Oceanologia, corrected, in press
Polish Academy of Sciences
Institute of Oceanology
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https://doi.org/10.5697/JDXM8520

Climate change mitigation and adaptation measures for the Gulf of Gdańsk region in relation to sea threats

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Abstract

The impacts of climate change are increasingly evident, with many societies affected annually. Coastal areas inhabited by c. 60% of the world's population, are especially vulnerable due to a large number of impacts, including real sea related threats. Implementation of mitigation and adaptation measures as well as challenging climate change threats must be among the top priority issues for decision makers of all levels. This study presents the results of the critical analyses of environment and climate related change in publicly available documents in the key economic and touristic region of Poland, the Gulf of Gdańsk. The authors have evaluated the detailed points in the process of identifying the awareness of climate change and implemented measures. The results show relatively high awareness of climate change related threats, however, insufficient information and planning regarding ocean-related threats and hazards. Few mitigation and adaptation measures addressing sea-based threats were identified. The authors compare the findings with available knowledge of climate change, measures undertaken in some ports and port cities and reflect on the urgent need of implementing multidisciplinary efforts to foster the effective management of coastal areas for the sustainable and safe future.

Keywords

Climate change; Ocean threats; Climate adaptation and mitigation; Development strategy; Gulf of Gdańsk

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Received: 19 February 2025; **revised:** 27 November 2025; **accepted**: 8 December 2025

1. Introduction

Ocean sustainability themes can be found in 38% of the established sustainable development tasks, consequently, activities related to the UN Decade of Ocean Science for Sustainable Development are increasingly common in scientific discourse and research planning (Boreo et al. 2019). More than 3 billion people rely on the oceans for their livelihoods, utilizing the ocean as a source of food, employment, health benefits (EEA, 2018) and additionally, along with the global population growth, more people are moving to coastal areas (Reimann et al. 2023). Such growth of coastal communities leads to the greater ocean use, involving more agricultural runoff, increased tourism, transport, and energy production (Wisz et al., 2020). This is also true for the Baltic Sea region, where the number of people inhabiting coastal cities within the southern Baltic amounts to c. 8.9 million, with the half of them living in Polish coastal cities (Interreg South Baltic Programme, 2021).

This trend contrasts with the observed and predicted climate change threats which coastal areas worldwide experience and will be facing in the future (Dumała et al., 2021). Therefore, alongside urgent mitigation efforts, adaptation strategies must be a priority for coastal areas (Garcia-Soto et al., 2021b). There are a number of approaches to that issue, including those provided by the UN Environment Programme (UNEP), involving among others the ecosystem-based adaptation (nature-based solutions and ecosystem services), knowledge analysis and networking (spreading knowledge) (UNEP 2023). On the other hand, UNEP promotes mitigation aiming at climate resilience and greenhouse gas emission reduction.

Such actions are being undertaken in various places including a good example of the practical adaptation and mitigation case in Rotterdam wherein in the 13th century local merchants and administrators built a 400 m long dam to control high bay waters and to facilitate drainage. Subsequently, the infrastructure was upgraded with new canals; currently, amidst ongoing climate change, it is viewed as an opportunity for improvement rather than a threat (C40 Cities, 2016). Other adaptation and mitigation activities include using green energy sources such as solar, wind, and hydropower, or collecting water using rooftop tanks or basement cisterns, which help reduce the energy required for freshwater treatment (Sharifi, 2021). These climate change induced actions are becoming a significant concern for various stakeholders, including researchers and decision-makers (Garcia-Soto et al., 2021a; Vye et al., 2020). Bibliometric and review studies demonstrate an increase in publications addressing climate-change impacts, adaptation, and mitigation across sectors. A global review by Sharifi (2021) highlights not only the rapid growth of adaptation and mitigation research but also the increasing tendency for these topics to be examined jointly rather than separately. This integration trend is reflected in environmental and marine sciences, where studies such as Tittensor et al. (2019) show that adaptation, mitigation, and biodiversity conservation are now frequently considered together in assessments of ocean change. At a broader science-policy level, the IPCC, 2022 similarly emphasizes that effective climate-resilient development relies on combining adaptation and mitigation strategies. This expanding global and sector-specific literature provides an essential background for understanding regional systems where climate-related risks are highly pronounced. The Baltic Sea is the subject of intensive climate research; frequently cited threats include eutrophication (algae blooms) resulting in poor water quality and decrease in biodiversity, poor health of fauna and flora in the sea e.g., decrease in cod populations. The eutrophication increase depends on light penetration in the water column affecting seagrass and algae life cycle which leads to a loss of suitable spawning habitats for cod (Bossier et al., 2021).

The climate change in the Baltic Sea also involves rising water temperature, decreasing ice extent, and an increase in precipitation in the northern part. As a result of these changes, many species have moved northwards (HELCOM, 2021). These environmental changes affect ecosystem services e.g., provisioning services like aquaculture activities, which rely on species abundance e.g. *M. edulis,* shift of the distribution with climate change or affects the cod population which does not reproduce in warm, low salinity waters, and thus is no longer suitable for fishing.

Gdańsk, the biggest Polish port city, faces flood related threats as a result of climate changes. However, the problem is not new and there was an attempt to approach it by constructing a bypass on the Vistula River east of Gdańsk (in 1895). The city remains vulnerable to several threats, including sea-level rise, stronger storm surges, increased water import from rivers and heavy rainfalls (Sanders et al., 2021).

Some of the adaptation and mitigation solutions to such problems involve efficient cooperation and communication with coastal communities, businesses and governments of all levels and other activities which are planned in the aspect of climate change threats and hazards. One of the challenges in this respect involves engaging a wide spectrum of society, especially those who lack a perceived connection to marine ecosystems (Evans et al., 2021). Successful education as part of this challenge requires that it is not only up to date with the current situation but being passed within the right context and form so that people can apply knowledge in real-life situations (Zielinski et al., 2021; Zielinski et al., 2022). Socio-psychological research reveals that even the right education rarely leads to changes in behavior (Stoll-Kleemann, 2019). Behavioral change is more likely when both internal factors including emotions, values and external factors (politico-economic, socio-cultural) are met. Terorotua et al. (2020) also mentioned the importance of institutional actors' decisions being important for climate change adaptation.

This study has been dedicated to the verification of the adaptation and mitigation approaches towards climate change, recognition of threats and hazards and applications of actions as described in regional, local and national strategies/documents related to climate, urban development and environmental management for the region of the Gulf of Gdańsk.

2. Material and methods

2.1 Study area

The study focuses on the Gulf of Gdańsk region. From the sea side, the Gulf is partially closed by the Hel Peninsula, and the gulf itself forms an indentation into the land area for a length of 75 km, while its width at the point of exit extends over about 110 km. The line between Cape Rozewie and Cape Taran is treated as an imaginary border between the Gulf and the open sea. The entire area of the Gulf of Gdańsk basin is approximately 6,300 km^2. The catchment area of the Gulf of Gdańsk alone is approx. 220,000 km^2 (Figure 1).

The coastline of the Gulf of Gdańsk is smooth, characterized by flat, sandy beaches and steep cliffs. However, the landscape of the Gulf is undergoing constant transformations as a result of eroding waves. The Gulf of Gdańsk is a sheltered basin. Serving as an inlet to the Baltic Sea, it offers a secure anchorage of the Baltic Sea, a very safe reservoir, with several ports and many small harbors, with easy, and accessible entry for sea-going yachts.

The main cities on the Gulf of Gdańsk include: Gdańsk, Gdynia, Sopot (the so-called Tricity), Wejherowo, Reda, Puck, Władysławowo, Jastarnia and Hel. In 2021, the three core cities were inhabited by c. 750,000 people, while the Tricity together with its metropolitan area have a combined population of between 1 and 1.5 million, depending on the definition of their boundaries.

The two major port cities in Poland are Gdańsk and Gdynia. The first one, Gdańsk, is a part of the Trans-European network and an important freight transport center, while Port of Gdynia specializes in heavy cargo. There are many other industrial developments present in the region, including the oil refinery and fish processing facilities. The

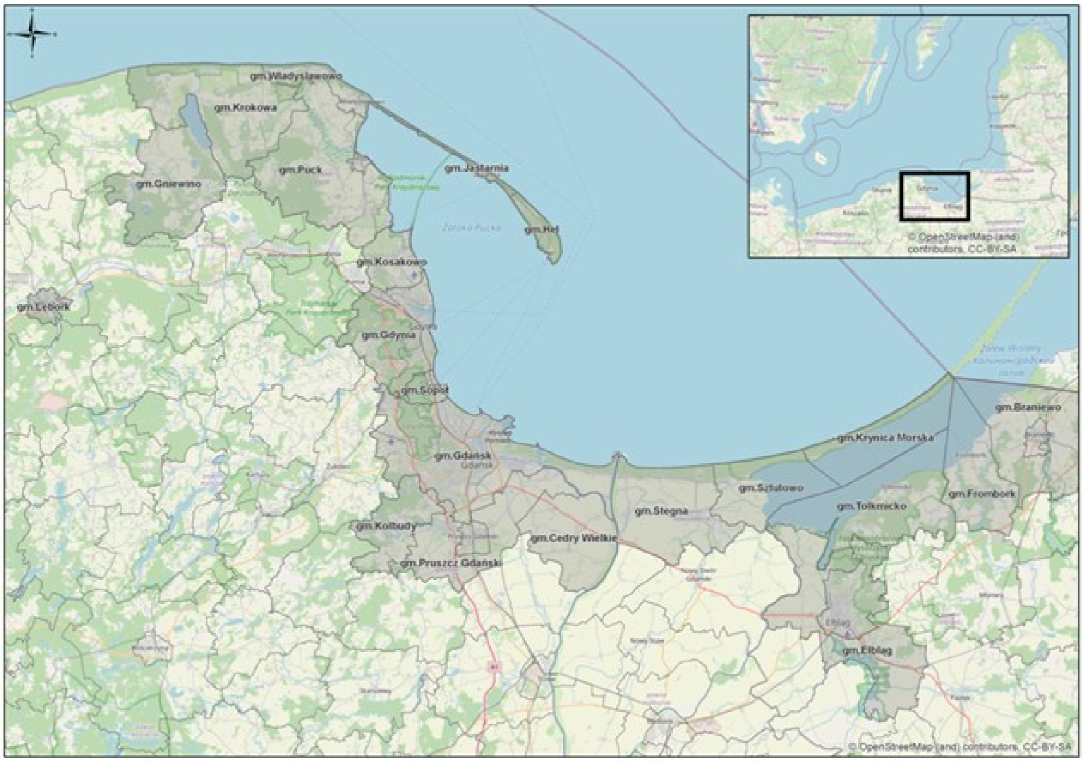

Figure 1. Study area. The Gulf of Gdańsk region, shaded areas are those covered in the analyzed documents (courtesy of Joanna Pardus).

entire region is known as a tourist centre, mainly in summer with about 10 million international tourists visiting the area.

It is expected that with long-term climate changes and associated threats such as the sea-level rise and coastline erosion the Gulf of Gdańsk area will be seriously impacted, which will have multifold consequences through the changes in coastal protection, shipping, development of offshore renewable energy resources resulting in many societal issues that may emerge (Weisse et al., 2021). Thus, it is crucial to include mitigation and adaptation measures in response to climate change threats in strategic documents for the entire region.

2.2 Methodology and analytical approach

All documents available for each city or town were analyzed (a complete list of analyzed documents available in attachments). The selection process focused on the documents that were up to date, addressed long term management of the area under study, included climate change related issues, or environmental protection strategies. The process of documents collection was conducted between January and February 2021. Initially, 50 documents were identified and reviewed. Subsequently, the selection was refined to include only those relevant to 2022, resulting in 33 documents for evaluation.

The sources included municipal websites, governmental portals, the BiP website, and project websites such as KLIMADA (klimada2.ios.gov.pl)[1]. The documents were selected for both coastal municipalities and municipalities identifying themselves as marine locations, even though they were located at a considerable distance from the coast.

The chosen documents were considered suitable due to their strategic and long-term character and therefore were likely to incorporate sustainable development concepts and address environmental issues (Piwowarczyk et al., 2012). These documents were assumed to provide reliable information on climate change-related threats as well as mitigation and adaptation measures. Mitigation refers to preventive actions taken before the occurrence of climate-related threats, aiming to reduce future impacts. Adaptation, on the other hand, involves measures implemented after a threat has occurred, designed to adjust to resulting consequences.

The text analysis was performed using MAXQDA Analytics Pro 2020 (Release 20.4.2). The evaluation process consisted of two stages. First, climate-, development-, and environment-related documents were analyzed and categorized by their scope of application (Local, Regional, National), as defined in Table 1.

[1] KLIMADA – IOŚ-PIB carried out the KLIMADA Project – Development and implementation of the Polish National Strategy for Adaptation to Climate Change (2012–2013).

Table 1. Division of analyzed documents by subject (environmental, development, climate) and by region as in documents (Local, Regional, National).

Category document type	
Environment	Environment management documents e.g., environmental protection programs at local, regional, or national levels.
Development	Planning documents for urban, regional, or national development e.g. city development strategies.
Climate	Documents focused on climate change adaptation and mitigation e.g. National Energy and Climate Plan.
Document location group	
Regional	Documents reflecting plans for provinces or integrated city-province development for environment, planning, or climate change.
Local	Documents addressing cities or towns for development, environment protection, planning future, or climate change.
National	Documents reflecting national changes for Poland in development, environment protection, planning future, or climate change.

Table 2 presents the frequency of documents within these categories and their relation to climate, development, and environment.

Table 2. Frequency of analyzed documents by category.

Category	Local	Regional	National
A. Climate	1	1	3
B. Development	13	8	0
C. Environment	6	0	1

Three sub-categories were defined for climate-related content including the climate change code: adaptation, mitigation and threats. All codes were discussed and agreed upon by the research team before their analysis. The content analysis followed Krippendorf's (2004) approach, based on hermeneutic interpretation of the text. The documents were examined systematically according to predefined criteria: subject category (environment, development, climate), spatial scope (local, regional, national), and thematic codes (adaptation, mitigation, threats). Every document was cross-checked to ensure consistency.

Climate change codes were adapted from UNEP's climate adaptation framework and modified for the needs of this study analyses (Table 3). To effectively address environmental and societal challenges and facilitate efficient knowledge transfer, it is crucial to engage all stakeholders. While many approaches exist, UNEP's framework is considered to be one of the most comprehensive and flexible, making it highly effective (UNEP 2017, 2019, 2022). The UNEP adaptation approach involves seven pillars: Ecosystem-based Adaptation, Knowledge, analysis and networking, World Adaptation Science Programme, National Adaptation Plans, Access to adaptation finance, Climate adaptation project list, Early Warning Climate Systems, and Climate adaptation resources and multimedia. In our analyses we decided to modify the UNEP approach and thus we created the following list of climate change related threats, mitigation and adaptation activities for the area of the Gulf of Gdańsk. Further analyses were conducted using MAXQDA Analytics Pro 2020 (Release 20.4.2) relying on the above-mentioned UNEP-based codes (Table 2). For the climate change threat codes (Table 2), each subcategory was divided into direct and indirect correlations with climate change as the assumption was made that some municipalities may describe threats that could be caused by things other than climate change in their opinion.

3. Results

No significant differences were observed regarding adaptation, mitigation measures, or threats between regional and local documents of development category $X^2(df = 2, N = 678) = 0.53, p = 0.82$ (Table 4).

Climate $[X^2(df = 4, N = 912) = 155.21, p < 0.05]$ and environment $[X^2(df = 2, N = 1,539) = 155.21, p < 0.05]$ related documents were significantly different in the number of identified adaptation, mitigation and threat codes depending on the analyzed document type: regional, local, national Table 4). Overall, adaptation codes were less frequent in all documents. There were in total 55 adaptation codes added in all documents. Environmental documents did not contain any adaptation codes and the greatest percentage of those were found in local development documents (62%, N = 8) (Table 2).

Conversely, mitigation (N = 1,923) and threat codes (N = 1,151) appeared with significantly higher frequency. Mitigations were found in the highest percentage (77%, N = 944) within local documents on environment related subjects and threats in 95%, N = 595 in national documents of environmental character (Figures 2 and 3). Regional documents of an environmental character have not recognized any threats (Table 3).

The statistical analysis included only marine related threats (EC-D, EC-F, EC-M, EV-F, EV-WO, LT-STR, WP-A, WP-OC) (Table 3). The frequencies of those ranged between 7–92.

Table 3. Most frequently found in all of the documents climate change codes: threats and all codes that were applied to look for adaptation, mitigation, UNEP modified (Codes taken from the UNEP, and modified for this project).

Code category	Code	Description
Threat	EV-WO	Extreme windstorms/storm surges/strong winds.
	WP-OC	Oxygen concentration, decrease in oxygen concentration, anaerobic zones, anoxia, hypoxia, suffocation, dead zones, methane release from the seabed, *not related to infusions into the Baltic Sea.
	EC-M	Morphology, health status of fauna and flora, reduction of animal size, calcification, impact on the local economy.
	LT-STR	Sea surface temperature changes.
	EC-D	Change in distribution of species. Change in flora, change in fauna, change in biodiversity, change in species composition, impact of species changes on the local economy (e.g., fisheries), effect of oxygen concentration on marine organisms, impact on local economy.
	WP-A	Acidification, increase in carbon dioxide concentration, hypoxia, anoxia, dead zones, eutrophication, *no influence of salt water.
	EV-F	Floods, rising groundwater levels, sea caused floods.
	EC-F	Changes in the food web. Fisheries, impact on the development of the coastal economy, trophic chain, nutrients, bioaccumulation, change of diet, change of ecosystem functions, impact on the local economy.
Mitigation	M5-WM	Waste/wastewater management and establishing related regulations, environmental strategies related to climate change natural waste selection, recycling, gas emissions, waste (e.g. plastic).
	M3-PTA	Productivity of the terrestrial and aquatic environment (ponds, watercourses, etc.). Water environment management, land environment management, preventive measures, increasing greenery in cities, not building on floodplains, construction of retention reservoirs, stream regulation, storm sewage system.
	M1-RED REDD +	Enabling municipalities to invest in activities conducive to the reduction of greenhouse gases, measures to prevent deforestation and destruction of forests, together with appropriate measures to raise public awareness. Reduction of greenhouse gases, meeting European requirements in greenhouse gas emissions, transport management, transport limitation, environmentally friendly domestic heating, green energy, monitoring of energy companies, photovoltaics, solar panels, replacement of heating systems.
	M1-LEG	Low-carbon growth. Increasing the efficiency of energy use, building financial resources for green energy, reducing greenhouse gas emissions and other pollutants through the use of renewable energy. Emission limits, European restrictions, emission reduction, low emission policy, strategies (LEDS).
	M1-CR	Changing plans according to climate changes, mapping threats and important areas.
	M2-RR	Supporting municipalities in environmental management in a way that leads to the reduction of natural hazards related to climate change. Green cities, environmental protection in relation to threats.
	M2-RRE	Public support during and after natural disasters, public consultation on natural hazards. Counteracting the effects of floods and storms (natural hazards), financial assistance, environmental and habitat restoration, maintenance of flood banks.
	M3-CE	Creating a favorable environment supporting municipalities, society, entrepreneurs in planning activities in a sustainable manner, not threatening the functioning of the entity European, national regulations/restrictions/guidelines, training/programs/meetings.
	M3-PM	Management of the marine environment taking into account environmental well-being. Protection of habitat biodiversity, scientific research, biodiversity management, environmental evaluation.
	M4-ME	Considering natural environment in spatial plans. Implementation sustainable development policy in city planning, adaptation of national restrictions.
	M4-SLI	Strengthening law and institutions; supporting national, European efforts related to the creation and application of laws, and strengthening the functions of institutes to achieve environmental and economic goals.
	M5-CE	Creating and enabling environment – chemical waste management, laying down rules on chemical waste and the management of chemical waste in general related to climate change.
	M6-EP	Favorable political environment shifts towards green economy, adaptation of sustainable consumption and production.
	M6-SB	Sustainable environment and business. Introduction of a sustainable development policy to transport, to the everyday life of cities green cities, use of biodiversity and ecosystem services.
	M6-SL	Balanced lifestyle and nutrition. Education about sustainable lifestyle and consumption.
	M7-IM	Information management support for cities in the process of creating, accessing, analyzing, using and communicating environmental information and knowledge education on ways of sharing knowledge on topics related to climate change in society and business, communication, society, consultations, professionals' cooperation, ecosystem services.
	M6-SL	Sustainable lifestyle and nutrition. Education about sustainable lifestyle and consumption (workshops, lectures, providing educational materials (leaflets, posters, books, etc.), promoting local products.
	M8-PK	Education, breaking down barriers between the scientific world and society, cooperation with decision-makers who protect the environment for the general good in their daily activities. Climate education, professionalism, cooperation, environmental protection.

Table 3. *Continued.*

Code category	Code	Description
Adaptation	EbA	Implementing projects that take into account the diversity and ecosystem services as part of adaptation to climate change. Healthy ecosystems can reduce the negative impacts of climate change e.g. coastal habitats such as dune forests, forests, flower meadows, provide a natural barrier during floods and storms.
	KaN	Knowledge, analysis and contacts. Spreading knowledge about climate change and best adaptation practices sharing own knowledge, from local to global scales.
	WaSP	Implementation of scientific knowledge to the adaptation decision-making process at the commune level. The overall goal of the Adaptation Science Program is to promote science in the context of adaptation to climate change.
	NAPs	Regional adaptation plans. Support for the society and municipalities in order to implement adaptation to climate change. The main goals of NAP: 1. Reducing sensitivity to the impact of climate change by building adapted space and flexibility in adapting to changes, e.g., building the city's resilience to low-emission pollution; 2. Adapting integration to new rules, regulations, programs, city plans, strategies.

Table 4. Frequency of occurrence of national, regional and local codes (Mitigation, Adaptation, Threat) in relation to climate, development and environment in the analyzed documents.

Total codes number	Regional	National	Local
A. Climate	338	486	88
B. Development	329	0	349
C. Environment	159	627	753

There was a significant difference in percentage of added threat codes depending on a document name (Regional, National, Local) and a threat relation to climate change (D – direct, I – indirect) [$X^2(df = 37, N = 306) = 249.76$, $p < 0.05$] (Figure 2). Across all documents discussed threats were addressed directly in correlation with climate change for the majority of cases (87%, $N_{total} = 306$) (Figure 2). In Local documents the greatest frequency was found for EV-F (Floods, rising groundwater levels, sea caused floods, N = 8) (Figure 2).

In Regional documents the greatest frequency was found for EV-WO (extreme wind storms, N = 42) (Figure 2).

In National strategies of all frequently added codes EV-WO (extreme wind storms, N = 45) appeared most frequently. Note that frequencies of recognized threats within local documents were much lower than in other two document groups of national and regional level. In one coded segment, EV-WO was described as a "threat of coastal abrasion". Rising sea level (especially in the southern part of the Baltic Sea), an increase in the intensity and frequency of extreme phenomena (storms, torrential precipitation, storms) favor the phenomenon of abrasion "Cliff-type coasts are particularly endangered by abrasion".

Excluding marine-related threats, L-AR (acid rains and air quality) was the most frequently cited threat in all of the documents N = 539, second EV-WO (Extreme windstorms/storm surges/strong winds), N = 92 and LT-STR, N = 62 (sea surface temperature). Marine related threats were found in 28% N = 1084 cases whilst threats related to land were mentioned in 72%, N = 1,084 times of all added threat codes.

There were in total 1907 mitigations found in all documents. There was a significant difference between the analyzed documents (regional, local, national) of different character climate, development, environment related documents and mitigation codes added [$X^2(df = 156, N = 1907) = 4,167$, $p < 0.05$] (Figure 3). In local ($N_{mitigation} = 727$) and regional ($N_{mitigation} = 157$) documents there was the greatest number of M5-WM-Waste/wastewater management and establishing related regulations found. However, climate-related documents contained few such codes; the majority were associated with environmental documents ($N_{M5-WM} = 600$).

An example of M5-WM coding can be given from the "Environmental Protection Program for the Krynica Morska Commune for the years 2016–2019 with a perspective for the years 2020–2023":

"Waste management and prevention of waste generation minimization of the amount of waste generated in the commune of Krynica Morska Development of selective waste collection". The M1-RED-Enabling municipalities to invest in activities conducive to the reduction of greenhouse gases mitigation was relatively often mentioned in national documents of climate and environmental character ($N = 52$). National documents highlighted the importance of M4-SLI-Strengthening law and institutions in 50 cases following mitigation codes (Figure 3).

The total number of adaptation codes found within all documents was 55 which constitutes merely 2% of all codes, including land-based threats $N_{total} = 3,046$. There was no significant difference between adaptations found in local, national or regional documents referring to climate of development character [$X^2(df = 17; N = 55) = 24.77$, $p = 0.09$]. None of the adaptation codes appeared in any of the environment related documents thus those were not included in further analyses.

4. Discussion

Although the strategic documents from major cities in the Gulf of Gdańsk acknowledge climate change, they lack clarity and user-friendliness, hindering the reader's ability to identify key points. Furthermore, these documents of-

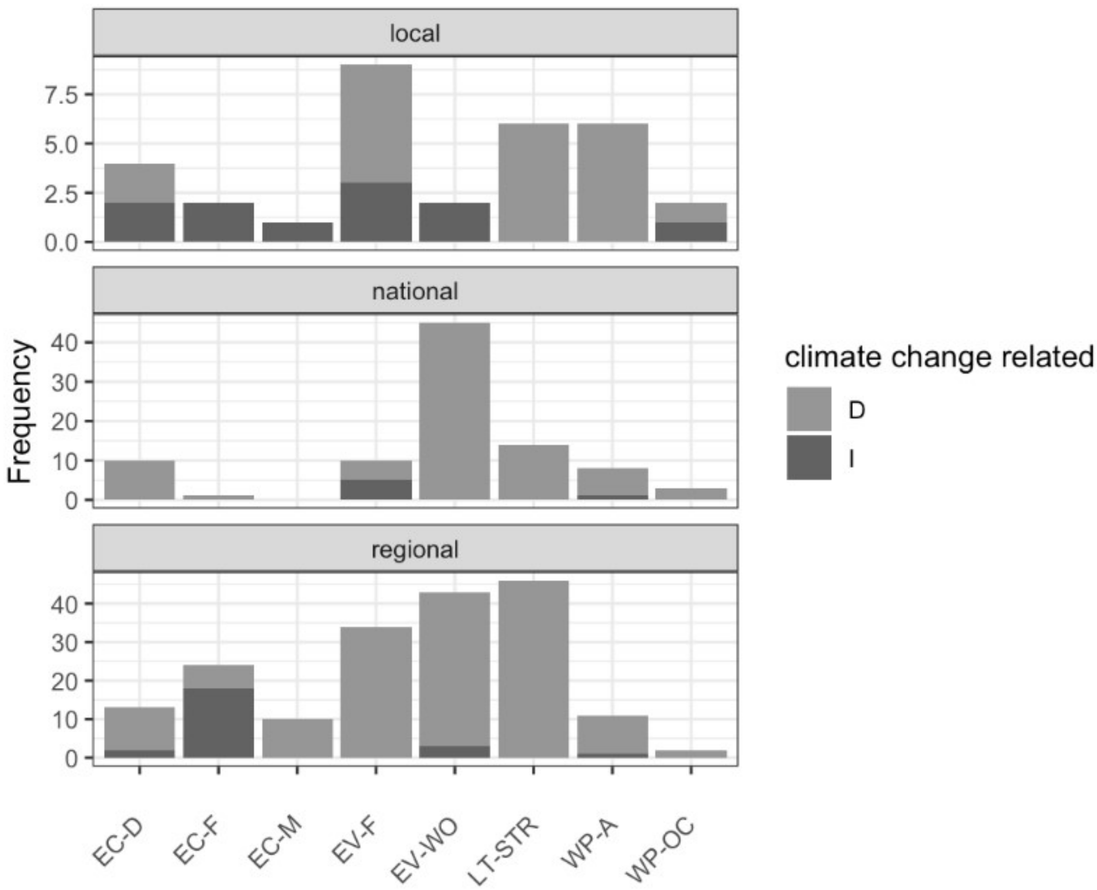

Figure 2. Frequency of marine related threats discussed in analyzed documents (EC-D-change in species distribution, EC-F-changes in food web, EC-M- Morphology, health status of fauna and flora, EV-F-Floods, rising groundwater levels, sea caused floods, EV-WO-Extreme windstorms/storm surges/strong winds, LT-STR-Sea Surface temperature changes, WP-A-Acidification, increase in carbon dioxide concentration, WP-OC-Oxygen concentration, decrease in oxygen concentration) with D-direct and I-indirect relation to climate change in text of documents.

ten fail to detail specific plans for mitigation and adaptation measures with regards to climate change. Identified threats are seldom directly linked to climate change, and when they are, the references are broad and non-specific. For example, one of the strategy documents vaguely connects climate change to significant disruptions in ecosystems and higher maintenance costs due to nature protection. It specifically mentions Gdańsk's high flood risk from sea level rise and the Hel Peninsula's vulnerability to storm surges, underscoring the significant potential for damage in densely developed urban areas, such as the Gdańsk lower town.

This represents a significant oversight, given that the analyzed cities, especially Gdańsk, are among the cities at most risk of flooding from the sea, while a potential range of damage in urban areas is high due to the high density of urban developments. Conversely, a 2023 document: "Adaptation and Mitigation to Climate Changes OMGGS plan" (issued in 2023) on adaptation and mitigation in the Tricity area addresses climate change including sea level rise for the Tricity proposing measures such as: monitoring the state of sea shores and the coastal water zone, taking into account the risk of flooding from the sea in investment plans in the coastal zone and coastal waters, preparing the documentation and construction of elements to provide protection against sea level rise and backwater, preventing erosion as well as developing good practices at the municipal level. However, the document lacks a specified timeline or descriptions of concrete actions.

The case of the Gulf of Gdańsk is not isolated and there is a significant number of positive examples of the coastal cities, which mitigate and adapt to climate change. Le (2020) analyzed urgent climate change threats in the coastal cities, reporting that floods of various character (storms, sea level rise, etc.) are the most frequently reported hazards in coastal developing cities (the analyses covered 45 cities, from 26 countries, in 4 regions, e.g. Bangkok, Thailand; Rio de Janeiro, Brazil, no EU countries). A paper published by Cabana et al. (2023) reviews articles and strategic documents around the world including Poland.

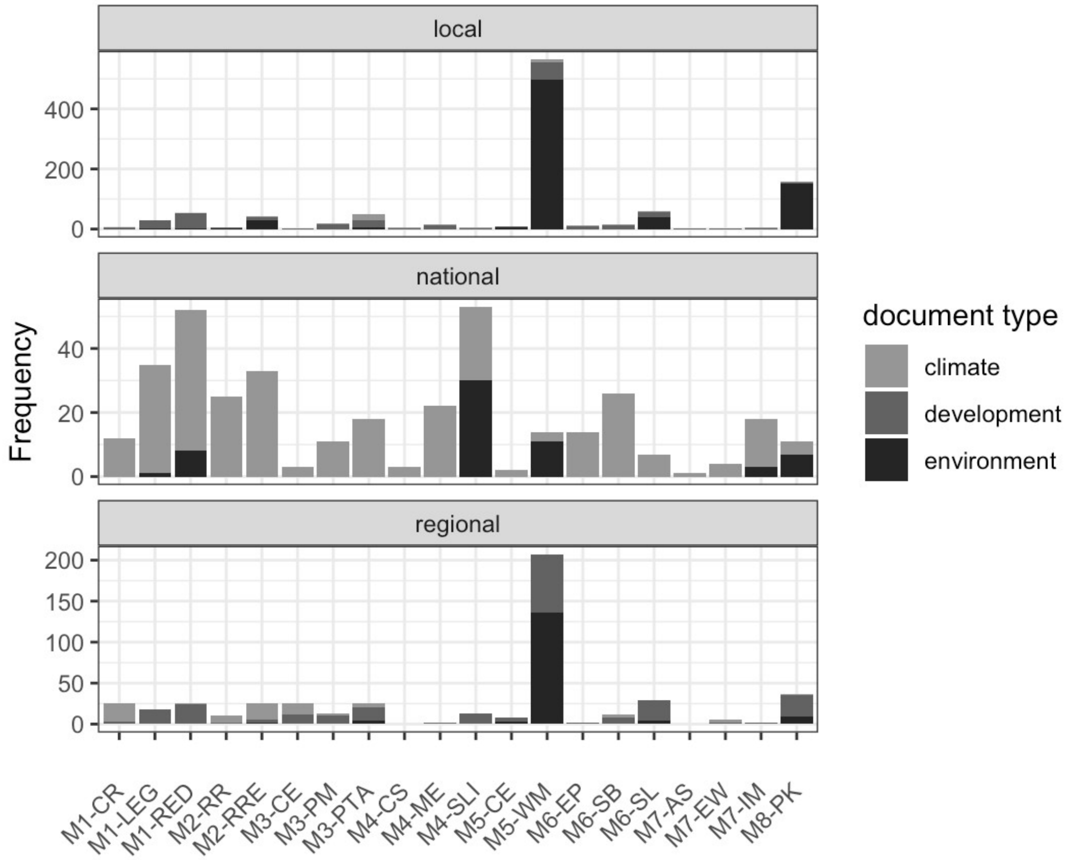

Figure 3. Frequency of mitigations (most frequent legends: M1-LEG-Low-carbon growth, Increasing the efficiency of energy use, M1-RED-Enabling municipalities to invest in activities conducive to the reduction of greenhouse gases, M4-SLI-Strengthening law and institutions, M5-WM-Waste/wastewater management and establishing related regulations, the rest of legends in Table 1).

The authors report that the majority (58%, $N = 650$) of them focus on coastal studies disregarding the ecosystems specification and that none of them follow all four phases of the adaptation policy cycle (assessment, planning, implementation and monitoring). Zimmerman and Faris (2011) provide examples of best practices in both mitigation and adaptation for North American cities. The authors further emphasize that the sea level rise has been a common challenge for the coastal cities for centuries and they stress the need for close cooperation among various groups of stakeholders in the process of protecting the coastal cities from ocean threats.

The absence of clear mitigation and adaptation measures in the Gulf of Gdańsk region is surprising given that its cities are members of the Union of the Baltic Cities (UBC) – an international network that prioritizes climate change response and sustainable development through its Sustainability Action Programme (UBC, 2021). In contrast, some Baltic ports, such as HaminaKotka in Finland, demonstrate commitment to sustainability by implementing certified environmental management systems (ISO 14001:2015) and aligning operations with the UN Sustainable Development Goals (Port of HaminaKotka Ltd., n.d.). However, publicly available information does not indicate specific strategies addressing sea-level rise or other direct marine-related climate threats at HaminaKotka, suggesting that even leading ports may lack targeted adaptation measures for coastal hazards.

The Swedish city of Gothenburg serves as another example of a Baltic port city that recognizes climate change threats. The city of Gothenburg is governed with the use of several documents including the above mentioned strategy and Environment and Climate Programme for the city 2021–2030. The Programme assumes the transformation of the city to a sustainable one till 2030. One of the goals of the programme is to increase biodiversity and improve sea water quality (its goals are based on some of the SDGs). Gothenburg recognizes the impact of climate change, particularly the rise in water levels due to the sea level rise, and has planned measures to mitigate these risks. Among the key initiatives to adapt to the change is the construction of a barrier to prevent flooding by 2070 (Environment and Climate Program for the City of Gothenburg 2021–2030) (City of Gothenburg, 2023; PreventionWeb, 2019). This concept is inspired by the measures taken to protect similar structures such as the barrier on the Thames river in London.

When discussing good practices in addressing the climate change, the Port of Rotterdam serves as a leading example. Its strategy focuses on becoming a global frontrunner in the energy transition by implementing measures such as large-scale hydrogen infrastructure, CO_2 storage projects (Porthos), and renewable energy integration. These efforts are complemented by climate adaptation initiatives, including flood risk management and nature-based solutions (Port of Rotterdam Authority, n.d.; World Economic Forum, 2019). A key component of this vision is fostering circular development among businesses within the port, while assessing climate impacts. Both the city and the port actively respond to rising sea level through implementing mitigation and adaptation measures. These include resilient infrastructures like barriers, dykes, or surge barriers e.g. Maeslantkering (movable barrier closing off the New Waterway in case of high tides). Water management measures complement these efforts, incorporating green roofs, water plazas as well as water storage facilities that retain excess water and release it gradually. Innovative urban design solutions, such as floating buildings further enhance resilience to changes in sea level. Research and collaboration between cities and ports underpin these initiatives. Collectively, these measures are embedded in strategic frameworks such as Rotterdam Climate Proof, Port Vision 2030, and the Water Plan (C40 Cities, 2016; Port of Rotterdam Authority, 2025).

This brief review suggests that the most sustainable ports are those integrated with sustainably managed cities, such as the Port of Rotterdam and the City Rotterdam, or the port of Gothenburg. However, a more detailed analysis of city strategies across all countries is required to confirm this observation.

Nevertheless, evidence suggests that the best outcomes occur when mitigations and adaptations measures are carefully planned and communicated to all stakeholders, including city residents and public services, to ensure readiness for climate change (Gargiulo et al., 2020).

One major challenge to be faced is that mitigation and adaptation measures cannot be uniformly applied across different locations due to variations in natural conditions and land use (Brunila et al., 2023; Cabana et al., 2023; Le, 2020). The lack of planning, as observed in the Gulf of Gdańsk case study, results in incomplete prevention and adaptation to climate-related impacts. Most measures currently focus on land-based activities, such as expanding bicycle routes, rather than addressing marine-related challenges, and very few, if any, consider the sea level rise. Several factors may explain this situation. One possible reason relates to findings by Dumała et al. (2021), who examined programs within the Union of the Baltic Cities and their contribution to sustainable development goals. The analysis of the programs suggests that most initiatives are of educational nature and are likely to be influenced by EU funding requirements and the need to project a climate-friendly image.

It is crucial to incorporate appropriate actions into regional, municipal, and national strategic plans and reinforce them through legislation to ensure their effective implementation. Drawing on experiences from other countries, as discussed in this review, could significantly support this process.

5. Conclusions

The review of the currently used strategic documents of the major cities around the Gulf of Gdańsk demonstrates while local authorities acknowledge climate change, their primary focus remains on threats and the consequences related to extreme atmospheric phenomena such as heavy rainfall and windstorms, as well as rainwater retention and biodiversity enhancement. Sea level rise and other marine-related threats are rarely mentioned in the documents reviewed. Most identified consequences concern tourism impacts rather than broader implications for an agglomeration of over one million inhabitants.

Few concrete measures for climate change mitigation and adaptation are proposed. While some strategies describe threats, they often rely on declarative statements without detailed plans of action or timelines. The most recent adaptation strategy for the Tricity area even questions the scientific consensus on climate change impacts over the coming decades, implying a reactive approach.

These findings contrast sharply with proactive measures adopted by other coastal cities worldwide. This paper highlights examples of well-designed adaptation strategies from Baltic cities and beyond. We conclude that authorities in the Gulf of Gdańsk region must urgently revise their perception of climate impacts and recognize the risks posed by sea level rise as well as more frequent storm surges, which could have devastating consequences if adaptation measures are not implemented promptly.

Acknowledgments

The original data collection and analysis were funded by the INTERREG Baltic Sea Region project Land–Sea-Act (#R098) and by a grant from the Polish Ministry of Science and Higher Education (5063/INTERREG BSR/19/2020/2). The extension and revision of the study were supported by the INTERREG Baltic Sea Region project BalticSea2Land (#C018) and co-financed by the Polish Ministry of Science and Higher Education under the program Co-financed International Projects (contract no. 5744/Interreg BSR 2021–2027/2023/2024/2).

We wish to extend our sincere thanks to Paulina Pakszys and Katarzyna Romancewicz for help with data collection process. Their contributions were essential to the completion of this study.

Supplementary material

Supplementary material associated with this article can be found here.

Conflict of interest

None declared.

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