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ASSESSING THE IMPACTS OF SEA LEVEL RISE ON LAND-USE ACROSS THE NORTH-EASTERN PARTS OF THE UAE COASTAL AREAS USING REMOTE SENSING TECHNOLOGY

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Declaration of Original Work

I, Khawla Ali Mohammed Albedwawi, the undersigned, a graduate student at the United Arab Emirates University (UAEU), and the author of this thesis entitled "*Assessing the Impacts of Sea Level Rise on Land-use Across the North-Eastern Parts of the UAE Coastal Areas Using Remote Sensing Technology*", hereby, solemnly declare that this thesis is my own original research work that has been done and prepared by me under the supervision of Professor. Taoufik Ksiksi, in the College of Science at UAEU. This work has not previously formed the basis for the award of any academic degree, diploma, or a similar title at this or any other university. Any materials borrowed from other sources (whether published or unpublished) and relied upon or included in my thesis have been properly cited and acknowledged in accordance with appropriate academic conventions. I further declare that there is no potential conflict of interest concerning the research, data collection, authorship, presentation, and/or publication of this thesis.

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Abstract

The consequences of global warming and climate change would result in a considerable rise in sea level. Other larger consequences on coastal lands, agriculture, buildings, and facilities are expected. The goal of this study is to assess the effects of Sea-Level Rise (SLR) on various land uses in the UAE's North-Eastern coastal districts (Fujairah and Kalba cities). Four SLR scenarios will be developed through the QGIS platform and the Landsat images that have been acquired from the USGS Earth Explorer. The area will be observed over 20 years (2000 – 2020). The second goal of this study is to develop a coastal vulnerability index that can support policy-makers and stakeholders in developing strategic plans in order to be prepared for the effects of this phenomenon in the most vulnerable areas. A confusion matrix was conducted to assess the accuracy of the land classifications in the study resulting in an 80% classification accuracy. The level of damages due to SLR in the year 2000 will rise to 21%, 27%, and 7% of the agricultural, built up, and open areas respectively. However, it will reach 29%, 28%, and 8% for the same areas in the year 2020. Around 15% of the study area in the year 2000 is considered to have high vulnerability to SLR where about 29% of the study area in the year 2020 is considered to have high vulnerability to SLR. The development projects in the study area have increased throughout 20 years and it is the most affected by SLR. It is widely assumed that any future actions and preparations to mitigate the impact of SLR should focus on the vulnerable areas mentioned above. Proper early planning for long-term consequences will definitely save time, resources, and effort.

Keywords: Sea-Level Rise, Land Use, Climate Change, Global Warming, GHG Emission, Landsat Images, Remote Sensing, QGIS Software.

Title and Abstract (in Arabic)

تقييم آثار ارتفاع مستوى سطح البحر على استخدام الأراضي عبر الأجزاء الشمالية الشرقية من الساحل الإماراتي باستخدام تقنية الاستشعار عن بعد

الملخص

إن عواقب الاحتباس الحراري وتغير المناخ ستؤدي إلى ارتفاع كبير في مستوى سطح البحر. ومن المتوقع حدوث عواقب أخرى أكبر على الأراضي الساحلية والزراعة والمباني والمرافق. الهدف من هذه الدراسة هو تقييم آثار ارتفاع مستوى سطح البحر على مختلف استخدامات الأراضي في المناطق الساحلية الشمالية الشرقية لدولة الإمارات العربية المتحدة (مدينتا الفجيرة وكلباء). سيتم تطوير أربعة سيناريوهات لمستوى سطح البحر من خلال برنامج (QGIS) وبالاستعانة بصور جوية (لاندسات) التي تم الحصول عليها من خلال الموقع (USGS Earth Explorer). ستتم ملاحظة تأثير ارتفاع مستوى سطح البحر على استخدامات الأراضي في منطقة الدراسة في السنتين (2000 - 2020). الهدف الثاني من هذه الدراسة هو تطوير مؤشر للضعف الساحلي الذي يمكن أن يدعم صناع القرار وأصحاب المصلحة في وضع خطط استراتيجية للتصدي إلى نتائج هذه الظاهرة في المناطق الأكثر عرضه لمواجهة ارتفاع مستويات سطح البحر. تم تصميم مصفوفة الارتباك لتقييم دقة تصنيفات الأراضي في الدراسة والتي كانت 80%. يصل مستوى الأضرار الناجمة عن ارتفاع مستوى سطح البحر في العام 2000 إلى 21% و27% و7% لكل من المساحات الزراعية والمبنية والمفتوحة بالتوالي. في حين سيصل مستوى الأضرار الناجمة من ارتفاع مستوى سطح البحر في العام 2020 إلى 29% و 28% و8% لنفس المناطق. حوالي 15% من منطقة الدراسة تعد ذات قابلية عالية للتأثر بارتفاع مستوى سطح البحر، في المقابل 29% من منطقة الدراسة لها قابلية عالية للتأثر بمستوى سطح البحر في العام 2020. مع مرور 20 سنة هناك تغيرات وزيادة في نسبة المساحات المبنية والمشاريع التنموية في هذه المنطقة ويعزى السبب إلى التركز السكاني ونشاط الحركة السياحية. من المفترض وعلى نطاق واسع أن أي إجراءات وتحضيرات مستقبلية للتخفيف من تأثير ارتفاع مستوى سطح البحر أن تركز على المناطق التي لها القابلية العالية للتأثر بهذه الظاهرة. ومن المؤكد أن التخطيط المبكر السليم للعواقب طويلة المدى سيوفر الوقت والموارد والجهود.

مفاهيم البحث الرئيسية: مستوى سطح البحر، استخدامات الأراضي، التغير المناخي، الاحتباس الحراري، انبعاث الغازات الدفيئة، صور جوية، استشعار عن بعد، برنامج QGIS.

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I would like also to thank my family for their continued motivation and for providing me a suitable environment to study and succeed in. Many thanks will go to my best friend Jawaher for always being there for me.

Dedication

I dedicate this work
To my persistent self
To my mother who pushed me hard to do this
To my sister who I always lean on
To every person frustrated me: and still I rise

أهدي رسالة الماجستير:
إلى نفسي التي لا تكف عن المثابرة
إلى أمي التي دفعتني بكل قوة إلى هنا
إلى أختي التي أتكئ عليها دائما
إلى كل من أحبطني وثبط عزائمي: انظر.. ما زلت أعلو

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List of Abbreviations

CVI	Coastal Vulnerability Index
DEM	Digital Elevation Model
GHG Emissions	Greenhouse Gases emissions
ROI	Regions of Interest
SCP	Semi-Classification Plugin
SLR	Sea Level Rise
USGS	United States Geological Survey

Chapter 1: Introduction

1.1 Overview

Climate change impacts the entire world and results in different consequences depending on the environment of each region. Usually those impacts extend for a very long period. A direct and serious consequence of climate change is sea-level rise. Accumulated heat-trapped from Greenhouse Gases emissions that are produced from deforestation and industrialization are causing global warming, more than 90% of the trapped heat is absorbed by oceans as per Nasa Sea Level Change Portal. As a result of this absorption there will be a rise in ocean temperature and the water will expand in what is known as hydro-thermal expansion. This thermal expansion leads to an increase in the world's ocean levels, melting the polar ice sheets, glaciers, and shift precipitation patterns pursuant to the National Geographic. The global mean sea level is currently at 3.3 inches/yr and the increase in the sea levels is inevitable and projected to accelerate in the coming decades regarding to (Global Sea Level, 2021). According to NASA Sea Level Change Portal, temperature measurements of the sea surface acquired by ships, satellites, and drifting sensors, as well as subsurface measurements and observations of global sea-level rise, have demonstrated that upper ocean warming caused sea level to increase owing to thermal expansion in the 20th century.

Sea level rise poses a serious hazard to coastal urban living, industrial, and touristic areas around the world. Storm surges will be more intense, flooding will occur much more frequent, and coastal regions will seriously negatively affected. In many situations, this is where dense population centers due to the current rapid urbanization in coastal cities, as well as vulnerable wildlife habitats, are found. Important and valuable ecosystems such as mangroves that are located on the coastlines, they assist in absorbing a huge percentage of Greenhouse Gases emissions, are expected to suffer erosion due to sea-level rise. African coastal cities and three-quarters of European countries will be impacted by sea-level rise for example; Spain, Italy, and the Netherlands. US coastal areas that are also similarly vulnerable to sea-level rise are experiencing severe flooding in more than 90 US cities, and this number is expected to be doubled by the year 2030. In addition to the Asian cities that will be highly affected too as stated in the World Economic Forum.

In UAE, around 80% of the population are living in coastal areas in close proximity to the seas along with major infrastructure (El Raey, 2010). Such areas are susceptible to SLR effects especially the North-Eastern coastal areas where Fujairah and Kalba cities are located on the seashore of the sea of Oman and facing the Indian Ocean, where there is a significant risk of cyclones and hurricanes. In contrast, other emirates are located along the coastal water of the Arabian Gulf and cyclones impacts are much lower. The aforementioned cities have already faced a sever hurricane in 2007, where the land-use and human life were severely disrupted (El Rafy & Hafez, 2007). Historically, it is well known that Fujairah and Kalba cities have fishing-based economy, large agriculture plantations, growing urbanization and tourist-attraction facilities along the coastline. Rising sea levels can contaminate soil and groundwater with salt, threatening life even further inland.

Tide gauges and satellite altimeters are the two most common techniques that are currently being used to detect sea-level rise. For more than a century, tide gauge stations all around the world have used a range of manual and automatic sensors to measure the daily high and low tides. Scientists can generate a worldwide average and modify it for seasonal changes by combining data from dozens of locations throughout the world. Since the early 1990s, sea level has been monitored from space using radar altimeters, which calculate the height of the sea surface by measuring the returning speed and strength of a radar pulse fired towards the ocean. The higher the sea level, the speedier and stronger the return signal in accordance with NOAA Climate. Satellite data and products have great advantages over field based measuring techniques. Generally speaking, they have lower costs, and can provide consistent daily global coverage with high levels of accuracy.

Ksiksi et al. (2012) has studied the impacts of sea-level rise on land use and mangroves areas in Abu Dhabi by using SRTM DEM, ArcGIS, and Google Earth for field observation of the study area. The study area has been classified through supervised classification into urban, total area, and mangrove areas and different scenarios of SLR has been developed to assess the impacts of SLR in addition to constructing of vulnerability index to determine the vulnerability of the study area toward SLR. In the SLR scenario of 3 m, the loss of the mangrove area will reach about 81% of its total area, about 39% of the urban area, and about 30% of the total land area. Land classifications requires accuracy assessments in order to determine how well the pixels were sampled into the correct land cover classes as stated in the study of Maxwell et al. (2021). Post classifying the map into water, agriculture, build up areas, bare lands, shrubs, and mixed forests. Maxwell et al. (2021) ran an accuracy assessment by choosing number of pixels in the classified map and match it with the real locations to build a confusion matrix and calculate the total accuracy by dividing the correct pixels over the total pixels. The Accuracy assessment resulted in that the map is 81.7% accurate (Ksiksi et al., 2012; Maxwell et al., 2021).

Furthermore, Duncan et al. (2018) have also used remote sensing data on their study to monitor mangrove forest resilience and resistance to sea-level rise. They have employed Landsat 5, Landsat 8, SRTM DEM data, and QGIS to classify the acquired images and construct the confusion matrix to assess the classification accuracy as well as to assess the capacity to monitor SLR resilience and resistance processes and factors individually across large spatial extents. Across their case study locations, they found generally low SLR resilience and resistance. They also discovered that site-specific resilience and resistance capacity and limits might be highly incompatible, emphasizing the importance of SLR vulnerability monitoring for optimal management (Duncan et al., 2018).

In the study of Hereher (2016), he assessed the coastal vulnerability of Saudi Arabia coastal cities in the Red Sea coast toward the sea-level rise. A series of Landsat 8 images and DEM that are encompassing the whole Red Sea were acquired. The area has so many lowlands cities and mangrove ecosystems that are considered to have the highest vulnerability to sea level rise. The study resulted in, urban areas and beaches are having high vulnerability to sea-level rise in addition to the areas of coral reefs and mangroves that constitutes 48% of the coast (Hereher, 2016).

Almost all of the coastal cities are building sea walls, water pumps, surge barriers, and overflow chambers to keep water out besides involving people-oriented measures comprising urban design and building resilience. Meanwhile, adopting restoration approaches for land recovery and mangroves ecosystems to adapt to flooding and paying more attention to Greenhouse Gases emissions mitigation is mandatory to guarantee future safety. Scientific research in this field would help to further study and understand the dynamic of sea level in the past and assign it to predict the future sea-level rise to take all the precautions and the preparedness toward mitigating its effects. Therefore, huge studies have been conducted on climate change and its direct contribution to sea-level rise around the world.

1.2 Literature Review

A series of recent studies and reviews have attested to the significant variation of average weather conditions and their severity on multiple world regions for example; Arnell et al. (2016), Abdi (2019), El Gayar & Hamed (2017), and Doyle et al. (2015). This literature review presents reviews and studies about climate change and its effects on sea-level rise and land uses on all levels globally, regionally, and locally.

1.2.1 Climate Change at Global Levels

Continental, regional and ocean basin scales have seen abundant long-term climate change. These changes include shifts in arctic temperatures and ice, precipitation patterns, the salinity of the ocean, sea-level rise, trends of wind, and Severe weather characteristics, including droughts, heavy rains, heat waves, and tropical cyclone strength as mentioned in the study of Change (2007).

A study conducted by Darwin (1995) about the economic adaptation on agriculture and climate change, stated that all the countries that highly depend on the agricultural economy have a higher chance of facing the serious effects of climate change. Any potential rise in global temperatures and changes in precipitation patterns over the coming century will affect global agriculture, especially if climate change is severe the production of all goods and services could decrease. Arnell et al. (2016) agreed on their literature that whenever the climate varies the crop planted varies as well. In order to offer a multi-sectoral evaluation, Arnell's report on the impacts of climate change around the world clarified the metrics that reflect certain measurable impacts of climate change, such as crop production and the total number of people flooded by coastal flooding. The three indicators that reflect a shift in vulnerability to impacts are water shortage, river floods, and crop suitability. Those indicators don't integrate adaptation effects to climate change except for crop productivity (Darwin, 1995; Arnell et al., 2016).

Furthermore, The Intergovernmental Panel on Climate Change (IPCC) reviewed many studies on the possible impacts of climate change and concluded that there is a relevance between the distribution of spatial and geographical impacts and the global overall impact when considering the global magnitude of climate change.

In El Raey's (2010) study he discussed that the recent climatological studies showed an increase from 1850 to 2005 by 0.76ºC on the global surface air temperature. In addition, a linear warming pattern of 0.13ºC per decade has been recorded over the last 50 years (IPCC, 2007). Prior research mentioned that the frequency and duration of frosts have been decreases and the number of heat waves has been increased (El Raey, 2010; IPCC, 2007).

1.2.2 Climate Change at Regional Levels

On the level of the Arab region, Elasha's (2010) research which is about the mapping of climate change threats and human development impacts in the Arab region focused on adaptation as a priority to ensure the success of national and international efforts to promote sustainable long-term growth. Prompt and instant actions should be taken to assure the strength of the adaptive capacity and minimize the susceptibility of sensitive systems to climate change, and boost the diversification of productivity for livelihoods. Arab countries have a high vulnerability to climate change in reference to their arid climates. They are viewed as homogenous entities. Formerly known that the Arab countries are adjusted to a warm and arid climate, however, a critical selection of appropriate adaptation strategies is necessary concerning the projected severe precipitation and temperature changes (Elasha, 2010).

As reported by the recent study of El Raey (2010) that the statistics showed the world total Greenhouse Gases (GHGs) emissions were about 33 thousand Tg (teragram) by the year 2000, and the Arab countries contributed about 4.2% of this total. For instance, the Kingdom of Saudi Arabia (KSA) contributed with a great proportion of the world's overall GHGs emissions followed by Egypt and Algeria from the Arab countries. Therefore, an uneven increase in surface air temperature from 1970 to 2004 ranged from 0.2 to 2.0°C witnessed in the Arab region (IPCC, 2007; El Raey, 2010).

Elasha (2010) in his review pointed out that the industrial revolution is one of the major reasons for boosting the concentration of CO_2 in the atmosphere what results in “global warming”. IPCC cautions that there will be massive species extinctions, reduction in the production of crops, starvation, and a constant rise in sea levels that most of the world’s coastal areas will be inundated consequently. Also, there will be an increase in water salinity, land degradation, and biodiversity what will impact the gulf land (IPCC, 2018; Elasha, 2010).

Arab countries are facing long-term prompt impacts of climate change on their water resources. A forecast drop of 25% in average annual precipitation, reduction of

23% in the total run-off beside a considerable decrease in groundwater recharge in Jordan particularly as addressed in the research of El Gayar & Hamed (2017) on climate change and water resources management in Arab countries. Alongside considering Egypt as a case study, that depends on the Nile river which is the main source of freshwater to afford all of the country's agricultural, industrial, and domestic sector demands. While reviewing the Nile flows scenarios, a projected rough reduction of 40% inflows by 2025 was presented in Elasha's (2010) study and it speaks volumes (El Gayar & Hamed, 2017; Elasha, 2010).

1.2.3 Climate Change at Local Levels

UAE has a dry subtropical environment with rare rainfall and year-round sunny days. Over the period 1970 - 2001, the average annual rainfall is approximately 120 mm per year as addressed in the review of Murad et al. (2014) that discussed the possible impact of climate change on water resources and considering Ras Al-Khaimah emirate as a case study. The UAE is going to suffer climate changes too. It is estimated that coastal, aquatic, and dryland habitats, buildings and infrastructures, agriculture and food protection, and areas of public health are the most vulnerable to climate change. The climate in coastal areas is hot and humid in contrary to the interiors where it is dry. Excessive temperature, storm waves, water stress, rising sea levels, dust and sandstorms, and desertification are possibly the impacts of climate change in the UAE also Any minor changes observed in weather patterns could influence the country's environmental, economic and social well-being (Murad et al., 2014).

The review of Radhi (2009) evaluated the potential impact of global warming in the UAE residential buildings and stated that the UAE is one of the greatest energy consumers per capita in the world because of the rapid population growth rates and the high economic expenditure as well as the low energy cost what cause an increase of the Greenhouse Gases emissions accordingly. In 2006, the net energy usage in the UAE was announced to be 52.6 Billion KW/H along with the total annual CO_2 emissions produced by the fossil fuels usage amounted to 137.8 million metric tons what makes it persuasive to be the dominant source of Greenhouse Gases emissions in the whole country of UAE. The literature of Shanks & Nezamifar (2013) which is about the impacts of climate change on building cooling demands in the UAE are pertaining to strongly suggests that the electricity use in UAE for the matter of air conditioning and cooling in buildings has increased and it will continue to increase in correlation with the increase on air temperature which the Greenhouse Gases represent the main cause to it. It is predicted by the end of the 21st century an increase in temperature and a decrease in precipitation levels in UAE as stated by The Environment Agency of Abu Dhabi and the Ministry of Energy. While the projection of the annual average temperature in the year 2050 is to be between 1.6°C and 2.9°C what shows to be warmer than the period 1961 - 1990 (Radhi, 2009; Shanks & Nezamifar, 2013).

According to the National Climate Change Plan for the United Arab Emirates (2017 - 2050), the growth of the UAE is going to be affected potentially if all of the impacts of climate change are left without management. The national climate change plan for the UAE revealed the country's plans and strategies toward the climate change challenges, Thus, to support UAE 's climate strategies that include covering both mitigation and adaptation measures. UAE should take into account the best international practices toward Greenhouse Gases emissions. Also, an important system will be developed called Measurement, Reporting, and Verification (MRV) to collect the data from all the sources of emissions in addition to carbon leakage that removes and substitute the atmospheric emissions through artificial and natural reservoirs. A policy on green growth and sustainable development is built in relevance to the climate plan.

In light of energy consumption, a clean energy strategy is implementing in Dubai in 2050 which is targeted to decrease the consumption of water and energy by 20% by 2020 and 30% by 2030 regarding National Climate Change Plan for the United Arab Emirates (2017 - 2050). Furthermore, to build sustainable cities like Masdar city and the sustainable city in Dubai. UAE is contributing to stimulating climate action and boost International Collaboration Worldwide (NCCP 2017-2050, 2020).

1.2.4 Sea Level Rise at Global Levels

One of the direct scientific implications of current climate change is the sea level rise associated with global warming and the melting of glaciers and polar ice caps. A study conducted by Dasgupta et al. (2007) which is a resource guide for coastal land managers, engineers, and scientists and have reported that the worldwide network of tide gages over numerous decades observed the sea level rose by 1 - 2 (mm/yr) in the 20th century. Over the last two decades, the sea surface heights exceeded 3 mm/yr. Dasgupta and his colleagues' study presented scenarios to show the projected global average sea level in 2100 to be higher than the current rate. (Dasgupta et al., 2007).

Doyle et al. (2015) claimed in their study that it is still unclear if the rising of sea levels is associated with human activities or climate change. Conversely, in the study of Titus et al. (1991) about Greenhouse Gases effect and sea-level rise they confirmed that the increase of the mass of water in the global oceans is the dominant cause of the sea-level rise, probably due to the melting of land-based ice sheets and glaciers. Based on general circulation model simulations that demonstrated the increase of CO_2 in the atmosphere and the other Greenhouse Gases that are strongly focused on polar latitudes is the main contributor to global warming. Sea level rise is observed to be the first indication of climate change. As well as Change (2007) discussed in his study from the physical science perspective that since 1961 observation of the depth of the ocean reached 3000 meters due to the average temperature of the global ocean. This depth allows the ocean to absorb 80% and more of the heat applied to the climate system. As a result of this warming, seawater is going to expand and raise sea levels. In both hemispheres, average mountain glaciers and snow covers showed a reduction. The reduction in polar ice volume can raise sea levels from 4 to 6 meters. From a physical point of view, even if the Greenhouse Gases concentrations have been stabilized the projected anthropogenic warming and rising sea levels will persist for decades due to the timescales correlated with climate processes and feedbacks (Change, 2007; Doyle et al., 2015; Titus et al., 1991).

Moftakhari et al. (2017) discussed the threats of the rising sea levels to the population and assets located in all the low-lying coastal areas around the world. Coastal areas are at risk for flooding from various drivers. In the absence of flood adaptation, annual losses of the global gross domestic product as expected by 2100 is around 0.3% to 9.3%, however, the percentage of the coastal landscapes that are projected to experience future flooding and have some capacity to respond dynamically to SLR only is 70% (Moftakhari et al., 2017).

The study of Pramanik et al. (2021) assured that the possible consequences of projected SLR on human activities in the coastal area are assessed using a Landsat 8 satellite image with a 30 m spatial resolution extracted from USGS. In addition to SRTM DEM data to determine the regional elevation of Mumbai's shoreline. Landsat 8 images have been used to explain coastal land-use patterns by applying a supervised classification technique to the LULC features. The vulnerability of India's coastal area was assessed using several socioeconomic variables, and it was observed that unsustainable urbanization, unplanned construction, and growing pressure from coastal erosion make Mumbai and the Kurla region highly prone to flooding (Pramanik et al., 2021).

Models of reconstructing the sea levels history to forecast the future climate change direction and impacts on natural and cultural resource assessments are considered to be quite beneficial in regard to the study of Doyle et al. (2015), the social and conservation plans to determine how and when the shorelines will be flooded in conjunction with the increasing sea level under climate warming are the primary concerns in many cases. An example of those models; the Sediment Stratigraphy Geology Models, present the earth on a cycle of cooling and warming periods also the sea level cycled on low-stands and high-stands. Where the high-stands occur through the warming and ice melt periods so the sea levels reach a high point before reverting the direction and fall again to another low-stands through the cooling periods (Doyle et al., 2015).

1.2.5 Sea Level Rise at Regional Levels

In the literature of Massoud et al. (2003), they mentioned that coastal zones on the Mediterranean Sea, the Red Sea, the Arabian Gulf, and the Atlantic Ocean are mostly occupied by Arab countries. A large number of populations are living along the coastline. Observations show a growth of tourism and the population in these coastal areas. A study done by El Raey (2010) displayed the total length of the Arab region coastal zone is equal to 34,000 km and 18,000 km is populated. The vulnerability of the Arab region to the passive impacts of climate change is extremely high. On the basis of the Climate Change Index (CCI), the region contains five out of ten countries that are most exposed to the effects of climate change, Somalia, Morocco, Iraq, Djibouti, and Egypt (Massoud et al., 2003; El Raey, 2010).

To define the vulnerability, it is when a system is unable to deal with, combat and recover from adverse climate change consequences like climate extremes and climatic variability as stated in the study of Elsharkawy et al. (2009) which has examined the effects of sea-level rise scenarios of 1-5 m on region, residents, agricultural and urban scale, and wetlands. It resulted in an indication that Qatar's land area will be reduced by 2.6% to 13% in conjunction with a 1 m and 5 m rise. 10% of the Egyptian population would be directly affected by a rise of 1 m especially on the Nile Delta that would experience a loss of 20% with a 5 m rise. Sea level rise of 1 m would affect about 5% of the UAE and Tunisia. Meanwhile, in the study of Al-Jeneid et al. (2008), they discussed the case of the Kingdome of Bahrain by executing satellite imagery analysis to identify the land uses and GIS estimation that resulted in an indication by 50 cm rise in sea levels will immediately inundate 11% of the Kingdom of Bahrain area. (Elsharkawy et al., 2009; Al-Jeneid et al., 2008).

The Coastal Vulnerability Index (CVI) based on remotely sensed pictures and government resources, aided by field surveys, was used to estimate the susceptibility of the Omani coast to abrupt sea level rise from storms and tsunamis in the study of

Hereher et al. (2020). According to the findings, high susceptible coastal zones to sea level rise account for 805 kilometers of coastline, primarily around the Al-Batinah plain in the north and some scattered sectors along the country's eastern coast. Major communities and infrastructure are concentrated in areas with a high CVI (Hereher et al., 2020).

To recognize weaknesses, strengths, threats, and opportunities of diverse aspects of Arab countries' climate adaptation a SWOT analysis was performed in the study of El Raey (2010). The pro-activity of preparing and designing strategies and initiatives to respond to future impacts covering all development sectors is constrained by the lack of structural climate change and sea-level rise. In addition, the vulnerability toward the sea level rise and its implications on water resources, tourism, food protection, and public health can’t be disregarded for all Arab countries. Furthermore, direct inundation may happen on areas of low lands due to sea-level rise for instance; the Delta of Mauritania, Nile delta of Egypt, and Mediterranean beaches in Tunisia which would probably result in severe impacts on the coastal shape, tourism, and resources. Risk reduction on a large scale is required in the Arab countries as the events of droughts, hurricanes, heat waves, sandstorms, and flash flooding are expected to extremely increase due to climate change (El Raey, 2010).

The study of Hereher (2016) leaned entirely on remotely sensed data, notably for mapping coastal regions. A coastal vulnerability index has been developed for Saudi Arabia's Red Sea coast. Climate change threatens 16 percent of Saudi Arabia's 1840-kilometer-long coastline. Because the coast is generally narrow, high, and close to basement complexes, it is expected that the coastline will be resistant to the effects of sea-level rise. However, coastal cities in the lowlands and mangrove ecosystems should have a negative reaction. Such ecosystem is highly valuable according to providing food in the form of wastes, a refuge for mollusks, shrimps, and fishes, fuel for human use, and nesting places for birds. They are coupled with coastal cities along the Red Sea coast; Jeddah, Rabigh, and Gizan are considered the most vulnerable cities to the sea level rise. The inundation of mangroves, wetlands, and coral reefs and the acceleration of coastal erosion is the most considerable impacts of sea-level rise in Saudi Arabia. The inundation of wetlands can threaten its rich biodiversity by loss as well as the threat of sandy beach erosion that will lead to being destroyed as an impact of storm waves (El Raey, 2010; Hereher, 2016).

1.2.6 Sea Level Rise at Local Levels

The United Arab Emirates will also experience serious impacts because of sea-level rise. The growth of the UAE population is described as accelerated growth. The growth rate of the UAE population is considered to be one of the highest rates around the world from 1975 - 2005. The reason behind mentioning the growth rate of UAE is that several environmental problems have resulted and particularly most of this population are concentrated on the coastlines and islands, especially in Abu Dhabi as reported in the literature of Ksiksi et al. (2012). In addition, most of the outstanding developments are located in the seashore and islands too. Another literature of El Raey (2010) supported the same idea of the development projects that targeted entertainment, tourism, and estate industries in reference to its richness with natural resources. Those natural resources in the UAE are known as valuable assets to be protected. Natural resources contributed to diversifying the economy of the country that has been increased recently. The UAE coastal areas are known to hold almost 85% of the population, more than 90% of the infrastructure, multiple vulnerable ecological subsystems, and significant cultural patrimony. Climate change will raise the sea levels, sea surface temperature and change the wave dynamic so, the coastal areas will be highly vulnerable to climate change and economic damages are expected to happen at a high rate. Melville-Rea et al. (2021) have agreed on their study that much of the UAE's low-lying coastline is shallowly sloped (about 35 cm per kilometer) and hence vulnerable to floods (Ksiksi et al., 2012; El Raey, 2010; Melville-Rea et al., 2021).

A study done by Ksiksi et al. (2012) to address the impact of sea-level rise on land use and mangrove areas by utilizing Landsat images, DEM, ArcGis, and constructing natural vulnerability index, resulted with approximately 1.5% of urban areas will be affected by 0.5m rise in sea level and in the worst scenario which is a 3 m rise in sea level will damage 40% of urban areas in the emirate of Abu Dhabi. Another study reported the damages of urban areas due to sea-level rise, such as Dasgupta et al. (2007) among MENA countries, and the highest level of impact was estimated for UAE. Around 5% of urban areas will be impacted by a 1 m rise in sea level and 13% by a 5 m rise in sea level on a country level. All UAE coastal cities will experience severe inundations as Hereher (2020) argued in his research that despite the United Arab Emirates has extended their area by initiating artificial islands and coasts, the expected sea-level rise constitutes a threat to these developments. Planning and implementing coastal protection structures may help to reduce the risk (Ksiksi et al., 2012; Dasgupta et al., 2007; Hereher, 2020).

The study of Hereher (2020) showed the inundated areas of UAE that range from 1,155 Km^2 to almost 5,000 Km^2 of UAE total area. Sabkhat area is a few meters above sea level, its vulnerability to seawater intrusion and changed salinity is very high. Moreover, a significant number of sensitive habitats and natural areas along the UAE shoreline would be threatened by rising sea levels. For instance, Ksiksi et al.

(2012) study summarized the total areas of mangrove forests that are located on the shoreline of the emirate of Abu Dhabi and probably would be inundated as an impact of sea-level rise. 0.5 m sea level scenario shows about 1.67 Km^2 will be impacted. Meanwhile, the 3 m sea level scenario will affect about 25.54 Km^2 of the total area of mangrove forests (Hereher, 2020; Ksiksi et al., 2012).

El Raey (2010) in his research proposed the idea of conducting a vulnerability index which is very helpful for such natural phenomenon to also minimize the impacts of sea-level rise and direct resources to address the issue. It can help governments to preserve recourses and time by understanding sea-level rise for the short, mid, and long-term. Moreover, carrying out research on drought and salt-tolerant crops. Various long-term sustainable environmental policies have been launched to keep urban air quality, implement strict regulatory regimes on industrial and other construction practices, and sustainably manage scarce water supplies (El Raey, 2010).

Meanwhile, Melville-Rea et al. (2021) on their recent study that sets out a possible roadmap for the UAE to use its capabilities to generate appropriate sea-level predictions for the area, which includes a number of coastal cities that are equally vulnerable to increasing sea levels. The study resulted in that despite its vulnerability to floods as a result of rising sea levels, the UAE is ideally positioned to lead technological development in climate adaptation due to its long-term policy perspective, financial capacity, and ambition for a sustainable knowledge-based economy, overcoming the Arabian Gulf's data gap for ocean, land, and atmospheric observations is the single most essential step in producing reliable flood forecasts, and by establishing an Antarctic research program, the UAE would be the first in the area to address the fundamental uncertainties that are driving global sea level rise (Melville-Rea et al., 2021).

1.2.7 Land-Use at Global Levels

The terrestrial environment can be changed by human actions at inconceivable rates, special scales, and magnitude. The main element of global environmental change is human land uses that derive the land cover change as stated in the literature of Council (1990). To emphasize this, Turner et al. (1994) discussed in their literature that the direct human sources of these changes come into two categories. Firstly, the world's industrial metabolism which is energy and material flows in the global economy industrial sector through processes of extraction of minerals, manufacturing, usage and disposal. Secondly, global land use and global land cover change. Industrial metabolism and land-use and land-cover change are both contributed to the global systematic changes such as deposition of Greenhouse Gases in the troposphere and stratosphere reduction of ozone (Council, 1990; Turner et al., 1994).

The entire industrial period 1850 - 2000 cumulated the emissions from the past land cover conversion and it is accounted for a third of total anthropogenic carbon emissions during this period as resulted from the study of Houghton (2008). Houghton developed a model to estimate the carbon stocks as a consequence of land-use change and called it a carbon accounting model. The calculations of the annual net flux of carbon showed that the estimated total net flux of carbon globally from land-use change is increased from 500.6 Tg C to 1712.5 Tg C in 1991 and decreased to 1409.9 Tg C in 2000. The global net flux over the period 1850 - 2005 was 148.6 Pg C, and 55% of the net flux was from the tropics. Over the period 1990 - 2005, South and Central America (11.3 Pg C) got the most regional flux. A good understanding of current and future developments is coming from good studies of historical land use (Houghton, 2008).

In reference to the research of Hertel et al. (2009), land use is significant to estimate climate change impacts. Changes in precipitations, temperature, extreme weather, and atmospheric concentrations defiantly will affect land productivity, carbon stocks, and overall production opportunities. It is essential to prepare models for land use. To characterize the climate change net damages including adaptation responses and costs; cropping system, pest control, changes in irrigation, and fire management. Otherwise, land use is very important to reduce Greenhouse Gases emissions, predominately because of farming activities emissions such as livestock and paddy rice production, bioenergy crops, and carbon sequestration in forests (Hertel et al., 2009).

In the literature of Cochrane & Barber (2009) they believed that the wildfire events will be an expedient of impacting land cover changes. Indication of Global Climate Models (GCMs) showed the global warming means will be 1.8 – 4.0°C by 2100 (IPCC, 2007). However, it is expected that regional warming will be much greater, probably to be as high as 10°C in the western Amazon. Multiple GCMs can predict moderate to severe reductions in regional precipitation (IPCC, 2007). Historically, Amazonian forests were extremely resistant to the spread of fire because of high moisture content and dense canopies. These forests can move from being highly fire-resistant to widely flammable in the near future due to being at risk of heating and drying. As the wildfire of the Amazon is almost powered by human action primarily, thus any fire scenarios must be addressed to the anthropogenic land use and land cover change. Climate changes and human land-use activities will contribute to potential fire regimes in the future.

The research of Dale (1997) emphasized that Initiating case studies for the relation between human drivers and land cover changes in a specific region is necessary. Whilst, it is more difficult to determine the main cause of land-use changes. The changes in land use have major environmental effects on different biological scales. The understanding of socio-economic and biological implications of land-use policies is important to project the impacts of specific land-management strategies. Such research will encompass interdisciplinary attempts to further understand the future effects of global change. The study of (Kim et al., 2012) emphasizes that satellite remote sensing data has proved to be useful in identifying recent climate-related changes in worldwide vegetation (Cochrane & Barber, 2009; Dale, 1997; Kim et al., 2012).

1.2.8 Land-Use at Regional Levels

There are 22 countries in the Arab region. Most of them are distributed along the coastal zones where a huge population lives in highly populated economic centers. Coastal zones of Arab countries are known to be rich in marine biological wealth inclusive of the high biodiversity of fisheries, coral reefs, and mangrove habitats. Accordingly, the coastal zones of Arab countries are counted as a significant asset that attracts national and international tourism as well as an important contributor to national economies as reported in the literature of Massoud et al. (2003). Agrawala et al. (2004) and Dasgupta et al. (2007) agreed in their literature that the Arab region is among the world’s most vulnerable regions to the adverse impacts of climate change. It will be particularly exposed to minimize agricultural productivity, higher prospects of drought and heatwaves, long-term dwindling of water supplies, considerable implications on human settlements and socio-economic systems, and loss of coastal low-lying areas (IPCC, 2007; Massoud et al., 2003; Agrawala et al., 2004; Dasgupta et al., 2007).

Most Arab countries' land uses precisely are exposed to severe impacts of sea-level rise. Massoud et al. (2003) mentioned in their literature that the agricultural sector is very important to the national economies since it is the top employer in numerous Arab countries. The impacts will increase by 2°C worldwide, as the annual discharge of water, which is critically low, is forecast to decline from 15% to 45% and the unusual heat extremes are also expected to affect about one-third of the land area and the local food production. Consequently, rural livelihoods deterioration and declining agricultural productivity will begin as noted to lead to migration flows to the urban areas. Regarding the projected growth in population that may be doubled by 2070, the region will face challenges on both rising food and water demand. Despite some Arab countries such as Lebanon, Algeria, Egypt, Tunisia, Saudi Arabia, and others have already started estimating their climate change vulnerability in collaboration with the international community, including these issues in the national policies and plans of all the Arab countries strongly require international support. Climate change consequences on Arab countries will increase the potential rise of inundation on the coastal zones with low elevation areas (Massoud et al., 2003).

The literature of Abahussain et al. (2002) proposed the concept of desertification that is well known and experienced in the Arab region as one of the major results of climate change. Desertification is the destruction of land caused by climate change and human activity in arid, semi-arid, and sub-humid dry regions (UNCCD, 1992). The seasonal and annual precipitation in Arab countries is described to be variable referring to their dryland ecosystems. The reason for marginal land use, cultivation, forestry, and land management at any particular location in the region is the uncertain rainfall and infertile soils. Approximately, an average annual rainfall of less than 100 mm is received by 52% of the region and more than 300 mm by 18%. Alqurashi & Kumar (2014) in their literature have discussed desertification in the case of Saudi Arabia, where the desert is predominant in more than 70% of biomes, the government has carried out intensive development programs financed by huge oil revenues what made changes in land use and land cover over the last 30 years. These developments have led to changes in the number of environmental compositions; landscape ecology, climatic system, and land cover patterns. However, The lack of planning mechanisms and awareness of the adverse effects has contributed to significant development excesses and a consequent degradation of the desert environment (Abahussain et al., 2002; Alqurashi & Kumar, 2014).

Available information in the literature of Shakhatra (1987) indicates that most of the land resources in the Arab region are either vulnerable to desertification or desertified. Therefore, food security and development in the region will be affected. 88.4% of the total area is vulnerable to desertification or desertified along with the study of Abdelgawad (1997) where he estimated about 86.7% of the overall area of the Arab region will be either vulnerable to desertification or desertified. There are main forms of prevailing desertification in the Arab region; wind erosion, water erosion , and salinization and waterlogging (Shakhatra, 1987; Abdelgawad, 1997; Sombroek, 1992).

1.2.9 Land-Use at Local Level

UAE has a special desert greening experience. Regarding published reports in the Abu Dhabi Statistics Center 2015, UAE has the largest carbon footprint in the world. A great deal of effort was made to establish green space by including urban vegetation and reforestation throughout the region. With the idea of greening the desert, UAE transformed the natural desert into productive farmland. as reported in El-Keblawy & Ksiksi's (2005) literature review. A study done by Abdelfattah et al. (2009) presented that Over 330,000 hectares of forest were planted to enable soil conservation until 2009 and 75, 283ha for the agricultural lands in UAE (Abu Dhabi Statistical yearbook, 2015 ; El-Keblawy & Ksiksi's, 2005; Abdelfattah et al., 2009).

Alqurashi & Kumar (2014) have investigated in their study the spatiotemporal dynamics of land use and land cover changes in the Eastern coast of the UAE from 1996 to 2016 and resulted in the vegetation and built-up areas are gradually growing. Along with the study of flood threats related to rapid growth. The simulations revealed that urbanization would intensify flooding induced by a particular storm due to disruption of the natural discharge and dramatically reduced infiltration. The impact of urbanization for small and moderate rainfall events is far more severe than for larger events pointing out that flooding from frequent rains would be more difficult as urban growth progresses (Alqurashi & Kumar, 2014).

Meanwhile, a study by Mohamed & Elmahdy (2018) was conducted in Dubai to study land use-land cover changes monitoring and analysis of Dubai emirate. This study presented that about 233.721 km^2 of the emirate of Dubai has been inhabited by constructed areas from 2000 to 2005. The evaluation of changes in the periods 2000 - 2005 and 2010 - 2015 assured that the total vegetation losses were observed to be more in the period from 2000 to 2005 than from 2010 to 2015. A rate of (6.35%) of changes in the built-up areas as indicated in the period from 2010 to 2015, while from 2005 to 2010 witnessed the most dramatic shifts in vegetation with a rate of (2.82%). The results of Abdi (2019) study on Decadal land use - land cover and land surface temperature change in Dubai and implications on the urban heat island effect, suggests that the magnitude of land surface temperature is significantly influenced by the composition of land cover features and the stabilized land and impervious surfaces cover percentage have the most primary impact. basically, the vegetation percentage is the most fundamental driver of mitigating land surface temperature (Mohamed & Elmahdy, 2018; Abdi, 2019).

Another study was conducted about the effects of land cover change on urban floods and rainwater harvesting in the emirate of Sharjah by Shanableh et al. (2018) and discussed the local flooding risk and it is based on several factors; precipitation, land slope, land cover, the existence of obstructions and local depressions and the efficiency of drainage facilities. A partial verification of flood maps was conducted via field observations of the locations of floods post the rainfall events. The urbanization impacts on the flood extent for multiple land use zones were investigated by integrating the results in a GIS environment. In Sharjah city, industrial and residential land-use areas are the most flood susceptible regions, as shown in the generated flood maps in this study. Nevertheless, because of the rapid urbanization in the residential land use zone, the increase in flood extent was significantly examined in the residential land use zone. Inconsistency, to the rapid urbanization in the city of Sharjah, the possibility of harvesting the rainwater has increased (Shanableh et al., 2018).

Sharaf et al. (2018) concluded in their research that Land-Use and Land-Cover (LULC) monitoring improvements are important for successful spatial management and environmental conservation strategies. Land-Use and Land-Cover (LULC) changes can include adverse consequences such as deforestation, soil degradation, or loss of biological diversity. Urban transformations were considered as one of the most analyzed changes due to the urban growth that is the worldwide phenomenon and the most permanent land alteration. Various tools and techniques were applied to analyze Land-Use and Land-Cover (LULC) changes and urban growth through extensive research; fieldwork, aerial photographs, and/or satellite imagery. Over the last 30 years and since major developments in sensor technologies, using very-high spatial resolution has faced two issues; high financial expenses and the inadequate amount of archived imagery years. Thus, from a longer temporal perspective, using remote sensing imagery (Landsat data) is the best choice to detect urban growth and take the advantage of it to mitigate or monitor climate change effects (Sharaf et al., 2018).

All the above-presented reviews and studies have thoroughly worked on the effects of climate changes on sea-level rise and land use. However not all the coastal zones have been covered. Since these impacts are globally projected, people should work together to preserve the global environment. On a local basis, the Abu Dhabi emirate has been studied from sea level rise and land use perspectives followed by Dubai and Sharjah emirates. While Fujairah, Ras Al-Khaimah, Um Al Quwain and Ajman are not studied despite all of them are coastal cities and the probability of confronting all the discussed impacts is high. Considering that the majority of UAE population are occupying the coastal cities hence the present study will cover Fujairah and Kalba cities that are located in the North-Eastern coast of the United Arab

Emirates. Fujairah and Kalba cities are known to hold recreational beaches, hotels and buildings, natural resources such as mangrove areas on Kalba creek, and areas of fishing. The current study will assist to further understand the dynamics of sea-level rise and its impact on lands use by using remote sensing variables since this area particularly, is facing the Indian Ocean what constitute a huge risk on land use.

The objectives of the current study are, therefore (1) to quantify the impact of sea-level rise on different land uses across the UAE coastlines using remote sensing technology, (2) to develop field vulnerability indices for sea-level rise and identify areas with high vulnerability for sea-level rise and (3) to predict the extent of the impact on coastal areas at different sea-level rise scenarios.

Chapter 2: Study Area and Methodology

2.1 Study Area

The North-Eastern parts of the UAE have been selected as the study area as they are the most susceptible parts to the natural disaster of the entire country for example; sea-level rise, earthquakes, and cyclones (Yagoub et al., 2020). The area is a coast line that is extending from Fujairah city to Kalba city. That is range from (25°06'36.3"N 56°21'30.6"E) to (25°03'13.9"N 56°21'44.1"E). This area is marked by high construction and growth plans that attract tourists as well as citizens. The recreational beaches and corniches are stretching all over the coast. Over and above that the population growth expands throughout the years for several common reasons; increase in the birth rate and decrease in the death rates. Almost 44 percent of Fujairah city population lives within 2 kilometers of the coast, putting them at danger of floods run-ups of 6 - 10 or 11 - 15 meters (Abdouli, 2010).

Fujairah city is located on the Eastern part of the Arabian Peninsula with an area of 1,450 km^2 and is bordered on the east by the Sea of Oman, on the west by Ras Al Khaima and Sharjah, and on the south by the city of Kalba, in the Emirate of Sharjah, overlooking the coast of Oman. Fujairah city extends over the Sea of Oman for a distance of 70 km from the village of Awsala to Dibba in the north, which is the border of the emirate on the coast. The waters of the Sea of Oman are known to be cooler than those of the Arabian Gulf, resulting in cooler weather in Fujairah and Kalba throughout the year. The rugged mountains, rivers, valleys, and oases, as well as the larger sandy beaches of Fujairah, are spectacular. There are many hot, cold, and mineral springs in the region. The area is strategically located along the Sea of Oman, from where vast quantities of oil are exported. Fujairah's temperature is milder than that of Abu Dhabi and Dubai because of its eastern position that is close to the Sea of Oman. The relaxed and peaceful environment of Fujairah attracts weekend tourists. The bulk of the region's urban areas are situated on low coastal plains, making them more vulnerable to floods induced by sea-level rise. However, the cities on the foot of the UAE's mountains are more vulnerable to be inundated by increasing sea level rise, such as Fujairah, Ras Al Khaimah, and Al Ain, for instance; floods in Al Ain 1982, 1988, 1990, and 1993 Al Qurayah, Fujairah 1995, and Sharm, Ras Al Khaima 1997 and 2009 (Yagoub et al., 2020). Thus, conducting studies to assess preservation methods for these cities and their biological and economical resources is necessary.

Kalba city is in the emirate of Sharjah with an area of 55 km^2. It is a Sharjah exclave on the north shore of Oman's Sea. In the south of the town “Kalba Creek”, that is a significant nature reserve and mangrove swamp by the Omani frontier. Kalba Mangrove is now closed to the public and is developed by the Sharjah Investment and Development Authority (Shurooq) as an eco-tourism destination. The water temperature in Kalba is cool where the warmest water temperature recorded was in 2010 and it was 78.6°F/25.9°C, and the coldest was recorded in 2019 at 73.6°F/23.1°C. In the south of Kalba, there is a lagoon of freshwater from the occasional rainfall and a mangrove forest called Khor Kalba with a large sabkha that surrounds the mangroves (Lindauer et al., 2017).

In June 2007, Fujairah and Kalba cities had experienced a strong cyclone that is called the “Gonu cyclone”. The Gonu cyclone first hit the Sultanate of Oman coast then the storm moved northwards to the Sea of Oman and the UAE's eastern coast, particularly the regions of Kalba and Fujairah, has seen a lot of loss of lives and destruction due to high waves and heavy rainfall (Ahmed et al., 2013).

Floods due to sea-level rise are apparent in hazardous areas that sometimes suffer heavy rainfall. However, the danger is not as high in arid regions like the United Arab Emirates (UAE), but it has expanded to new areas in cities that have become impervious due to pavement (lower penetration, poor uptake, less vegetation, increase runoff) (Yagoub et al., 2020). This study's identification of areas' vulnerability to sea-level rise would reinforce preservation guidelines.

2.2 Remote Sensing Protocol

In order to achieve the objectives of this research, two steps were followed. The first one was using the Landsat images for generating sea levels scenarios, land uses classification, and predicting the potential impact of the sea level rise on land uses. The second step was assessing the most vulnerable areas to this phenomenon based on the elevation of each area using the Digital Elevation Models (DEM).

2.3 Satellite Image Sources

Landsat images and Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM-30 m resolution) for the study area were acquired from the United States Geological Survey (USGS)—Earth Explorer website. The land use maps were produced using Landsat atmospherically corrected images for 2 different years and satellites; Landsat 7 for the study area on the year 31-Jul-2000 with cloud cover equals to 3% and Landsat 8 for the year 31-Aug-2020 with cloud cover equals to 1.34%. Landsat 7 satellite was first launched in 1999 it carries Enhanced Thematic Mapper (ETM+) sensor which is an updated version of the Thematic Mapper instruments that were onboard Landsat 4 and Landsat 5 satellites and provides 30 m resolution imagery that is ideal for classifying land uses within the UAE. It has a 16-

day repeat cycle. Landsat 7 contains eight spectral bands including a thermal and pan band. In addition to a pixel size of 30 m reflective and 60 m thermal. Landsat 7 was last used in 2003 due to some data gaps that have been acquired and delivered by the sensor. Therefore, in light of studying the variation in land use as a result of sea-level rise in the study area over 20 years, Landsat 8 images were required. Landsat 8 satellite was first launched in 2013 and carries the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS) instruments and provides 30-m spatial resolution for the bands 1 to 7 and band 9 and 15-m resolution for band 8. It has a 16-day repeat cycle same as Landsat 7. Landsat 8 contains nine spectral bands including a pan band. Landsat 8 acquires about 740 scenes a day on the Worldwide Reference System-2 (WRS-2) path system. Landsat 8 adds a new data source for monitoring land cover, with the potential to enhance the characterization of the earth's surface dramatically. As per the book of Jia et al. (2014), the OLI data quality was marginally better than the ETM + data quality in the visible bands, particularly in the near-infrared band, which showed a notable improvement; however, no significant improvement was seen in the shortwave-infrared bands. Additionally, in terms of land cover classification, the OLI data demonstrated good performance. In summary, OLI data were a trustworthy data source for land cover monitoring and offered continuity in the Landsat earth observation.

QGIS 3.16 Hannover with GRASS 7.8.4 software system was the main tool in this study to analyze the Landsat images and the DEM and classify the land in the study area what will make it easy to calculate the inundated areas due to sea-level rise from different sea-level rise scenarios (1 m, 2 m, 3 m, and 4 m). the different sea-level rise scenarios are selected based on previously published studies and scenarios identified by the IPCC. In addition to assessing the vulnerability of the variations of the land uses on the study area throughout 20 years to the sea level rise.

2.4 Image Classifications

Landsat images were projected using the local projection WGS 84 / UTM zone 40 and this step was done after overlaying the Landsat image to the Open Street Map that is acquired through installing the Quick Map Services plugin. Only supervised classification was performed by using the Semi-Classification Plugin (SCP) to the Landsat images in order to classify them into 4 classes (and 4 layers) (water, agriculture, built up, open area). According to Eastman (2003), in supervised classification the user creates spectral signatures for predefined categories like urban and forest, and the software that assigns each pixel in the image to the cover type with the most similar signature. Also it is the most common method for quantitative analysis of remote sensing image data (Richards & Jia, 2006). The supervised classification is done by choosing the band set of the Landsat image (band 1 to band 7 for the Landsat 7 and band 2 to band 7 for the Landsat 8) and clip the layers to the area of interest. After selecting the ROI (regions of interest), training inputs were created to store the ROI polygons that are drawn manually and spectral signatures used for the land cover classification. Classification layers will be extracted separately for each class through the raster calculator with the binary representation of for example; Agriculture is 1 value and everything else is 0 value. This will be repeated for each class.

2.5 Construction of SLR Scenarios

At this stage, a flood layer was produced by using the DEM. After clipping the DEM to the extent, the elevation threshold data which is the Sea-Level Rise (SLR) scenario will be extracted through the raster calculator. The newly created raster layer which is the binary representation of elevation 1 m and below and it will cover the inundated area with 1 m sea-level rise and the same will be done for the rest of scenarios 2 m, 3 m, and 4 m. The raster calculator will also be used to produce the inundated areas for each scenario and each class separately; the layer of sea-level rise scenario * class. The result will be a raster layer which is the binary representation of for example; a 1 m sea-level rise that will cover agricultural area. Therefore, 12 new layers will be produced. This was sufficient to count the values of the area of the raster layers by utilizing the “Raster layer unique values report” tool. Subsequently, unique values Table will be created in this way “1-water, 2-agriculture, 3-built up, 4-open area”, the desired values will be available in the attribute Table. The resulted areas have been converted from m^2 to km^2.

2.6 Construction of Confusion Matrix

The accuracy assessment is a critical last stage in the classification process, hence a simple and widely used tool for describing classifier performance and classification accuracy is the confusion matrix (Lewis & Brown, 2001). Confusion matrix determine the accuracy of the classification model through the ratio of the correct pixels to the total pixels chose. Typically, the purpose of developing an accuracy metrics is to describe the correctness of map products that depict real-world land-use (Maxwell et al., 2021). Ten pixels of each class on the classification layer has been chosen along with specifying the real locations of those pixels by right clicking the pixel in the QGIS. Google maps platform was used to get real-time navigations to reach each location of the 40 locations in the study area and assisted to validate each class classified in the map with the real-life classes (Lewis & Brown, 2001; Maxwell et al., 2021). The overall classification accuracy = No. of correct pixels/total number of pixels.

2.7 Construction of Coastal Vulnerability Index

The methodology of the Coastal Vulnerability Index (CVI) of the study area is based on Landsat imagery. That was used to classify the land use and Digital Elevation Model to model sea level rise scenarios. The CVI was developed based on the elevation of each area. Thus the lower the elevation the more likely the area is to be inundated with less significant sea-level rise. Land use on the criteria of vulnerability was ranked as from most vulnerable (agriculture, built up, open area) respectively and (1 m is the highest and 4 is the lowest) based on multiple studies reviewed. The most vulnerable areas are the areas that will be inundated with a sea-level rise of 1 meter because the same area will also be inundated when the sea level rise will be 2 meters, 3 meters, and 4 meters. The areas that have higher elevation might be inundated just by the high sea-level rise thus they are less vulnerable.

Each class was given a value regarding its vulnerability; the agriculture class will get 3 since it is the highest, the built-up class will get 2, and the open area will get 1 which means it has the lowest vulnerability, based on multiple studies reviewed. The study of Al Baky et al., (2020) presents that cropping or agriculture land areas, which are typically as depressions or low elevated zone in active and older floodplain, often receive flood water from major rivers as well as from local floodplain channels are likely to most vulnerable to flooding. This also applies to floods resulting from rising sea levels. Built up areas are slightly elevated what makes them less vulnerable to flooding. In addition, in the research of Kibria, (2016) he pointed out that sea-level rise would cause significant losses of the world’s agricultural area and its biodiversity and cause contamination of surface and groundwater with salt. That in terms of vulnerability during a flood event is more prioritized. In the research done by Deepak et al. (2020) buildings that are well built (concrete houses) and are in good condition are considered to be less vulnerable since they have more ability to withstand the effects of flood and sea level rise. Furthermore, the area with a higher population density and building density is more exposed to flood hazards. Also in the exposure viewpoint, built up areas and agricultural areas are more prioritized compare to open area in the assessment (Al Baky et al., 2020; Kibria, 2016; Deepak et al., 2020).

The layers that were produced before of which contains each sea-level rise scenario covering each class will be multiplied with the value of vulnerability assigned to each class for example; the raster layer of 1 m that covers the agricultural area will be multiplied by 3 therefore, it will result in showing the vulnerability of agricultural areas in case of 1 m scenario. All the 12 expressions have been entered into the “Raster calculation expression” tool and generated the vulnerability map of the study area to the all sea-level rise scenarios. CVI has an average rating of 5 scales equally distributed and ranging from very low vulnerability to very high vulnerability.

Chapter 3: Results

3.1 Changes in Land Cover 2000 - 2020

Each land-use class was specified on each Landsat image. Therefore, and referring to Figure 1, the total study area was 678.236 km^2 in the year 2000 by using Landsat 7 satellite image. The land use classifications are shown in Figure 1. Where the water represents 46% of the total area and the open area represents 47%, those two land-use classes are revealed to have the biggest area. Built-up areas in the year 2000 were representing 5% however the agricultural areas were representing 2% which is covering very few areas. In comparison to the total area in the year 2020, it was 798.913 km^2. s

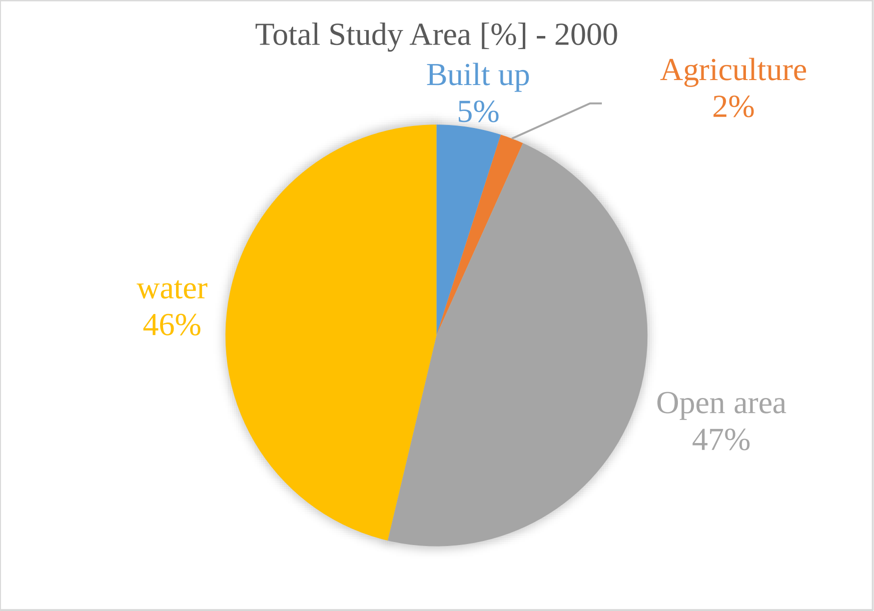

Figure 1: The study area on the year 2000 using Landsat 7 image.

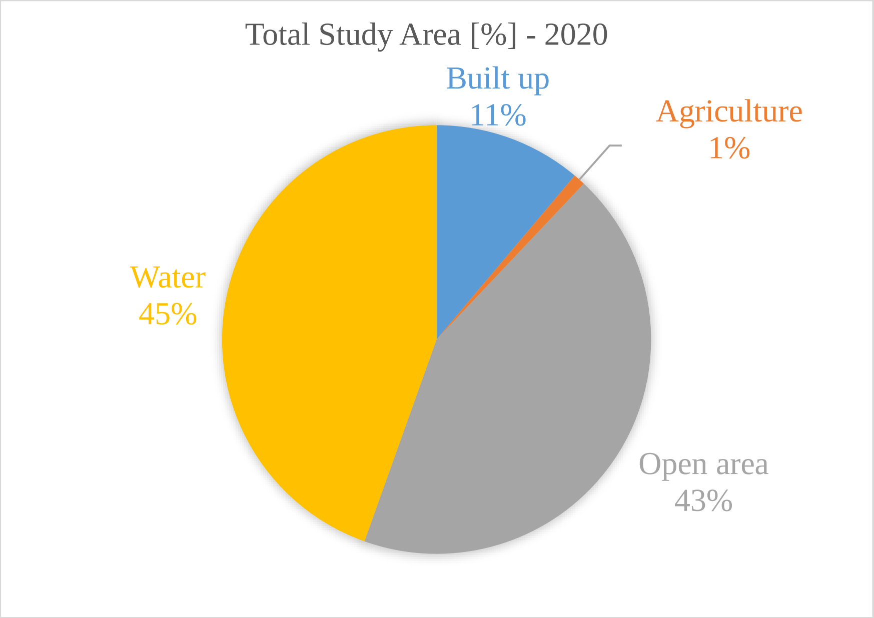

Figure 2: The study area on the year 2020 using Landsat 8 image.

The area has been extended to the North to cover the mangrove reserve on Kalba city and observe the effects of sea-level rise on such a valuable ecosystem. Figure 2 is showing the percentage of each land-use class in the year 2020, water area and the open area became less than the year 2000, 45% and 43% respectively, attributed to the increase of economic developments, coastal constructions, and all the development projects through 20 years. Built-up areas had increased by 6% and agricultural areas have decreased to be 1%.

3.2 SLR Effects on Land-use - 2000

Table 1 and Figure 4 summarized the results of four sea-level rise scenarios' effects on the land-use of the study area, Fujairah-Kalba coastline, in the year 2000. A significant difference in the flooded areas was found between the land use type and the sea level scenario ($p < 0.05$) Figure 3. Using Landsat7, the flooded areas in 2000 were highest in the open areas with 11.46 Km^2, under 1 m SLR scenario Table 1. The flooded open area represents 4% of the total open area. The damage was increasing as the SLR scenarios are increasing. Under 2 m, 3 m, and 4 m the flooded open area reached 15.10 km^2 (5%), 18.93 km^2 (6%), and 22.75 km^2 (7%) respectively. For Agricultural areas, the average flooded area was about 0.54 Km^2 that constitutes 4% of the total agricultural area in the study area., then increased to 14% and 21% respectively under 3 m and 4 m sea-level rise, which is around 1.73 km^2 and 2.57 km^2.

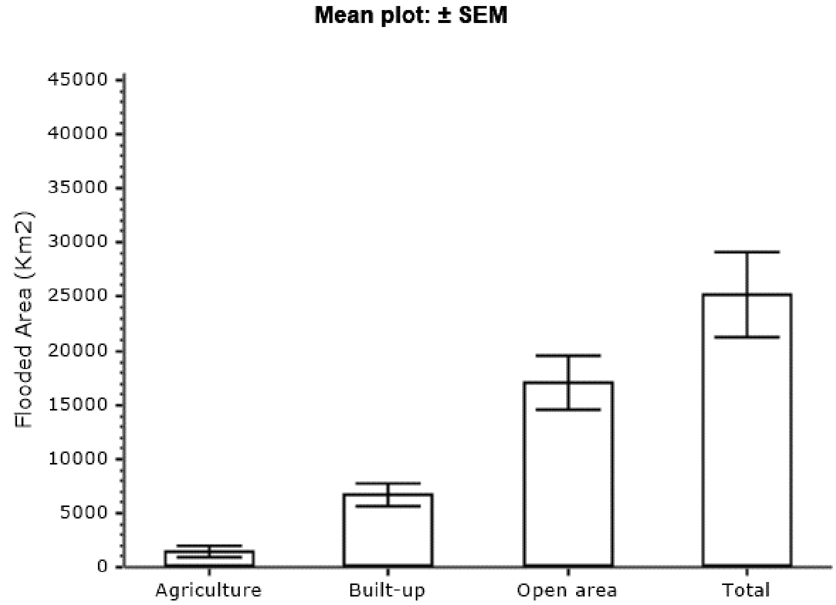

Figure 3: The standard error of SLR scenarios and the Land use in the year 2000 using Landsat 7 images.

Table 1: Inundated land use areas (in Km^2) due to 4 m sea-level rise scenarios, within the study area of the Fujairah-Kalba coastline in the year 2000.

	Agriculture	Built-up	Open area	Total
1 meter	0.54	4.72	11.46	16.71
2 meters	1.11	4.96	15.10	21.18
3 meters	1.73	7.84	18.93	28.51
4 meters	2.57	9.14	22.75	34.47

The flooded built-up areas due to different sea-level rise scenarios that occupy 33.45 km^2 of the Fujairah-Kalba coastline were: under 1 m and 2 m sea level rise scenarios around 4.71 to 4.96 km^2 (14% to 15%).

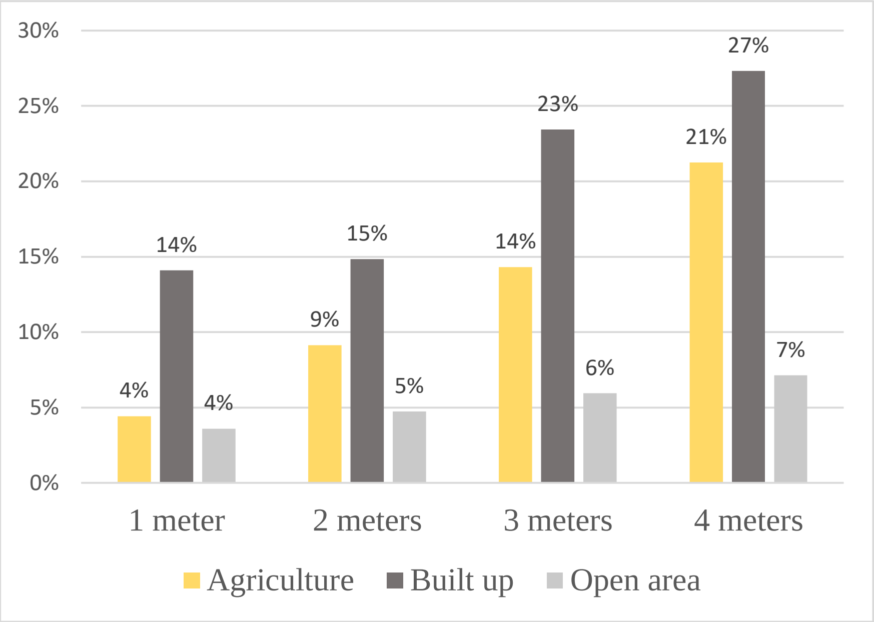

Figure 4: Percentages of land use areas inundated due to 4 m sea level rise scenarios, within the study area of Fujairah-Kalba coast line in the year 2000.

However, 7.84 km^2 (23%) of the built-up area will be flooded by a 3 m sea-level rise scenario. The maximum damage to the built-up area in the year 2000 will reach 27% (9.14 km^2) as a result of a 4 m increase in sea levels.

As SLR levels increase, the total flooded areas also increased in the year 2000 Table 1. The total flooded areas ranged between 16.71 km^2 under 1 m SLR scenario to almost 34.47 km^2 under 4 m SLR scenario.

Figures 5,6,7, and 8 are showing the effects of the 4 sea-level rise scenarios on the land uses on the study area within the year 2000 by using Landsat 7 satellite image.

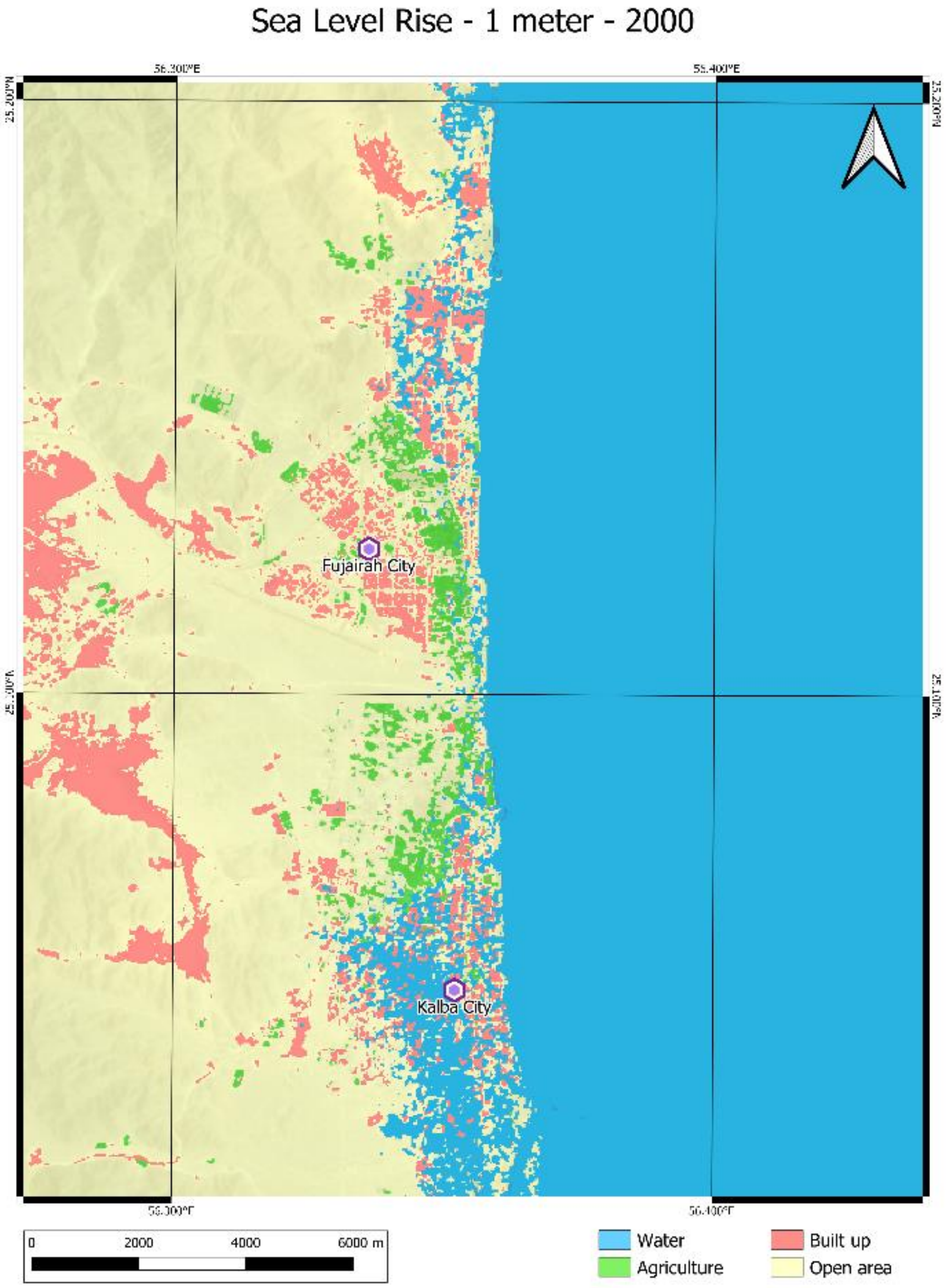

Figure 5: 1 m sea level rise scenario and its effect on the land use of the Fujairah - Kalba coastline in the year 2000.

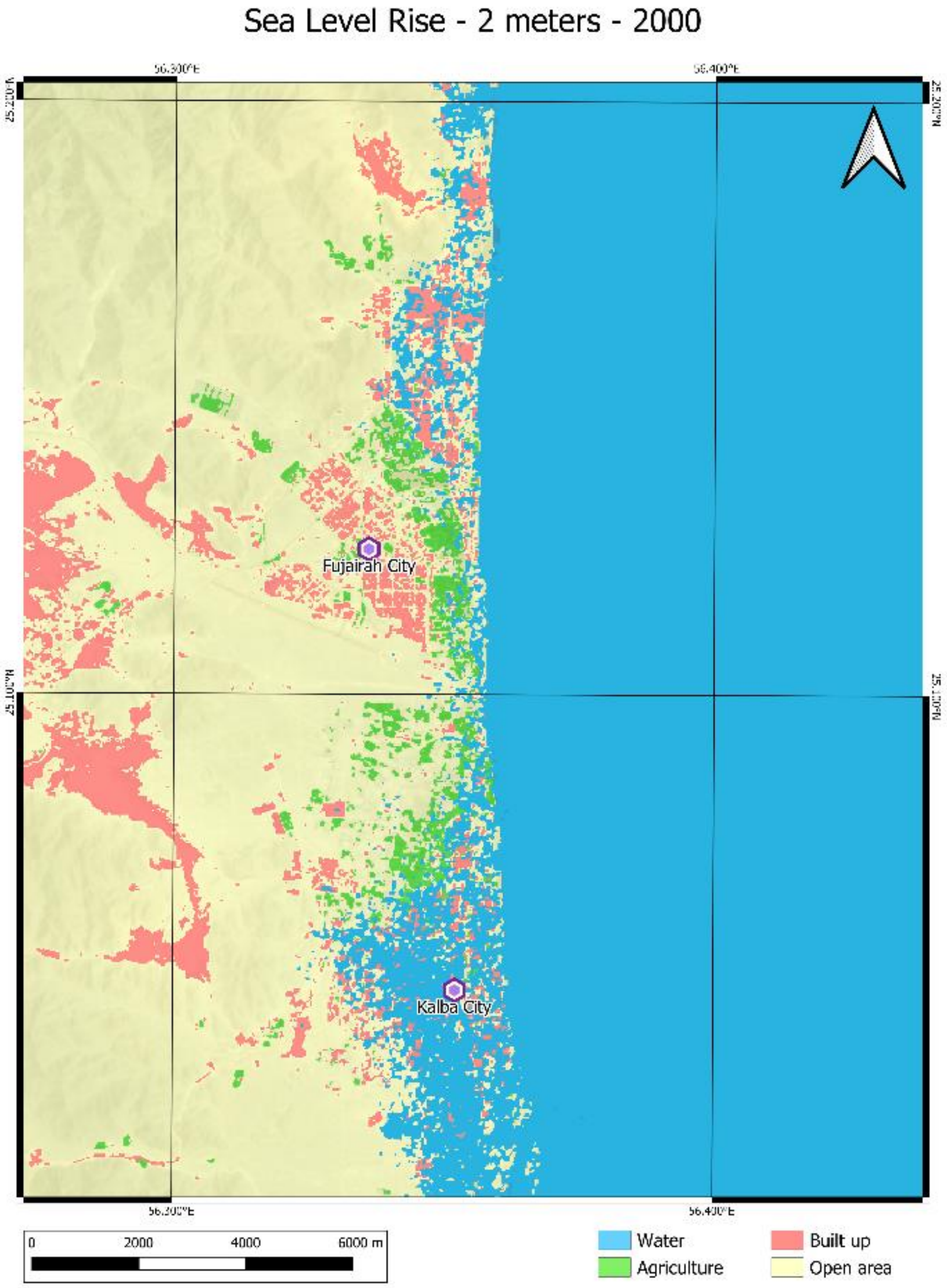

Figure 6: 2 m sea level rise scenario and its effect on the land use of the Fujairah - Kalba coastline in the year 2000.

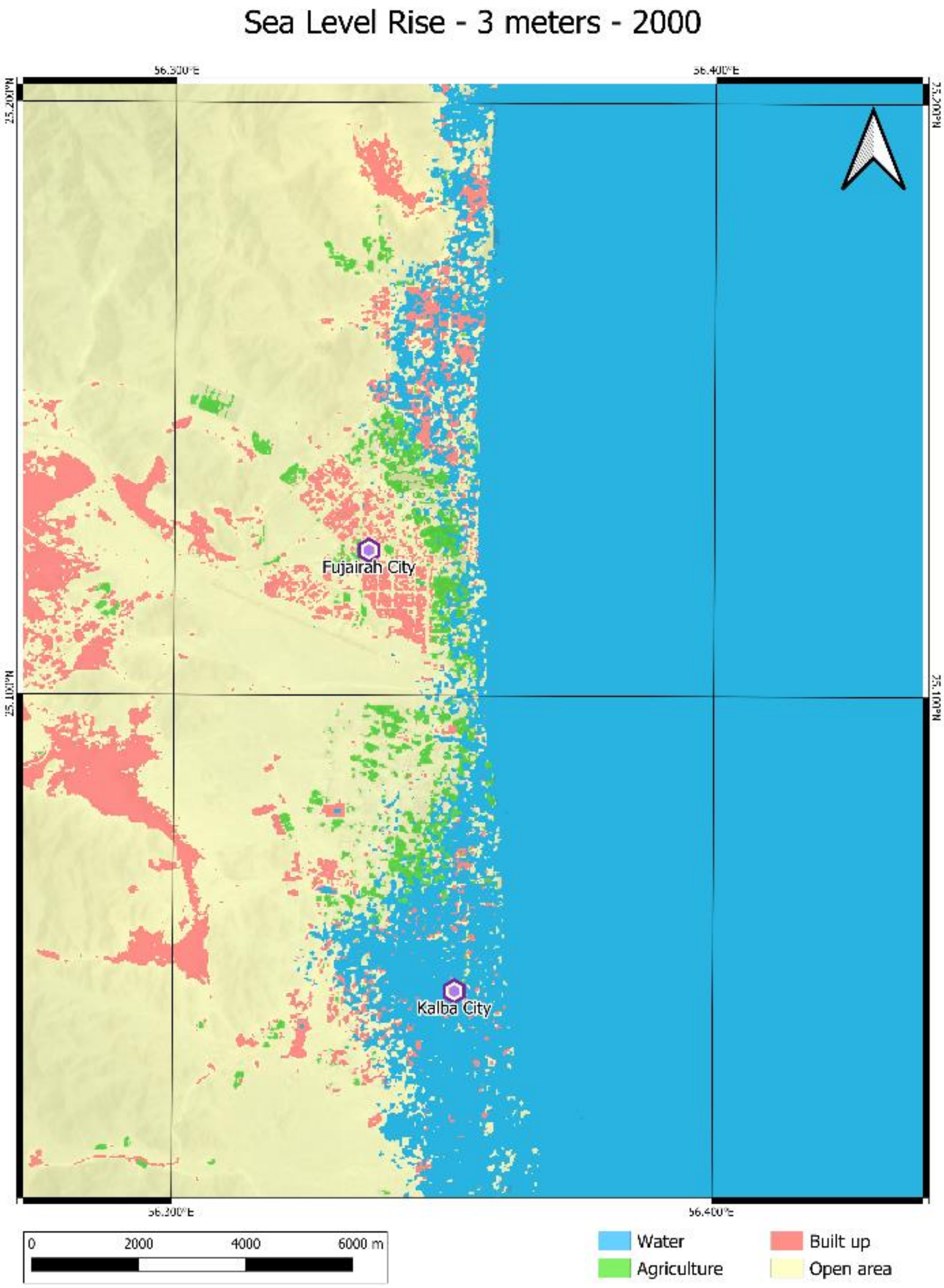

Figure 7: 3 m sea level rise scenario and its effect on the land use of the Fujairah - Kalba coastline in the year 2000.

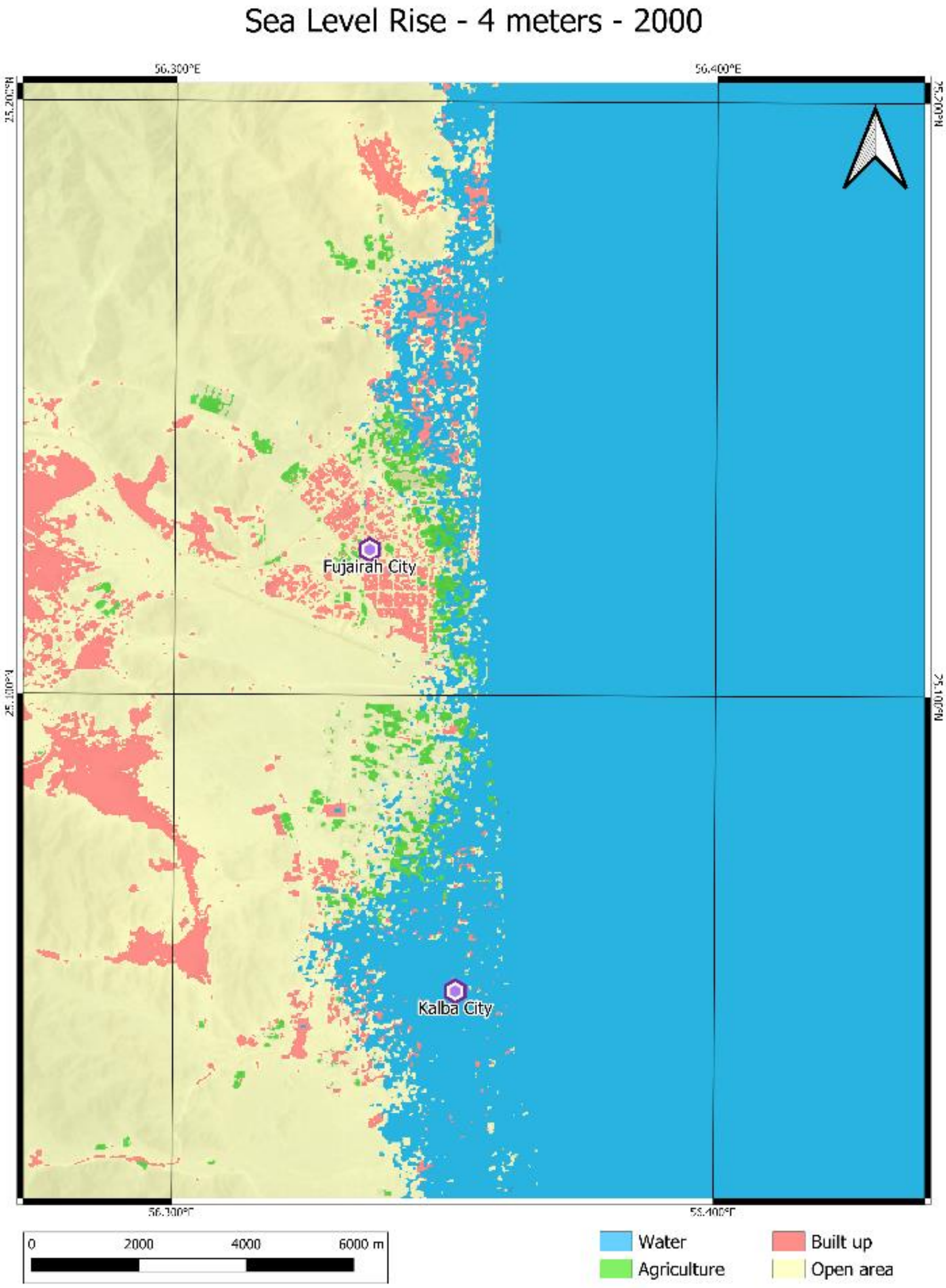

Figure 8: 4 m sea level rise scenario and its effect on the land use of the Fujairah - Kalba coastline in the year 2000.

3.3 SLR Effects on Land-Use - 2020

In comparison to the effects of sea-level rise in the year 2000, Landsat 8 was used to quantify the land-use changes over 20 years and the damages that will occur as a result of sea-level rise phenomena. Table 2 and Figure 10 are demonstrating the results of the total flooded areas of each land-use class under 4 different sea-level rise scenarios. A significant difference in the inundated areas was found between the land use type and the sea level scenario ($p < 0.05$) Figure 9. The total study area on this step is 798.91 km^2. Again, the flooded areas in 2020 were highest in the open areas with 16.16 Km^2 which is (5%) of the total open areas, under 1 m SLR scenario Table 2 Figure 10. the flooded open areas continued to increase as a result of the increased SLR. 19.60 km^2 (6%), 23.17 km^2 (7%), and 26.77 km^2 (8%) under 2 m, 3 m, and 4 m SLR. As shown in Table 1 and Figure 4, at a 1 m SLR scenario, 1.25 km^2 of agricultural areas will be flooded which is around 17% of the total agricultural area in the year 2020. The flooded agricultural areas continued to increase with 2 m, 3 m, 4 m sea-level scenarios with area of 1.59 km^2 (22%), 1.85 km^2 (25%), 2.14 km^2 (29%). By comparing the results of the year 2020 to 2000 there was a significant increase in the level of damage toward the agricultural areas in the year 2020 where it started with 17% and reached 29% at a 4 m sea-level rise scenario, comparing to 2000 where it started with 4% and reached 21% at a 4 m sea-level rise scenario. Referring to the broader area that has been covered in this step.

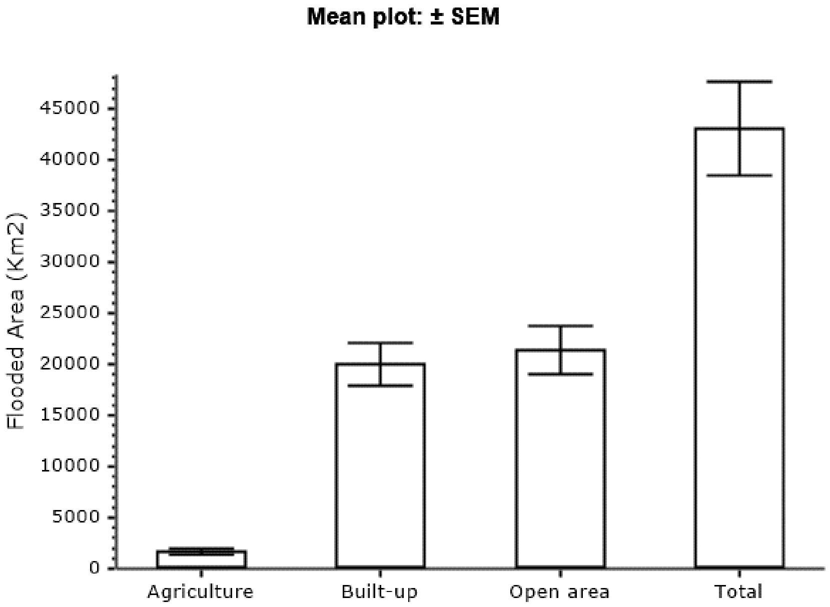

Figure 9: The standard error of SLR scenarios and the Land use in the year 2020 using Landsat 8 images.

Table 2: Inundated land use (in Km^2) areas due to 4 m sea-level rise scenarios, within the study area of Fujairah - Kalba coastline in the year 2020.

	Agriculture	Built-up	Open area	Total
1 meter	1.25	14.99	16.16	32.40
2 meters	1.59	18.43	19.60	39.62
3 meters	1.85	21.74	23.17	46.76
4 meters	2.14	24.72	26.77	53.63

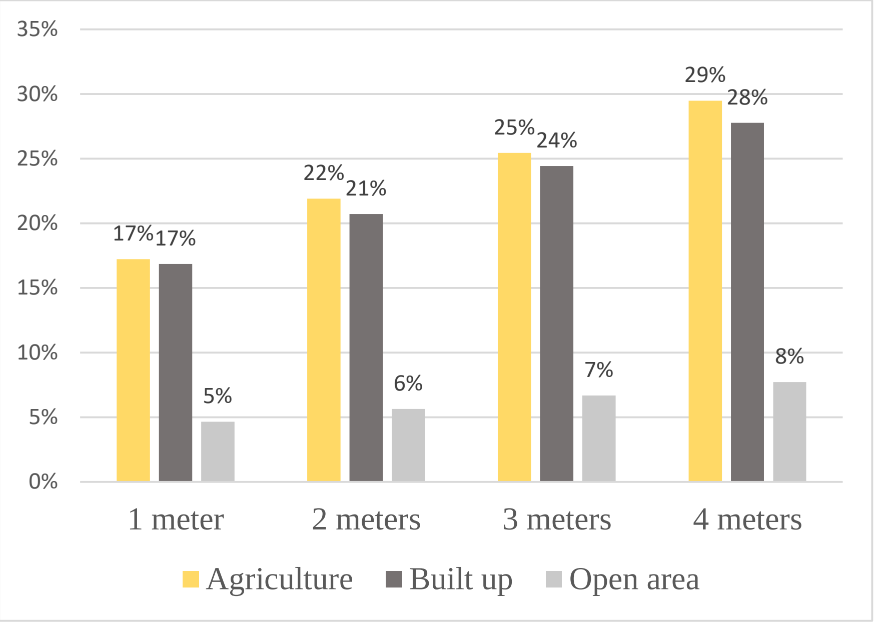

Figure 10: Percentages of land use areas inundated due to 4 m sea level rise scenarios, within the study area of Fujairah - Kalba coast line in the year 2020.

On the other hand, the flooded built-up areas in the year 2020 were 14.99 km^2 and regarding Figure 10 this represents 17% of the inundated area at 1 m sea-level rise scenario same as the amount of flood of agricultural areas at the same scenario. At 2 m scenario of sea-level rise 18.43 km^2 will be inundated which is around 21% of the total built-up area. At 3 m and 4 m sea-level rise scenarios, the flooded area will increase to 21.74 km^2 and 24.72 km^2 respectively and it is represented in Figure 10 by 24% and 28% of the total built-up area. These results go beyond the previous step that was implemented in the built-up areas of the year 2000 that started with 14% and reached 27% at the 4 m sea-level rise scenario.

Comparing to the total flooded area in the year 2000, the total flooded area in the year 2020 ranged from around 32.40 km^2 under 1 m SLR scenario to 53.63 km^2 under 4 m scenario Table 2.

Figures 11,12,13, and 14 are showing the effects of the 4 sea-level rise scenarios on the Lands uses on the study area within the year 2020 by using Landsat 8 satellite image.

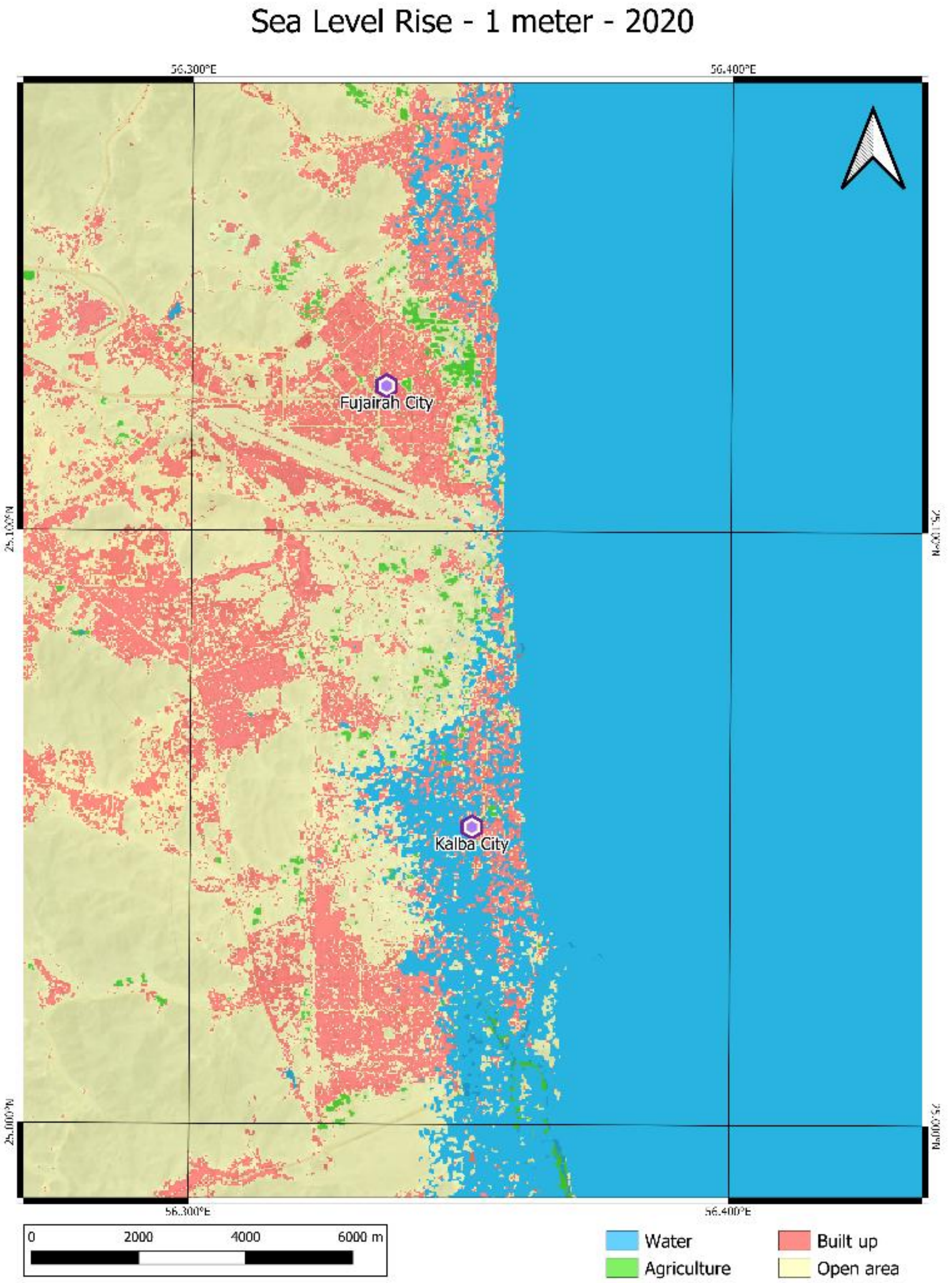

Figure 11: 1 m sea level rise scenario and its effect on the land use of the Fujairah - Kalba coastline in the year 2020.

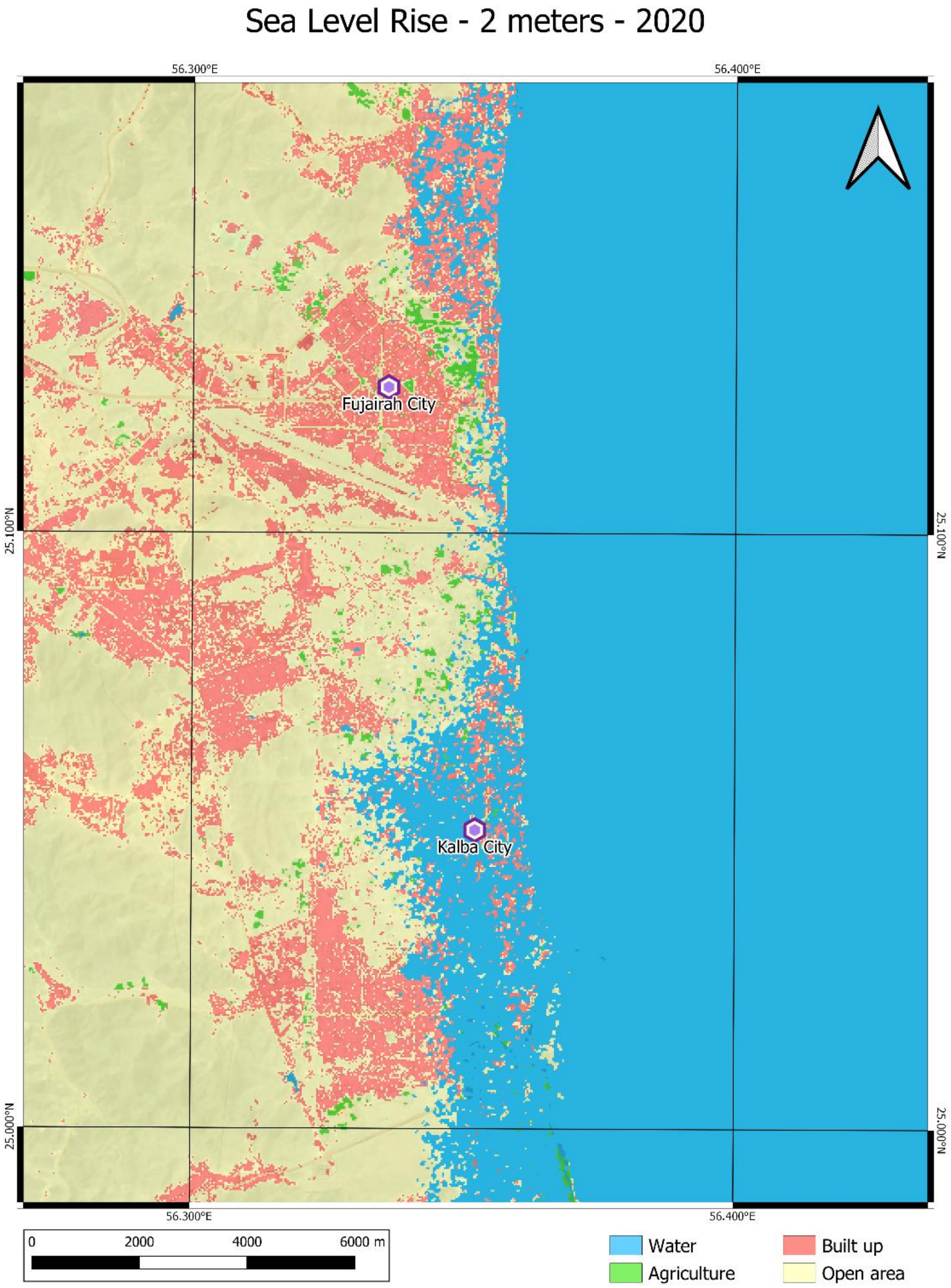

Figure 12: 2 m sea level rise scenario and its effect on the land use of the Fujairah - Kalba coastline in the year 2020.

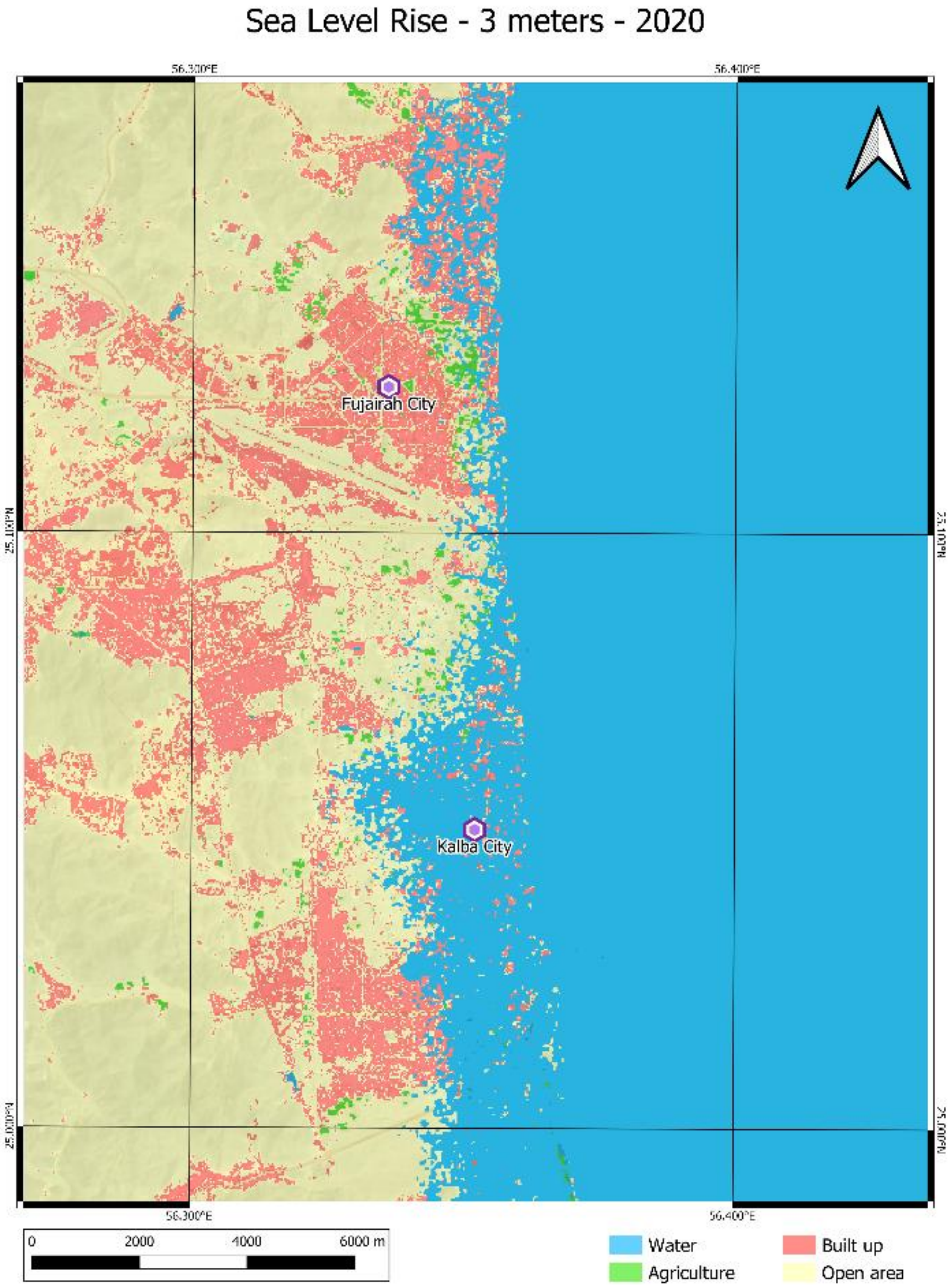

Figure 13: 3 m sea level rise scenario and its effect on the land use of the Fujairah - Kalba coastline in the year 2020.

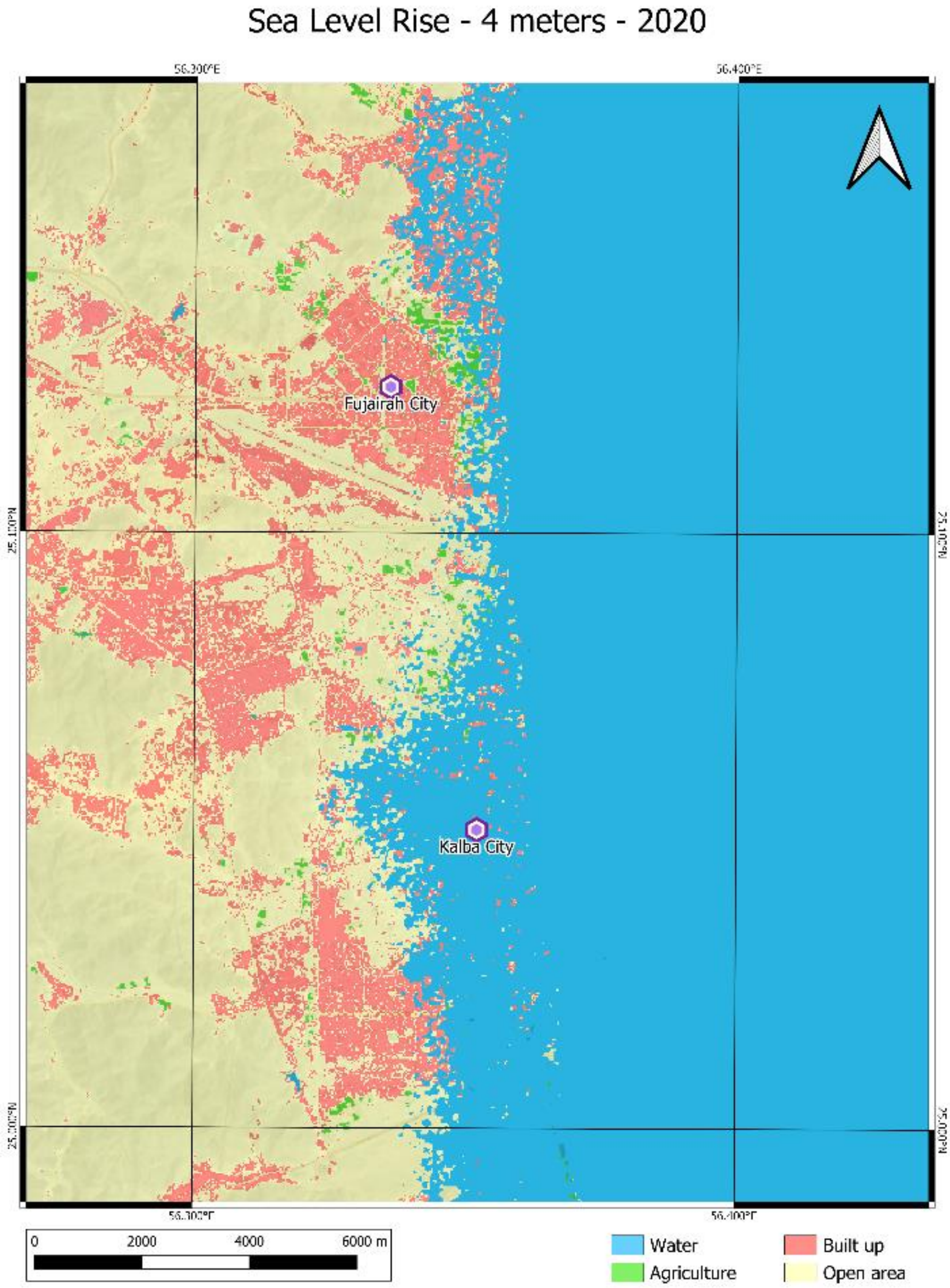

Figure 14: 4 m sea level rise scenario and its effect on the land use of the Fujairah - Kalba coastline in the year 2020.

3.4 Confusion Matrix

Table 3 is showing the constructed confusion matrix of the study area in the Landsat 8 image in 2020. Each pixel of each class has been validated in comparison to the exact real-location of that pixel. A trip of 7 hours has been spent on visiting the locations in the study area. Seven locations of the built-up areas in the classified map are matching correctly with the real-life locations where three out of the ten locations turned to be open areas in the real-life. However, eight locations of the agriculture areas are correct versus two wrong classified pixels, one of them is a built-up area which was a ladies' club and the other is an open land in the real-life. Seven locations of the open areas in the classified map are correct, where one locations appeared to be a building in a farm and the other two locations were area of plants, in Kalba cornich and in a fun land for kids in Fujairah city. All pixels of water class are visually located inside the sea water as validated by Google maps from the sea shore locations. 22 locations out of the total 40 locations are correct. In order to calculate the accuracy, the number of the correct pixels will be divided by the total pixels. In this study, 22 will be divided by 40 to give an accuracy of 80% for the classified layer to the real-life so the map is accurate in classifying the land-use.

Table 3: Confusion matrix of 40 pixels of the classified map in 2020.

Field Observation	Map				
		Built up	Agriculture	Open Area	Water
	Built up	7	1	1	0
	Agriculture	0	8	2	0
	Open Area	3	1	7	0
	Water	0	0	0	10

3.5 Coastal Vulnerability Index (CVI)

Table 4 and Figure 16 are illustrating the areas of vulnerability index to sea-level rise in both years 2000 and 2020 by using Landsat 7 and 8 satellite images. A significant difference in the vulnerability of the areas toward sea level rise ($p < 0.05$) Figure15. Generally, the majority of the study area is located in the areas of a low vulnerability index, which is around 19.05 km^2 (55%) and 23.20 km^2 (43.3%) for the years 2000 and 2020 respectively. The least areas are showing a very high vulnerability index to the sea level rise for both years with an area of 0.53 km^2 (2%) for the year 2000 and 1.25 km^2 (2.3%) for the year 2020.

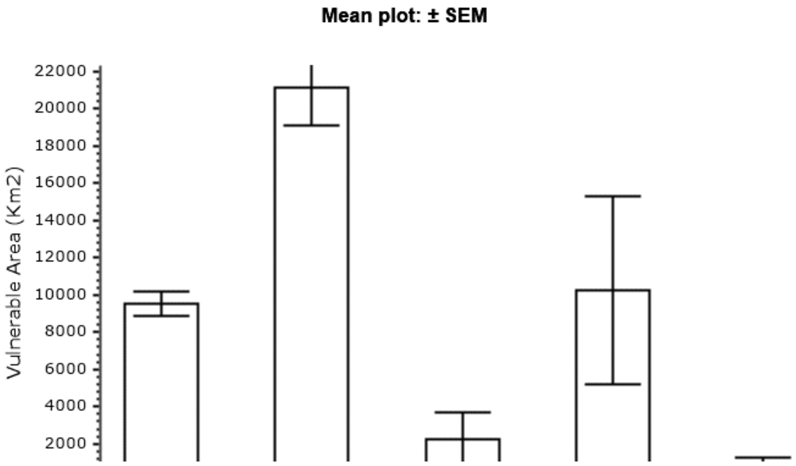

Figure 15: The standard error of coastal areas vulnerability to SLR scenarios.

Table 4: Vulnerability classification of the study area for years 2000 and 2020 by using Landsat 7 and Landsat 8 satellite images.

Coastal Vulnerability Index – Km^2					
	Very Low	Low	Moderate	High	Very High
L7 - 2000	8.95	19.05	0.74	5.20	0.53
L8 - 2020	10.15	23.20	3.70	15.33	1.25

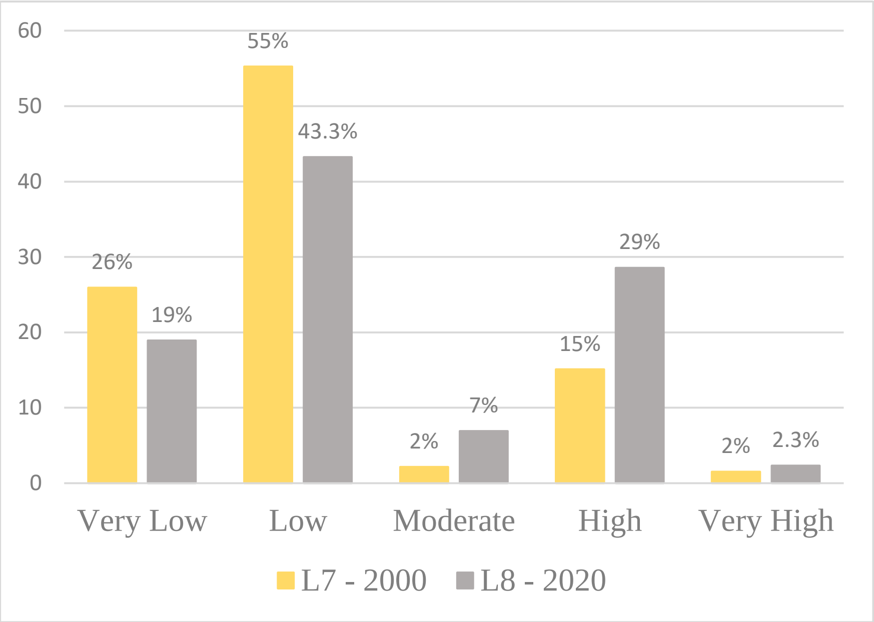

Figure 16: Vulnerability classification percentages of the study area for years 2000 and 2020 by using Landsat 7 and Landsat 8.

However, 29% of the study area showed a high vulnerability index which is equal to 15.33 km^2 for the year 2020, where it is 15% (5.20 km^2) for the year 2000. 26% (8.95 km^2) of the area in the year 2000 and 19% (10.15 km^2) in the year 2020 are showing a very low vulnerability index to sea-level rise. About 2% (0.74 km^2) of the study area in the year 2000 showed a moderate vulnerability index and 7% (3.70 km^2) of the study area in the year 2020. Figures 17 and 18 are illustrating the vulnerability of the study area each year.

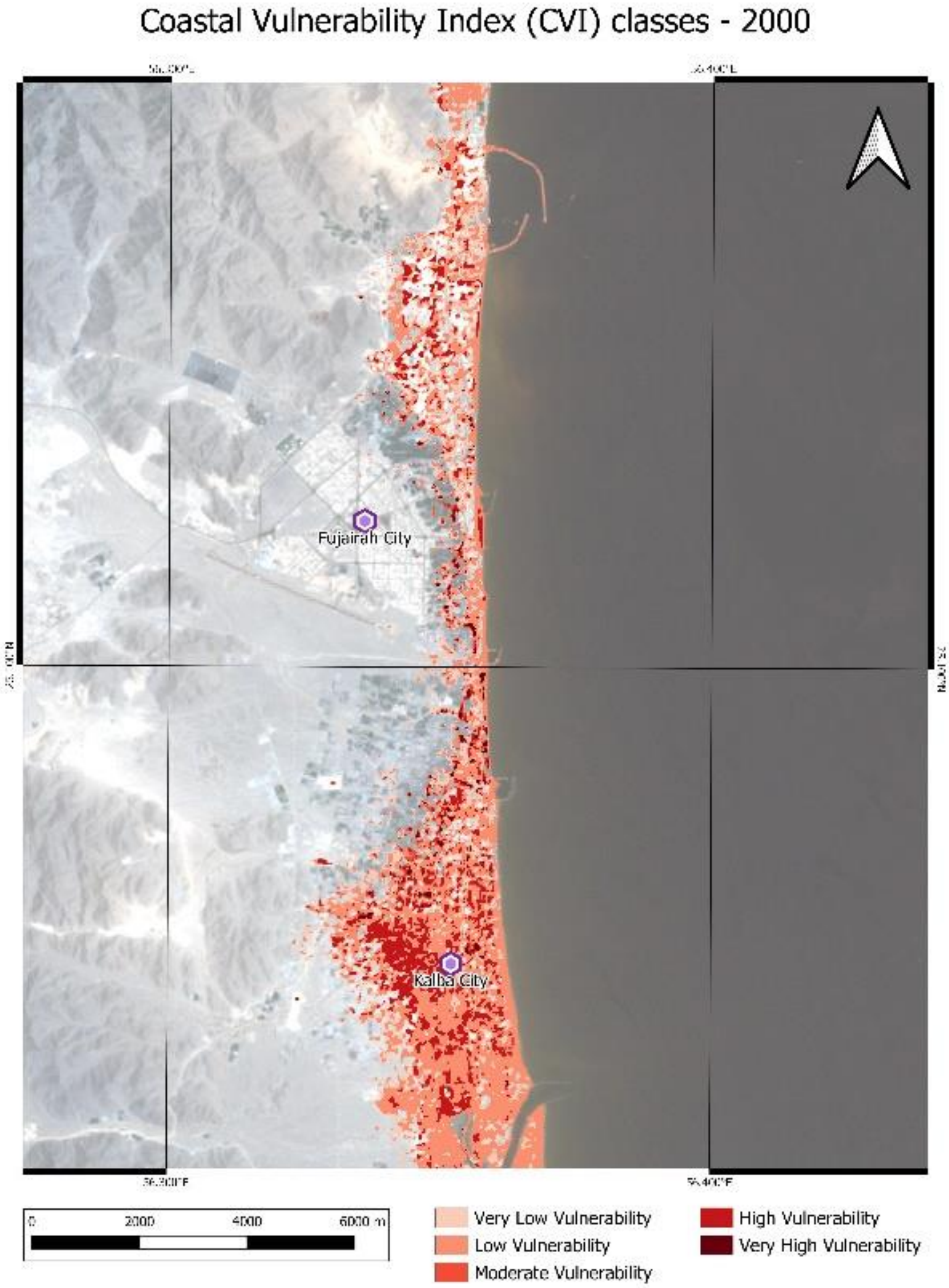

Figure 17: Coastal Vulnerability Index of the study area in the year 2000.

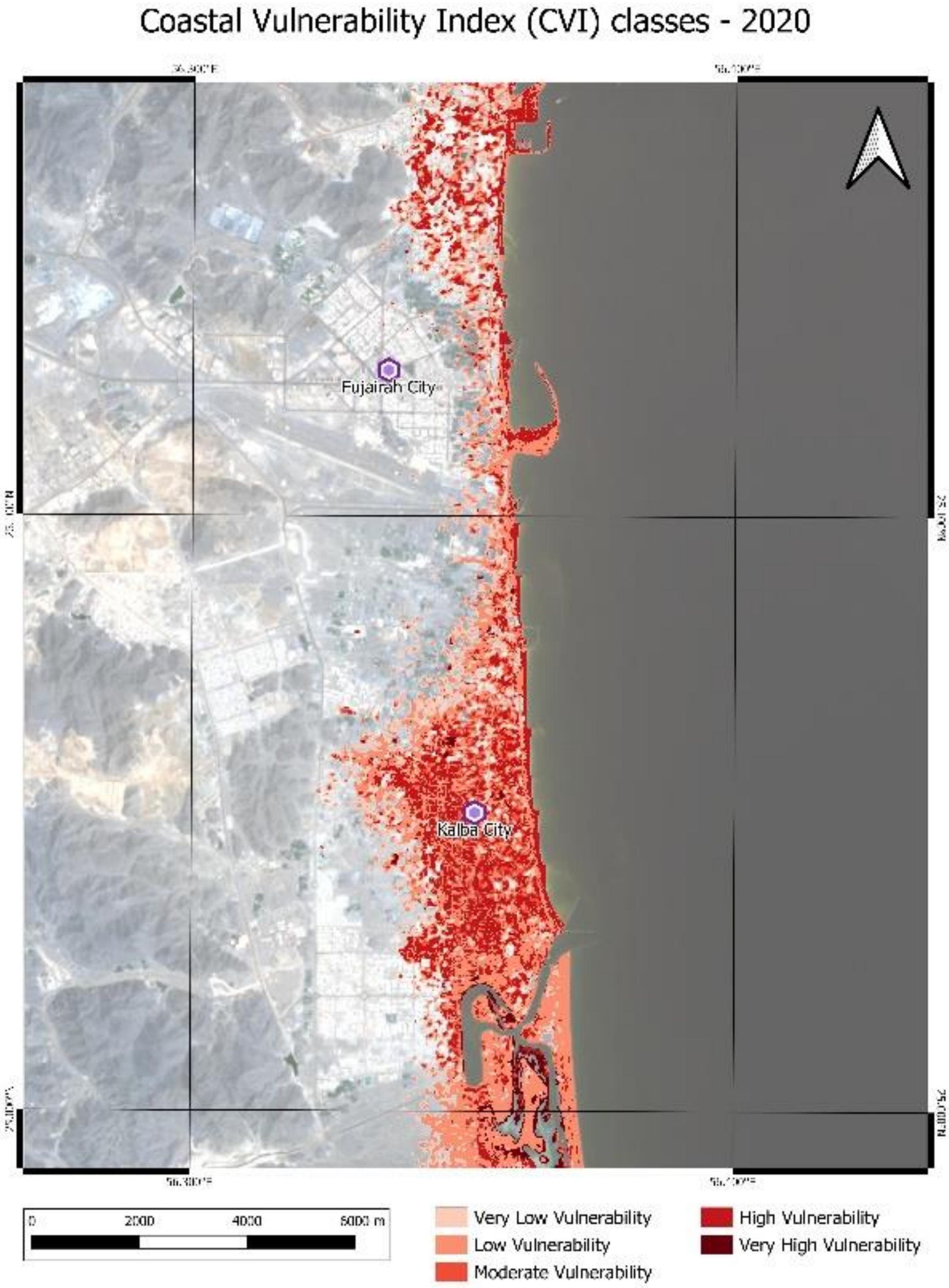

Figure 18: Coastal Vulnerability Index of the study area in the year 2020.

Chapter 4: Discussion

4.1 General Discussion

The present assessment shows that through 20 years the impact of SLR has extended as the land uses changed in the North - Eastern coastal areas in UAE. In the year 2020, the water and open areas have been decreased when compared to 2000. It may be related to the development projects in the area and it can be justified by the increased percentage of the built-up areas in the year 2020 which became 11% compared to 5% in the year 2000.

Focusing on the extent of SLR impact on the land uses of the year 2000, the built-up areas are showing to have the largest flooded areas percentages under the 4 - meter sea-level rise scenarios. It is ranging between 14% under the 1 m scenario and 27% under the 4 m scenario. In Abu Dhabi coastal area and as per the study of Ksiksi et al. (2012), the maximum damages of SLR to the urban areas can reach 40% under 3 m SLR. Where the study of Dasgupta et al. (2007) agreed that the UAE is expected to have the greatest influence on the urban extent (within the MENA region), with a 1 m SLR affecting 5% of urban areas and a 5 m SLR affecting more than 13%, on the country level. However, in the present study and by 2020, the flooded built-up areas ranged from 17% under 1 m SLR scenario to 28% under 4 m scenario where the average loss was less than 2000 but still it is huge related to the actual built up area that was 24.72 km^2 out of the total flooded area which was 53.63 km^2.

For the Agricultural areas during the year 2000, 4% will be flooded under 1 m SLR scenario and 21% under the 4 m SLR scenario, and the average loss for all the SLR scenarios is 12%. Comparing to the flooded agricultural areas in the year 2020, it is ranging from 17% under 1 m scenario to 29% under 4 m scenario with an average loss of 23.25% under all SLR scenarios. This loss of agricultural area is equal to 2.14 km^2 of the total flooded areas under the 4 m SLR scenario including the loss of the mangrove preserve on the Kalba city coastline. The loss of the mangrove preserve means the loss of various local wildlife species, marine life, and birds. In the paper of Ksiksi et al. (2012), the results showed 82% of the total mangrove area will be flooded under a 3 m SLR scenario which is equal to 25.5 km^2. It is worth noting that each result is expressing different UAE coast what should be considered as alarming results to the decision - makers. An action plan to combat these destructive impacts of the SLR on the UAE's coasts, especially mangrove ecosystems, is, therefore, both important and required.

Furthermore, areas with low elevations such as streets, public seating areas, playgrounds, schoolyards, and public plazas are importantly present in every city. The open area class represents all the aforementioned low elevation areas and the impact of different sea-level rise scenarios on them. In the year 2000, a 1 m scenario of sea-level rise, 11.46 km^2 (4%) of the total open areas on the Fujairah - Kalba coastline will be flooded. The percentage of the flooded open areas is increasing gradually with the 2 m, 3 m, 4 m sea level rise scenarios reaching 7% that is equal to 22.75 km^2 of the open areas total area. Basically, the flooded open areas are showing high flooding effects due to sea-level rise large areas are experiencing flooding from SLR comparing to the total affected areas. 5% of the open area will be flooded at 1 m sea level scenario in the year 2020, 6% at 2 m sea level scenario, 7%, and 8% at 3 m and 4 m sea levels scenarios which are equal to 23.17 km^2 and 26.77 km^2.

The confusion matrix is used to assess the accuracy of the classified layer that is used in this study. Also it reveals which classes are correctly classified and which are incorrectly classified. Seven out of ten pixels of the built up areas are correct and this shows 70% of accuracy of the built up areas in the study area. However, eight out of ten pixels are correct for the agricultural areas hence the agricultural areas were found to be more reliable with 80% accuracy. Also seven out of ten pixels are correct for the open areas that shows again 70% of accuracy, and the ten water pixels are correct which is absolutely accurate and matched to the real locations. According to the confusion matrix, the overall accuracy of the full map classification is 80% what makes the classified map to be convenient to the real land classification.

The assessment shows that the North-Eastern parts of UAE (Fujairah – Kalba cities) are vulnerable to climate change-induced SLR. In the year 2000, about 5.20 km^2 are of the total study area is considered to have high vulnerability to SLR which represents 15% of the total area. Where more than half of the impacted area is classified as low vulnerable and very low vulnerable by around 19.05 km^2 (55%) and 8.95 km^2 (26%). However, 0.53 km^2 are located in areas of very high vulnerability to SLR. Comparing to the same area in the year 2020, around 15.33 km^2 are located on the areas of high vulnerability which is represented by 29% of the impacted area. 23.20 km^2 (43.3%) is located in the low vulnerability areas to SLR. 1.25 km^2 of the study area are located in areas of very high vulnerability to SLR. This amount of damage is greater than what was in 2000 by 0.3%. 19% are located in the very low vulnerability areas which are less than 2000 by 7% and the areas that are on the moderate vulnerability to SLR increased by 5% than the year 2000. Figures 17 and 18 are demonstrating that the Kalba city is more affected by the SLR phenomenon than

Fujairah city it appears to be almost diminished in the 1 m SLR scenario and completely inundated under the 4 m SLR scenario.

It has been reported in the study of Ksiksi et al., (2012) that 3% of the study area in Abu Dhabi emirate is having a very high vulnerability index and 7% are having a high vulnerability index. Moreover, a research report by al Kabban, (2019) assessed the SLR effect on different aspects of the Abu Dhabi emirate. The vulnerability of the emirate population toward SLR was reported to be 16% of the governorate population will be impacted by a 1 m SLR, 23% by a 2 m SLR, and 30% of the total governorate population will be affected by a 3 m rise in sea level. However, computing the maximum inundation depth of the land cover classes was 13 m, 14 m, and 15 m in a 1 m, 2 m, and 3 m sea level rise scenarios respectively. It is notable that 92% of Abu Dhabi's emirate coastline will experience inundation in a 1 m SLR scenario owing to the low-lying area on the coast. On the other hand, a study has been conducted on the emirate of Ras Al Khaimah, resulted in a 2 m sea-level rise scenario that would leave Al Hamra Village in a serious situation due to its position to be surrounded by water from 3 sides, around 94,464 m^2 will be totally flooded (Arthur & Garland, 2016).

In comparison to other studies on the sea of Oman, it is anticipated that in the least SLR scenario, around 400 km^2 of total area would be flooded in the Sultanate of Oman. whilst, over 900 km^2 are possibly flooded in the highest SLR scenario as resulted from the study of Al-Hatrushi (2014).

4.2 Study Limitations

Remote sensing is a great tool for monitoring and forecasting the impacts of the increase in sea level. This is because of the ambiguity of the predictions, the number of possible results, and the ongoing change in projections. Continuous forecast changes need continuous flood model updates. During a longer length of time data is collected and patterns may be more accurately detected. Remote sensing is a significant data source for land use and land cover mapping and creates very easily new forecasts. In the context of global warming, climate change, and the rising seas, this flexibility is required in the long run.

This study was accomplished by using Landsat 7 and 8 images. Regardless that the resolution of both sensors is similar, finding images on the same date and for the same area will limit the opportunity of having absolutely clear images. Images are having few percentages of cloud cover that affect the vision of the study area. Furthermore, the study area is slightly increased in the Landsat 8 image analysis to cover the mangrove reserve in Kalba city where this area has been not included in the Landsat 7 image due to non-clarity in the data of the year 2000.

4.3 Future Studies

The European Space Agency (ESA) has announced the launch of a satellite to monitor the sea level rise that is called "The Copernicus Sentinel-6 Michael Freilich satellite" on 21st November 2020. This new satellite will provide a new overview of ocean topography and enhance the long-term record of sea-surface height measurements that began in 1992, using the most advanced radar altimetry technology. Measurements that are critical for climate science, policymaking, and, substantially, preserving the lives of millions of people who are threatened by sea-level rise. With the high number of populations living on the coasts, rising sea levels are at the top of the list of the major concerns climate change induced. Monitoring sea-surface height is essential for understanding the changes that are occurring so that decision-makers have the evidence they need to develop appropriate policies to help combat climate change and for authorities to safeguard vulnerable communities (New Copernicus Satellite to Monitor Sea-Level Rise Launched, 2020).

Climate change effects definitely will exacerbate the effects of sea-level rise what will make the natural disturbances like; hurricanes and seasonal sea storms get worsen. Since the study area has experienced a severe hurricane in 2009, H.H. Sheikh Sultan Alqasmi the rural of Sharjah Emirate has announced building wave breakers on the coastline of Kalba city. The number of wave breakers is 4, the length is 3.6km and they are 400m away from the seashore to protect the coastal area. This project assures the importance and the seriousness of the sea-level rise effects on the land uses, human lives, and the construction work on the coastline (Wam, 2021).

Chapter 5: Conclusion

This research aimed to assess the effects of sea-level rise on land use across the North-Eastern coastal areas in UAE specifically, Fujairah and Kalba cities. Based on remote sensing tools; Landsat images, the QGIS platform, and the confusion matrix showed high efficiency in classifying the land-use in the Landsat images and predicting the future extent impacts of sea-level rise on multiple scenarios, and by increasing the sea-levels more areas are going to be inundated and Kalba city was highly affected by SLR scenarios.

The supervised classification was performed in this study. The images were classified into 4 classes; water, built up areas, agricultural areas, and open areas. open areas were the most prominent land-use classification, accounting for approximately 47% in the overall area in 2000 and 43% of the overall area in 2020. Built up area have increased by 6% from the year 2000 to the year 2020. Furthermore, the accuracy of the classified images must be assessed. The confusion matrix was used to measure the accuracy in this study. The research achieved an overall classification accuracy of 80%, which is considered significant.

The vulnerability of the North-Eastern coastal areas of the UAE to sea-level rise may increase in the near future, due to the sustained increase of utilization of the coastal zones. This was illustrated throughout the study of the same area over 20 years. Kalba city showed to be more vulnerable to sea-level rise than Fujairah city, as it is located in low laying areas. Hence, the outcomes of this study may have direct uses in coastal development projects and might help decision-makers implement preventative management techniques in the most vulnerable locations in the North-Eastern coast.

The present study contributed to provide for the first time an overview of the SLR effects on the North-Eastern coastal areas. The whole emirates require such studies since the coast of the UAE extends 644 km on the Southern coast of the Arabian Gulf where the emirates of Abu Dhabi, Dubai, Sharjah, Ajman, Umm Al Quwain, and Ras Al Khaimah are spreading over it. While the coast of the emirate of Fujairah extends over the Sea of Oman for a length of 70 km (MOFAIC, 2021). To better utilize the new technology and use the new “Copernicus Sentinel-6 Michael Freilich satellite” data that has been launched recently by the ESA to monitor, predict, and mitigate SLR effects in the UAE North-Eastern coastline would be a potential future study.

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