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POLICY PAPER

THE ECONOMIC IMPACTS OF FLOODING IN EGYPTIAN PORT CITIES

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This study evaluates the economic costs for three Egyptian coastal cities of catastrophic flooding resulting from either sea-level rise or intense rainfall. Using a computable general equilibrium (CGE) framework, we assess the higher-order impacts of physical capital loss on both regional and national economies. Leveraging global flood hazard maps for various scenarios and return periods, and a 100-meter-resolution buildings-exposure model, which estimates the replacement value of residential and non-residential buildings at each floor level, we estimate the share of physical capital at risk. Our analysis covers Egypt's main port cities on the Mediterranean Sea (Alexandria, Damietta, and Port Said), taking into account seven scenarios and three intensities of destruction. Results indicate significant variability in economic impacts, with coastal flooding due to sea-level rise posing a more substantial threat to Port Said and Damietta, whereas pluvial flooding from intense rainfall would more heavily impact Alexandria. The findings underscore the need for targeted investments in climate resilience, particularly for coastal infrastructure, to mitigate future economic losses.

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1. INTRODUCTION

Urban vulnerability has become a focal point in the growing literature examining the impacts of global warming on human activities. This literature highlights the need for cities to adopt adaptation strategies that enhance their resilience, mitigate risks, and protect vulnerable populations in the face of climate change. Data for 2022 collected by the United Nations Population Division show that more than half of the world's population (56.9%) live in urban agglomerations. Thus, to talk about urban vulnerability is to focus on the vital matter of how most humans will deal with the consequences of changing climate patterns. Although economic and social vulnerability warrants an equivalent amount of attention, the focus on physical vulnerability is reasonable for its tangible aspect. It is easier to rely on objective climate forecasts produced by scientists to determine the necessary adaptation and mitigation measures. However, even this process needs a solid economic foundation, as preventive actions, which can reach a monumental scale, demand a careful cost-benefit analysis.

Water is the element most intimately linked to physical urban vulnerability. Water has a crucial attribute—cities tend to develop near sources of drinkable water and often navigable bodies of water. But water is also behind damage caused by extreme climatic events. Whether it is sea-level rise, intense precipitation, landslides, drought, or even storm surges, the excess or absence of water can cause significant disruption, material loss, and even endanger human life.

The focus on developing countries is intuitive for their diminished capabilities to adapt to climate change and their growing share of emissions. Should pledges to limit global heating be honored, these are the countries poised to suffer most from forcefully curbed emissions, as these currently grow in step with economic activity. Lost tax revenue could further restrict the already limited resource availability for climate-related policies.

Egypt is a testament to the importance of urban vulnerability. It is a developing country with inadequate infrastructure, a low urbanization rate (43% in 2023, according to the World Development Index[1]) that has remained stable in the past 25 years, and a harsh climate. Almost completely covered by the arid sands of the Sahara Desert, more than half of the country's more than 112 million inhabitants still live in rural areas, which might result in increased pressure on urban centers in the next few decades should urbanization intensify. Those who already live in cities are exposed to scorching temperatures, the threat of water scarcity, deteriorating infrastructure, high population density, inefficient public-land management, and inefficient housing policies (UN-Habitat, 2015). Paradoxically, the geographical positions of some major Egyptian cities either by the Nile River or the Mediterranean and Red Seas, expose their populations to pluvial flood hazard caused by heavy rainfall or storm surges intensified by sea-level rise (Arnous *et al*, 2022; Esmaiel *et al*, 2022). In the Nile Delta, coastal cities face the combined effect of sea-level rise and ground subsidence, the latter because of dams along the Nile which limit the natural flow of sediment to the Delta (UNDP, 2013). In Alexandria, the observed combined subsidence and sea-level rise rate, is 1.6 mm/year[2], and in Port Said it is 5.3 mm/yr. The difference is primarily because the rate of subsidence is reported as 0.4 mm/yr in Alexandria, but appears to be as much as 4.1 mm/yr in Port Said (Elshinnawy, 2008).

1. The urbanization rate of Egypt, when excluding the Greater Cairo Region, being around 30%.

2. In Alexandria, the presence of the Mohamed Ali Sea Wall (El Raey, 2010) and the coastal road (including the Corniche) which ranges between 2.4 and 12.3 m, relative to mean sea level (Frihy, et al. 2004) reduce potential losses to sea level rise.

Port cities in Egypt are particularly vulnerable to climate change (Torresan *et al*, 2020). Situated at or near sea level makes them highly susceptible to sea-level rise and coastal flooding. The Nile Delta, where several Egyptian port cities are located, is already experiencing erosion from reduced sediment flow caused by upstream dams and climate-related changes. This erosion, combined with sea-level rise, threatens urban infrastructure along the coast, amplifying the risks posed by extreme weather events, such as storm surges (Hassaan and Abdrabo, 2013).

In this paper, we focus on three port cities: Alexandria (Al-Iskandariyah), Damietta (Dumyāṭ), and Port Said (Bōrsaʿīd). We choose them because of their economic importance and their geographic location on the edges of the Nile Delta and influenced by their proximity to Egypt's Mediterranean coast. Our analysis suggests a strategy of applying an integrated framework developed for the *ex-ante* impact assessment of floods in local economies exposed to supply-chain disruptions caused by natural disasters. Our approach takes into account propagation channels for the impacts of extreme events in a systemic context, in its initial phase (short run). The goal is to explore the characteristics of the integrated model to assess the immediate higher-order economic costs of direct losses computed exclusively to infrastructure (i.e. non-residential buildings), and not to proceed with a systematic evaluation that would include mitigation responses, and is beyond the scope of this paper.

This paper is structured as follows: after this introduction, section 2 introduces different issues addressed in the study, focusing on the growing threats to Egyptian port cities of sea-level rise and intense rainfall, outlining the importance of assessing their higher-order economic impacts. In section 3, we explain the integrated modeling methodology, describing the data sources, particularly the granular building exposure models, and the flood scenarios considered. Section 4 presents the results for each of the three cities—Alexandria, Damietta, and Port Said—analyzing the variation in economic outcomes in seven flooding scenarios and under three levels of destruction intensity. Section 5 discusses the implications of these findings.

2. ISSUES

The Egyptian context provides a fertile case for developing a forecasting framework capable of estimating the economic costs associated with extreme climatic events. This is especially true as the 2022 UN Conference of the Parties (COP27) took place in Egypt and, among several other discussions, established a fund to compensate affected countries in the developing world. Quantifying potential costs is vital to determine the appropriate amount of investment to be directed towards climate mitigation and adaptation[3]. As with any other public policy, evidence is needed to corroborate the appropriation of limited public funds or the much-disputed resources of multilateral organizations. Given the initial commitment of developed countries to mobilize $100 billion annually for adaptation and mitigation projects in developing nations, a goal partially achieved since 2013 (OECD 2024), the flow of funds is expected to only increase with time.

A specific but nonetheless consequential factor that justifies the focus on Egypt is the catastrophic flooding that happened in October 25, 2015, and November 4, 2015, in Alexandria. Flooding occurred on both dates, but it was more severe on October 25-26, when over a short period heavy rain amounting to about 32 mm affected the city (Bhattacharya *et al*, 2018). A direct result of this rainfall, with an estimated return period of

3. In the case of Egypt, this would help in achieving the second goal of the "National Climate Change Strategy in Egypt 2050", namely *enhancing adaptive capacity and resilience to climate change and alleviating the associated negative impacts*.

50 years (Zevenbergen *et al*, 2017), was the loss of seven lives (Elboshy *et al*, 2019) and severe structural damage to 400 buildings in the El Mandara district alone. In the district of Wadi El Kamar, flooding threatened more than 100,000 lives with the destruction of homes, water-borne diseases, and damaged infrastructure. Old and insufficient drainage systems, coupled with excessive rainfall and poor maintenance, led to water accumulation that reinforced the need for the Egyptian government to improve infrastructure and preparedness.

2.1 Intergovernmental Panel on Climate Change Scenarios as Shared Modeling Components

There are various approaches to studying and informing the buildup of urban vulnerability and the resulting risk. A conjunction of climatology, biology, physics, and many other Earth sciences is required to assess how human activity will be affected by the changing climate. The forecasted disruptions need to be fed into models that then explore the channels through which physical occurrences lead to societal impacts. In the field of economics, there have been numerous attempts to do this, often built on some shared exogenous assumptions about the planet's future climatologic path, in order to facilitate comparability.

The Intergovernmental Panel on Climate Change (IPCC), created within the United Nations context, has established what it calls the Representative Concentration Pathways (RCPs) that define four different scenarios for greenhouse gas (GHGs) concentrations in the atmosphere in the year 2100 (IPCC, 2014)including students and researchers in environmental science, meteorology, climatology, biology, ecology and atmospheric chemistry. It provides invaluable material for decision makers and stakeholders: international, national, local; and in all branches: government, businesses, and NGOs. This volume provides:\n• An authoritative and unbiased overview of the physical science basis of climate change\n• A more extensive assessment of changes observed throughout the climate system than ever before\n• New dedicated chapters on sea-level change, biogeochemical cycles, clouds and aerosols, and regional climate phenomena\n• A more extensive coverage of model projections, both near-term and long-term climate projections\n• A detailed assessment of climate change observations, modelling, and attribution for every continent\n• A new comprehensive atlas of global and regional climate projections for 35 regions of the world","edition":"1","ISBN":"978-1-107-05799-9","license":"https://www.cambridge.org/core/terms","note":"DOI: 10.1017/CBO9781107415324","publisher":"Cambridge University Press","source":"DOI.org (Crossref. Further refinements turned the RCPs into Shared Socioeconomic Pathways (SSPs) that include the estimated impacts on the rate of global warming of different policies on GHG emissions and socioeconomic development. Both serve the purpose of harmonizing the underlying climatic assumptions necessary to further scientific inquiries, and have been utilized in the present study.

The economic models used to convert physical alterations into economic consequences can also vary widely in their nature and scope. While some may be limited to *ceteris paribus* projections that employ partial equilibria, others describe complex systems that interact and produce outputs true to general equilibrium modeling. Combining them with environmental frameworks results in the different Integrated Assessment Models (IAMs) used in studies that focus on the economic costs of climate change.

2.2 Related Economic Literature

Considered to be a seminal paper on climate projections deep into the future, Nordhaus (2018)nations have adopted minimal policies to slow climate change. Moreover, there has been no major improvement in emissions trends as of the latest data. The current study uses the updated DICE model to develop new projections of trends and impacts of alternative climate policies. It also presents a new set of estimates of the uncertainties about future climate change and compares the results with those of other integrated assessment models. The study confirms past estimates of likely rapid climate change over the next century if major climate-change policies are not taken. It suggests that it is unlikely that nations can achieve the 2°C target of international agreements, even if ambitious policies are introduced in the near term. The required carbon price needed to achieve current targets has risen over time as policies have been delayed. (JEL Q54, Q58 focused on the question of electing a probable IPCC scenario, suggesting that countries are more likely to follow a business-as-usual (BAU) pathway in which almost no climate-oriented policies are implemented or enforced. The implications of such a possibility, he argued, are not easily found in the IPCC's report. In his paper, he estimated additional, more-pessimistic scenarios that incorporate the notion of uncertainty around relevant parameters. The findings stress how intense (and indefinite) climate change might be, and the need to conduct studies that allow for wider sensitivity analysis.

The model work of Carleton *et al* (2022)we estimate age-specific mortality-temperature relationships and extrapolate them to countries without data today and into a future with climate change. We uncover a U-shaped relationship where extre6me cold and hot temperatures increase mortality rates, especially for the elderly. Critically, this relationship is flattened by higher incomes and adaptation to local climate. Using a revealed-preference approach to recover unobserved adaptation costs, we estimate that the mean global increase in mortality risk due to climate change, accounting for adaptation benefits and costs, is valued at roughly 3.2% of global GDP in 2100 under a high-emissions scenario. Notably, today's cold locations are projected to benefit, while today's poor and hot locations have large projected damages. Finally, our central estimates indicate that the release of an additional ton of CO2 today will cause mortality-related damages of $36.6 under a high-emissions scenario, with an interquartile range accounting for both econometric and climate uncertainty of [−$7.8, $73.0]. These empirically grounded estimates exceed the previous literature's estimates by an order of magnitude.","container-title":"The Quarterly Journal of Economics","DOI":"10.1093/qje/qjac020","ISSN":"0033-5533, 1531-4650","issue":"4","language":"en","license":"https://academic.oup.com/journals/pages/open_access/funder_policies/chorus/standard_publication_model","page":"2037-2105","source":"DOI.org (Crossref, a culmination of years-long research refinement, provided a representative framework for modeling economic impacts of climate change. For example, it is partly based on the IPCC scenarios, which allows for extensive sensitivity analysis. The global scope of the paper is commendable for its strong micro foundation and the possibility to make regional comparisons that show the unequal distribution of impacts. Furthermore, Carleton *et al* (2022) accounted for adaptation measures, which can vary according to an area's income level and preexisting climatic conditions. The physical channel studied, however, is ambient temperature, which although relevant, involves different mechanisms of action and adaptation in relation to water. And the chosen outcome variable, mortality, while later linked to monetary values through the concept of the value of a statistical life (VSL), differs from purely economic aggregates.

Equally rigorous was the inquiry undertaken by Desmet *et al* (2021)dynamic model of the world economy, this paper estimates the consequences of probabilistic projections of local sea level changes. Under an intermediate scenario of greenhouse gas emissions, permanent flooding is projected to reduce global real GDP by 0.19 percent in present value terms. By the year 2200, a projected 1.46 percent of the population will be displaced. Losses in coastal localities are much larger. When ignoring the dynamic response of investment and migration, the loss in real GDP in 2200 increases from 0.11 percent to 4.5 percent. (JEL E23, F01, Q54, Q56, but with analyzed outcomes that are closer to the objectives of this paper. Using topographical data for the entire planetary surface, the authors estimated the economic costs of sea-level rise. Here, not only is water the medium through which climate change affects human activity, but the nature of the modeling performed means that the outcome of interest is associated with economic costs. The regional dynamics are explicit, allowing agents to migrate by incurring some cost, a clear differentiator with respect to Carleton *et al* (2022)we estimate age-specific mortality-temperature relationships and extrapolate them to countries without data today and into a future with climate change. We uncover a U-shaped relationship where extre6me cold and hot temperatures increase mortality rates, especially for the elderly. Critically, this relationship is flattened by higher incomes and adaptation to local climate. Using a revealed-preference approach to recover unobserved adaptation costs, we estimate that the mean global increase in mortality risk due to climate change, accounting for adaptation benefits and costs, is valued at roughly 3.2% of global GDP in 2100 under a high-emissions scenario. Notably, today's cold locations are projected to benefit, while today's poor and hot locations have large projected damages. Finally, our central estimates indicate that the release of an additional ton of CO2 today will cause mortality-related damages of $36.6 under a high-emissions scenario, with an interquartile range accounting for both econometric and climate uncertainty of [−$7.8, $73.0]. These empirically grounded estimates exceed the previous literature's estimates by an order of magnitude.","container-title":"The Quarterly Journal of Economics","DOI":"10.1093/qje/qjac020","ISSN":"0033-5533, 1531-4650","issue":"4","language":"en","license":"https://academic.oup.com/journals/pages/open_access/funder_policies/chorus/standard_publication_model","page":"2037-2105","source":"DOI.org (Crossref. The data's global scope means that every coastal settlement is accounted for, similarly to what Carleton *et al* (2022)we estimate age-specific mortality-temperature relationships and extrapolate them to countries without data today and into a future with climate change. We uncover a U-shaped relationship where extre6me cold and hot temperatures increase mortality rates, especially for the elderly. Critically, this relationship is flattened by higher incomes and adaptation to local climate. Using a revealed-preference approach to recover unobserved adaptation costs, we estimate that the mean global increase in mortality risk due to climate change, accounting for adaptation benefits and costs, is valued at roughly 3.2% of global GDP in 2100 under a high-emissions scenario. Notably, today's cold locations are projected to benefit, while today's poor and hot locations have large projected damages. Finally, our central estimates indicate that the release of an additional ton of CO2 today will cause mortality-related damages of $36.6 under a high-emissions scenario, with an interquartile range accounting for both econometric and climate uncertainty of [−$7.8, $73.0]. These empirically grounded estimates exceed the previous literature's estimates by an order of magnitude.","container-title":"The Quarterly Journal of Economics","DOI":"10.1093/qje/qjac020","ISSN":"0033-5533, 1531-4650","issue":"4","language":"en","license":"https://academic.oup.com/journals/pages/open_access/funder_policies/chorus/standard_publication_model","page":"2037-2105","source":"DOI.org (Crossref achieved in their study.

Both papers show the need for insightful and granular forecasts of economic costs since those vary widely among and within countries. Even if the extensive reach of the papers is useful for macro analysis that makes comparisons between low- and high-income countries, for example, policymakers that work on lower levels of government (e.g. cities and states) need detailed data that can inform objective, local actions. The results of Desmet *et al* (2021) and Carleton *et al* (2022) can thus serve as a strong motivation for further, tailored analysis that draws on the many tools available to regional scientists.

There are, of course, a range of studies that already do localized reporting on the impacts of climate change. Some apply the general equilibrium methodology, but for restricted areas, such as Haddad and Teixeira (2015). They used detailed GIS data combined with firm-level census data to estimate the productivity loss caused by rainfall-induced flooding at a city scale. The output of this methodology can be leveraged by municipal policymakers to decide where or how much to invest at an almost street-by-street level.

Di Noia *et al* (2024) conducted a more comprehensive study, encompassing all of Italy. While their methodology shared some similarities with Haddad and Teixeira's work, it included needed adaptations to address the larger scale and stopped short of using a computable general equilibrium (CGE) model. Instead, the authors relied on an input-output (IO) matrix augmented by specific inventory dynamics that better describe the real behavior of firms. Both studies, however, showcased the viability (and usefulness) of harnessing geocoded data to supplement the previously described methods for estimating the costs of climate shocks.

2.3 A Mix of Strategies

This paper employs many of the strategies used in the previous attempts described in the reviewed economic literature, inspired by a combination of their findings and a focus on Egyptian cities selected to be of policy interest. The work of Nordhaus (2018)nations have adopted minimal policies to slow climate change. Moreover, there has been no major improvement in emissions trends as of the latest data. The current study uses the updated DICE model to develop new projections of trends and impacts of alternative climate policies. It also presents a new set of estimates of the uncertainties about future climate change and compares the results with those of other integrated assessment models. The study confirms past estimates of likely rapid climate change over the next century if major climate-change policies are not taken. It suggests that it is unlikely that nations can achieve the 2°C target of international agreements, even if ambitious policies are introduced in the near term. The required carbon price needed to achieve current targets has risen over time as policies have been delayed. (JEL Q54, Q58 underpinned the growing necessity for governments around the world to make anticipatory plans for adaptation and mitigation. Desmet *et al* (2021) dynamic model of the world economy, this paper estimates the consequences of probabilistic projections of local sea level changes. Under an intermediate scenario of greenhouse gas emissions, permanent flooding is projected to reduce global real GDP by 0.19 percent in present value terms. By the year 2200, a projected 1.46 percent of the population will be displaced. Losses in coastal localities are much larger. When ignoring the dynamic response of investment and migration, the loss in real GDP in 2200 increases from 0.11 percent to 4.5 percent. (JEL E23, F01, Q54, Q56 and Carleton *et al* (2022)we estimate age-specific mortality-temperature relationships and extrapolate them to countries without data today and into a future with climate change. We uncover a U-shaped relationship where extre6me cold and hot temperatures increase mortality rates, especially for the elderly. Critically, this relationship is flattened by higher incomes and adaptation to local climate. Using a revealed-preference approach to recover unobserved adaptation costs, we estimate that the mean global increase in mortality risk due to climate change, accounting for adaptation benefits and costs, is valued at roughly 3.2% of global GDP in 2100 under a high-emissions scenario. Notably, today's cold locations are projected to benefit, while today's poor and hot locations have large projected damages. Finally, our central estimates indicate that the release of an additional ton of CO2 today will cause mortality-related damages of $36.6 under a high-emissions scenario, with an interquartile range accounting for both econometric and climate uncertainty of [−$7.8, $73.0]. These empirically grounded estimates exceed the previous literature's estimates by an order of magnitude.","container-title":"The

Quarterly Journal of Economics”,”DOI”:”10.1093/qje/qjac020”,”ISSN”:”0033-5533, 1531-4650”,”issue”:”4”,”language”:”en”,”license”:”https://academic.oup.com/journals/pages/open_access/funder_policies/chorus/standard_publication_model”,”page”:”2037-2105”,”source”:”DOI.org (Crossref, with their global scope, further justified the room for government actions. Finally, Haddad and Teixeira (2015) and Di Noia *et al* (2024) serve as good examples of how to implement micro-founded forecasting frameworks.

Considerable work has been done within the Egyptian context. Most studies, however, are limited to physical projections, i.e. do not integrate an economic component into their modelling. Elshinnawy and Almaliki (2021) is a good example of a study that shared the initial methodology and assumptions (IPCC scenarios and detailed flooding simulation) but fell short in translating estimated physical impacts into economic phenomena.

Our study employs an integrated assessment model (IAM) that draws from global flood hazard maps and a 100-meter-resolution buildings exposure model (World Bank, 2024), combined with a CGE model developed and localized for Egypt by researchers at the University of São Paulo (USP) Regional and Urban Economics Lab (NEREUS), in collaboration with Zagazig University. Different climate change scenarios fed a privately developed global flood model, the Fathom Global 3.0, used to estimate the exceedance probability, the area, and the depth of possible inundation in the selected cities. Overlaying the flood maps with a proprietary dataset on the replacement cost of both residential and non-residential buildings, the analysts could determine the expected physical capital loss with increased precision, when accounting for the value and amount of floor space exposed to water.

After proper scaling and adjustment, the estimates are integrated into the CGE model. The resulting higher-order cost estimates take into account direct and indirect impacts and can support a variety of actions, including private and public investments in resilience and adaptation, and insurance and compensation strategies (Leon *et al*, 2022). The regional focus of these results enables interregional policymaking that takes into account the forecasted reallocations, thereby helping to preemptively mitigate potential losses.

2.4 Interegional Computable General Equilibrium Refurbishment

The results of an interregional computable general equilibrium model (ICGE) are only as precise and insightful as the quality of the data (i.e. structural coefficients and behavioral parameters) underlying its calibration. Developed countries and their resource-rich statistical organizations can collect and compile high-quality tables that have long substantiated a solid tradition of ICGE modeling. Lower-income countries, however, lack the necessary tools to facilitate the calibration process. This is not a definitive barrier—ingenious and laborious techniques have allowed, for instance, not only the proper estimation but further refinements of IO tables for a long list of developing countries with limited information.

An analysis by Haddad *et al* (2016) laid the foundation for the Egyptian context by estimating an interregional input-output (IIO) table built upon a crude, aggregated IO table at basic prices and a survey conducted by local governments on household income and expenditure. Additional information came from sectoral employment data and various socio-economic indicators by governorate. This comprehensive data collection and integration effort was essential for developing a fully specified interregional input-output database. That database, in turn, underpinned the construction of a detailed ICGE model that allowed for the analysis of the regional impacts of transportation infrastructure policies in Egypt (Elshahawany *et al*, 2017). By incorporating a GIS network for transportation and calibrating the model for 2011, Elshahawany *et al* (2017) marked the beginning of a structured approach to understanding and modeling the economic interdependencies within Egypt's regions.

The present paper's analysis ought to be grounded on a solid ICGE framework for maximum relevance and precision. Because the Egyptian IIO table available was based largely on data from 2011, it was possible (and recommended) to recalibrate the ICGE model with an updated version of the IIO constructed using more recent renditions of the original data. The same 2011 Supply and Use Table (SUT) made available by the Egyptian government was used in its 2018 release, as well as the other updated statistics such as governorate-level sectoral employment and consumer expenditure data.

2.5 Study Area

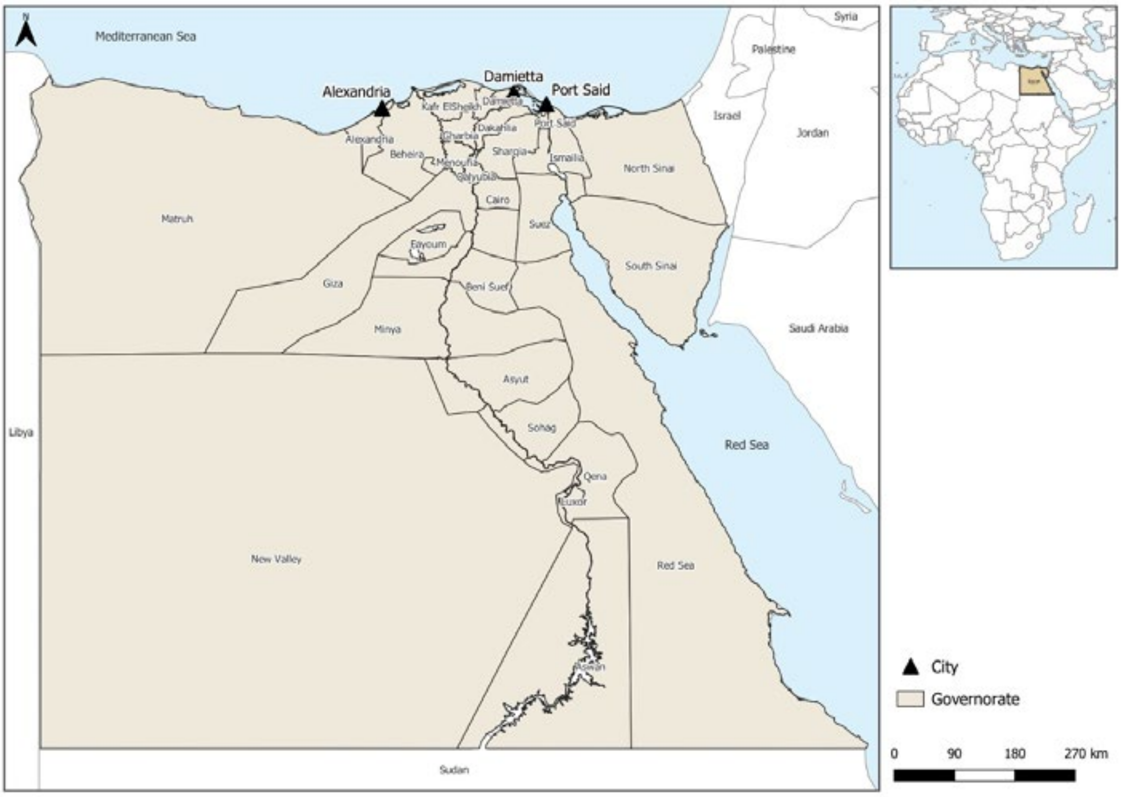
This paper focuses on three Egyptian port cities: Alexandria, Port Said, and Damietta. Although the port cities hold significance in terms of climate, they are not the most populous or affluent regions of the country. The Alexandria governorate ranks third in terms of GDP, with Port Said coming in at seventh. Damietta appears in distant seventeenth place.

Their location, however, is what makes them relevant for this study (Figure 1). Alexandria, Damietta, and Port Said are the three biggest coastal cities alongside the Nile Delta. They each surround a branch of the Nile River. This means all of them are exposed to pluvial and coastal flooding. Moreover, they are major commercial ports, consistently placed among the top-three container handling ports in Egypt[4].

4. See https://www.marineinsight.com/know-more/major-ports-of-egypt/.

Figure 1

Location of Selected Port Cities: Alexandria, Damietta, and Port Said



3. METHODOLOGY

3.1 Flood Exposure Risk Module

Once the ICGE model is calibrated with the latest available data, the attention turns to modeling the economic shocks applied to the equilibrium. Substantiating and then designing these shocks is central to this paper, for it delineates the phenomenon studied and thus greatly illuminates the interpretation of the results. Misunderstandings can arise if there is not a clear understanding of the nature of the shocks. The two-stage process, which serves as the basis for the shocks implemented in the subsequent simulation, is an integral part of this paper's IAM and thus calls for an explicit description.

We used the global flood-hazard maps that resulted from a global flood inundation model developed by Fathom, a private company specializing in geospatial data for catastrophe analysis and prediction. The product, the Global Flood Map, is derived from the Fathom 3.0 model with the following description[5]:

"[The] *Global Flood Map provides its users with* [… a] *set of* ***hazard data*** *and flood risk information* […]. *Available across all major flood perils: pluvial, fluvial and coastal, it revolutionizes how insurers, financial markets, engineers, corporates and governments can understand and integrate flood hazard and climate change data into their risk operations."*

5. The description draws on https://www.fathom.global/product/global-flood-map/.

The system integrates a 30-meter-resolution map of the world's terrain topography (FABDEM+) with a multi-model ensemble of global climate models. These models analyze and predict the behavior of processes that directly or indirectly affect flooding variables, such as sea-level rise, storm surges, and extreme rainfall.

To achieve this, the system uses a change-factor approach, applying relative changes to historical baseline data forecasted by multiple climate models. This method ensures that coarse-resolution climate model outputs are translated into flood maps, providing climate-conditioned hazard data for fluvial, pluvial, and coastal flooding globally at a 30-meter resolution.

Additionally, the system employs temporal and spatial smoothing to reduce the impacts of internal climate variability, extracting a clearer signal of forced climate change. By leveraging an ensemble of climate, hydrological, and sea-level models, the system estimates the uncertainty and confidence associated with future projections, capturing the spatial variability in projected changes.

The result is a framework that allowed the team to work with the flood maps provided by Fathom for future year and climate scenarios, covering various emissions pathways (including those set out by the IPCC) and warming levels. The model output is the water depth at 30-meter-resolution that almost goes down to city-block level. In the example provided in Figure 2, it is immediately noticeable that the model's resolution can be considered sufficient when superimposed onto an aerial view of each city.

3.2 Flood Types

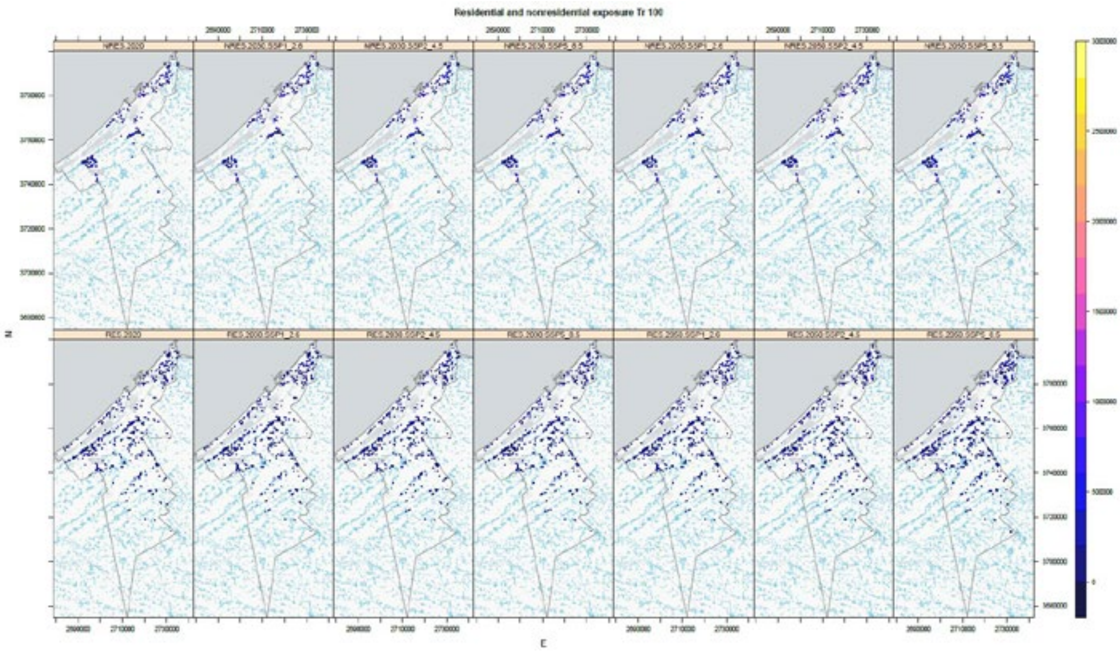
We used the flood hazard maps to analyze, separately, three different types of flooding: pluvial, coastal defended, and coastal undefended. The former is the direct result of heavy downpours on watersheds that channel water into rivers that cross urban settlements. As the runoff builds up and overflows, nearby human activity is affected, with topography (together with other factors such as land cover, soils, infrastructure, characteristics of the storms, etc.) determining where the water goes, how deep it gets, and for how long it stays there.

Coastal flooding, on the other hand, is the result of a combination of factors including short-term phenomena such as storm surges or high tides, and the long-term influence of sea-level rise. Storm surges occur when strong winds from a storm, such as a hurricane or typhoon, push ocean water toward the shore, causing water levels to rise dramatically and inundate coastal areas. High tides, particularly during spring tides when the gravitational pull of the moon and sun align, can further exacerbate the situation by raising the baseline water level. When these events coincide, they can create extreme water levels that overwhelm natural and artificial coastal defenses, leading to widespread flooding.

The two subcategories, defended and undefended, refer to the artificial interventions put in place to prevent coastal flooding and whether they are considered in the simulations. With a slow but steady rise in sea level, it is reasonable to expect that coastal settlements will seek to defend themselves through these interventions. For the sake of accuracy of economic impacts, it is thus recommended to take their effects into account, while also computing an alternative scenario in which nothing is done to avoid relying solely on forecasts. To obtain results stemming from the widest range of alternatives, all three types were included in the simulations for each emissions scenario.

Figure 2

Residential and Non-residential Buildings Exposure at Risk to Pluvial Flooding under Different Climatic Scenarios: Alexandria



Note: Return period (Tr = 100 years); RES = residential buildings; NRES = nonresidential buildings

Source: Word Bank (2024).

3.3 Climate Scenarios

One of the main strengths of the climate scenarios underlying the IAM used in this paper is its flexibility in relation to two intertwined dimensions: the intensity of catastrophic events, and the emissions context in which they occur. Both variables significantly influence the damages associated with floods. Therefore, it is crucial to perform sensitivity analyses to clarify how dependent the results are on these premises.

The intensity is straightforward to understand: natural phenomena, such as rain and storm surges, can happen at varying magnitudes. Usually, the intensity of each event is inversely proportional to its probability of occurrence, i.e. how often it happens. Thus, we can classify the events according to their incidence. The standard approach has been to use the statistical concept of 'return period', defined as the average time interval between occurrences of an event of a certain magnitude or intensity. For example, if a particular area experiences a 100-year flood, this means that such a flood has a 1% chance of occurring in any given year, indicating a return period of 100 years. It's important to note that the return period does not imply that the event will happen precisely once every 100 years. Rather, it represents an average recurrence interval based on historical data and probabilistic analysis.

In this paper, we use eight different return periods to produce a broad sample of results that cover both a more frequent event with a return period of five years all the way to a long return period of 1,000 years. The flood-hazard maps provide a flood footprint and associated flood depths for each of these return periods.

GHG emissions and their accompanying effects—e.g. atmospheric and maritime warming—alter the expected intensity of an event for the same return period in a base scenario. The pace at which humanity keeps pumping these gasses into the atmosphere is the crucial variable at stake here—catastrophic events have not been introduced by climate change, but rather intensified. But it is as hard to predict as it is important. In a general equilibrium framework covering such an extensive timeframe, one cannot ignore adaptations that alter the current path of emissions.

The IPCC, together with its respective research community, aware of this difficulty, and with the aim of standardizing research on the topic, established the Shared Socioeconomic Pathways (SSPs), a set of scenarios with holistic predictions describing plausible global developments that could lead to different challenges in terms of mitigating and adapting to climate change. There are five SSP narratives, each representing different socio-economic futures. They complement the purely climatic RCPs previously established in a similar fashion (Van Vuuren *et al*, 2011). Each combination provides a projected temperature increase pathway to be fed into the Fathom physical modelling and similar alternatives. We used the three scenarios described in Table 1 as well as a neutral scenario designated '2020', which intuitively holds fixed the relevant parameters recorded in the year 2020.

Table 1.

The SSP and RCP Combinations Used in the Simulations

SSP and RCP	SSP description	RCP description
SSP1 ('Sustainability - Taking the Green Road') + RCP 2.6	This pathway envisions a world making good progress toward sustainability, with increased equality, reduced consumption, and low carbon emissions.	Also known as RCP3PD (Peak-Decline), this is a low greenhouse-gas emission scenario with an initial radiative forcing peak of about 3 W/m², followed by a decline to 2.6 W/m² by 2100. It assumes significant mitigation efforts, with CO2-equivalent concentrations peaking at roughly 490 ppm.
SSP2 ('Middle of the Road') + RCP4.5	This scenario describes a world following historical trends without substantial changes or disruptions, leading to moderate challenges for mitigation and adaptation.	This scenario aims for a stabilization without overshoot at 4.5 W/m² by 2100. It represents a medium-low mitigation pathway, with a focus on reducing emissions. The expected CO2-equivalent concentration is around 650 ppm.
SSP5 ('Fossil-fueled Development - Taking the Highway') + RCP 8.5	This pathway envisions a world with rapid economic growth driven by the intensive use of fossil fuels, leading to high greenhouse-gas emissions and significant challenges for mitigation.	This scenario represents a high greenhouse gas emission trajectory, leading to a radiative forcing level of approximately 8.5 W/m² by 2100. It assumes continued growth in emissions and minimal efforts to curb them. The concentration of CO2-equivalent gases is projected to reach around 1370 ppm.

3.4 Physical Capital

We developed a 100-meter resolution buildings-exposure dataset with the replacement value for each floor of each building in the three Egyptian port cities studied, resulting in the determination of the physical capital potentially affected by flooding. This methodological advancement brings a marked improvement considering city centers often feature multistorey buildings, and a coarse generalization would assume a much greater exposure-at-risk potential than plausible.

The sole missing factor, which presents a viable avenue for further research, is a vulnerability assessment. The available data is valid only for determining the total amount of capital exposed to flooding—it does not offer any insights into how this contact might lead to temporary or permanent damage. A vulnerability curve specific to the type of building and damage depending on flood depth would be key to estimating the costs of damages. In its absence, we have allowed for three arbitrary shares—1%, 3%, and 5%—that serve as rough point estimates for potential damage. These percentages are intended to provide a range of possible outcomes, acknowledging the uncertainty in the absence of a precise flood-damage curve. While these figures are not definitive, they allow us to consider a first approximation of different scenarios for potential capital loss, and offer a basis for further refinement as more data becomes available. Future research should focus on developing and validating vulnerability curves that accurately reflect the susceptibility of various types of capital to water-related damage, thereby improving the reliability of loss predictions.

Tables 2 and 3 summarize the exposure data for the non-residential buildings. Caused by the rise in the sea level, coastal flooding (Table 2) is noticeably a greater threat for Port Said and Damietta than Alexandria. In a worst-case scenario—2050-SSP5 8.5—9.94% of the non-residential buildings (in value) in Port Said are affected by flooding from a common event with a return period of five years (13.23% with Tr=1,000), while only 0.87% of the non-residential buildings in Alexandria enter into contact with water in an extreme event with a return period of 1,000 years (0.50% with Tr=5).

Losses linked to extreme precipitation events (Table 3) seem to be more closely associated with the severity of the event (i.e. the return period) than with the warming scenario. This is intuitive if one assumes that melting ice caps are the cause of sea-level rise—in that case, the atmosphere's warming will permanently raise the water level, converting even common events into damaging circumstances. Rainfall intensity, on the other hand, seems to be less affected by warming scenarios in Egypt, instead varying more broadly along the recurrence dimension.

While coastal (defended) flooding from sea-level rise is generally expected to cause more widespread damage than pluvial flooding, Alexandria would be relatively less affected. However, the three port cities are at comparable relative exposure-at-risk in the pluvial context, but Port Said again faces the greatest relative potential impact.

Table 2

Non-residential Buildings Exposure to Coastal (Defended) Flooding (in % of the Total Stock)

Alexandria	Tr=5	Tr=10	Tr=20	Tr=50	Tr=100	Tr=200	Tr=500	Tr=1000
2020	0.10	0.25	0.32	0.34	0.36	0.38	0.39	0.41
030-SSP1 2.6	0.31	0.33	0.37	0.40	0.42	0.43	0.47	0.49
2030-SSP2 4.5	0.31	0.34	0.37	0.41	0.42	0.44	0.47	0.49
2030-SSP5 8.5	0.33	0.36	0.39	0.41	0.44	0.46	0.49	0.51
2050-SSP1 2.6	0.41	0.45	0.50	0.55	0.60	0.64	0.68	0.70
2050-SSP2 4.5	0.43	0.48	0.53	0.60	0.65	0.69	0.72	0.76
2050-SSP5 8.5	0.50	0.58	0.65	0.70	0.74	0.77	0.82	0.87
Damietta								
	Tr=5	Tr=10	Tr=20	Tr=50	Tr=100	Tr=200	Tr=500	Tr=1000
2020	0.01	0.53	0.96	1.06	1.11	1.19	1.34	1.41
030-SSP1 2.6	0.78	1.00	1.20	1.43	1.56	1.69	1.83	1.92
2030-SSP2 4.5	0.78	1.00	1.21	1.44	1.59	1.70	1.87	1.92
2030-SSP5 8.5	0.84	1.05	1.34	1.50	1.68	1.81	1.91	1.96
2050-SSP1 2.6	1.96	2.15	2.27	2.34	2.37	2.40	2.43	2.45
2050-SSP2 4.5	2.08	2.23	2.30	2.38	2.42	2.46	2.52	2.53
2050-SSP5 8.5	2.30	2.41	2.47	2.59	2.59	2.66	2.70	2.70
Port Said								
	Tr=5	Tr=10	Tr=20	Tr=50	Tr=100	Tr=200	Tr=500	Tr=1000
2020	0.20	1.71	4.11	5.43	5.95	6.40	7.22	7.48
030-SSP1 2.6	3.95	5.20	6.40	7.29	7.77	7.99	8.31	8.57
2030-SSP2 4.5	4.10	5.29	6.48	7.38	7.82	8.09	8.35	8.62
2030-SSP5 8.5	4.82	5.81	6.87	7.72	8.07	8.28	8.58	8.85
2050-SSP1 2.6	8.61	9.20	9.61	10.24	10.55	10.75	11.07	11.39
2050-SSP2 4.5	8.97	9.44	9.96	10.50	10.83	11.27	11.60	11.96
2050-SSP5 8.5	9.94	10.27	10.99	11.76	12.21	12.62	13.07	13.23

Source: Word Bank (2024).

Table 3

Non-residential Buildings Exposure to Pluvial Flooding (in % of the Total Stock)

Alexandria								
	Tr=5	Tr=10	Tr=20	Tr=50	Tr=100	Tr=200	Tr=500	Tr=1000
2020	0.01	0.05	0.20	0.86	1.66	2.53	2.87	3.72
030-SSP1 2.6	0.01	0.06	0.22	0.92	1.79	2.55	2.94	3.81
2030-SSP2 4.5	0.01	0.06	0.22	0.92	1.79	2.55	2.94	3.81
2030-SSP5 8.5	0.01	0.06	0.22	0.92	1.79	2.56	2.94	3.82
2050-SSP1 2.6	0.01	0.06	0.23	0.93	1.80	2.56	2.95	3.82
2050-SSP2 4.5	0.01	0.08	0.25	0.98	1.88	2.61	3.02	3.95
2050-SSP5 8.5	0.01	0.08	0.27	1.02	2.00	2.64	3.10	4.04
Damietta								
	Tr=5	Tr=10	Tr=20	Tr=50	Tr=100	Tr=200	Tr=500	Tr=1000
2020	0.00	0.09	0.29	0.73	1.37	2.32	2.63	4.00
030-SSP1 2.6	0.00	0.10	0.31	0.77	1.48	2.32	2.79	4.19
2030-SSP2 4.5	0.00	0.10	0.31	0.77	1.48	2.32	2.79	4.19
2030-SSP5 8.5	0.00	0.10	0.31	0.76	1.48	2.32	2.79	4.18
2050-SSP1 2.6	0.00	0.10	0.31	0.76	1.48	2.32	2.79	4.18
2050-SSP2 4.5	0.00	0.11	0.31	0.83	1.53	2.32	2.89	4.26
2050-SSP5 8.5	0.01	0.14	0.33	0.86	1.60	2.32	2.95	4.33
Port Said								
	Tr=5	Tr=10	Tr=20	Tr=50	Tr=100	Tr=200	Tr=500	Tr=1000
2020	0.00	0.00	0.00	0.30	1.32	3.58	4.14	6.70
030-SSP1 2.6	0.00	0.00	0.00	0.37	1.57	3.58	4.31	6.91
2030-SSP2 4.5	0.00	0.00	0.00	0.37	1.57	3.58	4.31	6.91
2030-SSP5 8.5	0.00	0.00	0.00	0.37	1.57	3.58	4.31	6.91
2050-SSP1 2.6	0.00	0.00	0.00	0.37	1.57	3.58	4.31	6.91
2050-SSP2 4.5	0.00	0.00	0.00	0.38	1.68	3.59	4.51	7.18
2050-SSP5 8.5	0.00	0.00	0.00	0.44	2.10	3.59	4.69	7.23

Source: Word Bank (2024).

3.5 Implementing the ICGE Shocks

Assessing the potential economic damages provoked by catastrophic floods requires, first, forecasting the physical impact brought about by water and then estimating how these impacts translate into economic costs. This section is focused on the two primary ways water affects human activity in the Egyptian cities studied: sea-level rise and floods caused by intense precipitation. Both circumstances have geographically distinct impacts on physical capital, the channel most clearly leading to economic costs. Although floods can also claim human lives and spread diseases, insufficient data makes it hard to estimate how these channels affect economic activity. Physical capital, on the other hand, is an explicit variable in a computable general equilibrium (CGE) framework, and as such can be easily modeled as a shock in a previously calibrated model, to obtain general implications for national and regional economies.

From the 100-meter resolution buildings-exposure model (World Bank, 2024) we have the estimate of the value of the capital stock represented by the building stock. Combined, the two datasets can yield an estimate of the share (in monetary terms) of total physical capital stock in a city exposed to damaging floods caused by excessive rainfall or sea-level rise. This analysis can be used in conjunction with a ICGE model to estimate the economic costs (i.e. direct and indirect output loss) of such climate shocks.

In this paper, the exposure-at-risk from flooding has been examined for a specific city's non-residential building stock; it would be imprecise, then, to apply to the capital stock of the entire city's economy the proportions obtained in Tables 2 and 3, which show the percentage of total non-residential built space in a city that is likely to be flooded under each flood type for each of the seven scenarios, a measure that is not equivalent to the likely damage costs that will arise. Employment in cities as a proportion of total employment in each region is thus used to scale the shocks. The implicit assumption here is that, since average sectoral productivity is the same across cities in a governorate (because of equilibrium conditions in the model's specification), capital intensity is also uniform. Uniformity guarantees that the amount of capital employed in each city is proportional to its share of total governorate employment (Table 4). Figure 3 illustrates the entire adjustment process. Three levels of damage (i.e. damage ratios relative to the full building replacement values of 1%, 3% and 5%) are proposed in order to obtain the loss of capital (i.e. the direct economic cost of the damages arising in each scenario and from each flood type).

Figure 3

Methodology Flowchart

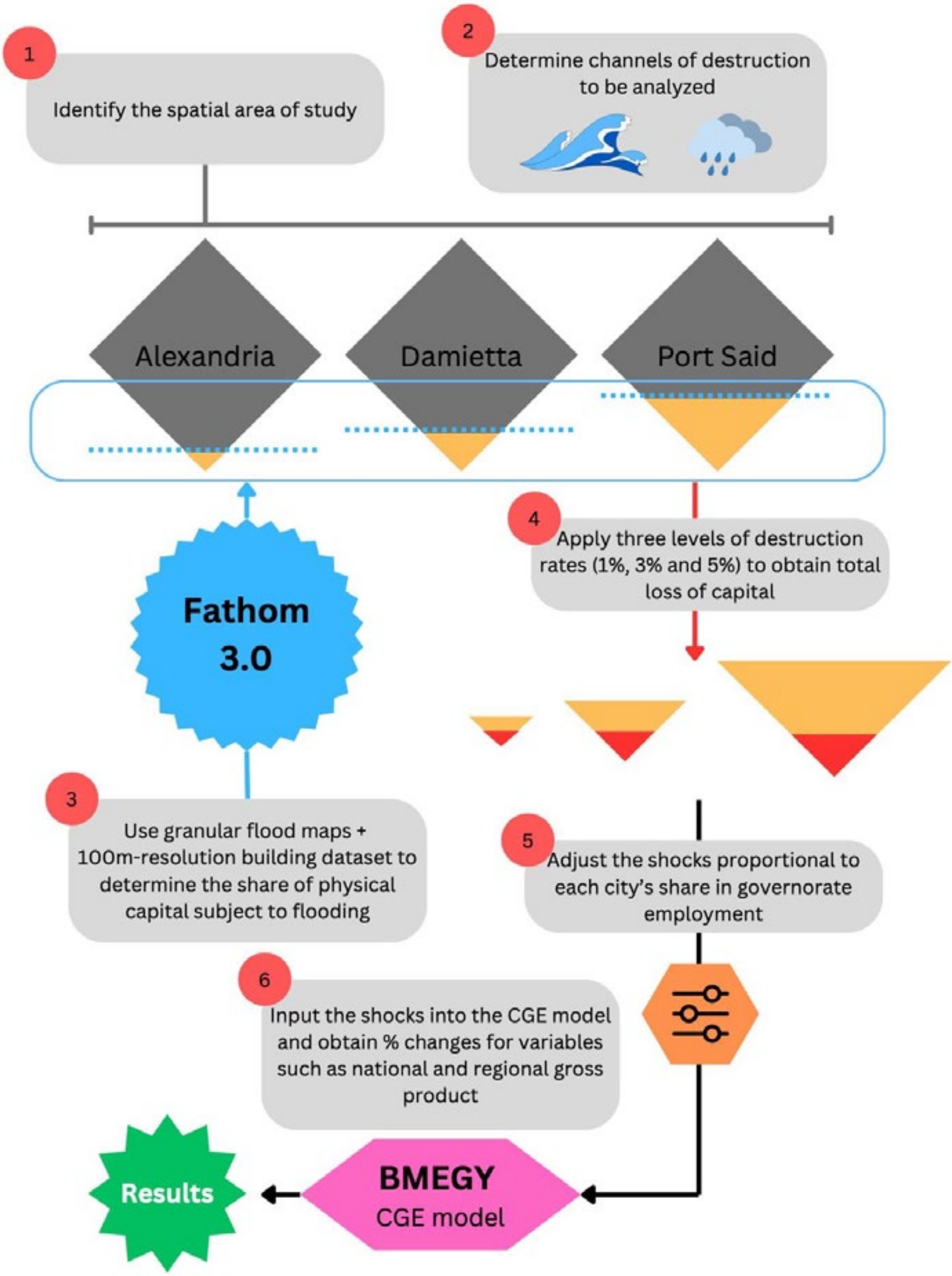


Table 4

Size Adjustment Factors: City's Shares of Total Governorate Employment

City	Governorate	Size adjustment factor
Alexandria	Alexandria	97.67%
Damietta	Damietta	19.53%
Port Said	Port Said	84.71%

The shocks were ready to be inputted into the ICGE model once the adjustments were applied. With a total of seven scenarios, eight return periods, three types of flooding, and three cities, up to 504 different shocks would need to be simulated. After removing null cases (i.e. when the shock was 0), the simulations were carried out for each intensity of destruction (1%, 3%, and 5%).

The results include the entire range of variables modeled by the Egyptian ICGE model. Subsequent sections focus on two main aggregates: national and regional output. The reported losses are measured in U.S. dollars.

4. RESULTS

What if floods had occurred in the Egyptian port cities in the benchmark year, according to forecasted damages in specific scenarios? What would be the difference in output for the city and other regions of the country? Results of the ICGE simulations for the different scenarios were computed under a short-run closure (exogenous capital stocks). In what follows, we first look at a set of results for the 2050 SSP2 4.5 IPCC scenario (return period of 100 years), with moderate challenges for mitigation and adaptation. Results for the remaining simulations are qualitatively similar.

4.1 Coastal (Defended) Flooding Due to Sea-level Rise

Table 5 shows the output loss from a local, regional, and national perspective. It shows that it is expected that a coastal flooding event would lower local output, for the highest intensity simulated case (5% damage ratio), by $11.9 million in Alexandria (0.0295% of total local output), $347,000 in Damietta (0.0211%), and $61.8 million in Port Said (0.4235%). Despite the localized occurrence of the simulated floods within the cities' limits, they would reduce output growth beyond their territories. In the case of Alexandria, a lower share of total output loss would spread to other regions (2.27% to other parts of the governorate and 2.70% to the rest of Egypt). For Damietta, 79.46% of total loss would accrue to adjacent areas in the governorate (19.29% of total output loss is local). Finally, $15.2 million worth of output loss related to coastal floods in Port Said (19.80% of the total) would spillover to other areas. Thus, from a spatial perspective, it is noteworthy that the economic effects are not only local; they spread across the space through production and income linkages. The effects of coastal floods are estimated to vary considerably across the different cities.

Table 5

Total Output Impact of Coastal Flooding: 2050 SSP2 4.5 (in $)

	1%	3%	5%
Alexandria			
City	-2,385,146	-7,157,861	-11,933,406
Rest of Governorate	-56,900	-170,757	-284,681
Rest of Egypt	-68,375	-205,690	-339,605
TOTAL	-2,510,420	-7,534,308	-12,557,693
Damietta			
City	-69,427	-132,368	-347,182
Rest of Governorate	-286,060	-545,402	-1,430,504
Rest of Egypt	-4,729	-8,378	-22,486
TOTAL	-360,216	-686,148	-1,800,172
Port Said			
City	-12,352,563	-37,068,926	-61,800,029
Rest of Governorate	-2,229,615	-6,690,873	-11,154,792
Rest of Egypt	-807,739	-2,440,684	-4,099,634
TOTAL	-15,389,917	-46,200,484	-77,054,455

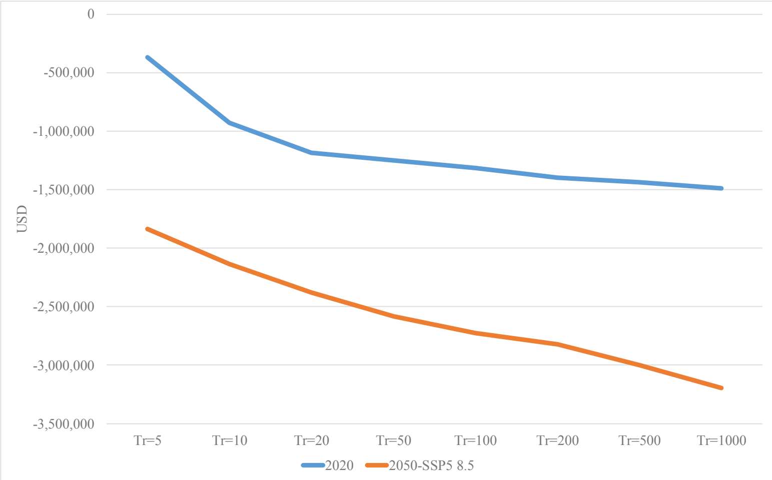
The next set of results looks at the two warming extremes—i.e. the current situation, assuming no further changes (the most optimistic setting, 2020), and the worst possible scenario proposed by the IPCC—2050-SSP5 8.5—in which GHG emissions accelerate and the atmosphere warms significantly above what is considered safe. Reported results refer to the most optimistic damage scenario in which only 1% of flooded capital is damaged. More conservative scenarios will naturally assume even larger damages, as seen above.

The charts in Figure 4 depict the projected impacts on the output of each region and the nation due to the previously assessed loss of physical capital. Although the lines are not especially vertical, meaning that the intensity of the event is not the biggest determinant of damages sustained, the distance between the blue and orange lines indicate the impact that warming can have on the severity of events. Even the rarest event (Tr=1000) under current climatic conditions (2020) is predicted to have less impact compared to the most common event (Tr=5) under the worst-case warming scenario (2050-SSP5 8.5), in the three cities for both local and national output.

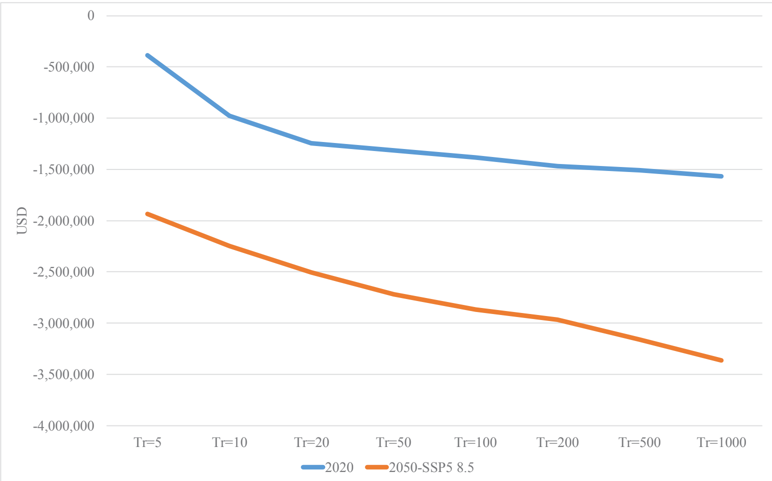
Figure 4

Losses Linked to Coastal Flooding

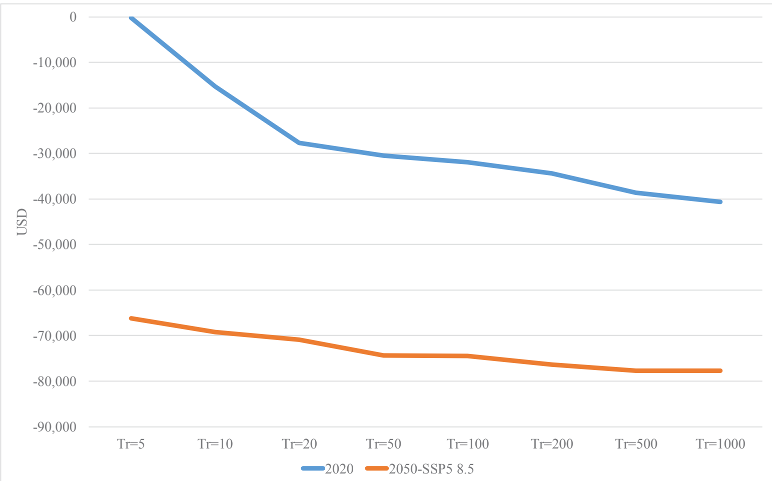
Alexandria: Local Output



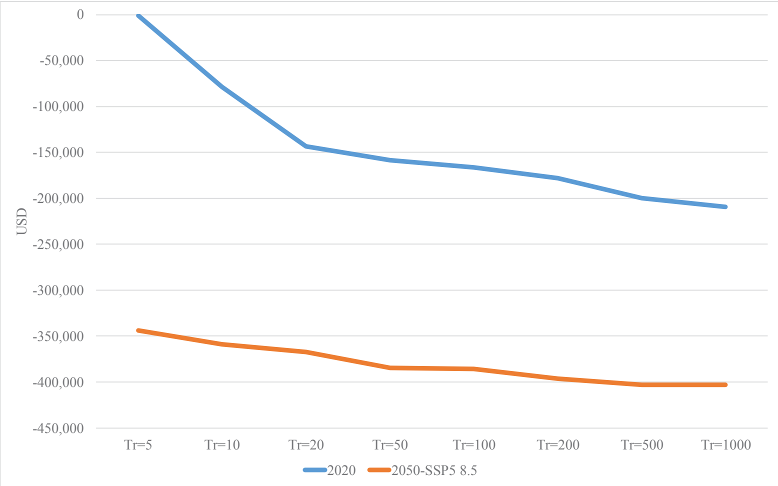
Alexandria: National Output



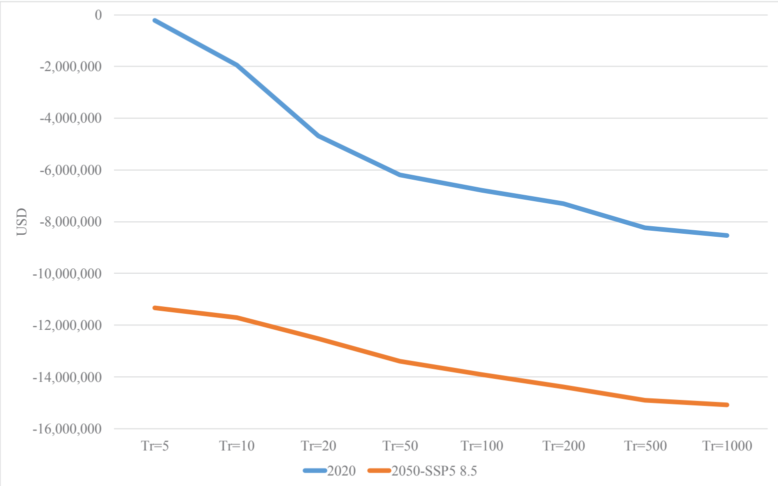
Damietta: Local Output



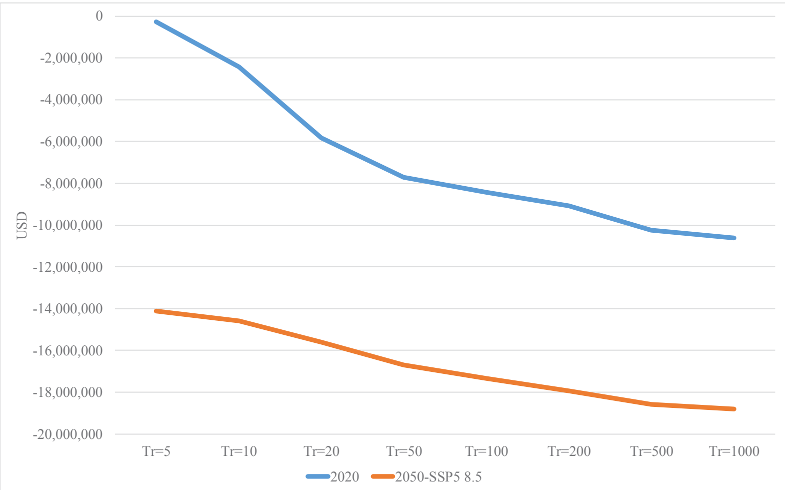
Damietta: National Output



Port Said: Local Output



Port Said: National Output



4.2 Pluvial flooding

While coastal flooding from sea-level rise is expected to cause more widespread damage than pluvial flooding in Port Said, Alexandria is the port city most at risk in the pluvial context, facing higher potential economic costs from damages to its non-residential buildings capital stock.

In monetary terms, the total output impact of the 2050 SSP2 4.5 scenario of pluvial flooding in Alexandria reveals local economic losses ranging from $6.9 million to $34.5 million, depending on the degree of vulnerability of the city's non-residential buildings (Table 6). National output loss may reach $36.5 million in the highest-intensity simulated case (5%). Considering only intra-city effects, Alexandria may face a reduction of 0.0833% of its output ($34.6 million), Damietta minus 0.0026% ($220,000), and Port Said minus 0.0557% ($9.6 million). Given the existing spatial fragmentation observed in Egypt, and the structure of spatial dependence observed in the data, the hierarchy of impacts shows more relevant impacts outside the respective governorates from shocks in Port Said (5.2% of total losses accrue to other governorates), and Damietta (4.3%). In the case of Alexandria, the impacts tend to be more concentrated within city limits (95.1%).

Table 6

Total Output Impact of Pluvial Flooding: 2050 SSP2 4.5 (in $)

Alexandria			
	1%	*3%*	*5%*
City	-6,913,770	-20,708,172	-34,467,010
Rest of Governorate	-164,934	-494,011	-822,240
Rest of Egypt	-197,916	-590,933	-956,871
TOTAL	-7,276,620	-21,793,115	-36,246,120
Damietta			
	1%	*3%*	*5%*
City	-44,128	-132,368	-220,609
Rest of Governorate	-181,823	-545,402	-908,980
Rest of Egypt	-3,359	-8,378	-14,476
TOTAL	-229,310	-686,148	-1,144,065
Port Said			
	1%	*3%*	*5%*
City	-1,920,556	-5,761,815	-9,603,657
Rest of Governorate	-346,657	-1,039,997	-1,733,443
Rest of Egypt	-124,496	-376,173	-627,598
TOTAL	-2,391,710	-7,177,985	-11,964,698

In the charts in Figure 5, we can see the forecasted economic losses stemming from the damaged physical capital. The distance between the scenario lines is small. This is further evidence that warming does not seriously influence how damaging episodes of intense rainfall are, although the distance between the scenario lines does increase with the return period. Global warming makes tail events more intense, even if marginally, in this context. The slope of the scenario lines on the other hand is more pronounced than in the coastal case. In Alexandria, a worst-case scenario event with a return period of 1,000 years should provoke around $15 million in lost local output, while one with a return period of 100 years would only cause losses of $8 million.

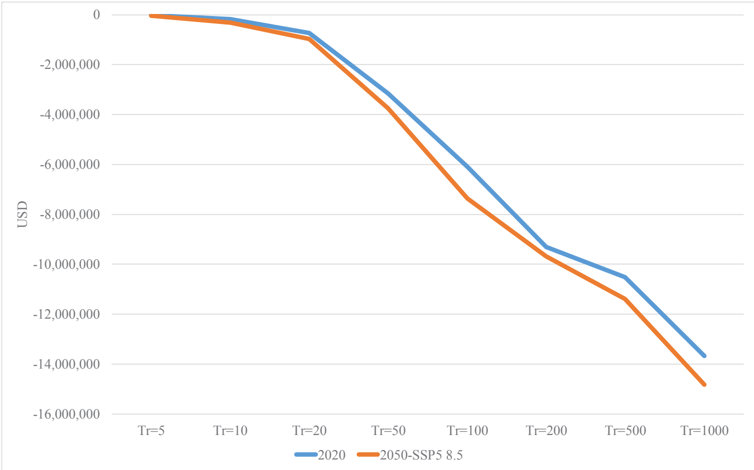
A different pattern is observed in the forecasted impacts of pluvial flooding in Port Said. For events up to a return period of 20 years, no damage at all is expected. However, as the events become more extreme, damages quickly add up and intensify the economic costs, which reach $8.1 million in lost local output and $11.9 million in lost national output in the worst-case scenario for a rare event (Tr=1000).

The public policy implication of these forecasts is that although tail events can inflict significant damage, they are not expected to be much higher than what can happen under current climate circumstances. Thus, any decision to invest in resilience must be based on a cost-benefit analysis that takes into account the probability of occurrence of the events studied, the cost of proposed interventions, and their impact on the expected flood extent and intensity. The discrepancy between cities is also noteworthy, showing the need for spatially focused policies.

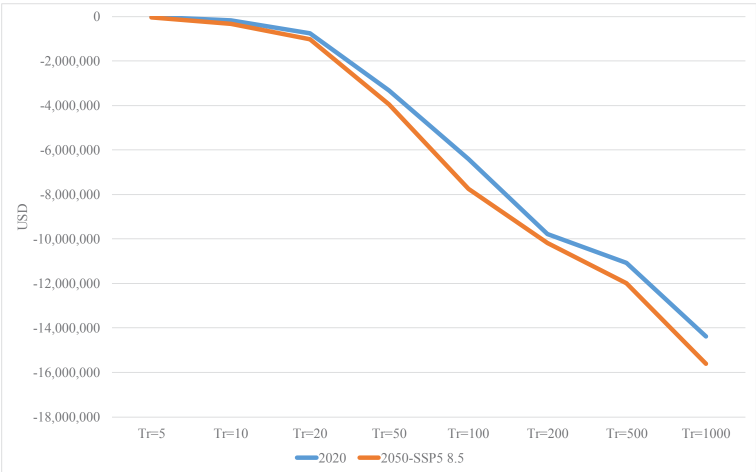
Figure 5

Losses Linked to Pluvial Flooding

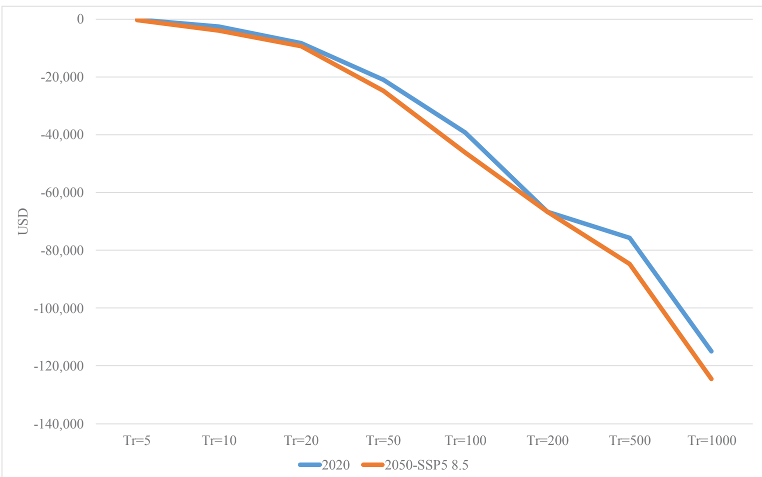
Alexandria: Local Output



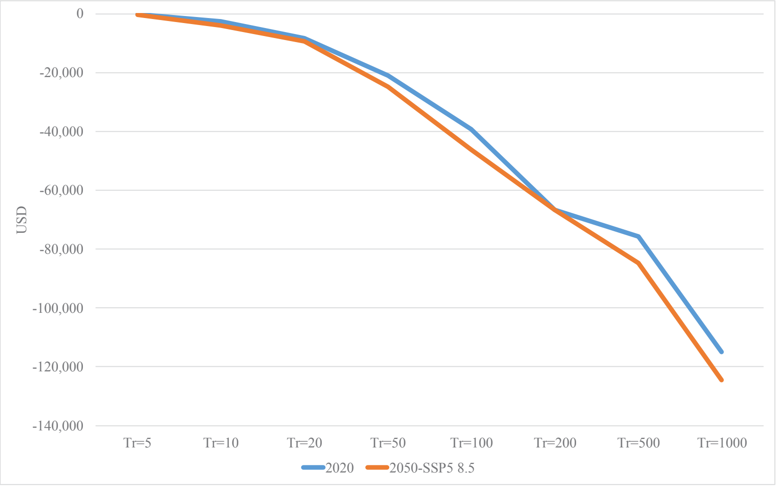
Alexandria: National Output



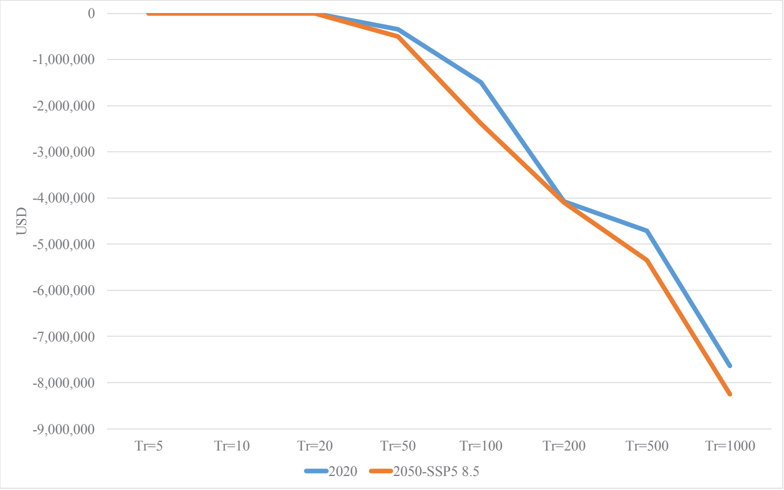
Damietta: Local Output



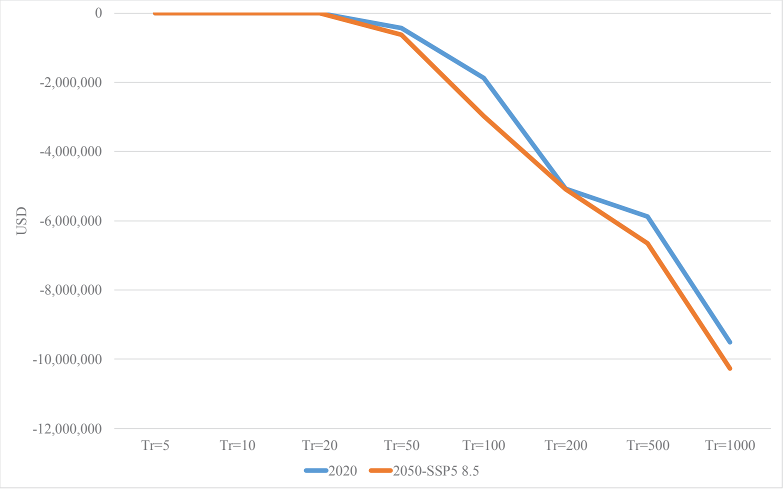
Damietta: National Output



Port Said: Local Output



Port Said: National Output



4.3 Summary

The example charts in Figures 6a and 6b, showcasing expected output losses for each scenario and return period for Alexandria, provide clear evidence of the bigger influence atmospheric warming has on expected economic costs of similar coastal-flooding events, compared to pluvial-flood events. Such differences suggest that the economic and structural losses resulting from heavy rainfall or extreme precipitation are more closely related to the intensity or rarity of these events, rather than to the specific levels of global warming—regardless of whether a low- or high-emissions scenario is applied, the losses correlate more strongly with the intensity and recurrence of the event itself, which are less sensitive to alternative SSP and RCP combinations used in the simulations. Moreover, increased global temperatures directly influence the likelihood of damaging coastal floods because of changes in sea levels in the Mediterranean basin.

From a public-policy perspective, the results present a clear necessity: in worst-case scenarios, damages would occur frequently and with amplified magnitude. Thus, investments to strengthen resilience can be directly benchmarked against the forecasted losses due to their high probability of occurrence. Additionally, the difference between coastal- and pluvial-flooding events is crucial for planning and mitigating the impacts of climate change on infrastructure and communities. The case of Alexandria suggests focusing on managing risks from rare but intense rainfall events and preparing for consistently higher-water levels along coastlines.

Figure 6a

Output Losses Caused by Coastal Flooding in Alexandria (Vulnerability 1%)

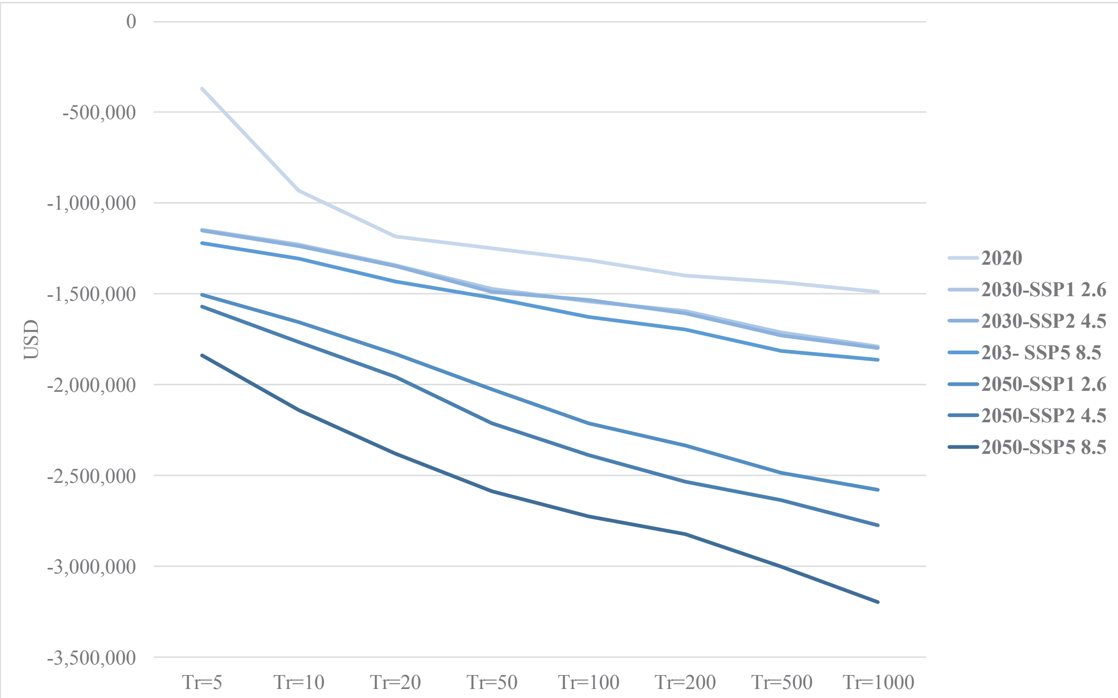
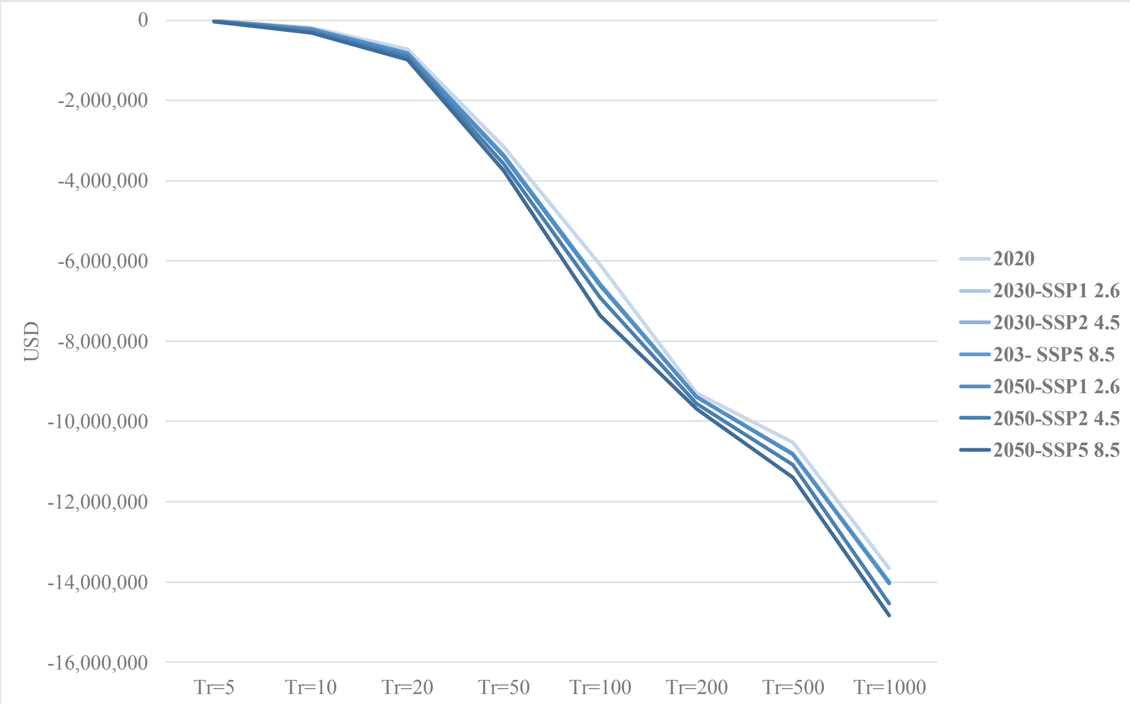


Figure 6b

Output Losses Caused by Pluvial Flooding in Alexandria (Vulnerability 1%)



5. FINAL REMARKS

One of the most studied effects of climate change is its impact on ice caps around the world and their accelerated melting. The scientific consensus points to rising sea levels as a direct consequence, although the rate and extent of this increase is still a hotly debated subject. Coastal cities at low elevations are exposed to the threat of eventual flooding and consequently loss of physical capital as buildings are inundated. The development of forecasts of the likelihood and severity of these floods is crucial for informing adaptation strategies and protecting coastal infrastructure.

Another predicted consequence of climate change in the Mediterranean region is the increased frequency and intensity of damaging weather events linked to excessive rainfall. The proximity to rivers and even the coast itself exposes the same cities mentioned above to the hazard of damaging flash floods caused by extreme precipitation. Therefore, developing forecasts of the potential impact of flash floods is crucial for mitigating future damage and ensuring community preparedness.

Finally, the great methodological challenge in this paper has been to establish a link between future climate projections, and business sectors and economic features at the local level. Additionally, a level of aggregation or disaggregation of analyses that makes this study relevant, and a faithful reflection of the 'local' realities must be established, and must also be feasible from the perspective of information and data handling. This is a critical issue in a study involving different cities with distinct economic structures and geographies. Hence, this paper has attempted to reconcile a macroeconomic general equilibrium perspective (which integrates sector-specific analyses in an aggregate fashion) with a local perspective.

City-specific studies seek to include climate variables and analyze their physical effects at the local level, while a nationwide model brings together an integrated interregional analysis and climate variables.

REFERENCES

Arnous, M. O., El-Rayes, A. E., El-Nady, H., & Helmy, A. M. (2022). Flash Flooding Hazard Assessment, Modeling, and Management in the Coastal Zone of Ras Ghareb City, Gulf of Suez, Egypt. *Journal of Coastal Conservation*, 26(6), 77.

Bhattacharya, B., Zevenbergen, C., Young, A. and Radhakrishnan, M. (2018). Extreme flooding in Alexandria: Can anticipatory flood management be a solution? *EPiC Series in Engineering*, 3, 252-257.

Carleton, Tamma, Amir Jina, Michael Delgado, Michael Greenstone, Trevor Houser, Solomon Hsiang, Andrew Hultgren, et al. (2022). "Valuing the Global Mortality Consequences of Climate Change Accounting for Adaptation Costs and Benefits." *The Quarterly Journal of Economics* 137 (4): 2037–2105. https://doi.org/10.1093/qje/qjac020.

Desmet, Klaus, Robert E. Kopp, Scott A. Kulp, Dávid Krisztián Nagy, Michael Oppenheimer, Esteban Rossi-Hansberg, and Benjamin H. Strauss (2021). "Evaluating the Economic Cost of Coastal Flooding." *American Economic Journal: Macroeconomics* 13 (2): 444–86. https://doi.org/10.1257/mac.20180366.

Di Noia, Jlenia, Alessandro Caiani, Luigi Cesarini, and Beatrice Monteleone (2024). "A High Resolution Input-Output Model to Assess the Economic Impact of Floods." *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.4728894.

Elboshy, B., Kanae, S., Gamaleldin, M., Ayad, H., Osaragi, T. and Elbarki, W. (2019). A framework for pluvial flood risk assessment in Alexandria considering the coping capacity. *Environment Systems and Decisions*, 39(1), 77-94.

El-Raey, M. (2010). Impacts and implications of climate change for the coastal zones of Egypt. In *Coastal Zones and Climatic Change*, D. Michel and A. Pandya (eds.). The Henry L. Stimson Center, Washington, DC.

Elshinnawy, I.A. (2008). *Coastal Vulnerability to Climate Changes and Adaptation Assessment for Coastal Zones of Egypt*. Ministry of Water Resources & Irrigation (MWRI). National Water Research Center (NWRC). Coastal Research Institute (CoRI). Cairo, Egypt.

Esmaiel, A., Abdrabo, K. I., Saber, M., Sliuzas, R. V., Atun, F., Kantoush, S. A., & Sumi, T. (2022). Integration of Flood Risk Assessment and Spatial Planning for Disaster Management in Egypt. *Progress in Disaster Science*, *15*, 100245.

Elshahawany, D. N., Haddad, E. A., & Lahr, M. L. (2017). Accessibility, transportation cost, and regional growth: a case study for Egypt. *Middle East Development Journal*, 9(2), 256-277.

Elshinnawy, Ibrahim A., and Abdulrazak H. Almaliki(2021). "Vulnerability Assessment for Sea Level Rise Impacts on Coastal Systems of Gamasa Ras El Bar Area, Nile Delta, Egypt." *Sustainability* 13 (7): 3624. https://doi.org/10.3390/su13073624.

Frihy, O.E., Iskander, M.M., Badr, A.E. and Lotfy, M.F. (2004). Effect of shoreline and bedrock irregularity on the morphodynamics of Alexandria coast littoral cell, Egypt. *Geo-Marine Letters*, Vol. 24, 195-211, November 2004.

Haddad, Eduardo Amaral, Michael L. Lahr, Dina N. Elshahawany, and Moisés Vassallo (2016). "Regional Analysis of Domestic Integration in Egypt: An Interregional CGE Approach." *Journal of Economic Structures* 5 (1): 25. https://doi.org/10.1186/s40008-016-0056-5.

Haddad, Eduardo Amaral, and Eliane Teixeira (2015). "Economic Impacts of Natural Disasters in Megacities: The Case of Floods in São Paulo, Brazil." *Habitat International* 45 (January):106–13. https://doi.org/10.1016/j.habitatint.2014.06.023.

Hassaan, M. A., & Abdrabo, M. A. (2013). Vulnerability of the Nile Delta Coastal Areas to Inundation by Sea Level Rise. *Environmental Monitoring and Assessment*, 185, 6607-6616.

Intergovernmental Panel On Climate Change, ed. (2014). *Climate Change 2013 – The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. 1st ed. Cambridge University Press. https://doi.org/10.1017/CBO9781107415324.

León, J.A., Ordaz, M., Haddad, E. et al. Risk caused by the propagation of earthquake losses through the economy. *Nat Commun* 13, 2908 (2022). https://doi.org/10.1038/s41467-022-30504-3

Muis, Sanne, Martin Verlaan, Hessel C. Winsemius, Jeroen C. J. H. Aerts, and Philip J. Ward (2016). "A Global Reanalysis of Storm Surges and Extreme Sea Levels." *Nature Communications* 7 (1): 11969. https://doi.org/10.1038/ncomms11969.

Nordhaus, William (2018). "Projections and Uncertainties about Climate Change in an Era of Minimal Climate Policies." *American Economic Journal: Economic Policy* 10 (3): 333–60. https://doi.org/10.1257/pol.20170046.

OECD (2024). *Climate Finance Provided and Mobilised by Developed Countries in 2013-2022*. Climate Finance and the USD 100 Billion Goal. OECD. https://doi.org/10.1787/19150727-en.

Torresan, S., Furlan, E., Critto, A., Michetti, M. and Marcomini, A. (2020), Egypt's Coastal Vulnerability to Sea-Level Rise and Storm Surge: Present and Future Conditions. *Integr Environ Assess Manag*, 16: 761-772. https://doi.org/10.1002/ieam.4280.

UNDP (2013). *Potential Impacts of Climate Change on the Egyptian Economy*. 143 pp.

UN-Habitat (2015). *Egypt Country Profile*, 20 pp.

Van Vuuren, Detlef P., Jae Edmonds, Mikiko Kainuma, Keywan Riahi, Allison Thomson, Kathy Hibbard, George C. Hurtt, et al. (2011). "The Representative Concentration Pathways: An Overview." *Climatic Change* 109 (1–2): 5–31. https://doi.org/10.1007/s10584-011-0148-z.

World Bank (2024). Climate Change and Future Flood Impacts in the Coastal Cities of Egypt. A WORLD BANK GPDRA D-RAS TEAM Report, April 2024, 41 pp.

Zevenbergen, C., B. Bhattacharya, R. A. Wahaab, W. A. I. Elbarki, T. Busker, and C. N. A. Salinas Rodriguez (2017). "In the Aftermath of the October 2015 Alexandria Flood Challenges of an Arab City to Deal with Extreme Rainfall Storms." *Natural Hazards* 86 (2): 901–17. https://doi.org/10.1007/s11069-016-2724-z.

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