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The Impact of the Red Sea Level Rise on Jeddah's Coastal Districts, Western Saudi Arabia

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Abstract. Segments of Jeddah's coastal areas are vulnerable to be claimed by sea water if the Sea Level Rise (SLR) of the Red Sea increased in the future. Therefore, this research focuses on the potential impacts of 1 m SLR on Jeddah's coastal areas by identifying the potential impacted districts and estimate the percentage of coastal area that might be affected by sea water. Due to the accuracy limitation of the available Digital Elevation Model (DEM) globally to analyze the SLR in centimeters intervals, the 1 m SLR scenario has been considered during this study as it presents an extreme possible scenario by 2100. The outputs of the study illustrated that 24 coastal districts within Jeddah area will be partially encroached by sea water. For SLR by 1 m, the low intrusion impacts illustrated in 7 out of 24 districts (< 10% of the total district area), a moderate intrusion impacts illustrated in 9 out of 24 districts (> 10% & < 45 % of the total district area) and a significant intrusion impacts illustrated in 8 out of 24 districts (> 45% of the total district area). This study might be used as a tool to support the decision makers to develop a disaster risk management plan to adapt, mitigate and protect the potential threatened areas within Jeddah city.

1. Introduction

Climate change takes place all over the world (Riebeek, 2007) due to the fact that the earth temperature has raised about 1^{o}C degree over the last century. As a result, glacial ice on both poles are melting gradually and increasing sea level height worldwide (Gosling, *et al*., 2011). Therefore, a percentage of low-land will be claimed by sea. Climate change is a statistical distribution of weather patterns over time. Temperature and rainfall patterns are the major factors to consider for climate change (Williams *et al*., 2012). SLR was estimated by intergovernmental panel of climate change (IPCC) in 2007 to be between 18 – 65 cm by the end of 21st century. However, recent studies estimated to expand the range of these values to reach more than 180 cm (Raye, 2010). Global warming is expected to be associated with an increase of the severity and frequency of extreme events (Tolba & Saab, 2009). These changes are expected to seriously impact water resources, food security, tourism, natural resources, and population. Previously impacts might have important implications on the sustainable development in the region (Raye, 2010). Climate change is historical and should be prepared for it ahead of time to limit the damage that is associated with it. This research will focus on the future impacts of SLR on Jeddah's coastal line, identify the potential impacted areas and, estimate the percentage of coastal area that might be claimed by sea in order to enable decision makers to prepare guiding people who lived in the vulnerable areas and mitigate/protect the vital infrastructure and planning for the future development. The outputs of this research were based on 1 m SLR in the Red Sea. The scenario has a moderate probability to occur based on a recent published study at "Nature Climate Change" journal indicated that all the previous mentioned scenarios were playing down the previous forecasting expectations due to the fact that the scenarios were built based on a mean global temperature raise by 2 ^{o}C from the pre-industrial era. The study showed that the likely range is global temperature increase will be 2.0 – 4.9 ^{o}C; with a median of 3.2 ^{o}C and just 5% possibility for the mean global temperature not to exceed 2.0 ^{o}C (Raftery *et al*., 2017). As a result, the scenarios should be re-evaluated to consider the recently published study's input; which will lead in a significant and dramatic changes in the forecasts. In 2014 IPCC Climate Change Synthesis Report, they forecasted an extreme event under RCP8.5 scenario projected the mean global raise in temperature would likely to be 2.6 – 4.8 ^{o}C (IPCC Climate Change Synthesis Report, 2014); the Nature study's results aligned perfectly with the 2014 IPCC Climate Change Synthesis Report, thus supporting their extreme RCP8.5 scenario, thus the probability of 1 m SLR within the Red Sea exists. In 2019, NOAA published its Arctic report card indicating that the year of 2019 was the record-breaking of the global ocean temperature; the first record-breaking was in 2018 (NOAA Arctic Report Card, 2019). These shocking results were associated with a recent analysis of satellite data that revealed astounding loss of 600bn tons of ice last summer as Arctic experienced hottest year on record. A new study in March 2020 showed with a confident level that Greenland's melting ice raised the global sea level by 2.2 mm just in two months (Velicogna *et al*., 2020; The Guardian Journal, 2020); prior this finding, the 2014 IPCC Climate Change Report stated that the average raise of the global sea level by the ice melting is 0.7 mm per year. The new study reveals a shocking fact and indicates that the most extreme estimated scenarios by IPCC have better chances to occur.

The population of Jeddah has jumped dramatically since 1950 to reach 3.6 million in 2015. Jeddah is a coastal city and it will be subject to a higher coastal vulnerability (Hereher, 2016). 1 m raise in SLR would affect around 244,000 people in coastal areas (43% of the total coastal population of Saudi Arabia)(Gosling *et al*., 2011). The coastal vulnerability index indicates that about 16% of the coast is under high vulnerability, whereas 44% of the coast is intimately low vulnerable to climate change. Higher vulnerable coastal segments include: Relatively flat and lowlands, coral reef and mangrove trees (Hereher, 2016). This study would provide a tool to support the decision makers to act decisively regarding potential displacement locations for the existing vital infrastructure and would ring a bell for a mitigation or adaption measures. In addition, it will enable the authorities for future planning with considering an extreme climate change. The result might be a tool to help the city planners and authority to make further decision about city development.

2. Study Area

The study area is focused on the whole Jeddah City (Fig. 1). Jeddah is located at the middle of the eastern coast of the Red Sea, Western Saudi Arabia. This area occupies a stretch of land along the shore, 70 km long and 20 km wide, lies between latitudes 21°15′ and 21°57′N and longitudes 39°06′ and 39°31′E. The city is bounded by the Red Sea to the west and several small mountain chains to the east. Most of the drainage systems have dissected the area starting from these mountains, which lies about 10 to 20 km inland (Youssef *et al.*, 2016). For the purpose of this study the suburbs areas will be included.

3. Data Sources and Methodology

This study is based on open source raster and vector data. The DEM was obtained from the National Elevation Data set provided by

United State Geological Survey (USGS). Higher resolution DEM was obtained from online sources by downloading ASTER GLOBAL DEM (resolution 1 ARC SECOND which is ~30m) from https://earthexplorer.usgs.gov/. ArcGIS was used to mosaic seven images obtained by USGS and then clipped the study area to identify Jeddah city's boundaries. The pixel type of the DEM properties was set as "floating point" and the pixel depth set as 32 Bit. The spatial reference was set as "WGS_1984_UTM_Zone_38N". The Mean Sea Level (MSL) was set as "Zero" as current sea level is identified as zero height, while the SLR by 1 m was set as "one" as the SLR by 1 m is identified as one meter height. The actual sea level rise was calculated by subtracting SLR from MSL; this would generate values as raster image, then it would be converted into vector data to enable calculating the areas that would be claimed by water for each district. Then by dividing the areas of encroached by water over the total area of the district we get the percentage coverage of each district. Then the product would be finalized through the ArcGIS layout by identifying the polygons for all the districts.

4. Results

The raise of sea level by 1 m identified 24 districts to be impacted. The impacted areas significantly differ from a district to another. Jeddah city has been divided into 6 zones; each zone contains 4 districts (Fig. 2). Table 1 shows the district names and their affected areas accordingly. The most impacted districts are located within the Southern region (Zone 1& 2) and Northern region (Zone 5 & 6) with an estimated significant to moderate value of risk. While the central region (Zone 3 & 4) is the lowest impacted areas with an estimated low value of risk.

Figure 2 provides a histogram of the percentage of the impacted areas for the districts. While Fig. 3 shows the total gross floor area in km^2 that have been impacted by sea water intrusion.

The outputs of the study illustrated that 24 coastal districts within Jeddah city will be partially encroached by sea water. For SLR by 1 m, the low intrusion impacts illustrated in 7 out of 24 districts (< 10% of the total district area), a moderate intrusion impacts illustrated in 9 out of 24 districts (> 10% & < 45 % of the total district area) and a significant intrusion impacts illustrated in 8 out of 24 districts (> 45% of the total district area). The visualization details of the potential impacted districts are shown in Fig. 5 - 28.

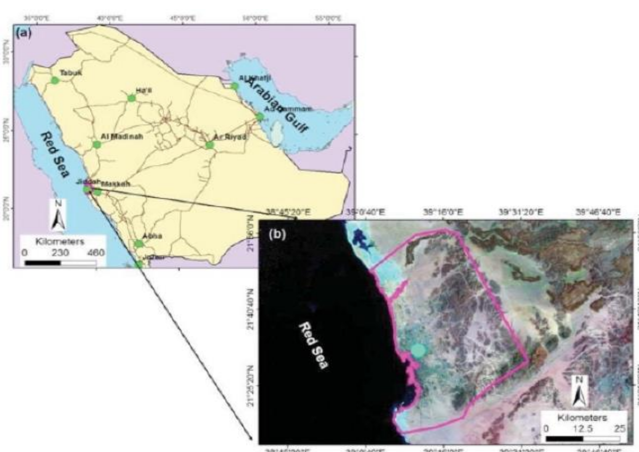


Fig. 1. Identifies the location of the study area.

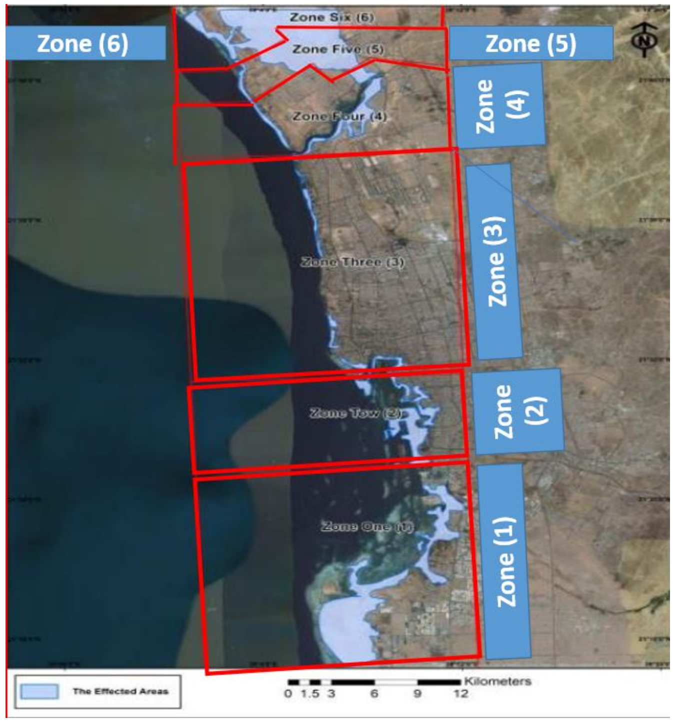


Fig. 2. Shows Jeddah's potential district impacted areas if the mean sea level rise by 1 meter.

Table 1. List the impacted district names and its coverage percentage for 1 m SLR. (24 impacted districts).

No	Zone No.	District Name	Impacted Area (%)	Impacted Area (km^2)	Impact Severity
1	1	Al-SAHIL	54.20	20	Significant
2	1	King Faisal Naval Base	32.09	9	Moderate
3	1	Al-Mahgar	50.01	2.3	Significant
4	1	Betrumeen	3.73	0.2	Low
5	2	Jeddah Sea Port	54.36	5	Significant
6	2	Al-Balad	24.19	0.26	Moderate
7	2	Al-Bagdadeyya	31.78	1.1	Moderate
8	2	Al-Ruwase	14.15	0.62	Moderate
9	3	Al-Hamrah	16.84	9.1	Moderate
10	3	Al-Andulus	7.95	1	Low
11	3	Al-Shate	5.98	1.1	Low
12	3	Al-Marjan	7.08	0.62	Low
13	4	Southern Obhour	38.55	5.4	Moderate
14	4	Northern Obhour	8.52	1.9	Low
15	4	Al-Sheraa	1.82	0.1	Low
16	4	Al-Amwaj	2.18	0.6	Low
17	5	Al-Fardous	72.51	4.5	Significant
18	5	Al-Swaryee	99.8	9.5	Significant
19	5	Al-Yaqoot	66.16	4.04	Significant
20	5	Al-Lolo	8	0.5	Low
21	6	Al-Manarat	33	5.9	Moderate
22	6	Al-Fanar	39	3.6	Moderate
23	6	Bohayrat	24	4.9	Moderate
24	6	Al-Zomorod	66.22	6.8	Significant

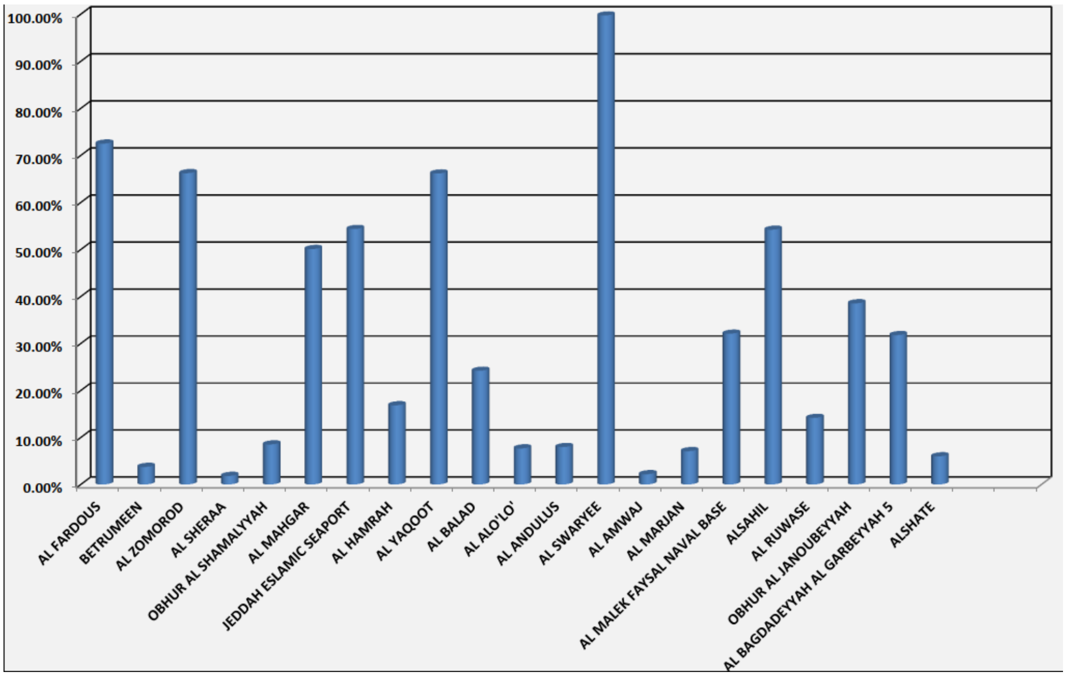


Fig. 3. Illustrates the percentage cover of the impacted areas by 1 meter sea water intrusion for the districts.

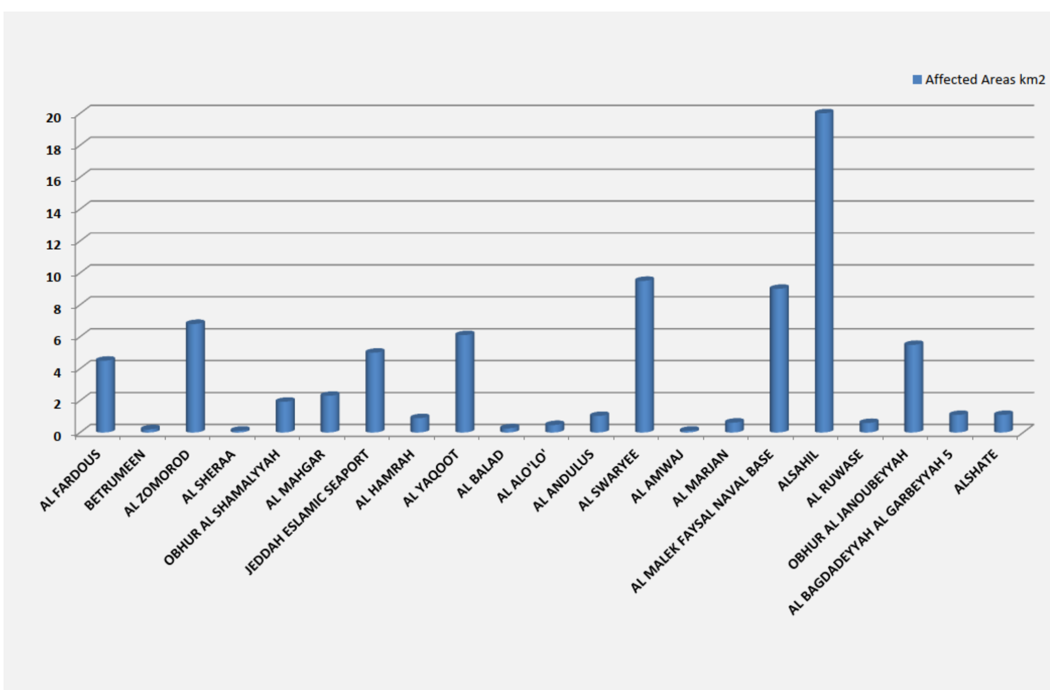


Fig. 4. Illustrates the impacted km^2 areas by 1 meter sea water intrusion for the districts.

Zone 1 – ALSAHIL Dist.

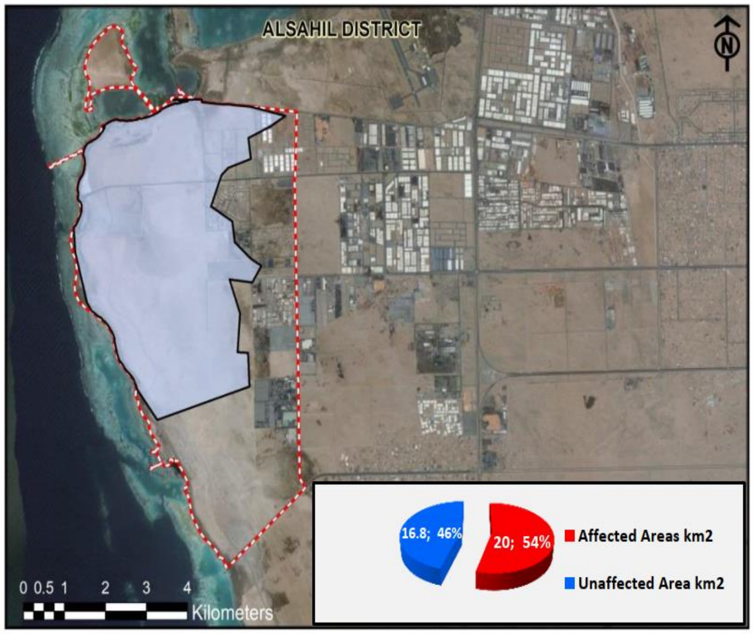


Fig. 5. Shows the impacted areas of AL-SAHIL Dist. by 1 m SLR within Zone 1.

Zone 1 – King Faisal Naval Base

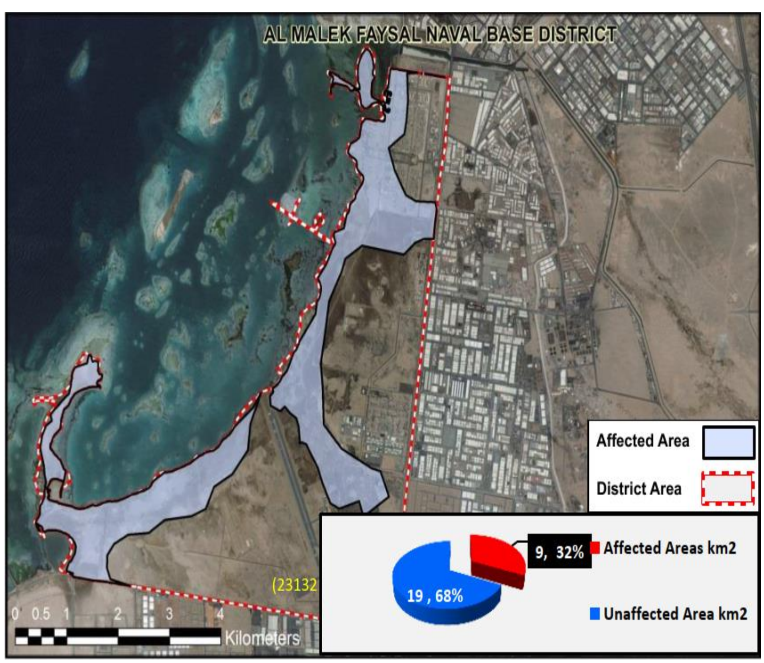
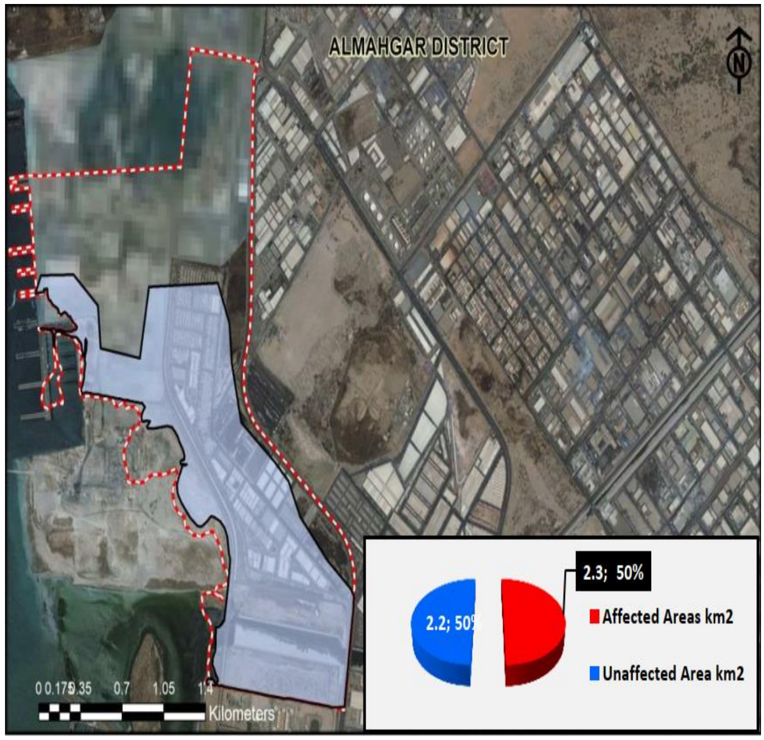


Fig. 6. Shows the impacted areas of King Faisal Naval Base by 1 m SLR. within Zone 1.

Zone 1 – Al-Mahgar Dist.



Figu. 7. Shows the impacted areas of AL-Mahgar Dist. within Zone 1.

Zone 1 – Betrumeen

Fig. 8. Shows the impacted areas of Betrumeen Dist. by 1 m SLR within Zone 1.

Zone 2 – Jeddah Islamic seaport

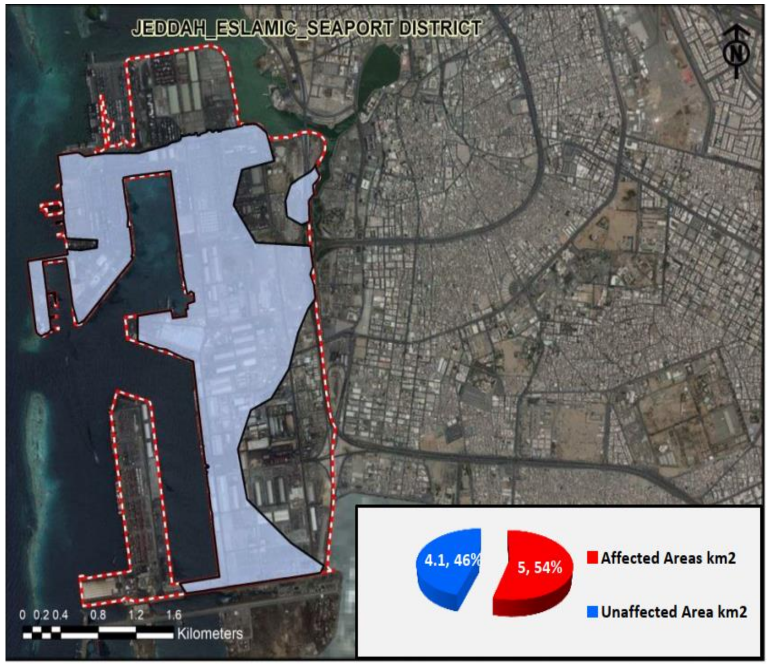


Fig. 9. Shows the impacted areas of Jeddah seaport by 1 m SLR within Zone 2.

Zone 2 – Al-Balad

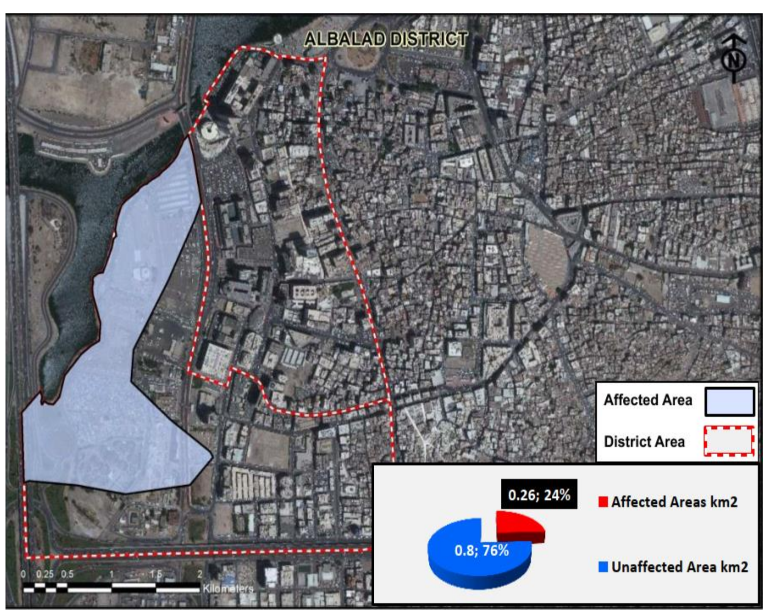


Fig. 10. Shows the impacted areas of AL-Balad Dist. by 1 m SLR within Zone 2.

Zone 2 – Western Al-Bagdadeyh

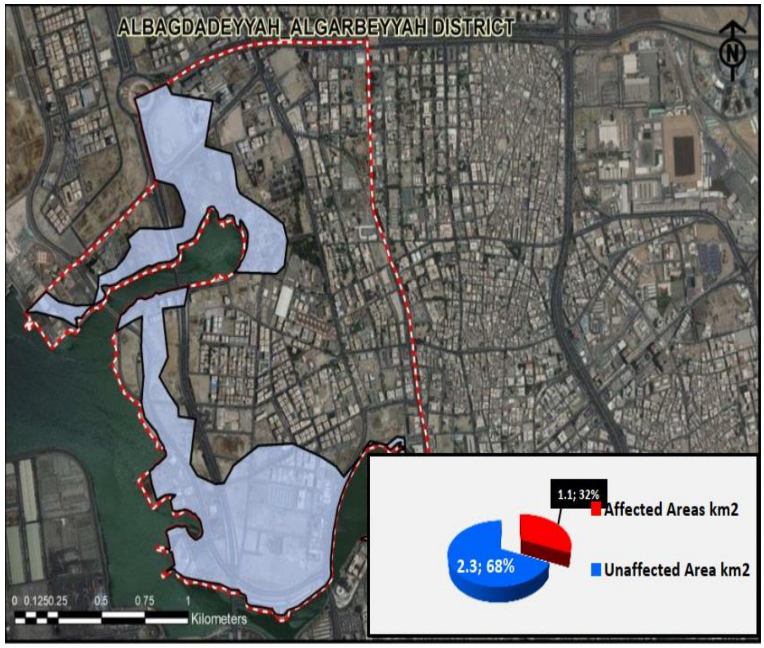


Fig. 11. Shows the impacted areas of W. Al-Baghdadeyah Dist. by 1 m SLR within Zone 2.

Zone 2 – Al-Ruwais

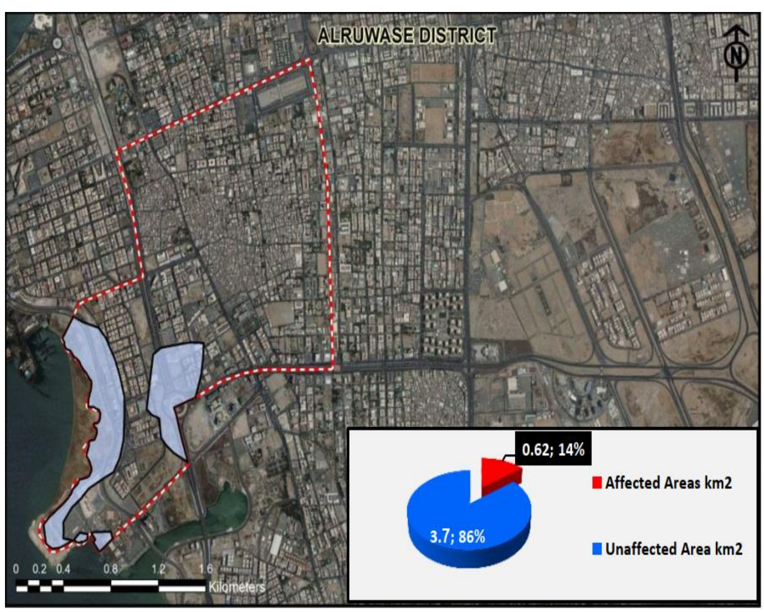


Fig. 12. Shows the impacted areas of AL-Ruwais Dist. by 1 m SLR within Zone 2.

Zone 3 – Al-HAmrah

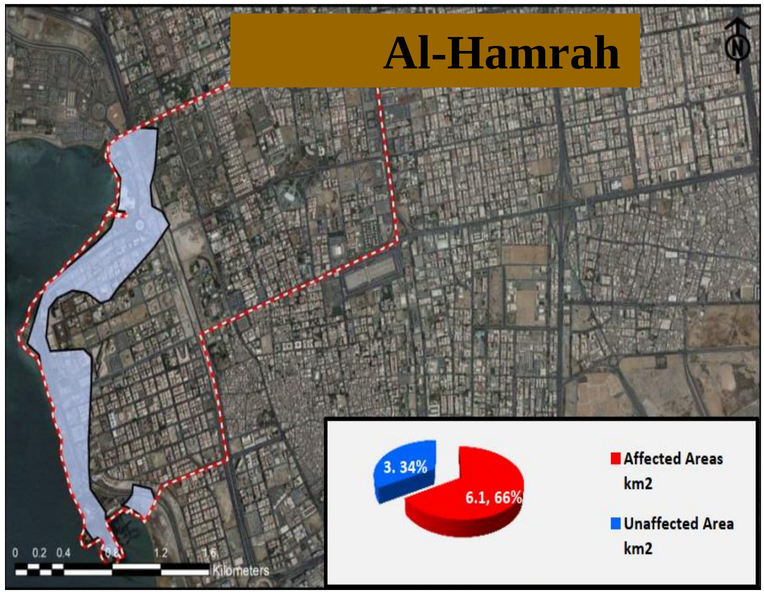


Fig. 13. Shows the impacted areas of AL-Hamrah Dist. by 1 m SLR within Zone 3.

Zone 3 – Al-Andulus

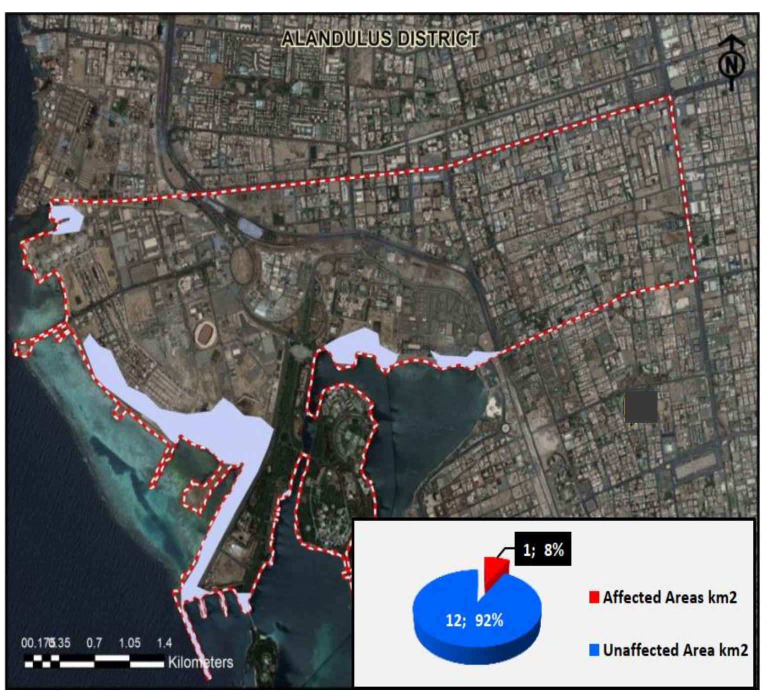


Fig. 14. Shows the impacted areas of AL-Andulus Dist. by 1 m SLR within Zone 3.

Zone 3 – Al-Shate

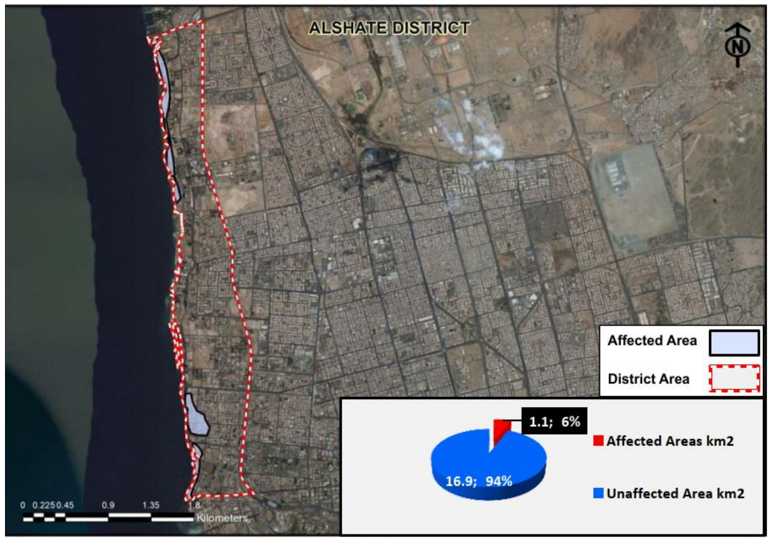


Fig. 15. Shows the impacted areas of AL-Shate Dist. by 1 m SLR within Zone 3.

Zone 3 – Al-Marjan

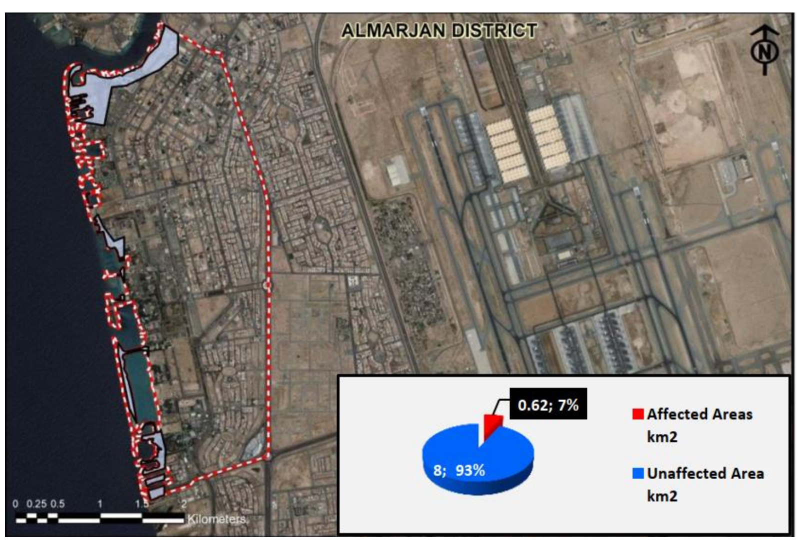


Fig. 16. Shows the impacted areas of AL-Marjan Dist. by 1 m SLR within Zone 3.

Zone 4 – Southern Obhour

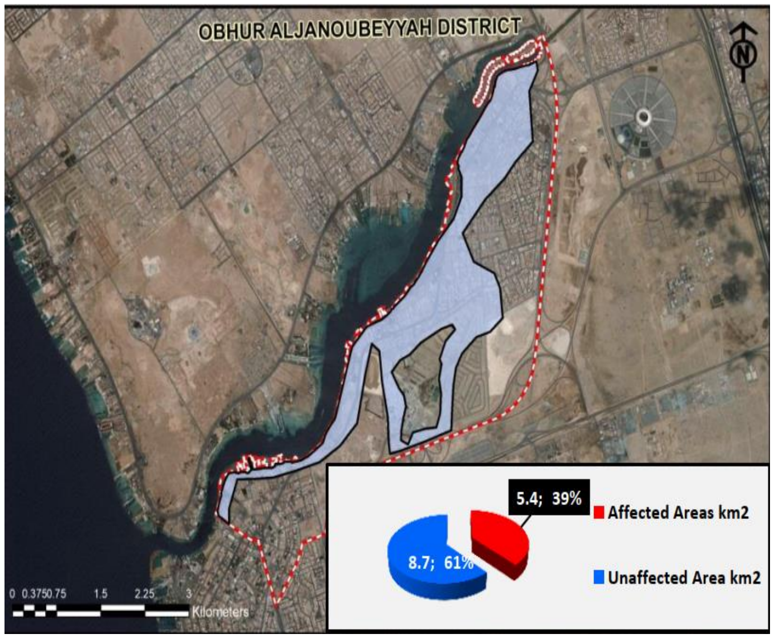


Fig. 17. Shows the impacted areas of Southern Obhour Dist. by 1 m SLR within Zone 4.

Zone 4 – Northern Obhour

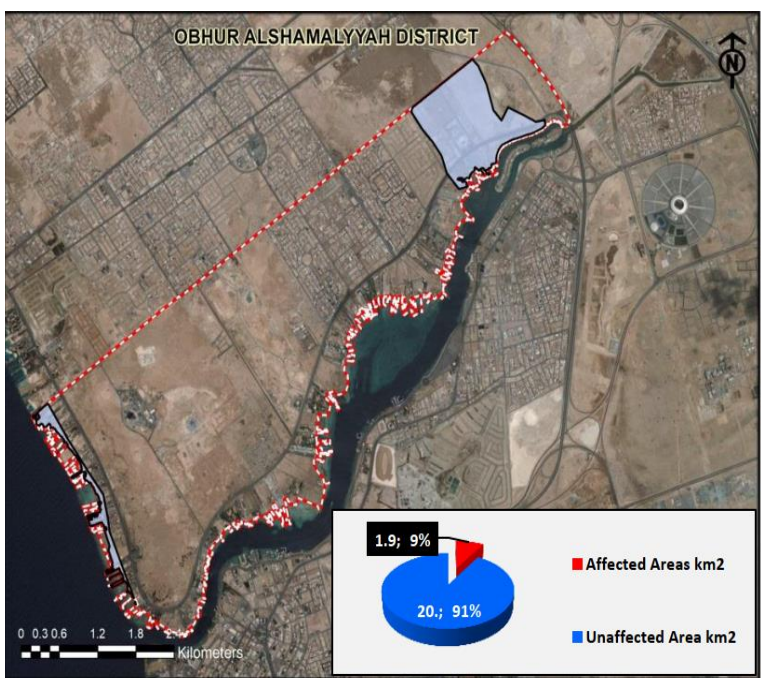


Fig. 18. Shows the impacted areas of Northern Obhour Dist. by 1 m SLR within Zone 4.

Zone 4 – Al-Sheraa

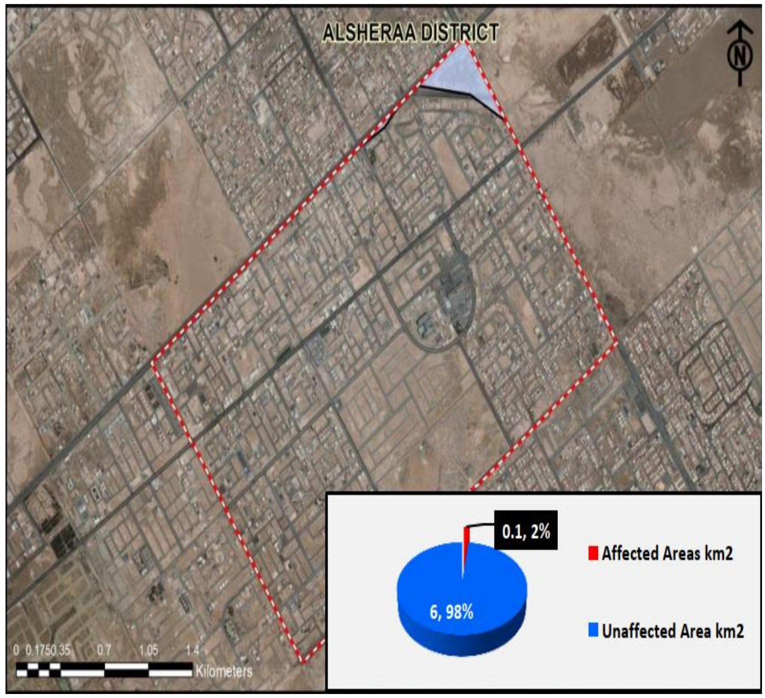


Fig. 19. Shows the impacted areas of AL-Sheraa Dist. by 1 m SLR within Zone 4.

Zone 4– Al-Amwaj

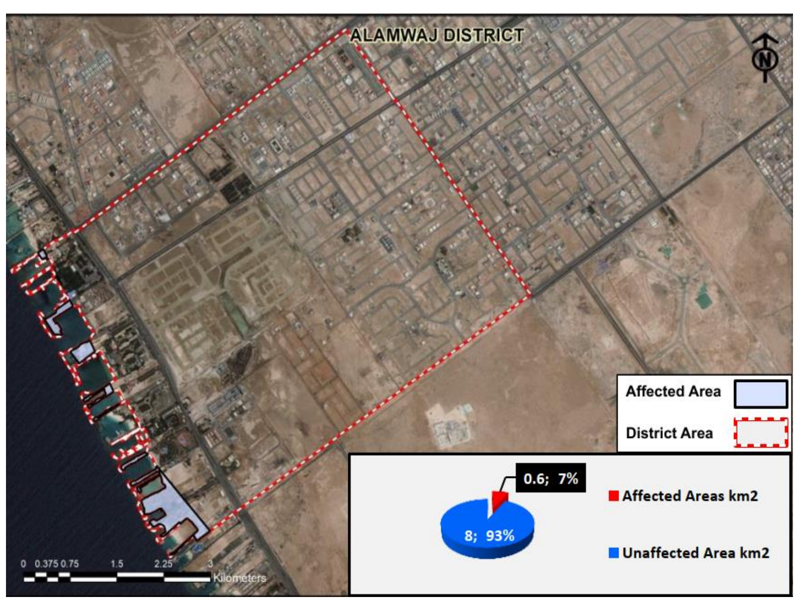


Fig. 20. Shows the impacted areas of AL-Amwaj Dist. by 1 m SLR within Zone 4.

Zone 5 – Al-Fardous

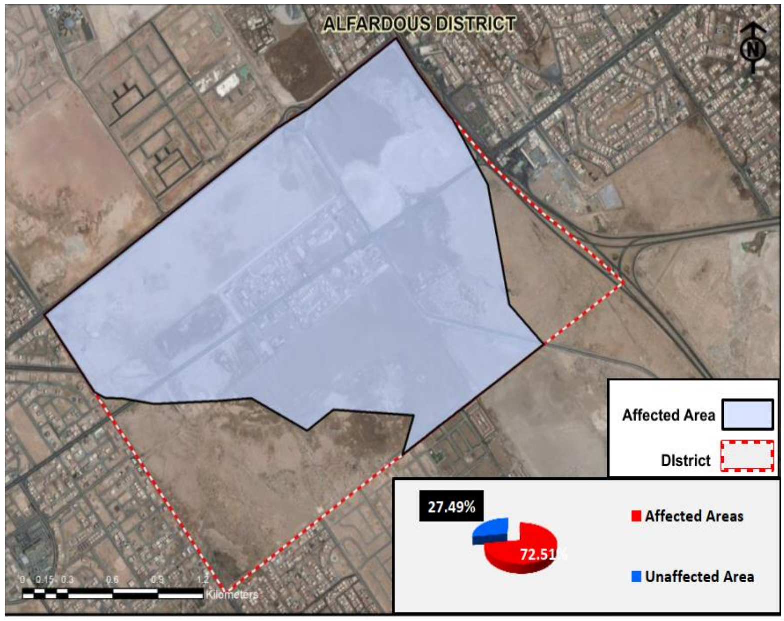


Fig. 21. Shows the impacted areas of AL-Fardous Dist. by 1 m SLR within Zone 5.

Zone 5 – Al-Swaryee

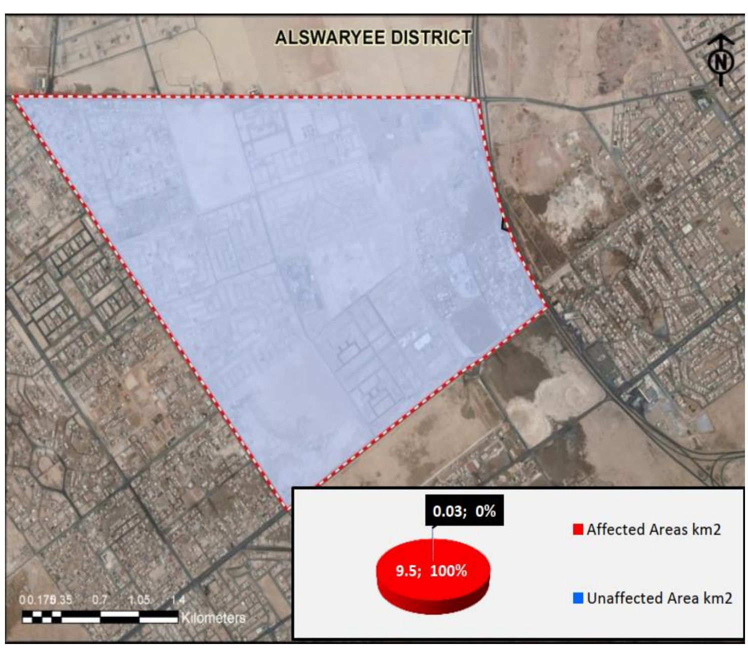


Fig. 22. Shows the impacted areas of AL-Swaryee Dist. by 1 m SLR within Zone 5.

Zone 5 – Al-Yaqoot

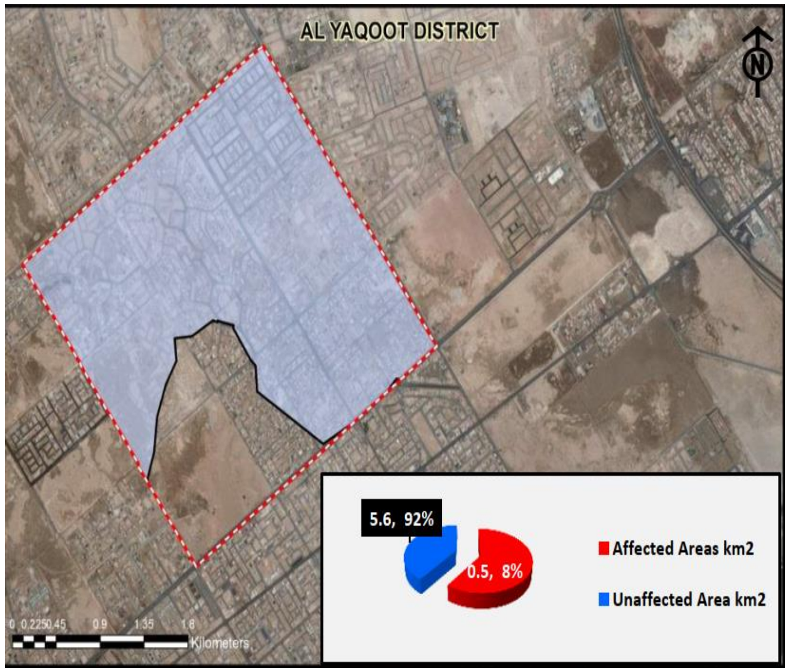


Fig. 23. Shows the impacted areas of AL-Swaryee Dist. by 1 m SLR within Zone 5.

Zone 5 – Al-Lolo

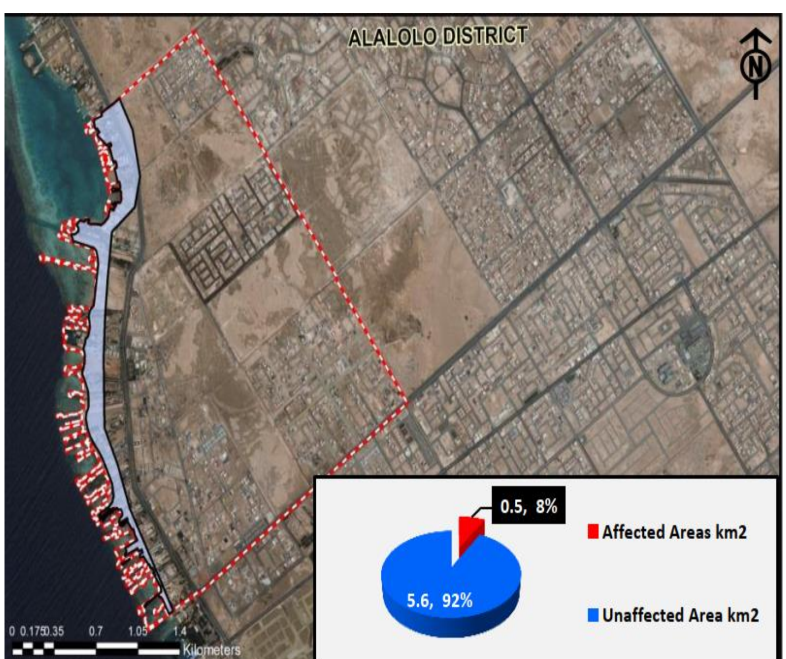


Fig. 24. Shows the impacted areas of AL-Lolo Dist. by 1 m SLR within Zone 5.

Zone 6 – Al-Manarat

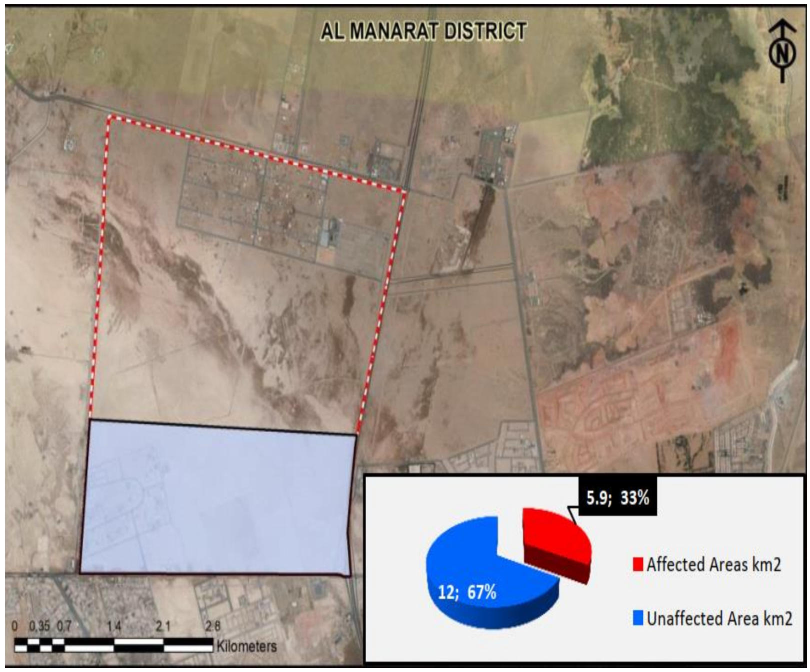


Fig. 25. Shows the impacted areas of AL-Manarat Dist. by 1 m SLR within Zone 6.

Zone 6 – Al-Fanar

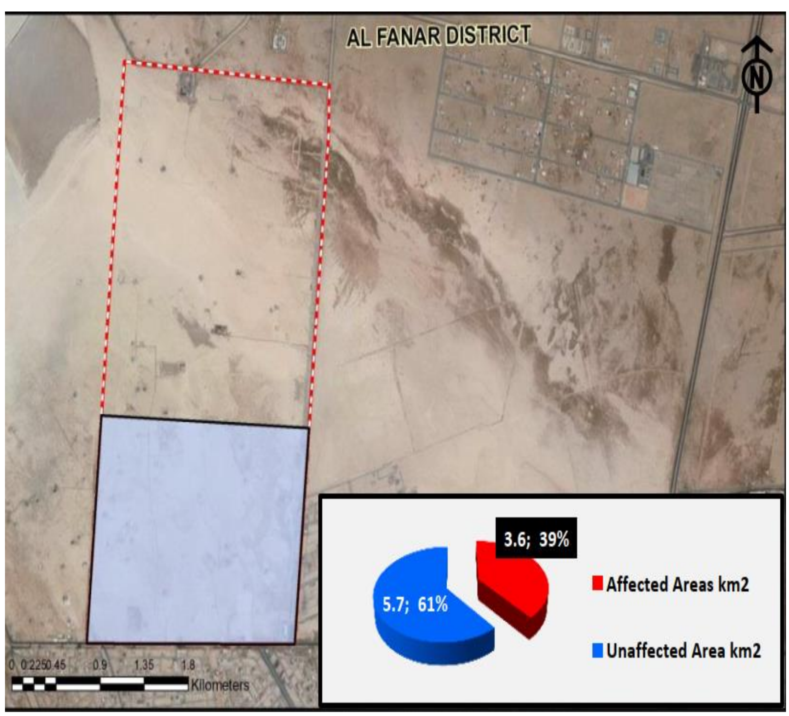


Fig. 26. Shows the impacted areas of AL-Fanar Dist. by 1 m SLR within Zone 6.

Zone 6 – Al-Bohyrat

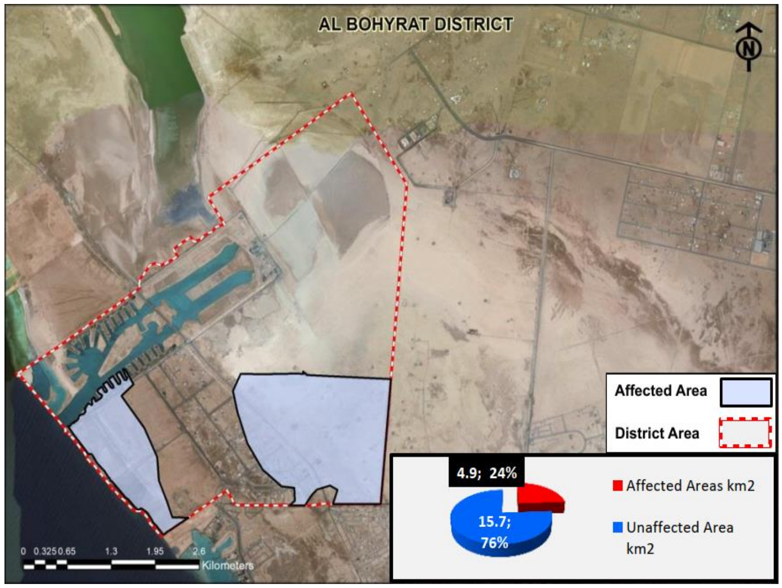


Fig. 27. Shows the impacted areas of AL-Bohyrat Dist. by 1 m SLR within Zone 6.

Zone 6 – Al-Zomorod

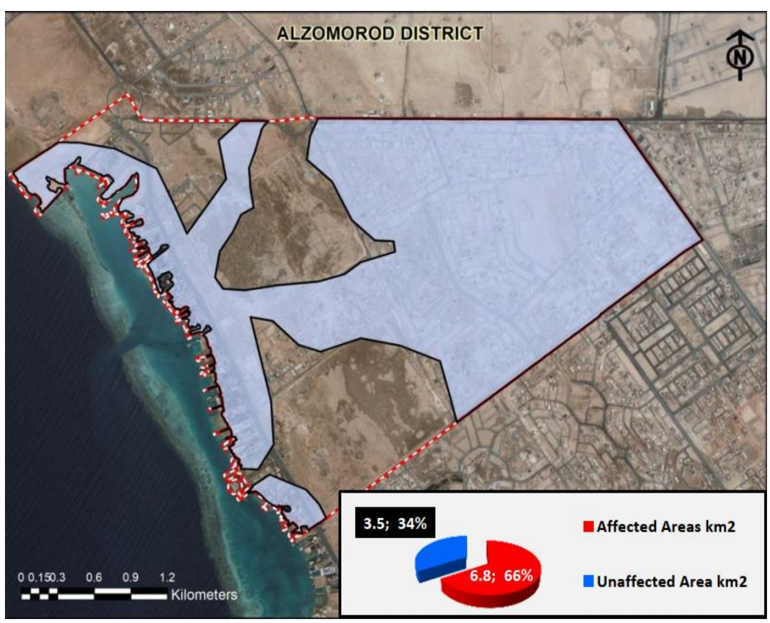


Fig. 28. Shows the impacted areas of AL-Zomorod Dist. by 1 m SLR within Zone 6.

5. Conclusion and Recommendation

Based on the study's results, the policies and measures should be developed based on the findings with the participation of city dwellers or stakeholder's. The outputs of this research would enable the authorities to develop several management actions related to a disaster risk management, ecosystem risk management and physical structural. The city would require a disaster risk management and engineering plans to develop such as an early warning system, hazard and vulnerability mapping, improved drainage, building codes and practices, storm and wastewater management, transport and road infrastructure improvement, sea walls and coastal protections structures, flood levees, water storage. In order to conduct this properly, the first step is to generate authenticate high resolution geospatial data (in cm intervals) and make it available for researchers; which will help to strengthen the research work possibilities around the country to improve the forecasting capabilities. The tide was not considered in the study; the high tide scenario would increase the percentage of the estimated land that might be claimed by the sea.

There are a set of recommendation based on the finding of this study:

- The stakeholders should survey the potential impacted sites in details and generate a detailed report explaining the current situation and the possible mitigation measures that can be taking into accounts.
- Obtain a high resolution DEM data (LiDAR) to confirm the preliminary results out of this study and plan accordingly.
- An emergency contingency plan should be developed to deal with SLR.

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تأثير ارتفاع مياه منسوب البحر الأحمر بمقدار متر واحد على أحياء مدينة جدة – غرب المملكة العربية السعودية

شهلا جميل طه خصيفان

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المستخلص. أجزاء من سواحل مدينة جدة والمناطق المتاخمة لها مهددة بالغمر جراء ارتفاع منسوب مياه سطح البحر الأحمر بمقدار متر واحد من منسوب سطح البحر الحالي بحلول عام ٢١٠٠م. وبناء عليه فإن هذا البحث قد ركز علي تحديد المناطق المعرضة للغمر بمياه البحر. مخرجات البحث حددت ٢٤ حيًا من أحياء مدينة جدة الساحلية والمتاخمة لها سوف تتعرض جزئيا للغمر بنسب مساحات متفاوتة. تأثير ارتفاع منسوب سطح البحر الأحمر بمقدار واحد متر سوف ينتج عنه تأثير ضئيل الخطورة لعدد ثمانية أحياء من إجمالي ٢٤ حيًا (أقل من ١٠٪ من المساحة الإجمالية للحي). وسوف ينتج عنه كذلك تأثير متوسط الخطورة لعدد ٩ أحياء (أكبر من ١٠٪ وأقل من ٤٥٪ من المساحة الإجمالية للحي)، وتأثير بالغ الخطورة لعدد ٧ آحياء (أكبر من ٤٥٪ من المساحة الإجمالي للحي). هذه الدراسة اعتمدت على البيانات المتاحة لتضاريس مدينة جدة من خلال الموقع الحكومي للمسح الجيولوجي التابع للولايات المتحدة الأمريكية. توصي هذه الدراسة كذلك بالبدء علي عمل مسح جيولوجي دقيق باستخدام تقنية الليدار لسواحل مدينة جدة، وذلك لإتاحتها للباحثين لعمل دراسات أكثر دقة.