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Practical Steps for Mitigating Climate Change-Induced Risks: A Guideline for Enhancing the Resilience of Vulnerable Egyptian Coastal Regions

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ABSTRACT

Climate change poses escalating threats to coastal regions globally, with sea-level rise (SLR) and flooding disproportionately impacting low-lying areas like Alexandria, Egypt. Studies project that 74% of Alexandria's population could face coastal flooding by 2100, while 30-40% of its coastal districts already reside in high-risk flood zones. Despite Egypt's National Climate Change Strategy 2050, implementation gaps persist, leaving adaptation efforts fragmented and reactive. This paper addresses this critical gap by developing a Coastal Resilience Guideline (CRG) tailored to Alexandria, introducing a hybrid governance approach that integrates adaptation and mitigation across multiple sectors. Through a systematic review of a) climate change risks, b) adaptation and mitigation strategies, including global case studies from the Netherlands, Bangladesh, Japan, and New York City, and c) policy gaps. The study identifies key challenges that include weak coordination, minimal integration of NbS, and insufficient representation of informal communities. The proposed CRG consolidates green and grey infrastructure into an actionable roadmap, backed by a phased action plan (2025-2040) that prioritises flood-resilient building codes, wetland restoration, and digital early warning systems. The findings align with Egypt's Vision 2030 and Sustainable Development Goal 11, positioning the CRG as a scalable, equity-centred model for climate-resilient urban development. By synthesising global practices into a localised guideline, this paper contributes actionable insights for policymakers, urban planners, and architects. It underscores the urgency of bridging policy-practice gaps through adaptive governance, offering a replicable model for Mediterranean coastal cities facing similar risks.

Keywords: Climate Governance, Coastal Adaptation, Nature-Based Solutions, Urban Resiliency, Sea-level rise.

INTRODUCTION

Alexandria – a city that has survived millennia of change – is now facing an existential threat from the sea. As the impacts of Climate change intensify globally, coastal cities like Alexandria are on the frontlines of a rising tide. Sea-level rise (SLR), storm surges, and recurrent flooding are no longer distant possibilities but urgent and escalating realities **[28]**.

The Intergovernmental Panel on Climate Change (IPCC) warns that coastal communities face disproportionate risks, necessitating urgent adaptation strategies **[27]**. Meanwhile, increased greenhouse gas (GHG) emissions from fossil fuel combustion are driving global warming, intensifying temperature rise and shifting weather patterns **[33]**. Consequently, extreme weather incidents, accelerated sea-level rise (SLR), and flooding have become more frequent and severe **[26]**.

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Low-lying coastal regions, particularly in developing nations that lack the necessary tools or infrastructure to respond effectively, face devastating socio-economic repercussions from flooding, including extensive environmental and infrastructural damage, disrupted livelihoods, and mass displacement **[39]**.

Developing nations, especially those with limited adaptation capacities, bear the brunt of these impacts. In the Middle East and North Africa (MENA) region, coastal populations are projected to rise from 60 million in 2010 to over 100 million by 2023, placing increasing pressure on fragile coastal systems **[48]**. Furthermore, urbanisation, poor land-use planning, and a lack of sustainable development are compounding risks through land loss, saltwater intrusion, and ecosystem degradation **[4,39]**.

Egypt, with over 3,500 km of coastline, is particularly vulnerable. Though it contributes minimally to global emissions, the country's Nile Delta and Mediterranean cities face some of the most severe climate threats [**27,45]**. Alexandria- Egypt's second-largest city, a historical and economic hub- faces a heightened risk of inundation and land loss due to SLR, where a 0.5m SLR could displace 1.5 million residents, while a 1 m rise may engulf 12-15% of agricultural land, displacing 6.7 million people **[12,18]**.

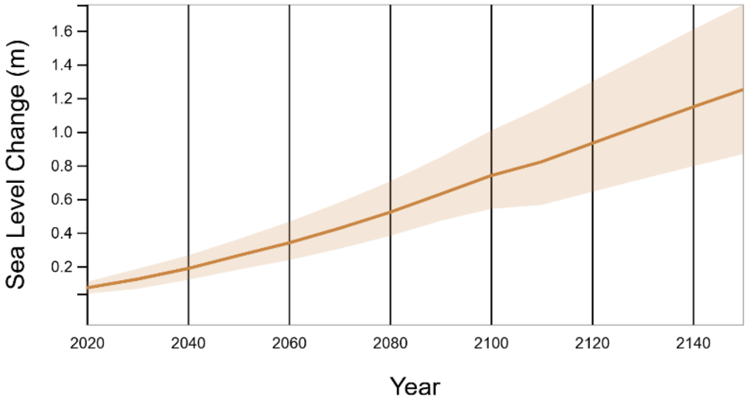

Figure 1. Estimated Total Sea Level Change (m) for Alexandria [33].

The projected population at risk in Alexandria will significantly increase by 2100, intensifying exposure to coastal flooding and degradation. Figure 1 showcases the projected SLR under the SSP3-7.0 scenario – a middle pathway reflecting Egypt's current urbanisation and emissions trends – Alexandria faces a 0.74 m SLR by 2100, which would directly submerge critical infrastructure in low-lying districts like Al-Max and El Dekhela **[12]**. This projection exceeds the Mediterranean average of 0.5 m, reflecting compounded risks from land subsidence and rapid coastal urbanisation **[24]**.

Despite longstanding recognition of Mediterranean coastal vulnerabilities dating back to the 20th century **[28,34],** adaptation efforts in Egypt remain fragmented. Critical gaps include inadequate flood risk assessments, weak early warning systems, insufficient adaptation measures, and poor land use planning **[2]**. While Egypt's National Climate Change Strategy 2050 and National Adaptation Plan (2011) outline resilience goals, implementation is hindered by financing shortages and institutional misalignment **[20,32]**.

To bridge these gaps, this paper proposes a **Coastal Resilience Guideline** (CRG) for Alexandria. The CRG introduces a hybrid approach that combines engineered infrastructure with nature-based solutions (NbS), while embedding inclusive, community-driven governance. It is designed to align with Alexandria's unique socio-economic and ecological contexts and offers a structured roadmap to advance adaptive urban planning and coastal resiliency.

RESEARCH AIM AND OBJECTIVES

This paper aims to develop a comprehensive *Coastal Resilience Guideline (CRG)* designed to mitigate the impacts of climate change-induced coastal flooding and to bolster long-term resilience in Egypt's vulnerable coastal areas,

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specifically Alexandria. Recognising the increasing threat posed by climate change, the CRG integrates a holistic approach that combines adaptation measures, mitigation strategies, and resilient design retrofits altered to Alexandria's socio-economic and environmental situation. The paper achieves this aim by undertaking a multi-faceted approach through realising these objectives:

1. Conducting a thorough analysis of the climate change risks, particularly sea level rise (SLR) and coastal flooding, affecting Egypt's coastal regions, with a focus on Alexandria,
2. Evaluating the effectiveness of existing adaptation and mitigation strategies and identifying their relevance and applicability to Alexandria,
3. Assessing the socio-economic feasibility of proposed guideline parameters by synthesising evidence from existing case studies and cost-benefit analyses in comparable coastal regions,
4. Proposing practical guidelines for mitigating coastal flooding through nature-based solutions and man-made engineered interventions, prioritising cost-effective, scalable, and socially equitable adaptation measures,
5. Providing recommendations for strengthening institutional coordination through community-driven decision-making and improving policy enforcement mechanisms to align with socio-economic priorities.

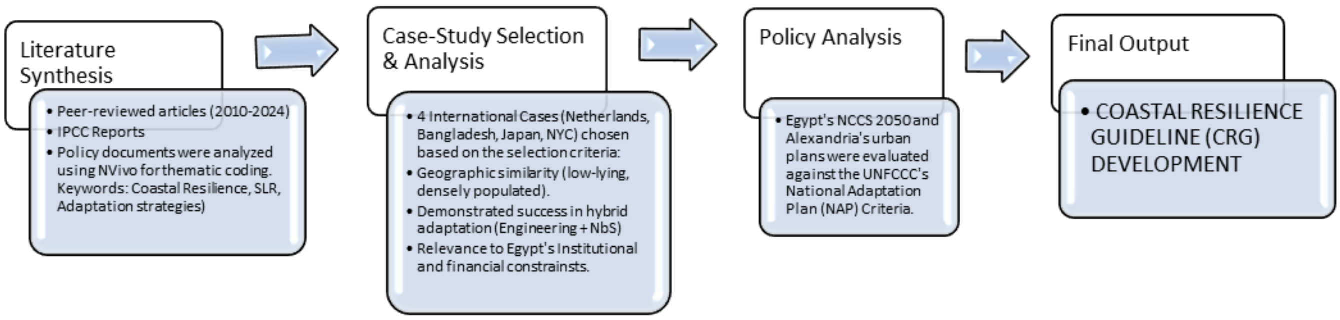

Figure 2. Research Method Workflow.

RESEARCH METHODS

This study employs a qualitative, literature-based methodology aimed at synthesising existing research, pinpointing adaptation gaps, and developing practical, context-sensitive guidelines for enhancing coastal resilience in Alexandria, Egypt. The method relies on an in-depth review of academic literature, global case studies, and policy frameworks to formulate the proposed CRG. The methodology is summarised in Figure 2 and is composed of four key components:

a. Literature Synthesis: A comprehensive review of scholarly articles, technical reports, and literature was conducted to examine three main thematic pillars:

a) Climate Change Risks – focusing on SLR, coastal flooding, and related vulnerabilities in the Mediterranean region.
b) Adaptation and Mitigation Practices – assessing structural, nature-based, and hybrid strategies implemented globally and regionally.
c) Policy and Governance Strategies – analysing national frameworks such as Egypt's National Climate Change Strategy (NCCS) 2050, National Adaptation Plan (2011), and Nationally Determined Contributions (NDCs).

This synthesis informed the baseline for understanding the trajectory of hazards, current strategies, and knowledge gaps within Egypt's coastal adaptation landscape.

b. Case Study Analysis: International case studies from deltaic or low-lying coastal cities such as the Netherlands, Bangladesh, New York, and Japan – were selected based on their geomorphological similarity to Alexandria in terms of vulnerability, subsidence-prone coasts, socio-economic constraints that include informal urban settlements or high population densities, and the implementation of hybrid adaptation models that combine engineered and nature-based solutions. As a result, the lessons learned from these contexts were used to extract

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applicable models for risk mitigation and urban resilience planning for Alexandria. Additionally, socio-economic feasibility was assessed through a qualitative synthesis of cost-benefit insights derived from these case studies, focusing on interventions that demonstrated affordability, scalability, and local acceptance. This indirect economic appraisal offers evidence-based justification for prioritising certain strategies within the CRG for Alexandria, particularly in the absence of primary financial modelling.

c. **Multi-Level Policy Review:** Policy analysis was conducted at both the national and subnational levels to evaluate the depth and coherence of adaptation planning. In addition to national strategies, municipal-level regulations and climate resilience initiatives in Alexandria were examined, where available, to identify enforcement challenges, institutional coordination mechanisms, and develop an understanding of the gaps between planning and implementation.

d. **Guideline Development:** These findings from literature, case study analysis, and policy review were triangulated to develop the Coastal Resilience Guideline (CRG), which prioritises cost-effectiveness and scalable solutions, hybrid approaches, community-driven governance enhancements, and practical steps for implementation custom to Alexandria's climate risk profile. Finally, stakeholder perspectives were inferred from documented reports, workshop proceedings, and consultation records embedded in policy and project evaluations.

While this study draws on secondary data sources, including policy documents, workshop records, and project evaluations, it does not include primary stakeholder interviews or surveys. As such, stakeholder perspectives were inferred rather than directly gathered. This constitutes a limitation, particularly in understanding on-the-ground implementation dynamics and local perceptions of resilience priorities. Future research should incorporate fieldwork through participatory methods, such as semi-structured interviews, community workshops, and Delphi techniques, to validate the CRG and enhance its responsiveness to stakeholder needs.

LITERATURE REVIEW

A systematic review of the literature was conducted based on the three main thematic pillars, i.e. climate change risks, with a focus on SLR and coastal flooding, Adaptation and Mitigation practices, and existing Policies and governance strategies. This structure enables a critical assessment of Alexandria's vulnerability within broader global and regional contexts, while identifying implementation gaps and informing the development of the Coastal Resilience Guideline (CRG).

Climate Change Risks

Global Trends in Sea-Level Rise and Coastal Flooding

Sea-level rise (SLR) is widely classified as a 'slow onset" climate hazard, yet its long-term impacts on low-lying coastal regions are profound and escalating. As such, enhancing the adaptive capacity of these vulnerable areas exposed to such risks has emerged in the recent decade as a global climate priority **[16,40]**. Recent satellite data reinforce this urgency, confirming that global sea levels are rising at an accelerating pace. Whereas, the Global Man Sea Level (GMSL) has increased from an average of 1.2 $\pm$ 0.2 mm/year (1901-1990) to 3.4 $\pm$ 0.4 mm/year in the satellite era (1993-2022) **[33]**, reaching an alarming 4.4 mm/year during the past decade (2013-2022). This surge is largely driven by the thermal expansion of ocean waters and the melting of

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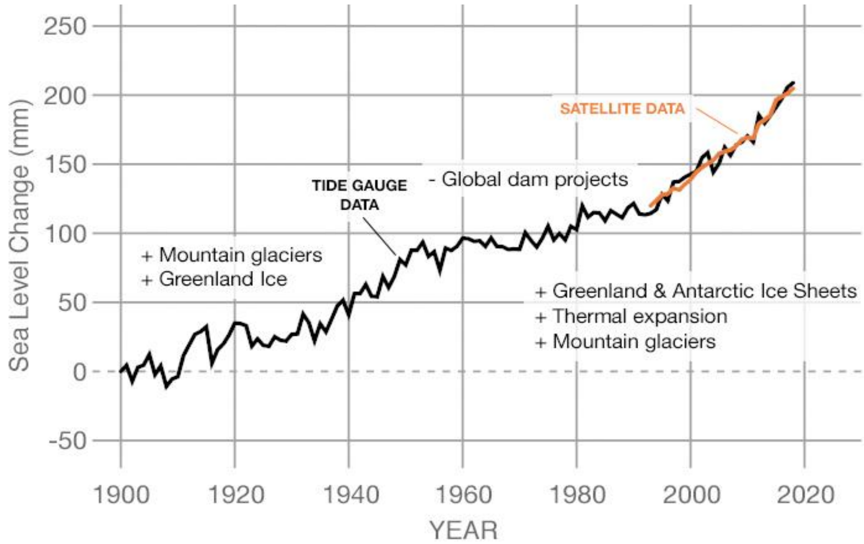

Figure 3. Sea level change in mm via satellite data [16].

Projections from the IPCC's Special Report on the Ocean and Cryosphere estimate that sea levels may rise between 0.24 and 0.32 m by 2050, depending on emission pathways, and up to 0.84 m by 2100 under high-emission scenarios **[23]**. Long-term projections for 2300 indicate a potential rise of 5 meters, underscoring the irreversible nature of SLR if current trends continue. The implications of SLR are multifaceted. Beyond permanent coastal inundation, SLR contributes to accelerated coastal erosion, weakening built infrastructure, saltwater intrusion, compromising freshwater aquifers and agriculture, increased frequency and severity of storm surges and extreme precipitation, widespread displacement of populations and economic disruption, marine ecosystem degradation and biodiversity loss **[46,48]**. Figure 4 illustrates the areas globally projected to be prone to flooding under a 2-meter SLR scenario, revealing the vast exposure of low-lying cities across continents, including significant portions of Egypt's Mediterranean coast and Delta region.

Figure 4. Areas Flooded by a 2-meter SLR [8].

To guide risk planning, the US Interagency Sea Level Rise Task Force developed five future SLR scenarios incorporating both global averages and regional variability. These scenarios—adapted from [41,33,24]—range from a low-emissions outcome of 0.3 m to a worst-case 2.0 m rise by 2100. Each scenario is associated with distinct planning thresholds and risk levels (See Table 1).

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Table 1: Projected Sea-Level Rise Scenarios for Alexandria under varying emissions pathways **[41,33,24]**

Scenario	Projected SLR (Relative to the 2000 baseline)	IPCC Emissions Scenario Basis	Risk Level & Planning Implications
Low	0.3 m	Lowest emissions scenario	Minimal: Basic adaptation and monitoring
Intermediate-Low	0.5 m	Moderate emissions scenario	Low-Moderate: Enhanced coastal defences
Intermediate	1.0 m	Intermediate emissions and warming	Moderate: Significant infrastructure adaptation
Intermediate-High	1.5 m	High emissions scenario	High: Extensive coastal planning & retrofitting
High	2.0 m	Worst case (extremely high emissions)	Severe: Comprehensive risk management required

The IPCC confirms that each additional 1°C of global warming increases the intensity of extreme precipitation events by approximately 7%, compounding flood risks in coastal areas **[24]**. Complementing this, another study estimates that by 2100, coastal flooding could place up to 20% of global GDP at risk, underscoring not only the humanitarian stakes but also the economic imperative for decisive action **[29]**. As such, the implementation of adaptation and mitigation strategies is no longer optional. Strategic and initiative-taking measures are essential to safeguard urban populations, infrastructure, and coastal ecosystems from irreversible damage.

Regional Risks in the Mediterranean and MENA Context

The Mediterranean region is a climate change hotspot, with higher-than-average warming, accelerated SLR, and heightened risk of coastal flooding **[27]**. Coastal cities across the Middle East and North Africa (MENA) region are particularly vulnerable due to dense urban development, subsidence-prone deltas, limited adaptive capacity, and ageing infrastructure. Projections indicate that coastal populations in the MENA region will rise from 60 million in 2010 to 100 million by 2030 **[49]**, amplifying the risk to human settlements and economic assets. SLR further exacerbates salinity intrusion, reduces agricultural productivity, and causes irreversible land loss, especially in delta regions. Furthermore, the MENA region's adaptive challenge is constrained by limited climate financing, fragmented governance structures, and inadequate early warning systems **[46]**. Regional studies call for urgent multi-level planning and localised risk assessments to inform coastal urban development policies.

Alexandria: A Coastal City at Risk

Alexandria, Egypt's second-largest city and a key economic and cultural centre, lies at the intersection of multiple compounding risks: low elevation, rapid coastal urbanisation, outdated infrastructure, and sea encroachment. A 1-meter rise in sea level could displace 1.5 million people and result in over $35 billion in economic losses, impacting housing, tourism, trade, and critical port operations **[49]**.

Studies predict that by 2100, up to 74% of Alexandria's population could face direct inundation **[5]**. Earlier assessments—such as **[12]**—estimated lower exposure percentages under more conservative assumptions. These discrepancies reflect the evolution of modelling tools, demographic changes, and varying emissions pathways. To account for such uncertainty, the proposed Coastal Resilience Guideline (CRG) adopts an *adaptive management approach*, prioritising flexible, no-regret strategies that remain effective across multiple future scenarios. The localised consequences of SLR in Alexandria are already evident based on saltwater intrusion, which is decreasing freshwater quality and soil productivity, shoreline erosion that threatens infrastructure and public spaces, and urban flooding that is occurring with increasing frequency due to outdated drainage systems and land subsidence **[2,10]**. Informal settlements in coastal areas face disproportionate risks due to a lack of formal land rights, evacuation plans, or resilient construction. These complex risks highlight the urgency of moving from short-term engineering fixes to

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comprehensive, multi-scalar resilience planning tailored to Alexandria's dynamic coastal landscape **[37]**. Figure 5 illustrates the extent of coastal flooding anticipated in Alexandria, highlighting the area most likely to become submerged and the proportion of the urban population at risk.

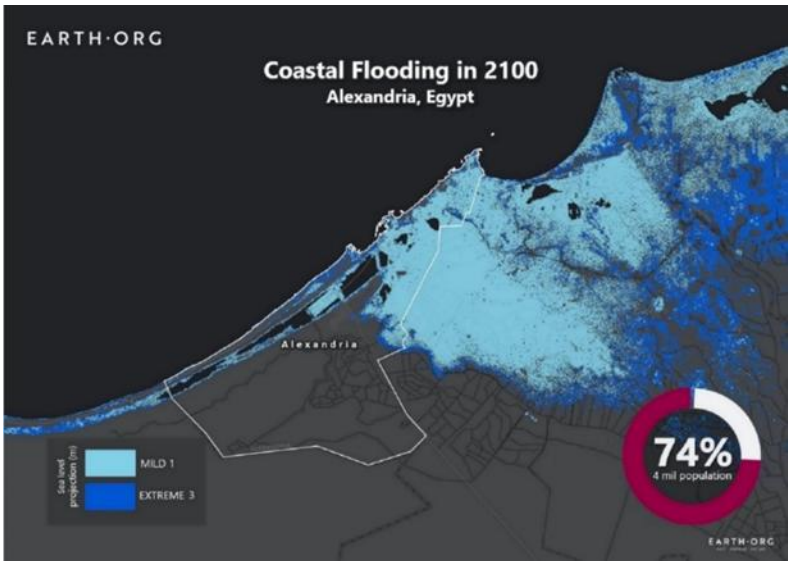

Figure 5. Map illustrating the projected inundation in Alexandria by the year 2100 due to SLR [12].

Adaptation and Mitigation Practices

Typologies of Adaptation and Mitigation Strategies

Adaptation and mitigation form the dual pillars of climate-responsive urban development. While adaptation focuses on reducing vulnerability to current and anticipated climate risks, mitigation addresses the underlying drivers of climate change, primarily greenhouse gas (GHG) emissions. In the context of high-risk coastal cities such as Alexandria, an integrated approach that combines both domains is essential to building long-term resilience. This section synthesises the primary typologies of adaptation and mitigation strategies relevant to coastal urban contexts, drawing on global literature and regionally transferable models.

Adaptation strategies are commonly categorised into four interrelated domains. The first is *engineered infrastructure*, which involves physical interventions to protect cities from SLR, flooding, and storm surges. These include seawalls, levees, elevated roads, drainage upgrades, and other structural defences that aim to shield urban assets from immediate hydrological threats **[11,31,34]**. While often effective in the short term, such grey infrastructure solutions are costly, rigid, and increasingly challenged by the intensifying nature of climate hazards, especially when not maintained or paired with more flexible, nature-inclusive systems **[35]**.

The second domain is ***nature-based solutions (NbS)***, which have gained significant traction in recent years for their dual capacity to mitigate risk and restore ecosystems. These include wetland restoration, mangrove planting, beach nourishment, and green belts that serve as ecological buffers against coastal hazards while enhancing biodiversity and water quality **[22,14,15]**. NbS are particularly well-suited to Mediterranean contexts like Alexandria, where shoreline degradation and saltwater intrusion are escalating due to urban encroachment and land subsidence. Moreover, they are often more cost-effective and socially accepted than hard infrastructure, especially when co-designed with local communities **[46]**.

Complementing these physical interventions are *institutional and policy measures*, which provide the legal, regulatory, and planning frameworks necessary to mainstream adaptation into urban governance. These include the enforcement of resilient building codes, integration of climate risk assessments into land-use plans, coastal zoning regulations, and the establishment of cross-sector coordination bodies **[1,14]**. However, in many Global South

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contexts—including Egypt—such measures remain underdeveloped or poorly enforced, limiting their transformative potential **[20,32]**.

A fourth and equally critical domain is *community-based adaptation (CBA)*. This approach recognises the importance of local knowledge and grassroots participation in enhancing resilience, particularly in informal settlements and marginalised coastal areas where institutional reach is limited. CBA includes participatory planning, local early warning systems, community-led ecosystem restoration, and public awareness campaigns that foster risk literacy and collective preparedness **[6,27]**. These strategies are increasingly supported by international adaptation frameworks, such as the Sendai Framework for Disaster Risk Reduction and the IPCC's Sixth Assessment Report, which emphasise equity and inclusion in climate governance **[42]**.

Mitigation strategies, while often addressed through national-level climate action plans, are deeply relevant at the urban scale, especially in coastal cities where emissions from buildings, transport, and industry are concentrated. Key mitigation pathways include *energy efficiency retrofitting* for buildings through passive cooling, insulation, and natural ventilation **[9]**; *renewable energy deployment*, particularly rooftop solar and small-scale coastal wind; and *sustainable mobility infrastructure*, including public transport electrification and bicycle networks **[7,47]**. Additional measures include the use of *low-carbon construction materials*, such as recycled aggregates or geopolymer concrete, and the promotion of *urban carbon sinks*—green roofs, tree planting, and preserved wetlands—that absorb carbon while improving microclimates and reducing flood runoff **[42]**.

When implemented in parallel, adaptation and mitigation strategies offer synergistic benefits that extend beyond climate protection. They contribute to health, energy access, biodiversity conservation, and poverty alleviation—especially when tailored to local needs and supported by coherent policy frameworks. The integration of these typologies into hybrid, context-specific interventions forms the foundation of the next section, which explores global case studies with direct relevance to Alexandria's coastal resilience challenges.

Table 2: Adaptation and Mitigation Typology Matrix.

Typology	**Description**	**Domain**
Engineered Infrastructure	Structural defences such as seawalls, levees, elevated roads, and drainage systems.	Adaptation
Nature-based Solutions (NbS)	Wetland restoration, green belts, mangrove planting, and ecological buffers.	Adaptation
Institutional and Policy Measures	Building codes, zoning regulations, land-use planning, and cross-sector governance.	Adaptation
Community-Based Adaptation	Early warning systems, public awareness, community engagement, and local risk mapping.	Adaptation
Energy Efficiency in Buildings	Passive cooling, retrofitting, and insulation to reduce urban energy use.	Mitigation
Renewable Energy Deployment	Solar PV, coastal wind turbines, and decentralised clean energy systems.	Mitigation
Sustainable Mobility	Public transport electrification, cycling infrastructure, and non-motorised mobility.	Mitigation
Urban Carbon Sinks & Low-Carbon Materials	Tree planting, green roofs, recycled materials, and climate-smart concrete.	Mitigation

Global Best Practice Case Studies and their Selection Criteria

The selected international case studies—Netherlands, Bangladesh, Japan, and New York City—were chosen based on five core criteria: (1) demonstrated success in implementing hybrid adaptation models that combine nature-based solutions with engineered infrastructure; (2) relevance to Alexandria's geomorphological characteristics, such as low

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elevation and subsidence-prone coastlines; (3) socio-economic constraints, including informal settlements and high population densities; (4) innovative governance frameworks that enable cross-sector coordination; and (5) scalability and replicability in developing country contexts. For instance, the Netherlands exemplifies long-term planning and integrated floodplain management; Bangladesh highlights the power of community-based NbS and cyclone preparedness; Japan offers high-tech, multi-layered risk defence and early warning systems; and New York's Rebuild by Design demonstrates participatory resilience planning in dense urban settings. These case studies provide diverse but transferable insights into effective coastal resilience planning, offering a valuable reference point for tailoring Alexandria's CRG.

The Netherlands' "Room for the River" program exemplifies a proactive flood-risk management approach that balances engineered defences with ecological restoration. Faced with rising sea levels and increased river discharge, Dutch authorities implemented a series of interventions—relocating dikes, lowering floodplains, and expanding temporary retention zones—to give water more space rather than resisting it entirely **[21,22]**. This initiative reduced flood risk by an estimated 40% and improved biodiversity, spatial quality, and public access to green areas. This model holds strong relevance for the Nile Delta, where heavy dependence on rigid infrastructure has limited urban adaptability. Alexandria could benefit from adopting similar floodplain zoning, restoring natural drainage basins (e.g., Lake Mariout's wetlands), and integrating multifunctional green spaces within urban expansion zones **[13]**.

Japan combines extensive engineered infrastructure with community readiness and digital technologies to reduce coastal risk. Its adaptation approach includes seawalls, elevated roads, hazard zoning, and high-tech early warning systems. Notably, disaster drills and evacuation compliance rates reach over 95%, indicating strong public engagement **[36,50]**. Japan's emphasis on public awareness, hazard mapping, and integrated evacuation systems could be emulated in Alexandria. Informal settlements along the coastline lack systematic outreach and are not integrated into official emergency protocols. Pilot community warning systems, combined with basic mobile alerts and signage, could fill this critical preparedness gap.

In Bangladesh, recurrent cyclones and sea-level rise pose significant threats to the Sundarbans Delta. The national adaptation strategy has emphasised community-based mangrove restoration, reinforced cyclone shelters, and inclusive evacuation protocols. Mangrove buffers were found to reduce wave energy by up to 66%, and cyclone shelters built on elevated plinths have drastically lowered fatalities during storm events **[15].** Alexandria's lagoon systems and degraded coastal margins could serve as sites for pilot NbS programs, such as salt-tolerant vegetation belts or community-managed green buffers. Empowering local stakeholders to participate in afforestation and climate literacy could strengthen resilience, especially in informal coastal communities **[14]**.

After the devastation of Hurricane Sandy in 2012, **New York launched the Rebuild by Design initiative**—a collaborative process that brought together architects, engineers, and local communities to co-create flood-resilient infrastructure. Projects include multipurpose levees that function as parks, permeable green streets, and elevated walkways. These interventions blended hard infrastructure with public amenities, gaining community support and long-term sustainability **[3,38]**. Alexandria could replicate this participatory approach by integrating community co-design in future adaptation projects. With over 40 informal communities along its coast, involving residents in designing dual-use spaces (e.g., floodwalls that double as promenades) could enhance both functionality and social acceptance **[13]**.

Table 3: Comparative Analysis of the key insights from Global Case Studies and the lessons learned that are relevant to Alexandria's context.

Case Study	Key Insight	Relevance to Alexandria
Netherlands	Hybrid floodplain management	Adaptable and supports green zoning.
Bangladesh	Community-led mangrove afforestation	Possible in coastal lagoons; fosters local participation.
Japan	Multi-layered defence and early warning systems	High-tech systems can be adapted using low-cost technologies.

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NYC	Participatory design of dual-use flood infrastructure	Aligns with its informal coastal settlements and public space needs.

These international models offer transferable lessons in balancing hard infrastructure with nature-inclusive and community-responsive interventions. They combine technical, ecological, and participatory approaches. Their comparative review informs the upcoming **Coastal Resilience Guideline**, ensuring it reflects tested, scalable strategies tailored to Alexandria's coastal vulnerability.

Alexandria's Local Adaptation and Mitigation Context

Historically, Alexandria's adaptation strategy has centred on engineered infrastructure, particularly seawalls, breakwaters, and wave deflectors aimed at shielding critical assets such as the Corniche, harbour, and adjacent residential zones **[11,17]**. While these interventions provide short-term protection, their design is often outdated, their maintenance inconsistent, and their ability to manage compound climate events increasingly uncertain **[10,35]**. Drainage and stormwater systems are also insufficient to control intensified rainfall, resulting in frequent urban flooding during extreme weather events **[30]**.

More recently, hybrid approaches have emerged. The UNDP-supported "Enhancing Climate Change Adaptation in Egypt's North Coast" project, for instance, has incorporated dune stabilisation, vegetated coastal buffers, and reinforced dikes along vulnerable segments of the northern coastline **[42]**. While promising, these initiatives remain in the pilot phase and have not yet been scaled or institutionalised within Alexandria's broader urban planning framework. *Nature-based solutions (NbS)* such as wetland restoration or green infrastructure are largely absent from municipal development plans, despite evidence from similar coastal contexts suggesting their high cost-effectiveness and ecological co-benefits **[14]**.

On a building scale, climate-resilient architecture and retrofitting practices remain underutilised. Current regulations do not mandate flood-proofing, elevation, or passive design elements in new constructions, and Alexandria's building stock lacks structural resilience to coastal hazards **[13,19]**. Initiatives to revise urban codes in line with international resilience standards have been proposed but have yet to be enforced or adopted on a large scale.

On the community level, efforts to enhance preparedness and risk literacy remain fragmented. The Alexandria Flood Management Project (AFMA) introduced early pilot warning systems and trained local volunteers in high-risk districts, achieving moderate success during seasonal storm events **[6,10]**. However, these efforts are neither integrated into city-wide systems nor linked with digital alert infrastructure. Moreover, informal settlements—many of which are located along the coast—are rarely included in emergency planning or risk mapping, leaving a significant portion of Alexandria's population underserved.

Mitigation practices have also received limited attention in Alexandria's local governance agenda. Opportunities for **energy** efficiency retrofitting, renewable energy integration, and low-carbon construction remain largely untapped. Few public buildings have adopted solar PV systems, and incentives for private-sector emissions reductions are scarce. Transport-related emissions remain high due to car dependency, poor public transport connectivity, and insufficient pedestrian infrastructure **[7,43,44]**. This lack of progress limits the co-benefits of mitigation, such as improved air quality, reduced urban heat, and long-term cost savings. Collectively, these challenges highlight the reactive, infrastructure-heavy, and institutionally fragmented nature of Alexandria's current climate response. While progress has been made, particularly through international partnerships and donor-supported projects, scaling and sustaining these efforts will require deeper governance reform, clearer regulatory mandates, and enhanced stakeholder inclusion. As the next section illustrates, closing these gaps demands a strategic guideline that synthesises best practices from global models and adapts them to the local urban, ecological, and socio-political context of Alexandria.

Policy Landscape and Institutional Gaps

Despite growing political momentum in Egypt's climate agenda, significant policy and implementation gaps persist at the local level, particularly in Alexandria, where coastal risks are among the highest nationally. While Egypt's

National Climate Change Strategy 2050 (NCCS 2050) and Enhanced Nationally Determined Contributions (2022) outline national priorities for resilience, these strategies remain only partially executed due to weak institutional coordination, underdeveloped local enforcement, and limited community engagement **[1,19,32]**.

A comparative review of the best global practices reveals Alexandria's uneven progress across five critical adaptation pillars:

- **Institutional Measures:** International models such as the Netherlands' ICZM mandate and Japan's cross-agency governance show the effectiveness of integrated, legally binding frameworks **[27,43,44]**. In contrast, Alexandria faces fragmented mandates, delayed NAP implementation, and a lack of clear coordination across municipal and national entities **[20,35]**.
- **Engineering Interventions:** While Alexandria has invested in seawalls and drainage upgrades, these measures remain reactive and outdated. Redundant systems and climate-informed infrastructure retrofitting are rare, unlike in Japan or the Netherlands, where resilient public infrastructure is mainstreamed **[10,15,34]**.
- **Nature-based Solutions (NbS):** Global leaders like Bangladesh and the Netherlands have integrated NbS at scale, but Alexandria's initiatives remain limited to pilot projects with minimal funding and technical support **[14,42]**.
- **Community-Level Adaptation:** International cases illustrate the success of early warning systems and participatory planning in high-risk areas. However, Alexandria lacks inclusive engagement mechanisms, with informal settlements excluded from planning processes **[6,30].**
- **Monitoring and Evaluation:** While Egypt has initiated GIS-based tools, Alexandria still lacks robust, localised tracking systems. Unlike countries with transparent performance indicators and adaptive feedback loops, Alexandria's adaptation efforts are not assessed regularly or updated based on evolving risks **[1,25]**.

Despite outlining broad adaptation goals in the NCCS 2050 and its NDC, Egypt faces substantial financing gaps that hinder implementation. Egypt's climate action plan requires approximately $246 billion in investment by 2030, yet only 12% of this funding has been secured to date. This shortfall significantly limits the deployment of large-scale adaptation infrastructure, green urban initiatives, and institutional capacity building. Moreover, international climate finance inflows to Egypt remain fragmented, and mechanisms like green bonds and adaptation trust funds are still underutilised at the municipal level. Bridging this gap will require enhanced private sector engagement, streamlined access to international climate funds (e.g., GCF, Adaptation Fund), and decentralised financing instruments aligned with local adaptation priorities in cities like Alexandria **[48,49]**.

A radar-based comparison shown in Figure 6 illustrates these disparities, showing moderate performance in engineering (60%) but significant lags in institutional coordination, NBS integration, and community participation (each at 40%). Such findings underscore the need for a holistic and decentralised coastal resilience model. Alexandria must move beyond fragmented, top-down measures and embrace hybrid approaches that integrate nature-based infrastructure, participatory governance, and targeted policy reform—aligned with both global benchmarks and local realities **[15,17].**

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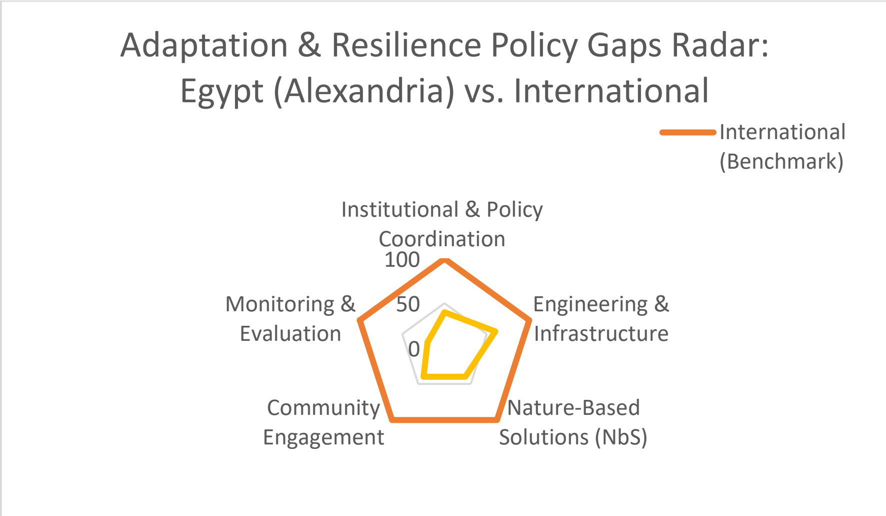

Figure 6. Alexandria's performance across key coastal adaptation domains compared to global benchmarks.

Literature Output and Summary

To assess the effectiveness and scalability of current adaptation efforts in Alexandria, Table 4 presents a targeted evaluation of key resilience measures across eight domains. It highlights the existing implementation status, identifies necessary improvements, and assesses each strategy's feasibility and cost-effectiveness. This diagnostic overview serves as a foundation for refining Alexandria's climate response by prioritising interventions with high impact potential and replicability, while also aligning with global best practices and local socio-environmental conditions. In summary, while Alexandria has taken important steps toward climate adaptation and mitigation, efforts remain fragmented and incomplete. Current interventions lean heavily on engineered infrastructure, while nature-based solutions, resilient architectural design, and inclusive, community-driven approaches are underutilised. Institutional coordination and monitoring frameworks require reinforcement, and mitigation practices—particularly in energy, mobility, and construction—lack consistent implementation.

Table 4: The Existing Adaptation Measures in Alexandria and their recommended improvement, feasibility, and cost-effectiveness.

Adaptation Measure	Existing Status	Recommended Improvement	Feasibility	Cost	Source
Seawalls & Coastal Defences	Partially implemented, limited maintenance	Regular upgrades and extensions to neglected areas	High	Medium	[11,17]
Drainage & Stormwater Systems	Insufficient for extreme rainfall	Comprehensive upgrade to climate-smart systems	Medium-High	High	[10,30]
Flood-Proof Infrastructure & Buildings	Minimal retrofitting	Integrate mandatory resilient retrofitting in building codes	High	High	[13,35]
Early Warning & Evacuation Systems	Limited pilot projects	Expand city-wide systems, regular training and community outreach	High	High	[10,6]
Nature-based Solution (NbS)	Small-scale and pilot projects only	Scale wetlands, green belts, and beach nourishment in vulnerable areas	Medium	High	[14,42]

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Adaptation Measure	Existing Status	Recommended Improvement	Feasibility	Cost	Source
Community Awareness & Engagement	Minimal and project-specific	Institutionalising campaigns, participatory planning, and support in informal settlements	High	High	[30,20]

Table 1. (Cont'd) The Existing Adaptation Measures in Alexandria and their recommended improvement, feasibility, and cost-effectiveness.

Adaptation Measure	Existing Status	Recommended Improvement	Feasibility	Cost	Source
Institutional Coordination	Fragmented institutional responsibilities	Establish centralised coordination; clarify and enforce institutional roles.	Medium-High	High	[1,32]
Monitoring & Evaluation Framework	Early-stage and irregular	Establish city-specific indicators and regular public reporting mechanisms.	Medium-High	Medium	[32,35]

PROPOSED COASTAL RESILIENCE GUIDELINES (CRG) FOR ALEXANDRIA, EGYPT

The proposed guideline for mitigating climate change-induced coastal flooding in Alexandria presents an integrative framework structured around **five interconnected pillars**: policy and institutional reform, infrastructure and building upgrades, nature-based solutions (NBS), community preparedness, and mitigation practices. Anchored in **Integrated Coastal Adaptation Planning and Coordination**, the guideline emphasises cross-sectoral alignment, climate-smart urban governance, and localised implementation.

Strategic Pillars of the Guideline

The proposed guideline presents an integrated, five-pillar framework for enhancing Alexandria's climate resilience. These pillars—policy and institutional reform, infrastructure upgrades, nature-based solutions (NbS), community preparedness, and emissions mitigation—are anchored in coordinated coastal adaptation planning. The CRG promotes cross-sectoral collaboration, climate-smart governance, and context-sensitive implementation across all tiers of urban management. Together, these interconnected pillars form a comprehensive roadmap toward adaptive, inclusive, and low-carbon coastal urban development.

These components are integrated through a dynamic **Monitoring, Evaluation, and Adaptive Management Loop**, ensuring that strategies evolve in response to updated flood risk models, community feedback, and technological advancement. This resilience guideline provides a more holistic and operational roadmap for Alexandria's climate response. Compared to the fragmented and reactive approaches currently implemented, the expanded framework offers:

- Integrated risk governance by aligning policy, urban planning, and resilience financing
- Scalable climate interventions through hybrid infrastructure and nature-based buffers
- Cross-cutting community empowerment, anchoring adaptation in local engagement and equity
- Targeted emissions mitigation, aligning with Egypt's NDC and Vision 2030 climate goals

Figure 7 summarises the core structure of the proposed CRG, highlighting strategic entry points for intervention and coordination across Alexandria's governance, infrastructure, and community systems.

The cross-pillar inclusion of Community Preparedness reinforces the principle that resilience must be fundamental, particularly in socially vulnerable areas. Similarly, the addition of a dedicated Mitigation Pillar ensures long-term sustainability by addressing urban emissions and energy vulnerabilities alongside adaptation. Challenges remain, especially in mobilising finance, harmonising institutional mandates, and building technical capacity. However, this structured and phased approach—drawing from global best practices—makes Alexandria better equipped to lead climate-resilient urban transformation in Egypt's Mediterranean corridor.

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To operationalise the Coastal Resilience Guideline, a phased action plan (2025–2040) is proposed, prioritising regulatory reform, ecosystem restoration, and digital infrastructure. Key actions include updating building codes for flood resilience by 2027, restoring 100 hectares of wetlands by 2030, and deploying city-wide IoT flood sensors by 2035. Successful implementation will require addressing major barriers: securing $2 billion through green bonds and international loans, establishing a cross-ministerial task force to resolve institutional overlap, and ensuring equity by directing at least 30% of NbS investments to informal settlements. These measures aim to integrate resilience across planning, finance, and governance structures in Alexandria.

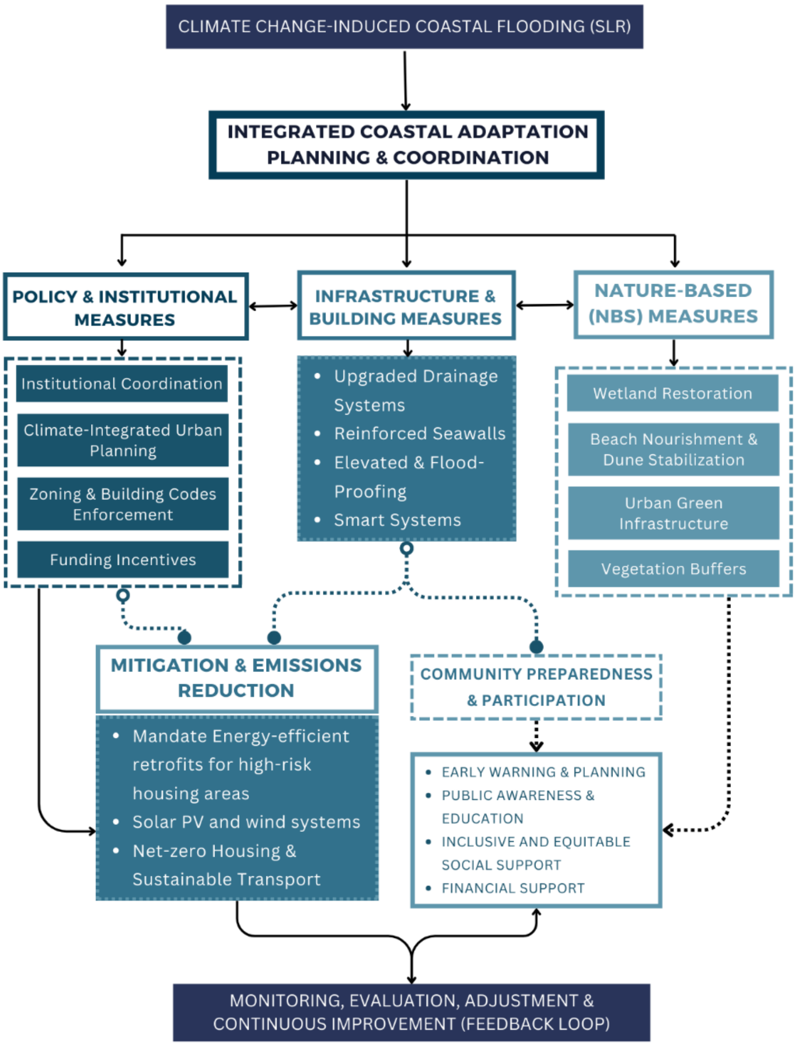

Figure 7. Coastal Resilience Guideline for Alexandria.

Barriers to CRG Implementation

Despite the promise of the Coastal Resilience Guideline (CRG), several structural and political challenges may impede its implementation. First, institutional fragmentation remains a major barrier; overlapping mandates across ministries and weak decentralised governance dilute accountability and delay coordinated action (Abdelaty et al., 2023). Second, technical capacity gaps at the municipal level limit the uptake of climate models, geospatial tools, and data-informed decision-making. Third, political prioritisation often favours reactive engineering over proactive, inclusive planning, particularly in informal settlements where land tenure remains contested. Corruption and procurement inefficiencies may further hinder the execution of large-scale adaptation projects, especially those financed through international funds. Overcoming these barriers will require governance reform, transparent climate budgeting, and targeted capacity-building programs for Alexandria's local institutions.

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CONCLUSION AND RECOMMENDATIONS

This paper underscores the urgent need for a cohesive and forward-looking approach to climate adaptation in Alexandria, one of the most vulnerable coastal cities in the Mediterranean. By identifying critical implementation gaps, reviewing global best practices, and tailoring a context-specific strategy, the proposed Coastal Resilience Guideline (CRG) offers a comprehensive roadmap for adaptive, inclusive, and low-carbon urban development. The analysis reveals that Alexandria's current efforts remain heavily reliant on isolated engineering solutions, with limited integration of community engagement, nature-based approaches, or emissions mitigation. In contrast, the five-pillar CRG framework advances a more holistic and strategic model that balances infrastructure upgrades with institutional reform, ecosystem restoration, public participation, and sustainable urban planning.

Grounded in the principles of Integrated Coastal Zone Management (ICZM), the guideline aligns with Sustainable Development Goal 11 (Sustainable Cities and Communities) and supports Egypt's Vision 2030 climate objectives. To operationalise the CRG, the following prioritised actions are proposed:

- **Immediate (2025–2027):**
  - Pilot a *resilience bond* to finance wetland restoration.
  - Integrate *climate projections into urban zoning* and update building codes to mandate flood-resilient design.
  - Launch *community engagement hubs* to involve residents, especially in informal settlements, in adaptation planning.
- **Medium-Term (2028–2032):**
  - Expand *nature-based solutions* (e.g., green belts, urban wetlands) linked to public health, tourism, and agriculture.
  - Incentivise *climate-responsive architecture* through subsidies, design competitions, and performance-based codes.
  - Deploy *Iot-based early warning systems* citywide to improve disaster preparedness.
- **Long-Term (2033–2040):**
  - Finalise and implement Egypt's *National Adaptation Plan (NAP)* with locally disaggregated targets for Alexandria.
  - Institutionalise a *city-specific monitoring and evaluation system* with public-facing dashboards for adaptive management.
  - Scale *green finance mechanisms*, including adaptation trust funds and municipal-level climate bonds, to sustain resilience investments.

With sustained political will, stakeholder coordination, and strategic financing, Alexandria can serve as a blueprint for Mediterranean cities navigating the intertwined challenges of climate risk, urban expansion, and socio-economic inequality.

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