

# Predicting the Extent of Inundation due to Sea-Level Rise: Al Hamra Development, Ras Al Khaimah, UAE. A Pilot Project

## Abstract

As new information is received, predictions of sea-level rise resulting from global warming continue to be revised upwards. Measurements indicate that the rise in sea-level is continuing at, or close to, the worst case forecasts (Kellet et al. 2014). Coastal areas are coming under increasing risk of inundation and flooding as storms are predicted to increase in frequency and severity, adding to the risk of inundation due to higher sea levels. Stakeholders, government agencies, developers and land owners require accurate, up to date information to be able to protect coastal areas. Geographic Information Systems (GIS) along with accurate remote sensing technologies such as LiDAR provides the best means for delivering this information. Using these technologies, this paper predicts the risk posed to a large multi-use development in the emirate of Ras Al Khaimah, UAE. This development, Al Hamra Village, is situated on the coast of the Arabian Gulf. Al Hamra's physical relationship to the Gulf is in common with other developments in Ras Al Khaimah in its and for this reason has been used as a pilot project. The resulting GIS model shows that Al Hamra is indeed at risk from predicted flood events. How this information can be used as a planning tool for numerous strategies is discussed in this paper.

## Keywords

Sea Level Rise • GIS • LiDAR

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## Introduction

One of the well-established consequences of climate change is that sea levels will continue to rise. The mechanism for this is well understood: as ocean waters heat up, thermal expansion of the water body occurs, while melt water from land-based ice caps and glaciers also contributes more water resulting in a rise in global sea levels (IPCC 2013). The most obvious effect of a rise in sea levels is the slow inundation of shorelines (Sanders 2007); but this is not the only result. Enhanced coastal erosion; as well as elevated storm surges and higher extreme tides, waves and greater wave run-up are all predicted consequences of increased sea levels. The same factors similarly increase the probability of floods and the degree and intensity of damage (Demirkenes et al. 2008; Muthusankar et al. 2013). Similarly, it has been predicted that the frequency of extreme wave events will rapidly increase. According to Kellet et al., what is now a once in a hundred year event is, by 2099, likely to occur two to three times a year (Kellet et al. 2014).

An eustatic increase in sea levels will impact most shorelines worldwide (Demirkenes et al. 2008). As 20% of the world's population lives within 35 km of the coast, it is estimated that by 2100 (Cohen et al. 1997) the amount of people suffering from coastal flooding could rise as high as 510 million (Nicholls 2002), which would represent a significant global threat (Poulter and Halpin 2008; Nicholls 2004). Much research has been done to predict and assess the future impact to coastlines, infrastructure and buildings. The results of this paper allow for the development of proper responses to this threat: planning policies, physical structures, and emergency preparedness (Sanders 2007).

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The southern Arabian Gulf, the subject area of this paper, with its recent development stands to be greatly affected by inundation (Garland 2010). Given the already high and probably continuing investment in infrastructure, as well as the growing coastal population of the UAE Gulf coast, it is prudent to consider the development of policies and tools to ensure that future coastal developments are undertaken to alleviate risk to investors, inhabitants and sensitive environmental areas. Many modern developments are constructed on land reclaimed from the sea: the most well-known being the Palm and World projects of Dubai. According to Hamdan (2007) the leaders of the Arab States have been slow to embrace the ideas of climate change and associated sea level increases.

The main aim of this paper is to determine the level of risk of sea-level rise to the Ras Al Kaimah Gulf coastline. This will be done by modelling the potential extent of inundation based upon several criteria. Relevant criteria include projected sea level rise scenarios (high and low) for the year 2099 as per the IPCC 2013 paper, and future tidal changes and extreme wave heights based on previous recorded government data. While it is predicted that storms will increase in both intensity and frequency (IPCC 2013), it is beyond the scope of this paper to quantify such forecasts. The non-inclusion of these forecasted storms will most likely result in an underestimation of coastal inundation. In order to predict a worst case scenario local, extreme wave events caused by low pressures and storms, as well as tidal changes will be combined. The greatest risk will occur when all of the above mentioned events take place simultaneously. As

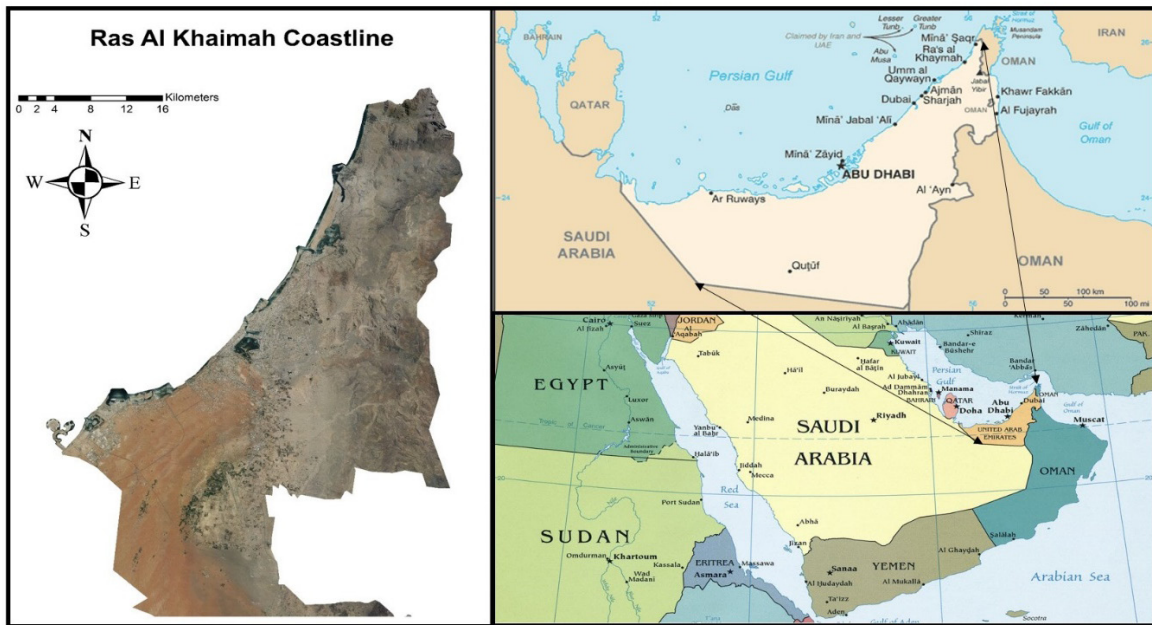


Figure 1. The Arabian Peninsula, United Arab Emirates and Ras Al Khaimah  
Developer & Author: Dr. Robert Arthur; Perry-Castañeda Library Map Collection - UT Library Online (Middle East Map & UAE Map),  
Source: Municipality of Ras Al Khaimah (2012) (Ras Al Khaimah Coastline)

predicting coastal vulnerability uses complex techniques, such as those suggested by Goble and Mackay (2013) that have not yet been assessed, a simple surrogate is employed; namely, exposure to open sea. GIS will be used to determine the extent of inundation within the coastal development known as Al Hamra Village. Using Light Detection and Ranging (LiDAR) technology, elevation data is recorded and utilized to model relief. All pixels with an elevation below the predicted sea level rise scenarios, which are outlined below, and are contiguous with open water will be considered inundated.

### Ras Al Khaimah

The emirate of Ras Al Khaimah is the northernmost in the United Arab Emirates. It consists of two separate territories divided by the emirate of Fujairah. The northern section is bordered to the north by Oman's Musandam peninsula and to the east by the emirate of Fujairah. This section includes the capital city of Ras Al Khaimah and a coastline on the Arabian Gulf. The southern portion is landlocked and reaches south to the border with Oman's main territory (Figure 1). The coastline of Ras Al Khaimah emirate is predominantly low-lying and sandy. The orthophotos (taken in 2012) provide a view of the topography of northern Ras Al Khaimah. Behind the coast is a low-lying plain backed by the Hajar Mountains (Figure 2A). The plain becomes narrower to the north as it approaches Oman's Musandam peninsula. Existing as a northern extension of the Rub Al Khali, or the Empty Quarter, the plain is composed mostly of red sand. The coast is marked by sand spits and several lagoons as well as a number of low lying islands. Construction projects and harbour dredging have interfered with the natural flow of sediments along this coastline (Goudie et al. 2000).

Ras Al Kaimah city has developed rapidly over the last decade, and there are significant plans for future developments. Recent coastline developments include Al Hamra Village (figure 2 B), the area under study, which is built on land partially reclaimed

from the sea. At the southernmost stretch of the coastline lies the Marjan Island development, which is built on four manmade islands, comprises 2.7 million square meters and extends 4.5 km into the Gulf. This development, now in progress, is similar to Al Hamra in that it will include residences, several hotels, a theme park and a 400 thousand square meter resort development. (A Hamra Village b, 2014). Further north along the coast is the Mina Al Arab development, another residential and hotel complex. The hotels are to be built on low lying island situated near the shore. Construction on the island has been placed on hold but is expected to resume shortly. The emirate of Ras Al Khaimah has a growing tourist industry that is based on these new developments as well as several completed resorts such as Cove Rotana and the Hilton Spa and Resort, both of which are built on low lying coastal areas. Other projects to be built on reclaimed land and low, near shore islands along this coastline are in the planning stages. These complexes are all at risk unless mitigating action is taken.

In addition to the endangered built environment, several stands of mangroves will also be negatively affected. These important and biologically diverse environments are impacted from the landward side, as urban development has limited their ability to migrate landward. These mangroves will require special attention by planners. The Jazirat area includes important historical and archaeological sites that are at risk of flooding. Thus, the need to proactively defend these locations is important to the economy, heritage, and well-being of the inhabitants along this coastline.

Data from Goudie et al. (2000) shows that the Ras al Kaimah coastline has a mean annual precipitation of 120 mm; while mean spring tides are between 1.7 and 1.9 m, with two wind drift potential peaks, one from the SE at 31.1% of the total, and the other at 35.51%. Waves greater than 2.44m occur only 1% of the time, normally in December and March during the north-westerly prevailing Shamal winds. The net longshore drift is probably

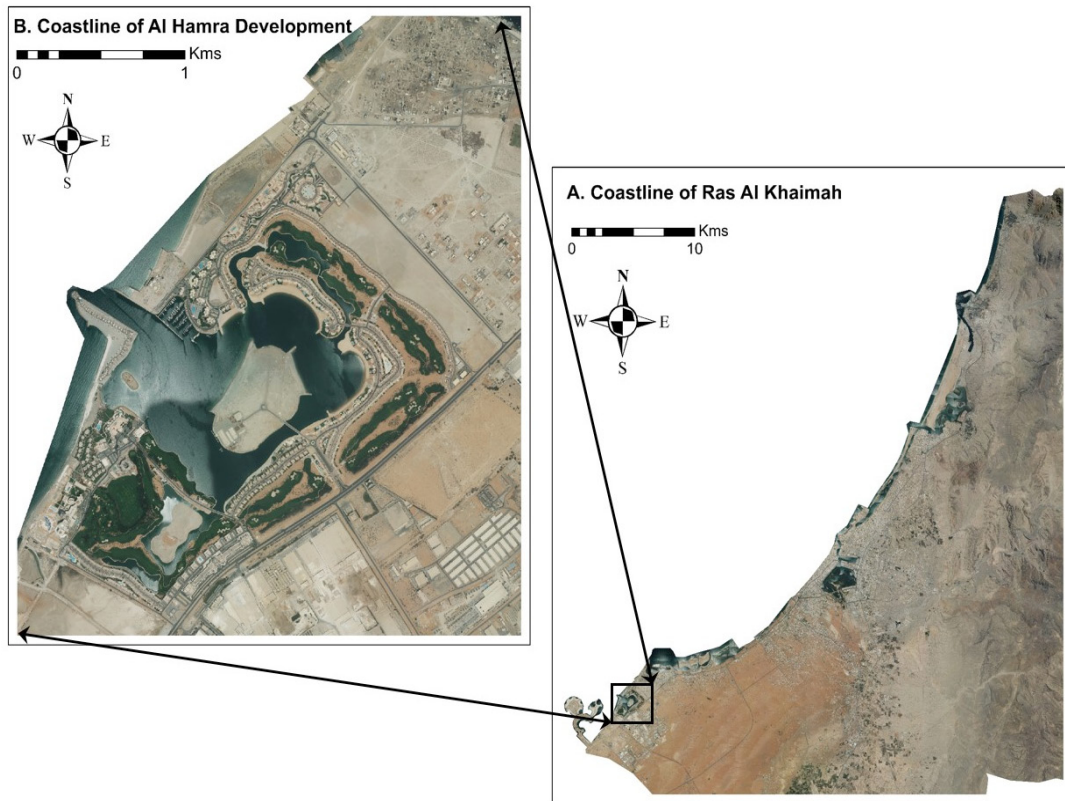


Figure 2. The Ras Al Khaimah and Al Hamra Village Coastline (Orthophoto 2012)

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Source: The Municipality of Ras Al Khaimah

northwards, although no rates of transport are available. The site sits on a narrow plain, composed of red dunes, sabkha (salt flats), and alluvial deposits. The plain narrows out towards Shams in the north, where the mountains slope directly into the sea.

#### Geomorphological change of the RAK shoreline

Using historical maps and documents, including more recent air photos, Goudie et al. (2000) assessed coastal geomorphological change along the Ras Al Kaimah coast since 1819. They concluded that the coastal zone may be divided into three distinct zones: a 14 km long southern section, with two sabkhas (salt plains); an 11 km long central zone on a long narrow lagoon, which includes Ras Al Kaimah city; and, finally, a 9 km long northern section, which incorporates a creek and an area of mangroves. Goudie et al. noted that the southern zone, at Jazirat al Hamra, has been significantly influenced by harbour construction and dredging, and is presently retreating at its southern end; although, north of this the historical maps suggest that it has been stable for a number of decades.

The spit located in the central zone migrated northwards at a rate of about 40 m a year from 1822 to 1958, later it breached close to its southern end. The southern part subsequently migrated northwards at about 140 m per year creating a continuous, detached bar. In addition to this, significant land reclamation has also taken place. The Jazirat Hulaylah zone in the north has a natural stability and its shoreline is far less likely to change due to natural causes than the rest of the region; although it is has also been significantly impacted by human intervention through the construction of a large custom free industrial complex (Goudie et al. 2000).

With respect to the present study, much of the Ras Al Kaimah shoreline must be considered geomorphologically mobile and, therefore; likely to change. This being the case, it is probable that higher future sea levels will exacerbate the natural rates of change, a consideration which should be included in the assessment of future risk to the region.

#### Expected sea level rise along the RAK coast line

An extensive review of all the information pertaining to changing sea level in the Abu Dhabi region; including possible storm and tide surges, and probable highest significant waves; was completed by Garland (2010). In the review, he included global information from Pfeffer et al. (2008), IPCC (2007), Rhamsdorf et al. (2007) as well as studies specific to the Arabian Gulf, most notably Mangor et al. (2008), Hossienibalam et al. (2007), Neelamani et al. (2007), Sultan et al. (1995), and El Sabh and Murty (1989).

Garland's analysis confirmed that sea level change in the Arabian Gulf mirrors global eustatic change. Furthermore, since much of the included data was gathered for Dubai, and Ras Al Kaimah is approximately 100km north east of Dubai, and 200km north east of Abu Dhabi, along the same coastline, Garland's conclusions are likely to be applicable to the area under study here. Further evidence of wind driven, storm surge waves occurred last year when two low pressure systems collided (Feb. 21, 2015). This recent storm brought ten foot high (3.05 m) waves to Sharjah, which is just 90 kilometres south of Ras Al Khaimah, forcing the closure of the Corniche (the main road that runs parallel to the coast) due to flooding (Emirates 24/7, 2014).

Table 1. Probable sea level rise scenarios for the southern Arabian Gulf

	Low scenario (Sultan et al., 1995)	Medium scenario (IPCC, 2013)	High scenario (Rhamsdorf et al., 2007)	Extreme scenario (Pfeffer et al. 2008)
Annual sea level change in mm	+2.1 mm	+6.6 mm	+9.0 mm	+20.2 mm
Sea level change by 2099 in m	+0.21 m	+0.59 m	+0.81 m	+2.0 m

Source: Garland, 2010

Table 2. Expected maximum flooding levels above present datum; comprised of sea level change, extreme tides, storm surges and high wave events; for Ras Al Kaimah by 2099

Expert total sea level rise by 2099	Sheltered sites (including storm and tide surges, but excluding waves and effects)	Sites exposed to open sea (including storm and tide surges, and expected highest significant waves)
+0.21 m (Sultan et al. 1995)	+4.1 m	+8.21 m
+0.59 m (IPCC 2007)	+4.59 m	+8.59 m
0.81 m (Rhamsdorf et al. 2007)	+4.81 m	+8.81 m
+2.0 m Pfeffer et al. 2008)	+6.0 m	+10 m

Source: Garland, 2010

Eight expected inundation level scenarios are suggested for the year 2099. These depend firstly, on specialist scientific studies by acknowledged experts, and secondly, on whether specific sites are sheltered, such as lagoons and harbours, or exposed to the open sea. The difference between exposed sites and sheltered sites vary significantly. The expert sea level rise estimations are shown in Table 1, with the final expected flooding levels; including sporadic effects of storm and tide surges and highest significant waves; are detailed in Table 2 as per Garland's (2010) analysis.

### The Study Area

The community of Al Hamra is situated around an inland lagoon and contains multiple high- and low-rise apartments (approximately 2,500), villas and townhouses (1,000), a marina, five hotel resorts including the five star Waldorf Astoria, a golf course, a shopping mall and a smaller strip mall (Al Hamra Village a, 2014). The development has approximately 4.3 square kilometres in area including a large lagoon. The development is 3.35 square kilometres of land area when the lagoon is excluded (Figure 2).

### GIS Modelling

The municipality of Ras Al Khaimah supplied GIS layers for this study, including LiDAR data for the entire emirate. The LiDAR data was collected using a Leica ALS50-II with a planned flight speed of 160 knots and an average point density per meter squared of 0.73. The raw LiDAR files were converted to 'LiDAR data' (.lasd) files within ArcGIS. LiDAR provides the most accurate elevation data which is especially important for areas with low relief as horizontal measurements can be drastically distorted (Fraile-Jurado and Ojeda-Zújar, 2013). The data required for this study was extracted from the larger LiDAR coverage of the entire emirate. It was then filtered for ground level points and assembled into a mosaic forming the overall study region (Figure 3). Once the mosaic had been completed it was transformed into a raster layer using linear interpolation and 'thinning'. Values were kept in the floating point format to

maintain precision. The 'coastline' and 'road' layers were created by 'heads-up' digitizing utilizing an orthophoto also supplied by the municipality. The orthophoto is a composite of red, green and blue layers and was also flown in 2012 on the same flight mission on which the LiDAR data was collected. Any pixels between zero and two meters that were also contiguous with the coastline were recoded and labelled as 'inundated' to show where water would permanently flood after a two meter rise in sea level. Pixels below two meters but not contiguous with open water were recoded as being just above the predicted sea level. The recoding of these non-contiguous pixels in this way was done because they represent isolated depressions in the landscape and as they are not connected to areas where water is moving inland, they will not experience flooding. This anomaly is a result of the method being used.

Connectivity was determined using the 8 point rule (D8) (Poulter and Halpin, 2008); any pixels contiguous with open water on either the sides or the corners of the pixels were deemed connected. This technique is known as the 'bathtub' approach and is the method most commonly used to assess coastal inundation using GIS (Kellet et al. 2018; Poulter and Halpin, 2008).

After the completion of the map predicting inundation for a two meter rise scenario, a count of the pixels indicated that 94,464 square meters would be inundated (see figure 3). Work within the GIS environment began by examining the two SLR scenarios; lowest and highest (see Table 1). The worst case for a two meter rise leaves the Al Hamra development in the precarious situation of being surrounded by water on two sides with significant encroachment on the third. The southern side has a lower elevation outside the development where extensive flooding would occur; this is not illustrated in figure 3. Figure 3 does show some areas outside the development where flooding would occur, which would then encroach back on the development. The development itself reaches not much higher than approximately five meters above the new mean sea level. Given the lowest possible extreme event as per table 2, the entire development would be flooded, with water surpassing the mall and entirely flooding the highway. The lower level scenarios for



Figure 3. Inundation Map for the Al Hamra Development

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Source: The Municipality of Ras Al Khaimah

sea level rise did not show any appreciable flooding; however, as the extreme event predictions begin at just over four meters, there is no need to model each of the eight possible scenarios: even with the most conservative estimate, the Al Hamra development would experience near total flooding. Given this worrying state of affairs, it would seem prudent for Ras Al Khaimah's government to explore remedial action.

GIS proves to be an excellent tool for predicting the effects of sea level rise. This is due to the ambiguity of forecasts, the range of possible outcomes, and the continuing change in forecasts as more studies are completed. Continual changes in forecasts require constant updates to inundation models. As data is collected over a longer period of time, trends can be identified with greater precision. GIS can incorporate additional data readily and develop new predictions with relative ease. This flexibility is necessary under the long term and varying conditions of global warming, climate change, and sea-level rise.

### Remediation

Studies of planning agencies in Norway and Australia have shown little direct preparation or action being taken to protect areas at risk from inundation due to sea-level rise. Generally, governments approach this problem through the reduction of

carbon emissions (Stokke, 2014; Taylor et al. 2013). Planning agencies tend not to commit whole heartedly to protective policies; firstly, because predictions of environmental damage invariably contain some measure of doubt and, secondly, because this is likely to take place over a long period of time. Furthermore, any change in, or downgrading of, the status of land already developed is likely to result in a backlash from the community (Kellet, 2014).

Kellet et al. (2014) identify three main methods that are available to planning agencies for the protection of endangered coastlines: protect, accommodate and retreat. There are two methods of protection: hard protection, which involves the building of structures, such as sea walls, levees, and dikes; and soft protection, which uses the natural environment, wetlands, mangroves, dunes, and tidal flats. Accommodation requires the modification of existing buildings and infrastructure so as to protect them from inundation and flood events. Retreat requires the movement of buildings from endangered areas to safer locations further inland. Furthermore, planning guidelines will restrict development in flood zones and encourage development in protected areas (Lee 2014). Sahin et al. (2013) suggest two other possible approaches: doing nothing and improving public awareness. The 'do nothing' strategy implies the acceptance of risk thus avoiding the costs of adapting (Sahin et al. 2013). Improving

public awareness does not directly protect endangered areas; rather, it works indirectly by affecting the market, decreasing values for properties in areas at risk and raising values for areas not at risk. It can also result in grass roots community action that pressures governments at all levels to address the issue.

### Conclusion

Each issue of the IPCC reports carries predictions of rising sea-levels due to global warming. GIS has proven to be a useful, effective and flexible tool for modelling and predicting which coastal areas stand to be most at risk from future sea-level rise, and the concomitant tidal and wave events. Current research indicates that the rise in sea-level is 'tracking at, or near, the upper limit of the IPCC worst-case projections' (Kellet et al. 2014). Government planning agencies at all levels will need to begin planning for remedial action in order to protect existing and future development along their coastlines. Regardless of the strategy or strategies chosen, GIS has the capability to predict, analyse and assess the risk for endangered coastal areas.

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- This paper has used GIS in a pilot project to predict the future risk faced by a large multi-use coastal development. A future study of the entire coastline of Ras Al Khaimah is now needed. Once a model is complete, updating can be accomplished in which data from new sources is incorporated with relative ease. This model can then be used in three ways: first, to assess the value of the existing buildings and infrastructure that are at risk; second, to develop new planning policies, such as set-back lines, through which future developments are restricted from flood zones; and third, as a tool for emergency preparedness should future extreme wave events occur.
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