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LOCAL, NATIONAL, REGIONAL CLIMATE CHANGE PROGRAMME

DESALINATION AND CLIMATE CHANGE

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

Executive Summary

Climate Change Research Group

UNIVERSIDADE DE SÃO PAULO

IO Instituto Oceanográfico

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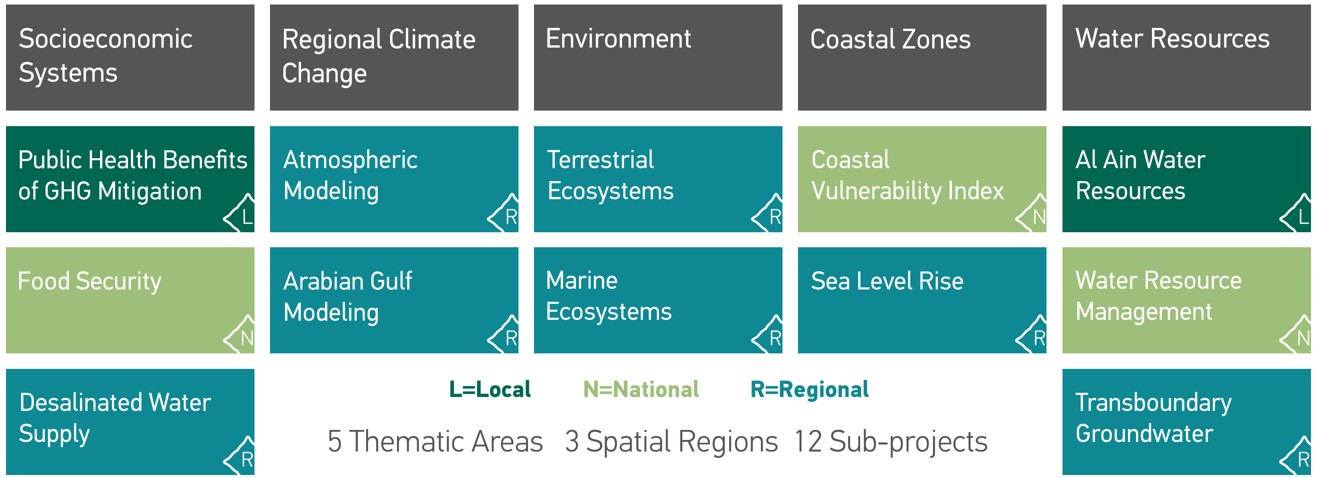

12 Sub-projects
Assess the Impacts, Vulnerability & Adaptation to Climate Change in the Arabian Peninsula

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About the Desalination & Climate Change sub-project

In October 2013, the Abu Dhabi Global Environmental Data Initiative (AGEDI) launched the “Local, National, and Regional Climate Change (LNRCC) Programme to build upon, expand, and deepen understanding of vulnerability to the impacts of climate change as well as to identify practical adaptive responses at local (Abu Dhabi), national (UAE), and regional (Arabian Peninsula) levels. The design of the Programme was stakeholder-driven, incorporating the perspectives of over 100 local, national, and regional stakeholders in shaping 12 research sub-projects across 5 strategic themes. The “Desalination and Climate Change” sub-project within this Programme aims to assess the vulnerability of the Arabian Gulf waters to climate change in the context of socioeconomic growth in the region.

1. Desalination and climate change context

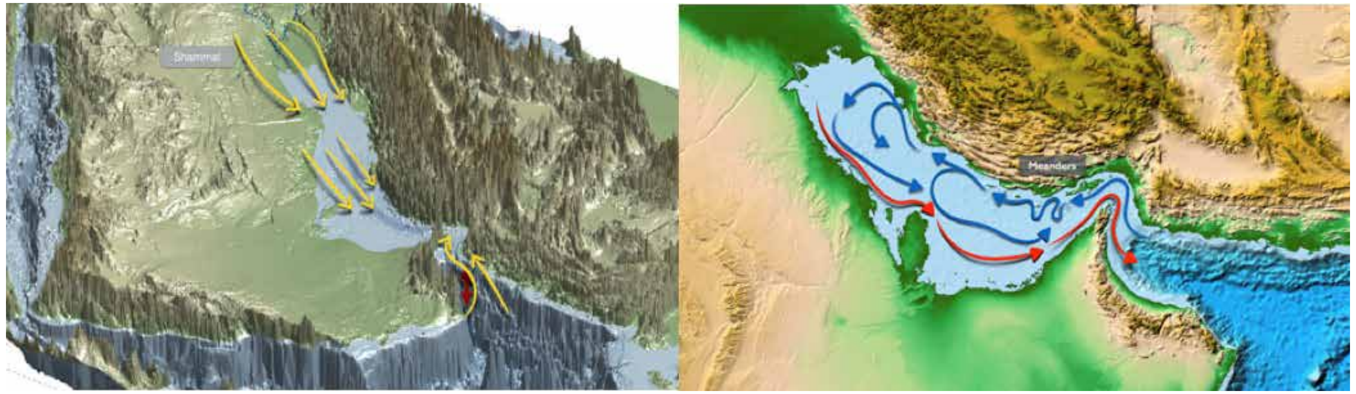
Under current conditions, the Arabian Gulf is already one of the most stressed marine environments on earth

It is a semi-enclosed, highly saline sea between latitudes 24°N and 30°N surrounded by a hyper-arid environment. The Arabian Gulf is characterized by salty ocean water inflow from the Gulf of Oman along the Iranian coastline and limited freshwater inflow via the Tigris, Euphrates, and Karun rivers at the delta of the Shatt al Arab in Iraq. Its bathymetry shows large areas of shallow water (less than 10 meters deep) with a maximum depth reaching about 110 meters along the central channel. Northwesterly Shamal winds affect Gulf waters in the winter, while southeasterly Shamal winds dominate in the summer (see Figure 1, left). Such winds significantly affect the Gulf's surface circulation patterns and contribute to counterclockwise flow along the entire Gulf (see Figure 1, below).

Compounding this highly saline picture of the Arabian Gulf is the fact that it is also a region of intense seawater desalination activity.

Today, most of the power and freshwater needs in the Arabian Peninsula region are met by the desalination of seawater (Uddin, 2014). Of the 100 largest desalination plants in operation, in construction, or planned in the world as of 2005, 47 plants, (accounting for 13.7 million cubic meters per day in production capacity, or 64%,) are in the eight countries bordering the Arabian Gulf namely, Bahrain, Iraq, Iran, Kuwait, Oman, Qatar, Saudi Arabia, and the UAE. The overwhelming majority of these large plants (i.e., 43 out of 47) use seawater from the Arabian Gulf as the feedstock to produce potable water, with the rest using either brackish water or wastewater to produce potable water. When considering units of all sizes - and based on initial estimates - there are currently over two thousand desalination plants of all sizes and feedstocks either operating, in construction, or planned for the Middle East, corresponding to about 13% of the world total (Global Water Intelligence, 2015).

Figure 1: Arabian Gulf topography and bathymetry showing wind patterns (left) and circulation (right)



In the Arabian Gulf region, most desalination plants are combined with power plants for electricity generation to meet on-site requirements and to satisfy national electricity needs.

There are three major types of desalination technology currently used in the Gulf for seawater: Reverse Osmosis (RO), Multi-Stage Flash (MSF), and Multi-Effect Distillation (MED). These desalination processes separate seawater (or some other source of water containing a high proportion of suspended solids) into freshwater which is then distributed to meet the freshwater demands of households, businesses, amenity, and industry; and concentrate (also known as retentate, brine, or reject) which can be disposed through a variety of ways such as surface water discharge, sewer discharge, deep well injection, evaporation ponds, land application, and thermal processes for near zero liquid discharge (Xu, et al., 2013).

All desalination technologies use high levels of electricity.

For reverse osmosis, the assumed technology of choice in the future, electricity requirements for desalination are directly related to the salinity of the feedwater. That is, the higher the salinity the greater the amount of electricity required to produce potable water, or the need to de-rate plant capacity. All three technologies can operate at feedstock salinity levels up to 50 ppt (World Bank, 2004). Typically, cogeneration of electricity and desalinated water takes place using high-efficiency natural gas combined cycle units. For multi-stage flash and multi-effect distillation technologies, extensive amounts of process heat are also required for the desalination process.

2. Approach

The environmental impacts of desalination are associated primarily with the waste stream that is discharged into the Arabian Gulf.

This waste stream consists of hot brine, treatment chemicals, and other trace elements. The environmental impacts associated with such concentrated brine discharges include increasing levels of biocides, chlorination, and descaling chemicals (Hopner and Lattemann, 2002; Younos, 2005; Dawoud & Mulla, 2012; Uddin, 2014). For the Arabian Gulf, this can lead to chronic toxicity and small-scale alterations to community structure in near-field marine environments, particularly for corals (Jenkins, Paduan, Roberts, Schlenk, & Weis, 2012; Uddin, 2014). Moreover, hot brine effluent from RO plants can be up to 85 ppt and 50 ppt for MSF units. As the effluent is heavier than seawater, it sinks to bottom and slowly circulates causing harm to sea grasses and other ecosystems on which a large range of aquatic life (e.g. dugongs) depend (Areiqat & Mohamed, 2005; Lattemann & Höpner, 2008; Mohamed, 2009).

Under climate change, the Arabian Gulf will become even more highly stressed, quite apart from any environmental impacts associated with increasing desalination.

As part of an earlier sub-project within the LNRCCP, the response of the Arabian Gulf to climate change conditions was modeled (Edson, et al., 2015). The study focused on the region between the Musandam peninsula near the Strait of Hormuz to the Shatt al-Arab delta. A Regional Ocean Model System (Shchepetkin & McWilliams, 2005) was validated to historical conditions and used to develop projections for the mid (i.e. 2040-2049) and late (i.e. 2080-2099) 21st century. This study found several key impacts regarding temperature and salinity for the Gulf, including changes in the dynamics and a likely increase of the Southwest coastal salinity, due to local effects of global warming. While this earlier study did not account for an increase in desalination activities to keep pace with future water demand, it was used as the starting point for an analysis of the combined impacts of desalination and climate change.

The overall goal of the sub-project is to better understand the future impact of desalination activity on the Arabian Gulf in the face of climate change.

Several core research questions were addressed:

1) How will the high levels of socioeconomic growth projected for each country in the region affect the magnitude of brine discharges into the Gulf over time?
2) How are key Gulf physical properties affected by the middle of the 21st Century due to the combination of climate change and intensified desalination activities? And
3) To what extent does climate change potentially exacerbate the environmental impacts of future desalination activity?

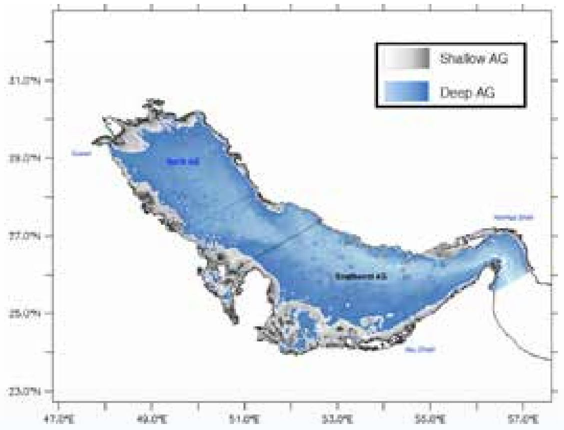


Figure 2: Spatial domain of the study

Study area

The focus of the study was the Arabian Gulf.

Specifically, the spatial domain of the entire Arabian Gulf. For the purpose of analysis, the Gulf was divided into two spatial sub-areas and two vertical sub-areas, as shown in Figure 2. The Northern Gulf area extends from the Shatt-al Arab in Iraq to just south of Jubail in Saudi Arabia. The Southern Gulf area extends from the southern parts of Bahrain through the Straits of Hormuz to the Gulf of Oman. The Gulf was further divided into shallow areas which refer to shallow water less than 20 meters in depth and deep areas which refer to waters greater than 20 meters in depth.

Desalination plant inventory

A desalination plant inventory was developed as a basis by which to estimate historical brine discharge levels to the Gulf.

Across the region, there are currently about 2,241 desalination plants (Global Water Intelligence, 2015). Of these there are 982 plants corresponding to the eight countries (i.e. Bahrain, Iraq, Iran, Kuwait, Oman, Qatar, Saudi Arabia, and the UAE) included in the study, which depend on seawater as the feedstock. And of these, there are 486 plants on both sides of the Gulf, accounting for over 14 million cubic meters per day of capacity, that discharge brine and other chemical by-products directly to the Arabian Gulf. The capacity and relative shares of these plants are summarized in Figure 3. These desalination plants form the basis for the estimation of the magnitude of brine discharges to the Gulf.

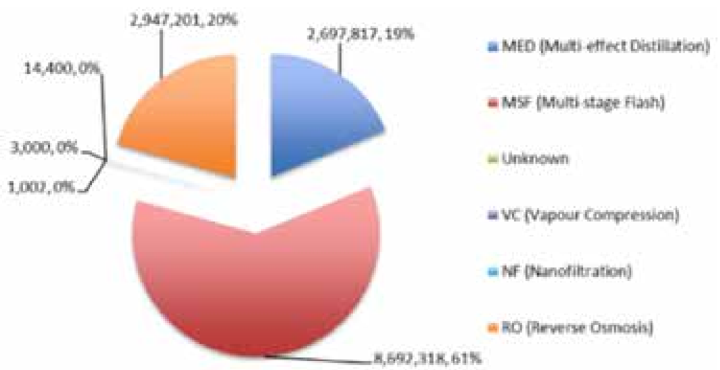
Brine discharge magnitude projections

Brine discharge magnitudes to the Arabian Gulf were estimated for the 2040-2050 period.

This involved a set of detailed assumptions and calculations. For the base year of 2010, it involved calculations for each facility regarding a) annual seawater intake (in million cubic meters), b) equivalent sea salt intake (million tonnes), c) water recovery (million cubic meters), d) brine discharge (million cubic meters), and e) equivalent sea salt discharge (million tonnes). For the years 2011 through 2050, calculations involved projecting the Base Year estimates based on assumptions regarding future water consumption per capita, regional population growth, and shifts to more efficient desalination technologies. To account for the uncertainty inherent in such projections, several brine discharge scenarios were considered to bracket uncertainty. Brine discharge magnitudes of 50, 80, 120, and 220 tonnes per second were subsequently modeled for the 2040-2050 period.

Figure 3: Summary of desalination plant capacity, by technology, that use Arabian Gulf waters as a feedstock (GWI, 2015)

	TOTAL CAPACITY	
Type	M3/D	Share (%)
MED (Multi-effect Distillation)	2,697,817	19%
MSF (Multi-stage Flash)	8,692,318	61%
Unknown	1,002	0%
VC (Vapour Compression)	3,000	0%
NF (Nanofiltration)	14,400	0%
RO (Reverse Osmosis)	2,947,201	21%
Total	14,355,738	100%



Regional ocean modelling framework

The previously developed regional ocean model for the Gulf was used as the modelling framework.

This is the model which was validated to historical Gulf conditions and then used to downscale the IPCC's Representative Concentration Pathway 8.5 (RCP8.5) to the middle of the 21st century. This modelling system is a robust programming system that can model the impacts associated with increasing levels of brine discharge. Essentially, the regional ocean model is a modular hydrodynamic system that includes the runoff or direct river forcing in real time. It proved effective in the simulation of hot brine discharges into the Gulf.

"Saline river" approach

Available computing resources limited the actual number of brine discharge points that could be effectively integrated into the regional ocean model.

[1]This is primarily due to the complexities involved in the integration of hyper-saline discharge from a set of desalination plants into a validated, fine-tuned, high-resolution regional ocean model in which climate change signals have been downscaled. Hence, the number and location of desalination plants were spatially reduced from the 486 plants into fourteen (14) representative points whose annual brine discharges were collectively equivalent to the magnitude from all plants. These representative plants are referred to as "saline rivers". These saline rivers were modeled as direct injections of hot brine into the Gulf. It is important to note that this modelling approach does not account for local effects in the immediate vicinity of the underwater brine discharge structures. That is, only far-field modelling was undertaken (i.e. using a roughly 1 km resolution). Near field modelling of the immediate zones of brine discharge (i.e. requiring less that a 5-meter resolution) was beyond the scope of the study.

Environmental data and outputs

The regional ocean model was used to simulate temperature changes in the Arabian Gulf under the combined influence of climate change and future desalination activities.

Many maps, animations, and databases were developed, some of which are available in the annexes of the Final Technical report, including impact on temperature, salinity, circulation patterns, residual currents, and mixing processes. Access to the various detailed databases used to construct the maps/animations as well as the maps/animations themselves are available online at the Desalination & Climate Change Inspector (www.ccr-group.org/desalination).

[1]Computing resources consisted of an SGI Cluster, based on Advanced Micro Devices (AMD) architecture. The modelling used 600 dedicated CPUs and 48 Tb of storage. While these computing resources are significant, they still required several calendar months per run for the entire number of desalination plants.

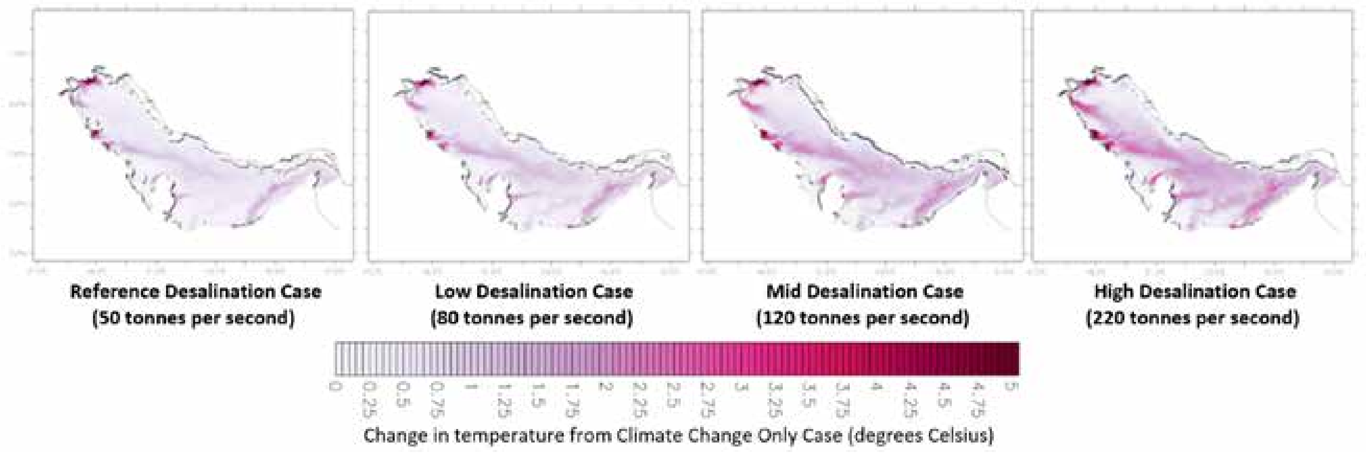
3. Impact of climate change and desalination on temperature

Desalination activities will significantly impact average surface and bottom temperatures throughout the Gulf

This is illustrated in Figure 4a which shows the difference in average bottom temperature for the four scenarios of future desalination activity over and above climate change. The differences in temperature correspond to the middle of the 21st Century (i.e. 2040 to 2049). Figure 4b summarizes the magnitude of average temperature change in shallow versus deep areas, as well as in southwestern versus northern areas. In the southwestern area of the Gulf, temperatures are projected to increase up to about 1.4 °C in deep areas in the High Desalination case. In the Northern Gulf, temperatures are also projected to increase up to about 1.4 °C in the High Desalination case, but in the shallow areas.

Figure 4: Change in average bottom seawater temperature from adding brine impacts to climate change

a) Mapped summary of results

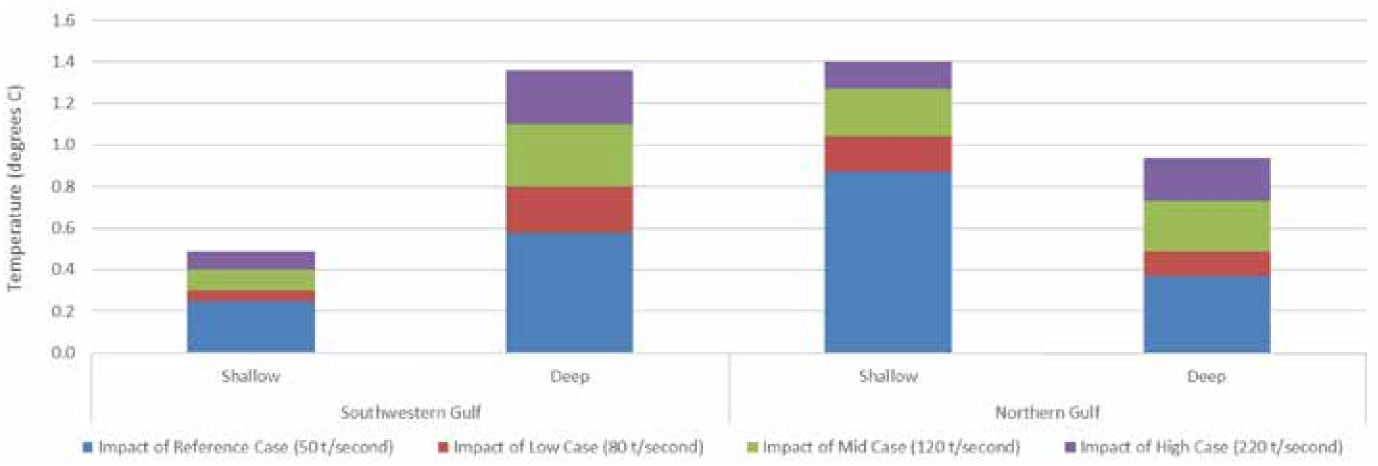


Desalination activities will also significantly impact maximum surface and bottom temperatures throughout the Gulf.

Desalination impacts on maximum temperatures far exceed those on average temperatures, as evidenced by three outcomes of the modelling for the Southern Gulf. First, bottom layers in deep areas of the Southern Gulf experience maximum temperature increase from desalination about 3 times greater than the average increase; 4.1°C average temperature increase compared to only a 1.4°C average temperature increase. Second, in surface layers in the Southern Gulf, climate change represents the overwhelming majority of the impact on maximum temperature, accounting for between 74% (1.0°C) and 91% (1.7°C) of the total increase in maximum temperature. Third, in bottom layers throughout shallow and deep areas of the Southern Gulf, desalination represents the entire impact on maximum temperature. Under climate change, maximum temperatures actually decrease in bottom layers through the Southern Gulf. With desalination, maximum temperatures are projected to increase up to 6.6°C and 4.2°C in shallow and deep areas, respectively.

Figure 4: Change in average bottom seawater temperature from adding brine impacts to climate change

b) Graphical summary of results (incremental average temperature change per desalination scenario)



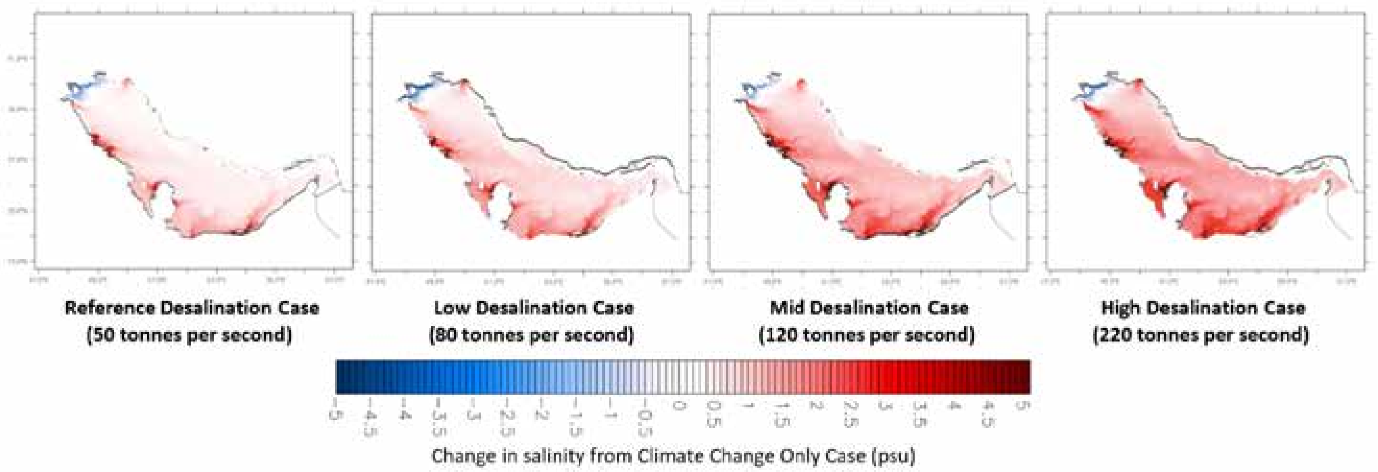
4. Impact of climate change and desalination on salinity

Desalination activities will significantly impact average surface and bottom salinity throughout the Gulf.

This is illustrated in Figure 5a, which shows the difference in average bottom salinity for the four scenarios of future desalination activity over and above climate change. The differences in average salinity levels correspond to the middle of the 21st Century (i.e. 2040 to 2049). In the southwestern area of the Gulf, average salinity levels are projected to increase up to about 1.5 practical salinity units (psu) in deep areas in the High Desalination case. In the Northern Gulf, average salinity levels are also projected to increase up to about 0.9 psu in the High Desalination case, but in the shallow areas.

Figure 5: Change in average bottom seawater salinity from layering Desalination Cases onto the Climate Change Only Case, 2040-2049

a) Mapped summary of results

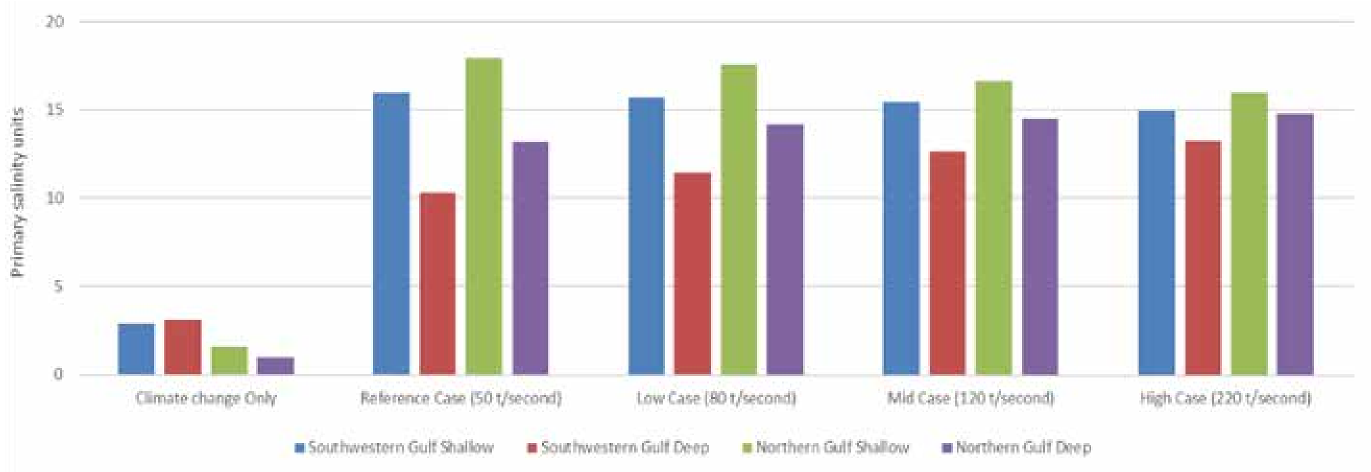


Desalination activities will also significantly impact maximum surface and bottom salinity throughout the Gulf.

This is illustrated in Figure 5b which shows the magnitude of how maximum salinity levels change relative to average salinity levels in shallow versus deep areas, as well as in southwestern versus northern areas. In the southwestern area of the maximum salinity is projected to increase up to about 1.6 psu in shallow areas above average salinity levels. In the northern Gulf, maximum salinity levels are projected to increase up to about 1.8 psu above average levels, also in the shallow areas.

Figure 5: Change in average bottom seawater salinity from layering Desalination Cases onto the Climate Change Only Case, 2040-2049

b) Graphical summary of results (difference between maximum and average salinity)



5. Caveats and limitations

It is important to note that there are cascading uncertainties inherent to the results.

This is common to research efforts of this type and is a direct function of the uncertainties underlying the Earth System Models that serve as the basis for regional modelling experiments. Such models typically display high internal variability and are in a constant state of improvement and software updating, as methods improve and scientific knowledge evolves. The following bullets highlight priority areas for further work that could help quantify and reduce these uncertainties, thus improving the basis for the future policymaking under climate change.

- Apply an ensemble approach to estimate impacts on the Gulf. A natural evolution of the current regional ocean-modelling framework would be to use several different experiments from the same ensemble (MPI-MR), reproducing the same ensemble approach to bracket uncertainties. This would increase the robustness of the understanding of overall Gulf dynamics. This would also enable a quantification of how uncertainties propagate within the regional ocean model itself.
- Capture the impact of climate change on local sea level rise. Future sea level rise may affect both seawater temperature and salinity. Sea level rise scenarios for the Arabian Gulf could be either a) integrated into the current modelling framework for explorations beyond the mid-century period or b) incorporated into an ensemble approach focused on specific internal variabilitie or even using direct outputs from multiple earth system models.
- Increase the number of saline rivers. Ideally, the spatial and performance characteristics of all existing and proposed desalination facilities would be represented at their actual brine discharge locations. For all Gulf countries, this would amount to 486 locations at present, with additional points to denote unplanned additions to meet future desalinated water demand.
- Run additional experiments to better characterize short-term and micro-scale Gulf dynamics. It would be good to extend and fine-tune Arabian Gulf circulation behaviour relative to short-term forcing sources to explicitly model, for example, the impact of tides, whose effects have been parameterized in the current modelling framework, and sea breezes, whose effects have been ignored in the current modelling framework.

6. Conclusions and recommendations

This study has explored the combined impacts of climate change and desalination on the physical properties of the Gulf.

Desalination is likely the only possible water supply option for the hyper-arid countries of the Arabian Peninsula. However, the intensification of desalination activities within an already stressed Arabian Gulf may pose adverse environmental implications under climate change. Desalination processes lead to hot brine concentrate that is discharged into the Arabian Gulf, leading to changes in temperature and salinity levels. When combined with changes in temperature and salinity levels from climate change, the resulting impacts suggest the need to assess potential options to mitigate these impacts.

The results of the study ultimately pose significant implications for water resource management in the region.

Water stress is a chronic condition for the Arabian Peninsula countries that has become one of the region's greatest planning challenges. This reality is driven by the region's hyper-arid environment, dwindling fossil groundwater supplies, strong economic growth, increasing urban populations, along with steady and encroaching effects of climate change. Given that there are no other long-term and sustainable options than desalinated water, one key planning challenge is to identify adaptation options that can increase the resiliency of the water supply system and improve the environmental performance of the desalination process under climate change.

There are numerous options and measures to mitigate the incremental changes in salinity and temperature from brine concentrate disposal (Cooley et al., 2013; Younos, 2005; Laspidou et al., 2010; Bombar et al., 2016; Jenkins et al., 2012; NRC, 2008).

Each disposal method has a unique set of advantages and disadvantages. It is recommended that planners in the region consider a number of key factors within future efforts to limit adverse impacts to the Gulf from desalination activities. These factors include the volume or quantity of the concentrate, the quality of the concentrate, the location of the desalination plant, capital and operating costs, and the ability for future plant expansion, amongst others. A brief overview of selected potential options is provided in the bullets below.

- Disposal to Front of Wastewater Treatment Plant. This option would involve the delivery of brine via pipeline to the front of a wastewater treatment plant. This would eliminate brine discharges to the Gulf but one major concern would be that if the concentrate volume is too large, the level of total dissolved solids in the brine concentrate could have a significant impact on the biological treatment process, possibly to the point of disrupting treatment performance.
- Disposal to End of Wastewater Treatment Plant. This option would involve the delivery of brine via pipeline to the back of a wastewater treatment plant and mix the brine concentrate with the treated water effluent. Mixing the treated wastewater with the high total dissolved solids of the brine concentrate would dilute the brine.
- Land Application. This option would involve the disposal of brine on land using spray irrigation, infiltration trenches, and/or percolation ponds. In this option, the brine concentrate could be used to irrigate salt-tolerant crops and grasses such as those used on golf courses. The feasibility of the option depends on the availability of land, the local climate, vegetation tolerance to salinity, and the location of the groundwater table.
- Deep Well Injection. This option would involve the injection of brine concentrate into deep aquifers that are not used for drinking water or amenity purposes. The depth of the injection wells typically ranges between 0.3 and 2.6 km below the earth's surface. Factors controlling the viability of this option are geological conditions, regulatory constraints, and proximity to aquifers for drinking water.
- Evaporation Ponds. This option would involve the construction of evaporation ponds where brine evaporates while salts accumulate at the bottom of the pond. The Gulf region's high evaporation rates actually favor this option. Pond liners would be needed in order to prevent saline water from leaking into the groundwater.
- Zero Liquid Discharge. This option would involve the use of an evaporator device to convert the liquid brine concentrate into a dry solid which could then be disposed of in a landfill. As a result, the brine water disposal challenge is converted into a solid waste disposal. Proper design of the landfill would be needed to prevent chemical leaching into the groundwater.
- Brine Concentrators. This option would involve the use of brine concentrators to reduce the volume of concentrate to about 2% of intake flow. Brine concentrators consist of heat exchangers, deaerators, and vapor compressors to convert liquid concentrate into concentrated slurry. With this technology, roughly 95% of wastewater can be recovered as high purity distillate with a concentration of total dissolved solids of less than 10 mg/liter.

An actual choice of mitigation option(s) depends on additional factors that tend to be very site-specific (NRC, 2008). These include hydrologic conditions, low season discharge levels, permitting requirements, the concentration of chemicals, and the toxicity of the brine (NRC 2008).

As a potential way forward, a 5-step process could be considered for new and/or existing desalination facilities, as outlined in the bullets below.

- Develop a comprehensive database: This would involve the design of country-level databases to document desalination plant performance characteristics (e.g. average daily brine discharge), site-specific factors (ambient seawater conditions in vicinity of the brine discharge outlet pipe), and brine mitigation option characteristics (e.g. costs and performance).
- Design a brine mitigation screening process: This would involve the design of country-level (i.e. stakeholder-driven) screening processes, as appropriate, for assessing the viability of mitigation options and prioritizing potential options for subsequent review.
- Undertake a multi-criteria assessment process. This would involve the implementation of the screening process to establish a priority ranking of mitigation options. The results of the process would be an ordinal ranking ranging from "1" (most desirable) to "5" (least desirable) for each potential mitigation option.
- Undertake modelling on priority mitigation options: This would involve modelling at either the regional or national level to assess the impact of the priority mitigation options identified in the screening process on the Gulf's physical properties as well as on greenhouse gas emissions and local air quality.
- Update environmental regulations: The results of the assessment could then be used as a basis for developing new environmental regulations regarding brine discharges to the Arabian Gulf from new and/or existing facilities.

Areiqat, A., & Mohamed, K. a. (2005). Optimization of the negative impact of power and desalination plants on the ecosystem. Desalination, 185(1-3), 95–103. doi:10.1016/j.desal.2005.04.038

Bombar, G., Dölgen, D, and Alpaslan, N., 2016. "Environmental impacts and impact mitigation plans for desalination facilities," Desalination and Water Treatment, Volume 57, Issue 25.

Cooley, H., Ajami, N., and Heberger, M., 2013. "Key Issues in Seawater Desalination in California - Marine Impacts" Pacific Institute

Dawoud, M. a, & Mulla, M. M. Al. (2012). Environmental Impacts of Seawater Desalination : Arabian Gulf Case Study. International Journal of Environment and Sustainability, 1(3), 22–37.

Edson, J, Wainer, I., and Ferrero, B, 2015. "Regional Ocean Modelling: A Numerical Study of the Impact of Climate Change on the Arabian Gulf", Final Report for AGEDI's Local, National, and Regional Climate Change Programme

Global Water Intelligence (GWI). 2015. DesalData database.

Hoepner, T. and Lattemann. S., 2002. "Chemical impacts from seawater desalination plants - a case study of the northern Red Sea", Desalination 152 (2002) 133-140.

Jenkins, S., Paduan, J., Roberts, P., Schlenk, D., & Weis, J. (2012). Management of Brine Discharges to Coastal Waters Recommendations of a Science Advisory Panel. Retrieved from http://www.waterboards.ca.gov/water_issues/programmes/ocean/desalination/docs/dpr051812.pdf

Laspidou, C., Hadjibiros, K., and Gialis, S., 2010. "Minimizing the Environmental Impact of Sea Brine Disposal by Coupling Desalination Plants with Solar Saltworks: A Case Study for Greece", Water, 2, pp. 75-84

Lattemann, S., & Höpner, T. (2008). Environmental impact and impact assessment of seawater desalination. Desalination, 220(1-3), 1–15. doi:10.1016/j.desal.2007.03.009

Mohamed, K. A. (2009). ENVIRONMENTAL IMPACT OF DESALINATION PLANTS. In the Thirteenth International Water Technology Conference, IWTC (pp. 951–964). Hurghada, Egypt.

National Research Council, 2008. "Desalination: A national prespective", Committee on Advancing Desalination Technology

Shchepetkin, A., & Mcwilliams, J. (2005). The regional oceanic modelling system (ROMS): a split-explicit, free-surface, topography-following-coordinate oceanic model. Ocean Modelling, 9(4), 347–404. doi:10.1016/j.ocemod.2004.08.002

Uddin, S. (2014). Environmental Impacts of Desalination Activities in the Arabian Gulf. International Journal of Environmental Science and Development, 5(2), 114–117. doi:10.7763/IJESD.2014.V5.461

World Bank, 2004. "Seawater and Brackish Water Desalination in the Middle East, North Africa and Central Asia", Final Report, December.

Xu, P., Cath, T, Robertson, A., Reinhard, M., Leckie, J., Drewes, J., 2013. " Critical Review of Desalination Concentrate Management, Treatment and Beneficial Use", Environmental Engineering Science, Volume 30, Number 8.

Younos, T., 2005. "Environmental Issues of Desalination", Journal of Contemporary Water Research & Education, Issue 132, pp 11-18, December

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.

For more information, visit www.ead.ae.

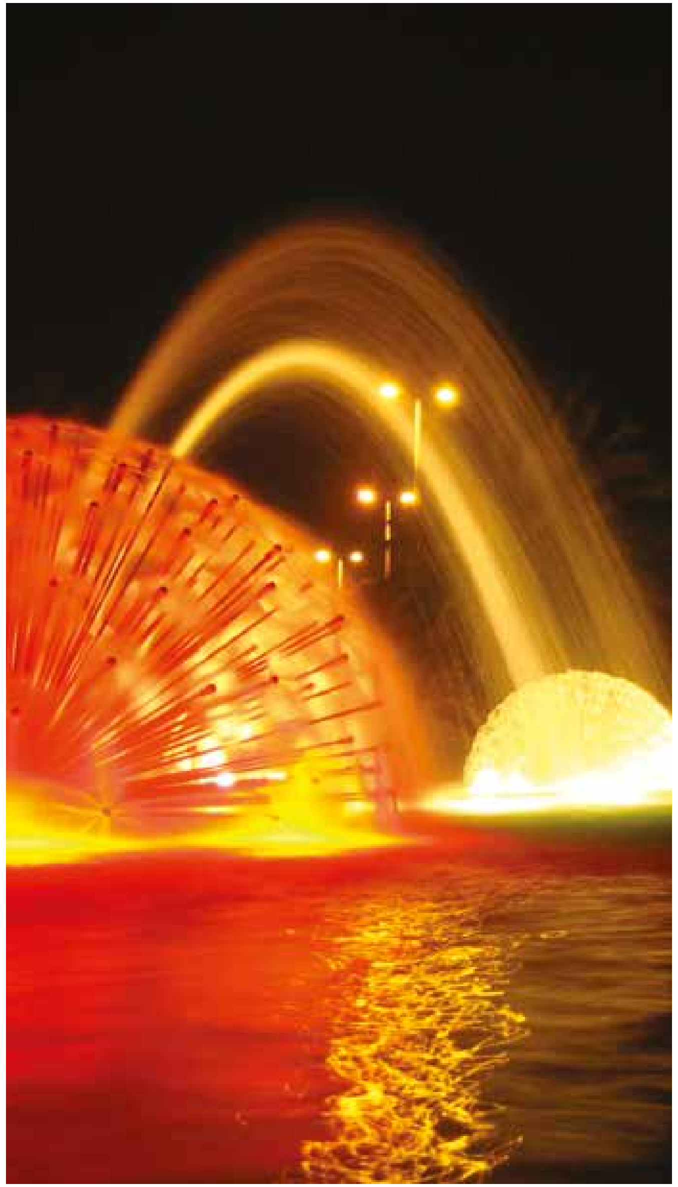
All reports and resources are available for download at www.agedi.org and on our Climate Change Inspectors Online Portal, http://www.ccr-group.org/cc-inspectors

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 in 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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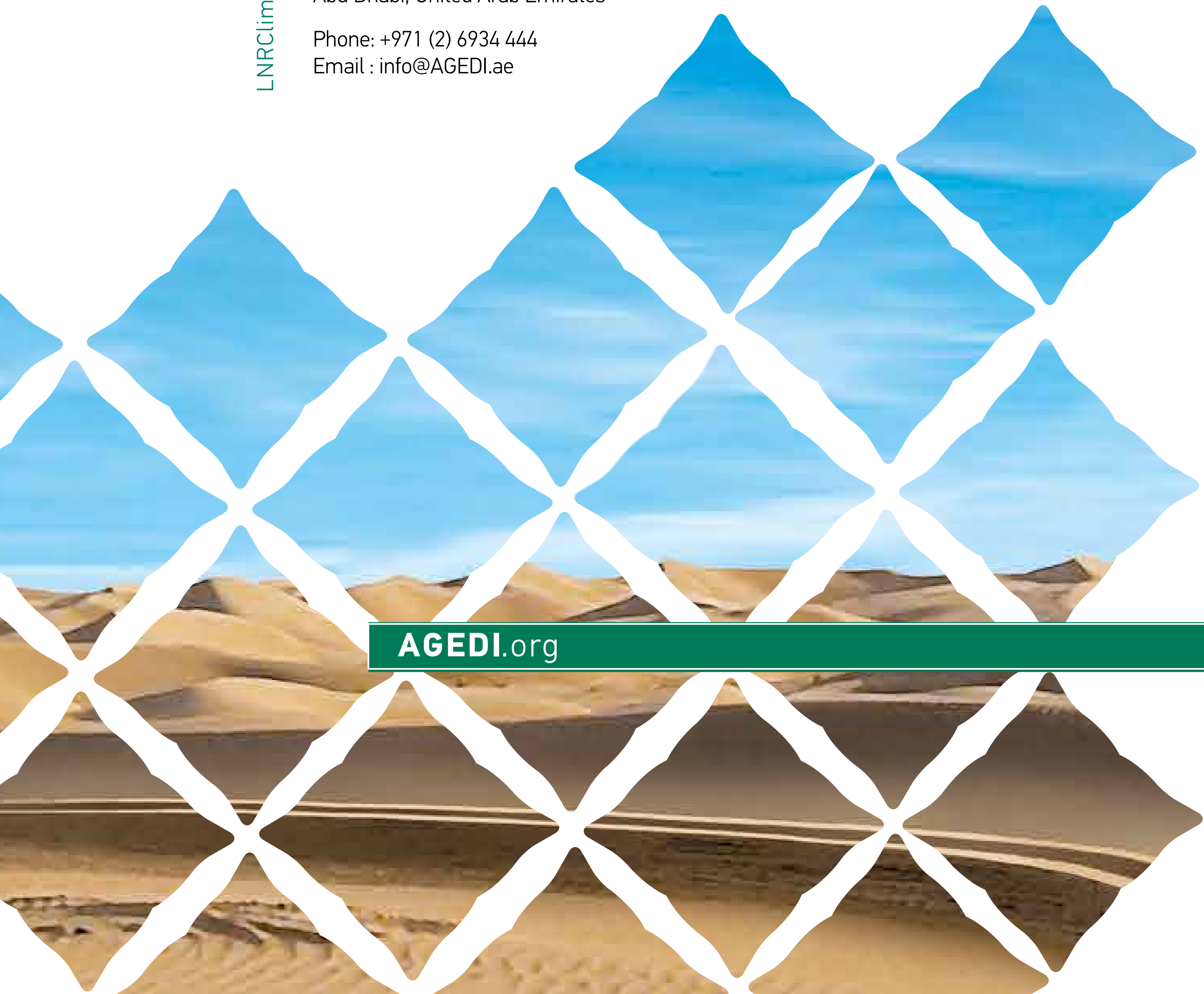

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