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A Qualitative Analysis of Climate Impacts on Egyptian Ports

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Abstract: Ports are vital in the global trading system but are also vulnerable to climate-related threats. This problem has not been widely studied, especially in Egypt. However, there is an urgent need to address climate-related threats to Egyptian ports, which could have significant economic and trade-related consequences. Therefore, exploring the Egyptian port administrations' and stakeholders' perceptions regarding climatic hazards is an urgent and essential matter for sustainable and resilient ports, considering their strategic economic importance. Consequently, this article is the first to examine how the port authorities perceive and respond to climate hazards in one of the most important and largest commercial Egyptian ports; it also explores their adaptation strategies and plans, considering the national agenda to develop the coastal ports respecting the sustainable development pillars, and fills the gaps in regional and national studies on seaports and climatic hazards. The paper focuses on the Great Alexandria Port, which includes the Alexandria and El-Dekheila ports. A questionnaire is designed and distributed in different port sectors for gathering relevant data and conducting interviews, discussions, and workshops. The findings declare obvious concern about developing the Egyptian ports under the national projects umbrella. Also, the port authorities are aware of the risks of climate change and believe some adaptation measures are necessary and could be essential soon. They are taking steps to adapt their ports, considering a specific strategy that includes rehabilitating infrastructure (breakwater and berths), functional facilities, and services, improving drainage systems to enhance their port's resilience, and achieving the 2030 Agenda for Sustainable Development. Our research findings suggest that there are opportunities for scientists to engage with the port stakeholders to proactively develop plans to alleviate climate change's effects on their ports.

Keywords: Egyptian ports; port management; climate impacts; questionnaire; adaptation; SDGs

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1. Introduction

Ports serve as vital gateways to trade, connecting various transportation modes and acting as the interface between land and sea. Also, they function as key transportation hubs, facilitating access to global markets and the movement of goods for different regions worldwide [1,2]. Therefore, they are essential for the worldwide economy and trading system and for enhancing the growth of industries, fisheries, and tourism activities [3]. In light of the anticipated surge in trade activities and coastal inhabitants, it is anticipated that maritime transportation volumes will experience a notable escalation in the ensuing

decades. This phenomenon will serve to underscore and enhance the pivotal role of ports in the global economic landscape [2].

Ports are at significant risk of climate hazards due to their location in coastal zones, deltas, and regions characterized by low elevation, impacting their facilities, services, and operations [4–6]. They are particularly vulnerable to the impacts of rising sea levels, storm surges, floods, and strong winds. The extent of vulnerability varies based on factors such as the type of port, its infrastructure construction, and location [1,4,7]. Moreover, the considerable development of physical structures and their indispensable function within global supply networks renders the repercussions on ports and their terrestrial entry points notably consequential in academic discourse. Consequently, it is crucial to develop effective adaptation strategies to address these challenges, given the strategic economic importance of ports [4,7].

The prospective consequences of climate change on coastal infrastructure encompass constraints on navigational flexibility, docking procedures, and loading/unloading activities attributed to elevated wind speeds. Moreover, diminished visibility arising from intense precipitation, challenges executing approach maneuvers due to notable wave height, overtopping, coastal inundation, and restrictions on terminal operations are envisaged outcomes. These changes will, in turn, affect the operability of ports, which rely heavily on wave conditions for activities such as ship entrance, exit, mooring, and cargo handling [2,8–13]. Additionally, an elevation in the average sea level poses a potential hazard to port activities as it reduces dock freeboard. This increase in sea level also alters wave propagation patterns, potentially affecting processes like wave agitation, siltation, and infrastructure and facilities stability within the harbor [12,14–16]. Additionally, climate change has repercussions on diverse facets associated with ports and the coastal milieu, encompassing safety and human health, recreational pursuits, tourism, and the overarching well-being of ecosystems. These impacts have significant financial and human implications for port operations and the surrounding areas [17].

However, one of the noteworthy ramifications of climate change, encompassing phenomena such as sea-level rise (SLR), concerning seaports is the manifestation of wave overtopping. SLR decreases the space on port breakwaters, making it easier for waves to pass over these structures. This leads to an increase in overtopping discharges, posing a potential threat to assets such as boats, goods, and warehouses located on the leeward side of the breakwater [11,12].

Many ports worldwide are either unaware or slow to recognize the potential risks of climate change and take appropriate measures to adapt [2]. However, certain ports are proactively formulating policies and strategies and conducting risk assessments to mitigate the repercussions of climate change. Economic pressures and the uncertainty surrounding climate predictions often limit the effectiveness of adaptation efforts. Despite the lack of visible local impacts, adapting ports globally and enhancing their resilience to climate change-induced storm events is crucial. Unfortunately, a recent survey revealed that only a few port authorities have started addressing this challenge [2]. As sea levels rise due to climate change, port authorities will face difficult decisions in managing risks associated with their activities. In the realm of maritime infrastructure, it is imperative for seaports to proactively foresee and prepare for the ramifications of climate change, including elevated sea levels, heightened occurrences of flooding, and more frequent instances of severe storms. This strategic anticipation is essential for the continued efficiency and resilience of these port facilities [10,17,18]. The lack of completed work and research in minimizing uncertainties related to decision-making and port planning regarding climate impacts on maritime infrastructure is a significant concern recognized by national and international organizations [3].

Suppose appropriate actions are not implemented to adapt. In that case, rising sea levels will lead to higher discharges that pose a significant risk to the existing functional and operational assets/services [11]. Also, as predicted, the escalation of sea levels is expected to correlate with a proportional increase in the number of ports subject to overtopping,

thereby yielding heightened economic ramifications [12,15]. Another noteworthy finding is that substantial cost savings are achieved by implementing adaptation measures, which prevent minimal damage compared to the option of no damage at all [12,19].

The focus on climate change's potential effects on beach systems has overshadowed the attention given to the impact on port operations and infrastructure. Nevertheless, ports have always been susceptible to extreme weather conditions, and climate change can potentially exacerbate these occurrences over a timeframe similar to the expected lifespan of harbor engineering structures [8,9]. In Egypt, although the ports sector has a significant contribution to the national income, it was observed that relevant research discussed planning and management issues, water quality and pertinent environmental problems, and entrance and navigational channel sedimentation issues, etc. (e.g., [20–22]), with no research about climatic impacts and relevant adaptation measures.

There is a lack of scientific investigations on the influence of climate change on ports and harbors, along with their corresponding adaptation measures [15]. Given the pivotal role of ports in the economic and societal fabric of urban centers, a compelling need arises to scrutinize the repercussions of climate change on these entities. Notably, the ports and coastal regions in the Mediterranean exhibit heightened vulnerability to the impacts of climate change [23]. In light of Egypt's pronounced economic dependence on tourism and coastal municipalities, assessing the ramifications of climate change on Egyptian ports and the communities along the coast is imperative.

No specific surveys or interviews have focused on the impacts of climate change on Egyptian ports. Therefore, this article is the first attempt to investigate the impacts of climate change on Egyptian ports, particularly the Great Alexandria Port, the largest commercial port along Egypt's Mediterranean coast. The article conducted surveys and interviews to gather primary data and bridge the existing knowledge gaps on the Great Alexandria Port. The research aimed to assess the administrators' perception of climate change impacts on port operations, identify potential operational problems caused by climate changes, and explore adaptation strategies. It also aimed to examine existing policies related to port adaptation issues and evaluate the extent to which climate change is considered in Egypt's port planning, coastal management, and climate adaptation policies.

The innovation in this paper lies in its comprehensive approach to provide a qualitative and descriptive analysis of the perceptions and experiences of the participants as well as investigate the attitudes, perceptions, views, and adaptation strategies of Egyptian port managers towards climate change issues and their impacts. The study mainly utilized a descriptive approach to present the findings from the questionnaire survey, interviews, and the implemented workshop with port managers, administrators, workers, and stakeholders. The formulation of a questionnaire that adheres to international standards and the involvement of various industry stakeholders demonstrate a novel and rigorous methodology. Furthermore, the paper offers insights into Egyptian managers' views on a sustainable port concept and relevant adaptive strategies for ports to enhance their resilience to climate change-induced events, which contributes to the broader discourse on sustainable development and climate resilience in the port industry.

2. Study Area

Historically, ports and the maritime transportation sector have served as a crucial nexus for global commerce. As highlighted in a recent assessment by the United Nations Conference on Trade and Development (UNCTAD), nearly 80% of the total global trade in weight is facilitated through maritime transport (source: https://unctad.org/rmt2022) (accessed on 1 September 2023). The geographical configuration of Egypt, with a coastline extending over 2900 km along the Mediterranean Sea, the Gulf of Suez, the Gulf of Aqaba, and the Red Sea, positions the nation strategically along significant international maritime shipping lanes and trade and transportation corridors. The presence of the Suez Canal further enhances this strategic positioning. Many world trade movements depend on the Egyptian ports and the Suez Canal, reducing tangible time and costs for different activities,

including the supply of fuel and logistics services. Its economic importance is not only for Egypt but also for all commercial institutions and companies that depend on transit through the Suez Canal.

According to the Maritime Transport Sector (MTS, https://www.mts.gov.eg/en/, accessed on 1 May 2023), Egypt has about 53 seaports, including 15 commercial ports (approximately 37.7 km length of berths) and 29 specialized ports. The ports are managed under a public and private landlord port model. The port authorities own and administer the infrastructure, while public and private companies provide port services.

These 15 maritime terminals are under the jurisdiction of four distinct port authorities, namely the Alexandria Port Authority (APA), the Damietta Port Authority (DPA), the General Authority for Red Sea Ports (RSPA), and the General Authority for the Suez Canal Economic Zone (SC Zone). The projected aggregate inbound and outbound cargo throughput for Egyptian port authorities in the year 2021 amounts to approximately 162.8 million tons, facilitated by a fleet of 11.59 thousand vessels. Egyptian ports also achieved transactions worth 156 million tons of goods in 2020; a statement of the movement of goods trading in Egyptian ports for 2022 (175.9 million tons) amounting to 61.63 million tons was recorded in Alexandria and El-Dekheila ports. The designed capacity of Egyptian ports is 170 million tons. The design capacity of Alexandria Port is 37.9 million tons, EL-Dekheila 27 million tons, Damietta 21.7 million tons, West Port Said 12 million tons, Arish 1.2 million tons, and East Port Said 12 million tons. Egyptian ports have different capacities and functions. Regarding methodology, the Great Alexandria Port (the most significant Egyptian commercial port) was investigated in this study. The port was selected due to its great socio-economic importance among the Egyptian ports.

2.1. Selected Egyptian Ports

Alexandria is situated on the western periphery of the Nile Delta, between the Mediterranean Sea and Mariut Lake. It holds significance as the second most prominent city within the Arab Republic of Egypt, serving as its primary port. The Great Alexandria Port occupies a leading position in the ports of the Arab Republic of Egypt regarding the volume of commercial traffic, as it handles about 60% of Egypt's foreign trade. Among the 15 Egyptian commercial ports (205 multi-purpose berths), 64 berths are located in Alexandria Port and 20 berths in El-Dekheila Port https://apa.gov.eg/en/page/port-information/about-port/ (accessed on 1 September 2023). Figure 1 shows the Great Alexandria Port layout.

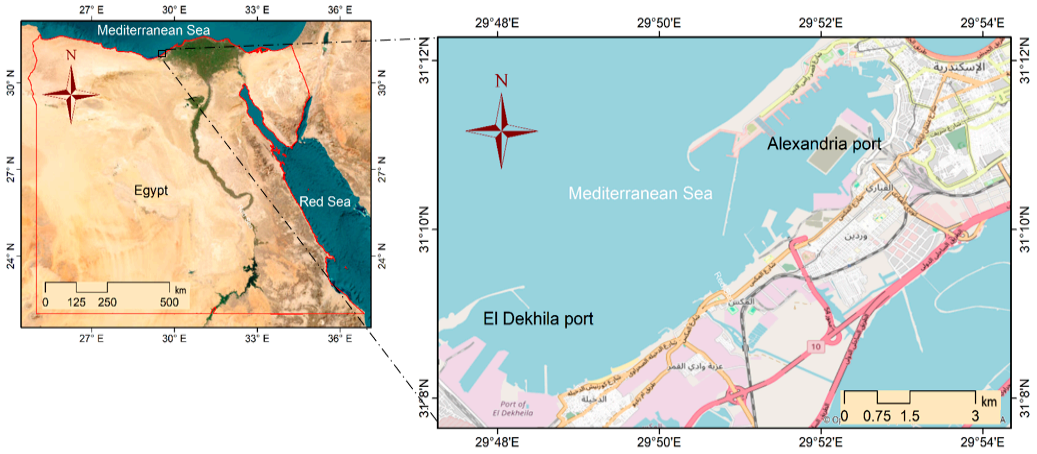

Figure 1. Layout of the Great Alexandria Port.

2.1.1. Alexandria Port

Alexandria Port is the largest and busiest port in Egypt. The Alexandria Port location is Latitude 31°11′ North and Longitude 29°52′ East. Alexandria Port has many traffic network connections, including road, rail, and inland waterways networks. The ort contains a dry bulk terminal divided into three berths with a total length of 758 m and depths ranging

from 10 to 14 m; a passenger and tourist terminal of 786 m in length and depths between 10 and 12 m; a ro-ro terminal with five berths with a total length of 916 m and depths from 10 to 12 m; a coal terminal accommodating four berths with an overall length of 1405 m and depths from 9 to 12 m; a general cargo terminal accommodating 22 berths with a total length of 3295 m and depths ranging from 6.5 m to 10 m; a container terminal with five berths, a total length of 1110 m, and depths ranging from 12 to 14 m, and a petrol terminal with five berths with an overall length of 1042 m and depths between 10 and 12 m.

Port Services: The port also provides different services such as marine services (pilotage and towage); cargo handling, including stevedoring, warehousing, and customs clearance; ship supply, including bunkering, fresh water, and purveyance; ship repair and maintenance; solid waste collection; ballast and wastewater reception facilities. In addition, the port has different service equipment, such as tugboats, pilot launches, water service launches, marine cleansing launches, mooring launches, floating cranes, and environment protection units.

2.1.2. El-Dekheila Port

El-Dekheila Port is a natural extension of Alexandria Port. The port location is Latitude 31°08′ North and Longitude 29°49′ East. Like Alexandria Port, El-Dekheila Port has many traffic network connections, including road, rail, and inland waterways networks. El-Dekheila Port contains a grain terminal that accommodates four berths with a total length of 1380 m, depths ranging from 12 to 15 m, and a total area of 110,000 m^2; a mineral terminal with a total length of 583 m, divided into two berths with depths between 14 and 20 m; a general cargo terminal with two berths of an overall length of 1050 m and depths ranging from 12 to 14 m; a container terminal with two berths, an overall length of 1550 m, and depths ranging from 12 to 14 m.

El-Dekheila Port provides the same service as Alexandria Port except for ship repair, maintenance, and ballast and wastewater reception facilities. In addition, the port has different service equipment, such as tugboats, pilot launches, mooring launches, services launches, marine decontamination units, and firefighting units.

3. Materials and Methods

A review article analyzed key contributions and methods employed to achieve eco-friendly operations in passenger ports from 2012–2022. The study revealed that qualitative approaches dominate the field, highlighting data-driven efforts to understand and manage port sustainability [24]. The methodology of our paper depends on qualitative analysis that was utilized in many papers. For example, to gauge port managers' perspectives on climate change adaptation, the research utilized an online survey targeting diverse ports globally [25]. Also, given the limited knowledge of port attitudes toward climate action, 18 Chinese organizations were investigated [26]. In addition, a questionnaire survey among port professionals and environmental specialists in Valencia shed light on the crucial role of climate change in port operations [27].

Furthermore, responses based on questionnaire analysis from 70 maritime sector leaders in Ireland, representing diverse stakeholders like regulators and port operators, exposed a significant lack of understanding of climate change [28]. Also, the questionnaire served as a key research tool to investigate the integration of environmental considerations into Greek TEN-T ports and their preparedness for future challenges [29].

Considering their sensitive location and worldwide reputation, Egyptian ports and relevant information are categorized as national security matters to the Egyptian government. Therefore, access to information about climate impacts on Egyptian ports and relevant adaptation strategies is difficult and usually insufficient. In addition, specific institutional constraints limit the availability of such relevant data. In general, the designed questionnaire is prepared to have an overview of the perception of the Egyptian managers, planners, and stakeholders of the Great Alexandria Port respecting climate change vulnerability, impacts, and uncertainties that could affect the port's operational performance

of provided facilities and services, infrastructure stability, and port strategy to adapt or mitigate potential risks.

Consequently, a Memorandum of Understanding (MOU) was signed between the research team representative to their academic/governmental institution and the Alexandria port authority to facilitate our task in data collection under the supervision of a specific group of their port managers assigned for this task. To collect the necessary data, a questionnaire survey, interviews, and workshops were implemented by the collaboration of the assigned teams. The questionnaire survey and interview methods are practical tools that were applied in different publications as a valid and trusted tool for investigating the port administration's perception towards the potential hazards of climatic change and their planning strategies [1,7,18,27,30,31]. Also, they could offer an overview of the participants' attitudes about the importance of climate change issues that could affect their workplace, and the presented survey questions are considered a relatively new topic. On the other hand, to enhance our understanding of the importance of climate impacts and proper actions/strategies by both port managers, interviews with relevant ports' assigned teams were also conducted, and a workshop was organized for different ports' relevant stakeholders, including senior port directors, port planners, environmental managers, policymakers, environmental academics, and young researchers with support from the assigned teams.

The formulated questionnaire adhered to the stipulations outlined in Egyptian regulations, accounting for prevailing political constraints and contextual nuances. The resulting questionnaire underwent meticulous development through consultation with subject matter experts and stakeholders within the port industry. It drew inspiration from various established survey instruments, notably the seaport survey questionnaire crafted by the Secretariat of the United Nations Conference on Trade and Development (UNCTAD). This instrument underwent meticulous development through consultation with subject matter experts and stakeholders within the port industry, including the International Association of Ports and Harbors (IAPH) [18]. The resulting questionnaire received extensive dissemination throughout the port industry, facilitated by the backing of the American Association of Port Authorities (AAPA).

The designed questionnaire was divided into three sections. For each section, questions were presented in different forms, such as multiple-choice, Likert-scale, and essay questions. Section 1 was designed to collect general information about the respondent's history in the field of ports and available information about the port's features, characteristics, trade volume, and relevant economic benefits. Section 2 was designed to have an overview of the respondent's perception of the potential impacts of climate change on their port, mainly in the past ten years, and damage/loss due to climate-related events, identifying which climate factors (sea level rise, high waves, winds, storm, heavy precipitation) have impacted the port and its operational efficiency, investigating the frequency and severity of the consequence of climatic factors and their impacts, exploring the operational threshold values of climatic factors, reviewing the recent climatic events that impacted the port operations and caused operational delays, shutdowns, economic/financial loss, etc. Section 3 was designed to explore the long-term port planning, the port's efforts in recording and monitoring climatic factors, measurements, environmental and operational conditions, planning for future scenarios in terms of protection and adaptation strategies to different potential hazards such as SLR, wave overtopping, berths flooding, etc.

Unfortunately, according to the MOU, a random sample of 100 participants in the questionnaire survey, including front-line workers and staff in different sectors within the port, was only allowed to be investigated and collected, as it was one of the main limitations of our study. In addition, an officially signed response to the questionnaire was received from the port administration. Therefore, the study utilized a mixed-methods approach, which included not only the questionnaire survey but also interviews and a workshop with port managers, administrators, workers, and relevant port stakeholders. This approach allowed for a more comprehensive understanding of the issues under investigation and provided multiple perspectives on the topic. Furthermore, some interviews were executed

between the research team and the assigned port team to investigate further environmental issues not mentioned in the questionnaire, if any, and the port's strategic current and future adaptation plans for climate change considering achieving sustainable development goals. Also, the organized workshop focused on the impacts of climate change on ports and the importance of collaboration between different stakeholders (academic and governmental institutions) in knowledge and data sharing to highlight the academic and governmental institutions' efforts towards the climatic impacts on Egyptian ports and proper adaptation strategies and future plans.

The study mainly utilized a descriptive approach to present the findings from the questionnaire survey, interviews, and the implemented workshop with port managers, administrators, workers, and stakeholders. This qualitative approach can offer valuable insights without the need for inferential statistics, where the primary aim is to explore perceptions, attitudes, and adaptation strategies without necessarily establishing statistical relationships. Therefore, we believe that the qualitative approach is appropriate. This aligns with the research objectives, nature of the data, and overall design, which prioritize rich qualitative insights over hypothesis testing. For this specific investigation, understanding diverse perspectives and experiences was deemed more suitable than statistically verifying pre-determined relationships.

4. Results

The designed questionnaire is directed to managers, employees, and workers in Alexandria and El-Dekheila ports and relevant stakeholders to investigate ports' attitudes, perceptions, views, and adaptation strategies toward climate change issues and their impacts. It investigates how port managers respond to the impacts of climate change. It explores how climate change might impact their port operations, what sea-level change would create operational problems, discovers what policies, if any, ports already have, and whether the ports have specific adaptation strategies toward the proposed future climatic scenarios. The collected data from the surveys, discussion, and implemented workshop were analyzed and discussed.

The assigned team distributed the designed questionnaire to different port sectors: (a) the central administration for technical and marine services; (b) the central administration for engineering affairs; (c) the central administration for movement; (d) the central administration for strategic management; (e) the general administration of environmental protection; and (f) the general administration of the information center.

Statistically, among 100 distributed questionnaires, 73 questionnaires were collected (response rate is 73%). Most respondents have an average of 10 to 20 years of experience working in the ports (49.3%), followed by an average experience of 5 to 10 years, then more than 20 years of experience, which represents 39.7% and 11%, respectively.

According to the port administration's official response, the average number of ships per year is about 1200 general cargo, 600 dry bulks, 400 liquids, 250 ferries, 25 tourists, 1500 containers, and 200 other vessels with different aspects. Regarding the maximum ship dimension used by the port services, they confirmed that the port receives Belita vessels, one of the huge vessels with a total length of 332 m, 42 m widths, and 13.4 m draft. They also confirmed the Alexandria port has different features and can receive different cargo vessels. Also, the port contains a multidisciplinary yard, specific yards for containers, and petroleum product trading stations.

4.1. Climate Change Impacts

This section investigated the respondents' perception of climate change impacts on their port. The official response of the port administration and about 75.3% of the respondents feel that the port has not been remarkably impacted by weather or climate-related events in the past ten years, 16.4% believe it is not impacted, and about 8.2% cannot judge. Only those who feel that the port is impacted were asked about identifying the type of impact (such as physical damage, operational problems, and operational/handling delays)

and the relevant extent of the impact (such as little impact, some impact, significant impact, do not know/not applicable). Their responses are relatively matched and fluctuated between the port having little, some, and significant impacts concerning operational problems and operational/handling delays, with a slight tendency to have some impact, as shown in Figure 2.

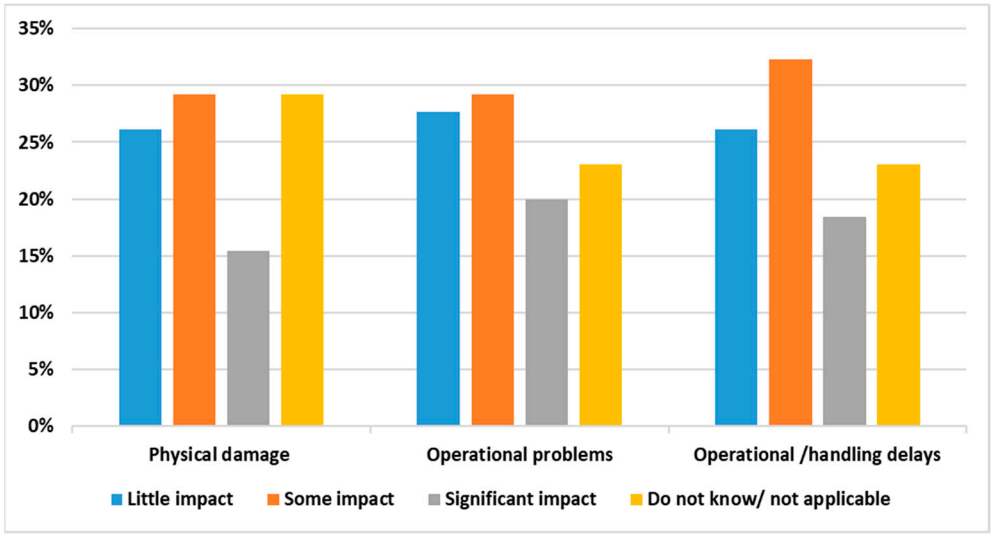

Figure 2. Type and extent of the impacts due to climate events.

The official response of the port administration and about 6.8% of the respondents believe that the magnitude of harmful effects/loss due to climate-related events has remained unchanged through the last decade. About 17.8% believe that the loss has increased, 8.2% believe that the loss has decreased, 12.3% show that it decreased because of a specific action, and 54.8% do not know or cannot judge, as shown in Figure 3.

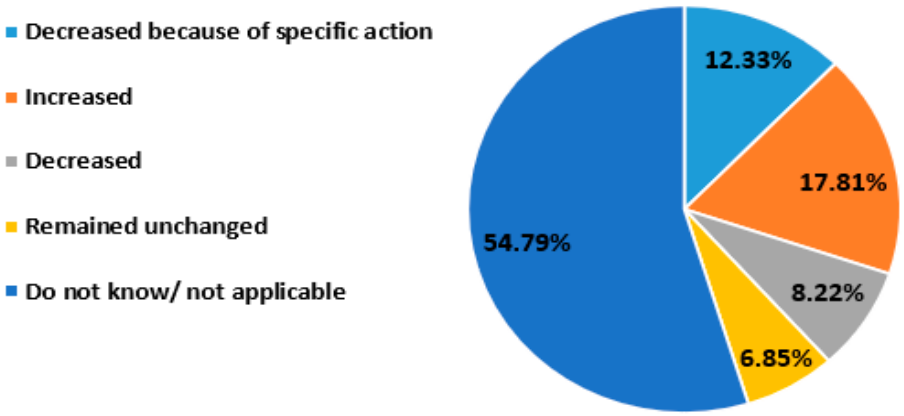

Figure 3. Type and extent of the impacts due to climate events.

The respondents were asked about which of the weather- or climate-related factors (such as SLR, storms, wave penetration, winds, and heavy precipitation) have affected the port and its operational efficiency and in which sector (such as infrastructure, ship operations, terminal operations, services, and facilities). The results indicate that SLR affects the terminals and their operations; storms affect the ships and terminal operations; wave penetration affects the infrastructure, ship operation, and terminal operation; winds affect the ship and terminal operations; heavy precipitation affects ship and terminal operations and services and facilities, as shown in Figure 4.

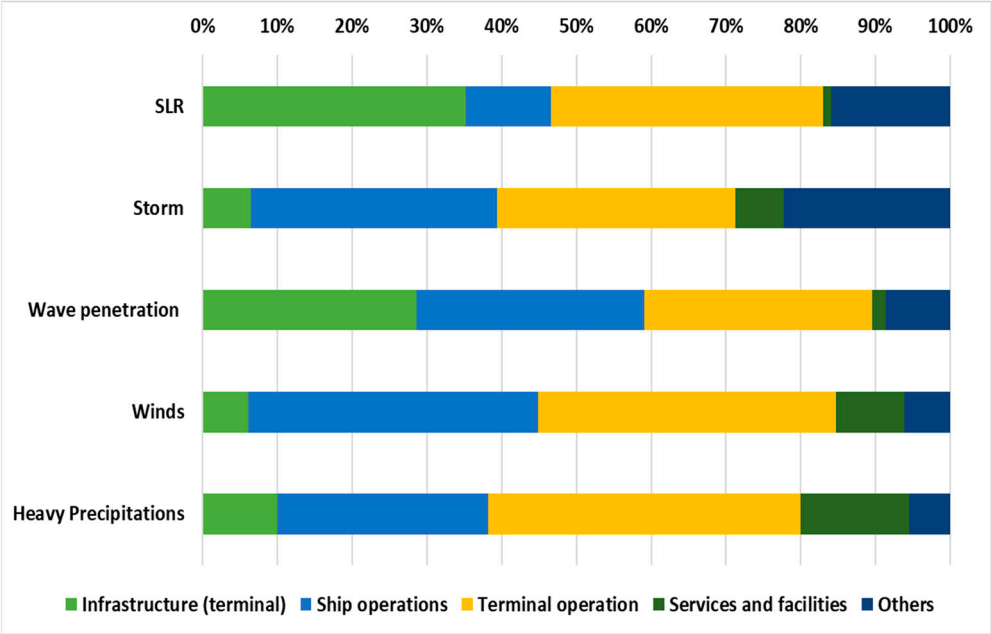

Figure 4. Climatic factors and their impact on the port elements.

To investigate the ramifications of climate change over the preceding decade on port operations, respondents were tasked with assessing the frequency and severity of resultant consequences across six specific inquiries using a five-point scale. The questionnaire explicated the definitions associated with the frequency and severity scales, as delineated below. Frequency ratings ranged from 1 (Never, denoting an absence of occurrences in the past decade) to 5 (Very Frequent, signifying incidents transpiring more than once annually). The severity of consequence assessments ranged from 1 (Negligible, representing minimal disruption with limited economic repercussions and no discernible impact on service continuity, requiring nominal time and recovery costs) to 5 (Catastrophic, indicating highly severe economic losses).

The initial inquiry posed by the questionnaire aimed to ascertain whether high wave-driven climatic alterations had previously exerted a negative influence on port infrastructure and the stability of docked/moored vessels. About 42.5% of the respondents show that high waves are seldom frequent, while 28.8% and 17.8% show they are sometimes and never frequent, respectively. Only 11% believe that they are frequent. Regarding the severity of consequences, 52.1% believe that high waves have minor impacts, and 37.0% feel that high waves have neglected impacts on the port facilities and the stability of ships resting. In contrast, 8.2% and 2.7% show that high waves have major and critical impacts, respectively. At the same time, no responses are received for catastrophic impacts on the port facilities and the stability of ships resting.

The second question asked whether the port's transport infrastructure and facilities (e.g., cranes and warehouses) and operational facilities were flooded or damaged due to flooding, heavy rains, and strong winds. About 34.2% of the respondents show that heavy rains and strong winds are seldom frequent, with the same response percentage selected as sometimes frequent. 16.4% of respondents believe they are never frequent, 13.7% believe they are frequent, and 1.4% indicate they are very frequent. Regarding the severity of consequences, 56.2% of the respondents show that the transport infrastructure and operational facilities have been minorly impacted due to heavy rains/strong winds, 23.3% show that the impacts could be neglected, 16.4% refer to major impacts, and 4.1% indicate that the heavy rains and strong winds have critical impacts on the port's transport infrastructure and facilities. At the same time, no responses were received for catastrophic impacts on the port's transport infrastructure and facilities due to heavy rains or strong winds.

The third question asked the respondents whether the port had been temporarily shut down/closed due to extreme weather conditions, including heavy winds, storms, and/or significant waves. A total of 4.38% and 24.7% of the respondents show that the port is seldom and sometimes frequently subjected to a temporary shutdown; 13.7% of respondents refer to frequent closing, 13.7% refer to no shutdown actions being taken, while 4.1% show the port shutdowns very frequently. A total of 54.8% and 23.3% of the respondents declare that the associated consequences of the damage/loss are minor and neglected, while 12.3% and 9.6% of the responses indicate that the associated consequences of the damage/loss are major and critical; no catastrophic consequences were detected.

The fourth question asked the respondents whether coastal erosion occurred at or adjacent to the port. In total, 47.9% and 30.1% of the respondents show that it is never frequent or seldom frequent, respectively, while 17.8% and 4.1% believe that coastal erosion occurs at or adjacent to the port sometimes frequently and frequently, respectively. A total of 52.1% and 39.7% of the responses declared that the associated severity of consequences is neglected and minor, respectively, and 4.1% of the respondents showed major or critical consequences; no catastrophic consequences were observed.

The fifth question asked the respondents whether deposition and sedimentation occurred along navigational channels. In total, 49.3% and 34.2% of the respondents show that the navigation channels are never and seldom frequently subjected to sedimentation issues, respectively, and about 9.6% and 6.8% of the responses declare that sedimentation issues sometimes and frequently appear in the navigational channels. A total of 52.1% and 39.7% of the responses declare that the associated consequences are neglected or minor; 4.1% of the respondents showed major or critical consequences, and no catastrophic consequences were observed.

The sixth question asked the respondents whether the overland access (road, railway) to the port was limited due to flooding, heavy rains, and strong winds. A total of 39.7% and 37.0% of the respondents show that the port is seldom and never frequently subjected to limited access, respectively, while 17.8% show they are sometimes frequent. In contrast, 2.7% of the respondents show they are frequent/very frequent, respectively. Regarding the severity of consequences, 54.8% believe that minor impacts were observed, and 37.0% feel that heavy rains and strong winds have neglected impacts on the overland access. In contrast, 5.5% and 2.7% show they have major and critical impacts, respectively. At the same time, no responses were received for catastrophic impacts on overland access. The summary of the results is presented in Figure 5.

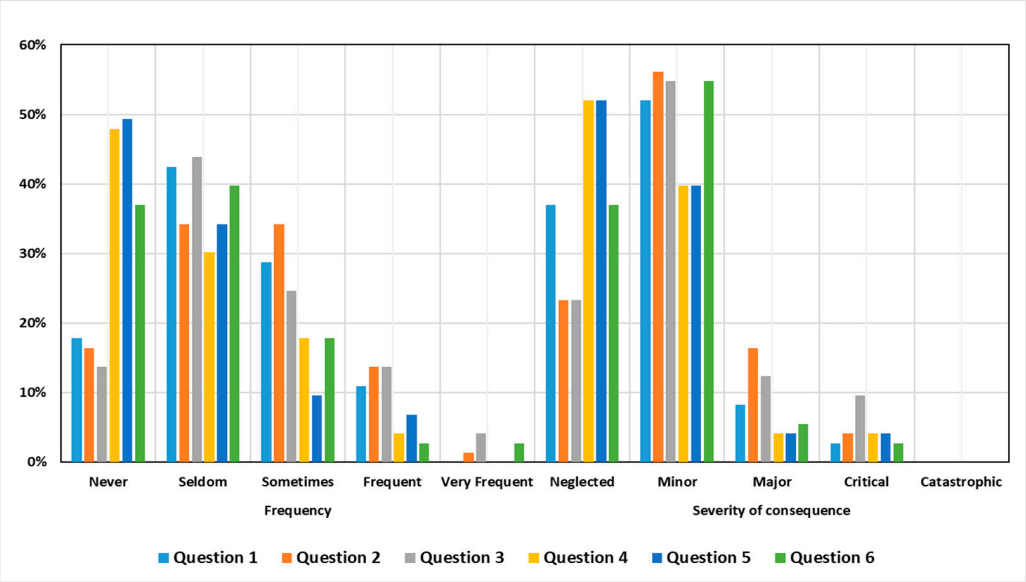

Figure 5. Frequency and severity of consequences of climatic issues.

However, most respondents, including the administration staff, believed that SLR, winds, heavy rains, storms, and wave penetration are the climatic phenomena/factors that will occur and increase in the future and may negatively affect the port's facilities/infrastructure/operations. Discussion with the assigned team and port stakeholders about the maximum limit (threshold values) for the aforementioned climatic phenomena shows that within the port, the threshold values for extreme water level/storm are up to 1.5 m, wind speed 70 km/h, and precipitations about 250 mm/day; higher values could affect the port's operationality and handling operations.

Port administration staff were asked to indicate the recent climatic events that impacted the port operations, which caused operational delays, shutdowns, economic/financial loss, physical impacts, fines (rate USD/h), etc. They explained that two clear events occurred; the first in March 2022, when Ayla's vessel (Lebanese cargo vessel) sank outside Alexandria Port's anchorage area due to intense storms, while the other recent event occurred in February 2023, when the sea level had lowered, causing tangible impacts and losses considering water depth inside the port. Furthermore, on the other hand, they confirmed that they did not receive any requests to activate additional insurance services or modify infrastructures by port users to secure them during heavy weather based on climatic conditions or due to climate changes.

On the other hand, they stated the average shutdown periods per year and relevant average economic loss (USD) could not be estimated accurately and may range from 10 to 15 days/year, but is tangible. However, some stakeholders show that no fines are required from the port during shutdown periods. It should be mentioned that the port authority is currently arranging with different marine and shipping agencies to be updated with the current and historical tide records and developing weather map forecasting techniques to prepare emergency plans during rough weather events and to avoid closing of temporary shutdowns as much as possible.

4.2. Climate Data/Adaptation

Most of this section's results were extracted from interviews and discussions with the port managers, assigned team, relevant stakeholders, and the applied survey. It was observed that most respondents did not respond to related questions because they considered these questions to be specialized questions, which the port authority should have responded to instead.

The respondents were asked whether the port has been implemented or if they are considering an adaptation plan/strategy for climate change. In total, 86.3% agree that the port has implemented an adaptation plan/strategy, while 13.7% believe the port has not implemented any strategy but will consider an adaptation plan/strategy in the future. The port administration confirmed that the port has a specific strategy for climate hazards concerned with adaptation and maintenance to infrastructure/terminal, dredging works, maintenance of warehouses and or operational facilities, and sea defense structure implementations or maintenance. Also, they declared that the port has had different measurements and records of climatic factors, such as water levels and winds (speed and direction), for about 20 years, which show a slight fluctuation over time and could indicate future trends. In addition, they stated that they are willing to consider waves (height, period, direction) and precipitation measurements soon.

It should be mentioned that the port administration is currently planning to evaluate the vulnerability to climate hazards and address future scenarios, considering the proper impact of SLR, storm, wave penetration, winds, and heavy precipitations on each infrastructure (terminal/breakwaters), ship and terminal operation, services, and facilities. Also, their adaptation strategy includes adjusting each of (a) the port's planning considering proper investments such as constructing new terminals, (b) the existing equipment (cranes and vehicles), and (c) rehabilitation of the infrastructure and related required maintenance.

Regarding the protective and adaptation measures, the port authority is currently considering different protective and adaptation measures in coping with climate change,

such as constructing a new breakwater, which is aligned and designed to protect the Great Alexandria port considering SLR projected scenarios; an environmental impact study for the proposed new breakwater was prepared and is currently under consideration for an executing agreement. Furthermore, the port is provided via an efficient drainage system to deal with heavy rains or flash flood events. Also, they consider replacing/upgrading existing sea structures and rehabilitating the drainage system, services, facilities, and emergency plan during closing or shutdown periods, which will be subjected to higher and more accurate implementing criteria to sustain operationality and operability.

5. Discussion

As integral components of the global economic infrastructure, Egypt endeavors to transform its ports into a hub for international trade and logistics; this transformation involves augmenting the port infrastructure, designating them as logistical hubs for activities such as shipping, unloading, packaging, re-exportation, ship manufacturing, maintenance, and financing, encompassing both heavy and light marine industries. Moreover, this initiative aims to establish seamless linkages between seaports, dry ports, and logistical centers. The anticipated financial outlay for the national port development project is estimated at approximately 115.6 billion Egyptian pounds. The overarching objectives of this national endeavor encompass the realization of sustainable development. In steering the blue economy, emphasis is placed on safeguarding economic and social rights for future generations, encompassing imperatives like ensuring food security, eradicating poverty, elevating living standards, augmenting income, fostering employment opportunities, ensuring safety, and advancing sustainable health, security, and political development. It also requires maintaining all ecosystem elements, reliance on clean technology and renewable energy sources, environmentally friendly products, and effective waste management.

Climate change is a growing challenge for ports, seriously threatening ports' operations and services, particularly those located along open coasts or in low-lying estuaries and deltas. They are vulnerable to the effects of climate factors, such as SLR, waves, storm surges, extreme weather events, and heavy precipitation. SLR is the most prominent threat to ports; sea levels could inundate low-lying port areas, damage port infrastructure, and make it more difficult for ships to dock and unload cargo. Higher and stronger waves could damage the port infrastructures and facilities and reach the agitation levels (based on breakwater overtopping or diffracted waves) within the ports, making it difficult for ships to dock and unload cargo. Storm surges are large waves generated by storms and can cause widespread flooding. Extreme weather events can cause significant damage to port infrastructure and disrupt port operations. Changes in precipitation patterns can lead to more frequent droughts or floods, which could affect port operations and port services. Although the impacts of climate change on ports are already being felt worldwide, the future of ports is uncertain in the face of climate change. In some cases, ports have been forced to close temporarily due to flooding or damage from extreme weather events. In other cases, ports have had to invest in expensive measures to protect themselves from climate change, such as building sea walls or raising port facilities.

Therefore, a questionnaire survey, interviews, and the implemented workshop with port managers, administrators, workers, and relevant port stakeholders were distributed through various sectors within both ports to investigate ports' attitudes, perceptions, and views toward climate change issues and their impacts on Egyptian ports (Great Alexandria ports), and to explore their strategies respecting the future scenarios of climate change. It is supposed that these diverse aspects of the respondents could reflect different views towards climatic hazards.

Regarding the Great Alexandria Port, most respondents believe that the climatic hazards could pose a real threat in the future, but currently, they do not feel any threat. Most of their responses reflect that attitude, notably when they confirmed that the port suffers from minor impacts based on some weather events. On the other hand, about 15 to 20% think climate change severely affects the port, while 25 to 30% identify that climate

change does not affect the port. The port's past performance during storm events has been exemplary. Even throughout the year, when temporary closures for a few days occurred, there were no economic losses or required fines. Although the respondents were asked about the common climatic factors that could impact their port in the future, they declared that SLR, waves, winds, and heavy rains could pose direct threats to the port operations. However, currently, the effect of SLR and high waves is still intangible, and the heavy rains do not pose a physical threat to the handling and operational facilities.

The projected waves and sea level rise (SLR) scenarios in the Mediterranean Sea shed light on the potential impacts on coastal regions. The statistical characterization of the Mediterranean Sea wave hindcast climate during the 1961–2018 period revealed that the spatially averaged Hs value varies between 1.1 m (mean wave height) and 4.20 m (90% wave height), while Tm ranges from 4.72 s (mean wave period) to 8 s (90% wave period) [32]. The study highlights the seasonality of wave climate along the Mediterranean coast of Egypt, with deepwater significant wave heights ranging from 0.35 to 0.62 m during summer, increasing to 1.13 m in winter, and reaching up to 7 m during individual storms. Furthermore, the study revealed the long-term trends in the mean wave height, identifying negative and statistically significant trends in the Levantine Sea, particularly between Egypt and Turkey. These findings provide valuable insights into the evolving wave climate in the Mediterranean Sea, with implications for coastal areas and infrastructure. On the other hand, the potential impacts of SLR and storm surge events emphasize the need to consider these factors in coastal planning and management. The projected SLR scenarios under different Shared Socioeconomic Pathways (SSP) are also outlined, indicating substantial increases in sea level by 2100 and 2150, with implications for coastal flooding and infrastructure resilience.

It should be mentioned that climate indicators such as those developed by the Expert Team on Climate Change Detection (ETCCDI) could be utilized for a comprehensive evaluation of extreme weather and climate events. The team developed 27 core indices covering a wide range of temperature and precipitation extremes. These indices help understand changes in extreme rainfall, SLR, and wave events, all of which can affect port operations and infrastructure. Respecting precipitation, ETCCDI data suggest a double whammy: less rain overall but more frequent and ferocious downpours. These torrential storms can quickly turn into flash floods. For SLR, the respondents believed that rising sea levels in the Mediterranean Sea, outpacing the global average, pose a double threat: gnawing amplified flood risks in low-lying areas (https://etccdi.pacificclimate.org/indices_def.shtml) (accessed on 1 December 2023). Therefore, it is recommended that port managers and scholars consider such climate indices for a better understanding of potential scenarios and prepare for the future to enhance the port managers' plans.

In addition, the respondents were asked about the port's strategies to deal with the potential impact of climate change; they confirmed that the port authority takes contemporary actions to reinforce their port. The potential climatic issue is included in their port development/strategic plan. The port is provided with an efficient drainage system considering the potential increase in storm flows or heavy rains that can help the port operations without any delays and maintain its vital services in the face of climate stressors. The port infrastructure is currently being rehabilitated to accommodate the future generation of vessels, considering future scenarios of SLR. The Great Alexandria port authority aims to construct a new breakwater and increase the terminal's capacity, investments, and relevant facilities. The port layout and breakwater alignments are subjected to different environmental studies, considering future sea levels and projected waves for better and more effective operations respecting wave agitation and safety of the anchored water area. The port also rehabilitates and regularly maintains different facilities and services, considering quality and safety criteria. Water quality, waste handling, and management are regularly monitored. When considering any new plans/developments within a port system, designers and port planners consider climate change issues in their plans early to prepare for an uncertain future.

The fact that many climate change impacts on the Egyptian ports are not readily evident/visible diminishes the responses to some questionnaire questions, as they are less likely to feel the urgency to respond seriously based on unfamiliarity with relevant impacts. However, it is evident that the Egyptian port development plan (national project) includes an adaptation strategy to the climatic hazards and their future scenarios, as it partially appears in their response to relevant questions respecting implemented/proposed adaptation strategies.

There is an imperative to devise efficacious approaches enabling ports to navigate the challenges presented by climate change effectively. Achieving this demands a concerted effort from stakeholders to integrate global and local perspectives, bridging the gap between localized experiences and international/national decision-making frameworks. It is crucial to note the prevalent financial constraints confronting most ports, thereby complicating decisions surrounding the timing, methods, and extent of commitment to suitable strategies and capacity investments for adaptation.

In response to climate change, two primary policy approaches exist: mitigation and adaptation. Mitigation aims to address the fundamental causes by diminishing greenhouse gas emissions, while adaptation focuses on mitigating the risks associated with the consequences of climate change. Despite certain efforts within ports and the broader shipping industry to regulate or diminish carbon emissions, the adaptation of ports to climate change remains a relatively nascent concern in numerous jurisdictions. Effectual adaptation hinges on ports' prompt consideration and strategic planning regarding climate change issues and vulnerabilities before significant impacts manifest, along with the subsequent remediation costs. A pragmatic and economically viable solution involves initiating a comprehensive process, commencing with identifying pivotal vulnerabilities, integrating climate change considerations into long-term decision-making processes, and establishing measurable trigger points for prospective actions that can be systematically monitored over time.

To foster resilience, ports face three primary alternatives: fortifying storm defenses, raising infrastructure levels to offset anticipated sea level rises, or undertaking complete relocation. Each option presents considerable challenges. Implementing robust coastal defenses introduces environmental complications such as coastal erosion and habitat deterioration, demanding substantial financial investments. Elevated ports risk operational incapacitation if their intermodal connections lack protection. The elevation process necessitates substantial infill volumes and fails to address potential vulnerabilities in the transport network linking the port. Lastly, port relocation mandates identifying an alternative site with adequate depth and transportation connectivity, a scarce resource in most coastal regions. The relocation process may disrupt local economies and introduce new and noteworthy environmental consequences in the designated relocation areas [2,17,33].

The economic benefits of the Egyptian ports are spread across a wide range of sectors, including transportation, logistics, manufacturing, agriculture, and tourism. They are essential to the economic well-being of Egypt, are a key part of the country's infrastructure, and contribute significantly to the national economy. Also, they generate jobs and income for the local population, attract foreign investment, promote economic growth, improve Egypt's trade balance, reduce import costs, and help protect Egypt's national security. The Egyptian government is committed to investing in developing these ports to ensure their continued importance to the national economy. In recent years, the government has invested in expanding the Alexandria port by constructing new terminals. These investments are expected to boost the economic importance of these ports further.

The economic loss due to climate change's impacts on the Egyptian ports is difficult to estimate with certainty, as it depends on several factors, including the severity of climate change, the specific impacts on the ports, and the measures taken to adapt to climate change. Some studies have attempted to estimate the potential economic loss. For example, a study by the World Bank estimated that a 1-m rise in sea level could cause economic losses of up to 6% of Egypt's gross domestic product (GDP). This loss would be primarily due to the inundation of coastal areas, including the ports of Alexandria and Damietta. Another

study by the International Monetary Fund estimated that a 5-m rise in sea level could cause economic losses of up to 16% of Egypt's GDP. This loss would be even more severe, as it would not only inundate coastal areas but also damage infrastructure and disrupt transportation and trade.

Scholars have investigated different topics related to ports, such as ports' performance, logistics, resilience of ports' strategies, factors of smart ports, ports' sustainability, development, and safety management. Others explored energy efficiency in ports, with a focus on renewable and smart energy management [34]. Also, they provided valuable insights into the importance of energy efficiency, demand response management, and sustainable port operations in saving energy costs [35]. A questionnaire survey among port professionals and environmental specialists in Valencia showed that among the top 10 environmental priorities for ports, Climate Change comes in at 6th, while Carbon Footprint sits at 8th [27]. A survey of 70 maritime sector leaders in Ireland refers to a significant lack of understanding of climate change [7]. Other scholars prioritized environmental concerns in every aspect of port activity—operations, planning, and development—which emerged as a key driver for enhanced environmental performance and a sustainable future [29]. Others highlighted the importance of incorporating potential climatic hazards and proper adaptation in the planning and design of a new port, which was highly recommended [6]. Most port organizations acknowledge the threat of climate change and advocate for further adaptation measures [26]. On the other hand, skeptical of adaptation strategies, port leaders still call for increased action against climate change [25]. On the other hand, some scholars showed that while larger ports dominate the research landscape, a critical oversight exists: small fishing ports and marinas face a disproportionate threat from climate change [15].

Research suggests that port managers acknowledge the significance of climate change but have implemented fragmented and isolated adaptation strategies. This emphasizes the importance of focusing on physical infrastructure and engineering projects and transforming ports' management and planning practices [1]. It serves as a timely reminder to policymakers and managers that they must effectively improve decision-making processes to address future climate change challenges. Consequently, there is an urgent need for additional research to be conducted on this subject [1].

It is important to note that these are just estimates, and the actual economic loss could be higher or lower, depending on the specific circumstances. However, climate change is a significant threat to the Egyptian economy. The government of Egypt is aware of the risks posed by climate change, and it has taken some steps to adapt to these risks. For example, the government has invested in constructing seawalls and other coastal protection measures. However, more must be done to protect the Egyptian ports from the impacts of climate change.

The following are some of the measures that could be taken to reduce the economic loss due to climate change impacts on Egyptian ports: building seawalls and other coastal protection measures to prevent inundation; raising the elevation of port facilities to make them less vulnerable to flooding; improving drainage systems to reduce the risk of flooding; developing early warning systems to alert port authorities to potential flooding events; diversifying the economic base of the ports to reduce their reliance on trade; investment in research and development to develop new technologies to mitigate the impacts of climate change. By taking these measures, the government of Egypt can help reduce the economic loss due to the impacts of climate change on Egyptian ports.

Egyptian national strategy for port development (2030 Agenda) considers achieving relevant, sustainable development goals; generally, sustainable, resilient, and adaptive ports to climate change could contribute to achieving several goals and creating a more sustainable future for all, such as SDG 9: Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation; SDG 13: Take urgent action to combat climate change and its impacts (mitigate and adapt to potential impacts); by investing in adaptation measures, ports ensure that they continue to function as essential nodes in the global trading system; SDG 14: Conserve and sustainably use the oceans,

seas, and marine resources for sustainable development; sustainable port practices could protect the marine environment as they interact with it. In addition to these specific goals, adaptive ports can also contribute to some other SDGs, such as SDG 2: End hunger, achieve food security and improved nutrition, and promote sustainable agriculture that ensures food is transported efficiently and safely and that it is available to people all over the world; SDG 8: Promote sustained, inclusive, sustainable economic growth, full and productive employment and decent work: Ports are major employers and contribute to economic growth in many ways. They could provide multidisciplinary jobs and promote economic growth; SDG 11: Make cities and human settlements inclusive, safe, resilient, and sustainable: Ports are located in cities, and they significantly impact the urban environment. Therefore, sustainable port practices could make cities more livable and sustainable.

6. Conclusions

There are apparent efforts and great interest in developing Egyptian ports considering future demand and achieving economic development objectives respecting sustainable development goals, as presented in the presidential interest through the Conference of the Parties (COP 27).

Therefore, it is essential and urgent to address the vulnerability of Egyptian ports to climate change to ensure that they remain sustainable and resilient and continue to play their strategic economic role. This article is the first academic research that investigates the impacts of climate change on the Great Alexandria Port. The main objectives of this study include getting a broad understanding of the attitudes, future vision, and perspectives of the port managers and relevant stakeholders towards climate change issues and how it could impact their port; identifying their plans/strategies for alleviation of the potential threats and proper adaptation measures; and detecting the most common climatic factors (SLR, waves, storms, and precipitation) they consider in their scenarios. The questionnaire survey, interviews, and the implemented workshop with port managers, administrators, workers, and relevant port stakeholders were distributed through various sectors within both ports to accomplish these objectives.

The survey revealed that, while most respondents considered climatic hazards a potential future threat, they lacked a sense of urgency due to the lack of a present threat. Most of their responses reflect that attitude, notably when they confirmed that the port suffers from minor impacts based on some weather events. On the other hand, about 15 to 20% think climate change severely affects the port, while 25 to 30% identify that climate change does not affect the port. The results show that the port works well even in storm events; throughout the year, the port could temporarily close for a few days without any economic loss or required fines.

The port authority takes contemporary actions to reinforce their port. The potential climatic issue is included in their port development/strategic plan. The port has an efficient drainage system, considering the potential increase in storm flows or heavy rains. The port infrastructure is currently being rehabilitated to accommodate the future generation of vessels, considering future scenarios of SLR. The Great Alexandria port authority targets constructing a new breakwater, increasing the terminal's capacity, investments, and relevant facilities.

These research findings are expected to fill the gaps in regional studies focused on the Mediterranean Sea, particularly in Egypt, and the need to increase focus and attention from different stakeholders and researchers in working together. Scientists and port operators can develop practical solutions to ensure that ports remain sustainable and resilient to the effects of climate change and continue to operate safely and efficiently, considering their sustainable role in the global economy. Effective adaptation for ports is essential to achieving progress on many of the Sustainable Development Goals (SDGs). This includes building resilient infrastructure (Goal 9), combating climate change (Goal 13), and conserving and using marine resources sustainably (Goal 14). In addition, adaptive ports could also contribute to some other SDGs, such as SDG 2: End hunger, achieve food security

(ensure food is transported efficiently and safely); SDG 8: Promote sustained, inclusive, and sustainable economic growth, full and productive employment and decent work for all; SDG 11: Make cities and human settlements inclusive, safe, resilient and sustainable.

This paper highlights the importance of collaboration between different stakeholders, including academic and governmental institutions, in addressing climate change impacts on ports. This emphasis on stakeholder engagement is a prominent aspect of the study. In addition, the paper offers Egyptian experiences and insights into the development of adaptive strategies for ports to enhance their resilience to climate change-induced events. The study addresses the practical implications of climate change on port management, providing valuable insights for port managers, administrators, and relevant stakeholders. The findings have direct relevance to the operational and strategic planning of ports. These innovative and prominent points contribute to the advancement of knowledge in the field of sustainable port management and climate resilience, making the paper a valuable contribution to the academic and industry discourse.

Furthermore, it is recommended that effective response plans should include approaches for involving port authorities, industry associations, government agencies, and local communities (stakeholder engagement strategies) in the implementation of adaptation measures and actionable recommendations and practical steps that port authorities and stakeholders can take to address the identified challenges and improve climate resilience. Furthermore, long-term planning frameworks should be developed that build upon numerical modeling-based climatic factors and operational performance impacts to establish sustainable and adaptive strategies for port operations in the face of climate change. This could involve scenario planning, risk assessment, and the development of adaptive management plans. By incorporating these elements, the port managers could have an integrated framework that provides a more robust and comprehensive response to climatic hazards, offering practical guidance and theoretical grounding for addressing the challenges identified in the context of climate change impacts on port operations.

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