SHEIKH SAUD BIN SAQR AL QASIMI FOUNDATION FOR POLICY RESEARCH
مؤسسة الشيخ سعود بن صقر القاسمي لبحوث السياسة العامة

Policy Paper 67 October 2023

Mapping the Growth of Mangrove Forests in the United Arab Emirates from 2010 to 2020

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Executive Summary

Mangroves have a long rich history in the United Arab Emirates (UAE). Over time they have served as an important cultural, economic and ecological resource. To fully conserve these important ecosystems, it is essential to have accurate maps of their current and historical extent. Remote sensing is an excellent tool for the creation of this type of data. This paper tests the use of the Google Earth Engine Mangrove Mapping Methodology (GEEMMM) (Yancho et al., 2020) to monitor mangrove change in the UAE from 2010 to 2020. The maps developed are consistent with other research and show mangroves in the UAE have expanded to a total area of 169 km2, which is an increase of 34 km2 over the ten years included in this study. It further proposes that Ras Al Khaimah could utilize this approach to continue monitoring mangrove change in order to improve conservation and better understand how environmental conditions impact mangrove ecosystem health.

Introduction

It is widely understood that the presence of mangrove ecosystems in the United Arab Emirates (UAE) has changed over time (Friis & Burt, 2020). In the UAE, the term 'mangrove' refers specifically to the gray mangrove (Avicennia marina) which is the only naturally occurring mangrove species in the Arabian Gulf (Alsumaiti & Shahid, 2019). Gray mangroves span across several countries, from Japan to New Zealand in the east, and to South Africa and the Arabian Gulf in the west (Spalding et al., 2010). Gulf populations are among the most high-latitude populations in the world, and these local mangroves are uniquely adapted to the extreme environmental conditions here (Friis et al., 2021).

Whether there are more or less mangroves in the UAE, depends on where and when you are looking. A complex set of ecological and development-related factors determine if mangroves are expanding or declining (Burt et al., 2021). There are numerous examples where urban development and expansion has degraded or replaced coastal ecosystems (Burt, 2014; Goudie et al., 2000). There are also examples of conservation efforts that have resulted in the protection of mangrove forests. The planting of mangroves in the Ras al Khor wetland in Dubai is one example of the extensive planting (i.e. afforestation) of mangroves in many areas across the UAE (Erftemeijer et al., 2021; Lamine et al., 2020; Ryan et al., 2012). There are also likely less direct ways (i.e. air and water pollution, dredging) that urban development has led to more or less desirable environmental conditions for mangroves (Embabi, 1993; Paleologos et al., 2019). Attempting to understand how all of these environmental changes affect mangroves is difficult. However, using satellite imagery to create maps of mangrove areas over time can help us understand where increased development or environmental change has impacted mangroves in the UAE.

This is not the first study to utilize remote sensing to understand mangroves in the UAE. In previous studies, remote sensing was used to quantify land cover and mangrove change in Abu Dhabi (Fares et al., 2009; Loughland et al., 2007; Yagoub & Kolan, 2006). Yagoub

and Kolan (2006) estimated that mangroves and other woody vegetation in Abu Dhabi decreased from approximately 123 km2 in 1972 to approximately 28 km2 in 2000. More recent work has focused on mangroves in the Northern Emirates and indicate that after years of mangrove loss there has been a significant growth in mangroves recently (Elmahdy et al., 2020).

By using Google Earth Engine (GEE), our research was able to cover a larger geographic area and without having to purchase satellite data. The results provide a new approach that can be used to create frequently updated maps in the future. Exploring historical data could also provide exciting opportunities to better understand the environmental conditions that support thriving mangrove ecosystems. Careful monitoring of the current mangrove ecosystems is an essential tool for conservation now and in the future.

Ecological Importance of Mangroves

Mangrove forests are biologically important ecosystems in the UAE. Gray mangrove roots stabilize sediments offering critical functions like shelter, nurseries, and feeding grounds for a range of animals and other plants (Nagelkerken et al., 2008). Additionally, UAE mangroves have impressive biomass and productivity rates, which make them important ecosystems for storing carbon (Spalding et al., 2010).

The mangroves support diverse biotic communities, including arthropods, mollusks, birds, fishes, and other plant species (Nagelkerken et al., 2008). Crabs are a vital element in the mangrove ecosystem, promoting nutrient recycling through their burrow construction and moving of sediments (Nobbs & Blamires, 2015). Mollusks populate the soft sediments and flats, and barnacles are occasionally found on pneumatophores of mangroves (Grizzle et al. 2018). Various species of fish also depend on the ecological functions of the mangroves (Al-Ghais, S., 1993). Birds heavily rely on mangroves for foraging and nesting, with some bird species breeding exclusively in these regions (Aspinall, 1996; Aspinall et al., 2002). Apart from the gray mangroves only a few plant species can cope with the extreme environmental conditions found in coastal areas of the UAE. It is evident that UAE mangroves play a significant ecological role; however, the specific functions and significance of UAE mangroves in coastal biological systems remain relatively understudied.

Cultural and Economic Importance of Mangroves

Unlike many parts of the world which have historically viewed mangroves as more of a nuisance than a resource, the UAE has a long history of seeing mangroves as an important economic and cultural resource (Beech & Hogarth, 2002; Beech & Kallweit, 2001; Lugo & Snedaker 1974; Uerpmann & Uerpmann, 1996). Given the high temperatures and limited freshwater resources, mangroves are the only natural evergreen vegetation. In the past, they were highly utilized for fodder and building materials while today, mangrove conservation provides eco-tourism opportunities and ecological benefits (Vaughan et al., 2019).

Mangroves have historically been used for food and construction which has been confirmed through archeological research. The giant mangrove whelk and mangrove crab, for example, are habitants of mangroves and have been found in the waste piles of Stone Age and Bronze Age settlements in the UAE (Beech & Hogarth, 2002; Beech & Kallweit, 2001; Goudie et al., 2000; Lindauer et al., 2017). Mangroves were also used to feed camels (Lieth & Lieth, 1993; Llewellyn-Smith, 2012), and for home construction and boat building in the region (Beech and Hogarth, 2002; Goudie et al., 2000).

The discovery of oil and a changing UAE economy in the 20th century resulted in less dependence on coastal ecosystems but also an increase in coastal development and environmental pressure on mangrove ecosystems (Burt, 2014). To ensure that mangroves were protected, H.H. Sheikh Zayed bin Sultan al Nahyan, President of the UAE, restricted harvesting and initiated plantings in the late 1970s (Lieth & Lieth, 1993; Saenger et al., 2002). During the 1980s and 1990s, there was interest in growing salt-tolerant plants, like mangroves, that could be used for food, materials, and other needs (Lieth & Al Masoom, 1993).

In the 21st century, the cultural and economic value of mangrove ecosystems has shifted from agricultural ecosystems, where resources are extracted, to ecosystems that should be conserved for their ecological and recreational value, as well as their "blue carbon" value in sequestering carbon dioxide (Schile et al., 2017). Through protection and planting programs developed in the previous decades there are signs of mangrove expansion (EAD, 2011).

From 1995 to 2019, tourism increased from less than 1% of the UAE gross national product to more than 9.2%. The growth in tourism corresponds with 20 million more visitors per year (WorldData.info, n.d.) . Mangrove parks provide an opportunity for visitors to experience the natural resources of the UAE. Kayaking tours are a popular way to explore the Mangrove National Park in Abu Dhabi and the mangrove ecosystems in Ras Al Khaimah. Ras al Khor in Dubai provides a walkway and bird-hides where tourists can observe flamingos (Ryan et al, 2012). These sites not only attract international tourists but also provide educational opportunities for local schools. The link between education, tourism and conservation were highlighted during a visit to the UAE by Prince William in February 2022, when his schedule included planting mangroves in Jubail Mangrove Park, which opened in January 2020 to help protect biodiversity and raise awareness of the UAE's mangrove ecosystems (Forster & Maxwell, 2022).

While mangroves provide eco-tourism opportunities, the economic growth of the region has led to habitat loss and environmental degradation in some areas due to coastal development (van Lavieren et al., 2011). At the same time there is an increasing interest by residents of the UAE to protect these ecosystems (Assaf et al., 2022). The majority of residents recently surveyed in Ras Al Khaimah support preservation of the mangroves over economic development, but the desire to protect these ecosystems does not seem to be driven by a knowledge of the important ecosystem services they provide (Assaf et al., 2022). Whether or not the general public can clearly identify the environmental and economic value of these ecosystems, there has still been an increased interest in seeing these ecosystems continue to thrive (Assaf et al., 2022).

Monitoring Mangrove Change

To fully understand the conservation of mangroves, it is necessary to first access tools that allow for mapping and monitoring the extent of the forest. Once we have the area of mangrove forests, we can then calculate the change in area of mangrove ecosystems over time. In the past, analysis of satellite imagery required specific remote sensing software, extensive computing power, and the purchase of actual satellite data (in this case Landsat data). However, the development of the Google Earth Engine (GEE) interface has made these types of analyses more accessible. The Landsat data has also been processed and is now available at no cost via Google's servers, which can be accessed via a web browser.

Mangroves from Space

The satellite data used for this analysis was collected from the Landsat satellite system. Landsat data has been collected around the world approximately every two weeks since the 1970s. The satellite sensors have changed over time, but the red and near-infrared radiation has been consistently included in the imagery at a 30 m by 30 m resolution (See Figures 1 and 2). A combination of red and near-infrared data was used to identify areas covered with mangroves.

Figure 1: Example of a true color Landsat image of Ras Al Khaimah.

Note. Mangroves can be seen as the dark green vegetation in the middle of the khor.

Figure 2: Example of color-infrared Landsat image of Ras Al Khaimah

Note. Note. Areas that are visualized as red have high near-infrared reflectance. These red areas are vegetation and the majority of the vegetation is mangrove.

Google Earth Engine Mangrove Mapping Methodology

The Google Earth Engine Mangrove Mapping Methodology (GEEMMM) was developed by Yancho et al. (2020) to enable mangrove mapping around the world. The authors provide a series of Google Earth Engine scripts that guide the user through the analytical processes. It requires knowledge of remote sensing and basic coding but is accessible to anyone with minimal experience of using the software. The script provides a series of global maps that define coastal areas where mangroves can exist, but users are also able to provide their own regionally appropriate maps. Users only need to define the region of interest for the mapping project, the time periods to be analyzed and the training data used to support classification of the imagery. The region of interest for this study included the entire UAE and the time periods selected were 2010–2012 and 2020–2022.

In January 2020, we visited several locations with various land cover types and recorded the geographic coordinates. The data set provided information that was then used to classify the satellite imagery into six classes which included water, sabkah, salt marsh, mangrove, roads and sand. For the purposes of our research we focused solely on mapping the mangroves.

Most of the coastal vegetation in the UAE is comprised of mangrove forests which makes it easier to map them accurately from satellite. This is not always the case with imagery and distinguishing between similar types of vegetation like mangroves and palm trees, for example, is oftentimes difficult. Distinguishing landcover types like vegetation versus water or vegetation versus sand is easiest. Trees along streets, green spaces, and salt marsh can also be mistaken for mangroves from space satellites. Therefore, we used high resolution imagery provided by ESRI in ArcMap to visually compare our results with areas that had been confirmed as mangrove forests from the 2020 and 2022 ground-truthing exercises (Figure 3). The initial results of the GEEMMM created maps that mapped all or most of the known mangroves in the UAE, but also erroneously included terrestrial vegetation, especially along roads, which it misclassified as mangrove (Figure 4), resulting in a biased over-estimate of mangrove area for the UAE. In order to improve the estimates, terrestrial vegetation was removed using a general map of the UAE boundaries (Figures 5 & 6). This extra step improved the map by removing street vegetation, but in some cases also removed some coastal mangroves and resulted in a conservative estimate of mangrove area. This process was also repeated for the maps created for 2010–2012.

Figure 3: High resolution imagery from ESRI Arc Map showing Ras Al Khaimah

Note. Mangroves can be seen as dark green vegetation in the center of the image.

Figure 4: Map of mangroves in Ras Al Khaimah for the 2020–2022 time period as calculated by GEEMMM which includes terrestrial vegetation

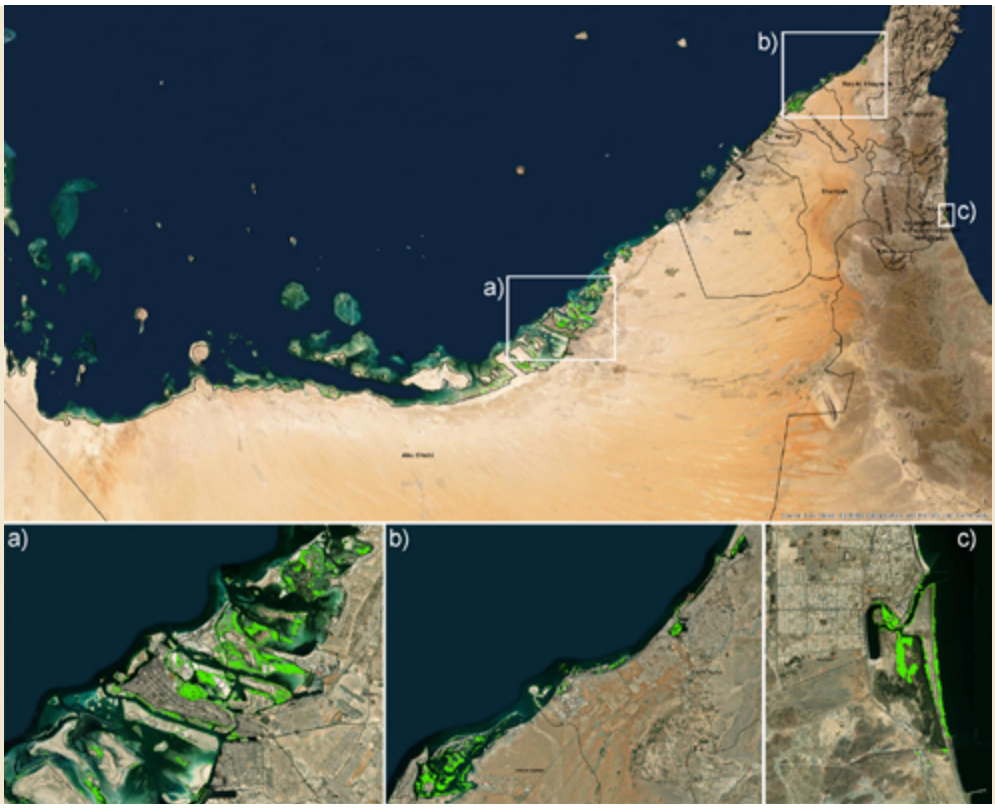
Figure 5: GEEMMM map of mangroves in Ras Al Khaimah with terrestrial vegetation removed for the 2020–2022 time period

Figure 6: GEEMMM map of mangroves in Ras Al Khaimah with terrestrial vegetation removed for the 2010–2012 time period

Mangrove Changes Across the UAE

The coastal topography of the UAE creates a patchwork of mangroves across the UAE. Most of the mangroves are found in coastal lagoons. However, as shown below in Figure 7, there are also areas of linear mangroves along shorelines. Findings from this study are consistent with studies on mangroves in the UAE and confirm the areas of mangrove ecosystems across the region. Similar to Al Habshi et al. (2007) (40 km2) and Moore et al. (2014) (136 km2), we calculated that in 2010 there were 135 km2 of mangroves in the UAE. The 2020–2022 map shows mangrove areas increased from 34 km2 to a total area of 169 km2. The increase in mangroves over the last decade is at least in part due to widespread planting efforts, but likely also includes areas of natural expansion as many are distant from shorelines and conservation areas (e.g., the interior lagoon of Weheil Island in Abu Dhabi). Further analysis of the data can help understand the human and environmental drivers of this change to support future conservation of these valuable ecosystems.

Figure 7: Map of mangrove extent across the UAE with detailed areas around a) Abu Dhabi, b) Ras Al Khaimah and Umm Al Quwain, and c) Fujairah



Policy Recommendations

This policy paper provides a proof-of-concept and a workflow that could easily create updated maps of mangroves across the UAE every couple of years. It could also be used to create a longer historic record of mangrove changes. For future mapping, the process would likely be more accurate with two minor modifications in approach.

First, the complex shorelines and extensive tidal zone of the UAE can lead to mangroves being mapped in non-coastal areas. One way to avoid this would be to create a more detailed map of the coastline. The boundary map that was used to create the maps presented above was far too coarse and resulted in a large section of mangroves being removed from the map in Ras Al Khaimah. Additionally, it may help to increase the amount of data collected for other types of vegetation, for example street trees, golf courses and parks, to increase the accuracy of mangrove classification versus other vegetated areas.

The analysis completed in this paper provides evidence that it is possible to create frequent maps of mangrove cover for Ras Al Khaimah and the wider UAE coastline. These maps are an essential tool for mangrove conservation. Being able to see the size and extent of mangroves allows decision makers to assess the success of past programs to plant or protect mangroves. They can also be used to find new areas of growth that could be protected in the future. Additionally, looking at the history of past mangrove change could be important to understanding the complex ways urban development has impacted these ecosystems with a holistic view of the entire UAE.

If there is interest in creating more frequent maps, decision makers could create policies to encourage public participation in data collection. The collection of land cover point data could be easily accomplished through a well-designed citizen science program. People can use their phones to collect the locations of mangroves and other landcover. A program called ODK was used to collect the data for this analysis and can be used on any Android device to collect the geographic coordinates, a verbal description, and a picture (for verification).

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