Mapping the impacts of projected sea-level rise on Cultural heritage sites in Egypt: Case study (Alexandria)

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Abstract

Alexandria is the second big city in Egypt that poses the main seaport and acts as an important industrial hub, providing 40% of the country's industrial output. Moreover, its coast is the home to large number of summer tourism, and cultural heritage sites. According to the Intergovernmental Panel on Climate Change (IPCC), and many studies Alexandria will be exposed to sea level rise that leads to sever coastal erosion and flooding. This will lead to major impacts on infrastructure, beaches and cultural heritage sites.

This research study investigates the status and vulnerability of five cultural heritage sites at Alexandria under four SLR scenarios based on the Representative Concentration Pathways (RCPs) and Shared Socioeconomic Pathways (SSPs). The mean projections of RCP 8.5 for 2046–2100 and SSP5 2081-2100 and SLR 2m are used in this research study. Then will be mapped using remote sensing and GIS techniques. As indicators for the pressure on future cultural heritages, we estimate the area loss and percentage of each cultural heritage sites. In addition to display the mitigation and adaption actions to reduce this risk such as Integrated Coastal Zone Management (ICZM) plans and projects. Results highlight need to increase these sites adaptive capacity, by implementing legislative reforms and incorporating climate change adaptation strategies as a fundamental approach in cultural heritage management.

Keywords: Cultural Heritage, Climate Change, Sea level rise (SLR), Representative Concentration Pathways (RCPs), shared socioeconomic pathways (SSP), Coastal flooding, Coastal Erosion and Alexandria

1. Introduction

Sea level rise (SLR) is considered as one of the main climate change threats on coastal cultural heritage sites.[1] In addition to other natural forces such as storms, currents and wave-action may result in coastal erosion that undermines or buries structures and artefacts. Global climate change and a rise in sea level are likely to exacerbate this problem. [2] SLR threatening the Outstanding Universal Value (OUV) of affected cultural heritage sites and potentially leading to losses in economic revenue as WHS are popular tourist destination.[3]

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[1] Francisco García Sánchez, et al, Cultural heritage and sea level rise threat: risk assessment of coastal fortifications in the Canary Islands, *Journal of Cultural Heritage*, Volume 44, 2020, PP 214.

[2] UNESCO, T*owards integrated management of Alexandria's coastal heritage. Coastal region and small island papers* 14, UNESCO, Paris.2003., PP79.

[3] UNESCO World Heritage Centre. *Policy Document on the Impacts of Climate Change on World Heritage Properties* https://whc.unesco.org/uploads/activities/documents/activity-397-2.pdf (UNESCO

Alexandria was founded in 331 BC by Alexander the Great to be one of the great cities in Mediterranean region. Archaeological sites of Roman and Islamic remains are scattered in the backshore at Alexandria, most of these sites were submerged, thereby, several researchers (Tousson 1934; Jondet 1916; E1 Sayed 1988) have concluded that there is strong indication for sea level rising in many historic times. [4] The analysis is focused on IPCC RCPs and SSPs future scenarios. The Representative Concentration Pathway (RCP) of the IPCC is a trajectory of greenhouse gas concentrations rather than pollution. Four climate modelling and research pathways were used for the IPCC's fifth Assessment Report (AR5) in 2014. Based on the amount of greenhouse gases (GHG) emitted in the coming years before 2100, the different climate futures outlined in the pathways are all considered feasible. [5] The RCPs was named after a possible series of radiative forcing values in the year 2100 (2.6, 4.5, 6, and 8.5 W/m^2, respectively). [6] Since AR5 the original pathways are being considered together with Shared Socioeconomic Pathways as are new RCPs that will be used IPCC Sixth Assessment Report on climate change.[7]

While Shared Socioeconomic Pathways (SSPs) are scenarios of projected socioeconomic global changes up to 2100. They are used to build greenhouse gas emissions scenarios with different climate policies. The scenarios are as follows: SSP1: Taking the Green Road; SSP2: Middle of the Road, SSP3: Regional Rivalry (A Rocky Road); SSP4: Inequality (A Road divided); SSP5: Fossil-fueled Development (Taking the Highway). They will be used to help produce the IPCC Sixth Assessment Report on climate change, due in 2021.[8]

Climate change has been acknowledged as a threat to WHS in recent years[9], no studies have explored this aspect for Egypt's coastal cultural heritage, leaving heritage managers and policymakers with little information on potential adaptation options. Therefore, previous work has called for more research identifying WHS at risk to inform adaptation planning and to ensure that their OUV is preserved.[10] It has expressed the need for more robust data and

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World Heritage Centre, Paris, 2008); Howard, A. J. Managing global heritage in the face of future climate change. The importance of understanding geological and geomorphological processes and hazards. *Int. J. Heritage. Stud.* 2013. 19, 632–658). PP6 41; Perry, J. World Heritage hot spots. A global model identifies the 16 natural heritage properties on the World Heritage List most at risk from climate change. *Int. J. Heritage. Stud*. 17, 2011. 426–441

[4] Justin Pollard; Howard Reid. *The Rise and Fall of Alexandria: Birthplace of the Modern World.* Viking. 2007. PP 2-7. ISBN 978-0-14-311251-8.

[5] IPCC. "*Representative Concentration Pathways (RCPs*)". Accessed on8 February2021

[6] Richard Moss; et al. *Towards New Scenarios for Analysis of Emissions, Climate Change, Impacts, and Response Strategies (PDF).* Geneva: Intergovernmental Panel on Climate Change. 2008. PP 132.

[7] "*Explainer: How 'Shared Socioeconomic Pathways' explore future climate change". Carbon Brief*. Accessed on February 2021

[8] Keywan Riahi, et al. *The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview, Global Environmental Change,* Volume 42, 2017, PP 153-168,

[9] G. Terrill. Climate change. How should the world heritage convention respond? *Int. J. Heritage. Stud*. 14, 2008. PP 390–403.

[10] UNESCO World Heritage Centre. *Policy Document on the Impacts of Climate Change on World Heritage Properties* https://whc.unesco.org/uploads/activities/documents/activity-397-2.pdf (UNESCO World Heritage Centre, Paris, 2008.

modelling approaches on local to regional scales, as adaptation planning takes place at a national level and specific adaptation measures are implemented at a local level[11]. This research study addresses the current research gap in exploring the impact of climate changes on the cultural heritage; the objective is to assess five Mediterranean cultural heritage sites at Alexandria that are exposed to risk from coastal flooding and erosion under four SLR scenarios up to 2100.

2. Study area

Alexandria is the largest city on the Mediterranean – also called the "Bride of the Mediterranean" by locals.[12] The city extends about 40 km (25 mi) at the northern coast of Egypt along the Mediterranean Sea. Alexandria is a popular tourist destination attracting more than 2 million tourists per year, and also an important industrial hub because of its sea port that receive natural gas and oil pipelines from Suez. Figure (1) shows the location map of the study area and Alexandria city. Alexandria was the intellectual and cultural Centre of the ancient Mediterranean world for much of the Hellenistic age and late antiquity. It was at one time the largest city in the ancient world before being eventually overtaken by Rome.[13]

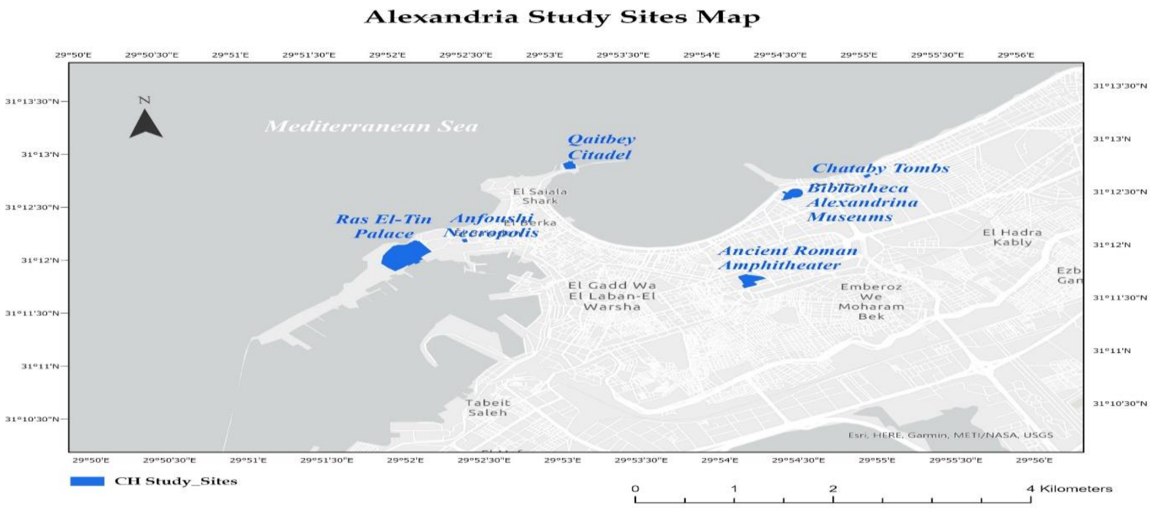

Figure 1: Map of Alexandria archaeological study sites

2.1. Chatby Tombs

The Chatby Necropolis lies in the ancient eastern quarter, which was accidentally rediscovered in 1893. It is the oldest necropolis in the city, probably it had begun to be used by the late fourth century BC, as had those to the south of it at Hadra.[14]

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[11] A. J. Howard, et al. Assessing riverine threats to heritage assets posed by future climate change through a geomorphological approach and predictive modelling in the Derwent Valley Mills WHS, UK. J. Cult. Heritage. 19, (2016).PP 388–391

[12] Salah El-Behnasi et al, *Mamluk Art: The Splendor and Magic of the Sultans* , Museum With No Frontiers, 2010. PP. 322

[13] Justin Pollard; Howard Reid. *The Rise and Fall of Alexandria. PP 53*

[14] Judith McKenzie, et al. *The Architecture of Alexandria and Egypt*, C. 300 B.C. to A.D. 700. 2007.PP 71

More affluent underground tombs have rock-cut architecture, such as Tomb A at Chatby with Greek architectural orders consisting of Doric and Ionic engaged colonnades. It contained burial vases from c. 250 bc.258 The loculi in it were closed with stone slabs decorated with painted doors, like the many examples at Chatby. And funerary couches (klinai) in it, following the Macedonian custom. The tombs are of a simple and elegant design typical of the Hellenistic period. The doorway of the main tomb leads into a hall, which in turn leads into a second hall and then to an open courtyard. East of the courtyard is a doorway leading to the burial chamber. A corridor leads from the central courtyard to the doorway of each tomb. On the East side of the courtyard is a prostas, or reception hall, for performing funerary rituals. By the third century BCE, the site was used by the general public and numerous loculi covered with doorway style loculus slabs were added to accommodate the masses of Alexandrians who would find their final resting place in these historic tombs.[15]

2.2. Anfoushy Necropolis

Anfushy Necropolis is situated at the west of the eastern harbor, where five Greek graves were found in the early 20th century, these date back to the Ptolemaic era (2nd and 3rd centuries BC).[16] All tombs at El-Anfoushi consist of an open courtyard and were cut into the limestone rock, and suffer annually by rising water table. The main difference between the tombs is, however, the lack of kline chambers in El-Anfoushi. The cemetery consists primarily of loculus's burials, but some of the chambers are individual ones, with a central burial in the main chamber which is attached with a smaller back cult chamber.[17] Anfushy tombs are cut into the limestone rock, and suffer a similar fate as those of Chatby, annually flooded by the rising water table. The main difference between the tombs is, however, the lack of kline chambers in Anfushy. Here the cemetery consists primarily of loculus burials, but some of the chambers are individual ones, with a central burial in the main chamber attached to a smaller back cult chamber.[18] The Archeological Commission warned of the danger of exposure of archaeological necropolis in Anfushy area of Alexandria to collapse, due to the increased level of groundwater, which had led to the erosion of the walls, are described in a report commissioned by the Minister of Antiquities, the region that includes months graves Ptolemaic, Romanian and Greek in the Middle East, threatening due to increased humidity, resulting from rising groundwater. The report pointed out that groundwater caused significant damage in necropolis, especially that rocky areas, have leaked salts to the walls, leading to fragmentation and thus need fast action to lower the water table down graves from all directions, and to address the main reason for the deterioration of the structural situation as well

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[15] http://www.alexandria.gov.eg/Alex/english/CHATBY%20%20NECROPOLIS.html

[16] Judith McKenzie , et al.The Architecture of Alexandria and Egypt, C. 300 B.C. to A.D. 700. 2007.p29

[17] . Roder, J., (1967) In: Die antiken Steinbr€uche der Mareotis, 2. Arch€aol, Anzeiger, pp. 118–121.

[18] Tzalas H (in press)The underwater archaeological survey of the Greek mission in Alexandria, Egypt (1998–2010), Marine Archaeology Centre, National Institute of Oceanography, Goa, India.

as to develop an emergency plan for the care of them, given the outstanding role in promoting tourism.[19]

2.3. The Citadel of Qaitbay

The Citadel of Qaitbay is One of the most significant historic military buildings. It is a 15th-century defensive fortress located on the Mediterranean Sea coast, in Alexandria moreover It is located in the same place of the ancient lighthouse of Alexandria, it is regarded as one of the seven wonders of the ancient world, was completely destroyed by a series of earthquakes between the ninth and fourteenth centuries and remains underwater near the entrance to Alexandria's Eastern Harbour.[20] At the end of the fifteenth century, Egypt. Sultan Al-Ashraf Sayf al-Din Qa'it Bay founded it, in 1477 AD (882 AH) by. The Citadel is situated at the entrance of the eastern harbour on the eastern point of the Pharos Island. It was built on the exact location of Alexandria's famed Lighthouse, which was one of the ancient world's Seven Wonders. The lighthouse continued to function until the time of the Arab conquest, then several disasters occurred and the shape of the lighthouse was changed to some extent, but it still continued to function until El-Ashraf Qaitbay found it.

it consists of three major functional architecture plans. Two walls divided into an inner wall and an external one. The inner wall was employed for soldier lodgings and ammunition stores while the external one connected all four defensive towers on each corner of the Citadel and finally the inner tower. Qait Bey Fort itself, comprising a square fortified building measuring about 30 m x30 m.21 According to world bank the coastal erosion and coastal flooding are threatening the Qaitbay Citadel.[22]It is directly on the coastline of the Mediterranean Sea that looks under high vulnerability to and sea level rise incidents or/and all the meteorological parameters anomalies.

2.4. Ras El Tin Palace

Mohamed Ali Pasha constructed the Palace in 1834 to serve as a second governing headquarters, close to Salah El-Din Citadel's functions. Architect Yezi Bek was tasked with designing and constructing the Palace. it took 13 years to complete.

Ras El Tin Palace was the summer residence of the Mohamed Ali family during the reign of Khedive Ismael. The Palace underwent a restoration process during the reign of King Fouad I, and was refurnished to reflect contemporary architecture in the distinctive architectural design. The Palace was annexed by a magnificent mosque. Khedive Ismail built a train station inside the Palace so that the family could move from Cairo to Alexandria and back.

2.5. Bibliotheca Alexandrina Museums

The Bibliotheca Alexandrina is a large library and cultural centre in Alexandria, Egypt, on the Mediterranean Sea's coast. The complex was

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[19] Morcos SA (2000) Early discoveries of submarine archaeological sites in Alexandria. Underwater archaeology and coastal management. Focus on Alexandria, UNESCO, Paris, pp43–51.

[20] Morcos et al., 2003 Towards Integrated Management of Alexandria's Coastal Heritage

[21] Morcos et al., 2003 *Towards Integrated Management of Alexandria's Coastal Heritage*. PP 40

[22] Salah El-Behnasi et al, Mamluk Art: The Splendor and Magic of the Sultans. PP340

formally inaugurated on October 16, 2002, as a commemoration of the Library of Alexandria, which was destroyed in antiquity.

The library has eight million books on its shelves, with the main reading room covering 20,000 square metres (220,000 sq ft). The complex also houses a conference center; four museums; four art galleries for temporary exhibitions; 15 permanent exhibitions; a planetarium; and a manuscript restoration laboratory. The Four museums are: (A) **Antiquities Museum** that was established in 2001, the BA Antiquities Museum is the first archeological museum to be situated within a library.[23] The primary aims of the museum are to promote research, creativity, and cultural awareness. Holding approximately 1,316 artifacts, the Museum collection covers from the Pharaonic period to Graeco- Roman period. The collection includes underwater antiquities from the Mediterranean seabed near the Eastern Harbour and the Bay of Abukir.[24] **(B) Manuscript Museum** that provides visitors and researchers with rare manuscripts and books. Established in 2001, the Manuscript Museum contains the world's largest collection of digital manuscripts. There are three sections housed within the museum: Rare Collections, Microfilm and Museographic Display.[25] **(C) Sadat Museum** contains many personal belongings of the Egyptian president Anwar Al Sadat. The collections include some of his military robes, his Nobel Prize medal, his copy of the Qur'an, a few of his handwritten letters, pictures of him and his family, and the blood-stained military robe he wore the day of his assassination.[26] (D)**History of Science Museum** is a permanent exhibition that highlights the historical aspect of science in Egypt during three major periods: ancient Egypt, Hellenistic Alexandria, and the Arab-Muslim World.

3. Methods

3.1. General framework.

The materials used in this research include; Satellite images data and processing Satellite images covering the last 48 years (1972–2020) [ls_1972 - 1984-1988-1990 1996-1999-2008-2011-2015-2020] were processed to monitor and determine the changes in the coastal zone of Alexandria. The used images were freely downloaded from the USGS website. and were geometrically corrected to the Universal Transverse Mercator (UTM) projection, Zone 36 North and the WGS84 datum. These images used for shoreline delineation.

For mapping projected sea level rise we using SRTM DEM to determine elevations of study sites and make the projected scenarios according to RCPs and SSP5 and SLR 2m respectively.

3.2. Study heritage sites data processing.

We use tangible cultural heritage sites data, in which each CHS is represented as a polygon, with longitude and latitude coordinates. We extract all cultural

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[23] "*Overview – Antiquities Museum". Bibliotheca Alexandrina*. Accessed on 2 April 2021

[24] "*Antiquities Museum – Museums – Bibliotheca Alexandrina".* Bibliotheca Alexandrina. Accessed on 2 April 2021

[25] "*Manuscript Museum – Museums". Bibliotheca Alexandrina*. 2 April 2021

[26] *"Sadat Museum". Bibalex.org*. 2 April 2021

CHS located along the Alexandria Mediterranean coast, we manually check each CHS and add further polygon data entries for serial sites based on maps and descriptions and its historic period.
we follow the methodology of Chang et al. [27] and Dassanayake et al[28] to represent each CHS position as accurately as possible. we use Google Earth TM satellite imagery to correct the position of misplaced CHS, where in doubt. we additionally compare photos and site descriptions provided on the literature review and archaeological mission reports. with photos of the Panoramio web service embedded in Google Earth™.

Next, we examine old CHS maps and made some on-site visits to examine sites and verify its borders correctly with review from specialists from ministry antiquities then digitize the outline polygon of each site with the help of Google Earth™ and ArcGis 10.6, resulting in one shape file for all study sites. Subsequently, we extract the CHS located in the Low Elevation Coastal Zone (LECZ) based on the lowest elevation value of each CHS polygon in the SRTM DEM. The LECZ represents all land with an elevation of up to 5 m in hydrological connection to the sea. This approach enabled to explore that all sites are potentially exposed to coastal flooding and erosion.

3.3. Flood risk.

For mapping flood risk on cultural heritage sites along Alexandria coast. SRTM DEM is used for this purpose. Digital elevation model (DEM) is the digital representation of the earth surface terrain. It is an essential component in the hydrological models.[29] The DEM of Alexandria study sites is generated from the Shuttle Radar Topography Mission (SRTM) data. it is used for detecting the study sites elevations Fig (2). According to Maher Amin and sadia El-Fatraiy research that proved SRTM and local DEMs have nearly the same accuracy in terms of RMSE, while ASTER DEM lies in a lower ranking, the accuracy of the ASTER DEMs was radically improved (49.5%), after the vertical shifts versus GCPs had been removed. The removed values could be considered as systematic shift and such model is thus considered a relative DEM. SRTM DEM can safely be used for updating the topographic maps of scale 1:50,000 over flat and steep terrain, because the RMSE of such DEM is less than half the contour interval used in such topographic maps, while ASTER DEM can be used safely for updating the smaller scale top geographic maps.[30]

[27] A. Y Chang. et al. Combining Google Earth and GIS mapping technologies in a dengue surveillance system for developing countries. *Int. J. Health Geography*. (2009). 8, 49 .

[28] Dilani Dassanayake, Andreas Burzel, Hocine Oumeraci, *Evaluation of Cultural Losses*. December 2012

[29] Islam Abou El-Magd, ElSayed Hermas, Mohammed El Bastawesy, GIS-modelling of the spatial variability of flash flood hazard in Abu Dabbab catchment, Red Sea Region, Egypt, *The Egyptian Journal of Remote Sensing and Space Science*, Volume 13, Issue 1, 2010, PP 81-88

[30] Maher M. Amin and Sadia M. El-Fatraiy. Accuracy Assessment of world DEMs versus Local DEM in Egypt. 2013, Civil Engineering Research Magazine CERM, Vol. 35.No. (3), Published by Faculty of Engineering, Al-Azhar University, Cairo, Egypt.

The SRTM data used have a spatial resolution of 3 arc seconds (approximately 90 m at the equator). Based on these data, we determine the area of each CHS located at elevation increments from 0 m up to 5 m in hydrological connection to the sea in a first step. Following that, we quantify flooded areas based on the scenarios. We assume the minimum elevation value of each CHS is 0 m for CHS located below 0 m according to SRTM data.

we used four SLR scenarios based on the Representative Concentration Pathways (RCPs). And Shared Socioeconomic pathways SSPs. We select the mean projections of RCP8.5 for 2046–2100 and SSP5 2081-2100 and SLR 2m scenarios as shown in table (1)

Table (1):SLR mean projections used in the study

Scenario	Global Mean Sea Level Rise (m)
RCP8.5 (2046-2065)	0.30
RCP8.5 (2081-2100)	0.63
SSP 5 (2081-2100)	1.32
SLR 2m	2.0

It is worthy to mention that there is gap in such studies to assessing flood risk based on the area of an object flooded; therefore, we assume that the OUV of a heritage site is seriously threatened if at least 10 % of the site is flooded. In a last step, we calculate the area and flood ratio.

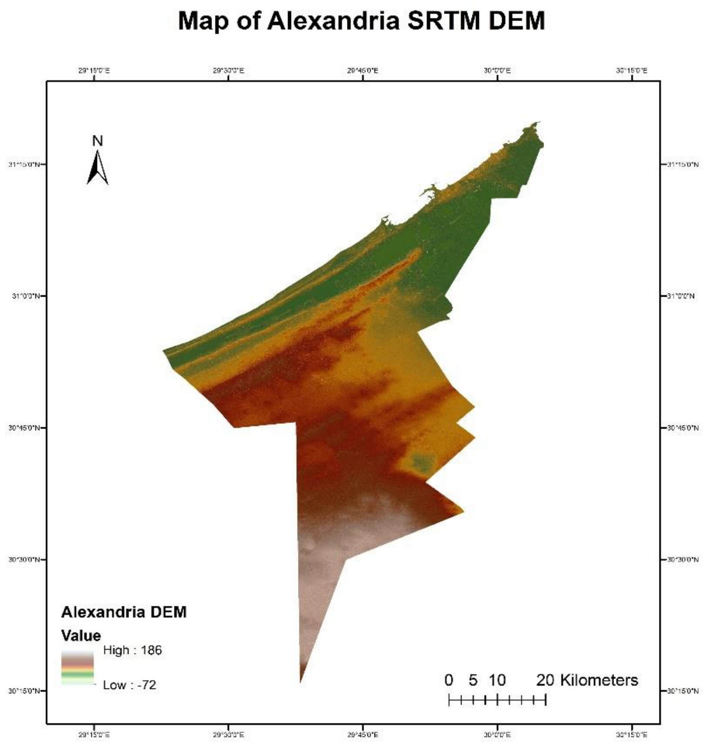

Figure 2: Map of Alexandria DEM with study sites

4. Results

Alexandria is built on a T-shaped peninsula, a land strip caught between the sea, lagoons and former lakes. Large parts of the city lie below sea level, which makes flood and drainage a critical issue. This geographical situation and the urban pattern make the City highly vulnerable to ecological hazards. According to a report by the World Bank (2011) the situation should worsen by 2030: the city is exposed to marine submersion, coastal erosion, earthquakes, flooding and water scarcity risks.[31]

Coastal Erosion

Alexandria Coast consists of sandy beaches separated by rocky headlands. Beaches are experiencing slow but chronic long-term erosion of about 20 cm/yr as a consequence of ongoing natural coastal processes combined with sediment deficiency. More than 50% of the sandy beaches between ElMontaza and ElSilcila,14.5 km long, have significantly disappeared following seaward widening of the Corniche high way (1998-2002), creating "sediment starved" coastal cells. Erosion risk map for 2030, risk is high in the outskirts.[32]

4.1. Coastal submersion Risk

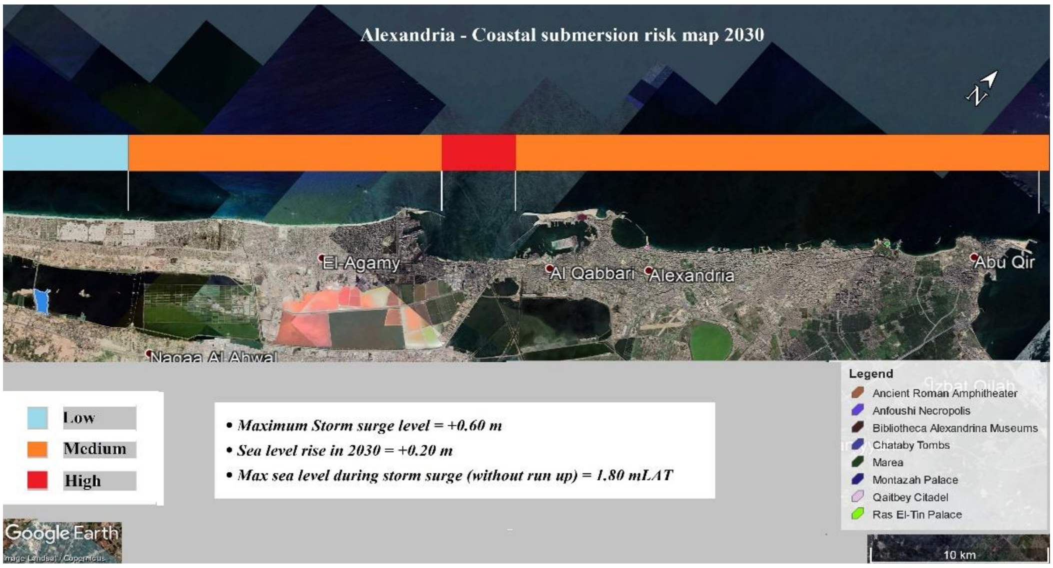

Figure 3: Alexandria coastal submersion risk map2030. Source: World Bank and redesigned by the researchers

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[31] World Bank Group, *World Bank Regional Study on Adaptation to Climate Change and Natural Disasters in The Coastal Cities of North Africa Case of Greater Alexandria*.2011. PP 12

[32] Ibid. PP 17

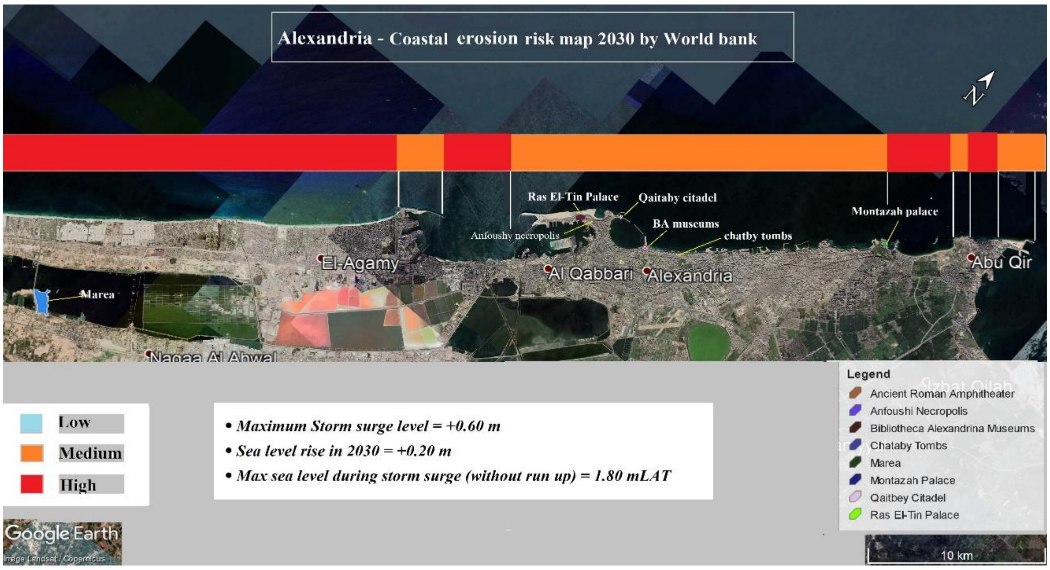

Figure 4:Alexandria coastal erosion risk map by 2030. Source: World Bank and redesigned by the researchers

Large area of the coastline is subjected to submersion risk during stormy periods. Storm surges in Association with the spring tides (high tides) rise water levels by 60 cm above normal. occasionally high tides occur in combination with storm surges and sea-level can produce waves sit-ups 1.6 m such as a storm surges can submerge the shoreline but low-lying areas and expanding around the lake Maryut and south of abuqir are protected by natural ridges and seawalls. submersion risk map for 2030, risk is high between Eldekhila and and the Western Harbour and some stretches in Abu Quir. Moreover, the city may face higher marine submersion as storm surges in association with spring tides (high tides) raise water levels by 60cm above normal, and can submerge the shoreline. Despite protection by natural ridges or sea walls, low-lying areas expanding around Lake Maryut and South of Abu Quir are not fully protected. As of today, the beaches of Alexandria, from Mandara to El Silcila, are experiencing chronic long-term erosion of ~20 cm/ yr. and water scarcity risks, along with an increase in seismic, land subsidence, and flooding risks.

According to Shaltout and Tonbol, the longest available time series of Alexandrian sea-level data from 1944 to 2006, indicates two regimes over the last century. Before the Aswan High Dam was constructed (1944–1963), Alexandrian sea levels had a strong noticeable rising rate of 0.5 cm per year; after the dam was built (1964–2006), the Alexandrian sea-level trend is weaker at approximately 0.2 cm year. The pattern prior to 1963 is most likely due to Nile sedimentation, which caused sinking of the land surface. Less sediment has been exported since the Aswan High Dam was built, and the rise is most likely due to climate change.[33]

[33] Elham M. Ali, Islam A. El-Magd, Impact of human interventions and coastal processes along the Nile Delta coast, Egypt during the past twenty-five years, *The Egyptian Journal of Aquatic Research*, Volume 42, Issue 1, 2016. PP.2

Terrain deformation, such as subsidence and uplift, has a negative impact on Alexandria. Between 5 to 9% of the measured points correspond to negative movement or land subsidence. The normal (i.e. non-tectonic) rate of subsidence is estimated to be about 0.04 centimeters per year. The areas of Alexandria city most affected are along the northern edge of Lake Maryut and in the southern part of the city between Gharb and Abu Quir districts.

Alexandria is a densely populated, economically and historically significant city on the Mediterranean coast;it has been subject to rapid subsidence due to the effects of the massive tsunami caused by the AD 365 Crete earthquake and subsequent seismic events over past millennial time scales.[34] Between the seventh and tenth centuries CE, the most significant subsidence occurred, causing sinking and collapsing some of the settlements constructed along Alexandria's Eastern Harbour below the water's level.35 A series of cross-sectional profiles in Alexandria's Eastern Harbour uncovered a collapsed Ptolemaic/Roman pier that had been submerged by seawater for over two thousand years, with its foundation (top) lying 8 to 9 m (5 to 6 m) below harbour waters (Goddio et al., 1998). Furthermore, 180 Pharaonic/Ptolemaic concrete blocks now sit 30 meters offshore from Alexandria's eastern harbor.[36] Spatial analyses of digital elevation data in Alexandria indicate that the most vulnerable area to SLR is the Nile Delta coastal region (NDR). Approximately 25% of the NDR's land elevation is equal to or below current sea level, mainly and especially on the NDR's north-western side. Therefore, even a 10-cm SLR will dramatically damage the north side of the NDR, which includes large lakes, tourist resorts, historical sites, fertile agricultural land, and four populous cities: Alexandria, Rosetta, Borolus, and Port Said.37[38]

According to the research results, SLR scenarios over Alexandria CHS, the research finds that as following the following table (2) shows five CHS Under Representative Concentration Pathway RCP 8.5 from 2045-2065 and RCP 8.5 2081- 2100. The table displays the CHS and its distance from sea and the flooded area in square meters as well as the ratio of flooding in percentage.

As shown below the flood area ranges from 0.05% of the total WHS at Archaeological Site of Ras El-Tin Palace to 21 % at Qaitbay Citadel. therefore, the most vulnerable site is Qaitbey Citadel that will lost about 21 % of its total area if the SLR risen to 30 cm. while the other site is still safe according the two mentioned scenarios. Moreover here is flooding map for the site under these scenarios as shown Fig(5).

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[34] Guidoboni. *Catalogue of Ancient Earthquakes in the Mediterranean Area up to the 10th Century* E. Guidoboni Istituto Nazionale di Geofisica, Bologna (1994) 504 pp.

[35] J. McKenzie. *The Architecture of Alexandria and Egypt*. PP 458.

[36] Morcos et al., *2003 Towards Integrated Management of Alexandria's Coastal Heritage*. PP 79.

[37] Mohamed Shaltout, Kareem Tonbol, Anders Omstedt, Sea-level change and projected future flooding along *the Egyptian Mediterranean coast, Oceanologia*, Volume 57, Issue 4, 2015, PP 295-301.

[38] Elham M. Ali, Islam A. El-Magd, Impact of human interventions and coastal processes along the Nile Delta coast, PP 1-10,

Table (2): CHS under SLR according to RCP 8.5.

Site Name	Distance from sea(m)	RCP 85_2065		RCP 8.5_2100	
		Flood area (Sq2)	**Ratio**	**Flood area (Sq2)**	**Ratio**
Qaitbey Citadel	25	2874.2	21 %	2874.21	21%
Ras El-Tin Palace	180	915.9	0.5 %	916	0.6 %
BA- Antiquities Museum	140	0	0	0	0
Chataby Tombs	117	0	0	0	0
Anfoushi Necropolis	300	0	0	0	0

While under SSP 5 Scenario the research finds that the flooded area ranges from 4% of the total of CHS at of Chatby tombs and Ras el-tin palace to 37 % at Qaitbey Citadel. Moreover, SLR 2m indicates that the most vulnerable and flooded CHS is Qaitbey Citadel with 44 % of its total areas will be exposed to flooding risk and the less sensitive site will be Cahatby tombs with 8% flooded area as shown below in table (3) and Fig (5).

Table (3): CHS under SLR according to RCP SSP5 AND SLR 2 m

Site Name	Distance from sea(m)	SSP5_2100		SLR_2m	
		Flood area	**Ratio**	**Flood area (Sq2)**	**ratio**
Qaitbey Citadel	25	5204.5	37%	6186	**44%**
Ras El-Tin Palace	180	6677.0	4%	22681	14%
BA- Antiquities Museum	140	6849.7	25%	8291	**30%**
Chataby Tombs	117	130.1	4%	286	8%
Anfoushi Necropolis	300	234.1	8%	604.352	**22%**

The findings of this research is agreeing with the same expectations many previous studies like world bank and UNESCO study "Towards Integrated Management of Alexandria's Coastal Heritage" that stated that the main consequences of occasional, cyclical higher sea-levels, especially in low-lying coastal archaeological sites such as Qaitbay citadel, Chatby, and Roushdy, will be sea flooding and disruption of groundwater flow. Seawater penetration of these sites will affect the archaeological monuments. Also, it referred to the threat of coastal erosion in Qaitabay citadel by wave action in addition to finding cavities below the platform lining the citadel. [39]

[39] *Towards Integrated Management of Alexandria's Coastal Heritage*. PP 35

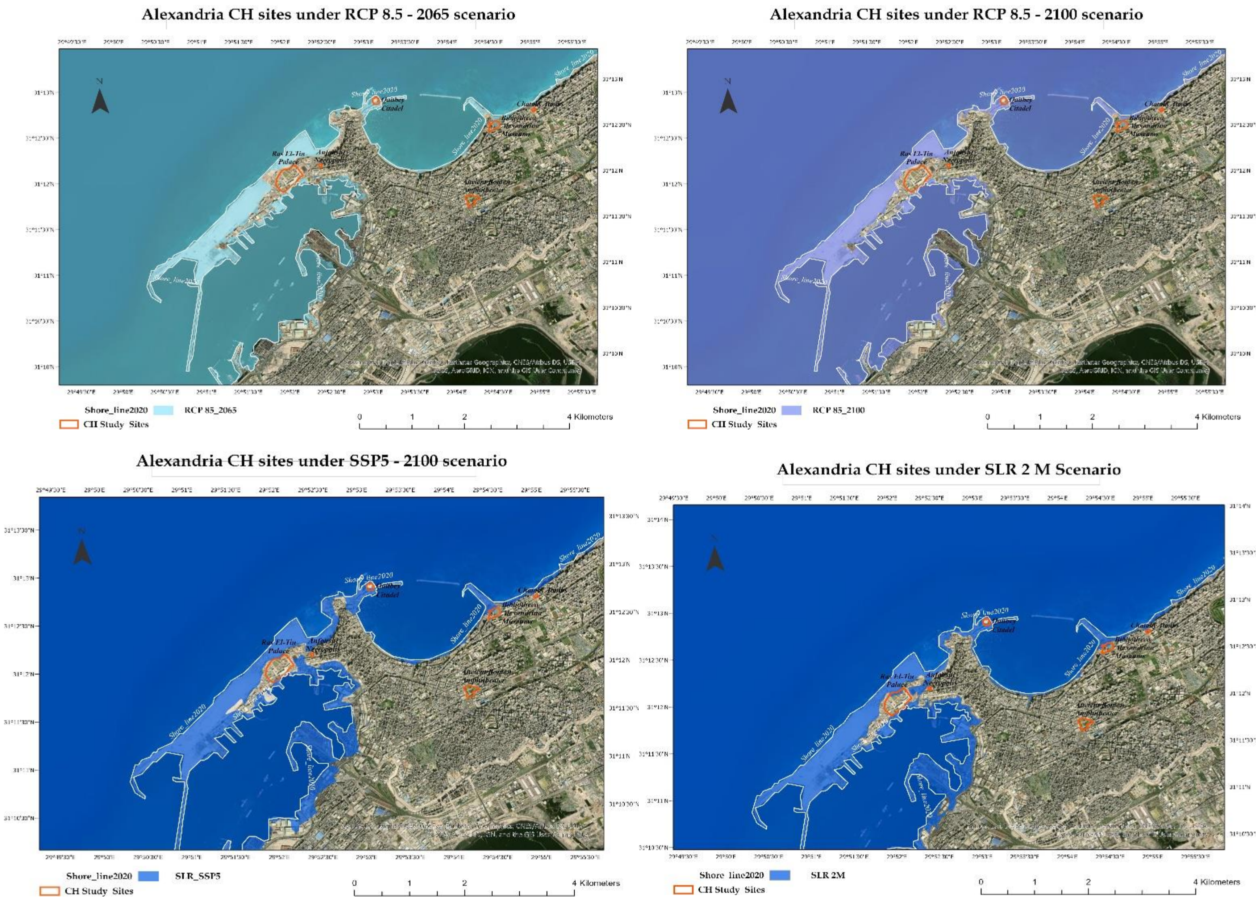

Figure 5: CHS study areas under different SLR scenarios

The following chart comparing different five CHS under different four SLR scenarios, and according to all scenarios the most vulnerable site is Qaitaby citadel.

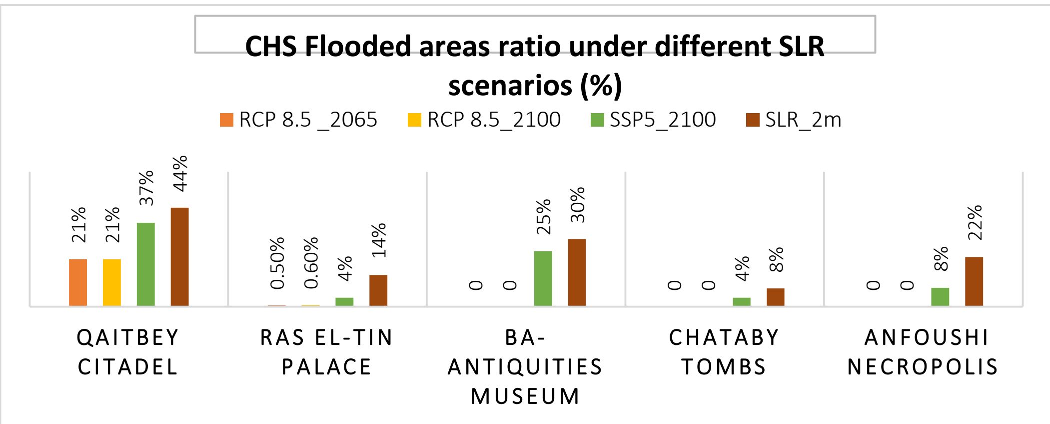

Figure 6:CHS Flooded areas ratio under different SLR scenarios (%)

The Egyptian government has recently expressed interest and commitment towards coastal, environmental and coastal management issues.[40]

[40] Elham M.Ali and Islam A.El-Magd. Impact of human interventions and coastal processes along the Nile Delta coast, Egypt during the past twenty-five years

For the adaptation and mitigation efforts of climate change impacts, the institutional capacity in Alexandria to manage these risks and prepare communities for potential future disasters and climate change impact is limited. The current organizational set-up of the emergency response systems remains highly centralized with limited horizontal and vertical coordination between agencies down to the level of local communities. But for the coastal erosion risk, the government makes serious and huge efforts to reduce the impact of coastal erosion on cultural heritage sites in Alexandria. In the early 1990s the Supreme Council of Antiquities, which is responsible for the Citadel, became concerned about erosion at its north-eastern perimeter and decided in 1991 to entrust the Coastal Protection Authority with taking the necessary protective measures to protect the Citadel from further wave damage. Work began on the project in 1993 and some180 concrete blocks, each weighing several tons, were placed about 30 m offshore from the Citadel.

In the recent time, Green climate fund and UNDP are funding the project of "Enhancing Climate Change Adaptation in North Coast and Nile Delta in Egypt (GCF) that started in 2018 and will continue to 2024. It is implemented by EEAA and Ministry of Water Resources and Irrigation (MWRI). One of the main objectives of the project is to reduce coastal flooding risks in Egypt's North Coast due to the combination of projected sea level rise and more frequent and intense extreme storm events. Through installation of low-cost soft dikes to alleviate impacts of extreme weather events on infrastructure and human settlements. In addition to the development of an integrated coastal zone management (ICZM) plan for the entire North Coast, to manage long-term climate change risks and provide Egypt with adaptability to impending flood risks.[41] The Egyptian General Authority for Coastal Protection- MWRI started to implant the biggest integrated marine engineering project of its kind to protect citadel in Alexandria, with cost of EGP 267 million, and it is expected to be finished in next December 2021, The project aims to protect the mother rock of the citadel, and the work of a marine tongue, is the largest project for an archaeological site on the Egyptian coasts.[42] Luckily nearly 74 % of the project is finished as shown in Fig (7).

Figure 7: Map of new and old wave breakers around Qaitbay citadel.

[41] Green climate fund, *Funding proposal of Enhancing Climate Change Adaptation in the North Coast and Nile Delta Regions in Egypt.* 2017.PP 2-19 thttps://www.greenclimate.fund/sites/default/files/document/funding-proposal-fp053-undp-egypt.pdf
[42] https://www.almasryalyoum.com/news/details/2226806

5. Conclusion

In conclusion, Alexandria city has numerous cultural heritage sites along Mediterranean coast that exposed to climate change impacts in different degrees such as coastal erosion and coastal flooding. The results of this study highlighted the importance of using new scientific tools and techniques such as GIS and remote sensing in addition to climate models in monitoring and management of cultural heritage sites especially the valued coastal sites. These new techniques are not only important from the scientific viewpoint but in providing information that can be used in development-planning, and helping to create early warning systems of climate change impacts especially extreme weather events and storm surges. that will support decision making in the field of cultural heritage management. Finally, it is recommended to foster research and development in this thematic area of studies that would improve our understanding and solutions to manipulate the impact of climate change on the culture heritage sites, provide solutions, scenarios and policies.

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تخريط التأثيرات المتوقعة لارتفاع منسوب سطح البحر على مواقع التراث الثقافي فى مصر: دراسة حالة الإسكندرية

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الملخص العربى

تعد الإسكندرية ثاني أكبر المدن المصرية، والتي تشكل الميناء البحري الرئيسي لمصر وتعمل كمركز صناعي مهم ، حيث توفر ٤٠ ٪ من الناتج الصناعي للبلاد. علاوة على ذلك ، فإن ساحلها هو أحد المقاصد السياحية الهامة لما يحتويه من شواطئ وعدد كبيرمن مواقع التراث الثقافي. ووفقًا للهيئة الحكومية الدولية المعنية بتغير المناخ (IPCC) ، فإن العديد من الدراسات قد أشارت الى أن الإسكندرية سوف تتأثر بإرتفاع مستوى سطح البحر الذي يؤدي إلى تآكل السواحل والفيضانات.وسيؤدي ذلك إلى تأثيرات كبيرة على البنية التحتية والشواطئ ومواقع التراث الثقافي. تبحث هذه الدراسة في تأثير ارتفاع مستوى سطح البحر على خمسة مواقع للتراث الثقافي المادى في الإسكندرية في إطار أربعة سيناريوهات مختلفه لإرتفاع مستوى سطح البحر SLRبناءً على مسارات التركيز التمثيلي (RCPs) والمسارات الاجتماعية والاقتصادية المشتركة .(SSPs) وقد تم استخدام متوسط توقعات RCP 8.5 لـ للاعوام من ٢٠٤٦ الى٢١٠٠ و SSP5 2081-2100 و SLR 2m في هذه الدراسة البحثية . ثم تم انتاج الخرائط التى تمثل تأثير هذه الظاهرة باستخدام تقنيات الاستشعار عن بعد ونظم المعلومات الجغرافية وخلصت النتائج لتقدير المساحة التى سوف تتعرض للغرق والضرر ونسبتها المئوية من مساحة كل موقع من مواقع التراث الثقافي وتستهدف الدراسة بهذا التقدير وضع مؤشر تقديرى وتحذيرى لمخاطر إرتفاع مستوى سطح البحر على مواقع التراث الثقافى محل الدراسه لدعم إتخاذ القرار السيلم للحفاظ عليها بشكل مبكر. بالإضافة إلى ذلك تعرض الدراسة إجراءات التخفيف والتكيف لتقليل هذه المخاطر مثل خطط ومشاريع الإدارة المتكاملة للمناطق الساحلية.(ICZM) . وأخيرا، تسلط النتائج الضوء على الحاجة إلى زيادة قدرة هذه المواقع على التكيف ، من خلال تنفيذ إصلاحات تشريعية ودمج استراتيجيات التكيف والتخفيف كنهج أساسي في إدارة التراث الثقافي.

الكلمات الدالة: التراث الثقافي، تغير المناخ، ارتفاع مستوى سطح البحر (SLR)، مسارات التركيز التمثيلية (RCPs)، المسارات الاجتماعية والاقتصادية المشتركة (SSPs)، الفيضانات الساحلية، التآكل الساحلي، الإسكندرية.