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Study

The Status of Coral Reefs in Aqaba:

Between Extinction and Restoration Efforts

Performance Index Center | KAFA'A

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Introduction

The city of Aqaba, located on the northeastern shore of the Red Sea, is a strategic and vital hub within Jordan's economic, environmental, and tourism landscape. As the Kingdom's only seaport, it serves as a key gateway for international trade and maritime tourism. Its unique geographic location, mild climate, and rich natural diversity make it a site of both national and regional importance.

Despite its distinguished status, Aqaba has, in recent years, faced a series of environmental challenges that have directly impacted its delicate marine ecosystem, foremost among them the coral reefs, which are among the most diverse and complex marine systems in existence. These reefs play an essential role in maintaining marine ecological balance, supporting fisheries, protecting coastlines from erosion, and offering remarkable aesthetic and touristic value. International reports, including those from UNEP, indicate that coral reefs worldwide have lost around **14**٪ of their cover over the past decade, with regional variability. This trend makes the protection of reefs in the Red Sea – including the Gulf of Aqaba – an urgent priority in light of escalating climate change, marine pollution, and unregulated human activities. However, coral reefs in the Gulf of Aqaba have demonstrated an exceptional ability to withstand rising water temperatures, ranking them among the most resilient globally. Yet, this natural advantage does not mean the absence of threats, these reefs still face increasing pressures from excessive tourism, coastal urban expansion, pollution from ports and boats, overfishing, and weak enforcement of environmental regulations.

In this context, Performance Index Center – KAFA'A launched this study under the Environmental Performance Monitoring Program in Aqaba, **2025**, as part of national efforts to assess the marine environmental situation and identify the key challenges and opportunities affecting the sustainability of coral reefs in the Gulf of Aqaba. This study is based on a scientific methodology combining field monitoring, analytical research, and review of national and international scientific

literature relevant to the topic. It also draws on interviews with stakeholders from both the public and private sectors, including boat and diving associations and port authorities, to build a comprehensive and accurate understanding of the current state of Aqaba's coral reefs.

The study aims to achieve the following objectives:

- Assess the current status of coral reefs in terms of diversity, distribution, and ecological health.
- Identify the main sources of pollution and environmental degradation and their impact on the marine system.
- Study the ongoing coral restoration and protection initiatives.
- Provide scientific and practical recommendations to support national decision-making and policies related to marine environmental management and resource sustainability.

Chapter One: The Impact of Glass-Bottom Boats on Coral Reefs at Al-Ghandour Beach

Glass-bottom boats are among the most popular tourist activities in the city of Aqaba, allowing visitors to admire the beauty of coral reefs and marine life without the need for diving. This type of tourism promotes Aqaba's image as a unique eco-tourism destination and provides a valuable source of income for boat owners and the tourism sector as a whole.

However, despite its economic and touristic importance, this activity has clear negative environmental impacts on the marine ecosystem, particularly when conducted in an unregulated manner or in the absence of proper oversight. Glass-bottom boats powered by conventional fuel engines are considered one of the main sources of pollution in coastal areas, leaving a direct footprint on coral reefs near the shore.

1.1 Types of Pollution Caused by Glass-Bottom Boats

Chemical Pollution

This type of pollution results from oil, grease, and fuel leaks from boat engines into the sea. These substances form a thin layer on the water surface that limits oxygen transfer and reduces photosynthesis in the symbiotic algae living within the coral tissues, leading to suffocation and weakened growth. Such pollutants also harm the microscopic marine organisms forming the base of the marine food chain.

Solid Waste Pollution

Some irresponsible tourism practices contribute to the increase of plastic and glass waste in the water, either due to improper waste disposal or from visitors throwing litter into the sea. These wastes cause suffocation among small marine

creatures, and plastics eventually decompose into microplastics that settle between coral structures, negatively affecting their micro-ecosystem.

Noise Pollution:

Glass-bottom boats generate loud noises from their engines during operation, disrupting the natural behavior of fish and marine mammals sensitive to sound. Studies have shown that continuous noise causes some species to flee their natural habitats and affects their reproductive and communication patterns.

1.2 Field Observations

During the field visit conducted by Performance Index Center - KAFA'A team to Al-Ghandour Beach, it was observed that tourism activity in the area is highly concentrated around glass-bottom boats, especially during peak tourist seasons and holidays.

The team interviewed the Deputy Head of the Glass-Bottom Boat Association in Aqaba, who explained that the association includes dozens of licensed boats and strives to coordinate operations among members to avoid maritime congestion that could harm coral reefs. He also noted that the association has implemented internal regulations imposing fines on boats that exceed designated zones or violate environmental guidelines.

Despite these efforts, the team observed certain negative practices that require stronger monitoring, such as the disposal of small waste items and the lack of regular maintenance for older boat engines, which release noticeable amounts of smoke and oil into the water.

Additionally, some coral reefs near the marina showed signs of damage and color changes due to sediment accumulation and surface pollution.

1.3 Environmental Analysis

Field observations indicate that the main issue is not the tourism activity itself but rather poor regulation and weak environmental control. Achieving a balance between eco-tourism and natural resource preservation requires implementing clear systems that define the number of boats allowed per area and enforce engine maintenance and upgrade standards.

The lack of environmental awareness among some operators and tourists also worsens the impact, as many do not realize that anchoring a boat over coral reefs for an extended period can cause severe mechanical damage from hull or propeller contact.

1.4 Proposed Alternatives and Solutions

→ **Transition to Electric Engines:**

A gradual shift from conventional engines to environmentally friendly electric motors is recommended, as these significantly reduce emissions and noise. This could be supported through partial government subsidies encouraging owners to switch within a defined timeframe.

→ **Environmental Licensing System:**

Operating licenses for glass-bottom boats should require periodic engine inspections to ensure compliance with environmental standards set by the Aqaba Special Economic Zone Authority (ASEZA) and the Ministry of Environment.

→ **Limiting Daily Boat Operations:**

To reduce pressure on coral reefs, a daily limit should be imposed on the number of boats allowed in each marine area, based on environmental carrying capacity studies.

→ **Strengthening Field Supervision:**

A joint inspection unit between ASEZA and the Ministry of Environment

should be established to monitor marine activities daily and enforce penalties when necessary.

→ **Raising Environmental Awareness:**

Training workshops should be organized for boat owners and tourism workers on coral reef protection, along with media and harbor campaigns targeting visitors to promote responsible tourism behavior.

Glass-bottom boats represent an important tourism icon for Aqaba, yet they also pose a potential pollution source if not managed scientifically and systematically. Achieving balance between tourism growth and marine conservation is a shared responsibility requiring cooperation between authorities, tourism associations, and boat owners themselves, ensuring Aqaba remains a model for responsible eco-tourism in the region.

Chapter Two: Cement Burial of Coral Reefs and Its Environmental Impacts

Coral reefs are among the most sensitive ecosystems to physical and chemical changes in their surrounding environment. Their survival depends on a delicate balance of temperature, acidity, water transparency, and seabed purity. Even minor alterations in these factors can disrupt coral growth or lead to gradual death.

In this context, one of the most concerning environmental issues in Aqaba is the burial of coral reefs with reinforced cement during certain coastal construction or expansion projects, whether for ports or tourism developments, without full adherence to required environmental standards.

2.1 Environmental and Chemical Impacts of Cement Burial

- **Increased Water Alkalinity:**

  When cement components react with seawater, they raise the water's alkalinity, disturbing the ionic balance of the marine environment. This increase causes calcium carbonate to precipitate onto coral tissues, hindering their natural growth process.

- **Reduced Water Transparency and Higher Turbidity:**

  Construction and reclamation activities increase suspended particles in the water, which reduces light penetration needed for photosynthesis by the symbiotic algae inside coral tissues. This limits energy production essential for coral survival.

- **Heavy Metal Contamination:**

  Certain types of commercial cement contain metallic elements such as hexavalent chromium, manganese, and lead. These can gradually leach into seawater, causing bioaccumulation in marine organisms and negatively impacting the entire food chain.

- **Microbial Imbalance in the Coral Environment:**

The accumulation of fine cement particles on coral surfaces blocks oxygen and nutrient exchange, disrupting the microbial communities that help clean and protect coral reefs.

2.2 Field Observations and Evidence

During coastal surveys conducted by Performance Index Center - KAFA'A team along Aqaba's shoreline, several scattered sites showed clear signs of landfilling or cement structure installation near coral reef areas.

In some of these locations, the team observed a noticeable decline in coral density and a color change from natural tones to grayish or whitish hues, an indicator of exposure to cement compounds and suspended materials. Local fishermen and marine workers also reported changes in water quality, including a faint odor and the appearance of a thin gray film on the water's surface following construction and expansion activities.

2.3 Scientific Analysis

Scientific reports on ocean acidification indicate that a sustained decrease in seawater pH by **0.1–0.2** units limits the ability of corals to build their calcareous skeletons. In the same context, the use of conventional cement in construction projects, which releases calcium and hydroxide ions into the water, leads to a localized and temporary increase in the alkalinity of the aquatic environment and constitutes a factor that disrupts the delicate biological balance of the surrounding coral reef system. Studies conducted in the Red Sea region, including reports from the Saudi Environment Authority **(2021)** and the United Nations Environment Programme **(2022)**, have documented that direct exposure to cement can destroy coral tissues within one week of continuous contact.

2.4 Legislative and Regulatory Framework

Although Jordanian environmental regulations require Environmental Impact Assessments (EIA) for all coastal projects, enforcement remains inconsistent in practice.
Project developers bear significant responsibility for ensuring their activities do not harm coral reefs; however, weak coordination among oversight entities sometimes allows violations of established environmental standards.

Performance Index Center - KAFA'A stresses the importance of strengthening joint monitoring among the Ministry of Environment, the Aqaba Special Economic Zone Authority, and the Marine Environmental Research Center to ensure strict compliance with environmental regulations in all coastal developments.

2.5 Proposed Alternatives and Solutions

- → Require comprehensive EIAs before the execution of any coastal project, including measurements of pH, dissolved oxygen, and proximity to active coral reef sites.
- → Encourage the use of eco-friendly marine cement, specifically formulated to have low alkaline emissions and free of harmful heavy metals.
- → Establish a national database identifying active coral reef locations and integrate it into investment project maps to prevent overlap or encroachment.
- → Enforce on-site environmental supervision during all construction phases through joint committees that include independent environmental experts from universities and research centers.
- → Adopt engineering alternatives to direct landfilling, such as temporary floating barriers or perforated structures that allow water circulation and prevent sediment buildup.

→ Provide training for construction teams and contractors on environmentally responsible coastal practices, and include environmental accountability clauses in project contracts.

This chapter highlights that coral reefs in Aqaba face a real threat from unregulated construction activities, especially when inappropriate building materials are used in marine environments. Repeated partial burial or reclamation without strict oversight poses a direct risk to marine biodiversity and endangers one of Aqaba's most valuable natural assets.

Protecting coral reefs from cement-related damage therefore requires rigorous enforcement of environmental standards and the integration of ecological considerations into coastal urban planning, ensuring the survival of these unique ecosystems for future generations.

Chapter Three: Diving Activities in Aqaba, Between Tourism and Sustainability

Diving activities in the city of Aqaba are among the main pillars of environmental tourism in the Hashemite Kingdom of Jordan. The waters of the Gulf of Aqaba are renowned for their high clarity and abundance of colorful coral reefs and diverse marine life. The area hosts more than twenty-one recognized diving sites along its coastline, making Aqaba an ideal destination for diving enthusiasts from around the world.

Despite this unique status, the steady rise in visitor numbers and divers, coupled with the lack of precise regulation of certain practices, has left visible environmental effects on coral reefs and the marine ecosystem. This challenge has become a focal concern for Performance Index Center - KAFA'A as part of its environmental performance monitoring program in Aqaba, emphasizing the importance of balancing tourism development with natural resource sustainability.

3.1 Environmental Challenges Linked to Diving Activities

- **Touching or Accidentally Breaking Coral Reefs:** Some divers, often unintentionally, touch or break sections of living coral while diving or trying to stabilize themselves underwater. This physical contact damages the coral structure and hinders its future growth.
- **Disturbance of Seabed Sediments:** Improper fin movements during dives can stir up sand and sediments, reducing water clarity and limiting light penetration essential for photosynthesis by the symbiotic algae that nourish corals.
- **Improper Anchor Deployment:** Boats that transport divers sometimes drop anchors directly onto coral reefs, causing direct mechanical damage to the coral tissues.

- **Overfishing Near Diving Sites:** Excessive or unregulated fishing around diving locations disrupts ecological balance by reducing the populations of fish species that help clean and protect coral reefs.
- **Weak Environmental Oversight:** Although diving activities are subject to regulatory guidelines, weak on-ground enforcement and varying compliance levels among private diving centers reduce their effectiveness.

3.2 Field Observations

During the field visits carried out by Performance Index Center - KAFA'A team, it was observed that most diving sites in Aqaba are managed by private centers offering training and guided tours. However, the level of environmental compliance varies widely from one center to another. Minor coral damage was noted in some sites, particularly near Coral Garden and the Cedar Pride Shipwreck, where slight color changes were observed in certain corals due to fine sediment accumulation from repeated diving activity. Interviews with diving instructors revealed that a large proportion of beginner divers do not receive sufficient training in responsible environmental diving, most training programs focus only on technical skills without adequate emphasis on environmental awareness.

3.3 Environmental Analysis

Environmental data analysis indicates that increasing pressure on diving sites gradually leads to a decline in coral diversity in nearshore areas, while offshore reefs remain more stable.

This variation correlates with the level of compliance with environmental regulations, sites that limit the number of daily divers show significantly lower rates of mechanical damage compared to unrestricted areas. Experts in the management of diving sites in some crowded areas recommend designating environmental rest periods, which may extend for several weeks between peak seasons, to allow better recovery opportunities for coral reefs.

3.4 Local and Regulatory Efforts

The Aqaba Special Economic Zone Authority (ASEZA), in cooperation with the Ministry of Environment and the Jordanian Diving Association, has taken several steps to regulate diving activities and ensure their sustainability. The key measures include:

- Designating official diving sites and prohibiting diving in environmentally sensitive zones.
- Requiring environmental licenses for all operating diving centers.
- Organizing periodic underwater cleanup campaigns with the participation of volunteer divers.

While these measures are valuable, the absence of a centralized electronic booking system to distribute diver numbers across different sites remains a significant challenge. Overcrowding in certain areas leads to more environmental damage than anticipated.

3.5 Proposed Alternatives and Solutions

→ **Mandatory Environmental Diving Training:** All diving centers should provide compulsory training on environmentally responsible diving, ensuring divers understand safe practices to protect coral reefs and marine life.

→ **Establish a National Diving Regulatory Authority:** A national body should be established to oversee diving activities and coordinate with international organizations such as **PADI** and **NAUI** to ensure global standards of eco-diving are met.

→ **Install Underwater Environmental Cameras:** Surveillance cameras should be placed in sensitive reef areas to monitor violations and document irresponsible behavior underwater.

- → **Adopt a Smart Electronic Reservation System:** An intelligent booking system should allocate divers across sites based on their environmental carrying capacity to avoid overcrowding.
- → **Expand Scientific Research Programs:** Encourage academic and institutional research on coral reef health in Aqaba through partnerships with local and international universities and marine research centers.
- → **Promote Eco-Friendly Diving Practices:** Motivate diving centers to use electric-powered boats and reduce plastic consumption within their operations.

Diving in Aqaba represents an essential tourism and economic asset for Jordan. However, if conducted irresponsibly, it also poses a real environmental challenge. Preserving coral reefs does not conflict with tourism promotion; in fact, sustainable tourism is the only path to ensure the survival of this natural treasure.

Therefore, Performance Index Center - KAFA'A emphasizes that environmental sustainability must be an integral part of Aqaba's marine tourism framework, to preserve its natural beauty while simultaneously ensuring continued economic prosperity for the local community.

Chapter Four: Mutah Wharf – Between Development and Environmental Footprint

Mutah Wharf is one of the most significant marine facilities within the Port of Aqaba due to its vital role in supporting commercial and tourism vessel operations and boosting the city's economic activity. It serves bulk grain carriers, general cargo vessels, roll-on/roll-off (RORO) ships, and cruise liners, making it a key component of Jordan's maritime infrastructure.

Over recent years, the wharf has undergone a series of structural expansion and modernization projects aimed at improving operational efficiency and enhancing logistical services. However, these developments have also required careful environmental assessment to ensure alignment with marine sustainability standards.

Technical Specifications of Mutah Wharf

- Length: **150** meters
- Width: **35** meters
- Draft (Depth): **23** meters
- Maximum Ship Capacity: **53,000** tons
- Uses
    - Loading and unloading of general cargo
    - Handling of bulk grains
    - Reception of roll-on/roll-off (RORO) vessels
    - Reception of cruise ships

These figures highlight the wharf's high operational capacity, enabling it to accommodate multiple ship types. Such versatility, however, also demands strict adherence to safety and environmental control measures during both operational and developmental stages.

4.1 Objectives and Drivers of Development

The modernization of Mutah Wharf came as part of a comprehensive plan to upgrade Aqaba's port facilities in line with the requirements of modern international trade. The main objectives included:

- Increasing capacity to accommodate large vessels and improve handling efficiency.
- Upgrading infrastructure using advanced engineering techniques to minimize time and energy losses.
- Strengthening environmental safety measures by improving marine drainage systems and reducing equipment emissions.
- Supporting maritime tourism by preparing the wharf to receive cruise ships as part of the Red Sea tourism route.

While the economic and developmental goals are clear, such expansions necessitate close environmental monitoring to prevent negative impacts on the sensitive marine ecosystem surrounding the area.

4.2 Environmental Measures Accompanying the Development

According to the 2023 Ministry of Environment Report, the Port of Aqaba management, in coordination with regulatory bodies, implemented several measures to mitigate environmental impacts during the development process. The most notable include:

- Installing temporary water barriers to prevent fine sediment dispersion caused by dredging and construction, thereby maintaining water clarity near coral reef areas.
- Limiting engine and equipment emissions within the allowable thresholds of the MARPOL International Convention for the prevention of marine pollution from ships.

- Relocating hazardous material handling to more remote areas of the southern port to minimize the risk of leaks into seawater.
- Implementing an integrated environmental management plan, including weekly water quality monitoring and sediment analysis to ensure the absence of industrial contaminants.
- Participating in environmental restoration projects, such as planting native, climate-resilient coral species in degraded zones near the wharf.

4.3 Field Observations

During the field visit conducted by Performance Index Center - KAFA'A team at the Mutah Wharf area, several observations indicated a noticeable improvement in water quality following the completion of construction.

Port workers reported that management had launched a regular maintenance program for the marine drainage system, which significantly reduced oil leakage incidents. A high level of coordination was also noted between the Port Authority and the Aqaba Special Economic Zone Authority (ASEZA) regarding environmental monitoring.

4.4 Environmental Analysis

Analysis indicates that the wharf development works have not resulted in catastrophic environmental impacts; however, the remaining impacts can be further reduced by adopting more advanced technologies for energy and emissions management.

Integrating artificial intelligence (AI) into port operation monitoring represents a promising step forward, it could predict pollution levels, optimize machinery use, and reduce fuel consumption and gas emissions.

In addition, the continuation of coral restoration programs near the wharf, in collaboration with the Marine Environmental Studies Center in Aqaba, provides an ecological counterbalance that supports natural recovery of the affected marine system.

4.5 Proposed Alternatives and Solutions

- → **Establish a permanent environmental monitoring unit** within the port to continuously track water quality and emissions, submitting monthly reports to the Ministry of Environment and ASEZA.
- → **Expand port capacity responsibly**, ensuring that any future extensions are preceded by comprehensive environmental impact assessments (EIA).
- → **Transition to clean energy** for cranes and heavy machinery, utilizing solar or hybrid systems instead of conventional fuel.
- → **Implement a digital smart logistics management system** powered by AI technologies to optimize efficiency and reduce emissions.
- → **Strengthen research partnerships** with local and international environmental institutions to monitor biodiversity in nearby marine habitats.

Mutah Wharf stands as a real-world example of the balance between economic development and environmental preservation. Structural advancement does not necessarily entail harming marine ecosystems, provided that development follows a scientifically sound, environmentally conscious approach.

Performance Index Center - KAFA'A reaffirms that stronger environmental monitoring and the adoption of clean technological solutions are the most effective pathways to ensure the sustainability of maritime development projects in Aqaba, benefiting both the economy and the environment simultaneously.

Chapter Five: The Phenomenon of Coral Bleaching in the Gulf of Aqaba

Coral bleaching is one of the most serious environmental problems threatening marine ecosystems worldwide. It represents a severe stress condition that affects coral reefs when surrounding environmental factors, particularly water temperature, change significantly. The increase in temperature forces corals to expel the symbiotic algae (zooxanthellae) that live inside their tissues and give them their vibrant colors. When these algae are lost, corals turn white and become weak and vulnerable; if the stress continues, they eventually die.

Although the Red Sea, and especially the Gulf of Aqaba, is among the few regions whose coral reefs have largely retained their resilience to climate change, the recent observation of limited bleaching events raises concern about the long-term future of these ecosystems under growing human and environmental pressures.

5.1 Main Causes of Coral Bleaching

- **Rising Water Temperatures:** The primary driver of coral bleaching is the increase in sea temperature. When the temperature exceeds a certain threshold (estimated at around 30°C in the Gulf of Aqaba), the coral expels its symbiotic algae, leading to discoloration and weakening.
- **Chemical Pollution and Wastewater Discharge:** Oil or chemical pollution disrupts coral metabolic functions, making them more susceptible to heat stress and disease.
- **Excessive Ultraviolet Radiation:** With the decline of natural water turbidity and the increase in transparency in certain areas, the amount of ultraviolet radiation (particularly UV-A and UV-B) reaching coral reefs rises, causing photo-oxidative stress to the symbiotic algae within coral tissues. This leads to cellular damage and increased production of reactive oxygen species (ROS), thereby promoting the expulsion of algae and enhancing the coral bleaching phenomenon.

- **Salinity Fluctuations:** Mixing seawater with freshwater from runoff or wastewater discharges alters the salinity balance of coral habitats, affecting their biological stability.
- **Marine Diseases:** Certain bacterial and fungal infections can spread rapidly among corals, especially when their immunity is weakened due to temperature rise or pollution.

5.2 Field Observations

During field visits to several coastal sites in Aqaba, Performance Index Center - KAFA'A team recorded localized partial bleaching in some coral colonies near areas of urban development and port activity.

These cases were relatively limited in scope, affecting only small patches, suggesting that coral reefs in Aqaba still maintain a high level of resilience compared to those in other parts of the Red Sea.

Interviews with researchers at the Marine Environmental Studies Center in Aqaba confirmed that long-term water temperature monitoring shows generally stable annual averages, with only minor seasonal increases that may explain the isolated bleaching events observed.

5.3 Scientific Analysis

Recent studies reveal that coral reefs in the Gulf of Aqaba possess a unique genetic composition that enhances their resistance to thermal stress compared to those in the southern Red Sea. This adaptation is believed to result from their historical exposure to gradual temperature fluctuations over thousands of years. Nevertheless, continuous human activities near the coast, such as urban

expansion, marine litter, and oil leakage, pose additional stressors that could gradually reduce this natural resilience. Field studies have shown that corals require a biological recovery period of at least several months after any bleaching event, and that providing a clean and stable environment during this time can greatly increase their chances of survival. In some field studies, survival rates have exceeded 80٪ at sites experiencing low levels of human pressure.

5.4 Local and International Efforts

Governmental and research bodies in Jordan, in collaboration with international organizations, have undertaken several initiatives to mitigate coral bleaching and enhance resilience. The most notable include:

- **Establishing a National Observatory** for monitoring coral reef health in the Gulf of Aqaba, equipped with sensors measuring temperature and water quality.
- **Launching coral restoration programs** in cooperation with universities and research centers, using advanced techniques such as **3D bioprinting** to rehabilitate degraded reefs.
- **Enhancing cooperation** with global networks such as the Reef Resilience Network and the International Union for Conservation of Nature (IUCN) to exchange expertise and best practices.
- **Implementing environmental awareness programs** targeting fishermen, boat operators, and divers to teach them how to minimize their impact on coral reefs.

5.5 Proposed Alternatives and Solutions

→ Expand the environmental monitoring network in the Gulf of Aqaba to track temperature and mineral changes with greater precision.

- → Increase funding for genetic research to understand the biological mechanisms behind coral resilience in Aqaba and integrate findings into restoration strategies.
- → Introduce marine environmental protection concepts into school curricula and eco-tourism programs to build lasting community awareness.
- → Encourage investment in green projects that reduce emissions and improve coastal water quality.
- → Strengthen regional cooperation among Red Sea countries to share data and monitor the geographic spread of bleaching events.

Coral bleaching serves as an early warning signal that calls for urgent scientific and regulatory action. While the Gulf of Aqaba's coral reefs exhibit remarkable natural resilience, they are not immune to the effects of climate change and intensifying human activities.

Preserving this unique ecosystem is both a national and global responsibility, requiring the concerted efforts of researchers, policymakers, and the community to sustain life within one of the world's most exceptional coral reef systems.

Chapter Six: Transition to Electric Boat Engines, A Sustainable Option for Aqaba's Future

Boats powered by internal combustion engines are among the leading sources of marine pollution in the city of Aqaba. With the continuous increase in the number of tourist and commercial vessels, emissions from fuel combustion, as well as oil and grease leaks, have risen, polluting seawater and creating noise that disrupts marine ecological balance. Environmental studies show that boats powered by internal combustion engines are among the significant sources of oil pollution in coastal areas, particularly in harbors and tourist sites crowded with small boats. In contrast, electric engines represent a clean and efficient alternative that reduces both chemical and noise pollution, enhances the tourism experience, and strengthens Aqaba's reputation as a regional model for eco-friendly marine tourism.

6.1 Environmental Impacts of Conventional Engines

- **Air Emissions:** Fuel-powered engines release large quantities of carbon dioxide (CO_2), nitrogen oxides (NO_x), and sulfur compounds (SO_x), contributing to global warming and local air pollution.
- **Oil and Water Pollution:** Fuel and oil leaks during boat operation or maintenance create surface slicks that block oxygen exchange and hinder the growth of marine microorganisms crucial to ecosystem health.
- **Underwater Noise Pollution:** Conventional engines generate strong underwater sound frequencies that disturb marine species such as dolphins and large fish, disrupting their communication, migration, and reproduction patterns.
- **Mechanical Vibrations:** Engine vibrations disturb seabed sediments, increasing water turbidity and negatively affecting coral reefs near navigation routes.

6.2 Advantages of Transitioning to Electric Engines

- **Zero Carbon Emissions:** Electric engines produce no exhaust gases or air pollutants, drastically reducing the carbon footprint of the maritime sector.
- **Noise Reduction:** Electric propulsion operates almost silently, minimizing disturbance to marine life and maintaining a calmer underwater environment.
- **Improved Water Quality:** With no fuel or oil involved, the risk of water contamination drops significantly, benefiting coral health and biodiversity.
- **High Efficiency and Low Maintenance:** Electric engines have longer lifespans, fewer breakdowns, and lower operating costs over time, making them economically attractive in the long run.
- **Enhanced Eco-Tourism Appeal:** The adoption of clean energy technology strengthens Aqaba's image as a sustainable tourism destination and positions it as a pioneering Arab city in green coastal development.

6.3 Related Local and International Initiatives

Several countries bordering the Red Sea and the Arabian Gulf, such as Egypt, Saudi Arabia, and the United Arab Emirates, have successfully implemented electric-boat pilot programs within their eco-tourism frameworks. These include establishing ports with electric charging stations and offering government incentives for the transition.

6.4 Proposed Alternatives and Solutions

→ **Develop a National Transition Plan:** Launch a phased national strategy to convert all tourist and recreational boats to electric propulsion within five years.

- → **Financial and Customs Incentives:** Offer subsidies, tax exemptions, and low-interest loans to help boat owners replace conventional engines with electric models.
- → **Build Electric-Charging Infrastructure:** Establish an integrated network of charging stations across the main marinas, ensuring user safety and accessibility.
- → **Technical Training Programs:** Conduct capacity-building workshops for boat operators and maintenance staff on the safe operation and servicing of electric engines.
- → **Adopt Clear National Regulations:** Enact and enforce environmental laws and technical standards that govern the use, safety, and performance of electric boats.
- → **Public-Private Partnerships:** Encourage collaboration between government and private sectors to design and invest in green marine projects, including the local manufacture or assembly of electric engines in Jordan.

Transitioning to electric boat engines represents a strategic milestone in Aqaba's journey toward sustainable environmental development. It simultaneously reduces pollution, enhances the quality of the tourism experience, and supports Jordan's national goals for climate action.

Performance Index Center - KAFA'A affirms that this transformation is not merely an environmental choice, it is a national necessity to protect the Gulf of Aqaba and preserve its unique marine life for future generations, ensuring the city remains a living, thriving, and sustainable coastal haven.

The Economic Impact of Environmental Challenges in Aqaba

1. Glass-Bottom Boats and Oil Emissions

Unregulated tourism activities involving glass-bottom boats have increased coastal water pollution, leading to a decline in the overall quality of the marine ecosystem and a reduction in Aqaba's appeal as an eco-tourism destination. For example, any significant deterioration in the quality of coastal waters can reduce Aqaba's competitiveness as a tourism destination, which may directly affect the number of visitors and the volume of tourism spending, as shown by economic models for similar coastal areas. In addition, oil leakage from these vessels is one of the main factors that can drive up the costs of cleaning beaches and seawater; international studies, including World Bank estimates in comparable spill incidents, indicate that cleaning one ton of oil in sensitive coastal environments can cost tens of thousands of dollars, depending on the nature of the shoreline and the sensitivity of the surrounding ecosystem.

2. Cement Burial of Coral Reefs

The use of cement in coastal reclamation or construction causes interconnected environmental and economic damage. When coral reefs are covered by cement or exposed to construction residues, they lose their ability to grow and their natural function as protective barriers against coastal erosion.

The degradation of these reefs leads to tangible economic losses, including higher costs of shoreline protection, reduced fish stocks, and declining revenues from eco-tourism activities such as diving and coral observation. Thus, protecting coral reefs represents both an environmental necessity and a long-term economic investment.

3. Unregulated Diving Activities

Diving is one of Aqaba's main sources of tourism revenue, with marine tourism accounting for over 40٪ of the city's total tourism income. However, coral damage caused by touching, breaking, or stirring sediments leads to reduced demand for diving trips and lower revenues for local diving centers. Because coral recovery is a slow process, these damages cause cumulative economic losses, exceeding 10٪ of annual revenues in the diving sector whenever coral diversity declines.

4. Development of Mutah Wharf and Port Activities

The Port of Aqaba is one of Jordan's most vital economic facilities; however, intensive port activity can produce environmental impacts that affect operational efficiency and maintenance costs. Increased turbidity or pollution in port waters can influence the quality of the marine environment and the performance of vessels and equipment, leading to additional expenses for cleaning, treatment, and routine maintenance. Furthermore, any deterioration of marine life within the port area may require operating entities to implement corrective actions or environmental restoration projects to maintain ecological balance, measures that demand additional financial and technical resources. Therefore, integrating environmental management into port operations is essential to ensure the sustainability of economic activity and to reduce future financial burdens associated with environmental impacts.

5. Coral Bleaching Phenomenon

Coral bleaching affects both the tourism and fisheries sectors, as the loss of coral diversity leads to a decline in small fish populations that depend on reefs as natural habitats. This negatively impacts local fishery productivity and the sustainability of marine resources. From a tourism perspective, the fading beauty of colorful coral reefs reduces the appeal of diving sites and eco-tourism activities, affecting the revenues of coastal tourism facilities. Thus, the bleaching phenomenon poses a

dual threat to the marine environment and the local economy, underscoring the need to intensify monitoring and rehabilitation efforts to preserve coral reefs as a vital natural and tourism resource for Aqaba.

6. Conventional Boat Engines

Fuel-based boat engines degrade both air and water quality and increase the need for maintenance in marine facilities. Analyses suggest that transitioning to electric engines could reduce fuel consumption by **60**٪ and lower the region's carbon emissions by **30**٪ annually, generating annual savings of about USD **1.2** million in the small-scale maritime transport sector alone. Reduced underwater noise pollution also improves the tourism experience and increases visitor stays in the city by approximately **10**٪, according to experimental estimates.

These findings demonstrate that every environmental threat in Aqaba carries direct and indirect economic costs, affecting tourism, fisheries, and coastal infrastructure alike. Investing in coral reef protection and regulating marine activities is therefore not merely an environmental expense, but an economically sound investment that preserves Aqaba's natural assets and strengthens its position as a leading Arab coastal destination.

Conclusion

This study reveals that Aqaba's marine ecosystem, despite its fragility, still possesses a remarkable ability to adapt and resist environmental stress, particularly its coral reefs, which have demonstrated an exceptional resilience to climate change and rising sea temperatures compared with other regions in the Red Sea and across the world.

However, this extraordinary natural advantage could gradually fade if human pressures continue without proper organization or effective environmental oversight. Unregulated tourism activities, coastal urban expansion, and pollution from ports and boats collectively pose serious threats to Aqaba's marine environment.

Performance Index Center - KAFA'A emphasizes that protecting this environmental resource does not mean halting development, but rather directing it within a framework of sustainability, where economic growth and environmental preservation progress hand in hand.

Sustainable development is, therefore, the only viable path to ensure the continuity of economic activity without depleting or damaging natural ecosystems. Aqaba's prosperity and long-term environmental health depend on adopting this integrated approach that respects both ecological limits and developmental ambitions.

Recommendations

In light of the findings presented in this study, Performance Index Center - KAFA'A recommends the following actions:

1. **Enforce stricter environmental regulations** to govern marine and coastal activities, imposing fines for violations that harm coral reefs or deteriorate water quality.
2. **Strengthen institutional cooperation** between research and studies centers, the Ministry of Environment, and the Aqaba Special Economic Zone Authority (ASEZA) to implement continuous marine environmental monitoring programs.
3. **Support national coral restoration projects** in collaboration with universities and research centers to rehabilitate damaged areas and revive degraded reefs.
4. **Adopt green technological solutions** in ports and marine transportation, including the transition to electric boat engines and the use of artificial intelligence (AI) in operational management.
5. **Expand community environmental awareness programs** highlighting the importance of coral reefs and their role in supporting food security and sustainable tourism.
6. **Integrate marine environment protection** into national development plans as a key component of Jordan's environmental and economic security.
7. **Encourage the private sector** to adopt environmentally responsible practices by offering incentives and tax exemptions for eco-friendly projects.
8. **Enhance regional and international cooperation** to exchange expertise and data on coral reef health monitoring throughout the Red Sea region.

Protecting Aqaba's coral reefs is not only a local responsibility but a global moral duty, as they represent a unique ecosystem that contributes to the balance of

nature and reflects Jordan's commitment to international environmental agreements.

Performance Index Center - KAFA'A believes that this study marks an important scientific and national step toward building a sustainable environmental framework, one that ensures Aqaba remains a vibrant marine habitat and a model of environmentally sustainable economic development for generations to come.

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