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Progress and gaps in climate change adaptation in coastal cities across the globe

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Coastal cities are at the frontlines of climate change impacts, resulting in an urgent need for substantial adaptation. To understand whether, and to what extent, cities are on track to prepare for climate risks, this paper systematically assesses the academic literature to evaluate evidence on climate change adaptation in 199 coastal cities worldwide. Results show that adaptation in coastal cities is rather slow, of narrow scope and not transformative. Adaptation measures are predominantly designed based on past and current—rather than future—patterns in hazards, exposure and vulnerability. City governments, particularly in high-income countries, are more likely to implement institutional and infrastructural responses, whereas coastal cities in lower-middle-income countries often rely on households to implement behavioral adaptation. There is comparatively little published knowledge on coastal urban adaptation in low- and middle-income countries, and regarding particular adaptation types such as ecosystem-based adaptation. These insights make an important contribution for tracking adaptation progress globally and help to identify entry points for improving adaptation of coastal cities in the future.

Coastal cities are engines of economic growth and innovation, yet they are also hotspots of disasters and climate risk[1–3]. These cities face increasing environmental changes such as record-breaking sea-surface temperatures[4] and in turn an increase in hazards such as tropical cyclones, floods, storms, erosion and heatwaves[5–7]. Such changes dynamically interact with urban vulnerabilities driven by, for example, inequality, poverty and inadequate infrastructure[8]. Yet, coastal urban risk is not uniform, as climate change impacts and risks vary across coastal cities depending on geomorphological conditions, climatic and human drivers of coastal change, urban development, and other factors[6,9,10]. In the face of future increases in urbanization and climate change impacts, coastal cities are under pressure to adapt to, and reduce, current and future risks to ensure sustainable and equitable urban development[11,12]. As centers of economic activities and key players in the global political economy with substantial capacities, coastal cities have the potential to shape and advance the future of climate adaptation in meaningful and innovative ways[13]. Although the need for transformative adaptation in coastal cities—that is, adaptation that changes the fundamental attributes of a social-ecological system in anticipation of climate

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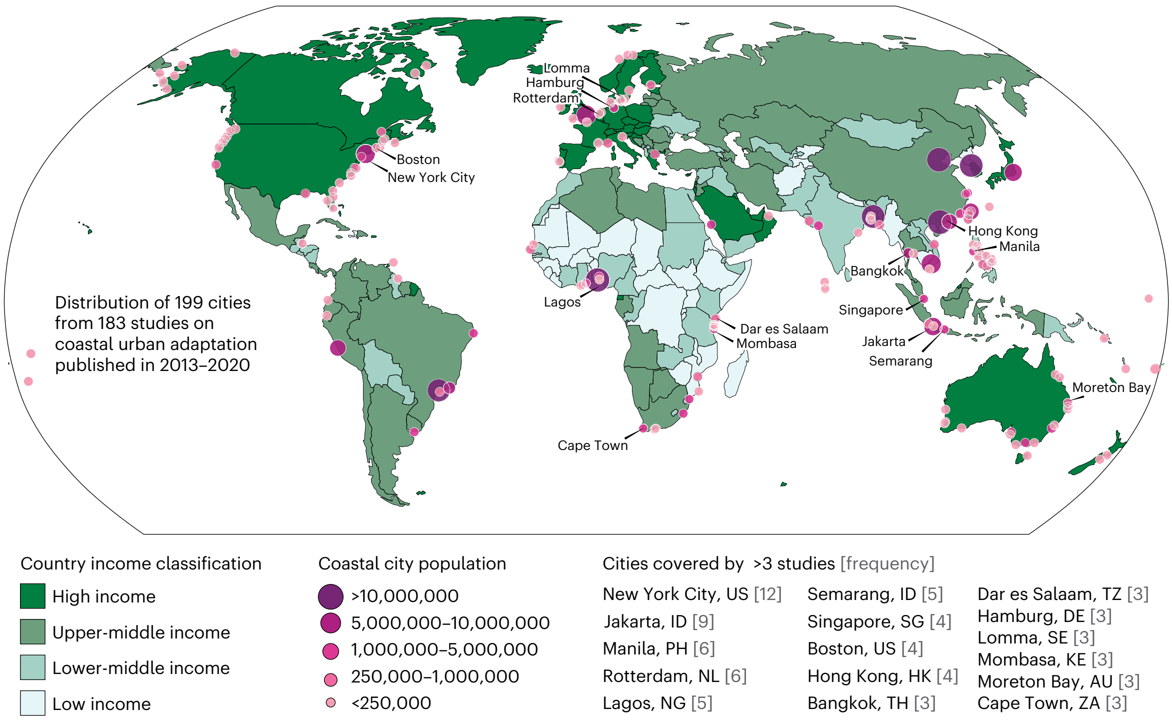

Fig. 1 | Geographical and economic distribution of coastal cities in the assessed literature. Green shading represents the country's income classification according to the World Bank[82]; the size and color of the dots visualizes the location of the covered coastal cities and their population size (Supplementary Data 3); the most covered coastal cities are listed according to frequency at the bottom right. Map source: Natural Earth[85].

change and its impacts[14]—has been stressed in principle[2,15], little is known about the actual progress of adaptation in coastal cities across the globe.

Given the unique challenges and opportunities in coastal cities as hotspots of risk and centers of economic activity, we argue that assessing their current state of adaptation is important, not least as a knowledge base for tracking countries' progress in climate action within the Global Stocktake under the Paris Agreement[16]. Understanding how coastal cities are responding to climate impacts is crucial for identifying successes and gaps, and for advancing adaptation efforts at large. Studies have assessed different types of urban adaptation, for example, institutional[17] or ecosystem-based[18], certain actor types involved in urban adaptation (for example, ref. 20), urban adaptation in particular regions (for example, refs. 19, 21–23) or coastal adaptation planning[24,25]. However, a systematic global assessment of the literature on empirical evidence for implemented coastal urban adaptation—including its response types, actors and level of transformation—does not yet exist. Such an assessment is particularly relevant in the face of the latest Intergovernmental Panel on Climate Change's (IPCC) report's finding that coastal cities tend to implement adaptation interventions reactively in response to high-impact events such as floods and storms[26], and that many gaps remain in urban adaptation to climate change induced hazards across regions[13].

This study therefore aims to provide a global analysis of empirical evidence of adaptation in coastal cities, including gaps and shortcomings. It also aims to inform policy and practice to advance effective adaptation strategies in response to current and projected climate impacts. To address these objectives, the study is guided by four questions that also serve to structure the results section: (1) How is evidence for coastal urban adaptation spread across the globe? (2) Which hazards and trends of exposure and vulnerability are reported? (3) Which actors are reported to be involved in which types of responses? And (4) what is the speed, scope and depth of reported coastal urban adaptation?

By answering these four questions, this study extends earlier assessments of the state of adaptation more generally[27] by systematically analyzing the empirical evidence of coastal urban responses to climate change, as published in the peer-reviewed academic literature. We assessed the state of adaptation in coastal cities as reported between 2013 and 2020, and examine major patterns in relation to average income levels and city size. Coastal cities here are defined as urban areas with central functions such as markets, medical services and schools; they are of relative importance to the surrounding area, regardless of population size; and are located entirely or partly on the coastline or within the low-elevation coastal zone (LECZ), or within the influence of coastal or tidal hydrology. Our sample covers adaptation activities in 199 cities reported in 683 articles, of which 183 were qualitatively coded using a questionnaire composed of 30 questions (see Methods for details). Our analysis is hence limited to what is being reported in the scientific literature and might include some hard-to-quantify biases that need to be addressed through additional datasets in the future, for example, by covering documents published by civil society actors on adaptation in coastal cities in the Global South where, according to our analysis, fewer studies are available than for higher-income countries. However, we argue that our approach and analysis nevertheless can provide highly relevant insights not only on urban adaptation research but also on the patterns of actual adaptation activities as adaptation research has been expanding massively, now capturing a wide spectrum of activities on the ground. Studies such as these therefore provide an increasingly important knowledge base for tracking adaptation activities[27].

Results

Evidence for coastal urban adaptation across the globe

The considered literature covers adaptation evidence from coastal cities in all regions and income groups, yet with some considerable differences (Fig. 1; see Supplementary Data 1.1 for a detailed list of countries covered in the sample). Most publications present evidence

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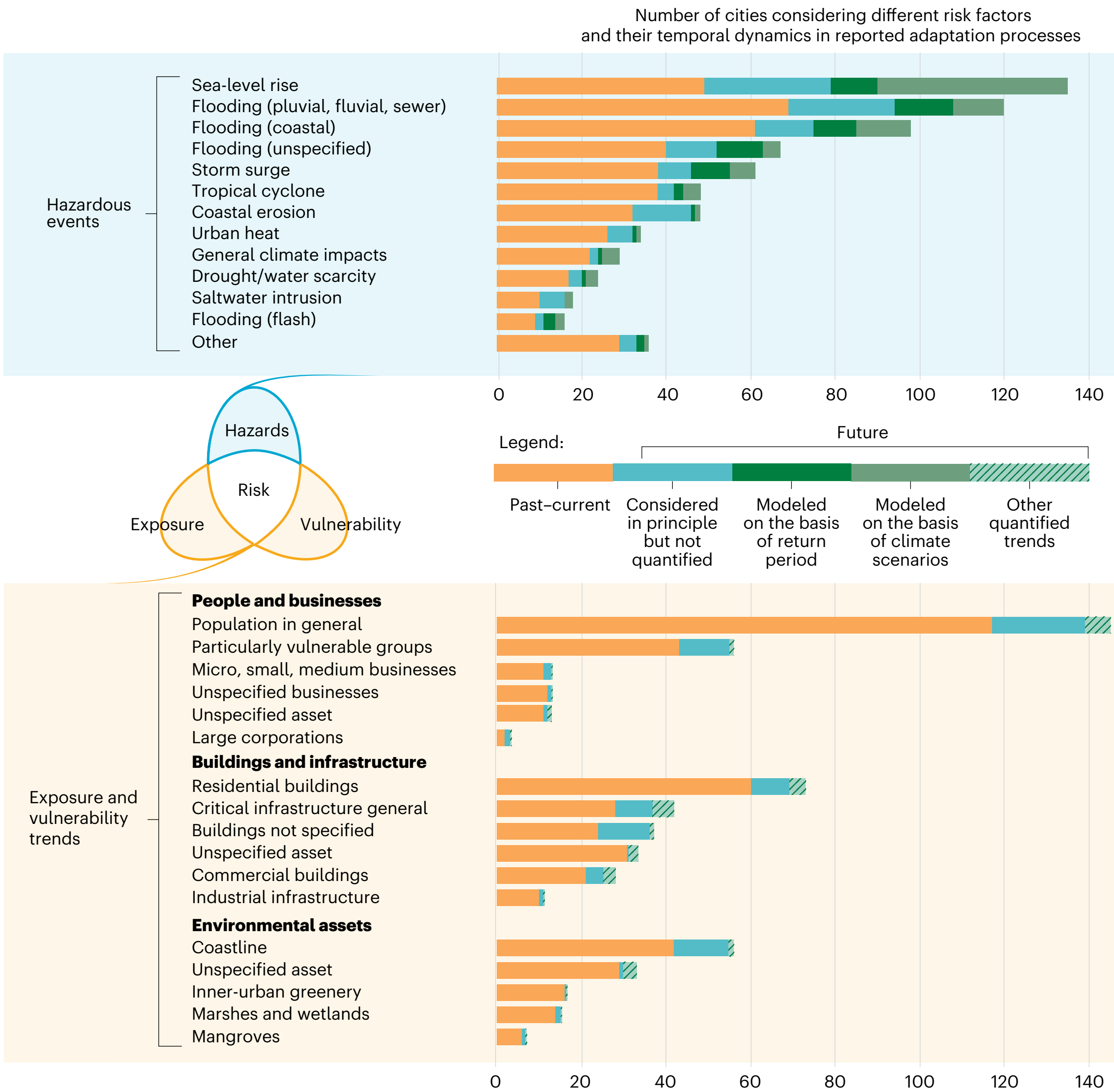

Fig. 2 | Risk factors considered in adaptation in the assessed coastal cities. Risk emerges from the interplay of hazards, exposure and vulnerability[14]. The figure displays the number of cities considering past and current patterns (orange bars), and future trends (blue and green bars) for different hazards (top), as well as the exposure and vulnerability of people and businesses, buildings and infrastructure, and environmental assets (bottom).

for adaptation from coastal cities in Asia (30%), followed by North America (23%), Europe (16%) and Africa (13%). Compared with the global share of inhabitants living in the LECZ between 0 m and 10 m above sea level[28,29], some regions are overrepresented. This is most evident for North America, Australasia and small island states, which are home to 5%, 0.6% and 0.5% of the global population in the LECZ, respectively, yet, in our sample of coastal urban adaptation evidence, they represent 23%, 11% and 3% of assessed coastal cities. Other regions are underrepresented, which is most evident for Asia given its high number of inhabitants in the LECZ. Although inhabiting 75% of the global population in the LECZ, only 31% of our assessed urban coastal adaptation evidence stems from this region.

The majority of adaptation in coastal cities is reported in high-income economies (56%), which is in stark contrast to the fact that only 16% of the population located in the LECZ live in such economies. Of the reported coastal cities, 19% and 24% of the population are in upper- and lower-middle-income economies, respectively. Given that upper- and lower-middle-income countries account for 34% and 43% of the global population in the LECZ[28,29], respectively, the coastal cities in these income groups are substantially underrepresented in our sample, meaning in the academic literature. Only 1% of the reported activities represent coastal cities in low-income economies (for example, Maputo, Beira and Inhambane in Mozambique). Given that the global population share of people who live in the low-income LECZ is about 8%, they are also underrepresented in our sample.

In terms of the coverage of different sizes of coastal cities (Supplementary Data 1.2), the assessed literature mostly presents evidence for adaptation in coastal cities with fewer than 250,000 inhabitants (48% of the reported cases). This pattern can partly be explained by our definition of coastal cities on the basis of their central functions, rather than population thresholds. Evidence for adaptation from mid-sized coastal cities with 250,000–1,000,000 inhabitants is less well-covered in our sample (the examples are mainly in North America and Europe). Thirty-five percent of the reported adaptation happens in coastal cities with >1,000,000 inhabitants, with a majority of cases in Africa and Asia. Some megacities (that is, cities with more than ten million inhabitants) such as New York, Jakarta, Manila and Lagos are covered by multiple studies (see Fig. 1). Most empirical evidence for adaptation in coastal megacities stems from Asia (57%), which aligns with the fact that 15 out of 20 coastal megacities are located in Asia[30], and also with Asia's high overall population share in the LECZ (75%)[28,29].

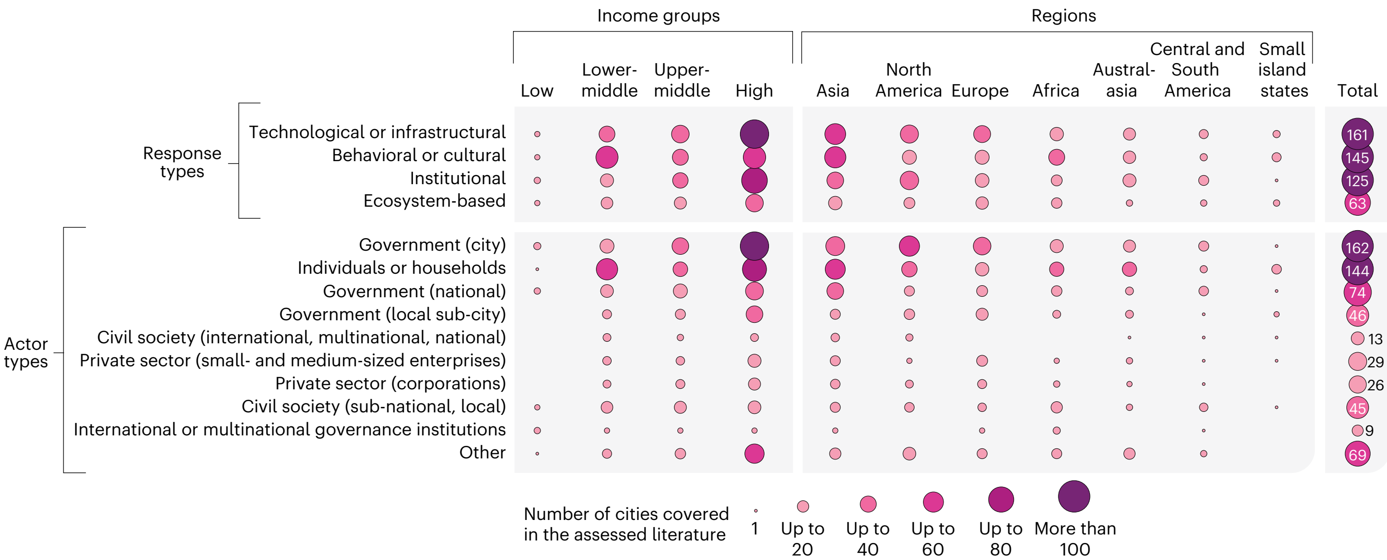

Fig. 3 | Response and actor types in the assessed coastal cities across income groups and regions. Response types are grouped (on the basis of work by Berrang-Ford et al.[27]) into technological (that is, enabling, implementing or undertaking technological innovation or infrastructural development), behavioral or cultural (enabling, implementing or undertaking lifestyle and/or behavioral change), institutional (enhancing multi-level governance or institutional capabilities) or ecosystem-based (enhancing, protecting or promoting ecosystem services for adaptation) categories.

Hazards and trends of exposure and vulnerability

In terms of hazards, the adaptation activities reported in the sample predominantly address sea-level rise, different types of flooding and, to a lesser extent, storm surges, cyclones and erosion (see Fig. 2). A majority of the assessed cases (65%) considers more than one hazard. Such consideration of multiple hazards is most evident for the combination of sea-level rise with storm surges, coastal and pluvial flooding, as well as coastal erosion. This finding suggests that multi-hazard considerations nowadays play a strong role in urban climate risk assessments, in line with what the conceptual literature would be calling for[6,10].

Studies predominantly consider past and current events with regards to hazard timescales and scenarios (Fig. 2). Studies often consider future hazard trends in principle but not in a quantified manner. Although modeled trends and scenarios are quite frequently used as a basis for adaptation to sea-level rise, flooding and storm surges, they are much less common for other hazards.

The picture is even more striking regarding how other risk factors—notably the exposure and vulnerability of people and assets in coastal cities—are considered. In the vast majority of coastal cities, reported adaptation considers only past and current patterns, with the population being the most important element considered, followed by particularly vulnerable groups, residential buildings and the coastline (Fig. 2). In scenarios in which future trends in exposed and vulnerable assets are considered, they are accounted for in a general or conceptual way, but not in terms of quantified scenarios. Across our sample, the consideration of the presented elements at risk correlates weakly with a country's income level. The higher the income group, the more likely that exposure and vulnerability aspects are considered (Supplementary Data 1.3).

Responses and actors

Most of the reported adaptation in coastal cities can be categorized as technological/infrastructural and behavioral/cultural adaptation (Fig. 3). But combinations of these two, as well as of technological and institutional responses, were also frequently reported. Ecosystem-based responses are the least reported across all world regions, particularly in low-, lower-middle and upper-middle-income countries.

The prominence of different response and actor types varies across country and income groups (Fig. 3), as well as city size. Most cases reporting technological or infrastructural responses are from coastal cities in high-income countries. The coverage of institutional responses shows a similar pattern. A correlation analysis confirms that the higher the gross national income (GNI) per capita, the more likely that institutional adaptation (Spearman's $\rho = 0.23$, $P < 0.01$) and less likely that behavioral adaptation (Spearman's $\rho = -0.35$, $P < 0.01$) is mentioned (Supplementary Data 1.4). Institutional responses are mostly reported to be implemented by state actors, especially city governments (Supplementary Data 1.5), which are the most commonly mentioned actor type across our sample. Correlation analysis reveals that the higher the GNI per capita, the more likely that the city government is assessed as an actor in adaptation (Spearman's $\rho = 0.30$, $P < 0.01$), and the less likely that individuals/households are mentioned (Spearman's $\rho = -0.23$, $P < 0.01$) (Supplementary Data 1.6). Our analyses also reveal that the bigger a city, the less likely that individual/household adaptation is mentioned (Spearman's $\rho = -0.30$, $P < 0.01$) and the more likely that a city government is assessed as an actor involved in adaptation (Spearman's $\rho = 0.20$, $P < 0.01$) (Supplementary Data 1.6).

Reported behavioral or cultural responses are most likely to be assessed together with individuals or households as implementing actors (Supplementary Data 1.7). This response type dominates the reported adaptation evidence in coastal cities in lower-middle-income countries. Accordingly, individuals/households are mostly reported as adaptation actors here, whereas state actors such as city and sub-city governments are less frequently assessed as implementers. In contrast to this, we find a low involvement of individuals in low-income economies; however, the very small number of cases in the low-income category needs to be considered here.

Although the assessed literature mostly presents adaptation evidence implemented by one type of actor (in our sample, mostly city governments followed by individuals/households), there is also reported evidence for multiple actors involved in urban adaptation. In many cases, individuals/households and city governments are mentioned together. Furthermore, combinations of city and national governments, or a combination of the two with the sub-city local government, are reported more frequently than other combinations (Supplementary Data 1.8).

Looking at adaptation types across regions (Fig. 3 and Supplementary Data 1.7), behavioral adaptation is less likely to be reported in North

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Income groups	Depth of adaptation			Scope of adaptation			Speed of adaptation		
	Low	Mid.	High	Low	Mid.	High	Low	Mid.	High
Low	50%	50%	0%	33%	67%	0%	0%	0%	100%
Lower-middle	60%	34%	5%	70%	23%	6%	75%	17%	7%
Upper-middle	59%	30%	10%	52%	35%	10%	62%	21%	16%
High	60%	30%	10%	61%	24%	15%	70%	16%	14%
Total share	60%	31%	9%	62%	26%	12%	69%	17%	13%

Proportion of adaptation reported with high level of confidence

Fig. 4 | Depth, scope and speed of the reported coastal urban adaptation across income groups. The depth, speed and scope of adaptation are dimensions of transformative adaptation[27,31]. Displayed numbers represent the share of studies evaluated to report low, medium or high levels of depth, speed and scope of adaptation within different country groups in terms of average income according to the World Bank[82].

American coastal cities (ϕ coefficient = −0.21, $P < 0.01$) and coastal cities in Central and South America, but more likely to be reported in coastal cities in Africa and Asia. For the last two, we find less evidence for institutional and ecosystem-based adaptation; these adaptation categories are more likely to be assessed in European and North American coastal cities. Evidence for technological adaptation is most likely to be assessed in European coastal cities; research on institutional adaptation evidence features most highly in North and South America.

Speed, scope and depth of adaptation

Transformative adaptation can be assessed along the dimensions of depth (how deep institutional, and other changes, are), speed (how fast adaptation is planned and implemented) and scope (with which geographical and sectoral breadth adaptation happens)[27,31]. Overall, we find that reported adaptation remains at rather low depth, scope and speed in coastal cities, across all income groups and regions, with little evidence of reduced risks due to adaptation (Fig. 4). Neither income level nor population size predicts more or less transformative adaptation (Supplementary Data 1.9).

Few examples of urban adaptation with deeper changes (that is, entirely new practices that involve deep structural reform, a fundamental change in mindset, major shifts in perceptions or values, and/or changing institutional or behavioral norms) stem from cities in high-income economies or small island states. Given the small number of cases featuring such fundamental forms of adaptation, we provide an aggregated overview of specific studies below.

Some cases reported self- or state-led resettlement[32,33] to adapt to climate change impacts in coastal cities. In cities such as Singapore and Hong Kong[34], and several Swedish cities[35], existing infrastructural measures are complemented by preparedness and recovery measures, as well as ecosystem-based approaches. Progress in the institutionalization and mainstreaming of basin-wide planning, the integration of adaptation into mitigation and development planning, and the establishment of legislation to reinforce adaptation in sectors such as construction, are considered as evidence of more transformative adaptation in coastal cities. We also identified evidence for medium adaptation depth across countries with different income levels, where the assessed responses reflect a shift away from existing practices, norms or structures to some extent. In coastal cities located in high-income countries in Europe, such as Rotterdam, Dordrecht and Helsinki, medium-depth adaptation is linked to the testing of innovative, design-oriented adaptation approaches, the development of collaborative governance approaches, and public–private partnerships for improving funding and innovation[36–40]. In smaller US coastal cities such as Dunedin and Fernandina Beach, changes towards cross-sectoral, comprehensive and more integrative risk management plans[41,42] were described. Bigger US cities such as New York and Miami Beach are implementing both large-scale infrastructure investments for flood protection[43–45] and planning, and/or complementary adaptation measures such as ecosystem-based and soft adaptation approaches[43,46].

In Asian coastal cities in lower- and upper-middle-income countries, medium-depth adaptation includes changes in adaptive behavior of individuals and households (for example, changes in livelihoods or migration[33,47–50]), as well as institutional-scale adaptations (for example, the establishment of new institutions responsible for adaptive planning, disaster risk reduction planning at various scales, or mainstreaming climate change policies in other sectors[51–53]). The only case with evidence of medium-depth adaptation in a low-income country is Maputo, Mozambique, which has mainstreamed climate change adaptation into its development plans, attributed clear responsibilities for addressing climate change impacts, and started participatory urban planning processes[54].

For the majority of coastal cities covered in our sample, adaptation remains at low depth across income groups and regions, meaning that evidence for adaptation largely represents expansions of existing practices, with minimal change in underlying values, assumptions or norms. Examples are a continuous focus on traditional infrastructural measures to avoid flooding[55,56], continued uptake of flood insurance[57], or incremental adaptation in the form of reactive coping due to limited capacities[58,59].

The scope of responses in our sample is mostly narrow, across both income groups and regions, meaning that evidence for coastal urban adaptation measures is largely localized and fragmented, with limited evidence of coordination or mainstreaming across sectors, jurisdictions or levels of governance.

The speed of coastal urban adaptation is mostly considered slow—especially in high-, upper-middle- and lower-middle-income countries, and a majority of regions. This means that adaptations are incremental, consisting of small steps and slow implementation.

Given that depth, scope and speed of adaptation were evaluated as rather low across our sample, it is not surprising that there is little evidence for risk being reduced through these measures. Although we identified some cases that present evidence for risks being overcome through, for example, ecosystem-based[60,61] and technological/infrastructural adaptation[45,62], some are linked to negative side-effects or lacking long-term perspectives[63] or even represent maladaptation[56,64,65].

Discussion

Based on the analysis of adaptation in coastal cities reported in the academic literature, we highlight five key findings and close by discussing their implications for research and policy-making in the field of coastal urban adaptation to climate change.

First, our assessment shows that the knowledge and coverage of adaptation in coastal cities is highly uneven, with some coastal cities

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receiving a lot of scientific attention, and large gaps remaining. For example, small and mid-sized coastal cities in Africa, Asia and Central and South America are currently not part of the global scientific debate, despite the fact that more adaptation might be happening on the ground, reported in other types of documents such as white papers or NGO reports. In our assessment based on the peer-reviewed and mostly English-language academic literature, coastal cities in low-, lower-middle and upper-middle-income countries are underrepresented. Given that cities in Africa, Asia, and Central and South America are expected to experience a highly dynamic interplay of urbanization, highly vulnerable informal settlements and future climate change impacts (see page 7 of ref. 66), this is a considerable gap in research that needs to be addressed urgently. Researchers and funding agencies should therefore make a dedicated push towards increasing the evidence-base, specifically in this segment of cities. Furthermore, other data sources such as non-peer-reviewed reports and other grey literature need to be assessed in the future to complement the evidence provided in the peer-reviewed scientific literature.

Second, we generally found that hazards, exposure and vulnerability are considered on the basis of past and current events and conditions. The use of future climate scenarios or other quantitative assessments taking into account future hazard trends remains scarce, and the picture is even more troublesome in terms of the future trends of exposure and vulnerability. Most reported adaptation is not based on a thorough consideration—let alone quantified scenarios—of future developments in the exposure and vulnerability of at-risk people, infrastructure, ecosystems and other assets. This leads to skewed assumptions on future risk, jeopardizing the relevance and validity of knowledge for adaptation planning. Although this finding confirms earlier observations with respect to the low consideration of future exposure and vulnerability trends in National Adaptation Plans[67] and cities[24], it is nevertheless striking given the high importance of dynamic changes in these domains for changing future risk in coastal cities, for example, through further coastal urbanization or ongoing socio-economic marginalization[6,8].

Third, we find that the lower the income group of the country the coastal cities are located in, the more likely individuals/households are reported as prime adaptation actors. At the same time, government responses and planned adaptation are more often reported in coastal cities in wealthier countries. This suggests that residents with limited resources in poorer coastal cities have to carry most of the adaptation burden[68], which is often met with behavioral changes due to the lack of institutional and/or technological support. These results corroborate other studies regarding the inequality in the urban adaptation gap (see pages 34 of ref. 66 and page 941 of ref. 26), which is most pronounced among the poor.

Fourth, the bigger a city, the more likely that technological responses and protection are assessed. This relationship was also found in other studies[69]. At the same time, there is a lack of reported empirical evidence on ecosystem-based adaptation. Technology-based measures such as flood-barriers or pumping installations are essential protective mechanisms in the short- and mid-term, for example, for storm water management. However, they can lead to a lock-in and maladaptive path dependency in the long-term if coastal hazards continue to rise and hard protection fails or reaches limits of financial and technical feasibility as well as cultural acceptance[70,71]. More research on alternative and complementary adaptation measures is therefore needed to guide mixed approaches in the future.

Fifth, our findings suggest urgent needs for transformative adaptation in coastal cities. Across all regions and income groups, scientifically reported adaptation in coastal cities remains at rather low depth, scope and speed. Neither income level nor population size predicted more or less progressive adaptation behavior. Given the high exposure and vulnerability of many coastal cities already today, this finding is alarming as adaptation to future climate change will require many cities to go beyond business as usual risk management to effectively manage and reduce the accelerating risks and vulnerabilities[2,15,72]. This finding affirms other assessments of urban adaptation[26] and stresses the persistent need for transformative adaptation in coastal cities. It is possible that the cumulative effects of incremental responses could, over time, lead to meaningful and even transformative adaptation; however, the speed and amount of change needed to mitigate current and future risks, could mean that incremental adaptation is tantamount to playing 'catch-up' as climate impacts accelerate.

The extreme changes in the oceans and coasts seen in the recent past, with, for example, new temperature records[4,73,74] and low sea-ice extent[75], highlights the scale and speed of adaptation that will be needed. Yet, taking the scientifically reported adaptation evidence as a proxy for the state of adaptation in coastal cities, our findings suggest that adaptation in coastal cities is rather slow, narrow, and fragmented (in other words, non-transformative) in an environment that is transforming rapidly. At the same time, our findings point towards an increasing range of adaptation activities in coastal cities. This evidence mapping can help to point researchers to blind spots in adaptation research in coastal cities and it provides entry points for improving urban adaptation planning.

Methods

We followed the ROSES protocol[76] to produce a systematic map of evidence for climate change adaptation in coastal cities (Supplementary Table 1). We base our findings on the combination of a systematic review of scientific literature on coastal urban adaptation to climate change across three reference databases (see Extended Data Fig. 1, which follows the ROSES flow diagram for systematic reviews[77]) with a content analysis based on a coding protocol, following the Global Adaptation Mapping Initiative (GAMI) process.

Relevant peer-reviewed, scientific, English-language literature on the topic of coastal urban adaptation was identified in a four-tiered search process.

Literature search and data extraction

Publications of the category 'cities and settlements by the sea' were extracted from the GAMI database—a systematic dataset comprising over 1,600 articles on climate adaptation. After a preliminary overview of the 361 resulting publications, further searches through the reference databases Web of Science and Scopus, and discussions among the co-authors (most of whom are well-acquainted with the literature in this particular field), it was decided that the GAMI selection did not adequately represent the large pool of existing literature on coastal urban adaptation. Hence, in a second step, a search string (in English) based on boolean search terms was used to systematically search Web of Science (Core Collection) and Scopus for relevant peer-reviewed, scientific literature over the years 2013 to 2020. The period stretches from the end of the IPCC's fifth assessment cycle to the cut-off date for considering scientific literature of the sixth assessment cycle. With this we extended the original GAMI search by one year; we did not include 2021 and 2022 due to the coding time-frame. Although the basis of the search string was adopted from the GAMI process[78,79], it was extended by tailored search terms to yield more topic-relevant publications. The search strings and respective hits can be found in Supplementary Information 1. In a final step, the results of all three searches were combined and duplicates were removed.

We are aware that systematic searches such as this are subject to limitations. Our approach neither considered grey literature such as reports, nor did it use non-English search strings, and thus it is predominately built on English-language publications, which might have led to biases in the results. We nonetheless decided to use this approach to take steps towards a global stocktake of adaptation in coastal cities on the basis of scientific, peer-reviewed literature, using it as a first indication for the state of knowledge on coastal urban adaptation, and as a proxy for understanding where coastal cities currently stand in adapting to climate change. From the perspective of the authors, the added value in these respects outweigh the limitations of the study.

Screening

A total of 683 scientific publications entered the screening process, in which the coders assessed whether a publication should be included in the analysis. Overall, only peer-reviewed publications were considered, which excludes conference contributions (further inclusion/exclusion criteria are listed in Supplementary Information 1). A total of 501 publications were excluded because they did not meet the inclusion criteria. Six publications were not available in English language, and two were either not accessible or not found. Requests to the authors for access were unanswered. See Supplementary Table 2 for an overview of all included, excluded and not found or accessible publications.

Coding

The included publications were analyzed via a systematic content analysis. The publications were distributed among coders considering their interests and capacities, ensuring that no coder analyzed their own publications. Using the online survey platform SoSci Survey Version 3.5.01, coders completed one coding questionnaire per city covered in the manuscript. This means that for one publication, several questionnaires could have been completed in the case that it dealt with two or more cities. In total, 183 publications (Supplementary Table 2) covering 284 cases from 199 cities and/or settlements with central functions such as schools, supermarkets and medical services were included in the coding and statistical analysis, as well as four unspecified urban areas. The literature database (Supplementary Table 2) and the coding database (Supplementary Data 2) can be found as supplements.

Data quality

We ensured coder consistency and reliability through an introduction to the commonly developed questionnaire; a code book/protocol with detailed definitions of all codes (Supplementary Information 1); a pre-coding period with interim meetings to discuss issues and confusions; and multiple other meetings with all of the coders involved. The coding included, among others, the following categories: hazard type; exposure and vulnerability; actor type; response type; and, as indicators for transformational adaptation, the depth, speed and scope of adaptation (see Supplementary Information 1 for the full list of codes and variables). About 10% of the entire dataset (that is, 72 publications) was double-coded to check inter-coder reliability. Conflicts regarding inclusion/exclusion arose to 12.8%. Of the 16 fully double-coded publications, inter-coder variability rose to a maximum of 22.2%, meaning a convergence in roughly 80% of provided answers, which was accepted as sufficient to consider the dataset as robust. The data, in the form of codes, were extracted from the ScoSci Survey platform, cleaned and statistically analyzed in IBM SPSS Statistics 23, following the original GAMI approach[78,80,81]. Coders provided their level of confidence (low, medium, high) to evaluate the depth, speed and scope of adaptation; the final analysis only considered medium- and high-confidence judgements to increase the robustness of the findings.

Data analysis

To obtain an overview of the dataset, descriptive statistical analyses were performed to assess the frequency and proportion of all variables. To identify potential patterns, frequencies were assessed across the World Bank income economies categories (hereafter income groups)[82] and also across regions following the classification used in ref. 27. Moreover, we used different correlation tests to explore potential relationships that two variables, GNI per capita[83] and city size (in terms of population, Supplementary Data 3), have with patterns of actor involvement, adaptation type and depth, and the speed and scope of adaptation. We are aware that income indicators and the urban population size are by far not the only factors influencing adaptation in complex socio-ecological systems[84]; however, they provide valuable, globally available and comparable starting points for not only describing, but also explaining, emerging patterns of urban coastal adaptation. Hence, our objective was to evaluate the existence of any relationship between these two variables (GNI per capita and city size) with our assessed variables. The Spearman's rank correlation was employed to ascertain the relationship between GNI per capita and city size with actor involvement. The correlation coefficient ranges between −1 and 1, indicating negative and positive correlations, respectively. The significance of the correlation coefficient is examined by the t-test, which assesses the null hypothesis that there is no monotonic relationship between the two variables. The null hypothesis is rejected if the P-value is less than 0.05. The relationship between adaptation actors and response categories was determined using the χ^2 test, which is a common statistical method for measuring the association between binary variables. The strength and direction of the association are represented by the ϕ coefficient. This coefficient, like the Spearman correlation, ranges from −1 to 1, with values close to −1 indicating a strong negative association, values close to 1 indicating a strong positive association, and values close to 0 indicating a weak or no association. The significance of the ϕ coefficient is also examined using a P-value.

To conduct a cross-sectional comparison of population data in the LECZ across different regions, we utilized "The Low Elevation Coastal Zone (LECZ) Urban-Rural Population and Land Area Estimates, Version 3" dataset[28]. Within this dataset, we specifically selected the population data from "Gridded Population of the World, Version 4 (GPWv4), Revision 11" and the elevation data from 'CoastalDEM90' as core datasets, due to their particular applicability in global-scale and coastal analyses. The analysis provides data about the share of residents living in the LECZ globally in the considered income economies and regions, which is used to understand the relative coverage of adaptation evidence reported in our sample.

The assessment of transformational adaptation in coastal cities builds on the coders' qualitative evaluation of the three dimensions of transformation[31]; that is, depth, speed and scope (definitions of the categories can be found in Supplementary Information 1) of the reported adaptation evidence. In addition, the confidence in their respective responses was assessed and only high- and medium-confidence evaluations were taken into account in the final assessment of speed, scope and depth.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

All data and analyses used for this study are available in the Supplementary Information, Supplementary Data, Supplementary Tables and Source Data. The Supplementary Information describes the searches (and their combinations) used to generate the literature sample, the inclusion and exclusion criteria for the literature, and a code book providing descriptions of all of the codes. Supplementary Data allows access to all correlation tables, the full coding database, and the list of sources for the city populations used in Fig. 1. The base layer[85] for Fig. 1 is publicly available, as are the LECZ population data[28], the country groupings according to average income levels by the World Bank[82], and the GNI per capita[83] used for the analyses. Supplementary Table 1 displays the full ROSES map report for the study; Supplementary Table 2 provides the full list of the included and excluded literature, including the author(s), title, journal, year and doi. Source Data are provided with this paper.

References

1. Hallegatte, S. Future flood losses in major coastal cities. *Nat. Clim. Change* **3**, 802–806 (2013).
2. Kuhl, L. et al. Transformational adaptation in the context of coastal cities. *Ann. Rev. Environ. Resour.* **46**, 449–479 (2021).
3. Pelling, M. *The Vulnerability of Cities: Natural Disasters and Social Resilience* (Routledge, 2003); https://doi.org/10.4324/9781849773379.
4. Jones, N. The ocean is hotter than ever: what happens next? *Nature* **617**, 450–450 (2023).
5. Becker, M., Karpytchev, M. & Hu, A. Increased exposure of coastal cities to sea-level rise due to internal climate variability. *Nat. Clim. Change* **13**, 367–374 (2023).
6. Glavovic, B. et al. in *Climate Change 2022: Impacts, Adaptation, and Vulnerability* (eds. Pörtner, H.-O. et al.) 2163–2194 (Cambridge Univ. Press, 2022); https://doi.org/10.1017/9781009325844.019
7. Laino, E. & Iglesias, G. Extreme climate change hazards and impacts on European coastal cities: a review. *Renew. Sustain. Energy Rev.* **184**, 113587 (2023).
8. Garschagen, M. & Romero-Lankao, P. Exploring the relationships between urbanization trends and climate change vulnerability. *Clim. Change* **133**, 37–52 (2015).
9. Magnan, A. K. et al. Sea level rise risks and societal adaptation benefits in low-lying coastal areas. *Sci. Rep.* **12**, 10677 (2022).
10. Magnan, A. K. et al. Status of global coastal adaptation. *Nat. Clim. Change* **13**, 1213–1221 (2023).
11. Rosenzweig, C. et al. in *Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network* (eds. Rosenzweig, C. et al.) 17–42 (Cambridge Univ. Press, 2018); https://doi.org/10.1017/9781316563878.007
12. Wolff, C., Nikoletopoulos, T., Hinkel, J. & Vafeidis, A. T. Future urban development exacerbates coastal exposure in the Mediterranean. *Sci. Rep.* **10**, 14420 (2020).
13. Adelekan, I. et al. *What the Latest Science on Impacts, Adaptation and Vulnerability Means for Cities and Urban Areas* (Indian Institute for Human Settlements, 2022); https://doi.org/10.24943/SUPSV209.2022
14. IPCC. *Climate Change 2022: Impacts, Adaptation, and Vulnerability* (eds. Möller, V. et al.) Annex II: Glossary, 1757–1776 (Cambridge Univ. Press, 2022).
15. Solecki, W., Pelling, M. & Garschagen, M. Transitions between risk management regimes in cities. *Ecol. Soc.* **22**, 38 (2017).
16. *Paris Agreement* (UNFCCC, 2016).
17. Patterson, J. J. More than planning: diversity and drivers of institutional adaptation under climate change in 96 major cities. *Glob. Environ. Change* **68**, 102279 (2021).
18. Frantzeskaki, N. Seven lessons for planning nature-based solutions in cities. *Environ. Sci. Policy* **93**, 101–111 (2019).
19. Aguiar, F. et al. Adaptation to climate change at local level in Europe: an overview *Environ. Sci. Policy* **86**, 38–63 (2018).
20. Klein, J., Juhola, S. & Landauer, M. Local authorities and the engagement of private actors in climate change adaptation. *Environ. Plann. C* **35**, 1055–1074 (2017).
21. Dilling, L., Pizzi, E., Berggren, J., Ravikumar, A. & Andersson, K. Drivers of adaptation: responses to weather- and climate-related hazards in 60 local governments in the Intermountain Western U.S. *Environ. Plann. A* **49**, 2628–2648 (2017).
22. Filho, W. L. et al. Strengthening climate change adaptation capacity in Africa—case studies from six major African cities and policy implications. *Environ. Sci. Policy* **86**, 29–37 (2018).
23. Reckien, D. et al. Quality of urban climate adaptation plans over time. *npj Urban Sustain.* **3**, 1–14 (2023).
24. Olazabal, M., de Gopegui, M. R., Tompkins, E. L., Venner, K. & Smith, R. A cross-scale worldwide analysis of coastal adaptation planning. *Environ. Res. Lett.* **14**, 124056 (2019).
25. Le, T. D. N. Theoretical frameworks in climate change adaptation planning: a comparative study in coastal cities of developing countries. *J. Environ. Plann. Manag.* **66**, 424-444 (2023).
26. Dodman, D. et al. in *Climate Change 2022: Impacts, Adaptation and Vulnerability* (eds. Pörtner, H.-O. et al.) 907–1040 (Cambridge Univ. Press, 2022); https://doi.org/10.1017/9781009325844.008
27. Berrang-Ford, L. et al. A systematic global stocktake of evidence on human adaptation to climate change. *Nat. Clim. Change* **11**, 989–1000 (2021).
28. *Urban-Rural Population and Land Area Estimates, v3 (1990, 2000, 2015)* (NASA, 2021).
29. MacManus, K., Balk, D., Engin, H., McGranahan, G. & Inman, R. Estimating population and urban areas at risk of coastal hazards, 1990–2015: how data choices matter. *Earth Syst. Sci. Data* **13**, 5747–5801 (2021).
30. *World Urbanization Prospects: The 2018 Revision* (United Nations, 2019); https://population.un.org/wup/publications/Files/WUP2018-Report.pdf
31. Termeer, C. J. A. M., Dewulf, A. & Biesbroek, R. Transformational change: governance interventions for climate change adaptation from a continuous change perspective. *J. Environ. Plann. Manage.* **60**, 558–576 (2016).
32. Albert, S. et al. Heading for the hills: climate-driven community relocations in the Solomon Islands and Alaska provide insight for a 1.5 °C future. *Reg. Environ. Change* **18**, 2261–2272 (2018).
33. Islam, Md. M., Sallu, S., Hubacek, K. & Paavola, J. Migrating to tackle climate variability and change? Insights from coastal fishing communities in Bangladesh. *Clim. Change* **124**, 733–746 (2014).
34. Chan, F. K. S., Chuah, C. J., Ziegler, A. D., Dąbrowski, M. & Varis, O. Towards resilient flood risk management for Asian coastal cities: lessons learned from Hong Kong and Singapore. *J. Clean. Prod.* **187**, 576–589 (2018).
35. Wamsler, C. et al. Operationalizing ecosystem-based adaptation: harnessing ecosystem services to buffer communities against climate change. *Ecol. Soc.* **21**, 31 (2016).
36. Blok, A. Climate riskscapes in world port cities: situating urban-cosmopolitan risk communities via Ulrich Beck's comparative tactics. *Glob. Netw.* **20**, 500–521 (2020).
37. Dircke, P. & Molenaar, A. Climate change adaptation; innovative tools and strategies in Delta City Rotterdam. *Water Pract. Technol.* **10**, 674–680 (2015).
38. Francesch-Huidobro, M. Collaborative governance and environmental authority for adaptive flood risk: recreating sustainable coastal cities: Theme 3: pathways towards urban modes that support regenerative sustainability. *J. Clean. Prod.* **107**, 568–580 (2015).
39. Gersonius, B., van Buuren, A., Zethof, M. & Kelder, E. Resilient flood risk strategies: institutional preconditions for implementation. *Ecol. Soc.* **21**, 26270012 (2016).
40. Mees, H. L. P., Driessen, P. P. J. & Runhaar, H. A. C. Legitimate adaptive flood risk governance beyond the dikes: the cases of Hamburg, Helsinki and Rotterdam. *Reg Environ Change* **14**, 671–682 (2014).
41. Díaz, P., Stanek, P., Frantzeskaki, N. & Yeh, D. H. Shifting paradigms, changing waters: transitioning to integrated urban water management in the coastal city of Dunedin, USA. *Sustain. Cities Soc.* **26**, 555–567 (2016).
42. Butler, W. H., Deyle, R. E. & Mutnansky, C. Low-regrets Incrementalism: land use planning adaptation to accelerating sea level rise in Florida's coastal communities. *J. Plann. Educ. Res.* **36**, 319–332 (2016).
43. Jeuken, A., Haasnoot, M., Reeder, T. & Ward, P. Lessons learnt from adaptation planning in four deltas and coastal cities. *J. Water Clim. Change* **6**, 711–728 (2015).

44. Molinaroli, E., Guerzoni, S. & Suman, D. Do the adaptations of Venice and Miami to sea level rise offer lessons for other vulnerable coastal cities? *Environ. Manag.* **64**, 391–415 (2019).
45. Wakefield, S. Miami Beach forever? Urbanism in the back loop. *Geoforum* **107**, 34–44 (2019).
46. Pinto, P. J., Kondolf, G. M. & Wong, P. L. R. Adapting to sea level rise: emerging governance issues in the San Francisco Bay region. *Environ. Sci. Policy* **90**, 28–37 (2018).
47. Alam, A. & Miller, F. Slow, small and shared voluntary relocations: learning from the experience of migrants living on the urban fringes of Khulna, Bangladesh. *Asia Pac. Viewp.* **60**, 325–338 (2019).
48. Buchori, I. et al. Adaptation to coastal flooding and inundation: mitigations and migration pattern in Semarang City, Indonesia. *Ocean Coast. Manag.* **163**, 445–455 (2018).
49. Rahman, M. K., Paul, B. K., Curtis, A. & Schmidlin, T. W. Linking coastal disasters and migration: a case study of Kutubdia island, Bangladesh. *Prof. Geogr.* **67**, 218–228 (2015).
50. See, J. & Wilmsen, B. Just adaptation? Generating new vulnerabilities and shaping adaptive capacities through the politics of climate-related resettlement in a Philippine coastal city. *Global Environ. Change* **65**, 102188 (2020).
51. Porio, E. Climate change vulnerability and adaptation in metro Manila: challenging governance and human security needs of urban poor communities. *Asian J. Soc. Sci.* **42**, 75–102 (2014).
52. Walch, C. Adaptive governance in the developing world: disaster risk reduction in the State of Odisha, India. *Clim. Dev.* **11**, 238–252 (2019).
53. Wong, E. et al. Policy environment for the tourism sector's adaptation to climate change in the South Pacific—the case of Samoa. *Asia Pac. J. Tour. Res.* **18**, 52–71 (2013).
54. Broto, V. C., Boyd, E. & Ensor, J. Participatory urban planning for climate change adaptation in coastal cities: lessons from a pilot experience in Maputo, Mozambique. *Curr. Opin. Environ. Sustain.* **13**, 11–18 (2015).
55. Malott, D., Robertson, L., Hiei, K. & Werner, H. Next Tokyo 2045: a mile-high tower rooted in intersecting ecologies. *CTBUH J.* **2**, 30–35 (2015).
56. Neise, T. & Revilla Diez, J. Adapt, move or surrender? Manufacturing firms' routines and dynamic capabilities on flood risk reduction in coastal cities of Indonesia. *Int. J. Disaster Risk Reduct.* **33**, 332–342 (2019).
57. Cannon, C., Gotham, K. F., Lauve-Moon, K. & Powers, B. The climate change double whammy: flood damage and the determinants of flood insurance coverage, the case of post-Katrina New Orleans. *Clim. Risk Manag.* **27**, 100210 (2020).
58. Ajibade, I., McBean, G. & Bezner-Kerr, R. Urban flooding in Lagos, Nigeria: patterns of vulnerability and resilience among women. *Glob. Environ. Change* **23**, 1714–1725 (2013).
59. Okaka, F. O. & Odhiambo, B. D. O. Households' perception of flood risk and health impact of exposure to flooding in flood-prone informal settlements in the coastal city of Mombasa. *IJCCSM* **11**, 592–606 (2019).
60. Lu, F. Research on the Performance and Enlightenment of New York Storm Surge Adaptive Landscape Infrastructure. *E3S Web Conf.* **118**, 03026 (2019).
61. Moyles, C. & Craul, T. Scenic hudson's long dock park cultivating resilience: transforming a post-industrial brownfield into a functional ecosystem. *J. Green Building* **11**, 55–77 (2016).
62. Spekker, H. & Heskamp, J. Flood protection for the city of Beira. *Bautechnik* **94**, 872–874 (2017).
63. Chuang, H.-W., Yang, S.-R., Ou, T. & Lin, T.-P. Climatic adaptation of coastal communities on the southwest of Taiwan. *J. Mar. Sci. Technol.* **24**, 1063 (2016).
64. Fenton, A., Paavola, J. & Tallontire, A. The role of microfinance in household livelihood adaptation in Satkhira district, southwest Bangladesh. *World Dev.* **92**, 192–202 (2017).
65. Fischer, A. P. Pathways of adaptation to external stressors in coastal natural-resource-dependent communities: Implications for climate change. *World Dev.* **108**, 235–248 (2018).
66. Revi, A. et al. *The Summary for Urban Policymakers of the IPCC's Sixth Assessment Report* (Cambridge Univ. Press, 2022); https://doi.org/10.24943/SUPSV511.2022
67. Garschagen, M., Doshi, D., Moure, M., James, H. & Shekhar, H. The consideration of future risk trends in national adaptation planning: conceptual gaps and empirical lessons. *Clim. Risk Manag.* **34**, 100357 (2021).
68. Johnson, L. et al. *Intervention: The Invisible Labor of Climate Change Adaptation* (SSRN, 2023); https://doi.org/10.2139/ssrn.4416499
69. Filho, W. L. et al. Assessing the impacts of climate change in cities and their adaptive capacity: towards transformative approaches to climate change adaptation and poverty reduction in urban areas in a set of developing countries. *Sci. Total Environ.* **692**, 1175–1190 (2019).
70. Aerts, J., Botzen, W., Bowman, M., Dircke, P. & Ward, P. *Climate Adaptation and Flood Risk in Coastal Cities* (Routledge, 2014); https://doi.org/10.4324/9781849776899
71. Haasnoot, M. et al. Defining the solution space to accelerate climate change adaptation. *Reg Environ. Change* **20**, 37 (2020).
72. Revi, A. et al. Towards transformative adaptation in cities: the IPCC's Fifth Assessment. *Environ. Urban.* **26**, 11–28 (2014).
73. Hobday, A. J. et al. With the arrival of El Niño, prepare for stronger marine heatwaves. *Nature* **621**, 38–41 (2023).
74. Turton, S. Global average sea and air temperatures are spiking in 2023, before El Niño has fully arrived. We should be very concerned. *The Conversation* (20 June 2023).
75. Thompson, T. Arctic sea ice hits 2021 minimum. *Nature* https://doi.org/10.1038/d41586-021-02649-6 (2021).
76. Haddaway, N. R., Macura, B., Whaley, P. & Pullin, A. S. ROSES for Systematic Map Reports. Version 1.0. *figshare* https://doi.org/10.6084/m9.figshare.5897389 (2018).
77. Haddaway, N. R., Macura, B., Whaley, P. & Pullin, A. S. ROSES Flow Diagram for Systematic Reviews. Version 1.0. *figshare* https://doi.org/10.6084/m9.figshare.5897389 (2018).
78. Berrang-Ford, L. et al. *The Global Adaptation Mapping Initiative (GAMI): Part 1—Introduction and Overview of Methods* (Protocol Exchange, 2021); https://doi.org/10.21203/rs.3.pex-1240/v1
79. Lesnikowski, A. et al. *The Global Adaptation Mapping Initiative (GAMI): Part 3—Coding Protocol* (Protocol Exchange, 2021); https://doi.org/10.21203/rs.3.pex-1242/v1
80. Thomas, A. et al. Global evidence of constraints and limits to human adaptation. *Reg. Environ. Change* **21**, 85 (2021).
81. Ulibarri, N. et al. A global assessment of policy tools to support climate adaptation. *Clim. Pol.* **22**, 77–96 (2022).
82. *World Bank Country and Lending Groups* (World Bank, 2019); https://datahelpdesk.worldbank.org/knowledgebase/articles/906519
83. World Bank Data Team. *New Country Classifications by Income Level: 2019–2020* (World Bank, 2022); https://blogs.worldbank.org/en/opendata/new-country-classifications-income-level-2019-2020?source=post_page
84. Dakey, S., Deshkar, S., Joshi, S. & Sukhwani, V. Enhancing resilience in coastal regions from a socio-ecological perspective: a case study of Andhra Pradesh, India. *Sustainability* **15**, 9565 (2023).
85. *Natural Earth: 1:10 m Physical Vectors—Free vector and Raster Map Data at 1:10 m, 1:50 m, and 1:110 m Scales* (Natural Earth, 2024); https://www.naturalearthdata.com/

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Author contributions
M.W., M.G., I.A., K.J.M., A.M., J.P., D.R. and N.U. conceived and designed the experiments. M.W., I.A., K.J.M., A.M., J.P., D.R., N.U., A.A., V.I.C., T.H., L.T.M.H., C.J.K., R.M., J.I.M.-S., G.N.A., M.N., A.M.N., B.P., A.R., G.S., N.S., I.V.C. and J.Z. performed the experiments. M.W., M.G., J.P. and J.Z. analyzed the data. The Global Adaptation Mapping Initiative Team contributed the materials and analysis tools. M.W. and M.G. wrote the paper.

Competing interests
The authors declare no competing interests.

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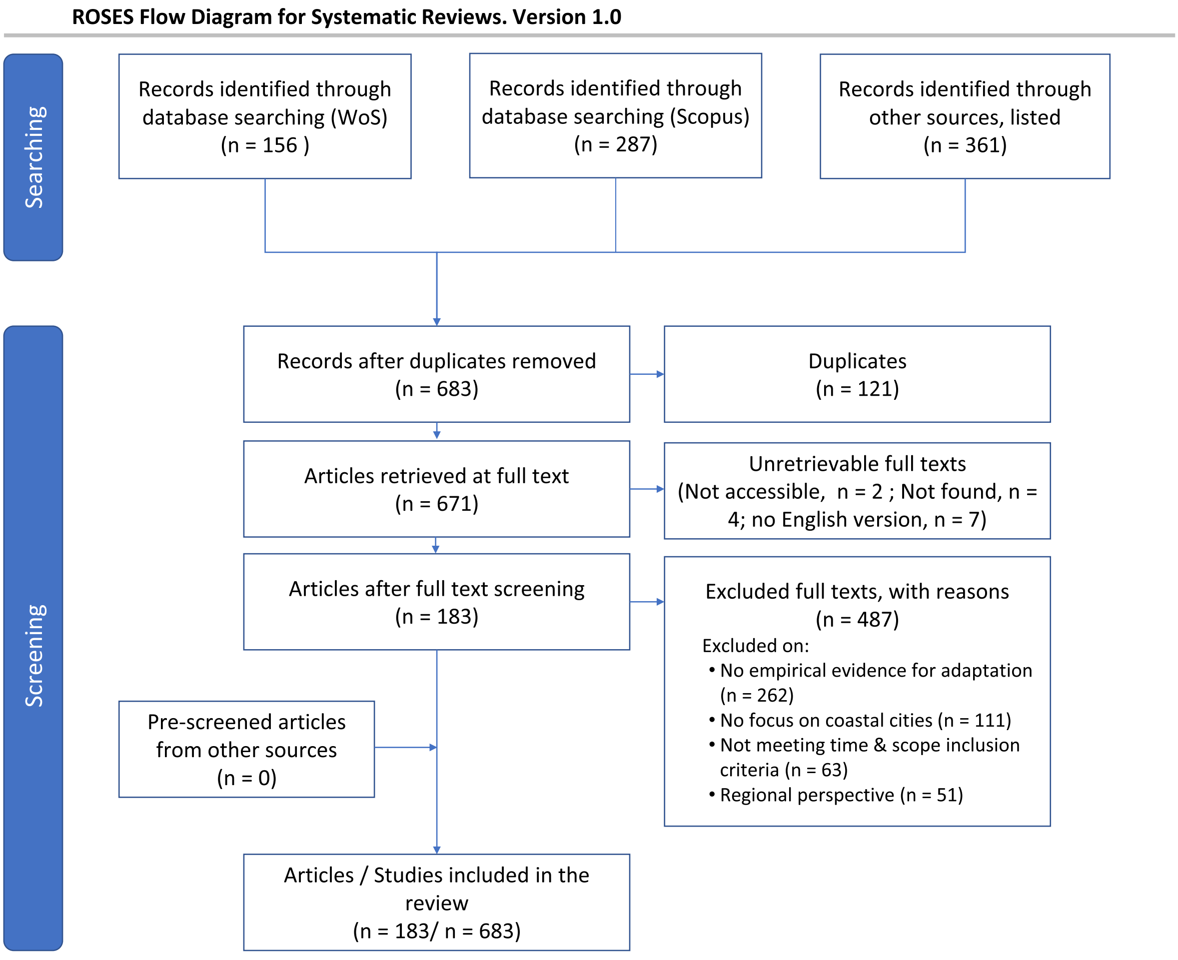

Extended Data Fig. 1 | ROSES flowchart for systematic maps. RepOrting standards for Systematic Evidence Syntheses (ROSES) were used to follow a standardized and transparent approach to searching and screening scientific literature. For each step in the process, numbers of publications are disclosed.

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Software and code

Policy information about availability of computer code

Data collection	SoSci Survey (Version 2.3.12)
Data analysis	IBM SPSS Statistics 23

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Source data:
1. Correlation tables
2. Coding database
3. Data sources for city populations

Supplementary information:
1. Searches, inclusion and exclusion criteria, and the code book
Supplementary tables:
1. ROSES map report
2. List of included and excluded literature
Data sources:
1. Base map for fig.1 : Natural Earth (n.d.). Natural Earth 1:10m Physical Vectors - Free vector and raster map data at 1:10m, 1:50m, and 1:110m scales. Accessible through: https://www.naturalearthdata.com/downloads/10m-physical-vectors/.
2. Population in the Low Coastal Elevation Zone (LCEZ): Center for International Earth Science Information Network - CIESIN - Columbia University (2021). Low Elevation Coastal Zone (LECZ) Urban-Rural Population and Land Area Estimates, Version 3. Accessible through: https://doi.org/10.7927/d1x1-d702.
3. World Bank income classification: World Bank (2024). World Bank Country and Lending Groups. Accessible through: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519.
4. World Bank GNI per capita: World Bank Open Data (2019). GNI per capita, PPP (current international $). Accessible through: https://blogs.worldbank.org/en/opendata/new-country-classifications-income-level-2019-2020?source=post_page--------------------------

Human research participants

Policy information about studies involving human research participants and Sex and Gender in Research.

Reporting on sex and gender	n/a
Population characteristics	n/a
Recruitment	n/a
Ethics oversight	n/a

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☒ Behavioural & social sciences ☐ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Behavioural & social sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	This mapping of evidence for ataptation in coastal cities is based on a mixed-methods approach for analyzing scientific publications. Quantitative and qualitative data was derived by anserwering a structured questionnaire for each coastal city mentioned in a publication. The statistical analysis includes counts, shares, and correlation analyses; the qualitative analysis builds on a qualitative content analysis of included publications.
Research sample	The literature searches identified a total of 683 scientific publications (without duplicates) in three data bases; GAMI Database, Web of Science and Scopus. 671 were retrieved at full text. 487 were excluded as they did not meet the defined inclusion criteria (i.e. presenting or reviewing evidence for adaptation in coastal cities). 183 scientific publications were fully coded and included in the analyses.
Sampling strategy	Systematic database searches with different search strings in Web of Science and Scopus in combination with data from the GAMI database. The final search string was determined by an evaluation of its comprehensiveness by the highly experienced experts of the author team. The sample size was not predetermined; the representativeness of the sample resulting from the searches was evaluated by the team of authors being knowledgable in the field.
Data collection	We extrcted all publications listed under the code "cities and settlements by the sea" from the GAMI dataset. Additional searches with the same search string were Wconducted in Web of Science and Scopus. All all dublicates were removed and the full publications were downloaded by the individual coders. The coding was implemented through an online questionnaire (soSciSurvey); one questionnaire per coastal city was answered by the coders. To chec for intercoder variability, 10% of the sample was double-coded, checking for consistency.
Timing	The searches and compilation of the reference list was conducted on 5th July 2021; the coding was implemented between August 2021 - June 2022
Data exclusions	487 publiactions were excluded from the analysis because they did not meet the inclusion criteria. Details can be found in the roses flow diagram for systematic reviews.

Non-participation	No participants involved.
Randomization	Radomization was not applied to the data as it was neither necessary, nor appropriate, given that we used the full dataset (all resulting publications from the search string).

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study	
☒	☐	Antibodies
☒	☐	Eukaryotic cell lines
☒	☐	Palaeontology and archaeology
☒	☐	Animals and other organisms
☒	☐	Clinical data
☒	☐	Dual use research of concern

Methods

n/a	Involved in the study	
☒	☐	ChIP-seq
☒	☐	Flow cytometry
☒	☐	MRI-based neuroimaging