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# Neighborhoods at Risk of Drowning in Alexandria in Light of Climate Change, Coastal Threat Sources and Means of Protection

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## ABSTRACT

Recently, statements were issued by some western officials and press articles stating that the city of Alexandria is facing a new existential threat resulting from climate change, and that it will be drowned due to climate change. In this article, I would like to clarify that the risks arising from sea level rise do not threaten the ancient city of Alexandria, which extends from Abu Qir in the northeast to Burg Al Arab in the southwest, as it is built at altitudes of 5meters up to 25 meters above sea level. Rather, the threat is limited to the urban expansions that were added to the south of the city at the expense of Lake Mariout on the one hand, and at the expense of the low agricultural lands south of the suburbs of Abu Qir, Maamoura, Montazah and Sidi Bishr al-Qibli on the other hand. The main sources of the coastal threat to these areas are the Abu Qir Bay in the north and the Max Bay in the west. These expansions can be protected from the invasion of the sea if the political will and economic capabilities are available, by making submerged armored concrete walls with the specifications mentioned in this article along the Abu Qir Bay and on the areas of the current gaps in the Max Bay.

It should also be noted that the original highlands of Alexandria are interspersed with some few depressions that are not directly connected to surface water sources, but are threatened by total or partial inundation in the event of a rise in the subsurface water level as a sequential effect of sea level rise. The most important of these are the Smouha, Al-Seyouf and Sporting depressions with a total area of about 2.5 km² as well as some depressions below sea level at the center of Abu Qir suburb with a total area of 1.0 km².

***KEYWORDS****: Alexandria, Climate change, Nile Delta, Abu Qir Bay, Max Bay, Lake Mariout*

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## 1. INTRODUCTION

### 1.1. The reality of climate change in the world

The increase in the temperature of the Earth's climate system is a fact that cannot be denied. It is derived from data, statistics and scientific observations published by the Intergovernmental Panel on Climate Change in its six reports (IPCC, 1990- IPCC, 2021), which confirm the increase in the global average temperature of the air and sea and ocean waters, the increase in the rates of ice and snow melting, and the rise in the global average sea level during the twentieth century. Continuous studies since the issuance of the third report of the intergovernmental body (IPCC, 2001) until the date of the issuance of the fourth report (IPCC, 2007), confirmed that the annual global average temperature during the twentieth century (1906-2005) witnessed a rise of 0.74 degrees Celsius. The increase in climate temperature has spread throughout the globe - but the northern hemisphere has been allocated a greater share of this rise, as the annual average temperature in the last fifty years has increased more than any previous fifty years about 500 years ago, and also more than it was during 1300 years preceding the twentieth century. The Arctic regions have also warmed nearly twice the global average over the last 100 years. The continents are also getting hotter than the oceans and seas. Scientific observations have also proven that the oceans have absorbed about 80% of the heat that was added to the climate system, and that the ocean temperature has increased to a depth of

3000 meters. And that the radioactive force on the Earth's surface (watts per square meter) arising from the totality of human activity is 14 times greater than that arising from solar energy since the year 1750.

Also, the sea and ocean levels have risen since 1961 at an average rate of 1.8 mm/year. Since 1991, this rate has increased to 3.1 mm/year. And the reason for this increase is the thermal expansion of the waters of the oceans and seas, in addition to the global warming caused by the melting of some snow and ice caps on the continents. As for the ice flats located in the polar regions, the results of graphical analyzes of the information received by satellites since 1978 showed that the ice flats in the Arctic have shrunk at a rate of 0.27% annually, and that this rate has increased in the summer seasons to 0.74% annually, and that the lost quantities of these flats in Greenland and Antarctica have contributed to the rise in sea level during the period from 1993 to 2003.

Scientists and experts also agreed in the reports of the Intergovernmental Panel on Climate Change that there is strong evidence that the current policies adopted to reduce carbon emissions will not be able to reduce these emissions during the next dozens of years. The emission of carbon dioxide will increase in proportion to the air by an amount ranging between 25-90% during the period from 2000 to 2030 and thereafter. And that the continuation of these emissions threatens to further global warming in the twenty-first century, at rates greater than what it was in the twentieth century. The Intergovernmental Panel stresses that by the middle of the twenty-first century, river flows will decrease, and the need for fresh water resources will increase around the middle and tropical latitudes, and many semi-arid regions around the Mediterranean basin, western United States, southern Africa, and northeastern Brazil will suffer from the decline in water sources as a result of these climate changes.

The most important thing that came in the fourth synthesis report of the Intergovernmental Panel on Climate Change (IPCC, 2007) was the warning against the continuation of global warming and the accompanying rise in sea and ocean levels for a few centuries, even assuming humanity's success in stabilizing the level of carbon dioxide emissions in the air. This is due to the fact that the Earth's climate system needs centuries to stabilize. Also, the different policies related to reducing the amount of emissions, which in turn differ according to the different economic conditions, the environmental programs implemented by countries, the extent to which these countries are able to replace fossil energy sources with other sources, the rates of development that depend on the rates of population increase, and the extent of individuals' willingness to change the lifestyle and behavior individual, all of this will make it very difficult, if not impossible, to reduce emissions over the next several decades.

With the difference of these elements and the absence of additional policies to reduce emissions, it is expected that the amount of emissions will increase during the period from 2000 to 2030 at least, as the proportion of carbon dioxide in the air increases by rates ranging between 25% and 90%, which threatens further global warming at rates greater than It was in the twentieth century. According to the scenarios based on the variation in the percentage of greenhouse gases in the air, the temperature will increase in the last ten years of the twenty-first century (2090-2099) with an average range between 1.8º C in the minimum emissions (which is the most optimistic scenario), and 4º C in the minimum emissions (which is the most optimistic scenario). percentage in the maximum emissions (which is the most pessimistic scenario) than at the end of the twentieth century (1980-1999). Thermal expansion of sea water at the end of the twenty-first century will cause the sea level to rise by 18-38 cm at a minimum, and 26-58 cm at a maximum from what it was during the period from 1980-1999.

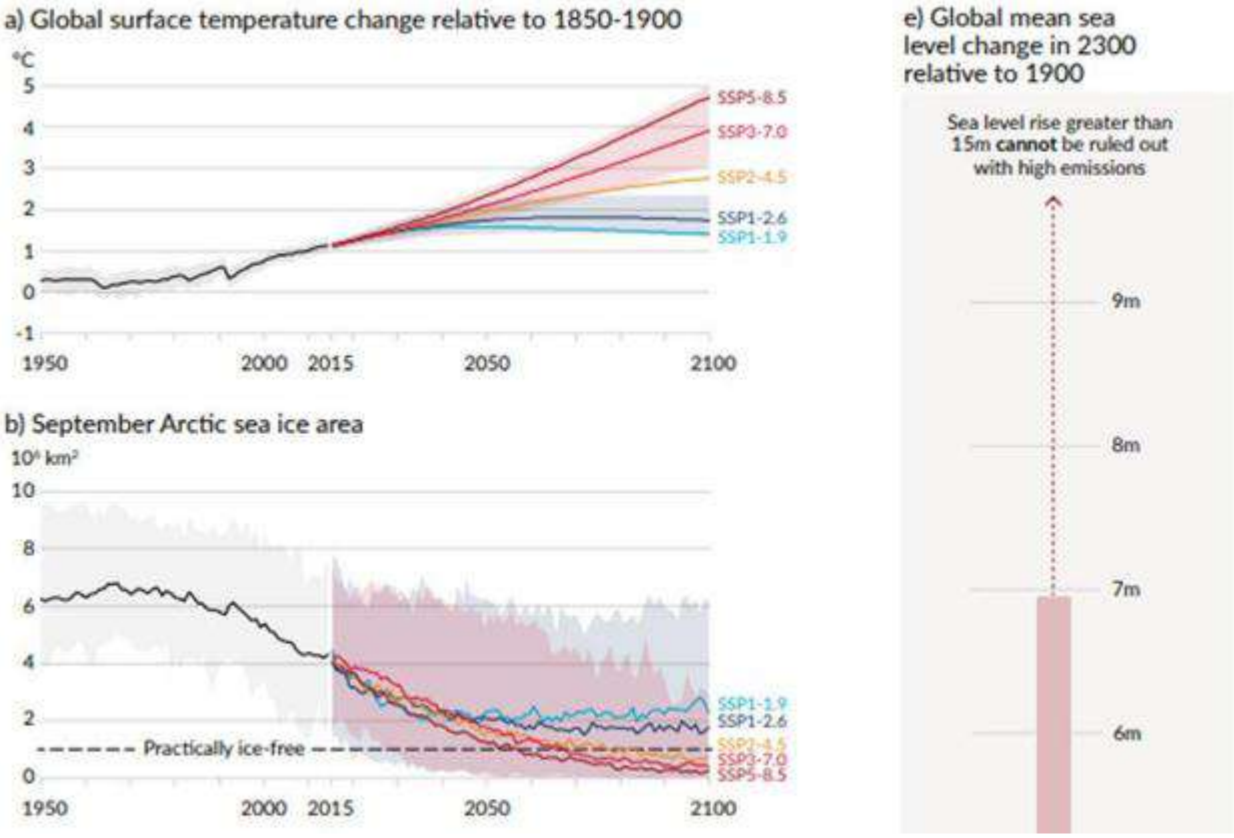
The opinions of scientists and experts who prepared the third report (IPCC, 2001) of the Intergovernmental Panel assumed that the increase in the global sea level comes mainly from the thermal expansion of sea water as a result of the increase in global warming, while the melting of land ice contributes to a small extent to the increase of this level. However, in the fourth and fifth reports (IPCC, 2007; IPCC, 2014) scientists and experts reconfirmed that their previous estimates regarding the expected increase in sea level during the twenty-first century do not represent the maximum rise of this level, due to the new information received about the rate of land ice melting in Greenland and Antarctica, and neither Includes updated information on the sliding of the western part of Antarctica towards the sea. Hence, it became necessary to modify the maximum previous estimates about sea level in the twenty-first century.

In the report on the Physical Science Basis, Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2021), it was stated that global warming over the past decades has led to a widespread shrinkage of the cryosphere, with mass loss from ice sheets and glaciers, a decrease in ice cover, and an increase in the temperature of the permafrost. The global sea level (GMSL) is accelerating because of increased rates of ice loss from the ice sheets in Greenland and Antarctica. Mass loss from the Antarctic ice sheet during 2007-2016 also tripled compared to 1997-2006. For Greenland, the mass loss has also doubled over the same period.

The total GMSL height for the period 1902-2015 as stated in the report is 0.16 m (possible range 0.12-0.21 m per year). While the GMSL rise rate for 2006-2015 came in at 3.6 mm per year (3.1-4.1 mm per year), which was unprecedented during the last century, and represented about 2.5 times the rate of 1901-1990 (1.4 mm per year). Total ice cover and glacier contributions during 2006-2015 is the dominant source of sea level rise (1.8 mm yr., with range 1.7 - 1.9 mm yr.), exceeding the effect of thermal expansion of ocean waters (1.4 mm yr. with range 1.1 - 1.7 mm).

The sixth international report on the physical science basis (IPPC, 2021) and the annexes published concurrently with this report on sea level rise and implications for low-lying islands, coasts and communities (e.g. IPCC, 2019) added that the loss of ice mass on a global scale, melting permafrost, decreasing snow cover and sea ice extent in the Arctic is expected to continue in the near term (2031-2050) due to rising surface air temperature (high confidence), with unavoidable consequences including on rivers runoff and local hazards (high confidence). The Greenland and Antarctic ice sheets are expected to lose mass at an increasing rate throughout the 21st century and beyond (high confidence). The rates and magnitude of these cryospheric changes are also expected to increase in the second half of the twenty-first century in the high greenhouse gas emissions scenario (high confidence). The global average sea level rise (GMSL) is also expected to be 0.39 m (0.26 - 0.53 m) for the period 2081-2100 under the lightest scenario of RCP2.6. As for the RCP8.5 scenario, the corresponding GMSL rise is 0.71 m (0.51-0.92 m) for the period 2081-2100 and 0.84 m (0.61-1.10 m) in the year 2100 (Fig. 1). The likely range extends beyond 1 meter in the year 2100 due to the larger expected ice loss from the Antarctic ice sheet.

In a recent study of the European Environment Agency (2021), the study showed that a rise in global mean sea level will increase the frequency of extreme sea level events in most locations. Increases in tropical cyclone winds and precipitation, and increases in extreme waves, along with relative sea level rise, also exacerbate extreme sea level events and coastal hazards. Future changes in the Earth's cryosphere are expected to affect water resources and uses, and changes in floods, avalanches, landslides and land destabilization will increase risks to infrastructure, cultural, tourism and recreational assets. Future shifts in fish distribution and decreases in fish abundance and fishing potential due to climate change are also expected to affect the income, livelihoods and food security of marine resource-dependent communities. It is also expected that the deltas and coastal cities rich in resources will experience moderate to high levels of risk after 2050 under the current adaptation.



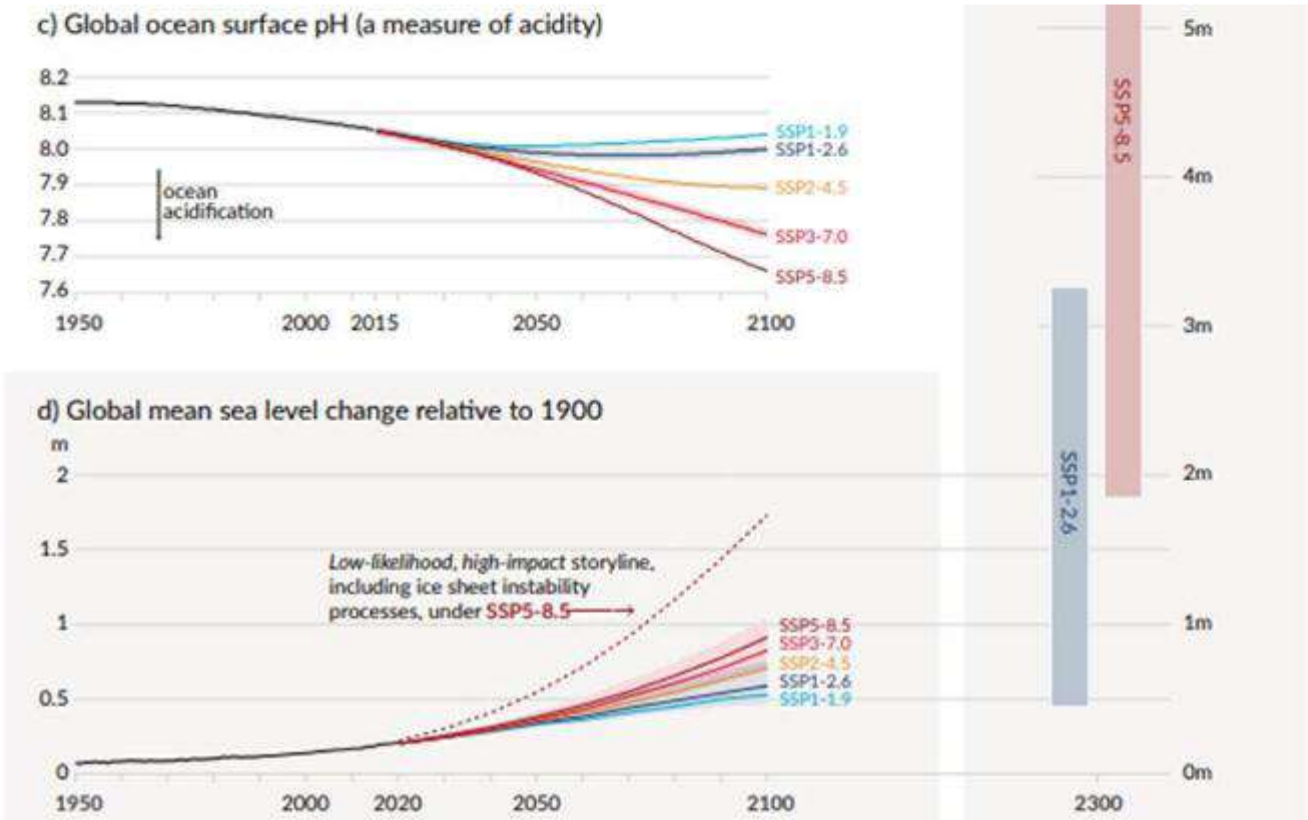



**Fig. 1: Selected indicators of global climate change under the five illustrative scenarios used in the report on the Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. The projections for each of the five scenarios are shown in colour. Shades represent uncertainty ranges. The black curves represent the historical simulations (panels a, b, c) or the observations (panel d). Historical values are included in all graphs to provide context for the projected future changes. Panel e): Global mean sea level change at 2300 in meters relative to 1900. Only SSP1-2.6 and SSP5-8.5 are projected at 2300, as simulations that extend beyond 2100 for the other scenarios are too few for robust results (IPCC, 2021).**

### 1.2. Threats facing the coasts of the Egyptian Delta as a result of climate change

The certain global rise in sea level due to the thermal expansion of the waters of the seas and oceans on the one hand, and the increasing rates of melting of the ground ice sheets in Greenland and Antarctica on the other hand is considered the greatest and certain danger facing the Nile Delta., not only during the twenty-first century, but also during the following centuries for natural and human reasons. The delta is a flat sedimentary land formed by the accumulation of river sediments that it throws into the sea at the estuaries, where the river loses its speed, and the tidal currents weaken from displacing the sediments, so the delta begins to build itself. The construction of the delta increases towards the front of the shore line as the shore line progresses and the load of the river accumulate at its confluence with the sea, and then its width increases towards the coast. The Egyptian delta takes the shape of a fan closer to the triangle, interrupted by the two branches of the Nile, and is characterized by the presence of several lakes on both sides of the two branches of the Nile along the coast, as a result of building natural sand barriers in some shallow bays that characterize the beach, or due to encircling a shallow part of the sea as a result of the continuous growth of delta sediments

The current area of the delta is about 24,500 km², which is equivalent to 2.45 percent of the total area of Egypt. It is characterized by continuous subsidence at its moist northern edges, especially at estuaries, and most of its northern parts do not exceed zero height, i.e. above the current sea level, with a width ranging from 7.7 km to 58.5 km along the coast of the delta (Fig. 2). Therefore, the coasts of the delta are vulnerable to being affected by the slightest rise in sea level, as this rise threatens about 4168 km² of dry and wet coastal lands (equivalent to 16.34% of the total area of the delta). These lands extend along the coast of the delta from the bay of Tina in the east to Alexandria in the west, with a length of 270 km. They include about 1253 km² of wet areas (lakes) and 2915 km² of dry areas along the northern coast of the delta (Ouda, 2010). These lands are separated from the sea by intermittent belts of sand dunes that represent natural barriers; their height ranges between 1.5 and 14 meters above sea level, and their width ranges between 1 and 10 km along the northern arc of the delta that extends between Port Said in the east and Abu Qir in Alexandria in the west. These belts arose from the accumulation of river sediments of sand and silt, which the river carried through its long journey from the headwaters to the estuaries in Damietta and Rashid, and then the air currents redistributed them along the coast.

The current problem is that these belts have been severely weakened, their areas have diminished, and the gaps between them have increased, as a result of their lack of the flow of river sediments from sand and silt since the establishment of the High Dam in 1969 on the one hand, and the continuation of the migration of dunes by winds in a southeast direction on the other hand. The river load is currently low to the point of nothing, and the transfer of river sediments to estuaries has become almost nothing. While the load of the river in 1964, before the closure of the river passage in front of the Aswan High Dam, ranged from 18 to 55 billion cubic meters annually of sediments, including the flood sediments, which amounted to 34 billion cubic meters. The river's load of suspended sediments was estimated at 111 billion kilograms annually, 93-98% of which reached estuaries during the flood seasons (Ouda, 2010).

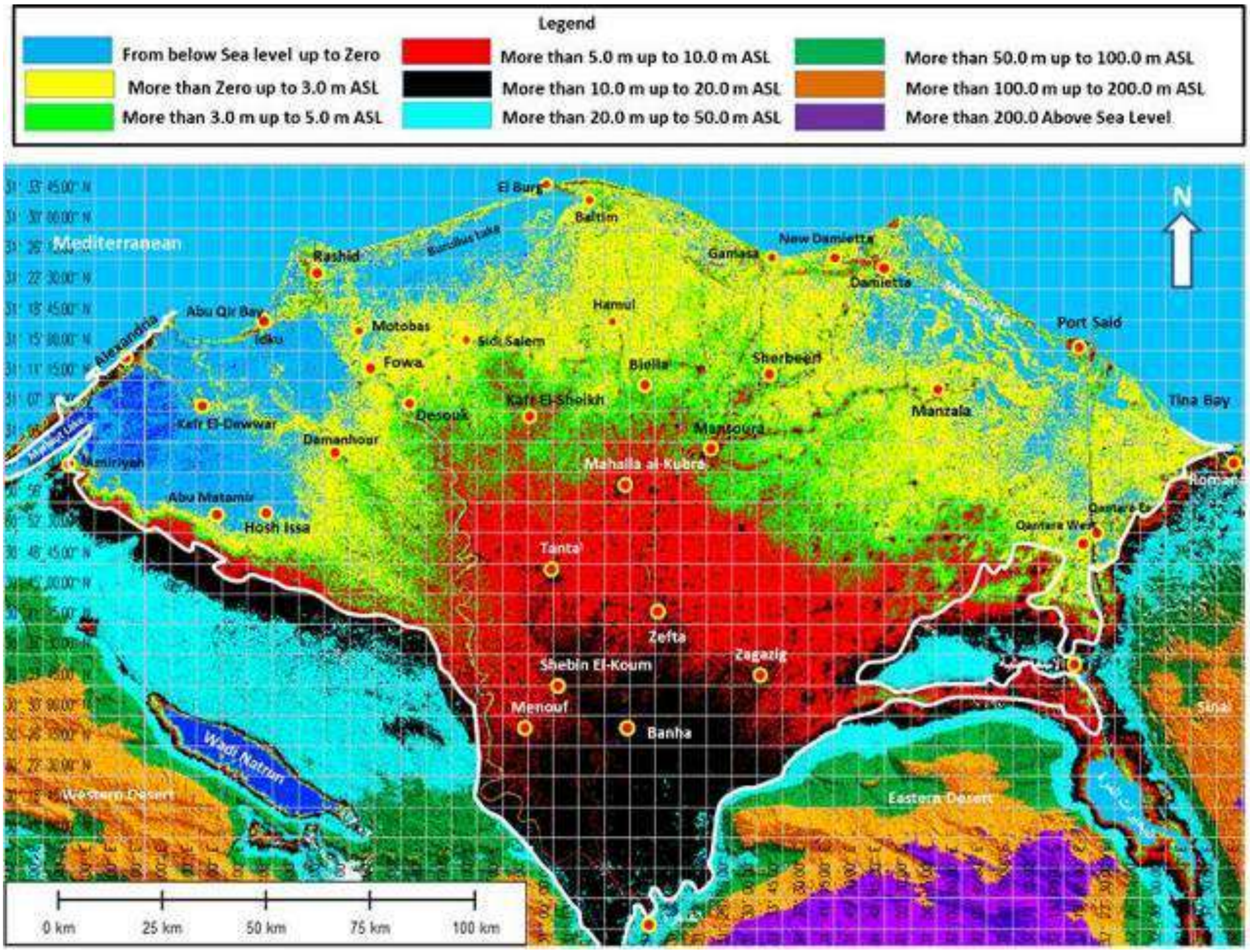



**Fig 2: Detailed topography of the Nile delta as it is the present status. White lines are the natural Eastern and western limits of the Delta. The total area of the Delta is 24450.0 square kilometers, assuming a fan-shape stretching from the Tina plain at east to Alexandria at west, and from the Mediterranean sea at north to west of the Greater Cairo before the branching of the Nile directly. The surface of the delta descends gradually from less than 20 meters above sea level at south to below zero level (below sea level) at north. The delta includes, from north to south, an area of ~ 4400 km² situated topographically below sea level, equivalent to 18%, of the total area of the Delta (space blue), an area of ~7000 km² of surface level ranging from sea level to 3.0 meters above sea level ,equivalent to 28.6% of the total area (yellow areas), an area of ~3600 km² of surface level ranging from more than 3.0 meters to 5.0 meters above sea level equivalent to 14.7% of the total area (light green areas), an area of ~5700 km² of surface level ranging from more than 5.0 meters to 10.0 meters above sea level ,equivalent to 23.3% of the total area (red areas), an area of ~3660 km² surface level ranging from more than 10.0 meters to 20.0 meters above sea level equivalent to 15% of the total area (black areas), then an area of ~90 km² of surface level situated more than 20.0 meters above sea level equivalent to 0.4% of the total area of Delta (After Ouda, 2012 b).**

The interruption of river sediments after the construction of the High Dam contributed to the high rates of erosion of the beaches along the northern arc of the delta. The delta outcrops inside the sea, which are called tongues, were eroded in both Rashid and Damietta. With a simple comparison between the topographical maps of the delta before the construction of the dam, and the maps designed on the basis of the information received by satellites today, it is clear that there is a wide morphological change that has occurred in both Lisan Rashid and Lisan Damietta, and the sandy belts separating the Burullus and Manzala lakes from the sea (Ahmed, 2002; Ouda 2010).

Also, the surface of the delta descends annually at unequal rates relative to its edges as a result of its skewed position. The northeastern side of the delta is lower than the northwestern side, declining at a rate of 5 mm annually, while the northwestern side is declining by 3 mm annually. As for the middle delta, the drop rate does not exceed 4.0 mm annually (Stanley et al. 1992; Stanley et al. 1996). The reason for this decline is the continuous pressure of sediments on the subsurface rocks, as well as due to some ground movements directed by faults. This continuous decline in light of the lack of the river's load increases the degree of salinity of the land, as well as affecting the groundwater, in addition to the consequent exposure of the coastal part of the delta to the invasion of the sea in the event of any local rise in sea level, even if the global sea level does not rise.

## 2. Previous Related Work

Scientific reports issued by United Nations organizations (the Intergovernmental Panel on Climate Change - the World Bank - the United Nations Environment Program), non-governmental scientific organizations, and news agencies have unanimously agreed that the Egyptian Delta is one of the most threatened sites by sea level rise. These risks combine with the side effects left by the construction of the High Dam to make the delta in imminent and certain danger. The situation is dangerous and requires quick treatment, and that any delay means more losses.

In a scientific study of the World Bank (Dasgupta et al., 2007) on about 84 developing countries, with the aim of knowing the effects of sea level increase on these countries - especially the effects on population, land, agricultural activity, populated cities, wet areas, and economic losses in case of increase in sea level from one meter to five meters. In this study, all information received from all scientific forums and institutes, international research centers, space agencies, marine sciences institutes, international centers for earth sciences, international centers for tropical agriculture, international food policy institutes, and international environmental research centers have been used - in addition to GIS analytics.

The study concluded that although the Middle East and North Africa represent the least affected areas by sea level rise in relation to all other developing countries - the impact of this rise on population, agriculture, wetlands, inhabited lands and economic losses will be more harmful in the Middle East and North Africa than in all other developing countries of the world, and that the Arab Republic of Egypt is the developing country most vulnerable to losses in the event of a one meter rise in sea levels. These losses are concentrated in the Nile River delta and including the displacement of about 10% of the total population of the Republic from their lands and cities.

Likewise, the Arab Republic of Egypt is the country most exposed to damage in terms of agricultural land and agricultural activity, where an increase in the water level by one meter (not three or five) affects about 12.5% of the total cultivated area in Egypt. As for the populated areas, the damages reach about 6% of the total areas in the Arab Republic of Egypt. In comparison with the other developing countries of the world under study by the World Bank, the Arab Republic of Egypt comes in the first place as the most affected developing country in terms of agricultural activity, then it also comes with Vietnam as the worst affected country in terms of population.

The World Bank report concludes that the current concentration in the air of greenhouse gases is sufficient to drive global warming completely during this century and the next. The climate will reach a maximum concentration of these gases before the world reaches a single agreement binding on all; and that the continued growth of greenhouse gas emissions with the attendant global warming will increase the sea level from one to three meters during this century. However, in the event of an unexpected sharp increase in the rate of dynamic movement of the western part of the ice mass in Antarctica, or a sharp increase in the rate of melting of ice mass in Greenland, this will contribute to raising the sea level from 3 to 5 meters. The report concluded with its warnings that the damages that will arise as a result of rising sea levels, even one meter, will be severe for many developing countries, especially three countries, namely the Arab Republic of Egypt, Vietnam and the Bahamas.

In local studies, the published statistics of El-Raey et al (1995, 1996), and El-Raey (2005) on the risks facing the Alexandria Governorate in case the sea level rises showed that about 45% of the population, 1.3% of the beaches, 53.9% of the factories, 55% of the Farms, 28% of the tourist places, 38% of the buildings, and 47% of the wetlands whose level does not exceed sea level, and that these areas are protected from drowning either naturally, or due to the presence of solid industrial structures. These areas are expected to increase if sea levels rise by 25 centimeters to 60% of the population, 11% of beaches, 56.1 percent of factories, 31% of tourist points, 44% of residential buildings, 59% of farms, 49% of wetlands. These areas increase when sea level rises to 50 centimeters to become 67% of the population, 47.8% of beaches, 65.9 factories, 49% of tourist points, 56% of residential buildings, 63% of farms, and 58% of wetlands. In the case of increasing the sea level to 100 centimeters, the total activities that will be below sea level are 76% of the population, 64% of beaches, 72% of factories, 62% of tourist points, 67% of residential buildings, 75% of farms, 98% of wetlands (lakes). El-Raey (2005) estimates the areas at risk of drowning in Alexandria if the sea level rises by 50 centimeters by about 31.7 km2, and the number of people forced to emigrate is about 1,512 million, and the number of jobs expected to be lost is about 195443.

However, these statistics did not include a breakdown of the threatened plains and depressions in the various neighborhoods of Alexandria, nor the sources of the threat, or the means of defense and protection. Geographical information and detailed elevation data from NASA's SRTM Radar Topographic Mission Shuttle were also not used in this study. Hence, the studies did not detail the gaps that cut through the shoreline and the sandy or limestone belts separating the sea from the shores of Alexandria, and the studies did not contain detailed topographical maps to clarify the current and future shoreline lines so that appropriate protection plans could be developed.

Frihy (2003) found that the values of relative sea level rise for Alexandria, Burullus and Port Said were 1.6, 1.0 and 2.2 mm/year, respectively. He concluded that not all of the coastal zones of the Nile delta are vulnerable to accelerated sea level rise at the same level. Finally, he categorized the Nile delta-Alexandria coast into 30% vulnerable areas, 55% invulnerable areas and 15% artificially protected coastal stretches

In a study by Daoud and Mohamed (2008) at the Survey Research Institute in Egypt to assess the risks of sea level rise on the Egyptian delta using the SRTM 3 elevation model, the authors concluded that the area of areas prone to drowning in the delta ranges from 292 km2 (about 2% of the delta area). To 2023 km2 (about 17% of the area of the delta) according to the sea level rise by an amount ranging from 25 centimeters to 100 centimeters.

Frihy et al. (2010) pointed out that an overall upward trend of relative sea level at different coastal cities in Egypt (Alexandria, Abu Qir, Rosetta, Burullus, Damietta and Port Said). fluctuates between 1.8 and 4.9 mm/year.

In September 2010, Assiut University published the first atlas on the risks of climate change on the Egyptian coasts and defense policies" (two volumes in Arabic), written by the current author (Ouda, 2010). This atlas includes the first extensive and detailed scientific study of the topography and geomorphology of the Egyptian coast, which is about 3,500 km long, based on the updated information and data received from the NASA Space Radar Topographic Mission Shuttle SRTM 4, with the aim of identifying weaknesses in these coasts, and the quantitative and qualitative size of the certain risks that will face These coasts. The study examined, in particular, the risks threatening the coasts of the delta, the sources of threat, as a result of the global rise in sea levels during this century. It also identified the low land areas, wet and dry, exposed to the risks of direct or indirect marine invasion through the northern lakes, and the areas threatened by partial inundation by subsurface water as a sequential effect of sea level rise; also areas of residential, agricultural and industrial lands threatened by the invasion. The study also included a proposal for traditional and non-traditional defense methods, which should be followed in order to avoid, reduce or adapt to all these risks.

According to the Atlas of Ouda (2010, 2011, 2012a and 2012b),the dry and wet coastal lands of the Egyptian delta that are subject to marine invasion in the event of a global sea level rise of a maximum of one meter during the current century range from 4147 $km^2$ in size to 17% of the total area of the delta as a minimum (which is the threatened coastal lands whose level does not exceed sea level) to 5,920 $km^2$, or 24.2% of the total area of the delta as a maximum (which is the threatened coastal lands whose level does not exceed one meter above sea level) (Fig. 3).

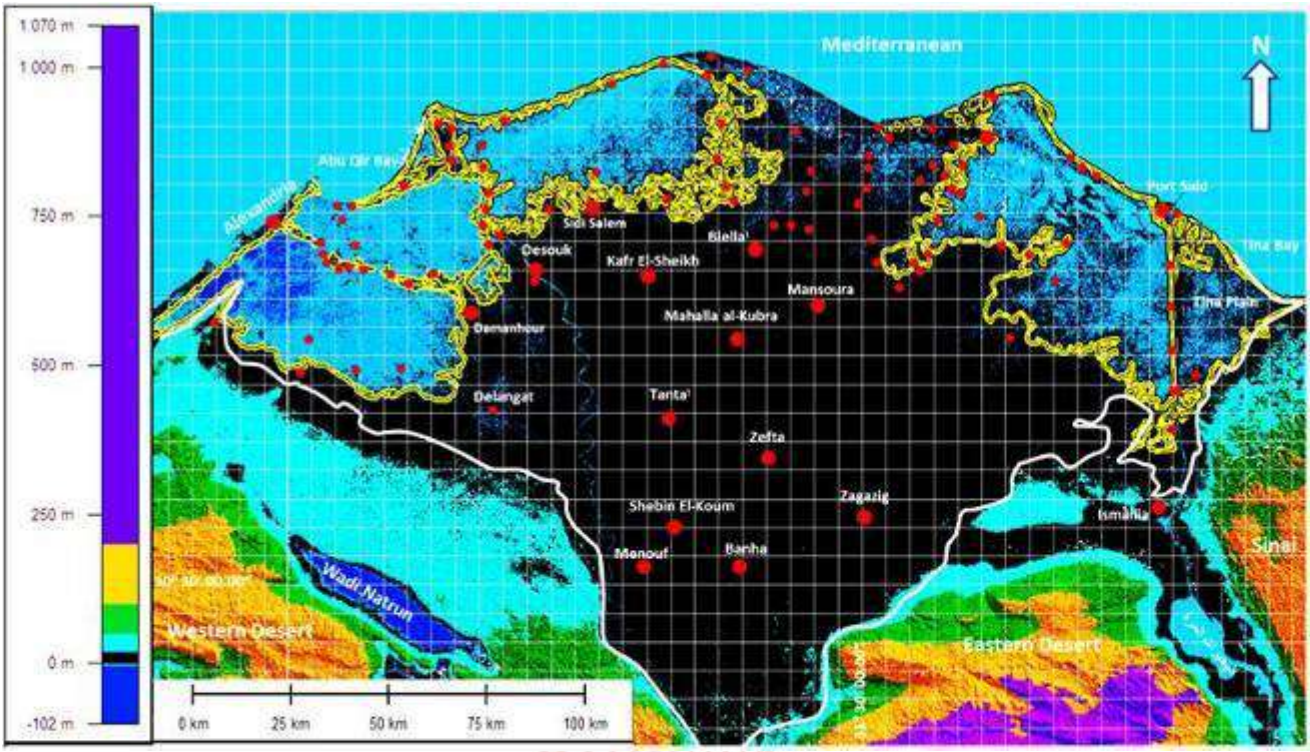



**Fig. 3: Simple Topography of the Nile Delta in case of sea-level rise by a maximum of one meter - showing the limits of areas threatened by direct invasion from the sea, indirect invasion through the northern lakes, or immersion by water leaking from the sea or the Suez Canal through the sandy subsurface soil. White line is the limit of the natural Delta. Yellow lines are the limits of threatened low-lying dry and wet lands (blue areas south of sea shore). The total area of these lands is 5938 square kilometers, representing about 24.28 % of the total area of delta. In addition, ~ 2075 square kilometers made up of cities, villages, roads and sand ridges and dunes situated more than a meter above sea-level are threatened by the siege and isolation as separated islands within the endangered areas. Thus, the total area which becomes at risk as a result of rising sea level by a maximum of one meter in the Nile Delta is equal to~ 8013 square kilometer, representing ~ 32.8 % of the total delta area. The black areas are dry lands with a level ranging from 1 to 20 meters above sea level. The red circles, which are located within the threatened areas are the most important cities and villages which are vulnerable to the dangers of sea level rise (After Ouda, 2012 b).**

The low-lying, dry and wet coastal lands exposed to the dangers of sea level rise include cities, villages, manors, roads, bridges, dunes, sandy hills, and dry lands whose level rises more than a meter above sea level, with a total area of 2113 km². These high areas will be subjected to complete sea blockade and isolation as isolated islands within the invaded areas; In addition to the damage to agricultural and industrial projects and public utilities established on these lands as a result of the naval blockade. Therefore, the total affected areas in the delta as a result of the sea level rise by a maximum of one meter will be 8,033 km², which is equivalent to 33% of the total area of the Egyptian delta (Fig. 3).

## 3. Methods of Study

The current study aims to determine the quantitative and qualitative size of the certain risks that will face some neighborhoods of Alexandria Governorate in the northwestern part of the delta, and the coastal threat sources, as a result of the global rise in sea level during this century (Fig. 4). The traditional defense policies that should be followed to avoid or reduce all these risks have been proposed in order to put the facts related to climate change and its impact before researchers, experts and decision-makers in Egypt to help develop and implement integrated short- and long-term defense plans to protect Alexandria from the dangers of sea level rise.

The current study is based on the consideration that the maximum remainder increase in the global average sea level (GMSL) during the twenty-first century is 100 centimeters, according to information given in the sixth report issued by the IPCC, and the special annexes published concurrently with the report during 2019-2021. As for what was mentioned in the scientific report of the World Bank directed to developing countries (2007) that the maximum sea level rise during this century is 300 centimeters, or what was mentioned in a study of the European Environment Agency (2021) that the rapid disintegration of the ice cover in Antarctica may lead to a sharp rise in the global sea level to 2.3 meters in 2100 - we don't work with it. Such a sharp increase in sea level is not expected by the Intergovernmental Panel to occur in this century, but rather during the next two or three centuries as a long-term effect of climate change - due to the greater ice loss expected from the Antarctic ice sheet. This is if emissions are not controlled so that the concentration of carbon dioxide in the atmosphere reaches 660-790 parts per million.

In this study, modern international mapping programs have been used, the most important of which is the Global Mapper versions 9-13 program to design detailed topographic and contour maps of the Egyptian coasts and to determine the damaged and safe areas in relation to sea level based on the information and digital data for ground elevations received from the Shuttle Radar Topographic Mission (SRTM) of NASA. This shuttle has built a high-resolution World-Wide Elevation Data (3-arc- second Resolution) system for most of the Earth's land surfaces. The fourth improved version of this information released in 2008 by CGIAR-CSI was used. The current human uses of the threatened lands in question have been determined through precise and direct electronic projection of modern satellite images on topographical maps designed with high accuracy. Worldwide high resolution color imagery from DigitalGlobe, and satellite images from BingMap, Google Earth Pro, and Google Maps were used. Also, GIS programs available to determine locations were used, such as The USGS Digital Elevation Model (DEM), USGS digital Raster Graphic (DRG) data, USDA National Agriculture Imagery Program (NAIP), Digital Chart of the World, Egypt. This is in addition to field visits to some threatened neighborhoods in Alexandria and its beaches.

This study includes detailed topographical maps of the threatened sites in Alexandria in their current state, and then placed them in the event of sea level rise; maps of short heights and colors to show the boundaries of the threatened lands in relation to the current and prospective sea level, and the sources of their threat; the satellite images corresponding to these topographic maps, represented by the lines of the new beach in the event of sea level rise, the threatened lands and their areas, and the sources of their threat; the effect of sea level rise on human uses of threatened land spaces, in order to determine the weaknesses in Alexandria, and the size of the gaps that permeate the coastal threat sources in order to determine the appropriate means of protection and the specifications of defense lines.

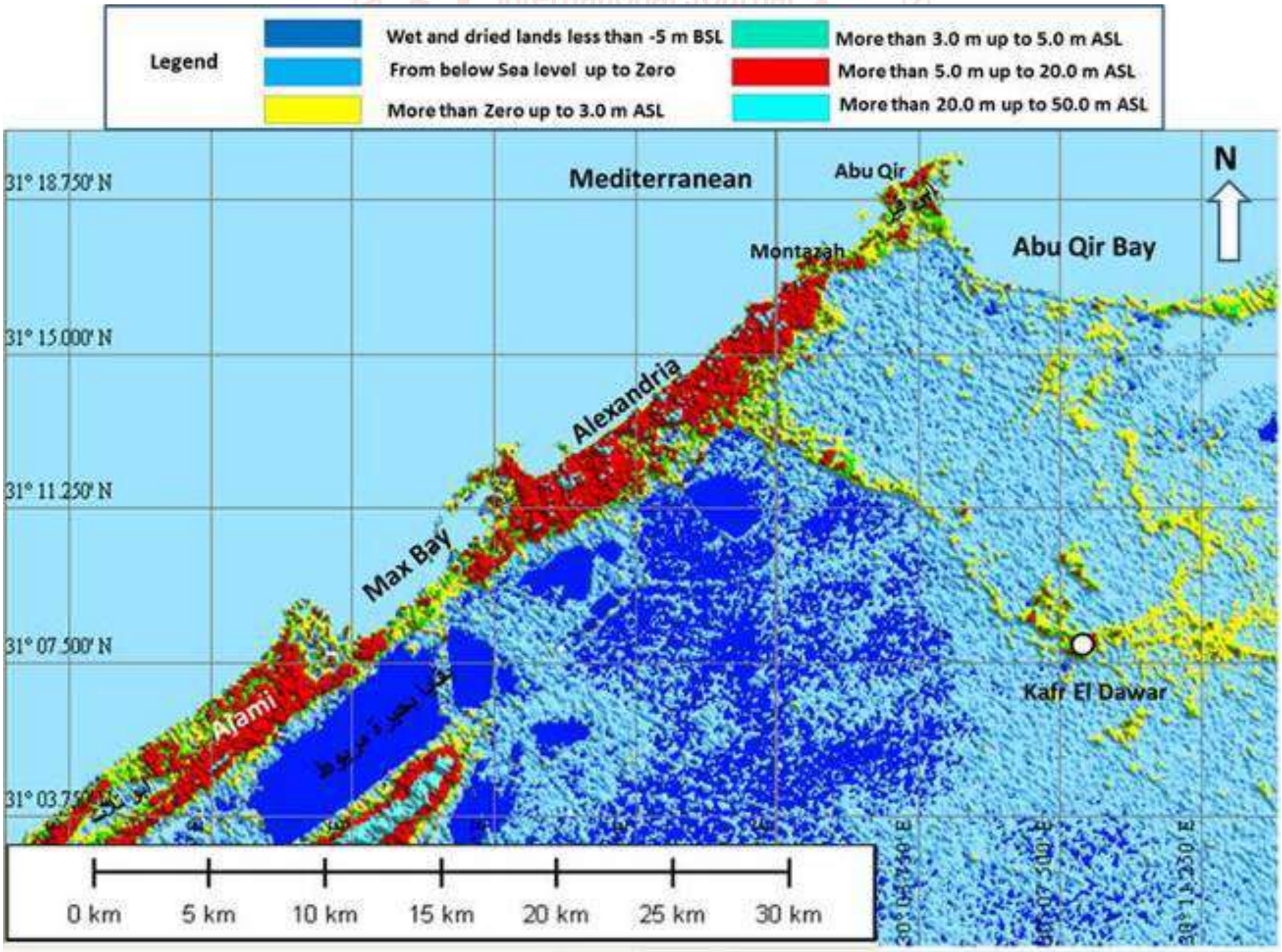



**Fig.4: Topography and geomorphology of the northwest corner of the delta, including the city of Alexandria, from Abu Qir in the north to Abu Talat in the south, and the wet and dry low plains extending south of Alexandria. The dark blue color south of Alexandria represents the flooded and**

**dried lands of Lake Mariout, whose level is less than -5.0 meters below sea level, which indicates that Lake Mariout occupied large areas in the past centuries, not less than 570 square kilometers before it was reduced now to 64 Square kilometers (after Ouda; 2010; 2012b.**

## 4. Results and discussion

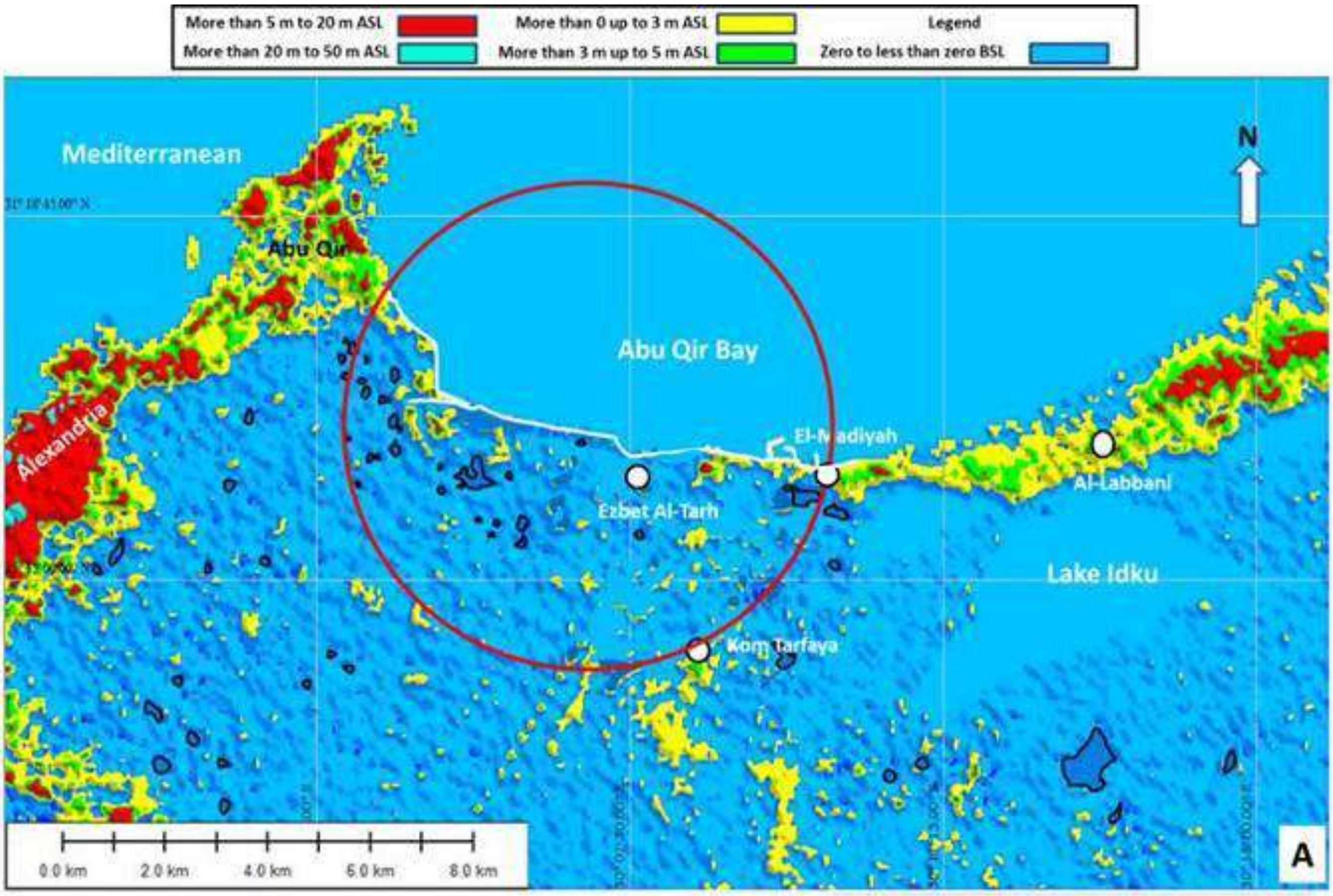
### 4.1. Sources of coastal threat to the city of Alexandria

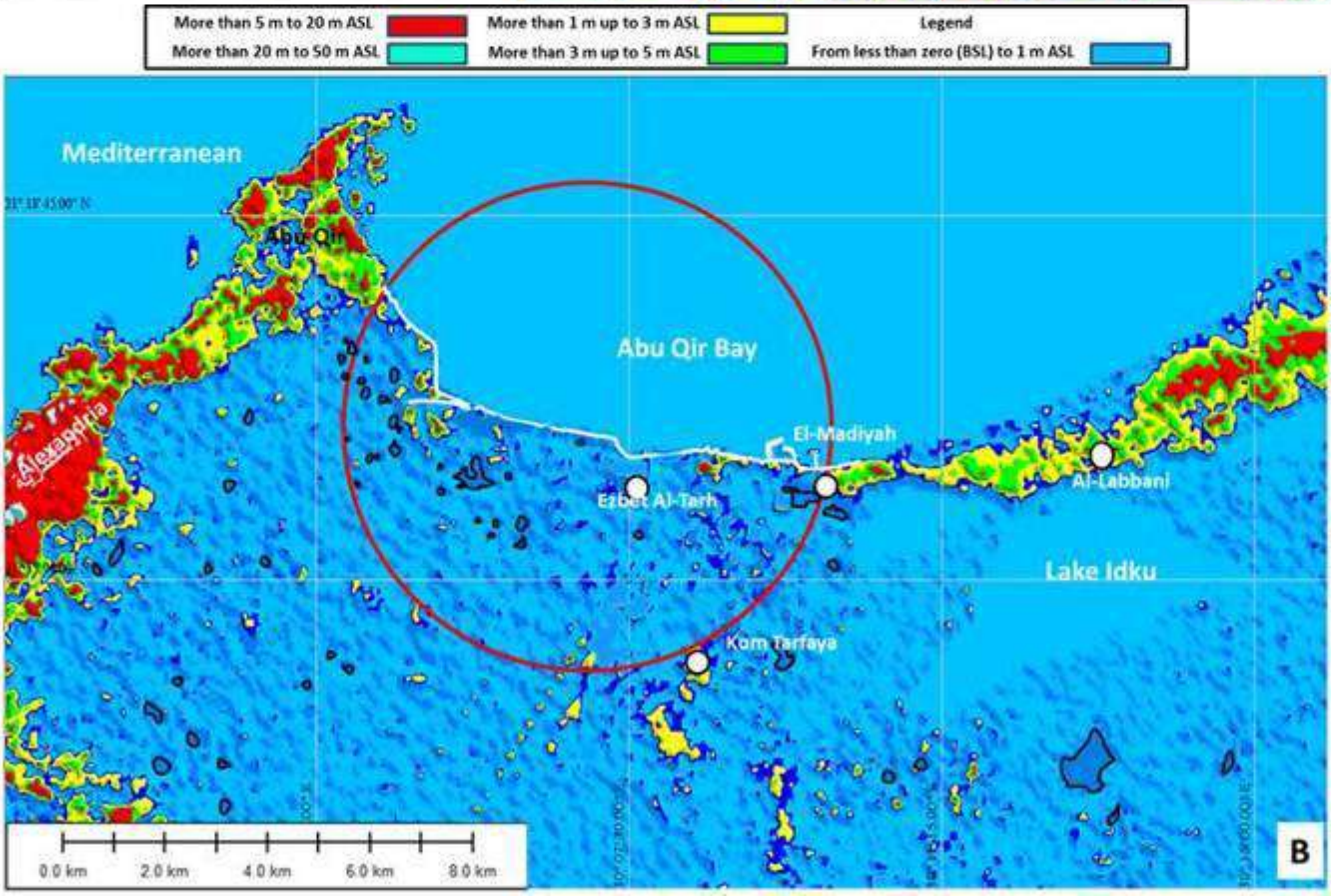
#### 4.1.1. Abu Qir Bay

The Abu Qir Bay was the mouth of one of the tributaries of the river, which disappeared before the mouth of the river receded to what it is now at Rashid. The submerged ruins in the Abu Qir Bay testify to the ancient cities of Heracleion and Canopus, which are now located at a depth of 8 meters at the bottom of the bay, and at distances of 1.6 km and 5.4 km from the coast, dating back to the period between the sixth century BC to the eighth century AD (Stanley et al. 2004) - attests that the southern coast of Abu Qir Bay has undergone a great morphological change during the modern human ages. These cities were buried and submerged under the waters of the bay due to the slippage of the subsurface soil as a result of the continuous subsidence of the edges of the delta near the estuaries due to the continuous pressure of sediments on the subsurface rocks, in addition to the accumulation of silt during the history of the river on the bottoms of the bay near the coast and the weight of these sediments on the bottom surface. All of this caused a decrease in the level of the coastal strip of the bay and the sliding of the installations built on it towards the sea, which is evidenced by the inclination of the submerged ruins in one direction (from the reports of the French mission IEASM 1992-2000 (The European Institute for Underwater Archaeology, Goddio, 2004)

The stories of the submerged cities in the Abu Qir Bay give clear indications about the danger of the construction currently being built on the southern coast of the bay and its exposure to the dangers of slipping upon the invasion of the bay, especially since the causes of the invasion meet in the current century between: a) the continuous decline of the delta at the estuaries, b) the certain increase in the level of The global sea surface due to climatic changes, c) the decrease in the level of the coastal strip that extends along the southern coast of the bay between the suburb of Abu Qir and Maadiyah by 83% from one meter above sea level (Fig. 5A and 5B), and d) the continuation of construction and accumulation along this coast.

The southern coast of Abu Qir Bay is the main source of threat to all the dry and wet low lands extending south of the bay until the Mahmoudiya Canal. The sandy belt that extends along this coast between El Maadiyah in the east and the suburb of Abu Qir in the west, which separates Abu Qir Bay and the plains to its south, has been eroded not only by coastal erosion factors, but also by the dense industrial and population activity that lies directly on the coast and which resulted in the dredging of the vast majority of the coastal sand dunes. In addition to the residential villages, there are two fertilizer factories, a residential fertilizer city, a steam power station, and the Abu Qir Gas Company, in addition to the Naval College and the Air Defense College. All this population, industrial and educational activity is concentrated directly south of the beach line, between the suburb of Abu Qir and the village of Maadiyah, with a length of about 10.5 km. The exploited coastal strip, which extends north of the Abu Qir-Maadiyah road and separates the sea from the low plains to its south, has an area of about 6.1 km$^2$, and it is low in level and there are gaps in it that are lower than sea level (up to -4 meters below sea level) by 66, 4%. The sand dunes are rare and scattered along the shore line and their level does not exceed 2 meters except for four or five spaced points ranging in height from 3.0 meters to 5.0 meters (and a maximum of 17.5 meters) above sea level (Figs.5A and 5B).




**5-A: Detailed topography of the northwestern coastal strip of the delta extending on the southern coast of Abu Qir Bay, between Alexandria in the west and Idku Lake in the east - as it is currently. The white line is the current shoreline of Abu Qir Bay. The blue land areas south of the shore line are low, dry or submerged plains (Idku Lake) whose level is below sea level up to -4.0 meters, except for the areas marked by black lines where the ground level is more than -5.0 meters below sea level. Note that the western part of the southern coast of Abu Qir Bay extending from the village of Maadiya in the east to the suburb of Abu Qir in the west (the red circle) is not separated from the plains to the**

**south by any coherent belts of dunes or hills except for some scattered dunes and sandy hills, whose level does not usually exceed 2.0 meters above sea level, and therefore any rise in sea level will result in the sweeping of these low plains across this part of the bay. Compare this figure with Fig. B, which shows the topographical situation at sea level rise by one meter. 5-B: Detailed topography of the same northwestern coastal strip of the delta that extends on the southern coast of Abu Qir Bay between Alexandria in the west and Idku Lake in the east - if sea level rises by a maximum of a meter. Note that there is no significant difference between what is currently the situation (Picture A) and the state of sea level rise by a maximum of one meter (Picture B), due to the lack of any buffer sand hills separating the Bay and the plains that border it to the south.**

While south of the shore line, sand dunes are almost non-existent due to human removal for construction or agricultural purposes. Therefore, an increase in sea level by a maximum of one meter would cause the sea to invade the majority of the coastal strip extending between El Maadiyah and the suburb of Abu Qir, as about 83% of the area of this coastal strip does not exceed one meter above sea level.

The Muhammad Ali Wall which was built in 1830 in Abu Qir Bay in Alexandria (Figs. 6-10), has exposed cracks, but the Ministry of Irrigation during the past years has tried to treat these cracks and restore the wall. Unfortunately, the wall is not suitable for restoration in order to protect the plains to its south. The wall is nothing but heaps of stones that extend along the southern shore of the bay of Abu Qir (Fig.8). They do not have a submersible under the soil to ensure that sea water does not seep through the subsurface soil in case the sea level rises, and its height is not enough to guarantee its protection from the rise in global sea level. The presence of leaks currently spreading on the coast directly south of the wall confirms the inability of this wall to repel the strong waves if they rise for any reason of the local rise (such as severe storms and tsunami waves) as a result of the gaps and openings between the walls (Figs. 7, 9 and 10). Then, how is the wall's ability to repel water in the case of an increase in the average global sea level by one meter Hence, the erosion and deterioration of this wall, along with its inability to counteract the certain rise in the global sea level, will threaten the sea's invasion of all the southern plains of the of Abu Qir Bay and the northeastern plains of Alexandria extending south of the neighborhoods of Mamoura, Montazah, Mandara and Sidi Bishr al-Qibli, where their level is all below sea level by an amount It usually ranges from -2.0 m to -5.0 m, with a maximum of -7.0 m.

What the Egyptian General Authority for the Protection of Shores is doing to protect the scaffolding in front of the Special Forces and the Naval College in the Mohamed Ali Wall has no effect on protecting the southern plains in the event of a global sea level rise. The wall along its length is subjected to the invasion of high waves in hurricane seasons due to the high water levels during the tide, in a manner that led to the flooding of the area with sea water many times, and the high waves led to collapses in many areas of the wall. The given satellite images (Figs 6, 7, 9 and 10). show the sea water invading the southern coastal strip of Abu Qir Bay despite the presence of Muhammad Ali's wall.


**Fig. 6**


**Fig. 7**


**Fig. 8** **Fig. 9**

**Fig. 6: Satellite image (Google Earth Pro) of the southern coast of Abu Qir Bay extending from the Naval College in the west to the Abu Qir power station in the east, showing the location of the Muhammad Ali's Wall along the shore line. Fig. 7: Satellite image (Google Earth Pro) of that part of the southern coast of Abu Qir Bay, which extends north of Ezbet Doctor, west of Samad City, showing the impact of the current sea invasion of the southern plains. Fig. 8: Picture of Muhammad Ali's wall along the shore line of the southern coast of Abu Qir Bay. Note that the wall is made of piles of stones interspersed with voids, cracks and fractures caused by collapses. Photo taken from the archives of the Ministry of Water Resources and Irrigation. Fig. 9: Satellite image (Google Map) showing showing Abu Qir Bay water seeps into the coastal plains south of the Naval College, despite the presence of the Muhammad Ali's Wall**

Consideration was given to the impact of long-term climate changes, not in the amount of sea level rise, but in the amount of excess water that will rush through the inter-holes spread in the southern sandy belt of the Abu Qir Bay, including the Muhammad Ali Wall. A rise in the level of the Mediterranean Sea by 10 cm means an increase in the amount of water in the sea by 250 billion cubic meters of water. This quantity will overwhelm any gap or a depression, no matter how small it is, along the coast of the Mediterranean Sea, unless the entire southern coast of the Abu Qir Bay, which extends about 10 km between El Maadiyah in the east and the suburb of Abu Qir in the west, is fully secured. It is assumed that this excess amount of water is distributed over all the low lands located on the coast of the Mediterranean Sea. But if we know that the Egyptian delta constitutes about 25% of the lowlands on the coast of the Mediterranean, this means that about 62.5 billion cubic meters of water at least could threaten the coasts of the Nile delta whenever the sea level increases by 10 cm. This is assuming that all countries bordering the coasts of the Mediterranean, other than Egypt, will not take any measures to protect their coasts. The more protection measures these countries take to protect their coasts, the greater the burden on the Egyptian delta to receive more sea water on its coasts.

### 4.1.2. The threatened plains between Abu Qir Bay and Mahmoudiya Canal

The topography of the southern coastal strip of the Abu Qir Bay portends the sea invading this strip, and then the sinking of vast areas of the land plains located to the south of the bay in case the sea level rises by any amount more than the current level, not only because of the sea level rise, but also because the level of these plains drops below the current sea level. The ground level of the plains south of the El Tabia - Rashid road ranges from -6.0 meters below sea level to one meter above sea level, with a depth ranging between 9 and 15 km in the south until Mahmoudiya Canal, and by 86% of the total area of the area extending south of the Abu Qir Bay between the Nile River (Rasheed Branch) in the east, Mahmoudia Canal in the south, and Alexandria in the west (1054 km²). Hence, an increase in sea level by one meter, this would cause the sea to invade about 83% of the area of the exploited southern coastal strip of Abu Qir Bay extending from Maadiyah in the east to the suburb of Abu Qir in the west, and whose level does not exceed one meter above sea level. This will lead to the invasion of about 908 km2 of dry (or dried) and wet lowlands extending south of Abu Qir Bay, between Rashid Branch in the east and Alexandria in the west, until the Mahmoudia Canal in the south (Figs. 11 and 12).

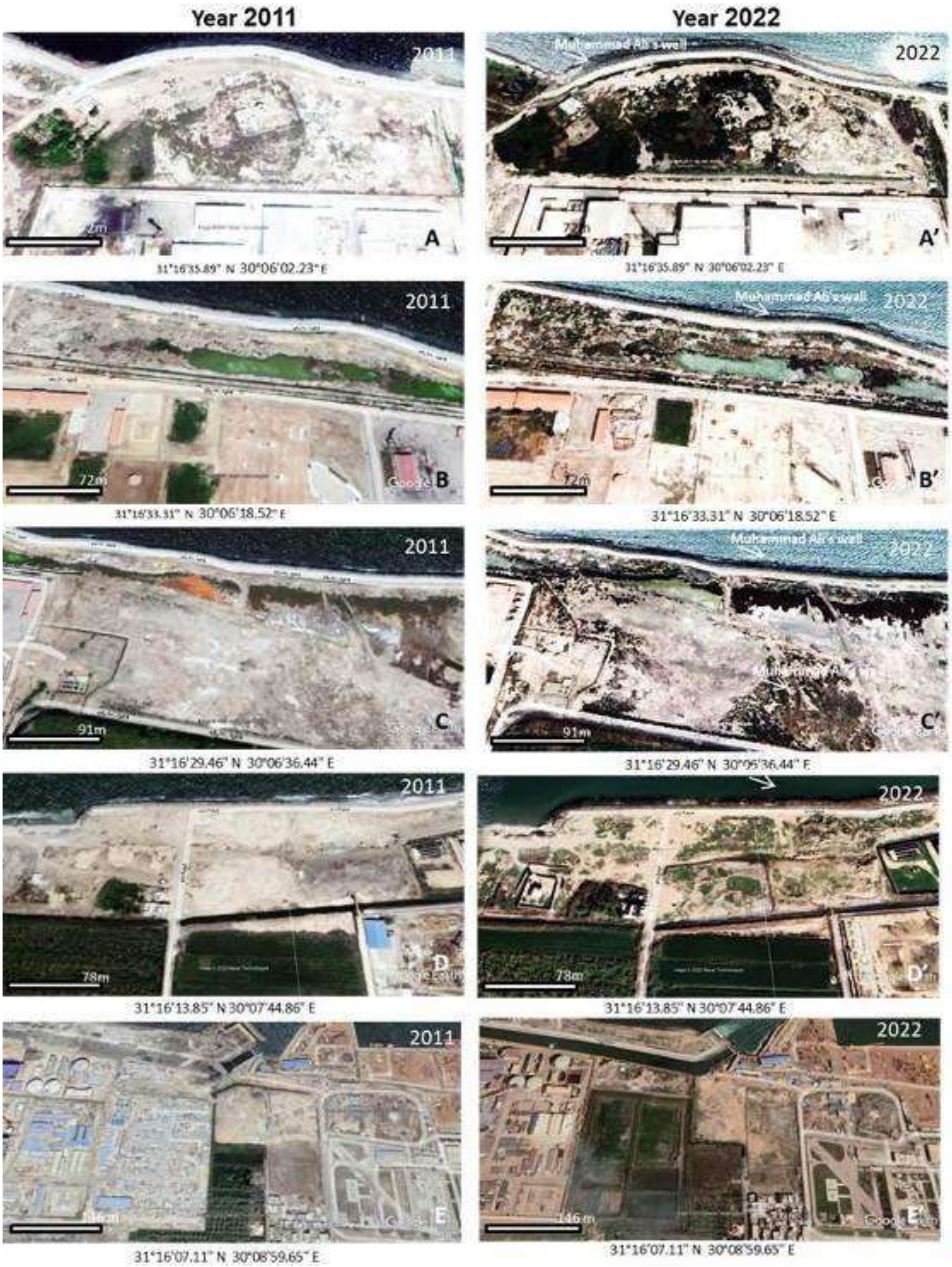



**Fig. 10: Satellite images (Google Earth Pro) showing the continuation of seepage of Abu Qir Bay waters into the southern plains along most of the coast during the time interval from year 2011 to year**

**2022 despite the presence of the Muhammad Ali's Wall: A-A' north Samad City, B-B' north Air Defense College, C-C' coastal plain between the Air Defense College and Ezbet El Tarh, D-D' coastal plain between Ezbet El Tarh and West Delta Power Station, E-E' coastal plain between the West Delta Power Station and the Abu Qir Petroleum site. Geographical north is oriented to the north of the image**

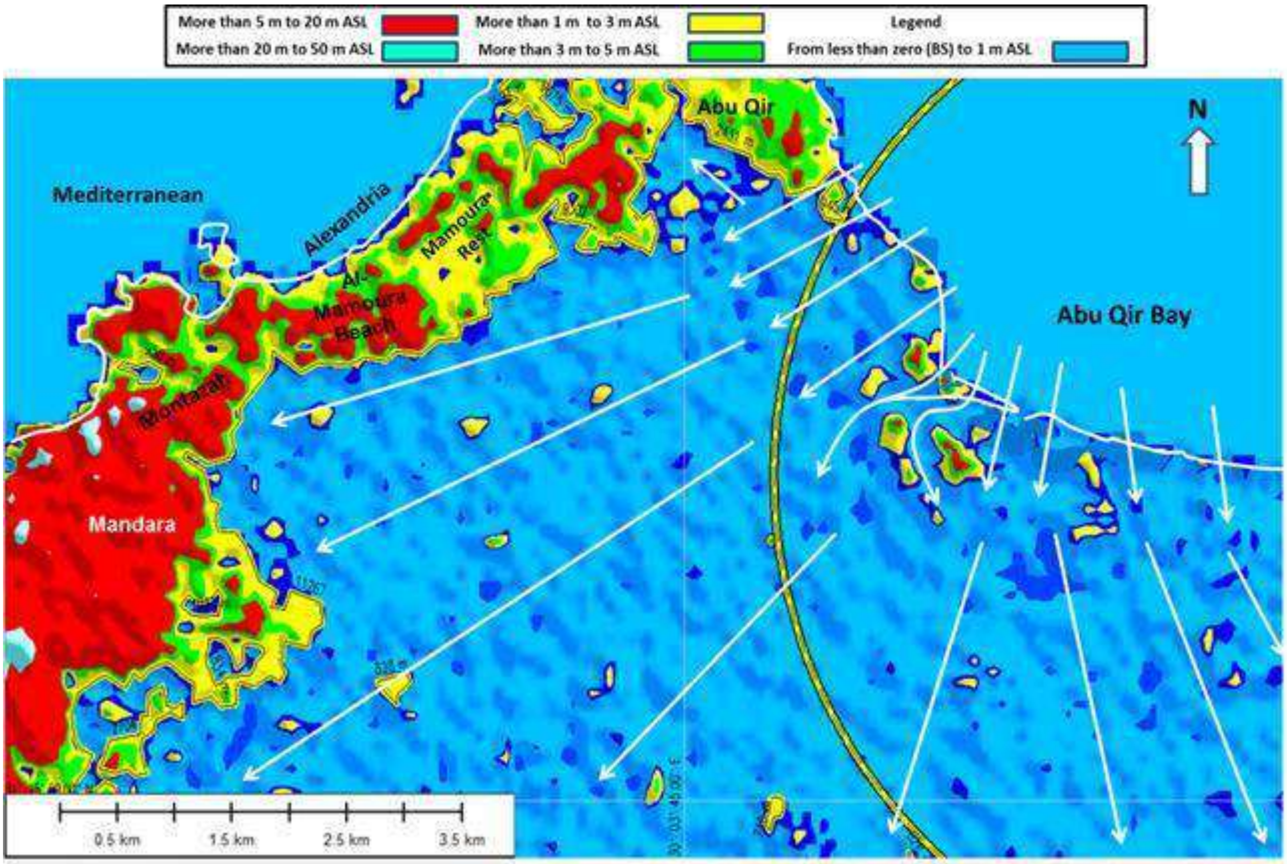



**Fig. 11: Detailed topography of the northwestern corner of the delta and the northeastern corner of Alexandria - when the sea level rose by a maximum of one meter, explaining the relationship of the gap along the southern coast of Abu Qir Bay (the yellow circle) to the low plains south of Alexandria (Blue areas). The white lines are the current lines for the beaches of Alexandria and the bay of Abu Qir. The white arrows show the path of the sea water as it swept through the gaps that cut through the southern coast of Abu Qir Bay, and from there to all the low lands (from -5 m below sea level to one meter above sea level) that extend south of the Bay to Mahmudiya Canal in the south between Damanhour in the east and Alexandria in the west - unless due protection measures are taken.**

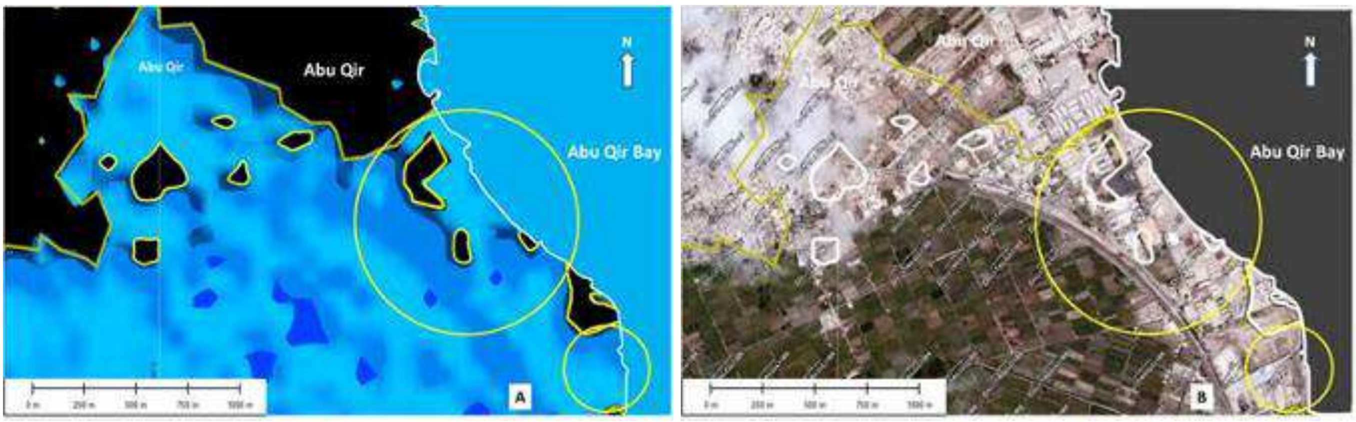



**Fig. 12 A: A brief topography of the western coastal strip of Abu Qir Bay, south of the suburb of Abu Qir, when sea level rises by a maximum of one meter. The white line is the current shore line. The yellow lines separate the high lands more than a meter above sea level (black areas) from the lowlands whose level ranges from one meter above sea level to -6.5 meters below sea level (blue areas of different shades). Yellow circles indicate the locations of the holes to be sweep through. Fig.12 B: Satellite image of the Digital Globe program for the same western coastal strip of Abu Qir Bay, south of Abu Qir, given in Fig. 12 illustrating the population and industrial uses of the coastal strip.**

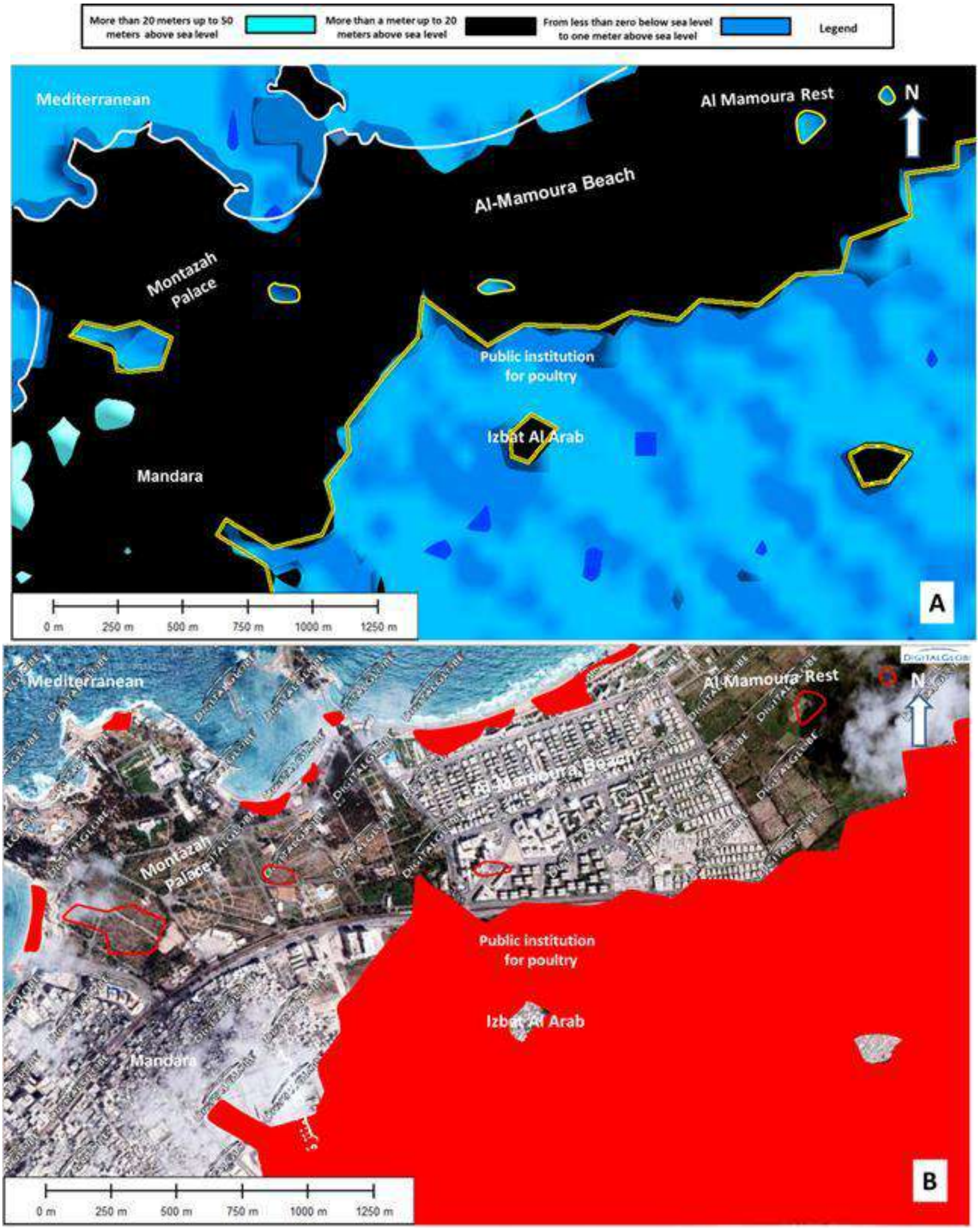



**Fig. 13 A: A brief topography of the coastal strip extending between Abu Qir in the east and Mandara in the west along the coast of Alexandria - explaining the effect of sea level rise of a maximum of one meter, and then the sweeping of the waters of Abu Qir Bay to the low plains extending to the south along the city of Alexandria from Abu Qir in the east to Montazah in the west. The white line is the current shore line. The yellow line is the line separating the high lands more than a meter above sea level (black areas), and the low-lying plains whose level is less than one meter above sea level down to -5.0 meters below sea level (blue areas). Note that parts of the beach are threatened by a direct invasion from the sea to the north, while the southern plains are threatened by a direct total invasion from the Abu Qir Bay to the east. Fig. 13 B: The satellite image of the Digital Globe program for the same coastal strip of Fig. 13 A showing the effect of sea level rise with a maximum of one meter and then the invasion of the low plains extending south of Alexandria from Abu Qir in the east to El Montazah in the west (red areas). Note that the northern shores are threatened by a direct invasion from the sea in the north. The areas marked by red lines are internal depressions whose level is lower than sea level, interspersing the heights of Qasr al-Montazah, and Al Mamoura.**

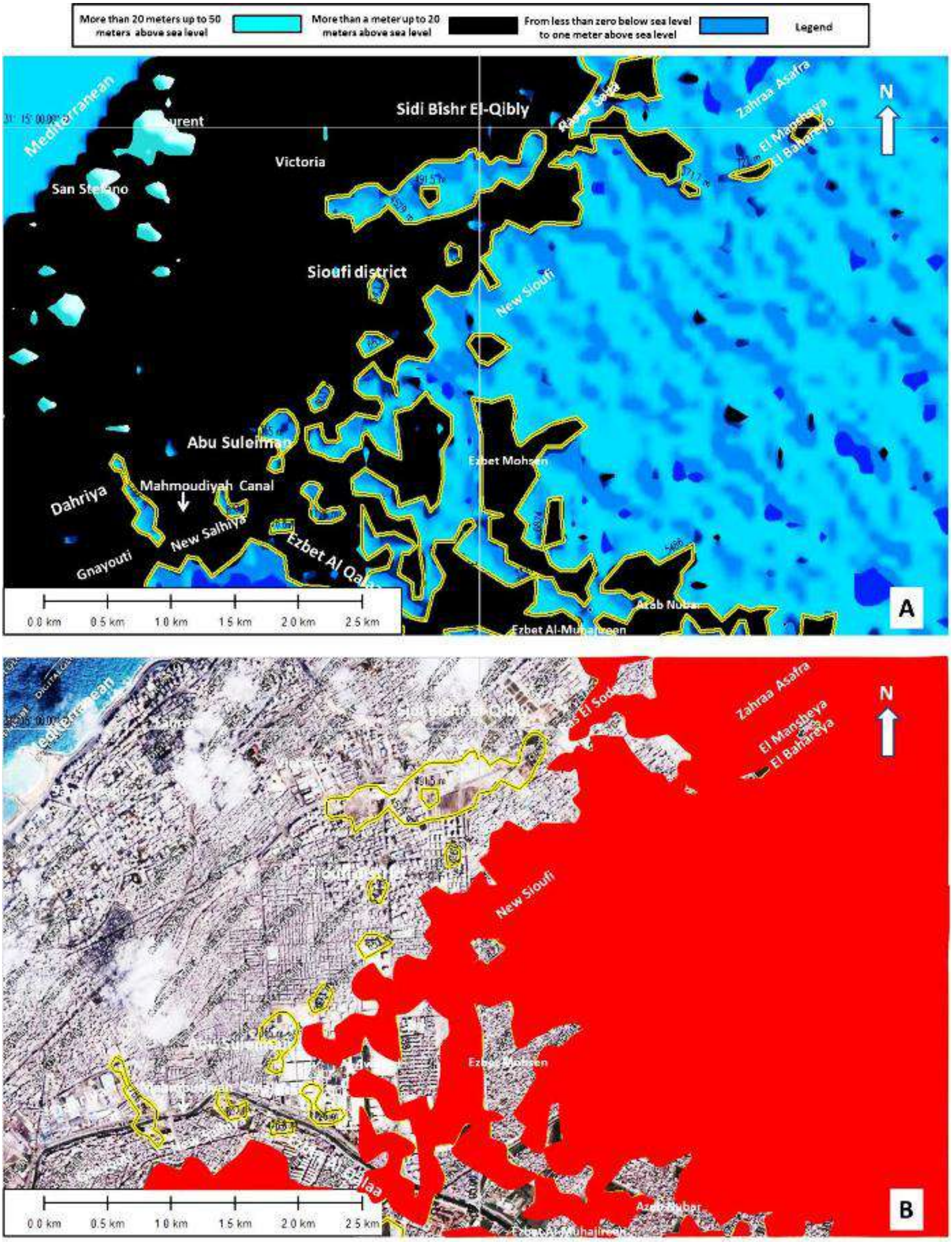



**Fig. 14 A: A brief topography of the middle area in Alexandria south of Abu Qir Bay - explaining the effect of sea level rise of a maximum of one meter, and then the sweeping of the waters of Abu Qir Bay to the low plains extending south of Alexandria from Abu Qir in the east to Al-Awayed in the west. The black areas are the lands whose level rises above sea level by more than a meter up to +20 meters. The blue areas are low plains less than zero below sea level up to one meter above sea level, and they are exploited in agricultural, residential, industrial and educational activities, all of which are**

**threatened by total invasion. Fig. 14 B: The satellite image of the Digital Globe program for the same middle area of Alexandria - given its topography in image 14 A when sea level rises with a maximum of one meter. The entire red areas are the dry lowlands which are threatened by the complete invasion.**

These lands include the Idku basins, the Abu Qir Qombaniya, the former English Qombaniyah, Mansha'at El Bahariya, the southern suburb of Abu Qir (Fig. 12), the southern neighborhoods of Montazah, Maamoura, and Sidi Bishr al-Qibli, including the new Obour City, the Montazah Economic Housing District (Figs. 13A and 13B), Al Tawfiqia and some of the lands of Dafshaw, Nubar, Khurshid, Khadra and Al Bayda (Figs. 14A and 14B). Likewise, most of the basins located south of Lake Idkou in the Mansha'at Boleen, the Kanayes, Birket Ghattas, Al Nakhla Al- Bahariya, Basantawai and Sekinda, in addition to the basins located west of the Nile River, between El-Atf in the south and El-Jedia in the north (north of Mahmoudiya and south of Rashid), north-east of Damanhour and south of Mahmoudia, between Aflaqa-Zarqun to the west and Ezbet El-Awam-El-Atef to the east. All the cities and villages that permeate these plains, whose level rises more than a meter above sea level (a total area of 146 km²), will turn into isolated islands and besieged by the marine-invaded plains, such as Al-Khadra, Al-Bayda, Kafr Selim, Al-Akresha, Mansha'at Boleen, Kom Al-Tarfaya, Ezbet Al-Tarh, Idku, Sidi Oqba and Taftish Adfina, Al-Nakhla Al-Bahariya, Basantawi, Khurshid, Nubar (Fig. 14A and 14 B) and other villages and farms south of Abu Qir and Al Maamoura (Figs 13A and 13B).

### 4.1.3. The Max Bay

The El Max Bay in Alexandria is separated from the low lands south of Alexandria, which occupies some of its area in Lake Mariout (or what is left of it), a coastal strip with a length of about 9 km that extends from the Qabbari station in the east to the Dekheila port in the west, and its width ranges from 100 to 2,000 meters (with an average of 500 meters to 1200 meters) from the sea in the north to Lake Mariout in the south (Figs. 15A and 15B).. This strip consists topographically of intermittent limestone hills ranging in height from 3.0 to 10.0 meters, interspersed with depressions representing ancient drainage channels whose level ranges from -6.0 meters below sea level to one meter above sea level. Contrary to what some researchers expect that the eastern part of the Max Bay known as the western port of Alexandria is the source of the threat to the low lands south of Alexandria, the elevation maps show that the middle part of the coastal strip of the Max Bay that extends between the western port (Al Wardyan) and Dekheila is the weakest part In this strip, where it represents the second source of threat to all the low lands south of Alexandria after Abu Qir Bay (Figs. 15B and 16).

The coastal strip between Wardyan and Dekheila, which is about 4 km long, is less in width than it is in Al-Qabbari-Al-Wardyan in the east and Al-Ajami in the west. Its width ranges from the sea in the north to Lake Mariout in the south from 650 meters to 900 meters, while its counterpart in Al-Qabbari- Al-Wardyan ranges in width from 1200 to 2000 meters, and in Ajami the width of this strip is about 3000 meters. Also, the limestone hills that make up this strip are lower between Al-Wardyan and Dekheila than in the case of Qabbari in the east and Dekheila in the west, as it ranges from 3.0 to 5.0 meters above sea level (and a maximum of 8.0 meters in a few locations). The hills are interspersed with many gaps that are lower than sea level, especially in the coastal part that extends between Wardyan and El-Max, as well as the coastal area directly east of Dekheila, while in Al-Qabbari and Dekheila, the limestone hills in these areas form dense and continuous chains without gaps or internal depressions and at a ground level that reaches a height of up to 17.5 meters.

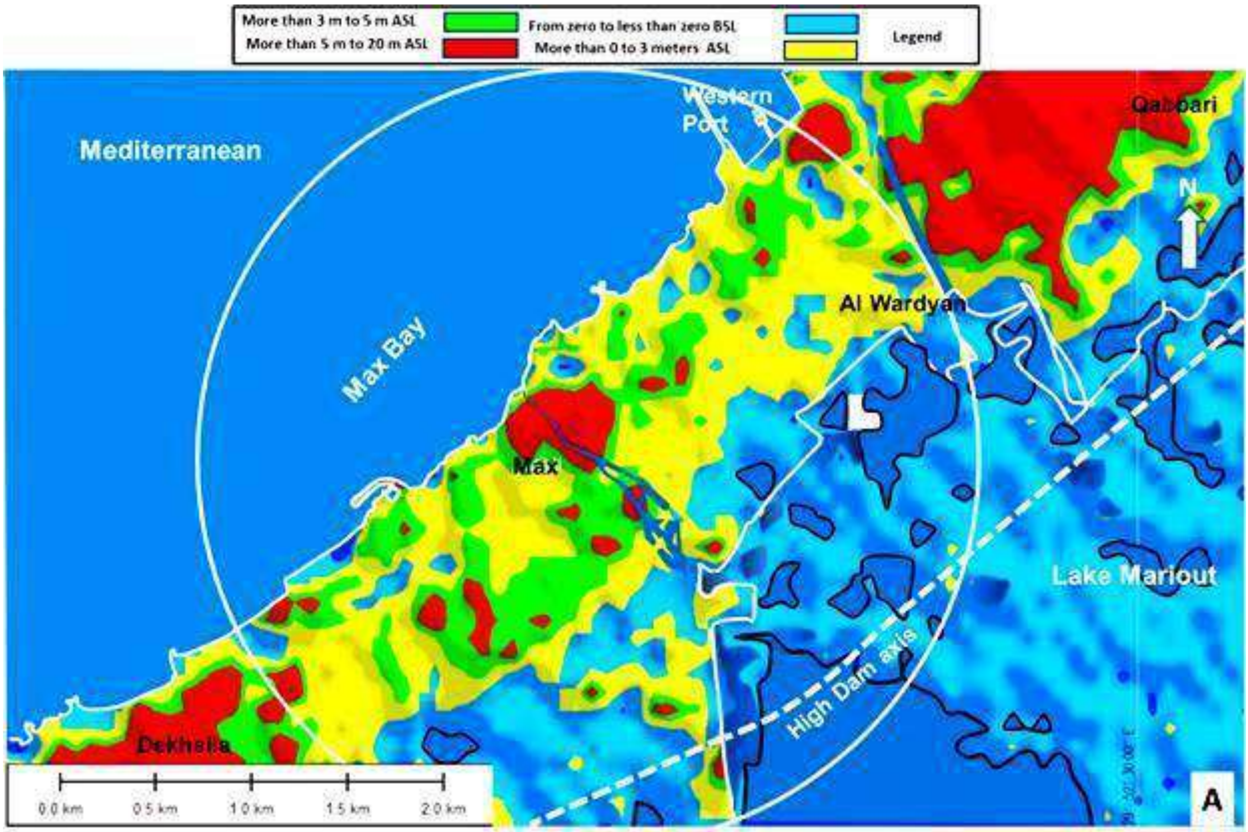



**Fig. 15 A: Detailed topography of the coastal strip extending on the coast of the Bay of Max in Alexandria, from El-Qabbari in the east to El-Dekheila in the west, The white lines are the current beach lines overlooking the sea in the north and Lake Mariout in the south after the drying, filling or dredging work that resulted from human activity. Blue land areas are dry or wet depressions whose level is less than sea level, including depressions less than zero to -5.0 meters (blue areas not marked with a frame), and depressions less than -5.0 meters to more than -8.0 meters (blue areas outlined with black frames) below sea level.**

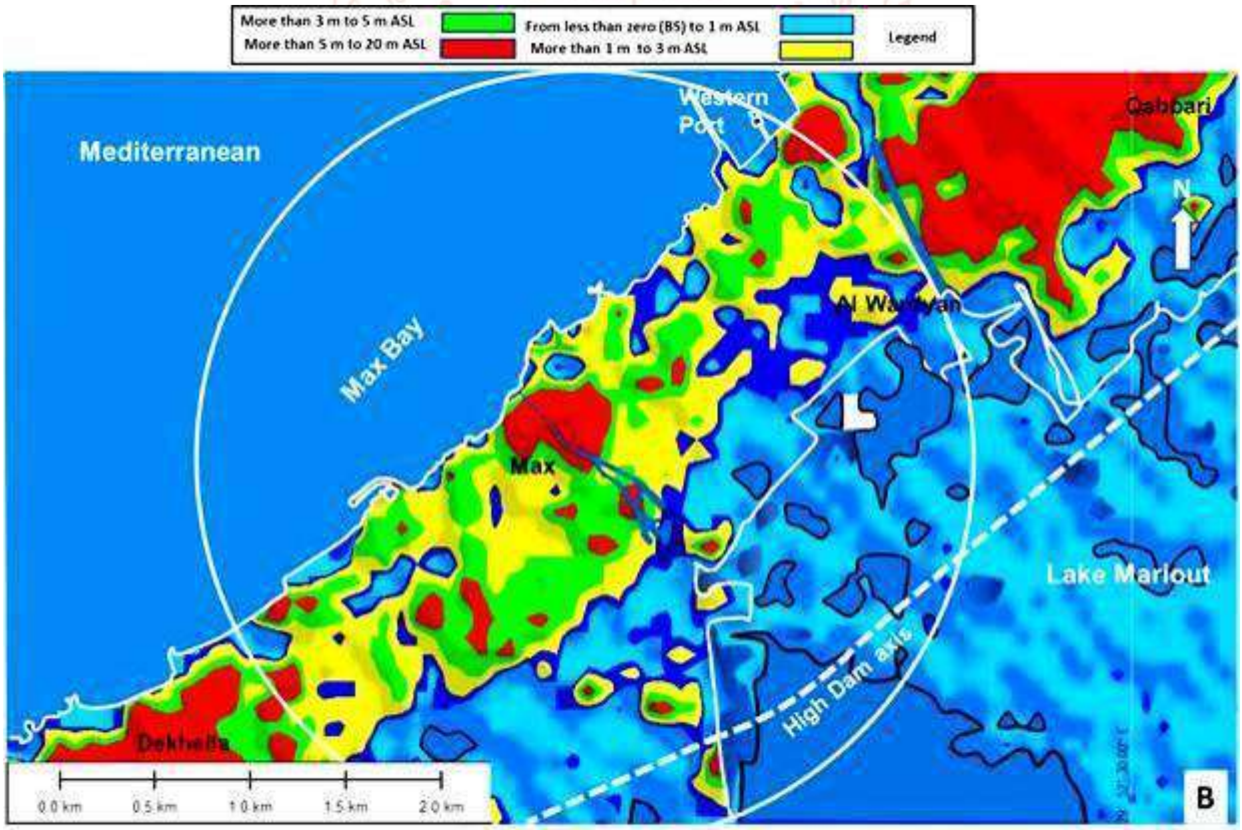



**Fig. 15 B: Detailed topography of the same coastal strip shown in Figure 15A - when the sea level rises by a maximum of one meter. The white circle indicates the most dangerous coastal strip along the bay of El Max, if the sea level rises by a meter or more. It extends along the coast with a length of 4.0-4.2**

**km between the Qabbari heights in the east and the Dekheila heights in the west, and its width ranges from 650 to 900 meters between the sea in the north and Lake Mariout in the south. Note the extent of the expansion of the interface gaps that permeate the limestone hills along the coastal strip in case the sea level rises by a meter or more, especially the sharp widening in the size of these gaps between the Al Wardyan and Max.**

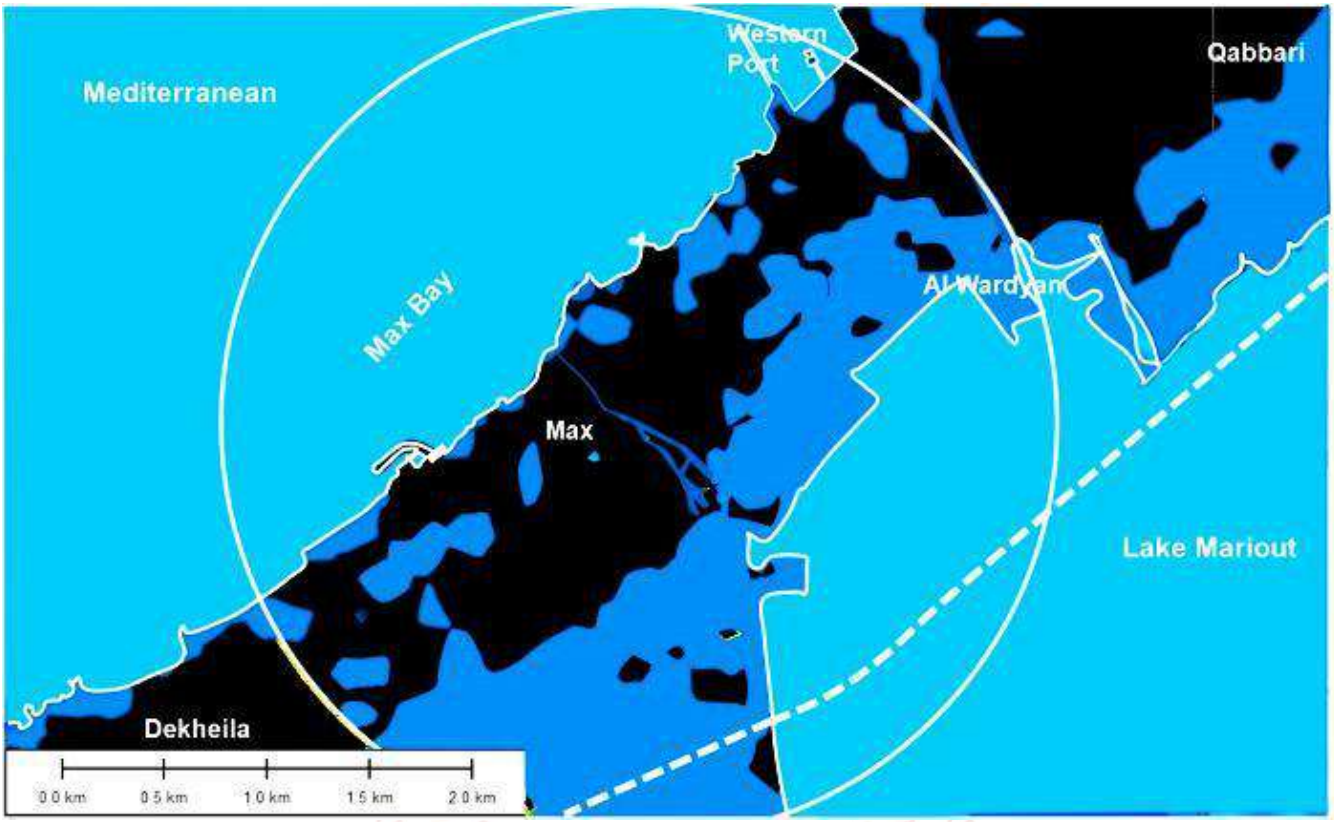



**Fig. 16: A brief topography of the same coastal strip given in Fig. 15 B. Black areas are more than one meter to 20 m above sea level. The blue land areas confined between the sea in the north and Lake Mariout in the south range from below sea level to one meter above sea level.**

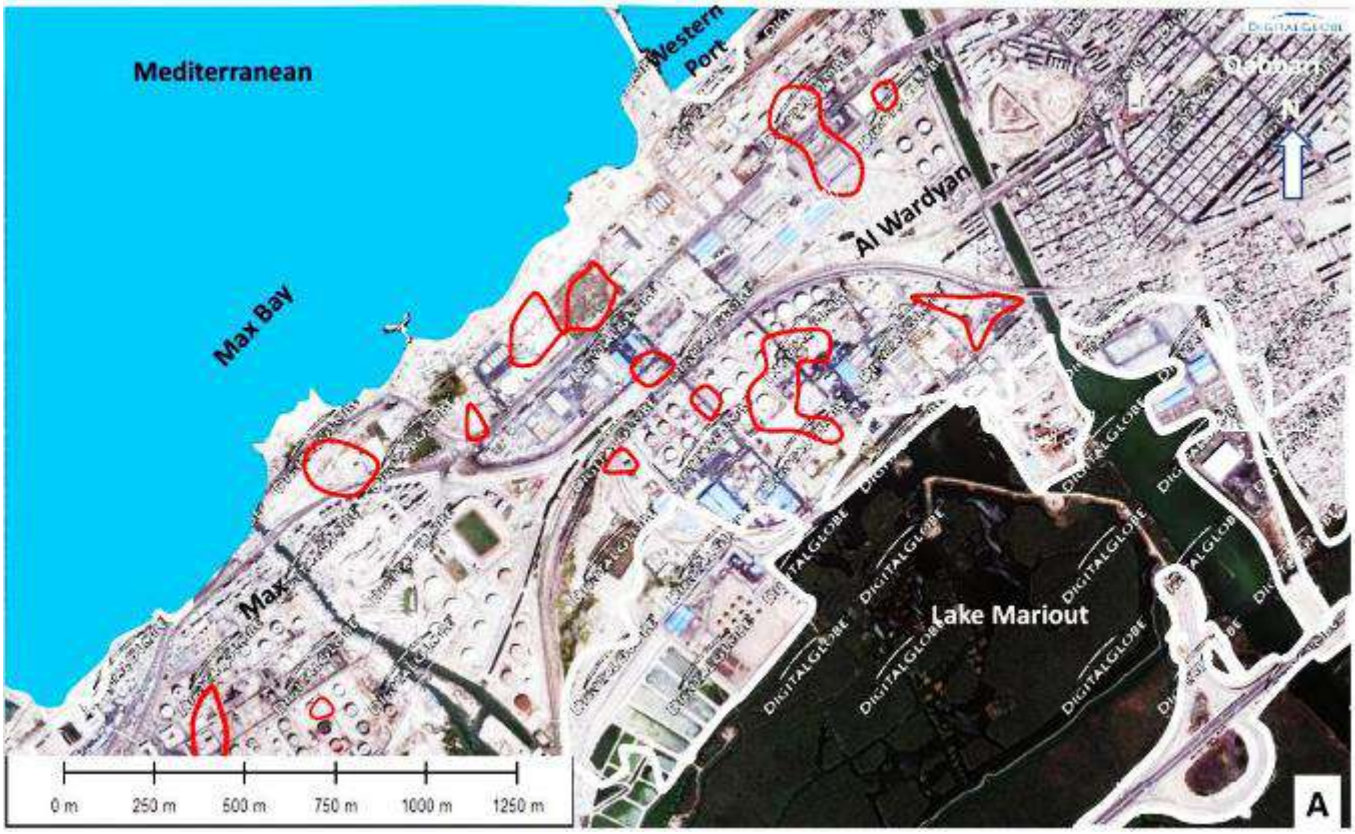



**Fig. 17 A: Satellite image of the Digital Globe program of the coastal strip extending along the Max Bay, from Al- Wardyan in the east to El Max in the west, and from the Mediterranean in the north to**

**Lake Mariout in the south - as it is the current situation. The areas delimited by white lines are the deducted and drained areas from the sea in the north or the lake in the south and currently exploited. The areas defined by red lines that cut through the heights of the coastal strip are inter-depressions whose level is less than sea level.**

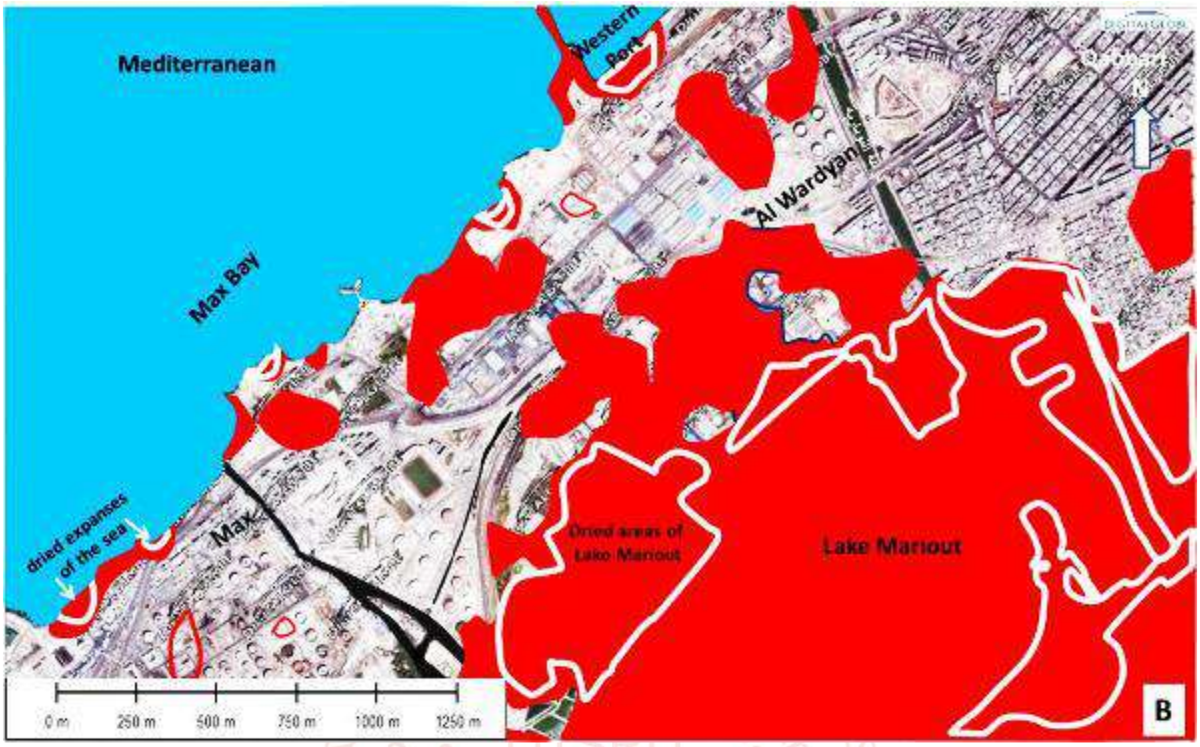



**Fig. 17 B: The satellite image of the Digital Globe program for the same coastal strip given in Figure 17A - showing the effect of sea level rise by a maximum of one meter. The entire red areas are the low lands, dry (or dried) or wet (Lake Mariout), threatened by direct invasion from the sea in the north (the northern depressions) and the indirect invasion from Lake Mariout to the south (the southern depressions), and it includes all the areas that were previously drained from the sea in the north or the lake to the south (the areas marked with white lines).**

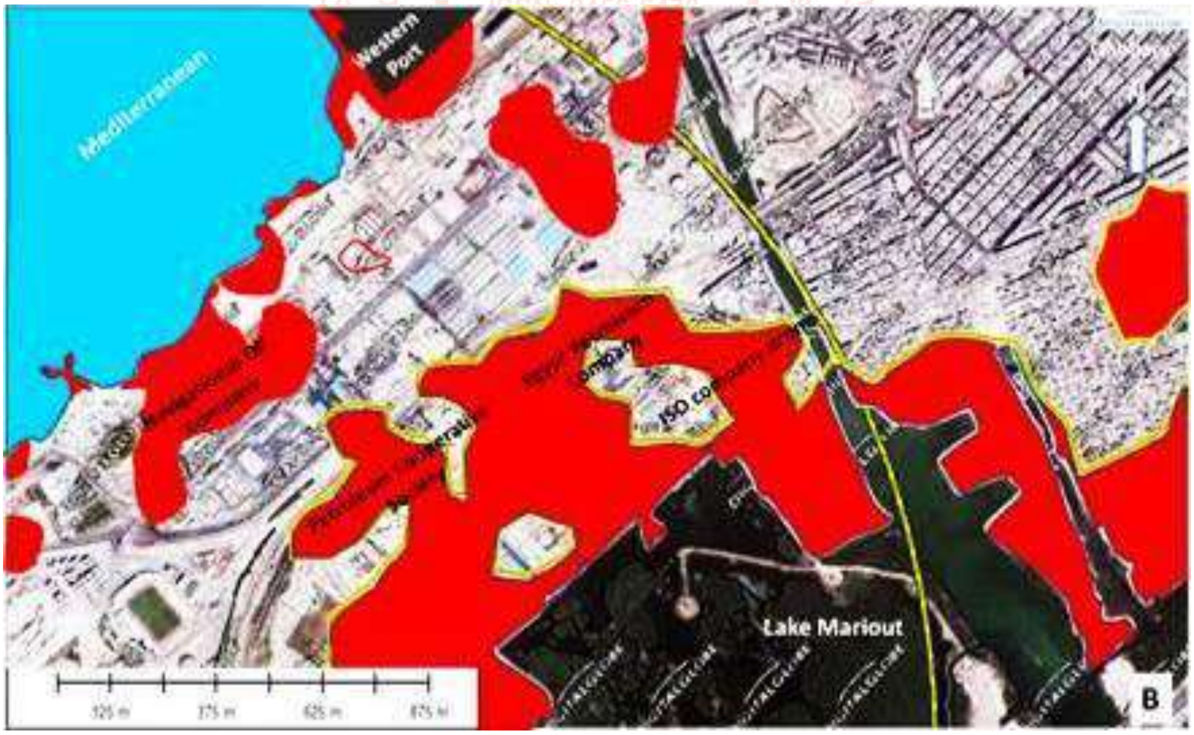



**Fig. 18: An enlarged satellite image of the Digital Globe program of the coastal strip extending from Al-Wardyan in the east to Al-Max in the west on the coast of the Max Bay in Alexandria - if the sea level has risen by a maximum of one meter, showing on it the most important petroleum industrial projects that are threatened by a direct invasion from the sea in the north or indirectly from Lake Mariout To the south, when its level rises.**

The part extending from this strip between Al-Wardyan in the east and El-Max in the west, as well as the part located directly east of Dekheila (Figs. 17A and 17 B), is the most dangerous part of El-Max Bay when sea level rises, as it spreads among the limestone hills in this strip some branching low depressions whose ground level ranges between -6.0 meters and + 1.0 meter, with a length of 2 km between Wardyan and El-Max, (1.1 km directly east of Dekheila). Some of these depressions extend from the shore line to Lake Mariout, south of the port, and then these depressions will work as sea passages between the sea in the north and the low plains in the south. These depressions constitute about 25% of the total area of the coastal strip extending between Wardyan and Dekheila, which is about 4.4 km², and they are preferably concentrated in the part between Wardyan and El Max, where they constitute about 40% of the area of this part of the strip, which has an area of 2.0 km². Most of these depressions have been exploited with the establishment of industrial facilities, but the decrease in its current level will expose these parts of the land strip to direct invasion in the event of a rise in sea level by a meter or more (Fig. 18).

Also, the shrinking of the width of the limestone hills that make up these parts of the land strip with the spread of sub-surface depressions between them will contribute to the intrusion of sea water south into Lake Mariout as well as the dry and drained low plains around it, whose level drops to 12.5 meters below sea level - unless the Max Bay becomes completely isolated from the coastal strip (see defensive policy below).

On this occasion, we would like to point out the instability of the sub-surface soil in the western port. It has become clear to some researchers that sedimentation has failed in both the eastern and western ports since the construction of the city of Alexandria by Alexander the Great in the fourth century BC until the present time (Stanley et al., 2006). The subsurface imbalance is a tangible phenomenon that can be determined by searching for ancient monuments in these areas, as well as by geologists and engineers in their studies when building the port. The soil under the sea floor is composed of sandy and clay deposits that follow the modern Epoch (Holocene) with a thickness of about 5-6 meters. These sediments are constantly deteriorating and slipping on the bottoms of the two ports, and their slip is always renewed when establishing rocky structures or buildings on the weak bottoms saturated with water. All the ruins sunken in the eastern harbor show a mixture of fractures in the construction materials, with distorted sediments, and a rake that fills the fractures in the ruins as a result of the loads on the weak bottoms. The cylindrical samples that were extracted by Stanley et al. (2006) show the phenomena of mass slipping, sediment movement and mud flow associated with the instability of bottoms and soil. The sub-surface imbalance in the western port does not only threaten the limestone hills that make up the coastal strip extending along the Max Bay, but it also threatens the sea walls that can be built along the shore to protect the installations located on the coast and the plains that border it to the south from rising sea levels. Therefore, great care must be taken when implementing measures to protect the coastal strip between Wardyan and Dekheila, so that the bay of Max does not become a source of threat to the vast lands to its south.

### 4.1.4. The threatened wet and dry lands southern Alexandria, east of the Max Bay

Increasing the sea level by up to a meter (which is the expected maximum at the end of the twenty-first century) and its sweeping of the depressions that cross the coastal strip extending between Al-Wardyan and Dekheila, especially between Al-Wardyan and El Max, will sweep the depressions that cross the strip, and then all installations Located on low-lying lands south of the shore line (e.g. installations of the Misr Petroleum Company, the Cooperative Society for Petroleum, the Nasr Company for Leather Tannery, the Medical Stone, the Amriya nursery, and the Petroleum Pipelines Company (Fig.18) .

Also, any increase in the level of Lake Mariout, whether as a result of water rushing from the Max Bay to Lake Mariout through the low-lying land passages extending between the sea and the lake (or through the subsurface soil) or because of the rise in the groundwater level as a sequential effect of the rise in global sea level, It will lead to the invasion of all the low lands south of Dekheila, Al-Max, Al-Wardyan, Al-Qabbari, Karmouz, Muharram Bey, Al-Hadra and Smouha (Figs. 19A, 19B and 20), and then all the residential, industrial, touristic, educational and administrative establishments built on these lands south of Qabbari Road - Nozha Airport (south of Mahmoudiya Canal). For example: the barrel facilities of the ISO company, the Alexandria Petroleum Factory, the oil and cake factories, the aluminum factory, the iron and steel company's warehouses, Nag Al-Arab, the Egyptian Export Company's warehouses, the Qabbari sewage station, the international road, the New Mansheya, and the Shona of the National Spinning and Weaving Company, Tram Club, Carrefour, City Center, International Park, Nozha Airport, new airport facilities and its annexes, Raba'a Nasiriyah, Ezbet Warshah, Alexandria University farm, Alexandria University new site, Ezbet Sabya, Ezbet El-Ginya, Ezbet Nady El Seid, and all the villages of Apis, as well as the bus station and the service station on Al-Qabbari Road - Muharram Bek, and others (Figs. 20, 21 and 22).

All of these inhabited places are built on dried lands of Lake Mariout, with ground levels that do not exceed, after drying, sea level. This is in addition to the remaining submerged parts of Lake Mariout (139 km²), and all agricultural basins extending east from Alexandria to Damanhour. Note that the area of dry lands extending south of the Mahmoudia Canal between Damanhour and Alexandria (Fig. 20), whose level is less than sea level, is about 1278 km², including all the dried and exploited lands from the original Lake Mariout south of Alexandria, and that these areas are expected to increase by 190 km² of dry lands if Sea level rise by one meter.

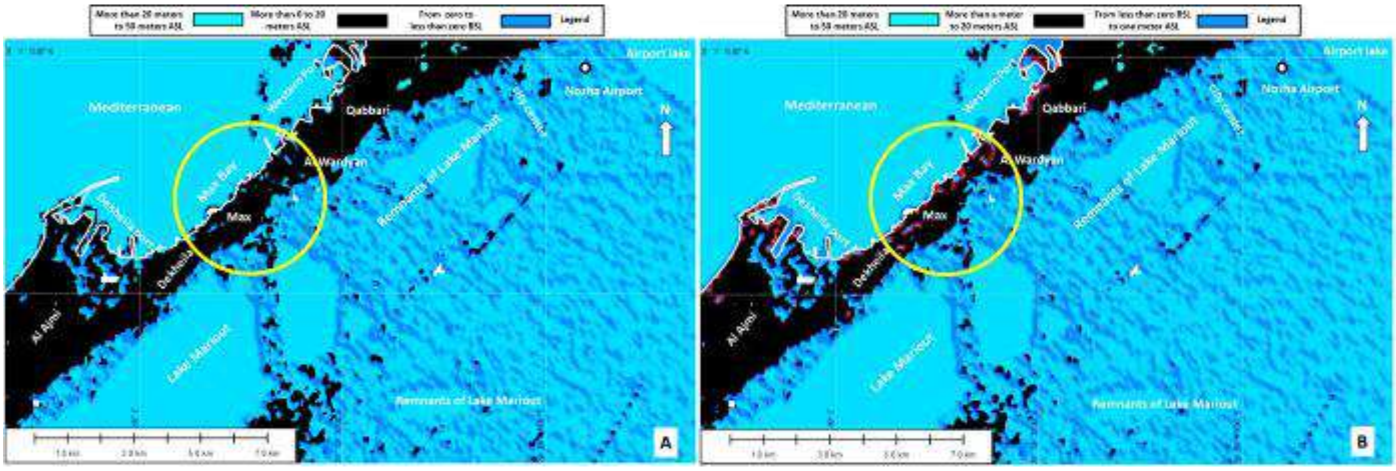



**Fig. 19 A: A brief topography of the coastal strip of the western part of Alexandria, extending along the Max Bay, from Qabbari in the east to Ajamy in the west, including the Western port and Dekheila port - as it is the current situation. The white line is the current shore line. Fig. 19 B: A brief topography of the same coastal strip given in Figure 19a, when sea level rises by one meter. The yellow circle shows the location of the gaps that permeate the limestone ridge that extends from Wardian to Dekheila, especially between Wardian and Max. The blue areas, with their different shades, are the plains that are in danger of being invaded if the sea level rises.**

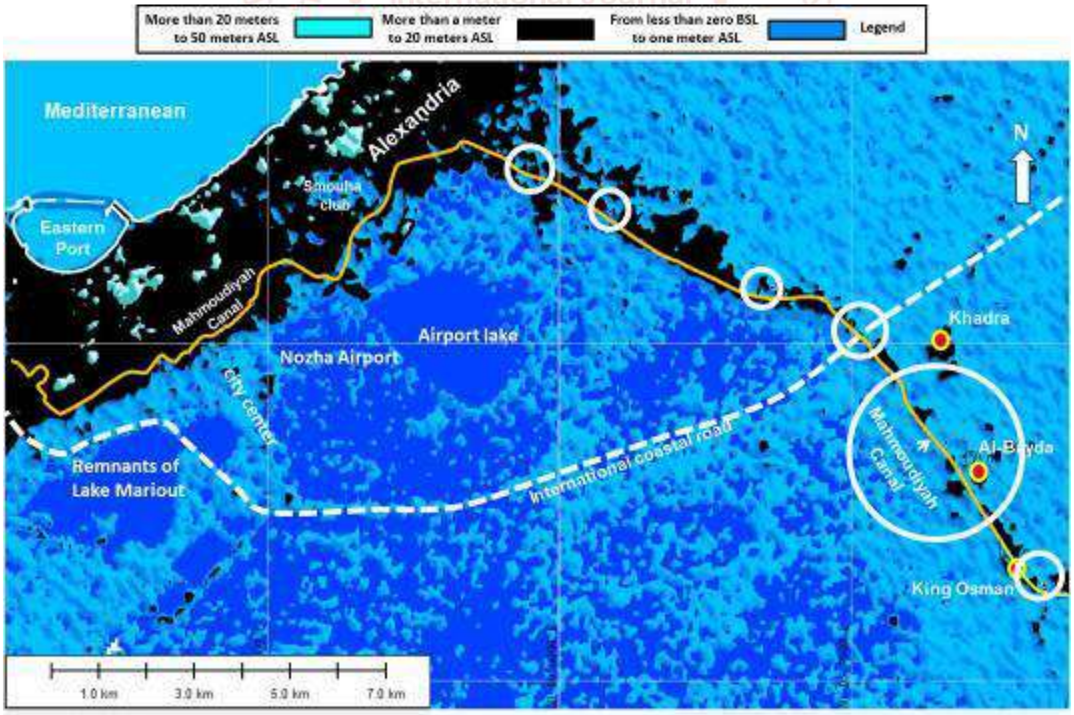



**Fig. 20: A brief topography of the middle part of the city of Alexandria extending from the entrance of Apis in the east to the Eastern port in the west and its relationship to the low plains extending to the south along the city of Alexandria - if the sea level rises by a maximum of one meter. The white line is the current beach line, and the orange line is the Mahmoudiya Canal. The blue areas (with different shades) are dry or wet low plains (Lake Mariout) whose level usually ranges from -8.0 m below sea level to 1 meter above sea level. These plains are threatened by sea invasion through the inter-holes that permeate the narrow sandy ridge chain extending along the Mahmoudiya Canal, especially between King Osman in the south and Alexandria in the north (the white circles), which in turn will act as auxiliary sea lanes on the rush of the waters of Abu Qir Bay from the northern plains to the southern plains, in addition to the gaps in the middle of the coastal strip extending on the Max Bay**

**between Al-Wardyan and Dekheila (Fig. 19 B), which will also serve as sea corridors between the Mediterranean and the southern plains if the sea level rises by a meter or more.**

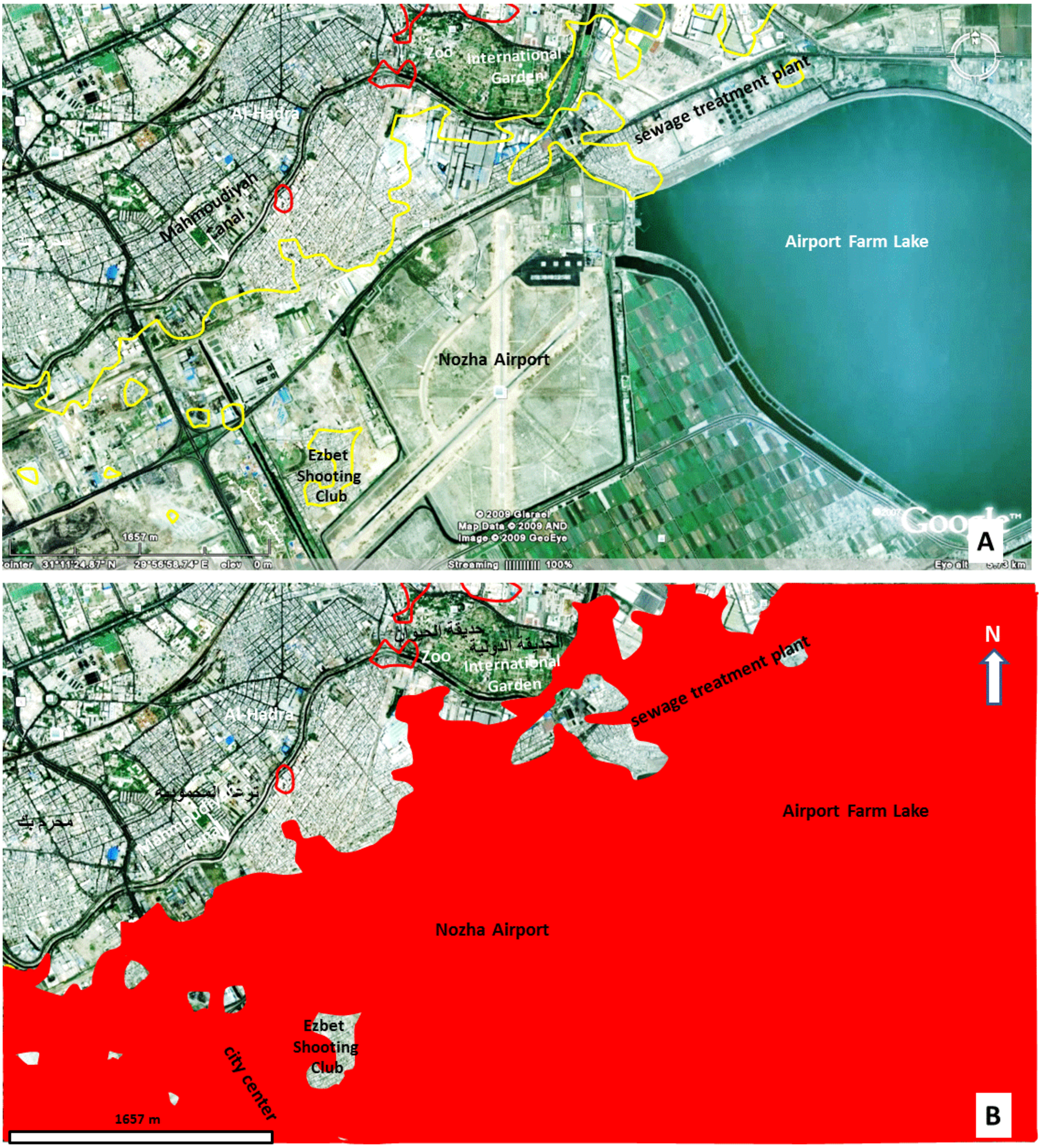



**Fig. 21 A: Satellite image of the Google Earth program for the threatened area south of Smouha, Al-Hadra and Muharram Bey, which includes Al-Nozha Airport and its annexes from the former airport lake, the International Park, City Center and others, in case the sea level rises by a maximum of one meter. The continuous yellow line is the new beach line between the high lands to the north, and the dry (or dried) or wet (Lake Mariout) low plains in the south. Fig. 21 B: The same image of Fig. 21 A, showing the areas which are threatened by marine invasion (fully red areas) - if the waters of the Abu Qir Bay invade the low plains extending south of Alexandria, or the sea invades the coastal strip extending between Al- Wardyan and El Max - unless protection works are done. Note the huge amount of residential, commercial, industrial and public utilities activities, in addition to the airport and its installations threatened by the invasion south of the Eastern and Central districts of Alexandria. The areas delineated by red lines are depressions within the city that are subject to**

**partial submersion in the event of a rise in the sub-surface water level as a sequential effect of sea level rise.**

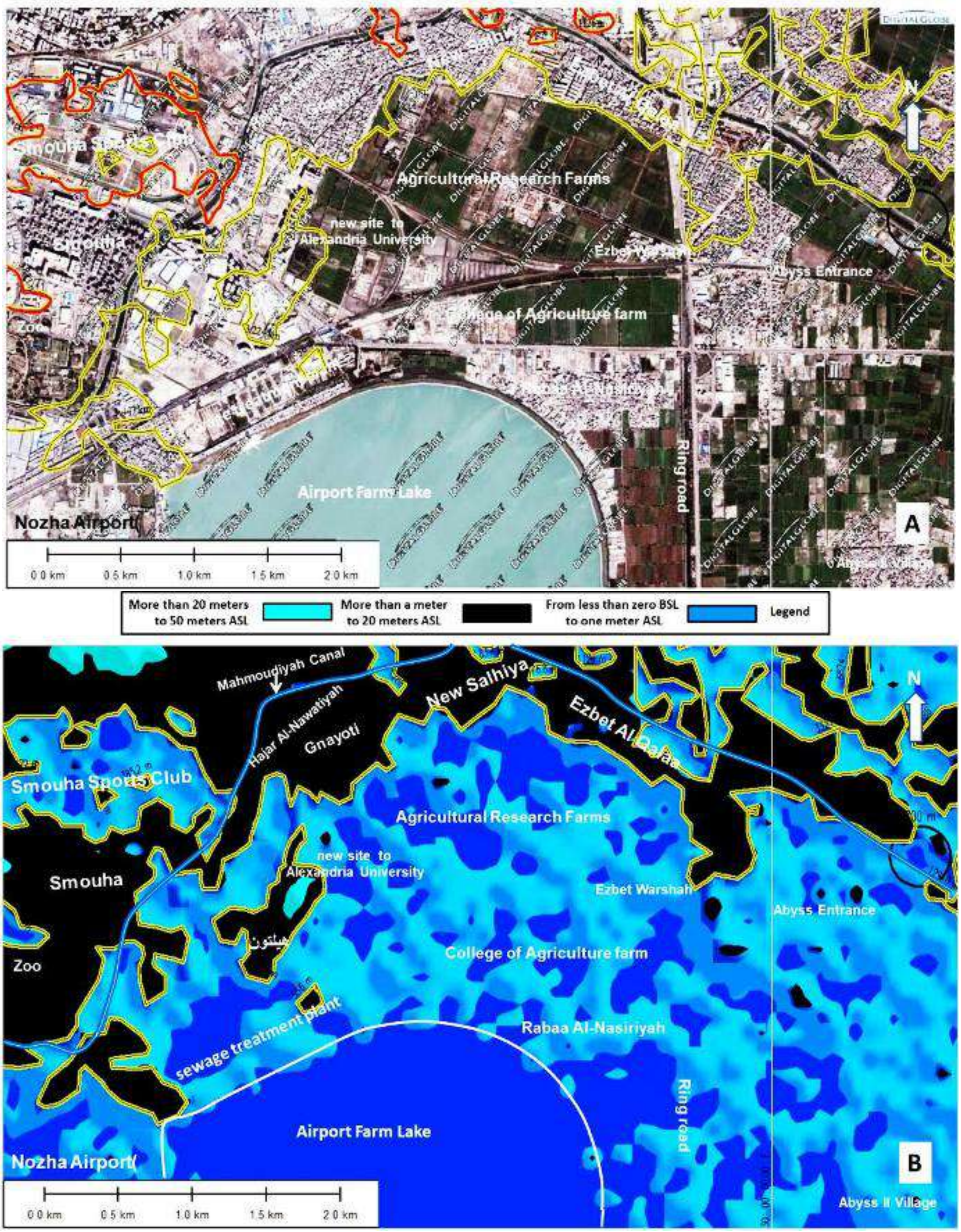



**Fig.22 A: Satellite image of the Digital Globe program for the southern region in eastern Alexandria, extending from the entrance to Apis in the east to Smouha in the west, and from Mahmoudia Canal in the north to the Airport Lake in the south, showing the residential, administrative, educational and recreational activities currently exploited, including Nozha Airport. The continuous yellow line is the new beach line between the highlands of Alexandria in the north and the low plains in the south if the**

**sea level rises by a meter. The areas defined by red lines are depressions whose level is less than sea level, interspersing the northern highlands of Alexandria. A brief topography of the same area whose satellite image is given in Figure 22a- explaining the effect of sea level rise with a maximum of one meter. and then the sweeping of the waters of Abu Qir Bay to the low plains extending south of Alexandria from Abu Qir in the east to Nozha Airport in the west, and the sea's invasion of the coastal strip extending between Wardyan and El Max. The white line is the shoreline of the airport lake, which is currently used as extensions to the new Alexandria airport. The blue areas are the exploited southern plains threatened by the invasion, whose general level is less than a meter above sea level to -10.0 meters below sea.**

#### 4.1.5. The Dekheila Port

The topographical examination revealed the prevalence of low gaps with a level ranging between -1.0 m and -6.0 m below sea level in the new port of Dekheila. These gaps combine to form a network of depressions that threaten the port's installations, berths, warehouses, and some residences located in Ajami, west of the port. The area threatened by any increase in sea level less than a meter is estimated at 1.2 km², or 40% of the total area between Dekheila port and Ajami, which is 3 km². In the case of an increase in the sea level by a maximum of one meter, the areas threatened by the invasion are estimated at about 1.65 km², i.e. 53% of the total area mentioned (Figs. 23A and 23B). The losses of this port are the most severe losses of the Egyptian ports as a result of the increase in sea level - unless protection measures are taken.

However, the entire port is completely isolated from Lake Mariout, which lies to the south of it, with a topographical elevation of limestone hills with a width of about 750 meters and a level ranging between 5.0 and 15.0 meters above sea level, and therefore it does not constitute a direct threat to Lake Mariout, with the exception of one depression between the port and the lake, about 500 meters long, located directly west of Dekheila. The ground level of this depression ranges from 2.0 meters to 5.0 meters, and thus it is not feared unless the sea level rises by more than 2 meters.

### 4.2. The depressions that permeate the heights of Alexandria city

The original heights of the city of Alexandria, which range mostly from 5 meters to 20 meters and a maximum of 25 meters above sea level, are also interspersed with some wide depressions that are not directly connected to surface water sources (the Mediterranean Sea), but are threatened by total or partial inundation if the groundwater level rises as a sequential effect of sea level rise. The most important of these depressions are the Smouha, Al-Seyouf and Sporting depressions, with a total area of about 2.5 km². The most dangerous of these depressions is the depression of the entire Smouha Sports Club (Figs. 24 A and 24 B), whose ground level ranges from zero to -5.0 meters (and a maximum of -20.0 meters in one location), followed by depressions located southwest of the club (Figs. 25A and 25 B), whose level drops to -3, 0 m (maximum -10.0 m in one location). Come next the depressions of Sporting Club and Al-Seyouf (west of Victoria), with a ground level of -3.0 meters below sea level (Figs. 25A and 25B). Many of these depressions have raised their level and dried up what was submerged in them, but their level after drying does not exceed sea level as a maximum. Most of these depressions are used as sports fields and parks, and there is no fear of them, as their level can be raised with sand with the use of reinforced concrete.

The center of Abu Qir suburb is also permeated with wide depressions below sea level down to -4 meters, extending 2.2 km long from east to west of the city, with a width ranging between 180 and 900 meters, and with a total area of about 1.0 km² (Figs. 26A and 26B). These depressions which are exploited both for residential and industrial purposes, are threatened by a direct sea invasion from the sea to the west. As for the depression that borders the city from the south (in the direction of Abu Qir Bay) and its area is about 0.35 km², it is subject to invasion from the Bay itself due to its lower level than sea level, and it was taken into account when calculating the total threatened areas south of Abu Qir Bay

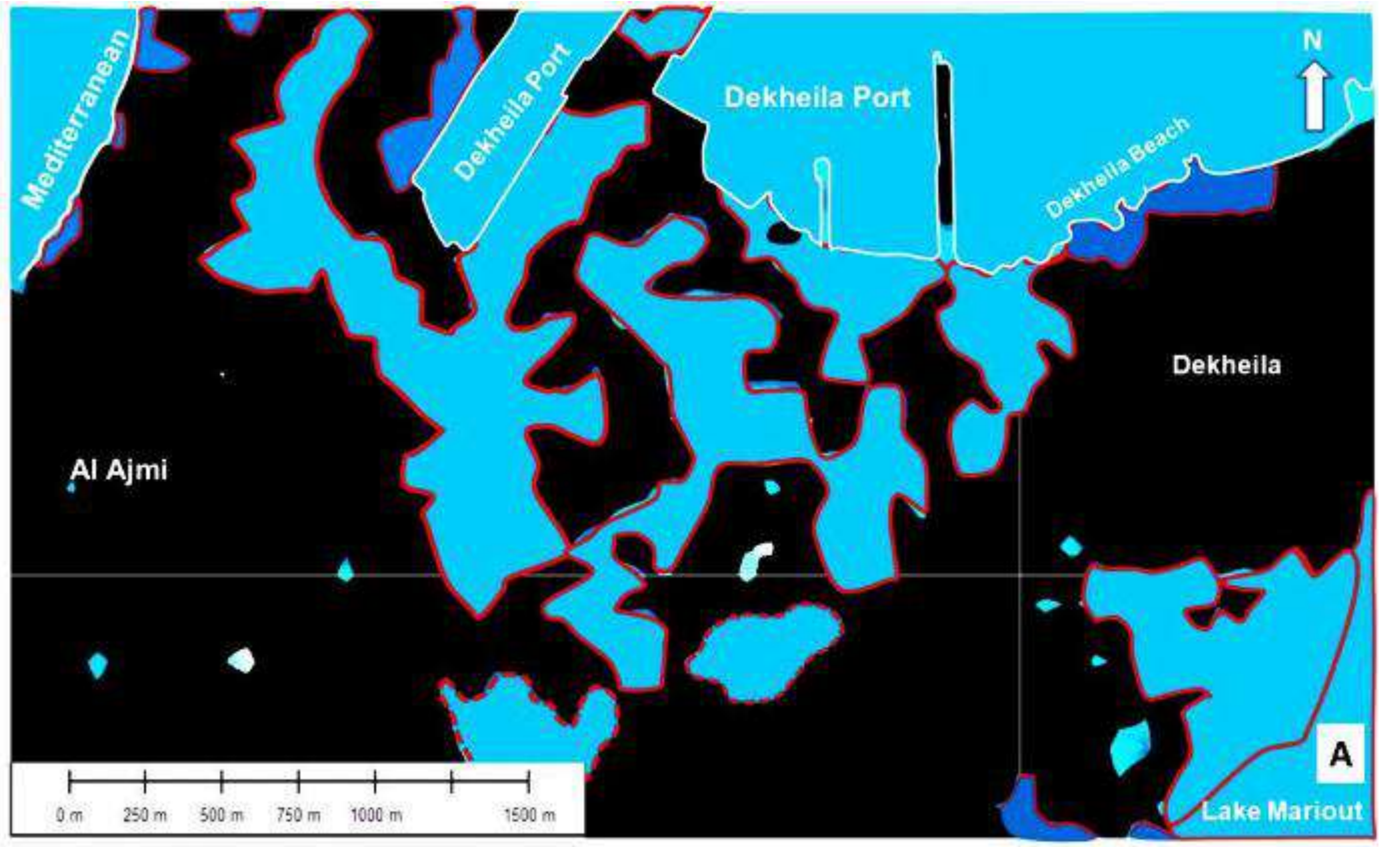



**Fig. 23 A: A brief topography of the coastal strip of Dekheila port extending from Dekheila in the east to Al- Ajami in the west on the coast of the Mediterranean Sea – when the sea level rises by a maximum of one meter. The white line is the current shore line. Black areas are dry lands that rise more than a meter above sea level. The blue land areas delimited by continuous red lines are dry (or dried) lowlands with a level ranging from -7.5 meters (maximum -12.5 meters) below sea level to one meter above sea level. Areas defined by broken red lines are Inter-depressions threatened by partial or complete inundation by subsurface water.**

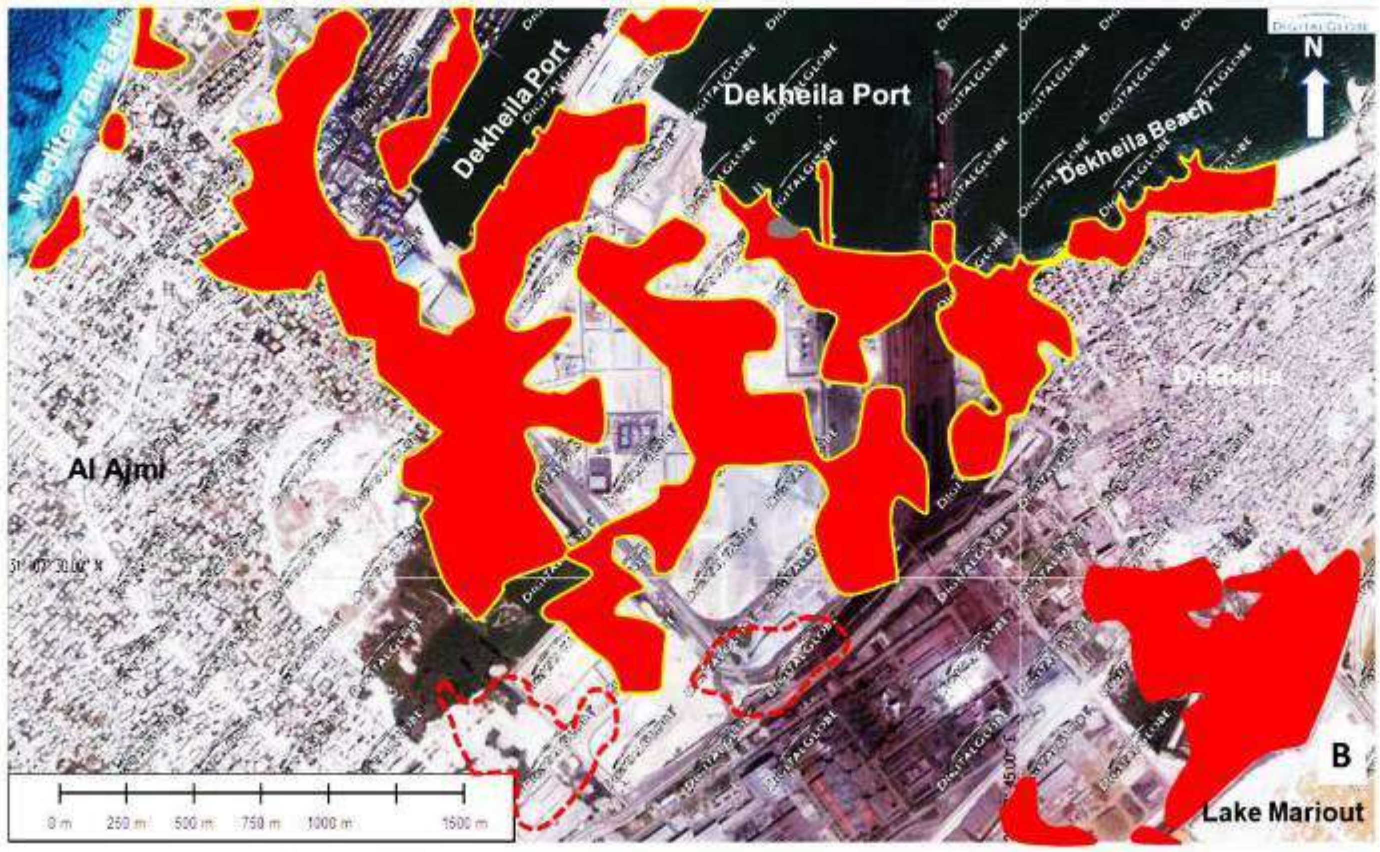



**Fig. 23 B: The satellite image of the Digital Globe program for the same coastal strip of Dekheila port, given its topography in Figure 23 A - explaining the effect of sea level rise by one meter. The red areas**

**delimited by yellow lines are the lowlands, dry (or drained) south of the shoreline, threatened by direct invasion from the sea. The completely red areas are the lands deducted from Lake Mariout, and they are also threatened by an indirect invasion from the lake if the Abu Qir Bay invades the low plains extending south of Alexandria from Abu Qir in the east to Dekheila in the west, or the sea invades the coastal strip extending between Al-Wardyan and Al- Max.**

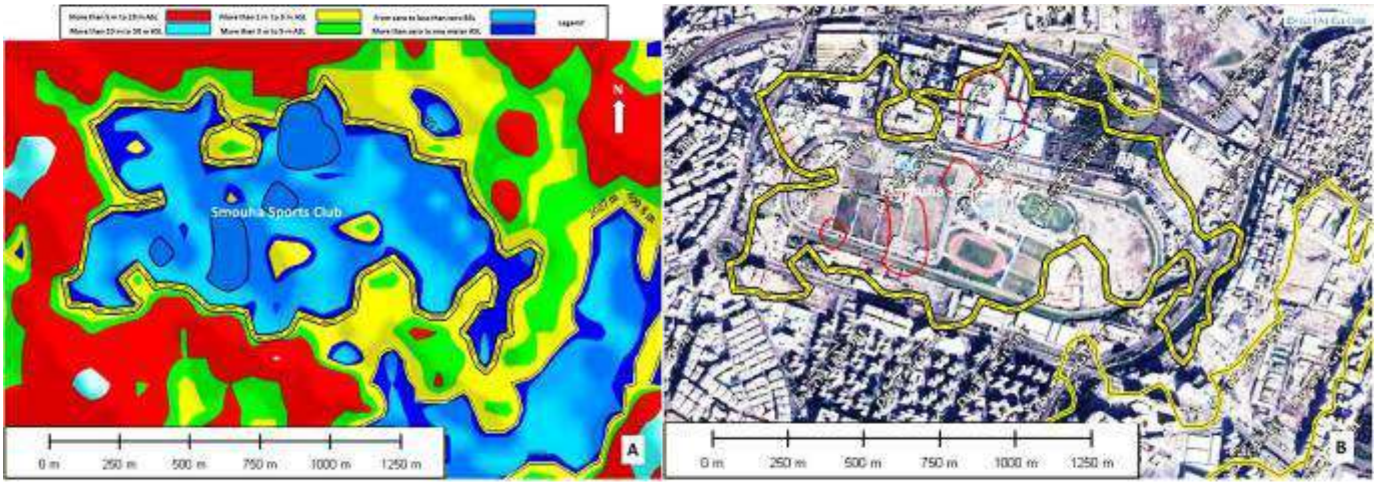



**Fig. 24 A: Detailed topography of the Smouha Sports Club depression and the surrounding depressions - explaining the potential effect of groundwater level rise as a sequential effect of sea level rise by a maximum of one meter. The blue areas (with different shades) are depressions threatened by partial inundation with their activities. Their ground level ranges from one meter above sea level down to -5.0 meters (with maximum -25 meters) below sea level. Fig. 24 B: Satellite image of the Digital Globe program for the Smouha Sports Club depression and the surrounding depressions, whose topography is given in Figure 24 A, showing the land uses of sports, administrative and residential activities. The yellow lines surround the low-lying areas threatened by partial inundation with their activities if the groundwater level rises as a sequential effect of sea level rise by a meter or more.**

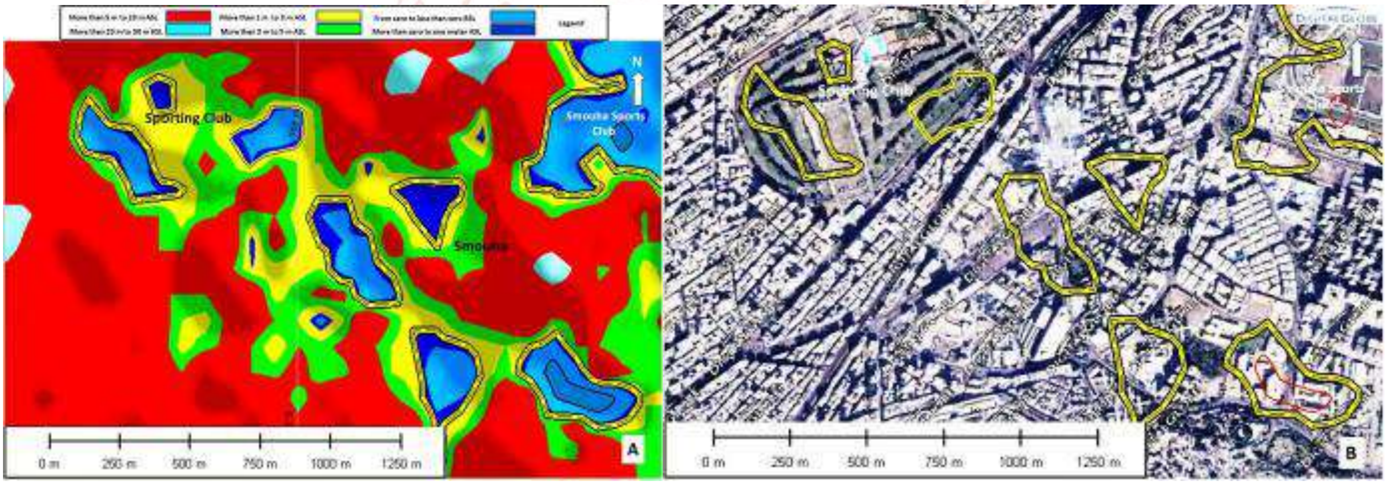



**Fig. 25 A: Detailed topography of depressions south and west of Smouha Club and inside Sporting Club in Alexandria that are threatened by possible partial flooding if the groundwater level rises as a sequential effect of sea level rise by a maximum of one meter. The blue areas (with different shades) are depressions threatened by partial inundation with their activities. Their ground level ranges from one meter above sea level down to -3.0 meters (with maximum -10 meters) below sea level. Fig. 25 B: Satellite image of the Digital Globe program for the same image whose topography is given in Figure 25 A, showing the land uses of sports, administrative and residential activities. The yellow lines surround the low-lying areas which are threatened by partial inundation with their activities if the groundwater level rises. The areas defined by red lines are below -3.0 meters to -10.0 meters below sea level, and these are the most dangerous submersible depressions.**

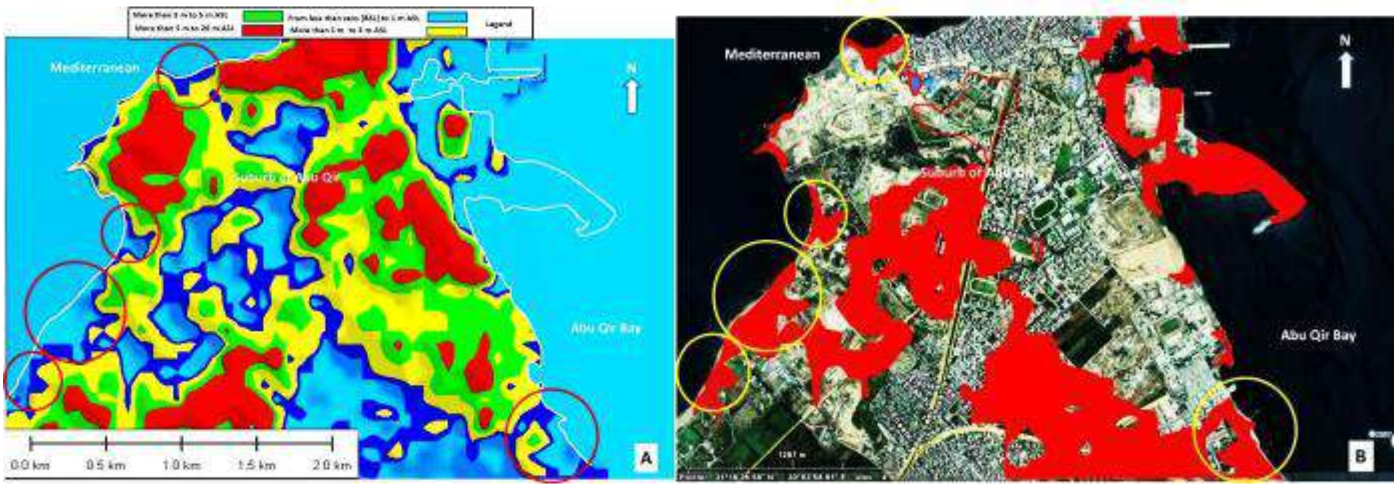



**Fig. 26 A: Detailed topography of the suburb of Abu Qir between Abu Qir Bay in the east and the Mediterranean Sea in the west - when the sea level rises by a maximum of one metre. The white line is the current beach line on either side of the suburb. The blue land areas (with different densities) that permeate the suburb are dry and exploited lowlands whose level is less than a meter above sea level up to - 4.0 meters below sea level. Fig. 26 B: A satellite image of the Google Earth program of the suburb of Abu Qir, whose topography is given in Figure 26 A, showing the effect of sea level rise by a maximum of one meter on the current land uses. The completely red areas are the low lands that permeate the suburb of Abu Qir and are threatened by a direct and complete sweep from the waters of Abu Qir Bay in the east and the Mediterranean in the west, through the wide gaps that cut through the beach lines on both sides of the suburb (Red circles in Fig. 26 A and yellow circles in Fig. 26 B). The vacant areas marked by red lines are depressions whose level is also below sea level, but which are not directly connected to the sea. However, this does not prevent it from being submerged by subsurface water**

### 4.3. Alexandria beaches

All the beaches of Alexandria overlooking the Mediterranean are affected to varying degrees by the increase in sea level. Alexandria's beaches are partially or completely artificial beaches, either cut off from the sea completely, or expanded at the expense of the sea, and therefore they are all subject to total or partial marine invasion if the sea level rises by any amount up to a meter. From a topographical point of view, the beaches most affected by a rise in sea level by no more than one meter are the shores of Abu Qir, Al Maamoura Al Shati, Sidi Bishr 1, San Stefano, Glim, Mustafa Kamel, Al Anfoushi, Ras El Tin Palace, and Hanovil in Ajami. All of these beaches are threatened with almost complete incursion unless the level of these beaches is raised to more than a meter (1.5 meters at a minimum) above the current sea level. The impact of this invasion extends to include the center of the suburb of Abu Qir, the sea cabins on the Maamoura beach, the tourism services on the Glim beach, the Mustafa Kamel cabins, some tourist installations in Anfoushi and Ras El Tin, and some residential installations in Hannoville. As for the beaches of Mamoura restroom, Mandara, Sidi Beshr 2 and 3, Al Saray, Loran, Tharwat, Stanley, Roshdy, Cleopatra, Al Bitash, Al Nakheel, and 6th of October, their beaches will be partially affected - but the impact will extend to include some installations in Bitash and the area east of the 6 October resort.

The risks facing some low-lying beaches such as the beaches of Maamoura, Shatby, Stanley, Sidi Bishr, Asafra and Mandara, and the beaches extending west of Alexandria to Burj Al Arab, do not compare their results with the risks facing agricultural lands and residential, industrial, and administrative neighborhoods built on low levels in the south of Alexandria governorate. The effect of increasing the sea level on the beaches is limited, regardless of its economic value. The dangers of this increase can be avoided by strengthening the beaches and raising their level with sand.

### 4.4. Conventional coastal defenses

Defense here does not mean only protecting the beaches from the impact of rising sea waves, as is the case in Alexandria Governorate. Rather, it is intended to protect all the low-lying coastal plains with their villages, cities and agricultural lands along the Abu Qir Bay and in the low-lying areas of the Max Bay from the global sea level rise, and then the matter is no longer limited to the establishment of a few breakouts or walls for waves, but extends to the following:

**First:** Erecting armored concrete walls that are partially submerged underwater and able to repel any invasion or marine intrusion into the ground. This is done in low coastal sites whose level is less than the current sea level or those where there are low coastal gaps that are less than a meter above the current sea level, through which sea intrusion would inundate vast areas of the lands located south of it. Armored walls mean concrete walls made of sand and chemically treated cement, in order to achieve the highest degree of rigidity, hardness and cohesion, and to ensure complete cohesion of sand grains used in concrete. These walls must be submerged below sea level at an appropriate depth to prevent subsurface leakage through soil injection operations with reinforced concrete, and that the armored walls must rise above sea level by no less than two meters. As for the thickness of these walls at each site, it is left to the specialized engineers to determine the thickness that is commensurate with the length and height of the gap and in a way that is able to resist the pressure of the excess sea water. The Dutch experience can be used to construct these walls or modify their specifications. This is a first line of defense. We would like to refer in this regard to the valuable research of Koraim et al. (2011) on methods and strategies that can be used to deal with the expected rise in sea level.. As for the locations, lengths, and depths of the submerged armored walls required to be built to protect the city of Alexandria, or in other words, to protect the northwestern part of the delta, we suggest them as follows:

1. One partially submerged armored concrete wall in front of the shoreline directly facing the Mediterranean Sea on the southern coast of Abu Qir Bay, which extends between the suburb of Abu Qir in the west and the village of El Maadiyah in the east, with a length of about 10 km, a depth below sea level of not less than 5.0 meters, a height of not less than 2 meters above sea level (total height 7.0 m) (Fig. 27).
2. One partially submerged armored concrete wall in front of the shoreline directly facing the Mediterranean Sea on the coast of the Max Bay in Alexandria, between the western port in the east and Dekheila port in the west, with a length of approximately 4.5 km, a depth of 5.0 meters below sea level, and a height of not less than 2 meters above sea level (total height 7.0 m) (Fig.28). This is with the necessity of great care when erecting concrete walls to protect this coastal strip due to the sub-surface imbalance in the western port (see above 4.1.3) so that the Max Bay does not become a source of threat to the vast lands to its south.
3. Two partially submerged armored concrete walls directly in front of the shore line facing the Mediterranean Sea on the coast of Dekheila port in Alexandria to protect the port's installations, berths and warehouses, with a total length of approximately 2.4 km, a depth of 5.0 meters below sea level, and a height of not less than 2, 0 meters above sea level (total height 7.0 meters) (Fig.29).

**Second:** Erecting cement ground bridges south of the shore line, with a height of no less than 2.0 meters above sea level, with flat surfaces and inclined sides to the north and south extending along the coast, or using existing roads after raising their level to 2.0 meters above sea level to take the place of these bridges as a second line of defense in the following locations:

1. A land bridge with a length of 10.5-11.0 km extending south of Al-Tabia Road - Rashid Line directly from the south of the suburb of Abu Qir in the west to Qantara El Maadiyah in the east, or using the same road as a bridge after raising its level in the low points to 2.0 meters above sea level (Fig. 27). This bridge is intended to strengthen the defense lines of the Beheira Governorate, as the failure of the first line of defense for any reason will result in the invasion of all the plains extending south of Abu Qir Bay.
2. A land bridge extending south of the city of Alexandria along the current northern Lake Mariout shore line extending from the borders of El Max in the west to City Center in the east, then it wraps around Nozha Airport along the ring road and from there to the northern border of the airport lake where it deviates east to Ezb Khurshid near the entrance to Apis ,with a total length of 22.0 km, and a height of not less than 2.0 meters above sea level (Figs.30-34). This bridge is intended to protect the residential, industrial, educational and social constructions and public utilities that were erected in the south of Alexandria on drained lands of Lake Mariout from the rise in the level of the lake in the event of sea water leakage to it for any reasons. A part of the route of the bridge required to be built applies to the axis of the High Dam south of Al-Qabbari, and another part is on the international road south of Moharram Bey. And a third part applies to the ring road south of the airport and City Center, where these roads can be exploited after raising their level to complete the bridge required to be built.

**Third:** Filling in and raising the level of dangerous depressions that permeate cities, suburbs or residential neighborhoods, by using cement mixtures with sand in the following places:


**Fig. 27: A satellite image of the Google Earth program of the southern coast of Abu Qir Bay extending from the suburb of Abu Qir in the west to the village of Maadiyah in the east - showing the proposed lines of defense (white lines), which are two lines of defense, the first of them (the continuous white line),It is represented by a submerged reinforced concrete wall in front of the shoreline directly facing the sea with a length of about 9.5 km, a depth below the current sea level of not less than 5 meters, and a height above the current sea level of not less than 2.0 meters (total height of 7 meters), extending From the south of the suburb of Abu Qir in the west to the village of Maadiyah in the east. The second line (the white dashed line) is represented by a land bridge whose height is not less than 2.0 meters above the current sea level, with horizontal surfaces and inclined sides to the north and south, and with a length of 10.5 to 11.0 km, it extends directly south of Al-Tabia - Rashid line From the south of the suburb of Abu Qir in the west to Qantara El-Maadiyah in the east. The same road that currently exists can be used to build this bridge after raising its level in low points to 2.0 meters above sea level.**

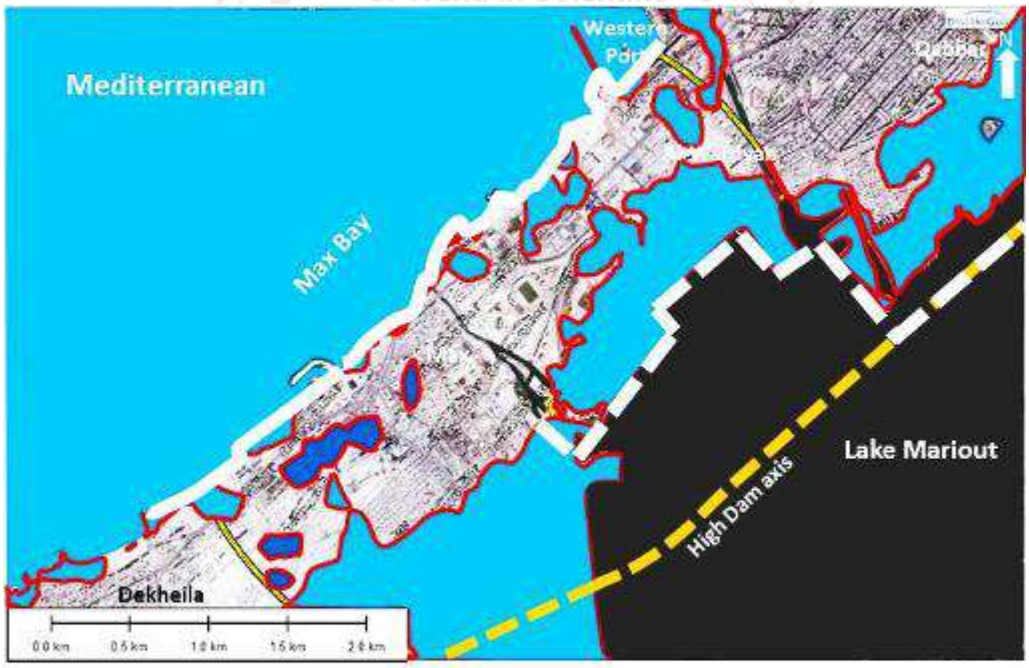



**Fig. 28: Satellite image of the Digital Globe program of the coastal strip extending on the coast of the Max Bay in, from Wardyan in the east to Dekheila in the west, and from the Mediterranean in the north to Lake Mariout in the south - showing on it the effect of sea level rise by a maximum of one meter and the proposed defense lines. The white lines are the lines Defense. The continuous white line along the shoreline is represented by a submerged reinforced concrete wall directly in front of the shoreline facing the sea with a length of about 4.5 km, a depth below sea level of 5 meters, and a height above sea level of 2.0 meters (total height of 7.0 meters). The white dotted line is the proposed second line of defense, represented by a land bridge extending along the current northern Mariout Lake shore line from the Max border in the west to the entrance of Apis in the east. Note that part of the bridge applies to the axis of the High Dam. See the extension of this bridge in the following figures.**

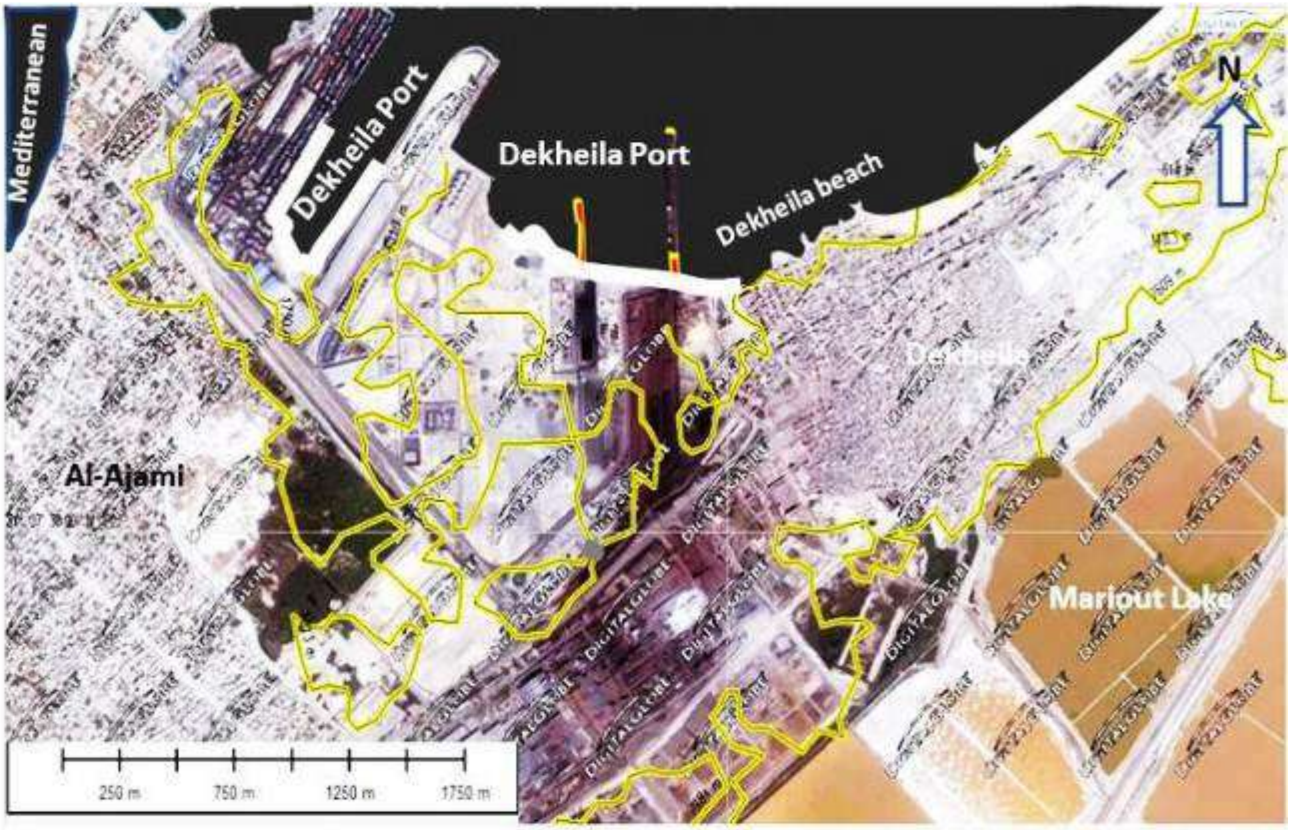



**Fig. 29: Satellite image of the Digital Globe program of the coastal strip extending from El Max in the east to El Dekheila port in the west - showing the proposed defense lines to protect El Dekheila port. The white lines are the proposed first lines of defense to minimize losses. They consists of two submerged armored concrete walls; each one is 5 meters deep below sea level, and two meters above sea level (with a total height of 7 meters). The total lengths on the shores of the Dekheila port are about 2.4 km without the concrete wall extending east between Al-Wardian and Dekheila (see the previous figure).**

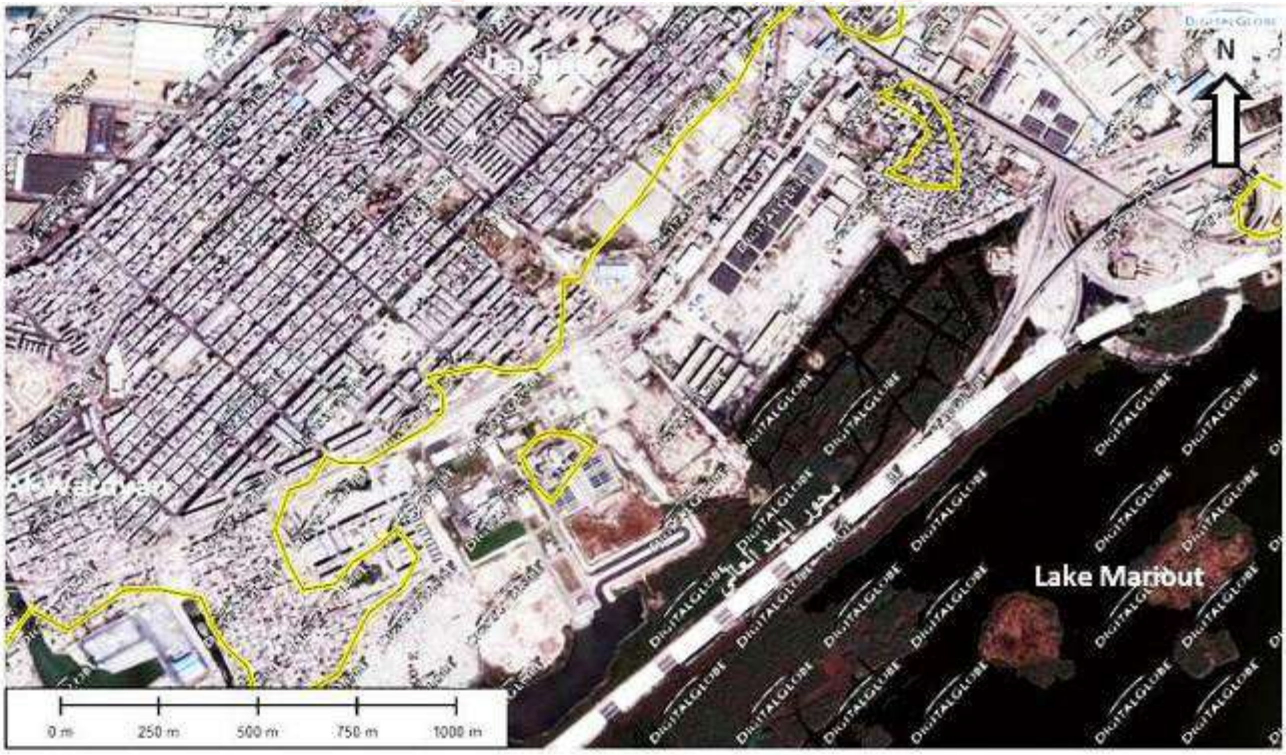



**Fig. 30: Satellite image of the Digital Globe program for the southern part of western Alexandria, extending along Lake Mariout, between Al-Qabbari in the east and Al-Wardyan in the west – showing on it part of the proposed path of the second defense line (the white dashed line). It applies in this part of western Alexandria to the High Dam axis road and its eastern extension to the new international road after raising the level of the low-lying areas of these roads to 2.0 meters above sea level**


**Fig. 31: Satellite image of the Digital Globe program for the southern part of central Alexandria, extending along Lake Mariout, between Nozha Airport in the east and Al-Qabbari in the west - showing on it part of the proposed path of the second defense line (dashed white line). It applies in this part of the center of Alexandria to the new international road until its meeting with the Alexandria-Cairo desert road, then its deviation eastward to the ring road after raising the level of the low areas of it to 2.0 meters above sea level**

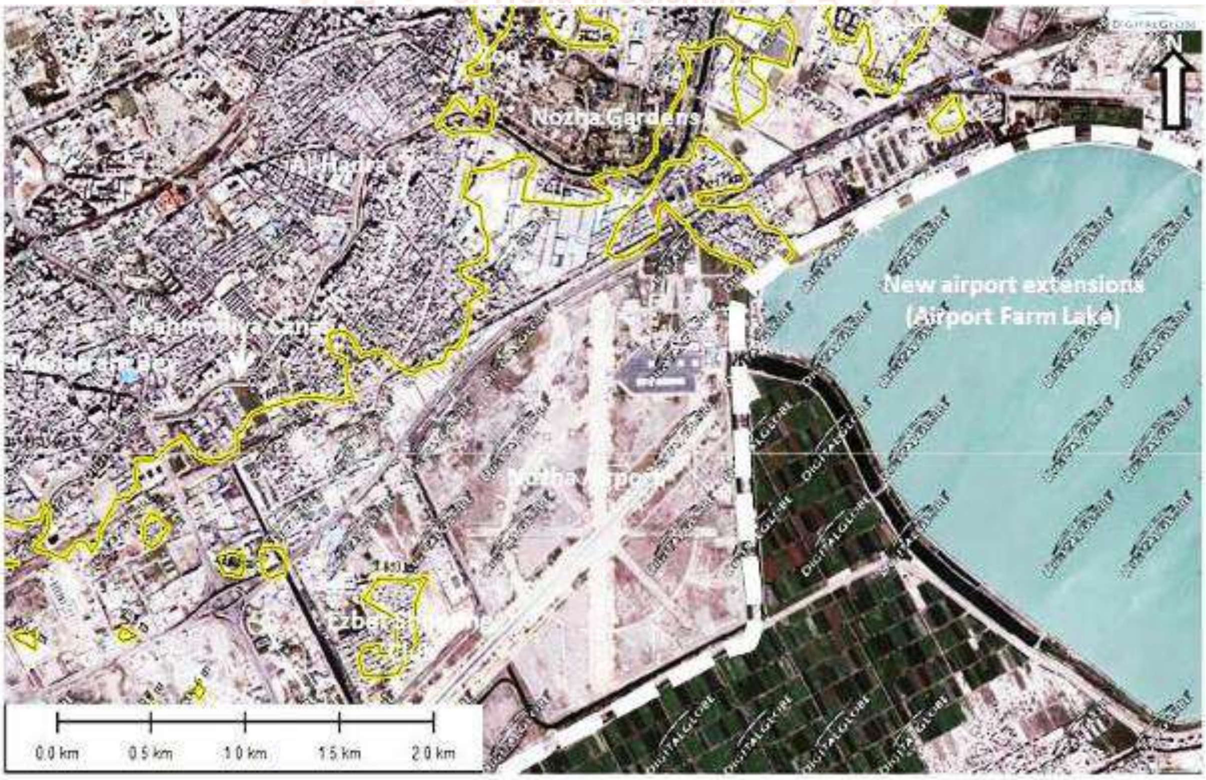



**Fig. 32: Satellite image of the Digital Globe program for the southern part of eastern Alexandria extending from Airport Lake in the east to City Center in the west - showing on it part of the proposed path of the second defense line (the white dashed line). The defense line applies in this part of the center of Alexandria to the ring road and its extension to Nozha Airport, where it deviates north around the airport, and from there to the Alexandria-Cairo Agricultural Road along the northern border of the Airport Lake, after raising the level of the lower parts of it to 2.0 meters above sea level.**

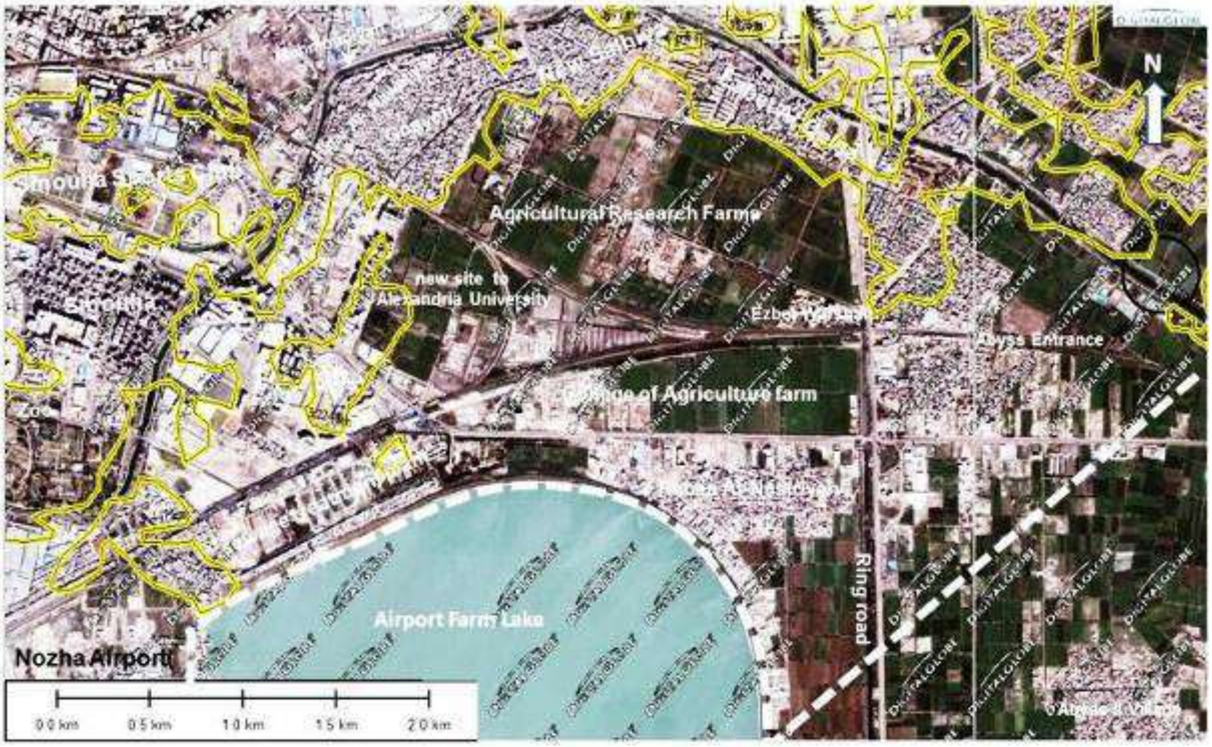



**Fig. 33: Satellite image of the Digital Globe program for the southern region in eastern Alexandria, extending from the entrance to Apis in the east to Smouha in the west, and from Mahmoudiyah Canal in the north to the airport lake in the south - showing the end of the proposed path of the second defense line (the white intermittent line). The line of defense in this part of the center of Alexandria represents a bridge that extends around the northern border of the airport lake and from there to (Alexandria-Cairo Agricultural Road) south of the Mahmoudiyah Canal near the entrance to Apis at a level not less than 2.0 meters above sea level.**

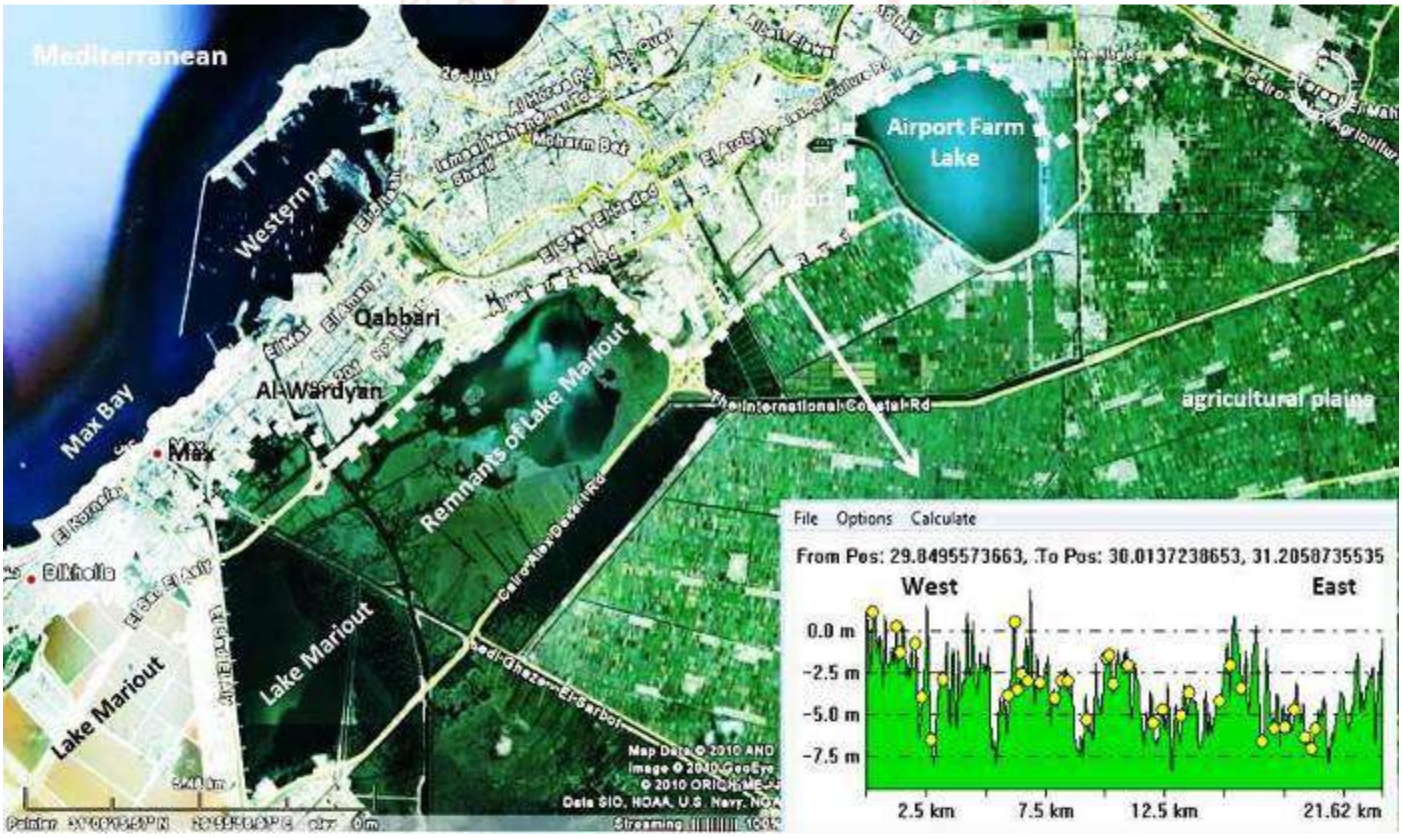



**Fig. 34: Google Earth satellite panorama of the coastal strip of the city of Alexandria, extending from the Sharq district in the east to El-Dekheila in the west, and from the sea in the north to Lake Mariout in the south, including the Western port and the Max Bay- showing the proposed second lines of defense (white dashed lines). The second line of defense is represented by a land bridge extending along the current northern Mariout Lake shore line from the Max border in the west to the City**

**Center in the east, then extending around Nozha Airport along the ring road and from it to the northern border of the airport lake where it deviates east to Azab Khurshid near the entrance to Apis, with a total length of about 22 km, and a height of not less than 2.0 meters above sea level. The attached diagram shows the path and terrain of this bridge. A part of this path applies to the High Dam axis road south of Qabbari, and a second part applies to the new international road, south of Muharram Bey, and a third part applies to the ring road south of the airport and City Center, where these roads can be exploited after raising their ground level to 2.0 meters above sea level.**

1. Smouha, Al-Seouf and Sporting depressions in Alexandria, with a total area of about 2.5 km². The most dangerous depression is the entire Smouha Sports Club, whose normal level ranges from zero to - 5.0 meters (and a maximum of -20.0 meters in one of the sites). Followed by the depressions located southwest of the club, whose level drops to - 3.0 meters (and a maximum of - 10.0 meters in one of the places). Then the depressions of Sporting Club and the depressions of Al-Seouf (west of Victoria) with a level of - 3.0 meters below sea level (Figs. 24-25). Many of these depressions were raised and dried up, but their level after drying does not exceed sea level as a maximum.
2. The depressions in the middle of the suburb of Abu Qir, while avoiding the construction of installations on them. These depressions extend for a length of 2.2 km from the east of the city to its west, with a width ranging between 180 and 900 m and a total area of about 1.0 km². Their ground level drops to - 4 meters below sea level in some locations (Fig. 26).

**Fourth:** Raising the level of the northern beaches of Alexandria from Abu Qir in the east to Ajami in the west by throwing free sands on the low parts facing the sea to raise it to a height of 1.5 - 2.0 meters above the current sea level.

## 5. Conclusion

The risks arising from sea level rise do not threaten the ancient city of Alexandria, which extends from Abu Qir in the northeast to Burg Al Arab in the southwest, as it is built at elevations ranging mostly from 5 to 20 meters (and a maximum of 25 meters) above sea level. The threat is limited to the urban expansions that were added to the south of the city at the expense of Lake Mariout on the one hand, and at the expense of the low agricultural lands in the north of the city south of the suburbs of Abu Qir, Maamoura, Montazah and Sidi Bishr al-Qibli on the other hand.

The southern coast of the Abu Qir Bay and the middle part of the Max Bay are not the only sources of threat to the city of Alexandria, but they are the two sources that threaten the entire northwest of the delta (west of the Rosetta branch) during this century as a result of the certain increase in the global sea level with a maximum of one meter above sea level the current sea.

The southern coast of Abu Qir Bay, which extends between the suburbs of Abu Qir and El Maadiyah, is the main source of threat to all the lands of the Beheira Governorate and the south of Alexandria, which extends south of Abu Qir Bay (south of the Tabia - Rashid Road) between the Nile River (Rasheed Branch) in the east, Mahmoudiya Canal in the south, and Alexandria in the west. The threatened lands account for about 86.5% of its current total area (1053 km2), where its level ranges from -6 meters below sea level to one meter above sea level, between the northern coast and the Mahmoudiya Canal.

Muhammad Ali's wall, which was built in 1830 in Abu Qir Bay in Alexandria, is not suitable for restoration in order to protect the plains to its south. The presence of leaks currently spreading on the coast directly south of the wall confirms the inability of this wall to repel severe waves if they rise for any reason of the local rise (such as severe storms and tsunami waves) as a result of the gaps and openings between the walls. The high waves also led to collapses in many areas of the wall. Therefore, the wall is not suitable for resisting the invasion of the sea if the global sea level rises to a meter.

Contrary to what some researchers expect, that the eastern part of the Max Bay known as the western port of Alexandria is the source of the threat to the low lands south of Alexandria, the elevation maps show that the middle part of the coast of the Max Bay, which extends between the western port (Wardyan) and Dekheila, with a length of about 4 km, is the weakest coastal part in the city of Alexandria. The limestone hills that extend along this part of the bay coast are interrupted by depressions and branching holes, ranging in ground level between -6.0 m and +1.0 m, and therefore it represents the second source after Abu Qir Bay to threaten all low lands south of Alexandria and extending to Damanhour in the east and the desert backs in the south in the event of an increase in sea level by a meter. As a result of the sea crossing of these depressions, all installations located on lands with low levels south of the shore line will be invaded. Also the installations which are built on dried lands of Lake Mariout, with ground levels not exceeding, after drying, the sea level, if not lower. This is in addition to the remaining submerged parts of Lake Mariout (139 km²), and all agricultural basins extending south of the Mahmoudia Canal to the desert and which attains about 1278 km², including all the dried and exploited lands of the original Lake Mariout south of Alexandria, and these areas are likely to increase by 190 km² of dry land if the sea level rises by a maximum of one meter.

The urban expansion threatened by the invasion of the sea can be protected through the establishment of armored cement walls partially submerged under the water (through soil injection operations) in the face of the shore line and capable of repelling any marine invasion into the ground or subsurface leakage at a depth below sea level of not less than 5.0 meters, and a height above sea level of not less than 2.0 meters (with a total height of 7.0 meters). As for the thickness of these walls at each site, it is left to the specialized engineers to determine the thickness that is commensurate with the length and height of the gap and in a way that is able to resist the pressure of the excess sea water. The Dutch experience can be used to construct these walls or modify their specifications. The locations of these walls are the southern coast of the Abu Qir Bay, between the suburb of Abu Qir in the west and the village of Maadiyah in the east, with a length of about 10 km, as well as on the coast of the Max Bay in Alexandria, between the western port in the east and the port of Dekheila in the west with a length of about 4.5 km.

The losses of the Dekheila port in Alexandria are the most severe losses of the Egyptian ports as a result of the increase in sea level - unless the necessary protection measures are taken. The area threatened by any increase in sea level less than a meter is estimated at 1.2 km², or 40% of the total area between the port and the Ajami, which is 3 km². In the case of an increase in sea level by a maximum of one meter, the areas threatened by the invasion are estimated at about 1.65 km², i.e. 53% of the total area mentioned. The port can be protected by erecting two partially submersible reinforced concrete walls directly in front of the shore line with a total length of approximately 2.4 km facing the Mediterranean Sea with the same specifications (5 meters depth below sea level and 2 meters high above sea level).

As for the second line of defense, it includes erecting cement ground bridges south of the shore line, not less than 2.0 meters above sea level, extending along the coast, or using existing roads (such as Al-Tabiya Road - Rashid Line) with a length of 10.5-11.0 km along the southern coast of Abu Qir Bay after raising its level to 2.0 meters above sea level. As well as south of the city of Alexandria along the current northern Lake Mariout shore line extending from the border of Max in the west to City Center in the east, then it turns around Al-Nozha Airport along the Ring Road, and from there to the northern border of the Airport Lake, where it deviates east to Ezb Khurshid near the entrance to Apis for a total length 22.0 km, and an elevation of not less than 2.0 meters above sea level. Part of the route of the bridge required to be built applies to the axis of the High Dam south of Qabbari, another part is on the international road south of Muharram Bey, and a third part applies to the ring road south of the airport and City Center, where these roads can be exploited after raising their level to complete the bridge required to be built.

We should not fail to note here that the original highlands of Alexandria are also interspersed with some few depressions that are not directly connected to surface water sources, but are threatened by total or partial inundation in the event of a rise in the subsurface water level as a sequential effect of sea level rise. The most important of these depressions are the Smouha, Al-Seyouf and Sporting depressions, with a total area of about 2.5 km², the most dangerous of which is the Smouha Sports Club depression. Most of these depressions are playgrounds and parks, and many of them have raised their level and drained what was submerged in them, but their level after drying does not exceed sea level.. Also, the center of the suburb of Abu Qir is interspersed with wide depressions below sea level up to -4 meters, with a total area of about 1.0 km². These depressions are exploited for residential and industrial use.

Likewise, all the beaches of Alexandria overlooking the Mediterranean are affected to varying degrees by the increase in sea level. They are all subject to complete or partial invasion if the sea level rises by any amount up to a meter - but the risks facing these beaches do not compare their results with the risks facing agricultural lands and residential, industrial and administrative neighborhoods built on low levels in the south of Alexandria Governorate. The effect of increasing the sea level on the beaches is limited, regardless of its economic value. The dangers of this increase can be avoided by strengthening the beaches and raising their level with free sands.

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