The Use of SRTM in Assessing the Vulnerability to Predicted Sea Level Rise in Yanbu Industrial City, Saudi Arabia

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Key words: Sea Level Rise, Coastal Inundation, SRTM, Vulnerability, DEM

SUMMARY

Sea level rise (SLR) has become a challenging global issue especially in coastal areas that host a large percentage of the world population. The phenomenon of sea level rise is expected to result in increasing coastal inundation and erosion. The physical, environmental and human processes including economic systems and social structures in coastal regions, which are densely populated, may be disrupted. Yanbu Industrial city is located at the coast of Red Sea in the Western part of Saudi Arabia. The city houses a lot of investments running to billions of Riyals. Unlike most coastal areas in the world which are densely populated, the population of Yanbu Industrial City is moderate. Despite the control measures on population by the Royal Commission for Jubail and Yanbu, the population of the city in rapidly increasing in recent time due to industrial activities. This paper attempts to examine the different scenarios of the sea level rise and its consequences on Yanbu Industrial City. Analyses of these scenarios were carried out using Digital Elevation Model (DEM) from Shuttle Radar Topography Mission (SRTM) with high resolution remote sensing data (for visualization) within Geospatial Information System (GIS) environment. This study uses a minimum scenario of SLR of 1m by the year 2100. The result is overlaid on the demographic and land use data of the city to estimate the likely impact on land use and population of the area. The results show that the industrial city is vulnerable to sea level rise.

SUMMARY (Arabic)

أصبح ارتفاع مستوى سطح البحر (SLR) قضية عالمية صعبة وخاصة في المناطق الساحلية المأهولة بنسبة كبيرة من سكان العالم. من المتوقع أن ظاهرة ارتفاع مستوى سطح البحر تؤدي إلى زيادة الغمر والتآكل الساحلي. إنه من المحتمل أن العمليات الفيزيائية والبيئية والبشرية بما في ذلك النظم الاقتصادية والهياكل الاجتماعية في المناطق الساحلية ذات الكثافة سكانية العالية قد تتعرض للإختلال.

إن مدينة ينبع الصناعية مدينة ساحلية تقع على ساحل البحر الأحمر في الجزء الغربي من المملكة العربية السعودية وتصل الإستثمارات فيها إلى المليارات من الريالات. وتتميز مدينة ينبع الصناعية على نظيراتها من المدن الساحلية المكتظة بكونها ذات كثافة سكانية متوسطة. وعلى الرغم من تدابير الرقابة السكانية من قبل الهيئة الملكية للجبيل وينبع فإن عدد سكان المدينة في تزايد سريع في الآونة الأخيرة بسبب الأنشطة الصناعية.

يسعى هذا البحث إلى دراسة السيناريوهات المحتملة عند إرتفاع مستوى سطح البحر وما لذلك من آثار على مدينة ينبع الصناعية. وقد تم تحليل هذه السيناريوهات باستخدام النماذج الرقمية للارتفاعات (DEM) من رادار مكوك بعثة الطوبوغرافيا (SRTM) مع بيانات الاستشعار عن بعد ذات الدقة العالية (للرؤية) داخل بيئة نظام المعلومات الجغرافية المكانية (GIS). وتستخدم هذه الدراسة سيناريو الحد الأدنى من SLR بمستوى متر واحد بحلول عام 2100. وقد غطت نتيجة التحليل الخريطة الديموغرافية والأرضية للمدينة لتقدير التأثير المحتمل على المساحات الأرضية المستخدمة أو المأهولة. كما تبين النتائج أن المدينة الصناعية عرضة لآثار إرتفاع مستوى سطح البحر.

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1. INTRODUCTION

1.1 Vulnerability

Vulnerability is a concept that is perceived in very different ways by scholars from different domains of knowledge, and even within the same domain. For instance, natural scientists and engineers tend to apply the term in a descriptive manner whereas social scientists tend to use it in the context of a specific explanatory model (Fussel, 2007). Liverman (1990) noted that vulnerability ‘‘has been related or equated to concepts such as resilience, marginality, susceptibility, adaptability, fragility, and risk’’. Fussel, (2007) added exposure, sensitivity, coping capacity, criticality, and robustness to the list. Several definition has been given to vulnerabiliuty. In this work, the definition of the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report is adopted.

According to McCarthy et al. (2001), IPCC defines vulnerability as "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes". Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity. Vulnerability therefore, "can be used in different policy contexts, referring to different systems exposed to different hazards" (Fussel, 2007). Vulnerability to climate change and sea level rise depends on some factors.

1.1.1 Vulnerability factors

According to the United Nations (2004), four groups of vulnerability factors are considered to be relevant in the context of disaster reduction: viz.:

i. ”physical factors, which describe the exposure of vulnerable elements within a region;”
ii. ”economic factors, which describe the economic resources of individuals, populations groups, and communities;”

iii. ”social factors, which describe non-economic factors that determine the well-being of individuals, population groups, and communities, such as the level of education, security, access to basic human rights, and good governance; and”

iv. ”environmental factors, which describe the state of the environment within a region” (United Nations, 2004).

All of these factors describe properties of the vulnerable system when exposed to different hazard and under different condition. The system being considered in this study is the sea level rise.

1.2 Sea level rise

Sea level rise (SLR) is the changes in the in the the level of the surface of the sea with respect to the land, taken to be the mean level between high and low tide, and used as a standard base for measuring heights and depths. Experts on the sea level rise triggered by climate change have long known that it will proceed faster in some places than others and it is a continuous process. This will cause coastal flooding, inundation and other environmental problems. The impacts of which would disrupt the physical, cultural and socio-economic systems in the coastal region. It therefore, poses one of the major environmental challenges and major concerns of today. This has made the United Nation General Assembly to adopt the establishment of Intergovernmental Panel on Climate Change (IPCC) under the United Nations Environmental Programme (UNEP) and the World Metrological Organization (WMO) as the leading international body for the assessment of climate change and its attendant sea level rise. In the light of this, various countries also set up National action plan on climate change and collaborate with IPCC in other to cater for the the challenges posed by the phenomena (Aleem and Aina, 2012).

One of the challenges of climate change and sea level rise is the coastal erosion and inundation. Coastal erosion is wearing away of the coast by waves or other agents, which shape the coast, because the power of wave has a significant influence on the coast. Such influence is aided by sea level rise. This will definitely affect the socio-economic activities of the coastal and densely populated region of the world. The causes of sea level rise may be attributed to the following factors:

i. the increase in water volume that results mainly from thermal expansion of the ocean,
ii. melting of mountain glaciers,
iii. an accelerated discharge of glacial ice from the ice sheets to the ocean,
iv. contributions from thawing of permafrost,
v. sediment deposition and the continuing adjustment of the ice sheets.
vi. "geological uplift or subsidence processes occurring in ocean basins and on continents can also influence long-term local sea level changes, and can exacerbate coastal flooding and inundation in many areas" (Li, 2009).

The impact of these factors and the extent of sea level on the immediate coastal environment depend on the scenarios, which are enumerated below.

1.2.1 Scenarios of Sea Level Rise

In order to study the impacts of climate change and SLR on societies, different climate modeling groups have developed scenarios of SLR given expected rise in temperature. The key issues in the simulation of the scenarios are modeled considering the parameters like: combinations of demographic change, social and economic development, and broad technological developments (Aleem and Aina, 2012). The scenarios are used to predict the sea level rise to year 2100. Geospatial techniques such as Digital Elevation Model (DEM) have been used by several authors to study, analyse, assess and predict the vulnerability of different scenarios of sea level rise on global and local communities.

Warrick et al (1996) made projections of thermal expansion and of loss of mass from glaciers and ice-sheets for the 21st century for the IS92 scenarios using two alternative simple climate models. Several other authors have based their prediction on the scenarios. Onyenechere (2010) presented a vulnerability analysis with climate change and accelerated sea level rise (ASLR) of 1.0m. The study equally showed the projections of other parameters in the vulnerability analysis. Aleem and Aina, (2012) also used ASLR scenarios in assessing vulnerability to coastal flooding due to sea level rise in Lagos Mainland Nigeria with the use of digital elevation model.

1.3 Digital Elevation Model (DEM)

A Digital Elevation Model refers to a quantitative model of a part of the earth's surface in digital form (Burrough and McDonnell, 1998). A DEM consists of a two-dimensional array of numbers that represents the spatial distribution of elevations on a regular grid; they are particularly useful in regions that are devoid of detailed topographic maps. (Forkuor and Maathuis). DEMs (Digital Elevation Models) can be divided into two viz.: Digital Terrain Models (DTM) and Digital Surface Models (DSM). "DTMs represent the terrain's elevation, whereas DSMs represents the surface elevation of objects in the landscape" (Sande et al., 2012). Though ASTER GDEM and STRM DEM datasets are Digital Surface Models, but they are used as Digital Terrain Models.

There are several methods of generating DEM, depending on the area of coverage, accuracy, cost, topography and availability of equipment. The available methods include but not limited to following:

- Traditional land surveying methods of mapping to produce topographic map. Contour from such map can be used to generate DEM.
- Photogrammetric techniques - DEM can be derived from contours that are extracted with photogrammetric techniques from aerial stereo photographs but currently digital photogrammetric software is being used.
- Satellite Methods - DEMs can be generated from optical satellite images using any elevation extraction methods (Jacobson, 2003). Programs are now available in MATLAB and similar programming languages for the extraction of DEMs. SPOT, a remote sensing satellite, was the first satellite to provide stereoscopic images that allowed the extraction of DEMs (Nikolakopoulos and Chrysoulakis, 2006). Advances in space technology have now resulted in many more satellites such as SRTM, ASTER, IKONOS, Quickbird and so on.

- Google Elevation Data: Google elevation data is available to the public but the permission from Google limits the usage to applications within the Google earth and Google map environment.

Uses of satellite images for DEM generation have tremendous advantages over traditional methods, because DEMs cover large and inaccessible areas and equally available online. It can nowadays be easily produced (near) real-time and within a relatively short time and at remarkable cheaper costs (Forkuor and Maathuis, 2012). Example of the satellites global DEM, available online is SRTM.

1.4 Shuttle Radar Topography Mission – SRTM

Shuttle Radar Topographic Mission (SRTM), undertaken by National Aeronautics and Space Administrations (NASA) and US National Geospatial-Intelligence Agency (NGA), collected interferometry radar data which has been used by the Jet Propulsion Laboratory (JPL) to generate a near-global (80% of earth's land mass) DEM.

DEMs from the SRTM are available at three spatial resolutions:
(a) 1 arc-second DEM (30-m resolution) which covers only the United States
(b) 3 arc-second DEM (90-m resolution) covers the entire world; and
(c) 30 arc-second (1-km resolution) covers the entire world

SRTM has been the first mission using space-borne Interferometric Synthetic Aperture Radar (InSAR). "An extensive global assessment revealed that the data meets and exceeds the mission's 16m (90 percent) absolute height accuracy, often by a factor of two" (Rodríguez et al., 2006). Since its release in 2005, the user community has embraced the availability of SRTM data, using the data in many operational and research settings.

1.4.1 Uses of DEMs from SRTM

DEM from SRTM has been used for various studies by several authors in different part of the world. The SRTM mission has been a breakthrough in remote sensing of topography (Van Zyl, 2001), producing the most complete, highest resolution DEM of the world (Farr et al., 2007). The mission has satisfied studies such as:

- Delineation of areas vulnerable to inundation - Farr and Kobrick (2000) used SRTM DEM data to map topographic gradients along the Nile Delta in Egypt, in order to delineate areas vulnerable to inundation if the sea rises above its current level

- Impacts of flooding due to sea level rise - The terrain analyses are very important in depicting the areas that could be affected by some phenomena such as sea level rise. Li et al. (2009) concluded that SRTM has been successfully used for assessing the impacts of flooding due to sea level rise.

- Hydrological studies - SRTM provides means to obtain important hydrological or hydraulic parameters for broader-scale assessment of large catchments areas. Schumann et al. (2008) reported that some other studies on large areas have used SRTM data to derive the following:

(i) "water slope and discharge with an absolute percentage error of 4.03 (max: 27.35) for the Amazon River" (LeFavour and Alsdorf, 2005) and

(ii) "water volume and inundated water surface area of the Three Gorges Reservoir" (Wang et al., 2005).

(iii) "hydraulic variables can also be derived similar to those generated by the REFIX model especially in estimating the water stages",

Other uses of DEMs were summarized in Forkuor and Maathuis (2012) as follows:

i. archaeology (Menze et al., 2006),
ii. (commercial) forestry, e.g. height of trees (Simard et al., 2006),
iii. hydrology (Lane et al., 1994) and
iv. analysis of glaciers (Bishop et al., 2001).

- In flood inundation modeling - elevation data constitutes one of the most important model boundary conditions in flood modeling is the elevation data. SRTM provides surface elevation data which is now used for flood inundation modeling. Hydraulic information from SRTM DEM can be retrieved, with high potential especially for ungauged basins near the coast, where such information is required. In most cases SRTM performed better compared to other DEMs.

1.4.2 Comparing SRTM and other DEMs:

In the studies by Li et al. (2009), Dasgupta et al. (2009), Sande (2011) and Babu et al. (2012); GIS and DEM data (SRTM, ETOPO and GDEM) were used to assess the vulnerability of sea level rise and comparative analysis of the result were carried out. Studies such as Sande (2011) have found that ASTER GDEM1 data is less accurate than SRTM in modeling risks and vulnerability associated with SLR.

Forkuor and Maathuis (2012), compared SRTM and ASTER GDEM with Referenced DEM. Their study has revealed that SRTM is "closer" to the Reference DEM than ASTER, "although both products are useful and are an excellent replacement for local 1:50 000 hypsographic data both in absolute and relative terms. The relative assessment further confirms that various surface processes can be appropriately studied when using these global elevation data sets, which is a great asset to geomorphologists. Here the relative assessment conducted is more focused to hydrological processes, one of the terrain processes important in geomomorpholgy"

Aleem and Aina (2012) also compared SRTM and ASTER-GDEM2 and concluded, on the basis of their analysis that STRM performed better than ASTER-GDEM2 in assessing the vulnerability of sea level rise. In this study, SRTM has been adopted to study the vunerability to predicted sea level rise in Yanbu Industrial City of Saudi Arabia.

1.5 Aim and objectives

The main aim of this study is to use DEM from SRTM data for assessing vulnerability to coastal flooding and inundation due to predicted sea level rise. The specific objectives of this study are:

- to obtain scenarios of global sea level rise from literature.
- to assess the vulnerability of Yanbu Industrial City to coastal flooding and inundation using the scenarios.
- to assess the impact of inundation on land use and population

1.6 The study Area

The study was carried out in Yanbu Industrial City, popularly known as Yanbu Al-Sina'iya in Arabic, which literarily means Industrial Yanbu in Madina Province of Saudi Arabia (Figure 1). The city, established around 1975, is located on the Coast of Red Sea about 350km North of Jeddah, one of the major ports in the Kingdom. The city is located on: Latitude 23^{0} 59' 57.840''N (23.9994) and longitude 38^{0}13' 39.000''E (38.2275).

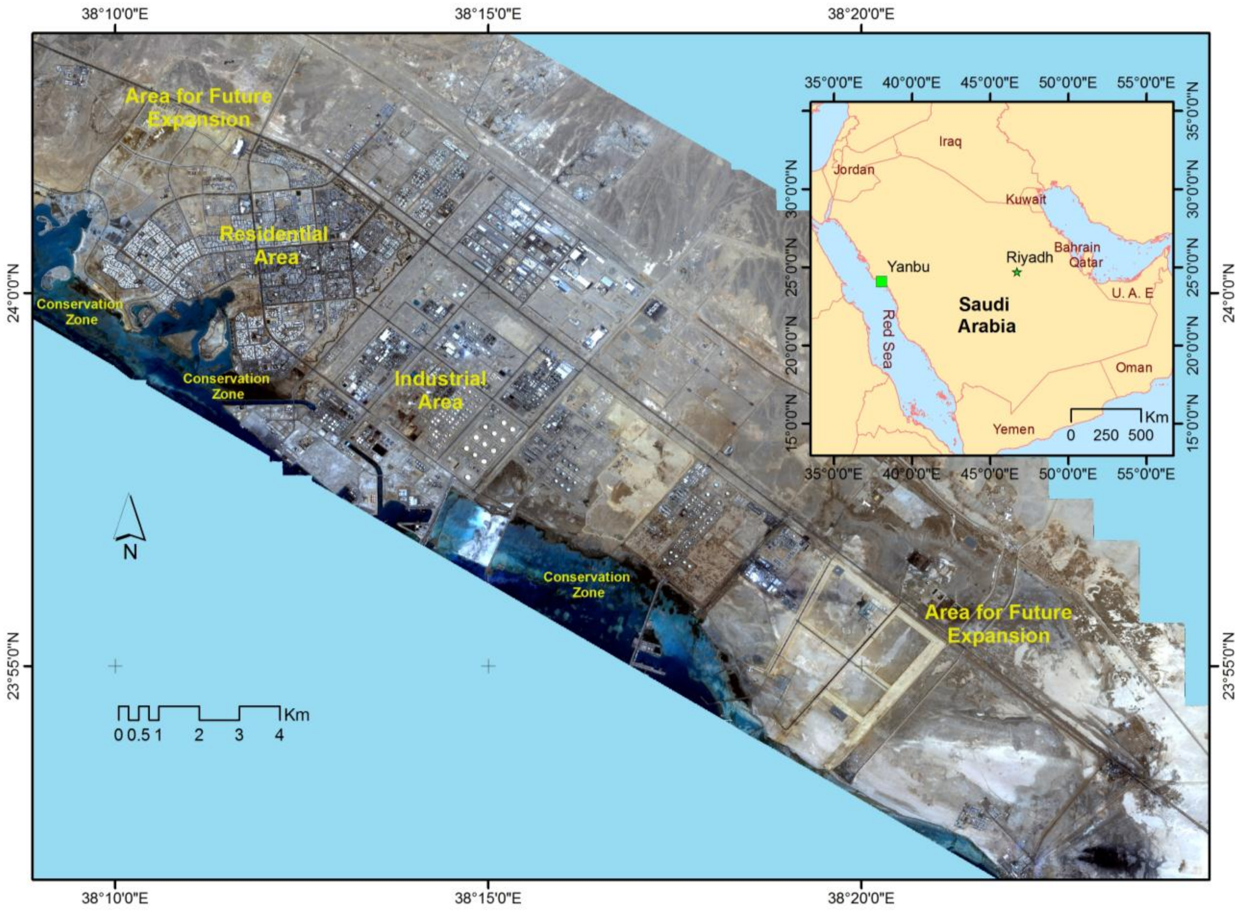

Figure 1: Land use Pattern of Yanbu Industrial City

Yanbu is an important petroleum shipping terminal and is home to three oil refineries, a plastic factory and several other petrochemical plants. It is the country's second port (after Jeddah) and serves as the main port for the holy city of Medina. Yanbu existing area is about 185 km². RC Yanbu expansion area is about 420 km². Its residents are mostly expatriates and high class Saudis. The population of the area is growing with Saudis in particular, while the Non Saudi is reducing at the rate 1% per annum (RCJY, 2012).

Yanbu Industrial City can be regarded as a Low Elevation Coastal Zone (LECZ), which is defined by Mcgranahan (2007) as "the contiguous area along the coast that is less than 10 meters above sea level", where large percentage of the world population resides. Unlike, other coastal cities, which are densely populated, the population of Yanbu Industrial City is moderate because, it is controlled by the Royal Commission for Jubail and Yanbu – a government agency established under Royal Decree. The building and allocation of residential quarters lies with the Commission, which is good control measure on the population of the city.

1.5.1 Population and Land Use of Yanbu Industrial City

Population of Yanbu Industrial city is 91479 based on 2010 Kingdom of Saudi Arabia Census. The net budget of Royal Commission at Yanbu is about 2.4 billion SAR while the expenditure for the period exceeded the budget totaling 2.6 billion SAR for the year 2012. This is quite a huge sum of money. The investments located within this city will require adequate protection to forestall loss of these investments and live of the capable human resources (mostly expatriates) to sea level rise and increase flooding in this coastal city, since, "settlements in coastal lowlands are especially vulnerable to risks resulting from climate change" (Mcgranahan, 2007). This when happened will affect the land use pattern of the city.

Land use of Yanbu Industrial City comprises of 4,240 hectares for community and residential area, the water front covers about 381 hectares and buffer / open space is about 2100 hectares of land. This work aimed at studying the effect of sea level rise on the land use pattern of

Yanbu Industrial City using the freely available online DEM from SRTM.

2. MATERIALS AND METHOD

2.1 Materials

DEM data of the SRTM (global land cover facility) were downloaded from the Consortium for Spatial Information (CSI) web portal (http://srtm.csi.cgiar.org/) (International Centre for Tropical Agriculture (CIAT), 2004). CSI DEM data (Void-filled seamless data) of 3 arc-second DEM (90-m resolution) which is available for the study area were originally processed (by changing the projection to Universal Traverse Mercator (UTM- Zone 37) and cell size to 90m) using ARCGIS software (Figure 2).

The demographic data was obtained from Socioeconomic Data and Applications Center (SEDAC) (Center for International Earth Science Information Network (CIESIN), Columbia University; United Nations Food and Agriculture Programme (FAO); and Centro Internacional de Agricultura Tropical (CIAT), (2005). The data contain estimated population count of Saudi Arabia in grid format for year 2000.

2.2 Method

Generally, studies of inundation due to sea level rise adopt a minimum scenario of 1m SLR, but studies like Sande et al. (2012), have included storm surge in their sea level rise analyses. Also, the RMSE of SRTM DEM compared with LiDAR or GPS data have been found to be around 2m to 5m (Sun et al, 2003; Tachikawa et al, 2011; Sande et al, 2012 and Schumann et al, 2007). Thus, this study adopted scenarios of 1m, 2m, 3m and 5m, to cover the expected SLR of 1m, storm surge and the difference between SRTM and GPS or LiDAR data.

ArcGIS software was used to carry out the analyses by extracting the areas that could be vulnerable to inundation based on the different scenarios. The results of the extracted areas were overlaid on land use and demographic data to compute the effect of inundation on land use and population.

The population data for 2012 was estimated from the SEDAC data based on 5% annual population growth as stated in the economic plan of Yanbu Industrial City (RCJY, 2012).

3. RESULTS AND DISCUSSIONS

3.1 Results

The results of the analysis are shown in Figure 2 to Figure 6 below. Figure 2 shows the elevation of the area ranges between 0 and 67m above sea level.

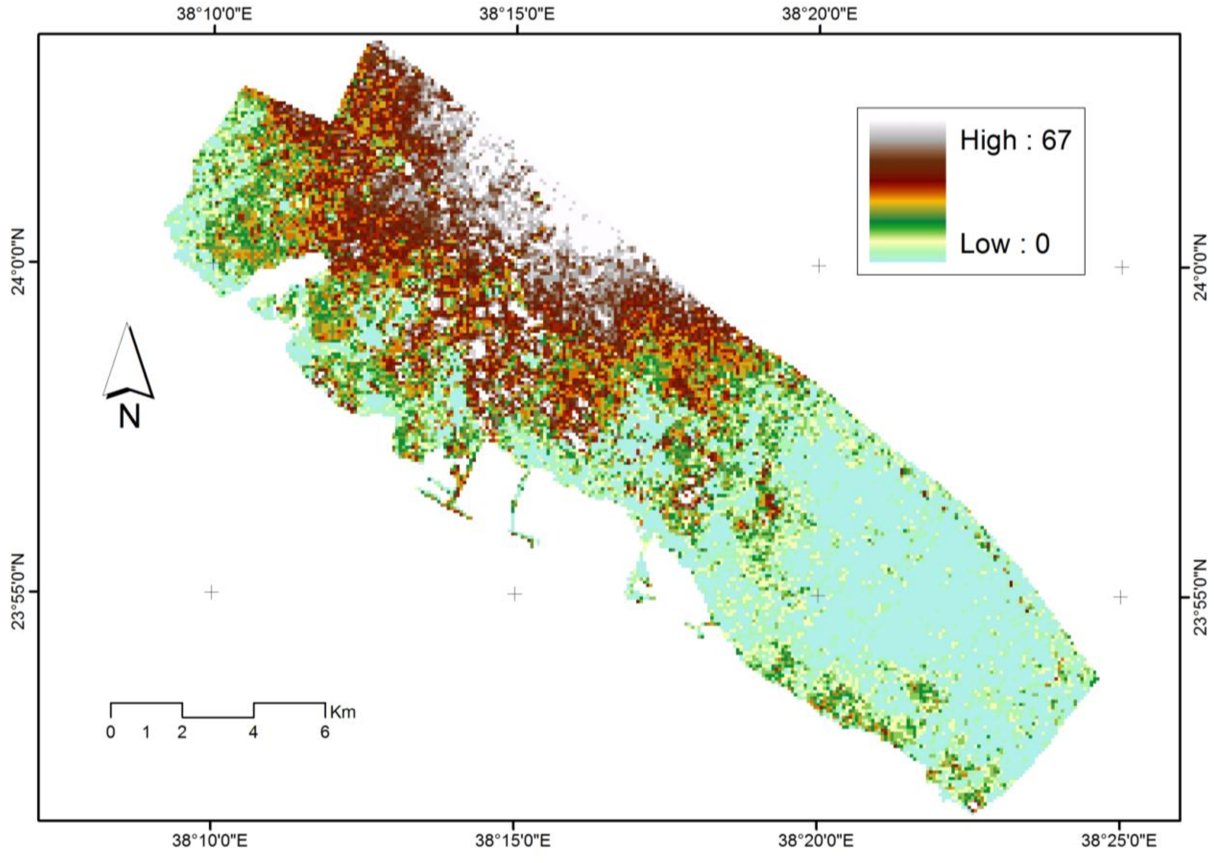

Figure 2: The SRTM DEM of Yanbu Industrial city

Figures 3, 4, 5 and 6 show the areas that will be inundated when the sea rises by 1m, 2m, 3m and 5m respectively.

Table1 shows the estimate of the land use to be affected by different scenarios of SLR, while Table 2 shows the estimate of the population to be affected by different scenarios of SLR.

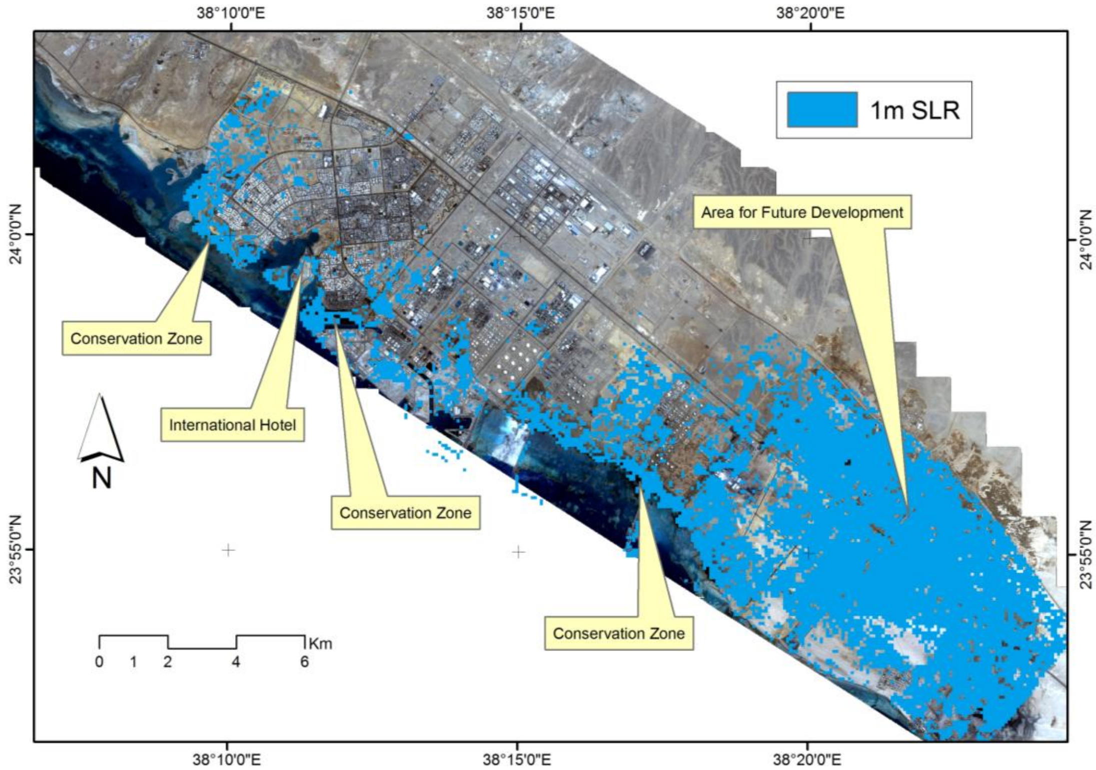

Figure 3: Area Affected by 1m Sea level Rise in Yanbu Industrial City

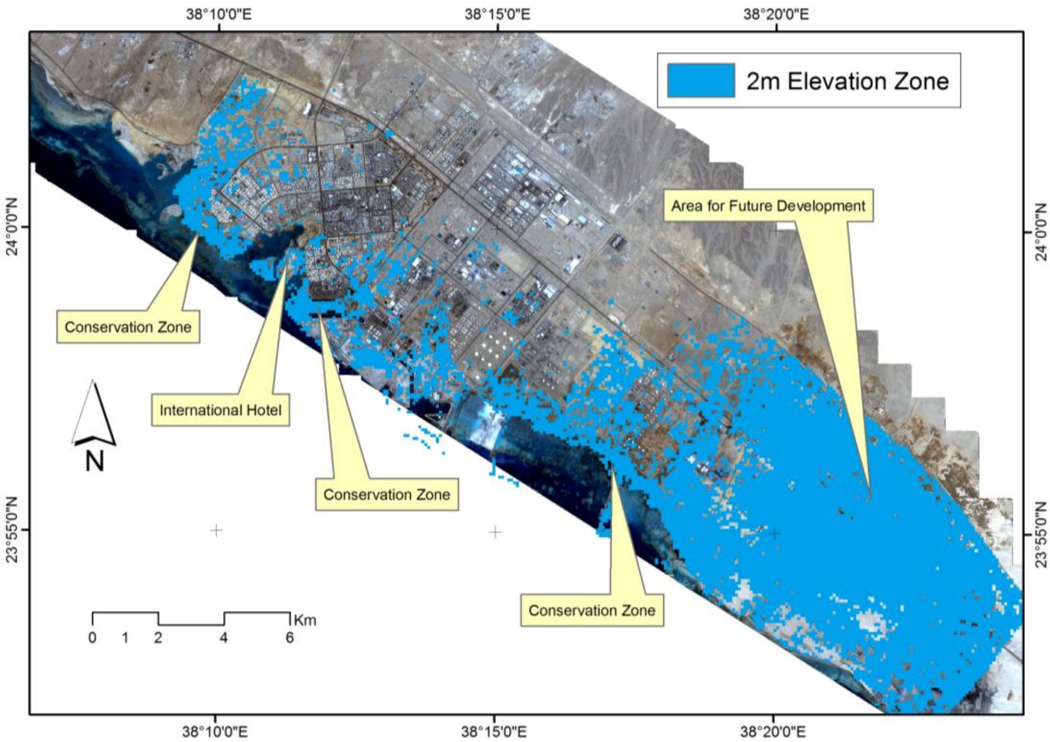

Figure 4: Area Affected by 2m Sea level Rise in Yanbu Industrial City

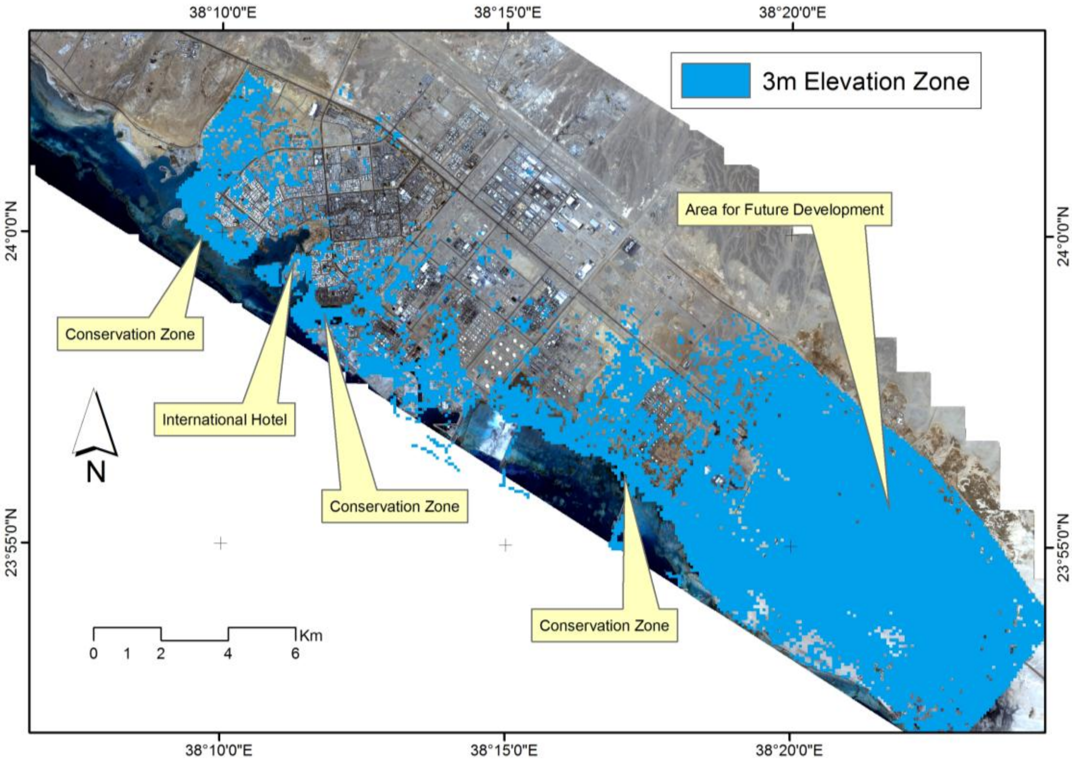

Figure 5: Area Affected by 3m Sea level Rise in Yanbu Industrial City

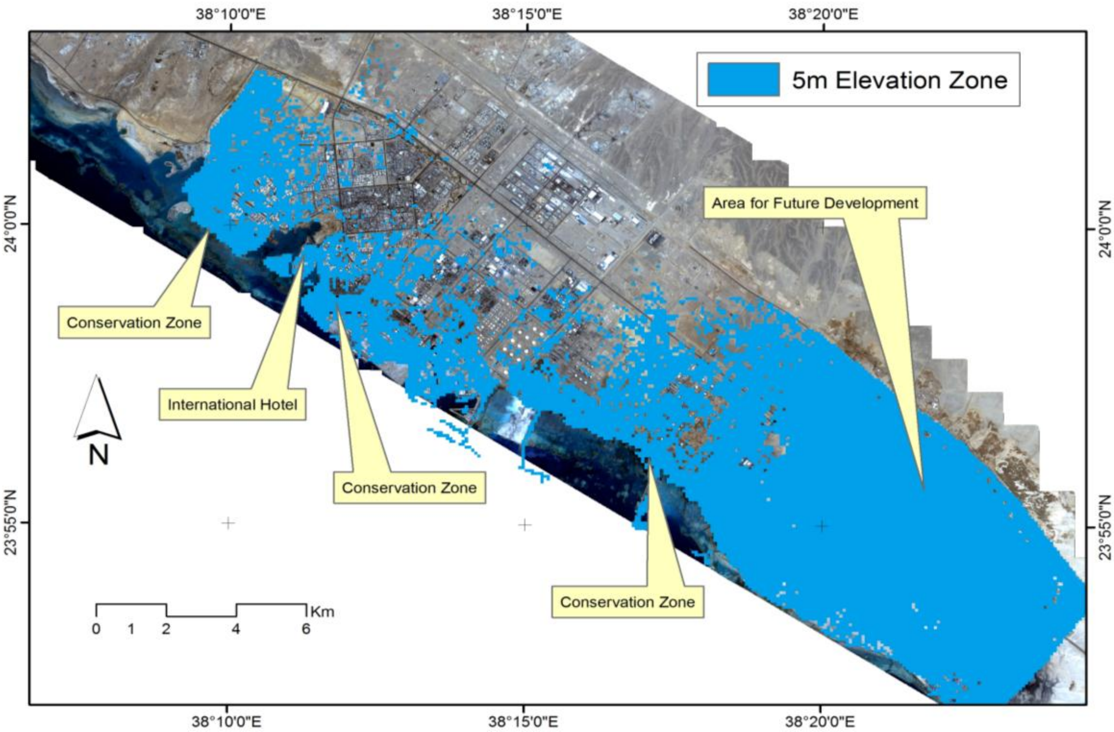

Figure 6: Area Affected by 5m Sea level Rise in Yanbu Industrial City

Table 1: Estimates of Affected Land Use Patterns by different Scenarios of SLR.

Scenarios of SLR	**Residential**	**Industrial**	**Area For Future Development**	**Total Area**
1	50.706	271.188	421.524	743.418
2	72.819	341.091	482.193	896.103
3	99.63	397.872	518.805	1016.31
5	158.598	504.468	558.09	1221.16

Table 2: Estimates of Affected Population by different Scenarios of SLR.

Scenarios of SLR	Estimated Area to be affected	Year 2000 Population	Projected Population for 2012
1	743.418	17000	30530
2	896.103	18000	32325
3	1016.307	20000	35917
5	1221.156	22000	39500

3.2 Discussion

According to the different scenarios the impacts of sea level rise were predicted for Yanbu Industrial City. A sea level rise of 1 m (Figure 3) could potentially flood a total area of 743.418 hectares, which represents all the land below 1m elevation. The whole areas for future expansion would be affected. A sea level rise of 2m (Figure 4) could potentially flood a total area of 896.103 hectares, which represents all the land below 2m elevation. A sea level rise of 3m (Figure 5) could potentially flood a total area of 1016.307 hectares, which represents all the land below 3m elevation. A sea level rise of 5m (Figure 6) could potentially flood a total area of 1221.156 hectaress, which represents all the land below 5m elevation.

The greatest impacts will be in the area designated for future development, which covers more than half of the areas to be affected by 1m to 3m inundation. Other land uses will also be affected even at 1m inundation. For example an international hotel, all the three conservation zones, residential and industrial areas are at risk of 1m inundation.

The conservation zones contain mangroves and coral reefs which are very important to the ecosystem, especially in a desert where such are very scarce to come by.

About 30530 people will be affected when the sea level rises by 1m and this figure can rise to about 39500 at a scenario of 5m.

4. CONCLUSION AND RECOMMENDATION

4.1 CONCLUSION

DEM data from SRTM was used in a GIS environment to analyse the vulnerability of coastal flooding and inundation due to the impacts of sea level rise. Scenarios of sea level rise for 1m, 2m, 3m and 5m were used for the analyses. The study indicates that SRTM DEM data is suitable for depicting areas prone to inundation due to sea level rise in the study area.

Considering the current rates of global sea level rise which is about 1.8 mm/year (Church et al. 2004), and 2.5 mm/year as indicated by Cazenave et al. (2008); the sea level should rise only between 0.18– 0.25 m by the end of this century (Hereher, 2010). This might not pose a major threat to Yanbu Industrial city but the predicted 1m rise by the year 2100 is a major challenge, especially now that the IPCC scenarios are being reviewed to take into consideration recent melting of Polar ice and other factors.

4.2 RECOMMENDATION

The author recommends as follows:

1. Coastal defences such as raised coastal sand dunes, coastal ridges and elevated coastal strips should be built along the coast to act as the first barrier that help protect inland areas, particularly existing low-laying lands, from inundation and sea surges.
2. Since a rise in sea level by 1m will affect most of the areas for future expansion, we therefore recommend that sand filling and other prevetive measures should be carried out before the construction works are commenced.

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