or resettlement (Oppenheimer et al., 2019). Migration towards coasts can be a driver of vulnerability and exposure, especially in urban areas (Reimann et al., 2023b, 2023a), where it increases population numbers and densities and often also includes people with higher vulnerability, such as migrant workers without social security (Hari et al., 2021). Migration away from the coast due to climate change impacts has been discussed prominently and controversially in the context of displacement and climate refugees (Boas et al., 2019; Lincke and Hinkel, 2021; Farbotko and Campbell, 2022). Planned relocation in the form of resettlement programmes or managed retreat is a type of adaptation, especially to sea level rise (Ferris and Weerasinghe, 2020). However, there is uncertainty regarding the precise number of people exposed to increasing sea level as well as its implications for potential climate-related migration. On the one hand, there are several model-based studies with a wide range of assumed population numbers exposed to inundation related to different sea level rise and population projections, but without considering potential adaptation (Hauer et al., 2019; McMichael et al., 2020). On the other hand, studies including assumptions on coastal protection and autonomous adaptation as well as evidence from local case studies demonstrate that exposed populations may have rather higher threshold for out-migration (Esteban et al., 2020; Bachner et al., 2022).

Besides the potential to reduce risks, all these forms of human mobility can have significant human security impacts since they may involve losses of livelihoods, homes, place attachment, identities, social networks and the potential for conflict between individuals and communities (Black et al., 2013). Hence, they are discussed from an environmental justice perspective (Siders, 2019; Ajibade et al., 2020) but also as necessary responses and opportunities in the face of projected climate change impacts in coastal areas (Haasnoot et al., 2021; Bower et al., 2023). At the same time, immobility is increasingly discussed, that is, people or communities who cannot or do not want to move despite climate change impacts (Farbotko et al., 2020; McMichael et al., 2023).

Societal stability and conflict

There are many conflicts in coastal regions (Dahlet et al., 2023), from war and civil war to tensions over the impacts and consequences of weather extremes or disputes over coastal protection and who pays. Populated coastal regions are particularly sensitive to conflict and multiple environmental hazards (Stepanova and Bruckmeier, 2013). Climate-conflict links may affect human security, where climate change is a driver of conflict risk, while conflict can drive climate risk (Mach et al., 2020; Scheffran, 2022). Coastal storms, floods and sea level rise can undermine the conditions for stability and peace in vulnerable and fragile populations. At the same time, conflict can weaken protective and adaptive capacities against climate impacts. Combined effects of conflict and climate change can destroy dams and dikes and undermine aid and cooperative arrangements for climate protection. Multiple compound risks can trigger a vicious circle of mutually enforcing crises (Buhaug and Von Uexkull, 2021).

Inland and coastal climate-conflict risks can be connected, for example, when people move to the coast where they participate in violent conflict, end up in urban slums or are exposed to coastal risks. Failure to secure the lives and assets of coastal populations can lead to social disruption, tension, instability and displacement. Coastal infrastructures are vulnerable to both climate and conflict impacts, including energy systems and military facilities (Howland, 2022). Other forms of coastal conflict involve interest groups, notably those threatening or conserving marine ecology and biodiversity. In the world's "oceans of conflict" (Nyman, 2013), climate change is one of multiple stressors in fishery conflict, particularly in the North-East Atlantic, East China Sea, West African coast and the Arctic (Spijkers et al., 2021).

Coastal hotspots

Islands

The literature on human security concerns on small islands often focuses on questions of habitability of low-lying islands due to sea level rise (Farbotko, 2010; Kelman, 2018; Spencer et al., 2024). While there is increasing evidence that large shares of island populations will be faced with inundations by 2050 (Mycoo et al., 2022), there are also studies demonstrating how reef islands can adjust to sea level change, offering alternative opportunities of adaptation beyond relocation (Masselink et al., 2020; Kench et al., 2023). Moreover, the question of what such evidence, together with other observed climate impacts, means for habitability remains debated due to multiple and diverging perspectives on when experiences of inundation become unbearable (Moftakhari et al., 2018; Spencer et al., 2024) or an island becomes effectively uninhabitable (Farbotko and Campbell, 2022). Besides potential inundation due to sea level rise, also the other dimensions of human security are highly relevant and with increasing evidence in the scientific literature, especially regarding Small Island Developing States (SIDS), but also other island geographies (Petzold and Magnan, 2019; Duvat et al., 2021; Mycoo et al., 2022; Ortiz et al., 2023b).

Especially in low-lying atoll or barrier islands, basically all housing and infrastructure are located on or close to the coast. In these cases, hurricanes or tropical cyclones can devastate whole islands and their infrastructure. The island of Barbuda, for example, was devastated and had to be evacuated entirely after Hurricane Irma in 2017 (Burn et al., 2022). Apart from extreme events and impacts on critical infrastructure, there is a strong focus in the literature on climate-related impacts on the tourism sector since they make up a significant share of many economies of SIDS and other island types (Posen et al., 2023). Depending on the island context and the specific kind of tourism, slow-onset hazards, such as sea level rise, ocean warming, or shifting seasons, as well as fast onset events, such as flooding, can affect individual tourism activities, sites and periods as well as whole tourism economics (Wolf et al., 2021; Carrillo et al., 2022).

Food and water insecurity on small islands result from cyclones, droughts, saline intrusion and ocean warming that directly impact agriculture and fisheries. Food security is threatened, especially by the observed decline in fisheries, which affects the main diet in many small island communities (Mycoo et al., 2022). Hence, climate change impacts island communities' ability to produce, import or purchase food (Barnett, 2020). Accordingly, there is increasing attention to the social dimensions of food security in small islands, with poor population groups particularly affected (Lincoln Lenderking et al., 2021).

Climate impact on the wellbeing of island communities is closely linked to food insecurity due to potential undernutrition. Other prominent health impacts result from the increasing and shifting range of vector-borne diseases (Thomas et al., 2020). Relatively little but increasing attention in the literature is being paid to mental health impacts on islands, for example, anxiety and stress due to changing weather patterns and depression due to the inability to adapt livelihoods to climate-induced environmental changes and degradation (Kelman et al., 2021). Related concepts that are gaining prominence and with relevance to islands are those around non-economic loss and damage (Thomas and Benjamin, 2020; McNamara et al., 2021), ecological grief (Cunsolo and Ellis, 2018) and solastalgia (McNamara and Westoby, 2011) due to climate change-induced degradation and loss of habitats and landscapes. Going beyond the traditional concept of health, there are attempts to widen our understanding of wellbeing, which is especially important for climate-affected indigenous communities such as those on Pacific islands, who consider, for example, people-place connections and traditional knowledge systems central parts of wellbeing (Sterling et al., 2020).

Human mobility in the context of climate change has different dimensions and human security implications on small islands. In many island and archipelagic communities, such as in the Pacific, migration is part of people's livelihood strategy and, therefore, an important aspect contributing to the security of these populations (Connell, 2016). On the other hand, forced displacement or migration due to climate risk is considered a last resort, if at all (Thomas et al., 2020; Piggott-McKellar and McMichael, 2021). Nonetheless, due to the potential loss of habitability of islands due to climate impacts, relocation of communities is increasingly discussed as necessary and important part of risk reduction in response to climate change (Magnan et al., 2022). Human security concerns around climate-induced migration, displacement or retreat on small islands relate to the resulting loss of place attachment, livelihoods, financial resources, community cohesion and social networks (Dannenberg et al., 2019). Moreover, climate-induced migration and relocation can lead to conflicts between migrants and host communities and within migrant communities, for example, due to power struggles, ethnical conflicts and competition for land (Donner, 2015). However, there is little evidence for such conflicts (Weir and Virani, 2011; Kelman, 2015).

Coastal settlements and megacities

A great deal of literature on climate change impacts on coastal settlements deals with coastal megacities and impacts on critical urban infrastructure and livelihoods (Pelling and Blackburn, 2013). Many of the most vulnerable coastal cities lie in the tropics, including megacities such as Mumbai and Guangzhou and other major agglomerations such as Abidjan or Guayaquil (Hallegatte et al., 2013). Impacts on critical infrastructure such as roads and harbours do not only directly affect cities and their populations but also trade networks and supply chains and are therefore felt far beyond the city context (Glavovic et al., 2022). Most affected by environmental pressures and hazards related to climate change in urban areas are low-income populations in the Global South (Adelekan et al., 2022) and underprivileged ethnicities (Gran Castro and Ramos De Robles, 2019) who suffer from social or ethnic exclusion, low-quality or non-existent infrastructure, little tenure security and restricted access to resources and services.

The literature on food insecurity due to climate change focuses rather on rural or smaller coastal settlements than on megacities, with a higher degree of resource-dependent and subsistence populations, for example, in coastal Bangladesh, where increased salinity impacts the agricultural harvests and fisheries (Hanazaki et al., 2013; Lam et al., 2022). Nonetheless, especially the fishing sector is still an important economic element in many larger coastal cities, such as Jakarta, on which many livelihoods depend (Padawangi, 2012). Water insecurity in coastal cities is caused by a growing demand of increasing urban populations and changing water availability due to climate change (Flörke et al., 2018). Desalination of sea water as a response to water scarcity in coastal cities may reduce water stress but can negatively impact coastal and marine ecosystems (Roberts et al., 2010).

Health security in coastal cities is affected by extreme events, such as tropical cyclones, hurricanes and flooding. Flooding can result in the spread of waterborne diseases, to which especially populations in informal settlements are vulnerable, who lack adequate flood protection and suffer from insufficient sanitary infrastructure (Dawson et al., 2018). In the coastal megacities of Mumbai, for example, a large share of the population lives in slums, which experience inundations regularly due to pluvial flooding (Romero-Lankao et al., 2016). Other coastal cities that suffer from subsidence also experience coastal flooding, with marginalised communities most affected (Nurhidayah and McIlgorm, 2019; Cao et al., 2021).

Sea level rise is expected to trigger displacement from coastal settlements, differing between geographic and socioeconomic contexts. Forced displacement is expected to be less relevant in larger coastal cities of the Global North (Magnan et al., 2022) where high investments are made to protect valuable assets, real estate and infrastructure. Smaller towns and rural areas already deal with managed retreat (Dannenberg et al., 2019). Moreover, in several megacities of the Global South, especially the informal settlements face forced evictions due to their vulnerability to flooding, which can result in conflicts and unsustainable outcomes for the affected populations (Ahmed and Meenar, 2018; Ajibade, 2019). While impacts on mental health are documented mainly in smaller coastal settlements and resource-dependent communities, the stress of worsening urban flood events for low-income communities and potential forced displacement has mental health implications, especially for the poor and marginalised ones (Neria and Shultz, 2012; Lane et al., 2013; Garrett et al., 2019).

River deltas and estuaries

River delta regions benefit from the combination of abundant water, agriculturally fertile floodplains, ports, economic production and trade, contributing to human wealth and wellbeing. Many of the largest port cities are located in delta formations (Campanella, 2010), and more than 300 million people live in 40 deltas, including all the major megadeltas (Ericson et al., 2006). A large number of people live in the river deltas of the Ganges-Brahmaputra, Pearl River and Nile. Populations face human security risks when river deltas and estuaries are vulnerable to the combined effects of climate change and intensive human use, both from the land and ocean sides, which interact in complex ways (Nicholls et al., 2020). The ecological sensitivity in transition zones makes them predestined to become hot spots for climate change impacts. Physical variables (temperature, salinity, flow direction and velocity) and societal parameters (e.g., resource use, sediment input or removal, water quality impairment and sediment discharge) interact with secondary effects in delta regions of flooding, water shortages or droughts.

Rising sea levels in river deltas can lead to flooding, subsidence, saltwater intrusion, loss of coastal wetlands or declining quality of agricultural land. Since the beginning of the 21st century, 85% of the world's largest river deltas have experienced severe flooding, at least temporarily submerging some 260,000 km^2 of land area (Syvitski et al., 2009). Considering the predicted changes in rainfall variability, extreme weather events and rising sea levels, highly vulnerable areas in coastal or deltaic regions will be increasingly challenged (Tessler et al., 2015) by large-scale damages and loss of life (Brondizio et al., 2016). Climate-related hazards affect exposed infrastructures and resources and, in the long term, may lead to societal impacts on life and health, eventually resulting in migration, resettlement and displacement from delta regions. Cities in urban deltas of developing countries face compounding effects of high exposure and low adaptive capacities (Bangalore et al., 2019). In many delta regions, the most affected are the urban poor, for instance, the Black poor during Hurricane Katrina 2005 (Kates et al., 2006) or informal settlers in the 2015 flood in the Jacuí River delta (Pereira Santos et al., 2022).

These challenges affect all major river deltas, to different degrees depending on geographic location (Scheffran and Link, 2019). The most vulnerable urban deltas in 2050, measured as a share of gross domestic product (GDP) losses, would be Guangzhou, Mumbai, Kolkata, Guayaquil, Shenzen, Miami, Tianjin, New York, Ho Chi Minh City and New Orleans (Ovink, 2015). Without fundamental changes, about 2 billion people could be affected by 2050 and 4 billion by 2080. Key problem factors in selected river deltas are spatial pressure, flood vulnerability, drinking water shortages, ageing or inadequate infrastructure, coastal erosion and loss of environmental quality and biodiversity (Ovink, 2015).

While the Mediterranean Basin is largely rocky, river deltas face increased erosion patterns, decreased sediment discharge, intensification of floods, saltwater intrusion and loss of biodiversity, multiplied by climate change. Besides the Italian Po Delta, these issues concern the Spanish Ebro Delta, where human management has had a higher impact than climate change (Fatorić and Chelleri, 2012). The heavy urban use of Nile water in the Cairo region also has a negative impact on water quality in the delta. Therefore, (mostly fossil) groundwater is regularly used to irrigate agricultural land. This results in saltwater inflows into groundwater or land subsidence when groundwater aquifers are drained (Mabrouk et al., 2018), increasing the relative effect of rising sea levels. The Nile Delta cannot be easily protected by hard coastal protection measures (Link et al., 2013; Mabrouk et al., 2018).

The Pearl River Delta (PRD) is sensitive and variable due to the strong monsoon, dense river network and significant effects of erosion and sedimentation. The combination of rapid economic development, population growth and climate change makes the PRD vulnerable to flooding and other disasters (Yang et al., 2015). Even small-scale sea level rise increases storm surge risk and post-storm reconstruction costs. Damage is high in low-lying urban areas with high levels of prosperity and vital infrastructure. In large cities such as Hong Kong, Shenzhen and Guangzhou, the population is particularly vulnerable to flood hazards.

In other parts of the world, delta vulnerability to climate change also combines with local factors, such as agricultural livelihoods in Bangladesh sensitive to salinity intrusion (Khanom, 2016), or civil conflict and violent skirmishes between herders and farmers in Kenya's Tana River Delta (Kirchner, 2013).

Coastal adaptation

Coastal governance

Overall, there is increasing evidence of adaptation in coastal areas around the globe, especially in urban areas, which, however, is still far behind the adaptation potential and need, and lacking of long-term pathways approaches based on early warning and anticipative governance (Magnan et al., 2023a). Political ecology approaches in coastal governance include issues of power and politics, knowledge and narratives, scale and history, justice and fairness (Zou et al., 2023). Facing human security risks in coastal regions, effective and integrative governance is needed to shape coastal futures through institutions, norms, rules, laws and procedures that manage, implement and monitor policies at local to global scales. Governance can be adaptive to maintain a desired state under changing conditions, polycentric with multiple decision-making bodies and multi-level, including local to global scales (Jordan et al., 2018; Carlisle and Gruby, 2019). Multi-level governance, coordination and knowledge co-production across societal actors are required also for more transformational adaptation (Ratter and Leyshon, 2021; Rölfer et al., 2022; Niamir and Pachauri, 2023), although there is limited evidence of implemented governance concepts for transformational coastal adaptation (Bouwer et al., 2022).

Climate and ocean governance can use the power of governments, nature and communities utilising different forms of governance capacity that need to be coordinated to resolve conflicts (Kullenberg, 2010). For example, in terms of coastal critical infrastructure, this implies building early warning systems and adaptive capacity across different levels of organisation, especially where it comes to the task of effectively implementing local adaptation actions (Huddleston et al., 2023). However, the current academic evidence base is strongly biased towards assessing risk, planning and monitoring rather than implementing coastal adaptation, and lacks an integration of existing coastal management and governance instruments with climate change adaptation frameworks (Cabana et al., 2023). A synthesis to understand and manage cross-sectoral governance conflicts highlights conceptual differences and commonalities across disciplines to develop problem-solving frameworks of coastal and marine governance, including ecosystem-based management, adaptive co-management, integrated management, collaborative governance and marine spatial planning, and others (Bellanger et al., 2020).

Coastal management and protection

Coastal protection against human security risks of climate change is a societal task that relies on government measures and resources to prevent coastline retreat and defend settlements and infrastructure at the shore and hinterland from storm- or sea level-related flooding and erosion. Engineering-based hard structures (such as breakwaters, dikes or seawalls) (Sorensen, 2006) are complemented by soft measures embedded into social and ecological systems, involving the participation of stakeholders and social-science perspectives (Magnan et al., 2022; Philippenko and Le Cozannet, 2023). These measures are coordinated in coastal management, which increasingly is integrated, ecosystem-based and climate-resilient, including risk assessment, watershed management and catchment rehabilitation, sustainable land and water management, coastline protection, adapted to the specific conditions of coastal cities, islands, deltas and marine habitats (Hinkel et al., 2018; Bouwer et al., 2022; Petzold et al., 2023).

Coastal management strategies group around adapting, defending and armouring a coastal area or abandoning or relocating part of it, depending on benefit, cost and risk assessments (Gopalakrishnan et al., 2016; Kovalevsky and Scheffran, 2022; NOAA, 2023; Sengupta et al., 2023). Several studies focus on coastal adaptation to climate change and sea level (Bongarts Lebbe et al., 2021; Griggs and Reguero, 2021) and the institutional adaptive capacity building of Swedish coastal zone management (Storbjörk and Hedrén, 2011), others address path dependency in coastal cities of the Asia-Pacific (Nunn et al., 2021b) and proactive adaptation of rapidly changing coasts (Brown et al., 2017). Some highlight maladaptation of seawalls along island coasts (Nunn et al., 2021a) and the diffusion of hard protection to coastal erosion and flooding along island coasts in the Pacific and Indian Oceans (Klöck et al., 2022). In specific small and low-lying island contexts, also land reclamation and island raising are being implemented (Brown et al., 2023).

The diversity of approaches in coastal areas includes internal relocation as an adaptation strategy in Rangiroa Atoll, French Polynesia (Duvat et al., 2022) and contestation of coastal restoration and risk reduction in Louisiana (Gotham, 2016). To regulate ocean grabbing, a large-scale marine protected area for the sea of Rapa Nui is suggested by Aburto et al. (2020). Economically efficient flood protection standards for the Netherlands are considered by Kind (2014). The contribution of Earth observation in coastal climate services for small islands is discussed by Rölfer et al. (2020). Coastal adaptation planning can use scenario-based stakeholder engagement and preferences in coastal planning (Tompkins et al., 2008), stakeholder perception of climate vulnerability detection using Fuzzy Cognitive Mapping (Gray et al., 2014) and stakeholder analysis of climate change and water management in the Dongjiang River basin in South China (Yang et al., 2018).

Nature-based solutions

According to the World Conservation Union (IUCN), nature-based solutions (NbS) are defined as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human wellbeing and biodiversity benefits" (Cohen-Shacham et al., 2016, p. 5). The IPCC focuses on NbS contributions to climate adaptation and mitigation benefits for coastal regions, including synergies with biodiversity protection and ecosystem services. While the carbon-sequestering mitigation role has dominated much of the earlier discussions, NbS contributions to climate adaptation are increasingly emphasised.

Many studies demonstrate that coastal and marine ecosystems, including wetlands and mangroves, have considerable value as carbon sinks in 'blue carbon' sequestration and other ecosystem services such as hydrological regulation, coastal protection, biodiversity and contributing to human livelihoods, especially of pastoralists and fishermen (Conant et al., 2017; Leifeld and Menichetti, 2018; Seddon et al., 2019). Mangrove restoration can promote local and national adaptation, depending on the extent and nature of coastlines (Taillardat et al., 2020). The global value of coastal wetlands for storm protection is demonstrated by Costanza et al. (2021), while Schueler (2017) presents NbS to enhance coastal resilience, and Landry (2011) discusses coastal erosion as a natural resource management problem from an economic perspective. Challenges of NbS in coastal research for coastal engineers are addressed by Scheres and Schüttrumpf (2020) and socioecological impacts of coastal flood mitigation by Inácio et al. (2020).

Examples of regional perspectives address flood risk management using NbS in Nouakchott, Mauritania (Senhoury et al., 2016), coastal protection on the Islands of Amrum and Föhr in the North Frisian Wadden Sea (Jordan et al., 2023), and ecosystem-based urban climate change adaptation and wellbeing in Kiribati, Samoa and Vanuatu (Kiddle et al., 2021). Capacity building on ecosystem-based adaptation helps to cope with extreme events and sea level rise. It increases coastal resilience to extreme weather events and sea level rise on the Uruguayan coast (Carro et al., 2018). Here, a participatory process involved the community and institutional stakeholders in selecting and prioritising adaptation measures, including soft measures (green infrastructure) such as revegetation with native species, dune regeneration, sustainable drainage systems and reducing use pressures.

Community-based adaptation

Adaptation to climate risk can also build on and promote community resilience. For example, many coastal and small island communities are place-based communities – that is, depending on the local environment to secure their livelihoods – and have traditional and local knowledge that makes them adaptable to environmental changes (Kelman, 2010; Hiwasaki et al., 2015). Dense social networks and strong place attachment in such communities may also contribute to their adaptability to environmental change (Petzold and Ratter, 2015; Carmen et al., 2022). Accordingly, there is a move from top-down approaches to community-based adaptation (CbA) approaches, for example, in SIDS (McNamara et al., 2020).

Examples of CbA in coastal areas are collective coastal afforestation in Bangladesh (Rawlani and Sovacool, 2011) or communal water resource management, agricultural management and disaster risk community action plans in Vanuatu (Clarke et al., 2019). However, besides the suggested advantages of CbA as a locally led and context-specific form of adaptation, there have always been concerns in the literature regarding responsibilities and representation, effectiveness regarding larger-scale issues, and barriers to long-term success (Forsyth, 2013; Piggott-McKellar et al., 2019; Westoby et al., 2020).

Conclusions

The human security lens addresses the interactions, multifaceted impacts and systemic risks to the vital core of human lives in different coastal contexts, such as islands, deltas and coastal megacities. Coastal regions and their growing populations are exposed to multiple local environmental and global climate hazards, threatening human life, health and infrastructures, water, food and fisheries, driving displacement and relocation to and away from the coast, as well as various forms of conflict interacting with social vulnerability. Climate change acts as a threat multiplier in interconnected vulnerable infrastructures, linkages between water and food, mobility and conflict, resulting in vicious circles of compounding and cascading impacts with severe risks to societal stability and novel challenges to coastal governance regimes. Vulnerability and adaptation of fishery, agriculture and aquaculture interact along coasts, connecting land, sea and rivers.

While the potential consequences of climate change in coastal areas are severe, they can be prevented by appropriate governance mechanisms which contain human security risks before they overwhelm the limits of adaptation (Dow et al., 2013; Thomas et al., 2021). An integrative human security perspective focusing on protecting freedom and capacity to live with dignity can contribute to identifying whether incremental adaptation or rather transformational measures are required with respect to observed and projected climate change impacts. Anticipatory and transformational governance approaches would rely on early warning, model-based simulation and preventive policies, which are more promising and less costly than disaster and crisis management. Besides hard and soft coastal management interventions, integrative approaches of climate resilience and transformational adaptation across multiple scales can build on NbS and CbA adequate to the respective geographical coastal environments. To avoid maladaptation and combined human security risks that reduce local resilience, coastal management and adaptation must not only tackle individual concerns but adopt a holistic human security approach. To this end, human security research needs to understand trade-offs and synergies in the growing body of research, for example, on mental health, urban–rural interactions, movements and sustainable transformations of coastal settlements that strengthen human security, especially of marginalised coastal communities.

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