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Urban Risk Assessments: Framework for Identifying Land-uses Exposure of Coastal Cities to Sea Level Rise, a Case Study of Alexandria

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Abstract Climate change is widely seen as one of the most serious threats confronting humanity, owing to the rapidly rising greenhouse gas emissions. Sea level rise (SLR) is believed to be the most serious challenge posed by climate change; as the climate changes, SLR is accelerated impacting all low laying coastal regions worldwide, especially in developing countries. Egyptian coastal cities, particularly Alexandria governorate, are seen as desirable places for population and tourism, even though they are among the most likely regions worldwide to face severe SLR threat. This paper aims to provide a simple methodological framework that can be applied by developing countries with limited resources to detect SLR hazard impact on coastal land uses and to study future SLR land exposure scenarios as a mandatory step in urban risk assessment process. The framework relies on the integration between remote sensing techniques and Geographic Information System (GIS) technology and depending on free easy access data. Results for the case study area shows that by the end of the century, 17% of Alexandria governorate will be submerged due to SLR, additionally SLR will have a significant impact on beaches and tourist destinations, which play a crucial part in the economic development of Alexandria governorate and will undoubtedly have a direct impact on it.

Keywords:. Climate change; Land uses; Remote sensing; Sea level rise.

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1 Introduction

Climate change is regarded as one of the world's most serious threats. Greenhouse gas emission is increasing rapidly, that since 1850, greenhouse gas concentration has raised by 47% to reach an average of 414 ppm by 2020 [1]. In addition, 95% of the twenty warmest years occurred between 2001 and 2020 [2], which indicates that the current emissions are tracking around the highest scenario pathway according to the fifth assessment report from Intergovernmental Panel on Climate Change [3], and even with the world's efforts to minimize the emissions of greenhouse gas, climate change will not stop [4].

Sea level rise (SLR) is considered as the most serious impact of climate change [5]. The dominant factors that cause SLR are related directly to global warming such as water thermal expansion and ice sheets melting [2], and as climate keeps changing, SLR is accelerated. There is evidence that sea level had risen more rapidly during this century than in the previous two centuries [6],[7], moreover the change rate is accelerating as global mean sea level rose with a rate of 1.7 mm/yr during the period 1901 to 2010, while for the specific period 1993-2010 the rise rate was increased to 3.2 mm/yr [8], therefore coastal cities around the world are predicted to face tough SLR challenges [3], especially in developing countries which are expected to face a displacement of more than 50 million inhabitants by the end of this century due to SLR [9], [10].

It is clear that climate change is an international problem; however, its impact varies from a region to another as stated by the United Nations Development Programme (UNDP). Egypt's dense population makes it greatly vulnerable to climate change issues which have an influence on all aspects of development, specially tourism and agriculture which are particularly vulnerable to temperature variations [11]. As a consequence, one of the most significant hazards that Egypt is greatly predicted to experience due to climate change is SLR [12], [13]. This hazard is affecting all the 11 coastal governorates in Egypt with a total of 36 coastal cities along the Egyptian coasts which extend for an approximate length of 3500 km along both Red and Mediterranean seas [14]. The last is considered to be more vulnerable to SLR due to its low topography in comparison to the Red Sea coasts, specially Alexandria governorate, which is considered as one of the most areas in Egypt that is expected to be impacted the most by SLR [15].

SLR is a tough challenge for Alexandria governorate, it is estimated that with only a 50 cm SLR, all economic sectors in Alexandria will be impacted [11], additionally, the total damage cost expected for Alexandria by the end of this century is more than 635 billion of US dollars under the highest Representative Concentration Pathway (RCP) 8.5 scenario. As a result of this hazard and in order to encounter this threat, there is evidence that the Egyptian government has shown a growing awareness to the serious problem of SLR since the beginning of the century, especially in Alexandria governorate. Serious actions are taken in order to protect hazard regions and to minimize the impact of climate change as shown in **Fig. 1** [16]–[19], as in 2021, about one billion Egyptian pound was assigned for coast protection works in Alexandria [20]

Egyptian coastal cities, particularly the Mediterranean coastline, are regarded as an attractive stunning regions for population, where amazing beaches are attracting local and international tourists [21]. The majority of activities such as Trade, fishing, shipping, tourism, agriculture and so on, take place along the narrow strip adjacent to the coastline, which results in densely populated areas and growing human population. Moreover the problem of unplanned urban growth where most habitats tend to settle in flat low-lying areas with lower cost regardless the high hazard accompanied such as SLR hazard [22], [23].

Urban risk assessment of natural disasters relies heavily on prediction scenario studies to better deal with mitigation measures. modelling and simulation of hazard and identifying exposed areas are crucial steps for a successful urban risk assessment [24], [25]. The comparison between images of different dates provides an assessment of changes occurred in a certain area during a certain period of time that helps in monitoring land-use changes over time and detecting urban growth patterns. this can be accomplished perfectly through the integration between remote sensing and Geographic information systems (GIS) technology which are proved to be highly valuable tools for coastal management researches [26]. Remotely sensed images offer resources that provide high resolution data for any region around the world, offering a great opportunity to assess natural hazards, especially for developing countries where natural disasters are threatening a far larger number of people [27], while GIS techniques helps in the spatial analysis and the production of enhanced processed images in urban applications [28].

A

B

Fig. 1 a) shows the coastal protection barriers that line the East part of Alexandria [18]. b) a 1933 photograph of Stanley Beach located in Alexandria compared to the same site in 2019, showing the enormous impact of SLR on tourisms areas [19].

This paper provides a simple methodological framework that can be applied on coastal cities worldwide, particularly in developing countries where governments cannot afford the high cost of using aerial photography techniques, thus, this paper is limited to the use of free easy access data which is freely available and easy to be obtained by any researcher. The data was processed using a GIS software to make needed spatial analysis, this process only requires a minimal training and a computer with suitable high-resolution screen [29]. Free-cost available data was gathered and examined to detect the most suitable free dataset for paper purposes.

For the process of tracking past land-uses changes in the study area, free easy access Landsat imagery was used to obtain land use-land cover data (LULC) for Alexandria. This tracking process depends mainly on remote sensing technique because of its advantages in mapping and analyzing land changes over a certain period of time [30].

The main objective of this paper is to provide a simple framework that can be applied in coastal cities particularly in developing countries to help in hazard tracking and assessing processes. Additionally, the framework was applied to the case study area of Alexandria governorate in order to firstly, analyze the history of SLR impact on different land-uses in Alexandria, especially on Mediterranean beaches which are considered one of the most attractive tourist destinations worldwide. Secondly, to study the future land exposure scenarios and to detect SLR future impact on present land-uses assuming that no urban expansion or land-use changes will occur in areas at risk of SLR, and then estimating the beaches capacity expected to be lost due to SLR.

2 Data and Methods

2.1 Case study

The case study area of Alexandria governorate is located on North Africa on Egyptian North coast, city center Latitude and longitude coordinates are 31° 12' 56.30" N and 29° 57' 18.97" E. According to the Egyptian Central Agency for Public Mobilization And Statistics, Alexandria is the most densely populated governorate on the Mediterranean Sea with population of 5.2 million resident by 2018, also it is considered as one of the most preferred locations for urban tourism [31].

Alexandria coast extends for 31 km from Abu Qir city at the East to El-Dikheila city at the West, the coast holds pocket beaches that reach to 1.6 km long as presented in **Fig. 2**. Coastal beaches slopes is about 1:30, there is evidence that the majority of Alexandria's coastal beaches are eroding at a rate of 20 cm/year for the period 1955 to 1983 [32].

The study period starts from 1992 directly after beaches replenishment [33] to 2019, this 27 years were divided into three minor periods, 1992-2001, 2001-2010 and 2010 to 2019 to clarify the results, also for a better analysis of SLR historical impact on Alexandria coastal beaches, the administration boundaries downloaded from Humanitarian Data Exchange project [34] were used to specify the exact boundaries of the study area. Moreover, results were separated for the two major regions, East region that includes the old part of the governorate where coastal protection exists, while the West region is the new part of the governorate as shown in **Fig. 3**.

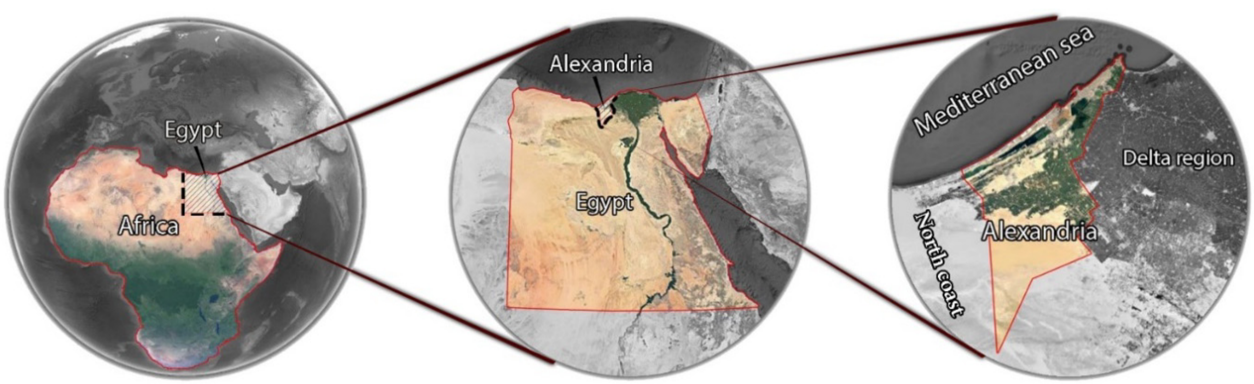


Fig. 2 Case study area of Alexandria governorate located on the North coast of Egypt.

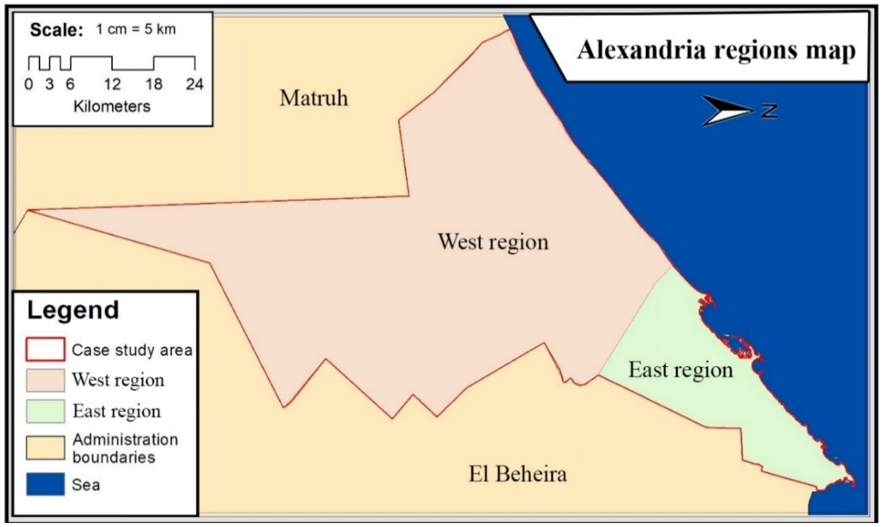


Fig. 3 Major Alexandria regions map.

The continuous monitoring of natural hazards is the foundation of risk management and urban risk assessment fields including the analyzing processes, which provide useful information to study future scenarios. Relying on monitoring techniques, this paper is mainly divided in to two parts, the first focuses on monitoring the history of SLR hazard, while the second part focuses on studying the future SLR hazard scenarios as shown in **Fig. 4**.

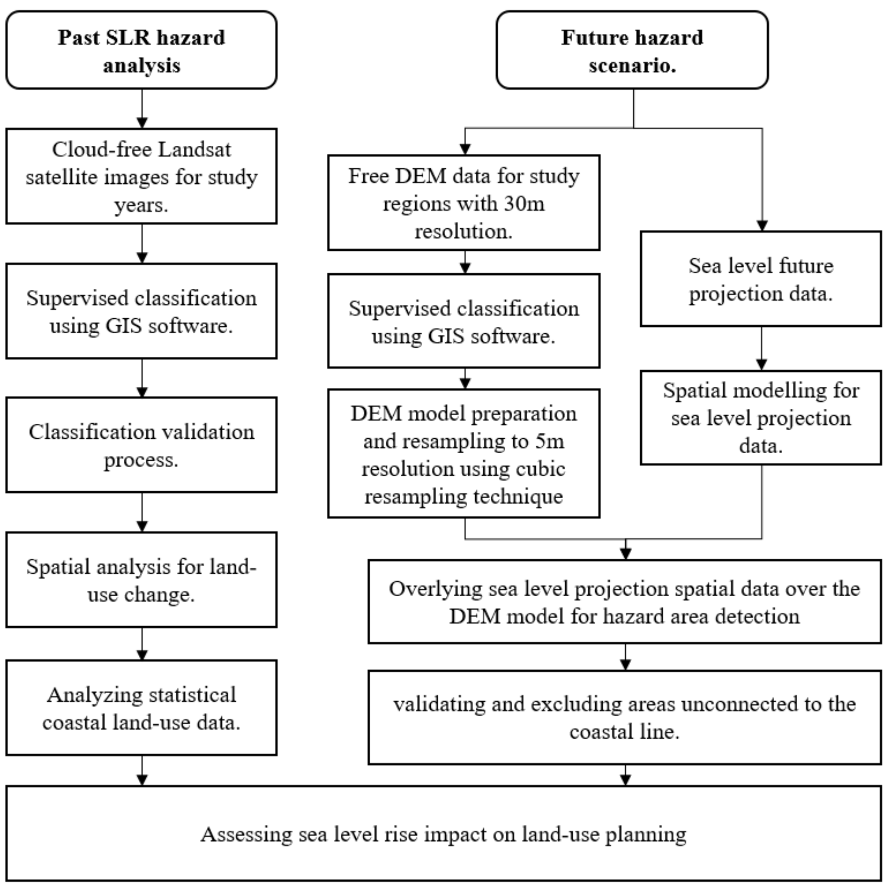


Fig. 4 Methodological framework.

2.2 Past SLR hazard analysis process

This paper provides an application for monitoring and analyzing the impact of SLR over different land-uses by using free easy access data. Landsat images provide a continuous sufficient data for most earth's spots, which is essential for monitoring process. The most recent available Landsat imagery files for each study year were downloaded from the Earth Explorer tool from USGS available at (Earthexplorer.usgs.gov)[36]. Landsat 8 OLI/TIRS file was used for year 2019, Landsat 7 ETM+ file was used for years 2010 and 2001, while Landsat 4-5 TM for year 1992, the downloaded files were checked to be within half a month period in a year with almost free cloud cover.

A supervised classification was applied using Maximum Likelihood Classification technique which is proven to produce the best accuracy with Landsat TM and ETM+ images[37] [38]. The land-uses were classified into 5 main categories which are water, urban, beaches, vegetation and desert, then sea level history data was retrieved from the sea level anomaly dataset in the data analysis tool provided by NASA/JBL which is available through the data analysis tool at (Sealevel.nasa.gov), this dataset was used to check the SLR rate through the study periods.

Coastal beaches spatial data was verified to be connected to the coastline using GIS software analyzing tools, then anomalies were corrected using high resolution satellite maps available through google earth, also the maximum number of beach visitors at a time in relation to its area was calculated using the average user area for urban Mediterranean beaches Illustrated by [21].

Accuracy assessment is a mandatory step to validate classified maps, KAPPA validation is a well-known technique for land cover classification accuracy assessment, this technique is used to quantitatively verify how well were the pixels sampled compared to the ground truth land cover classes [40], thus, an accuracy assessment using kappa coefficient was applied to verify the used classification technique using 250 sample points selected randomly [41][42].

2.3 Future hazard scenarios process

For studying future SLR scenarios, DEM files and sea level projection data were used to detect hazard areas. SRTM DEM files with 30m resolution for the Egyptian north coast were downloaded from (earthexplorer.usgs.gov) in GEOTIFF format and processed using GIS software to fill no-data pixels. A mosaic of adjacent DEM tiles was made in order to create one continuous DEM, the file then was clipped to the case study area boundaries and the result was resampled from 30m cell size DEM to 5m cell size using the cubic resampling technique which is proven to be the best resampling technique for smooth continuous DEM raster [43].

The future projection data of SLR was used over the DEM data to detect future hazard areas. Alexandria local sea level projection tool available at (Climateanalytics.org) which rely on sea-level projections provided by [45] and Antarctic ice-sheet contributions from [46]. This useful tool is used to predict how much will sea level rise by providing sea level data for each climatic change future scenarios. The sea level data for years 2030, 2050 and 2100 was obtained using the highest scenario pathway data (RCP8.5) as the current emissions are almost tracking around it. The SLR data were processed spatially alongside the DEM data using a GIS software in order to detect SLR hazardous areas for years 2030, 2050 and 2100, a summary of the used datasets is presented in **Table 1**.

Table 1 Summary of used data sources.

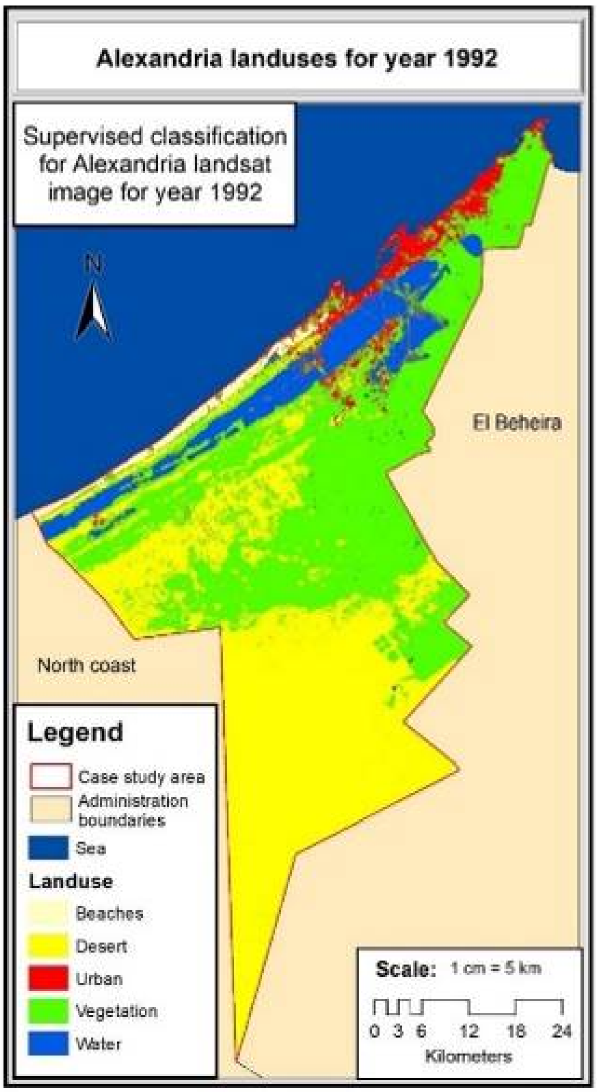
Category	Details		Source
Landsat	year 1992	Landsat 4-5 TM, Date Acquired: 3 October	United States Geological Survey, Downloaded from earth explorer tool at https://earthexplorer.usgs.gov/
	year 2001	7 ETM+ , Date Acquired: 25 September	
	year 2010	7 ETM+ , Date Acquired: 4 October	
	year 2019	8 OLI/TIRS, Date Acquired: 19 September	
DEM	SRTM, 30m resolution		
SLR history	sea level anomaly dataset from NASA/JBL		http://sealevel.nasa.gov/data-analysis-tool
SLR projection	local sea level projection tool by Climateanalytics.org		http://localslr.climateanalytics.org/

3 Results

The result section shows the spatially analyzed SLR data for Alexandria governorate, thus, for an enhanced results presentation, this section is divided into two main parts following the methodology. The first part includes the past SLR hazard analysis and a scope on the historical impact of SLR on the coastal beaches areas, the second part shows the predicted future scenarios results including the spatial data of SLR impact over different land-uses.

3.1 Past SLR hazard results

Land-uses in Alexandria have changed rapidly during the past 27 years as supervised classified land cover maps clarify in **Fig. 5** and **Fig. 6**. A massive decrease in beaches areas can be observed from **Table 2**, beaches lost 88.2% of its total area in 27 years starting from 1992 to 2019, while water areas including lakes, fisheries and coastal eruptions had increased by 8.6% over the study period. **Fig. 7** shows that beaches seem to vanish over the study period, replaced by water and urban areas, on the other hand, urban areas increased significantly by 438.7% for the same period.



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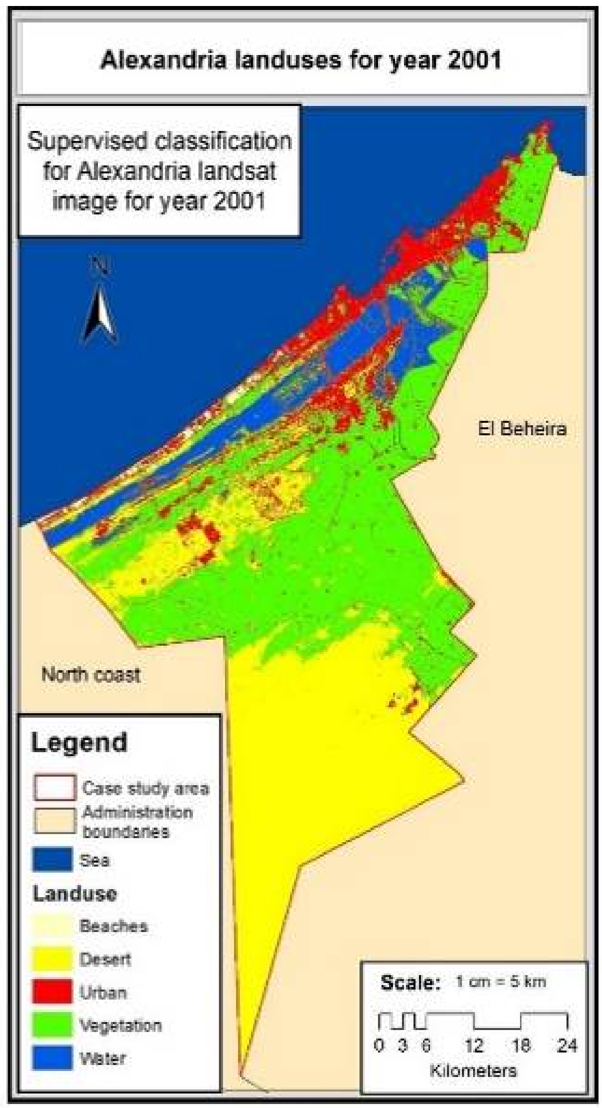

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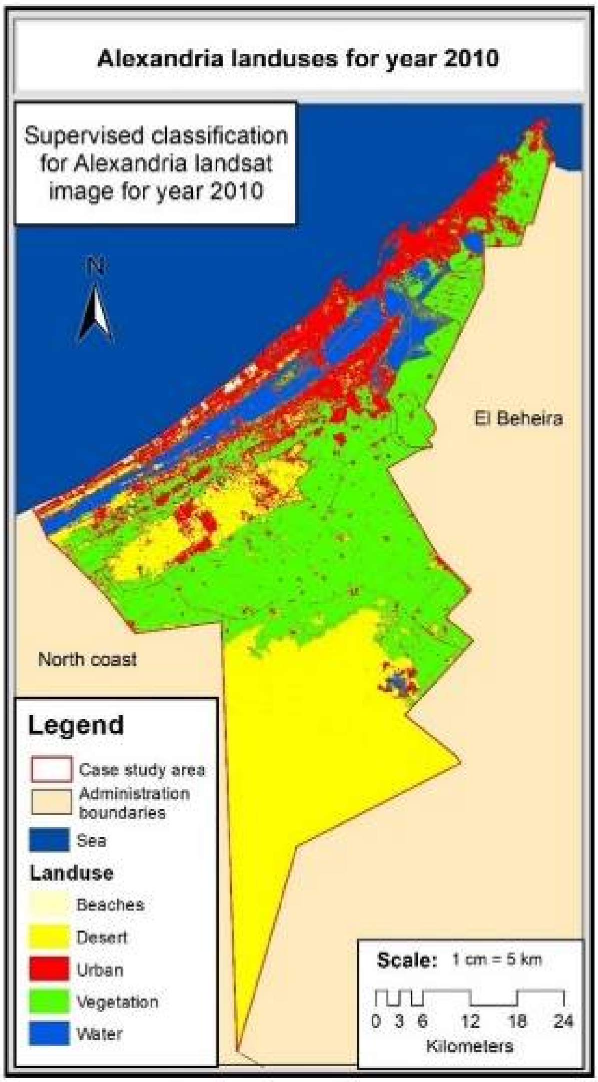
Fig. 5 Alexandria land-uses for years: a) 1992, b) 2001.



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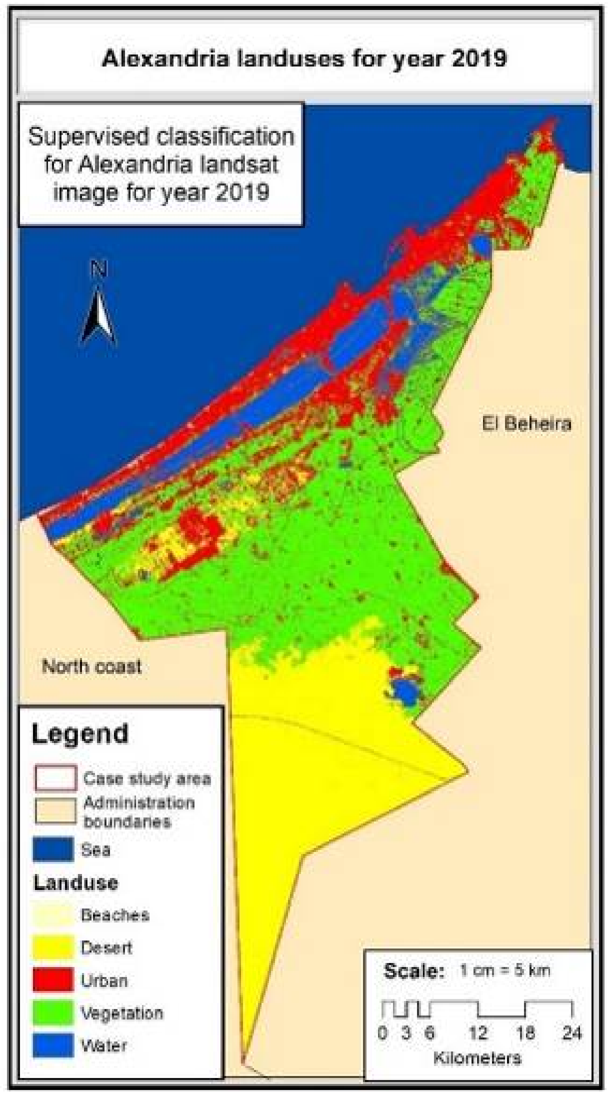


b

Fig. 6 Alexandria land-uses for years: a) 2010, b) 2019.

Table 2 Alexandria land-uses conversion for period 1992 – 2019.

	Land-use	Beaches	Vegetation	Water	Desert	Urban
1992	**Area (acres)**	9606	253345	49475	272305	22949
2001	**Area (acres)**	4013	247807	46411	231869	77580
	Relative percentage	-58.2%	-2.2%	-6.2%	-14.8%	238.0%
2010	**Area (acres)**	3088	237898	43987	214627	108081
	Relative percentage	-23.1%	-4.0%	-5.2%	-7.4%	39.3%
2019	**Area (acres)**	1129	249144	53738	180033	123637
	Relative percentage	-63.4%	4.7%	22.2%	-16.1%	14.4%
Overall	**Total change (acres)**	**-8477**	**-4202**	**4262**	**-92272**	**100688**
	Total percentage	**-88.2%**	**-1.7%**	**8.6%**	**-33.9%**	**438.7%**

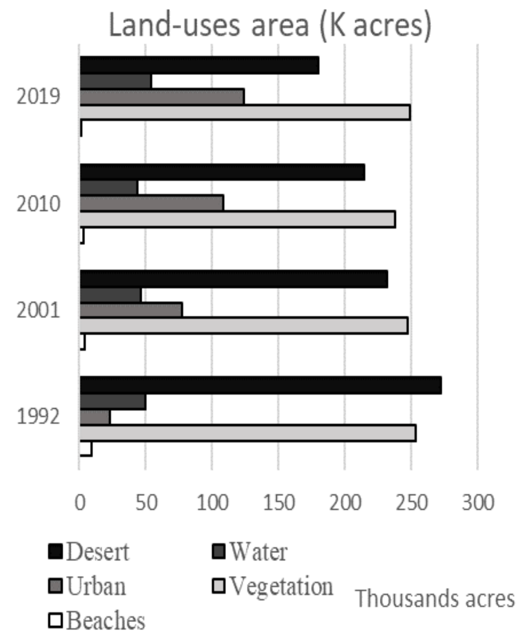


Fig. 7 Land-uses conversion ratio.

A classification accuracy assessment was applied on 2019 land cover map to validate the used supervised classification technique. A total of 250 random test points covering all classified classes were used to verify the classification accuracy, as presented in **Table 3**, the accuracy of classes classification ranged from 80% for beaches to 100% for water bodies with a total accuracy of 95.2%, and with Kappa coefficient of 0.935 which gives an indication of an almost perfect reliability of classification accuracy [47].

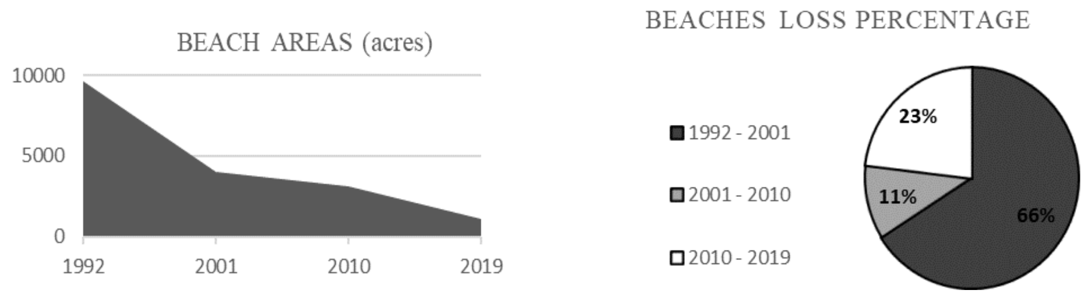
Only 11.8% of Alexandria beaches area in 1992 still exist by year 2019, while the other 88.2% of beaches area in 1992 was lost or converted to other land-uses as shown in **Table 4**, The beaches total area decreased dramatically for the whole study period, but the major decrease is shown to be in the period 1992 to 2001 with 66% of the total loss as **Fig. 8** illustrate. Focusing on SLR impact on beaches, Alexandria lost a total of 196.5 acres of beaches that was flooded by the sea for the study period with a total capacity loss of around 165,000 visitors as indicated in **Table 5**. The major area loss was during the period 1992 to 2001 with 90% of the total loss and an estimation of 149,000 capacity loss as shown in **Fig. 9**.

Table 3 Classification pixels validation results, rows show the classified pixels using the GIS software, while columns indicate the exact ground truth defined by the researcher for the same pixels.

	Water		Urban		Vegetation		Beaches		Desert		Total
Water	30	100%	0	0%	0	0%	0	0%	0	0%	**30**
Urban	0	0%	65	93%	5	7%	0	0%	0	0%	**70**
Vegetation	0	0%	2	3%	68	97%	0	0%	0	0%	**70**
Beaches	0	0%	2	20%	0	0%	8	80%	0	0%	**10**
Desert	0	0%	1	1%	2	3%	0	0%	67	96%	**70**
Ground Truth	**30**		**70**		**75**		**8**		**67**		**250**

Table 4 Beaches conversion data for study period.

Year	Area (acres)	Loss (acres)	Relative percentage	Overall percentage	Loss percentage
1992	9606	0	-	100.0%	0.0%
2001	4013	5592	-58%	41.8%	66.0%
2010	3088	925	-23%	32.1%	76.9%
2019	1129	1959	-63%	11.8%	100.0%



a b

Fig. 8 a) Beaches total area graph for case study. b) Beach loss for different equal periods percentage.

Table 5 Beach areas erupted by water and beaches capacity lost.

Period	Area loss (acres)	Percentage	Capacity loss (visitors)
1992-2001	177.64	90%	149248
2001-2010	5.71	3%	4799
2010-2019	13.18	7%	11072
1992-2019	**196.53**	**100%**	**165119**

a b

Fig. 9 a) Beaches capacity lost due to SLR over study period. b) Beaches area replaced by water.

The impact of SLR on beaches seems to vary spatially over the study area, thus, the analysis was applied spatially upon the two main regions of Alexandria governorate, the east region which include the protected old part of the governorate and the new west region. The beach loss due to SLR in the West of Alexandria is much more significant than the East, as a total of 196.5 acres of all Alexandria beaches were lost, only 9 acres was in the East while 95.3% of the loss happened in the West of Alexandria as presented in **Table 6.**

Table 6 percentage of beaches area Impacted by SLR on each of East and West of Alexandria.

Year	Total area (acres)	East	West
1992 - 2001	177.6	4.8%	95.2%
2001 - 2010	5.7	0.8%	99.2%
2010 - 2019	13.2	3.8%	96.2%
Total	**196.5**	**4.7%**	**95.3%**

3.2 Future hazard scenarios results

Sea level by year 2030 is predicted to rise by 14cm, which is enough to submerge 15% of Alexandria governorate, this percentage only increase to 17% by year 2100 as presented in Fig. 10. The results also shows that the major SLR hazard comes from the Eastern side of Alexandria, specially from Abu Qir city and the Delta region at the East of Alexandria. The most impacted land-use is water areas including lakes and fisheries, followed by agriculture which is predicted to loss about 36,000 acres by 2030. In addition, the major loss for beaches areas is predicted to happen by 2100 as illustrated in Fig. 11, while urban areas will lose about 17% (21,000 acres) of its 2019 total area by 2100 as shown in **Table 7.**

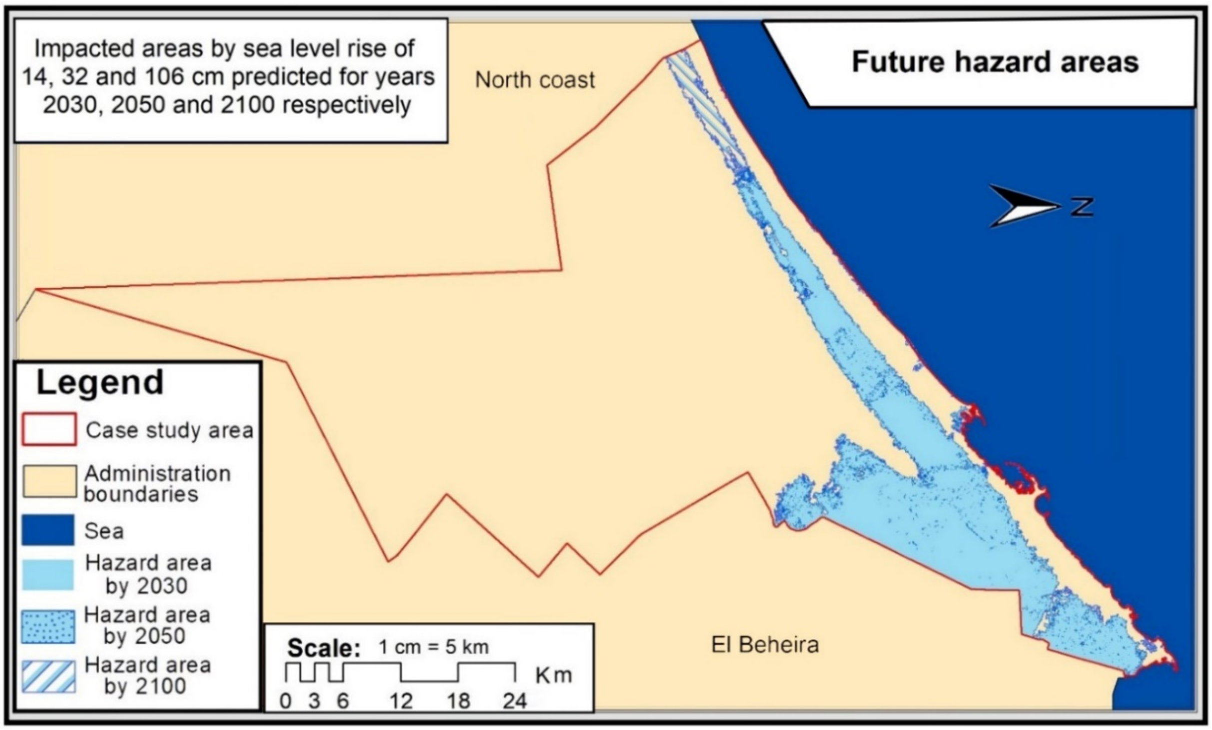


Fig. 10 Areas at hazard of SLR for years 2030, 2050 and 2100.

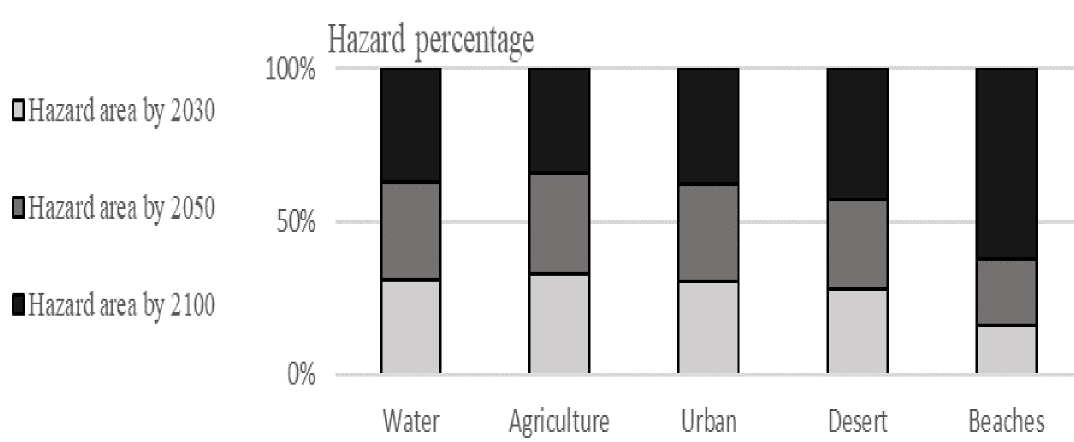


Fig. 11 SLR hazard area percentage for each land-use for years 2030, 2050 and 2100.

Table 7 Impact of sea level rise for years 2030, 2050 and 2100 on the total areas of 2019 land cover map.

Land-use	Total area in 2019 (acres)	Hazard area by 2030 (14 cm sea level rise)		Hazard area by 2050 (32 cm sea level rise)		Hazard area by 2100 (106 cm sea level rise)	
		Hazard area (acres)	Percentage	Hazard area (acres)	Percentage	Hazard area (acres)	Percentage
Agriculture	249267	36567	14.67%	36921	14.81%	38319	15.37%
Beaches	1137	48	4.19%	65	5.75%	183	16.13%
Desert	179901	70	0.04%	75	0.04%	108	0.06%
Urban	123637	16955	13.71%	17746	14.35%	21270	17.20%
Water	53738	37741	70.23%	38219	71.12%	45130	83.98%
Total	**607681**	**91380**	**15%**	**93026**	**15%**	**105010**	**17%**

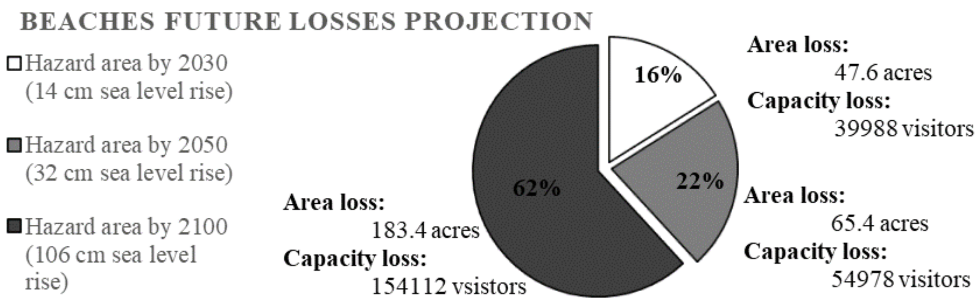


Fig. 12 Beaches projected future area and capacity loss due to SLR.

Results show that SLR will have a significant influence on beaches area, which is predicted to lose 16.13% of its present total area by year 2100 by the mean of SLR. **Fig. 12** shows that by 2050, only 65 acres of Alexandria beaches will be impacted by SLR, while this area will be tripled to 183 acres by 2100, reducing beaches overall capacity by about 154,000 visitors in half a century period.

4 Discussion

SLR had an increasing impact upon different land-uses in Alexandria governorate since 1992, especially the front line of the governorate with many tourism and coastal beaches areas. The results indicate that SLR past impact on Alexandria is much less than the predicted future hazard, one of the reasons for that is the coastal protection work which has done a great job since the beginning of this century, but it will not last efficiently forever and might lead to an enormous economic loss if the sea level increased over the protection work resulting in an area loss of 17% from the total governorate area by year 2100.

The main objective of this paper was to provide a simple framework to detect and predict SLR hazard for developing countries, and this framework was tested on one of the most likely regions in the globe to suffer from a severe SLR threat. The paper is limited to the use of free easy access data, which is proven to be with accepted accuracy and gives a reliable result. It may be possible to get higher accuracy if enhanced paid data sources were used with the same methodology provided in this paper.

4.1 Past SLR hazard analysis

The results of SLR history analysis indicate that SLR had a rising impact on all coastal land-uses, but mostly on coastal beaches areas which seem to vanish due to SLR, moreover, results show that there is a coastal erosion at a horrible rate of 500 m^2 monthly during the period 2010-2019. As consequences, SLR is predicted to have an enormous impact on agriculture, water bodies and urban areas as these classes are dominating the SLR hazard areas, moreover urban area is increasing in the hazard zone with a higher rate than outside it. future research could be required to resolve the gap between urban planning authorities and the integrated Egyptian coastal zone management plans.

The findings also show that the first phase of coastal protection works which started by year 1998 as mentioned in [17] strongly decreased SLR impact for the following decade, especially on the East district of Alexandria, but for the period 2001 to 2019, SLR hazard started to increasingly accelerate again, this could be related to the urgent protections that were planned only as a short time plan to stop SLR hazard, not accounting the future SLR hazard.

4.2 Future hazard study scenarios

SLR hazard increases dramatically as time passes with a predicted significant impact on different coastal land-uses in Alexandria, this will lead to an enormous economic loss. It is shown that only after 1 decade, 15% of Alexandria total area will be at hazard of SLR, and by the end of this century approximately one fifth of the urban areas will be impacted, also beaches are expected to loss 16% of it is capacity, leaving several tourists areas with almost no beaches.

It is urgently needed to reconsider SLR hazard by integrating them in all planning levels and in decision making processes in order to mitigate the predicted impact of SLR. The results showed that the protection works had successfully reduced the impact of SLR during the last decade in the protected area of Alexandria, while the majority of losses occurred in the unprotected area, but these protections started to damage and will not be enough to effectively reduce SLR hazard for the following decade. Integrating SLR hazard mapping in strategic planning process is crucial in order to help reducing SLR future hazard, moreover, analyzing and determining the planning variables controlling urban sprawl is a mandatory step, a considerable adjusting for these variables may lead to directing urban Development away from SLR hazard areas.

This paper paves the path for more future research related to SLR hazard, especially in Alexandria governorate, where more future work is needed to clarify the gap between strategic plans and the strategic Egyptian coastal zone management plans, which led to a high rate of urbanization in the low laying areas predicted to be impacted in the near future by SLR hazard. Also, much more research is required to detect the driving forces of urban areas over coastal zones and to develop a reliable methodology to control this urban sprawl by altering the driving forces. Moreover, the hazard maps presented in this paper open the way for more precise SLR protection assessment research that can serve as a useful guide for decision makers and planners.

5 Conclusion

SLR is a tough challenge facing most coastal countries around the world, especially developing countries. This paper provides a suitable, easy and free application for both, monitoring of SLR hazard impact on coastal land uses and for studying the future SLR hazard scenarios, using best available free cost data with suitable resolution for the paper purposes. The processes of this application are easy to be followed and are better suited to developing countries.

SLR had a huge impact on Alexandria governorate during the study period, especially on beaches area which seems to vanish. The coastal protection efforts in the east region of the governorate postponed SLR hazard but didn't stop it. It's predicted that 17% of Alexandria governorate will be drowned by the end of the century if no effective measures are taken, SLR will have a significant impact on all land uses specially beaches and tourist places, which play a vital role in a leading tourism governorate like Alexandria and will undoubtedly have a direct influence on its economics.

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