AGEDI

مبادرة أبوظبي العالمية للبيانات البيئية

Abu Dhabi Global Environmental Data Initiative

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هيئة البيئة - أبوظبي

Environment Agency - ABU DHABI

LOCAL, NATIONAL, REGIONAL CLIMATE CHANGE PROGRAMME

COASTAL VULNERABILITY INDEX

- Atmospheric Modelling
- Arabian Gulf Modelling
- Terrestrial Ecosystems
- Marine Ecosystems
- Transboundary Groundwater
- Water Resource Management
- Al Ain Water Resources
- Coastal Vulnerability Index
- Desalinated Water Supply
- Food Security & Climate change
- Public Health Benefits of GHG Mitigation
- Sea Level Rise

Executive Briefing

Climate Change Research Group

The authors of this report are Gregg Verutes, Melissa Rosa, Lauretta Burke and Chris Reed.

Local, National and Regional Climate Change Programme 2013-2016

Socioeconomic Systems	Regional Climate Change	Environment	Coastal Zones	Water Resources
Public Health Benefits of GHG Mitigation (L)	Atmospheric Modelling (R)	Terrestrial Ecosystems (R)	Coastal Vulnerability Index (N)	Al Ain Water Resources (L)
Food Security (N)	Arabian Gulf Modelling (R)	Marine Ecosystems (R)	Sea Level Rise (R)	Water Resource Management (N)
Desalinated Water Supply (R)				Transboundary Groundwater (R)

L=Local N=National R=Regional

5 Thematic Areas 3 Spatial Regions 12 Sub-projects

12 Sub-projects
Assess the Impacts, Vulnerability & Adaptation to Climate Change in the Arabian Peninsula

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1. Introduction

Globally, natural habitats provide a wide variety of benefits to people, known as ecosystem services, which are estimated to be worth between US$127-145 trillion/year (Costanza et al. 2014).

Locally, the value of natural habitats is also recognized as providing important services. Within the emirate of Abu Dhabi, a contingent valuation assessment was undertaken that showed the beach amenity valued between US$8.3 million/ha and US$13.8 million/ha (Blignaut et al. 2016). These ecosystem goods and services are an important natural resource, providing coastal communities with livelihood benefits including provisioning services (e.g. fisheries, aquaculture production), regulating services (e.g. shoreline protection and flood control) and supporting services (e.g. filtration of pollution and habitat for aquatic and terrestrial species). The challenge is also quantifying how these benefits will change under alternative climate and development scenarios and linking these results to the beneficiaries (coastal populations and land holders who demand these services).

Faced with growing intensity of human activities and climate change, coastal communities seek a better understanding of how modifications to the biological and physical environment can affect their exposure to storm-induced erosion and flooding.

By analyzing the current distribution of shoreline protection services provided by coastal-marine habitats, we can assess their role in future protection of coastal settlements. This information can be used to assist decision-making from the national level to emirate and local levels. The role of habitats can be a useful metric towards designing coastal plans and developing specific recommendations for development, rehabilitation and restoration strategies in the UAE coastal zone.

Referred to as "nature's shield" by Arkema and colleagues (2013), some coastal and marine habitats, when healthy, buffer the coastal zone from storm-induced erosion and flooding.

Through the process of wave attenuation, which varies by habitat type, coastal distance, depth and other factors, a wave's energy can be reduced as it approaches the shoreline. Unlike bulkheads and seawalls that increase wave reflection and energy, natural habitats improve wave attenuation, decreasing wave heights from both wind and waves by up to 80% (Bilkovic et al. 2016). Reductions in wave energy increase sedimentation and accretion of marsh, for example, provides further sediment stability and coastal protection (Gedan et al. 2011, Manis et al. 2015).

Coastal development and engineered solutions to protect these assets can erode ecosystem integrity and reduces ecosystem service capacity overall (Bilkovic and Roggero 2008, Long et al. 2011, Patrick et al. 2014).

Shoreline armoring structures are fixed on the coast, meaning their effectiveness at preventing erosion is likely to decrease with sea-level rise (Sutton-Grier et al. 2015). Natural habitats, however, can continue to accrete sediment and increase elevation, allowing the shoreline to adapt and maintain its relative position as sea levels rises (Gedan et al. 2011, Spalding et al. 2014, Manis et al. 2015, Gittman et al. 2016). Bulkheads and revetments are also susceptible to overtopping (i.e. seawater rising over the top of the barrier) that can cause significant erosion and property damage during storms (Currin et al. 2008, Gittman et al. 2014) while habitats reduce wave energy, storm surge, and flooding (Gedan et al. 2011, Barbier et al. 2013) and maintain or increase elevation under storm conditions (Currin et al. 2008, Gittman et al. 2014). As coastal development increases, habitat conservation and rehabilitation ("nature-based strategies") offer a unique opportunity to ensure shoreline protection through "hard" (e.g. revetments) and "soft" (e.g. dune stabilization) measures, while also maintaining or enhancing coastal habitat and ecosystem services.

With climate change, the intensity, frequency, and geographic scope of regional cyclone generation and subsequent storm surges may enhance the importance of natural habitats in reducing systematic risks to coastal areas of the UAE.

One of the most common and widely accepted approaches to the assessment of coastal zone vulnerability is the Coastal Vulnerability Index (CVI) developed by Gornitz et al. (1991). This approach combines the coastal system's susceptibility to change with its natural ability to adapt to changing environmental conditions and yields a relative measure of the system's natural vulnerability to the effect of sea level rise. The methodology provides a basis to objectively determine the relative risks due to future sea-level rise within a near-term time frame. It has been applied in numerous settings including the US, Australia, Canada, Brazil, India, Argentina, and Bahrain.

The CVI provides a quantitative indicator of the relative risk that physical changes will occur under climate change based on a set of criteria.

The approach combines a coastal system's susceptibility to change with the ability of its natural habitats to adapt to changing environmental conditions, and yields a relative measure of the system's natural vulnerability to the effects of sea-level rise. It may be used to identify areas that are at risk from erosion and/or permanent or temporary inundation. The criteria used to develop a CVI are flexible and depend on the unique development challenges and characteristics of the coastline to be examined. Typical criteria can include tidal range, wave height, coastal slope, shoreline change, geomorphology, erosion, and historical sea level rise rates, the latter always being one of the criteria considered. The selection of the number and type of indicators to use in a given coastal setting depends on the nature of the near-term coastal planning challenges and questions.

2. Approach

The overall goal is to better understand the near-term vulnerability of the UAE given changes in climate and human use in the coastal zone.

The outputs of the effort represent a contribution to the development of a national framework on near-term coastal zone planning, policy, and information dialogues regarding climate change. There are three major objectives: (1) Acquire the various types of physical databases necessary as inputs to a CVI; (2) develop the coastal vulnerability index for the entire UAE coastline to identify those portions at highest risk from climate change and illustrate the nature of that risk; and (3) develop an interactive “CVI Inspector” tool to visualize the results of the assessment for subsequent use in near-term coastal management and planning at the emirate and national levels.

This study aims to identify exposed shoreline and vulnerable coastal communities and in so doing, highlight areas where natural habitats are reducing the number of people and assets at risk to coastal hazards.

The spatial scope of the study is shown in Figure 1 and includes seven coastal emirates and the current distribution of six natural habitats: 1) coral reefs, 2) mangrove forests, 3) salt marshes, 4) seagrass beds, 5) coastal sand dunes, and 6) oyster beds. There were several key research questions, as outlined in the bullets below.

- Which sections of the UAE coastline are most exposed to coastal hazards from climate change and other factors?
- How the distribution of risk-reduction will be provided by nearshore and coastal habitats change under future habitat and climate change scenarios?
- How can these findings inform future planning and management including conservation and restoration of habitats that protect coastal populations, infrastructure and other assets?

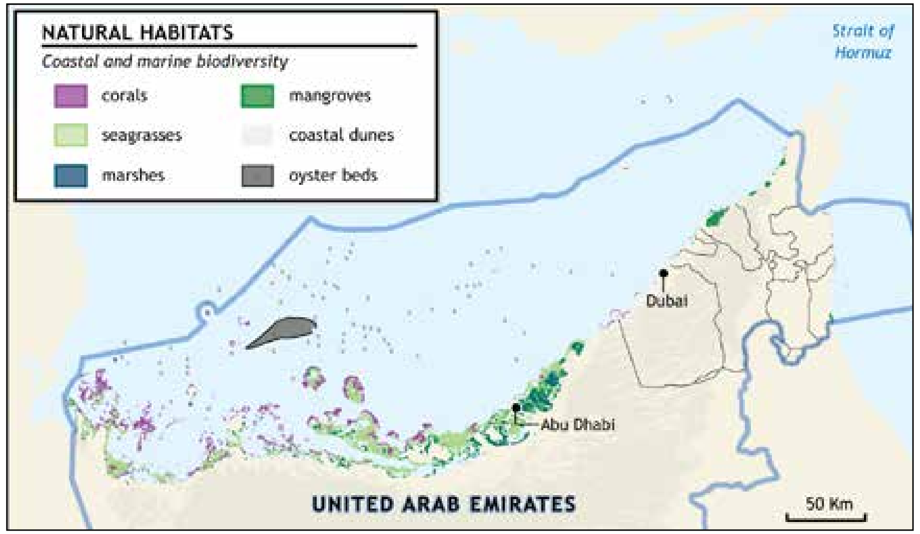

Figure 1: Map of UAE study area including the seven coastal emirates (white lines), EEZ (blue lines) and six natural habitats considered in this assessment to provide coastal protection services.

3. Natural habitats in the UAE’s coastal environment

Natural habitats play an important role in both current and future shoreline protection of people and property in the UAE coastal zone.

In addition to protection from hazards, coastal and marine biodiversity provide a suite of environmental services to the UAE people. Six natural habitats are particularly important relative to climate change as they are known to attenuate waves, including their historic range, threats, and benefits delivered to people. A review of the benefits of natural habitats below sets the stage for a broader natural capital mapping effort with the goal of making the case for nature-based strategies to support coastal resilience under climate change, including shoreline protection and other important ecosystem services.

- **Mangroves.** The largest extent of mangroves is found in the Umm Al Quwain and Ras Al Khaimah emirates, followed by Abu Dhabi. These salt-tolerant trees and shrubs mainly Avicennia marina are densely distributed along the southern shores of the Arabian Gulf, confined to low-energy, intertidal areas (Naser, 2014; Saenger, 1997). Mangroves provide a host of other ecosystem services, including water quality, amenity services, habitats for a variety of terrestrial and marine fauna, and productivity of the Arabian Gulf (Al-Maslamani et al. 2013), including shelter for commercially and recreationally important fish and shellfish, protecting the broader biodiversity of the coastal ecosystem and community structure of different species of coral reefs (Mumby et al. 2004). The extensive root systems of mangroves anchor soil which can mitigate the effects of wave action during storm events, including shoreline erosion and sedimentation. Mangrove ecosystem services alone, not including carbon sequestration, have been valued at U.S. $193,845 per hectare of intact ecosystem as a global average (De Groot et al. 2012). The below-ground, sediment pool is a sink for carbon sequestration (Sifleet et al. 2011). They filter pollutants and improve the quality of coastal and nearshore waters, support the livelihoods of coastal-dependent communities, and are a source of revenue from ecotourism.

- **Corals.** Corals are currently protecting the coastlines of all seven emirates. Corals of the UAE were once extensive in the 1960s and 1970s with Acropora dominated reefs extending across most of the Arabian Gulf coast, occupying hundreds of square kilometers of nearshore waters from western Abu Dhabi to Ras Al Khaimah (Burt et al. 2011). In the Arabian Gulf, extremes in temperature, salinity and other physical factors restrict the growth and development of corals to patchy forms (Sheppard et al. 2010). Coral reefs were also widely distributed across the northern emirates and along the east coast in the Sea of Oman. Coral reef ecosystems feature both biological diversity and high levels of productivity, providing a wide range of important habitats for fisheries in the Arabian Gulf. Additionally, coral reefs can slow incoming waves and protect mangrove and sea grass habitats from strong currents and storms. Coral reefs also provide recreational values and economic benefits such as increased tourism revenues.
- **Seagrass beds.** Seagrasses front about 30% of segments along the coastline of the Emirate of Abu Dhabi. Three species of seagrass occur in the Arabian Gulf, Halodule uninervis, Halophila stipulacea and Halophila ovalis (Phillips, 2002) and are generally tolerant to salinity and temperature extremes. Seagrasses provide important ecosystem services such as stable coastal habitat for many species of fish and invertebrates, and maintain coastal water quality and fisheries production (Naser, 2014). Seagrass habitats serve as a foundation for complex food chains and nursery grounds for certain shrimps, pearl oysters and other organisms of importance to the Arabian Gulf's commercial fisheries (Erftemeijer and Shuail, 2012). They also provide feeding grounds for several threatened species in the Arabian Gulf, such as the green turtle and support the largest population of dugongs known outside of Australia. Furthermore, they supply food and shelter for coral reef associated species and nutrients and energy to sabkha substrate, which helps stabilize the substrate and minimizes the effect of wind erosion and retains water in coastal soils. Seagrass beds play an important role in climate regulation by typically sequestering as much as twice the carbon per unit areas as that of temperate forest in the tropics.


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- **Salt marshes.** These are biologically diverse habitats that continuously accumulate sediment and are suited to both fresh and saltwater. These intertidal ecosystems are primarily found in sheltered regions of the Arabian Gulf coast. Salt marshes are valuable ecosystems that provide habitat for a variety of both commercially and recreationally important marine wildlife, including fish, shellfish and foraging shorebirds. Healthy salt marshes also filter nutrients and sediment from passing water, protect coastlines against wave damage and erosion, mitigate flooding by holding excess storm waters, and regulate water levels during periods of dry weather. The ecosystem services provided by marshes include fisheries production, pasture lands, ecotourism and climate regulation. They inhibit methane creation and contain a range between 900 and 1,700 tonnes of CO2 per hectare (Sifleet et al. 2011). Salt marshes are typically converted for agricultural use or lost to coastal development, particularly through dredging, filling and draining and from the construction of roads (Burt, 2014). Marshes are also increasingly under pressure from rising sea levels.

- **Coastal sand dunes.** These habitats currently exist in appreciable quantities in the Abu Dhabi and Ras Al Khaimah emirates. Most of the surface of the present day UAE is a sand desert. In many areas near the coast, the sand is stabilized by vegetation, although the natural flora has been altered in recent times by extensive grazing of domesticated animals. Their contribution to coastal protection and tourism has been acknowledged in local coastal plans but the wide range of provisioning, regulatory, cultural and supporting services they provide are often overlooked. Coastal sand dunes in the UAE are most threatened coastal development activities that include hardening of shoreline for resorts and residential superstructure (Burt, 2014).
- **Oyster beds.** The Gulf Pearl Oyster traditionally offered a source of local wealth to the region long before the discovery of oil. Pinctada radiate and P. margaritifera (collectively referred to as 'pearl oysters') are large bivalves that can tolerate a wide temperature range and found on rocks between 5 and 25 meter depths (Carter 2005). Oysters are currently cultured for pearls in Qatari waters and harvested for their edible flesh and shell on a limited basis. Despite their ability to adapt to subtropical environments and survive in polluted water, globally 85% of reefs have been lost due to fisheries extraction, coastal degradation and other anthropogenic pressures. Like many shellfish species across the globe, the Gulf Pearl Oyster has lost its dominant role as an ecosystem engineer including supporting the historically productive oyster fishery.

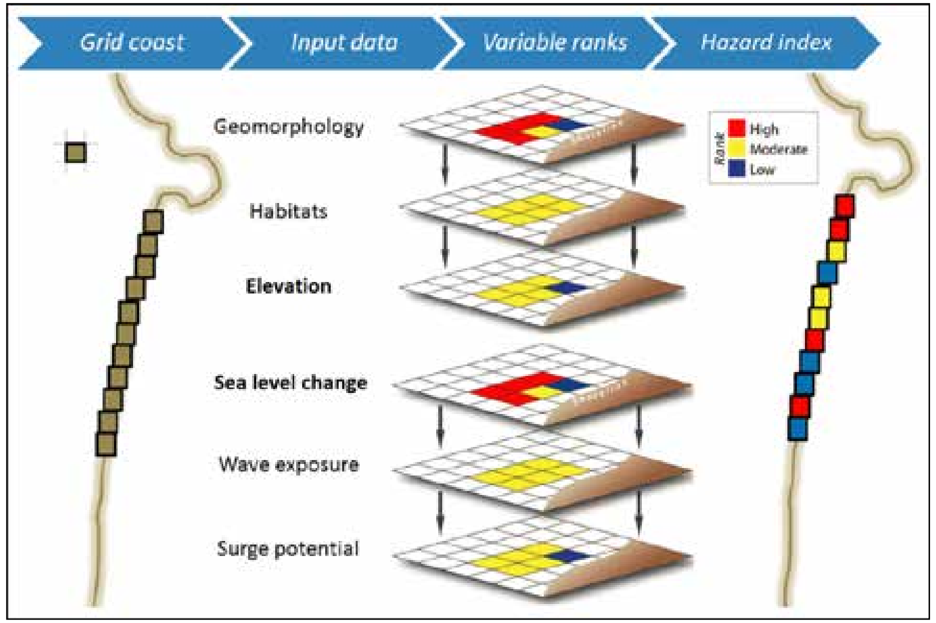

Figure 2: Conceptual diagram of the InVEST coastal vulnerability model (Arkema et al. 2013).

4. Modelling framework

The InVEST coastal vulnerability model was used to estimate the relative exposure of each 250 m^2 segment of the UAE coastline to hazards from climate change risks (e.g. increased frequency of storm events).

Model inputs serve as proxies for various complex shoreline processes that influence susceptibility to erosion and flooding. Inputs include information about climatic forcing (using data on wind and wave activity and storm surge potential), shoreline type (geomorphology), presence of natural habitats, and elevation. InVEST calculates an exposure index based on the distribution of coastal habitats, elevation, wind and wave characteristics, shoreline type, relative sea level change and surge potential. The index is overlaid with socioeconomic data to identify where populations and critical infrastructure are most vulnerable to storm waves and surge. Model outputs serve to quantify the protective services offered by natural habitats to coastal communities in terms of risk-reduction. Figure 2 illustrates a sampling of the types of data inputs to characterize the UAE's coastal zone vulnerability under climate change.

Scenarios were used to illuminate choices and consequences.

The InVEST coastal vulnerability model offers a snapshot of coastal protection services at a given time. Alternative futures were explored driven by the effects of climate change and human impacts on habitat quality and function. Each habitat input layer was later refined based on various mapping efforts to characterize threat level to and quality of six habitats known to attenuate waves. Maps of this historic distribution, current habitat quality and a complete loss of habitat function were combined with near, mid and long-term projections for net sea level rise to create seven plausible habitat/climate change scenarios. The habitat/climate scenarios are snapshots across an 80-year time horizon (2020 - 2100).

5. Coastal Vulnerability Inspector

The CVI for each segment of the UAE coastline incorporates an enormous amount of spatial-based information.

To represent this information in a way that can be useful to coastal planners in the UAE, an online interactive tool called the "CVI Inspector" has been developed (http://www.ccr-group.org/coastal-inspector-home). The tool offers a way to directly access the InVEST tool to explore climate change scenarios, scrutinize vulnerable segments of the coastline, and illustrate the spatial extent of natural habitats protecting the coastline.

To first order, the CVI Inspector provides the CVI for each 250-meter segment of the UAE coastline

Based on three climate change scenarios for sea level rise, the InVEST coastal vulnerability model classified between 4 and 32% of the UAE coast (within one kilometer of the shoreline) as "highest exposure" areas – currently home to more than 175,000 people and extensive coastal assets.

The coastal zones of the Emirates of Ajman and Dubai are most exposed to hazards relative to the other five coastal emirates. More than 75% of Ajman's shoreline will fall into the highest exposure category (top 25th percentile based on a distribution of index scores for nine habitat/climate scenarios) by the year 2050. Dubai is next at 36%, while less than one-quarter of the coastline for the remaining emirates will be highly exposed. The model classifies the Emirates of Abu Dhabi, Fujairah, and Sharjah as least exposed to hazards overall due to elevated coastal areas, lower probability of storm surge, extensive natural habitats, and relatively less exposure from local and ocean-generated waves. As an example, Figure 3 shows a CVI Inspector screenshot from the Emirate of Abu Dhabi near the Qatari border. The highly exposed coastline (red line segments) within the selected area (white box) is driven by storm surge potential and coastal geomorphology variables with the highest exposure rank.

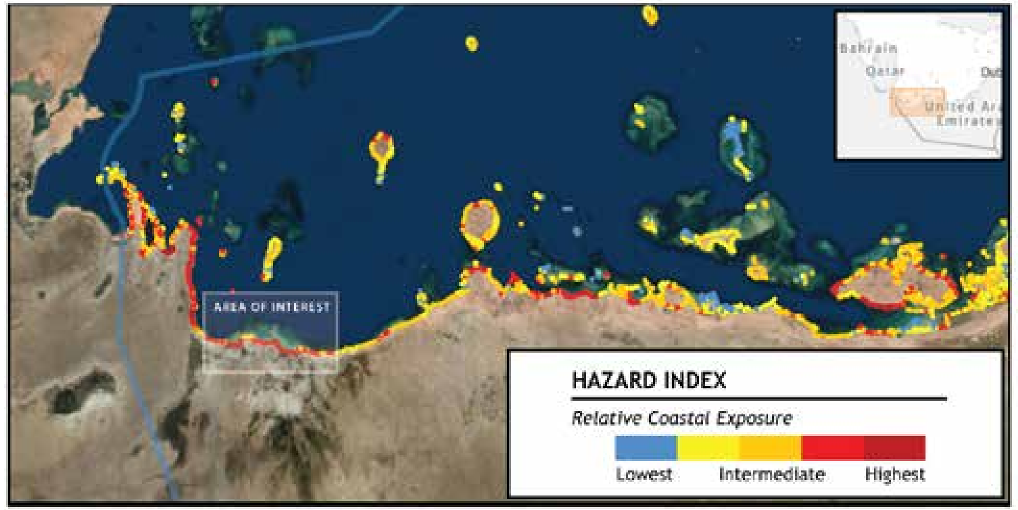

Figure 3: Screenshot from the online CVI Inspector tool.

The CVI Inspector can also be used for scrutinizing specific areas/activities of interest in the UAE.

For example, marine dredging activities may contribute to and accelerate the impact of coastal erosion over time. Since erosion tends to be accentuated on the downdrift side of coastal structures, this can have significant economic impact, as these beaches now require continuous ongoing maintenance and are being lost to grain fields (i.e. rigid coastal protection structures built from the ocean shore that interrupts water flow and limits the movement of sediment) or detached breakwaters. While the engineered solutions to protect these developments have claimed to consider sea level rise, it is unclear whether they also account for storm surge and local hydrodynamics, including overtopping risk and severe erosion events caused by the funneling of water around these structures during current storm events and future storm events under climate change. Detailed patterns of accretion and erosion, highlighting the typical pattern of longshore drift in Dubai as well as other emirates are incorporated in the CVI Inspector.

It is important to note that the CVI methodology incorporated into the Inspector has some important caveats and limitations.

First, the CVI model relies on a "protective distance" parameter to estimate the minimum coastal distance needed for a habitat type to be classified as offering protection. Few field or lab experiments have documented the distance over which different natural habitats effectively attenuate waves and reduce energy as they approach the coastal zone. Second, the CVI is essentially a simple, screening approach, enabling the identification of particularly vulnerable locations without extensive data requirements. Third, The InVEST coastal vulnerability model is limited by the quality and accuracy of spatial input variables that comprise the index.

Empirical (observed) data on coastal erosion and inundation can help to validate this coastal protection assessment for UAE. Major model assumptions and limitations include:

- The model does not account for processes that are unique to a region, nor for interactions between the six variables.
- The model does not predict changes in shoreline position or configuration.
- The model does not consider any hydrodynamic or sediment transport processes.
- The model assumes that the habitat data reflects the current or a snapshot of past/future distributions of coastal habitats, and that habitat distribution and abundance are constant.

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About

AGEDI

Under the guidance and patronage of His Highness Sheikh Khalifa bin Zayed Al Nahyan, President of the United Arab Emirates, the Abu Dhabi Global Environmental Data Initiative (AGEDI) was formed in 2002 to address responses to the critical need for readily accessible, accurate environmental data and information for all those who need it.

With the Arab region as a priority area of focus, AGEDI facilitates access to quality environmental data that equips policy-makers with actionable, timely information to inform and guide critical decisions. AGEDI is supported by Environment Agency – Abu Dhabi (EAD) on a local level, and by the United Nations Environment Programme (UNEP), regionally and internationally.

For more information, visit www.agedi.org.

The Environment Agency – Abu Dhabi

The Environment Agency – Abu Dhabi (EAD) was established in 1996 to preserve Abu Dhabi's natural heritage, protect our future, and raise awareness about environmental issues. EAD is Abu Dhabi's environmental regulator and advises the government on environmental policy. It works to create sustainable communities, and protect and conserve wildlife and natural resources. EAD also works to ensure integrated and sustainable water resource management, to ensure clean air and minimize climate change and its impacts.

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All reports and resources are available for download at www.agedi.org and on our Climate Change Inspectors Online Portal, http://www.ccr-group.org/cc-inspectors.

CCR Group

Climate Change Research Group (CCR Group) is a sustainable development research and consultancy firm focused on the intersection of energy, climate and development. Our network of specialists works with international development organizations, national and local governments, as well as non-governmental institutions to formulate policy frameworks, technical assessments and capacity building programmes.

Since CCR Group's founding in 2009, we have lead projects across Africa, the Middle East, Eastern Europe, Asia and the Americas. Because each client faces a unique set of challenges based on local context, we have experience developing strategies for multiple issue areas within sustainable development. Thematic issue areas and services for CCR Group include: Climate Change Adaptation Strategies; Greenhouse Mitigation Analysis; Climate Change & Disaster Risk Management; Climate Change, Agriculture & Food Security; Climate Change & Water Security; Climate Change & Public Health; Power Supply & Renewable Integration Modelling; Air Pollutant & Greenhouse Gas Emission Scenarios Modelling; and Capacity Strengthening Programmes.

For more information, visit www.ccr-group.org.

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Abu Dhabi Global Environmental Data Initiative

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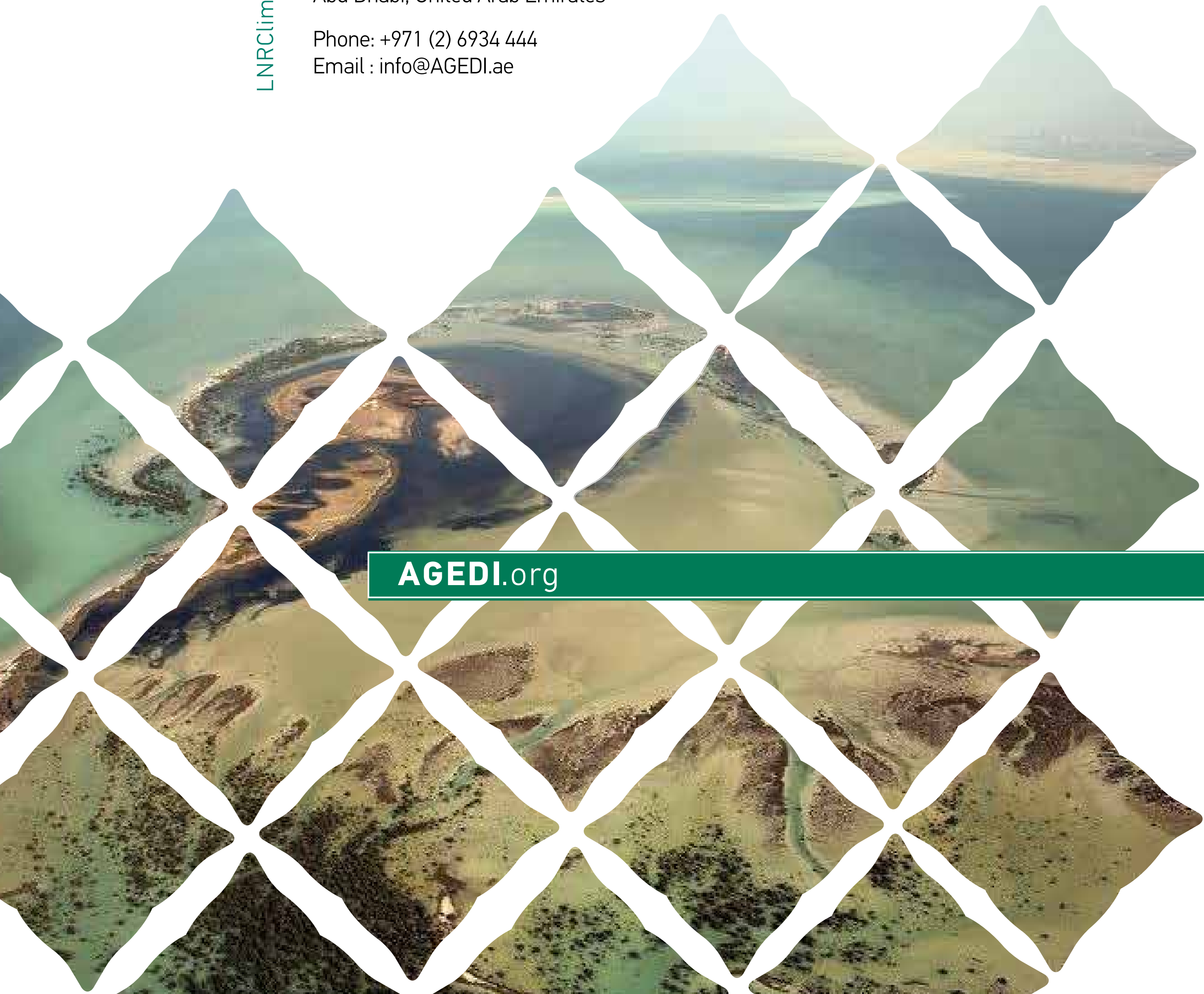

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