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Sea Level Rise and Abu Dhabi Coastlines: An Initial Assessment of the Impact on Land and Mangrove Areas

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Abstract

The effects of climate change are now becoming more detectable because of the alarming rate of observed changes in our planet. One of the more devastating outcomes of climate change has been sea level rise (SLR). The present study aims at developing preliminary models of SLR and its effects on the coastlines of Abu Dhabi Emirate. A second aim has also been to develop a natural vulnerability index for decision makers and stakeholders to develop action plans in areas most vulnerable to SLR. For urban areas, the level of damage due to SLR would rise to 9.45% and 15.89% in a potential 1.5 m and 2 m SLR scenarios; respectively. The maximum damage to the urban areas would reach about 40% in case SLR attains the 3 m level. Mangrove Ecosystems affected would reach 25.54 Km^2 (or about 81.5% of the study area) under a 3 m SLR scenario. The total land areas that would be affected by the different SLR scenarios reaches a staggering 528 Km^2 (or 30% of the study area) at the 3 m SLR scenario. More than 3% of the impacted area (when considering any of the SLR scenarios) is classified as very highly vulnerable. More than 7% is classified as highly vulnerable. It is strongly believed that any future interventions and preparations to alleviate the impact of SLR should take into account the vulnerable areas highlighted above (i.e. 10.3%). The estimates reported here highlight the gravity of the potential mangrove and land areas affected, even under the lowest SLR level. Early planning for longer term implications will certainly save both time and resources.

Keywords: Climate change; Coastal ecosystems; Global warming; Coastal mangroves; Coastal erosions

Introduction

Most ecosystems of the world will be severely affected by many aspects of climate change, including sea level rise (SLR). The IPCC is highly confident that there has been an increase the rate of sea level rise [1]. Coastal ecosystems will very likely be substantially more impacted than other ecosystems [2]. The increasing rates of SLR as a result of global will worsen inundation and episodic flooding tide in low lying coastal areas [3]. The degree and severity of the effects will depend on our prediction and our preparedness. Human-induced climate change is a living fact and increases in greenhouse gases are warming the Earth. The Intergovernmental Panel on Climate Change (IPCC) has developed a range of 35 climate projections based on several climate models [4]. The projections state that global averaged surface temperatures will increase by 1.4 to 5.8°C from 1990 to 2100 [5]. Accurate predictions of climatic changes due to the above factors are therefore needed in order to properly prepare for any detrimental effects on the livelihood of any country. The above is certainly true when it comes to rising sea level due to global warming. Advanced planning for targeted sections of coastline would minimize and offset anticipated losses, and reduce threats to coastal development and human safety [6-8].

Rising sea level is a direct result of global warming and climate change and has been predicted for many decades globally and regionally. Variations in predictions are enormous in many instances. Even the IPCC estimates have been criticized as too conservative [9]. Kerr [9] concludes that an improved estimate of sea level rise (SLR) puts the increase at roughly 3.5 times the IPCC projections. This is a serious prediction as a one meter sea level rise would flood 17% of Bangladesh, for instance, displacing tens of millions of people, and reducing its rice-farming land by 50% [9]. Globally, it would create more millions of environmental refugees and inundate vaste areas in many parts of the world [10]. These studies provide further evidence that we must take action to address global warming as soon as possible to avoid such consequences [11].

And coastal ecosystems are more prone to such devastating effects, because of the direct and immediate effects of negative impacts of climate change such as SLR on coastlines and the associated vegetation.

Coastlines are undergoing constant changes because of natural and human induced factors [12]. The impact of climate change and associated sea level rise will reshape coastlines in the future [12]. It was predicted that coastal mangroves will undergo landward progression with possible coastal erosions in response to increased seal level. Even with a considerable degree of uncertainty in using remote sensing to separate mangrove areas from other land cover categories [13].

In contrast, mangroves on the lower limit of its habitat will suffer an average loss of 10 to 15% of its global area [14]. The current rise in sea level will mostly damage arid mangroves including those dominating the UAE coastlines [14].

Potential impacts of SLR will not be distributed uniformly within the Arab region. Egypt, Saudi Arabia, Algeria and Morocco will have the highest impact of SLR [15]. Twelve million people in Egypt, for instance, will be directly affected under a 5 m SLR scenario [15]. As percent of total population, the UAE, Qatar and Bahrain will experience the highest population impact because of SLR [15]. Estimates report that as much as 7.5% of the population of MENA (Middle East and North Africa) region will be affected by a 5 m SLR, and more than

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7% of wetlands will be damaged [16]. Unfortunately, nearly the entire population of the UAE, particularly in Abu Dhabi emirate, is concentrated on the coastal strip, islands and associated estuarine systems. In addition, most of the ongoing developments throughout the country are either located on the seashore or on man-made islands.

Approximately 5% of the population of United Arab Emirates would be impacted by a 1m SLR [16]. The urban extent of the region would also be significantly impacted. In Egypt, Libya, United Arab Emirates, and Tunisia, the impact reaches approximately 5% with a 1 m SLR, 6 to 7% with a 2 m SLR, and approximately 10% with a 5 m SLR. The wetlands of Qatar and to a lesser extent Kuwait, Libya, and United Arab Emirates would be significantly impacted by SLR [16].

An integrated approach to deal with rising sea level is therefore necessary in order to predict the environmental as well as the socio-economic effects. The concept of Integrated Coastal Zone Management (ICZM) is considered a good approach for this purpose, because it can combine the control of socio-economic development patterns, natural hazards prevention, and natural resource conservation at the same time [17]. This was also a recommendation of a study conducted in Egypt [18]. Using ICZM, therefore, in identifying coastal areas vulnerable to the effects of the expected rise in sea levels would go a long way in predicting the outcomes.

The objectives of the current work are therefore to (1) assess the impact of SLR on the coastline of Abu Dhabi Emirate, (2) identify susceptible coastal portions of Abu Dhabi Emirate, (3) assess the impact of 5 SLR scenarios on mangrove population and (4) develop a vulnerability index that incorporates simple natural variables that are critical for Abu Dhabi Emirate.

Materials and Methods

Study area

The study area is a large section from Abu Dhabi coastline. It ranges from 24.4.58N and 54.17.46E at the lower left corner to 24.38.21N and 54.42.24E at the upper right one. This area is characterized by heavy developmental plans. Also it contains many important mangrove forests. The study area includes Abu Dhabi city and Saadiyat and Yaas Islands to the East.

Approach

The main software packages used in the data preparation and data analysis are ESRI Arcgis 9.3. Arcgis was used for the Shuttle Radar Topographic Mission (SRTM) data analysis and the creation of the Digital elevation model (DEM) acquired from NASA database. Arcgis (arc-Hydro) was used to develop SLR scenarios. Google earth pro, together with field observations, were used to identify mangrove distributions, other various land uses, ecological status as well as the human activities within the study area. The source of the DEM data was the NASA - SRTM (DEM-30 m resolution). Some information for the sea floor bathymetry of the study area was acquired from The GEBCO Digital Atlas (GDA). Landsat-7 images, referenced under N-40-20 (year 2000), were used as the baseline data. Field observations on mangrove distribution, variations of land uses, urban development and coastal variability were acquired between May and September 2009. Ground truthing was conducted between May and December 2009.

Methods

LANDSAT images were projected using UTM zone 40 N (WGS-84 datum). The DEM of the study area was extracted from the SRTM e20n40 data files. A hill- shade grid of the area was generated from the DEM using the ArcGIS Spatial Analyst extension. Hill shading provides a three-dimensional view of an area in two-dimensions by calculating illumination of each cell of an image based on the specified sun azimuth and altitude. A vertical exaggeration factor was applied to give more depth to a map surface. The following parameters were used for this project to create the shaded relief map: sun azimuth - 315°; sun altitude - 45°; vertical exaggeration was 15. The extracted DEM file was converted from raster to points using the Arcgis spatial analyst. The elevation data points were then extrapolated using the Inverse Distance Weight (IDW) tool of the Arcgis spatial analyst extension to refine the resolution of the original DEM file (cell × cell size) from 0.0083, 0.0083 into 0.0016, 0.0016 cell × cell. The calculated DEM was classified into 30 classes. The final DEM file was then used as the input DEM file into the Arc-hydro model to produce the sea level inundation scenarios. Five scenarios were produced (SLR from 0.2 to 0.5 m; SLR from 0.5 to 1.5 m; SLR from 1.5 to 2 m; SLR from 2 to 2.5 m and SLR from 2.5 to 3 m; referred to in the rest of the document as 0.5, 1.5, 2, 2.5 and 3 m scenarios. The various SLR scenarios were selected based on previously reported studies and the IIPCC reported scenarios. The area of the inundated land after each SLR scenario was calculated using the Arcgis Spatial analyst toolbox [19].

Urban areas, total land and mangrove plantations within the study site were estimated using a supervised classification of the Land Sat satellite image, using ERDAS imagine [20]. Each classified layer (i.e. mangrove, land and urban) was intersected with an inundation extent (for each SLR scenario) to produce exact areas affected by the SLR.

The natural vulnerability index was developed using an average rating - based on 5-scales between 1 and 5 of a combination of slope elevation, coastlines and presence or absence of urban and mangrove areas, within a predefined grid.

Results

Urban areas

Urban areas in any country constitute the core of human well-being and provide indications on standards of living of the population. In Abu Dhabi area, nearly all human settlements are concentrated along the coastlines. This exacerbates the effects of SLR on urban areas. In a 0.5 m SLR scenario about 1.5% of the urban areas will be affected (Table 1 and Figure 1). The level of damage due to SLR would rise to 9.45% and 15.89% in a potential 1.5 m and 2 m SLR scenarios; respectively. The maximum damage to the urban areas would reach about 40% in case SLR attains the 3 m level. Reports indicate a much less effects of SLR on urban areas. It is very important to note that our results reflect losses in relation to the study area, while other investigations - such as that of [16] - report losses in urban areas at country levels. But still there is a strong agreement that the highest level of impact on urban extent (within MENA region) was estimated for the UAE [16], with 5% of the urban areas affected by a 1 m SLR and more than 13% affected by a 5 m SLR [16].

SLR Scenarios	Area - Km^2	Percent Loss
0.5 m	8.1	1.46
2.0 m	88.5	15.89
2.5 m	147.5	26.47
3.0 m	220.5	39.57

Table 1: Areas of urban (developmental) loss due to 5 potential sea level rise (SLR) scenarios, within the study area of Abu Dhabi Emirate.

Mangrove plantations

One of the main objectives of the present work is to assess the potential impact of SLR on mangrove plantations. Table 2 and figure 2 below summarizes the total areas of mangrove forests that would potentially be inundated because of SLR, assuming 5 scenarios. A total of about 1.67 Km^2 (or 5.35% of the study area) will be affected under a 0.5 m SLR. A total of more than 14 Km^2 (or about 44.7% of the study area) will be affected under a 1.5 m scenario. The maximum area affected reaches 25.54 Km^2 (or about 81.5% of the study area) under a 3 m SLR scenario. The above estimates highlight the gravity of the potential mangrove areas affected, even under the lowest SLR scenario. The estimates in the present study are far more alarming than what was reported by [8] in the Pacific Island countries. By the year 2100, a reduction in area by as much as 13 percent of the current mangrove plantations of the 16 Pacific Island countries and territories where mangroves are indigenous are possible [8]. It is worth noting that our results refer to percentage of the study area rather than percentage of the total UAE area. It is therefore imperative as well as necessary to adopt an action plan to overcome such devastating effects of SLR on the UAE coastlines, specifically mangrove ecosystems. These ecosystems have ecological, social and economic values. Consequently and compared to just a few decades ago, the ever-increasing number and strength of forces affecting coastal ecosystems, including mangroves, require coastal managers to respond and adapt to ensure the sustainability of valued ecosystem services and products [8].

Total land area

The total land area that would be affected by the deferent SLR scenarios (Table 3 and Figure 3) would reach a staggering 528 Km^2 (or 30% of the study area). At the 0.5 m SLR scenario, 3.5% of land would be affected, while at the 1.5 m, 2 m and 2.5 m SLR scenarios, 14.5%, 20% and 27.1% of land would be affected; respectively. This again an alarming indication of how much loss would the area is subjected to even in case of the lowest SLR scenario. If we extrapolate this at the Emirate level, it would mean about 0.8% of the total land area of Abu Dhabi Emirate would be lost in case of a 3 m SLR scenario. While this percentage may seem to some as minimal, it is crucially important to note that the loss would be concentrated on the coastal areas, where most people and infrastructure is located. It is also far less than what was projected by [15] for Qatar and Bahrain to be about 13.5% and 7% of their land; respectively.

Natural vulnerability index

When dealing with phenomenon such as SLR, it is prudent to develop a vulnerability index to highlight areas where intervention should be targeted. This will minimize the impact of SLR and will direct resources to address the issue.

In general terms, areas of high vulnerability of any potential SLR impact are located between Musaffah and the main Island of Abu Dhabi city, some parts of Madinat Khalifa 1, 2 and 3, and parts of Musaffah industrial area (Figure 4).

For the areas with low current urban extent, large parts of Saadiyat Island show high vulnerability index. The main reason for such high vulnerability indices is the fact that the above areas are characterized by low altitudes (very close to sea level heights) and lack of natural barriers, as many urban developments have impacted their physical features.

More specifically, more than 3% of the impacted area (when considering any of the SLR scenarios) is classified as very highly vulnerable (Figure 4). More than 7% is classified as highly vulnerable. It is therefore believed that any future interventions and preparations to alleviate the impact of SLR should take into account the areas highlighted above (i.e. 10.3%). Any longer term planning should subsequently take into account the areas classified under moderate vulnerability (4%).

In comparison to other studies, our results suggest lower

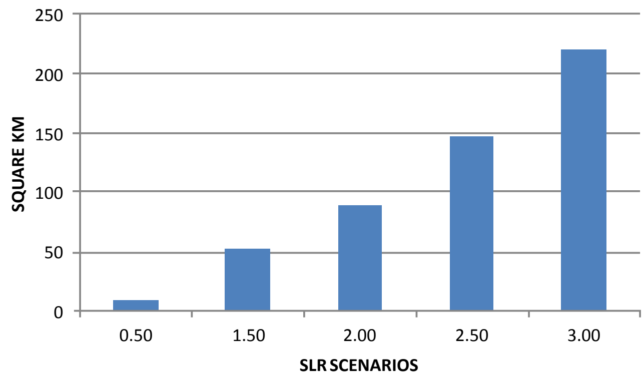

Figure 1: Areas of urban (developmental) loss due to 5 potential sea level rise (SLR) scenarios, within the study area of Abu Dhabi Emirate.

SLR Scenarios	Area - Km^2	Percent Loss
0.5 m	1.7	5.35
1.5 m	14.0	44.7
2.0 m	20.2	64.61
2.5 m	23.4	74.59
3.0 m	25.5	81.5

Table 2: Areas of mangrove loss due to 5 potential sea level rise (SLR) scenarios, within the study area of Abu Dhabi Emirate.

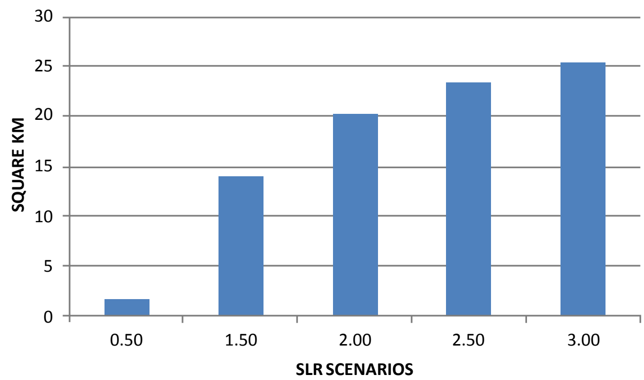

Figure 2: Areas of mangrove loss due to 5 potential sea level rise (SLR) scenarios, within the study area of Abu Dhabi Emirate.

SLR Scenarios	Area - Km^2	Percent Loss
0.5 m	60.4	3.5
1.5 m	252.7	14.5
2.0 m	348.3	20.0
2.5 m	471.7	27.1
3.0 m	528.3	30.3

Table 3: Areas of total land areas affected due to 5 potential sea level rise (SLR) scenarios, within the study area of Abu Dhabi Emirate.

percentages of coast- lines affected by SLR. Regionally [21] reported 17.37% of the total area of Bahrain will be inundated under a 1.5 m SLR. While [22] reported 30% of US coastlines are at very high risk of SLR. The vulnerability assessment did include wave surges and tide ranges, while in our study we included a combination of slope elevation, coast lines and presence or absence of urban and mangrove areas, within predefined grids. The study done in Brazil reported 33% of the study area as having high and very high natural vulnerability index [17].

Regardless of the percentages, it is important to highlight that long term planning would minimize the potential of moderately threatened areas moving into higher classes and therefore would require much more resources and time.

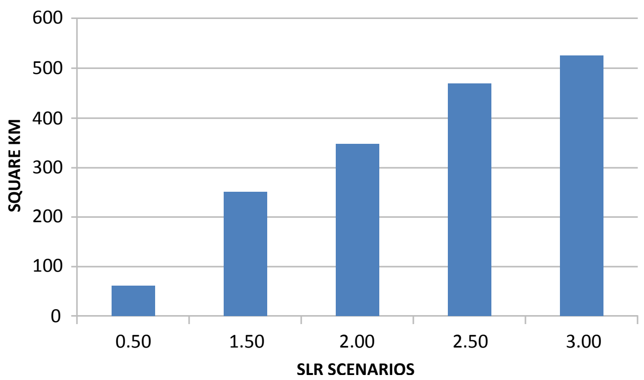

Figure 3: Areas of total land areas affected due to 5 potential sea level rise (SLR) scenarios, within the study area of Abu Dhabi Emirate.

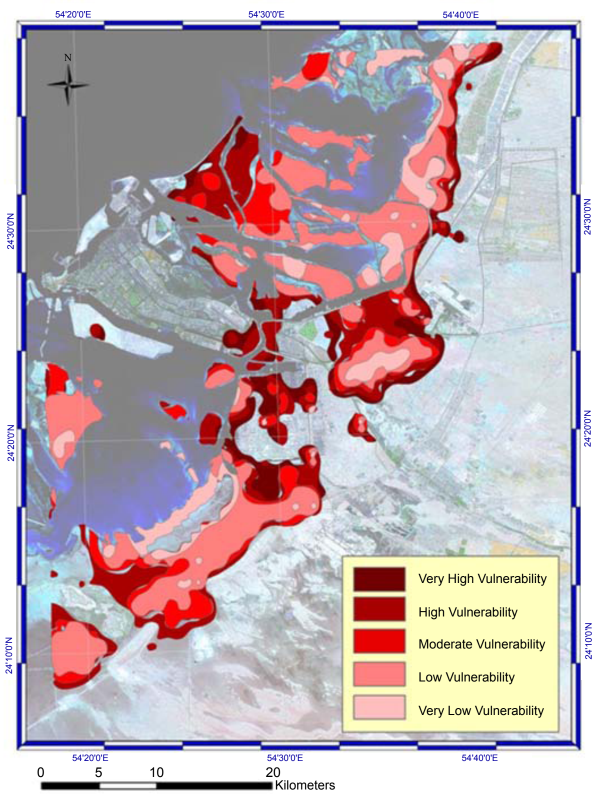

Figure 4: Natural Vulnerability Index (NVI) classes in the study area. Please see text on details about how NVI was calculated.

Vulnerability Classes	Area - Km²	Percent of Study Area
Very High	55.0	3.2
High	123.8	7.1
Moderate	70.4	4.0
Low	206.0	11.8
Very Low	71.5	4.1

Table 4: Vulnerability classification of the study area. Please see text for details on estimation methodology.

Early planning for longer term actions saves both resources and time, which certainly would lead to improved standards of living for many generations to come.

Conclusion

The impact of SLR is imminent and requires careful long term planning to minimize its expected effects in Abu Dhabi Emirate. Our modeling shows a relatively lower percentage of areas classified as highly and very highly vulnerable to SLR (10.3% of the study area). But because of the large populations living on the coastlines of Abu Dhabi coupled with the current developments on coastlines, very careful planning is to be adopted to minimize the impact of SLR on our population and economy. A strategic plan has to be adopted and implemented first in areas identified as having high and very high vulnerability indices (Table 4), and ultimately implemented in areas identified as having moderate natural vulnerability indices.

In order for the UAE to improve its preparedness to any potential effects of SLR, a community based strategy has to be implemented sooner than later. Such approach would integrate the management of coastlines, improve coastal site management, and highlight the necessity to improve management of marine protected areas, reduce stresses on ecosystems (e.g. mangrove plantations), develop a management plan for ecosystem rehabilitation and improve community awareness on coastal ecosystem management.

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