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Original Article

Analysis of the Change in Sea Level of the Mediterranean Sea and the Syrian Coast Between 1955 and 2023 AD and the Risks Resulting from it at the Regional and Local Levels

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Abstract - *The research aims to clarify the number of factors causing the rise in the level of the Mediterranean Sea, whether factors related to the global change in sea level as a result of terrestrial warming, represented by the water rise resulting from the thermal expansion of the oceans, the melting of glaciers and ice sheets, and internal factors related to the geological situation, structural movements, the topography of the Mediterranean Sea, water balance and exchange, water, wind force, etc. This research also shows the changes in the level of the Mediterranean Sea during different geological eras. It analyzes the nature of the current change in the level of the Mediterranean Sea between 1955–2022 AD. The research also aims to clarify the potential hazard effects of rising Mediterranean Sea levels, as the cities overlooking this sea are among the areas highly exposed to the risk of rising sea levels, including the towns and capitals of many Arab countries, and to identify areas vulnerable to submergence on the Syrian coast in particular. The study also includes an analysis of the factors behind the decline in the level of the Mediterranean Sea and the Syrian coast following the 2023 earthquake in Turkey and northern Syria, leading to an attempt to predict the future change in this sea level by analyzing the studies presented by the Intergovernmental Panel on Climate Change (IPCC).*

Keywords - *Coasts, Delta, IPCC, Mediterranean Sea, Recession, Turkey earthquake.*

1. Introduction

Future sea level rise is a real threat to many coastal residents, including the Mediterranean and the Syrian coast. A large part of the Mediterranean population lives in areas close to sea level, and the global warming resulting from the increase in the proportion of greenhouse gases in the atmosphere causes a rise in global sea level. For decades, we have been accustomed to discussing the dangers of the rise in the Mediterranean Sea level resulting from global warming, threatening many deltas, islands, and coastal cities in the Mediterranean with drowning. However, contrary to all expectations, we are surprised by the phenomenon of the recession of the Mediterranean coasts on many of its shores. This phenomenon appeared noticeably on February 9, 2023, after the earthquake in Turkey and northern Syria on all shores of the Mediterranean simultaneously. This research is focused on clarifying the factors causing the change in the Mediterranean Sea level between rise and decline over time and trying to predict future sea level change and identify the areas most threatened by submergence at the local and regional levels to take appropriate and proactive measures to protect against submergence.

2. Research importance and Aims

- The strength of the impact caused by the rise in the Mediterranean Sea level on many Mediterranean coasts, especially the deltas.
- The increasing fragility of the Syrian coasts as a result of the rise in sea level.
- The unprecedented recession of the Mediterranean coasts on many of its shores following the earthquake in Turkey and northern Syria in 2023 AD.

So, this present study aims to: 1-Study the factors causing the change in the level of the Mediterranean Sea in terms of the Mediterranean Sea being affected by the change in the amount and size of the global water mass and terms of the set of internal factors affecting the level of the Mediterranean Sea.2- Clarify the change in the level of the Mediterranean Sea

across different geological eras, including the Quaternary era. 3-Analyze the total changes that occurred in the level of the Mediterranean Sea between the rise and decline between 1955 and 2023 AD. 4-Detecting the areas most affected by the change in sea level at the local and regional levels, and 5-Analyze the factors causing the sudden recession of the coasts of the Mediterranean Sea on most of its shores following the earthquake in Turkey and northern Syria in 2023 AD.

3. Materials and Methods

3.1. Study Area

The Mediterranean Sea is located between the three continents of the Old World (Africa, Asia, and Europe) and extends between latitudes (27°) and (47°) north and longitudes (10°) west and (37°) east.

3.2. Research Methodology

The inductive approach was used to analyse all available data and then extrapolate the current situation and the general trend of the rise in the Mediterranean Sea level. The deductive approach was used to analyse all data on the changes in the Mediterranean Sea level and process them over time to extract the results.

3.3. Geographical Research Methods

The statistical analytical method, which included modeling and analyzing data, was used in statistical operations, and the cartographic method was used in preparing appropriate maps for the research using the Ark map program.

4. Results and Discussion

4.1. Factors causing the change in the Mediterranean Sea level

4.1.1. Factors Related to the Change in the Global Sea Level Caused by the Global Warming

These factors included water rise resulting from thermal expansion of the oceans and melting of glaciers and ice sheets.

Water rise resulting from thermal expansion of the oceans

Ocean water expands by absorbing heat from the air above it, as the water level of seas and oceans rises by 16 cm for every one degree Celsius increase in temperature. Another study provides an increase of 30 cm for a one-degree Celsius increase in temperature. These studies only concern the surface layer of water in actual contact with the air above it and its thermal changes (up to 100 m depth only). The deeper layer of water (up to a depth of approximately 1000 m), consisting of cold water in the winter at high latitudes, will remain immune to the rapid fluctuations in the water surface.

Melting of glaciers and ice sheets

Global warming, with its resulting temperature rise, is accompanied by the melting of terrestrial glaciers, causing their water to flow into water bodies, raising their level [1]. The receding of snow and ice causes greater absorption of solar radiation in Polar Regions, which leads to an acceleration in the rate of global warming and, consequently, a rise in the level of seas and oceans (Figure 1).

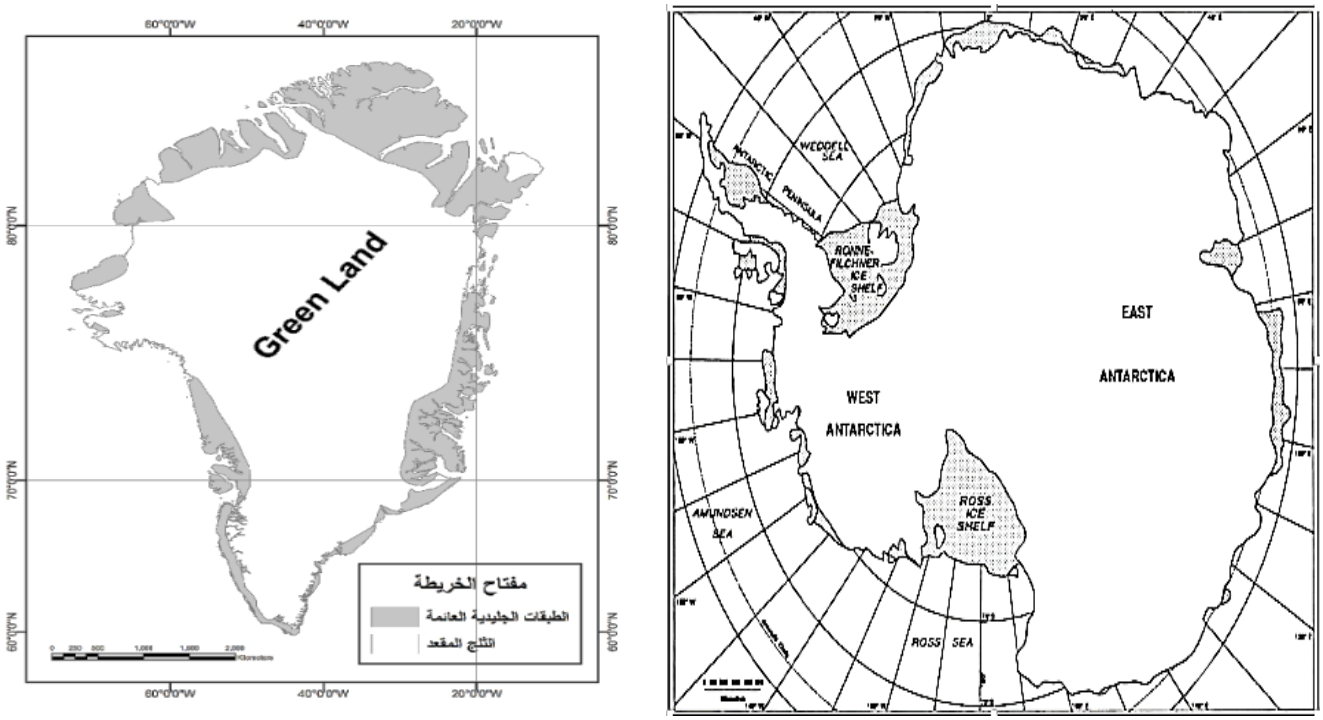

Fig. 1 The ice of the Antarctic (right) and Greenland (left): The shaded areas represent floating ice sheets, while the white areas indicate the seated ice (attached to the ground). The ice in Antarctica contains an equivalent of 65 m of sea level height, while the ice in Greenland contains an equivalent of 7 m of sea level rise

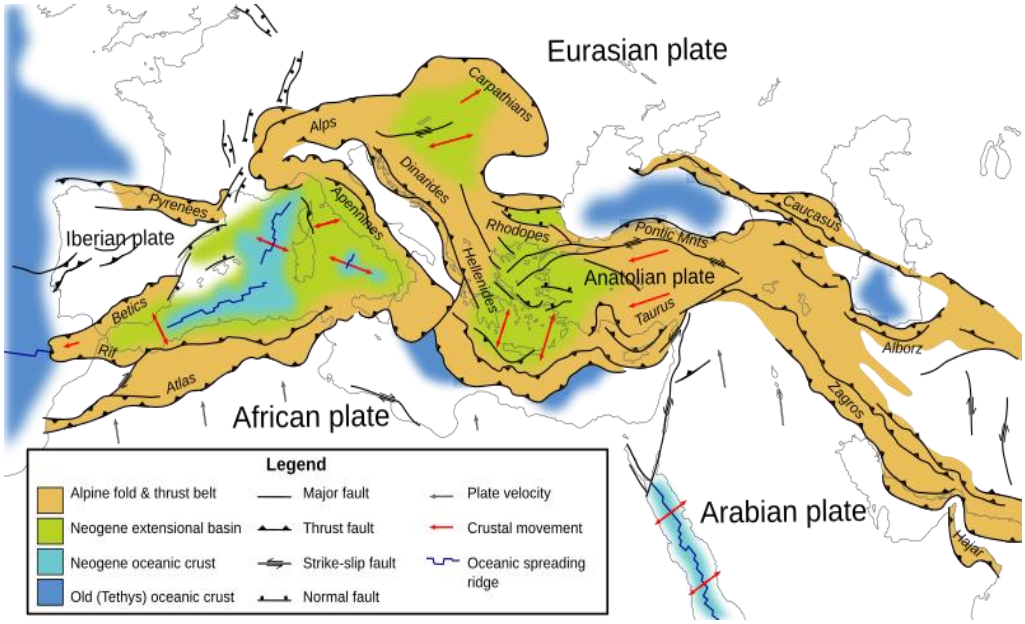

Fig. 2 Tectonic map Mediterranean [2]

4.1.2. Internal Factors

The internal factors include the geological structure and tectonic movements, as well as the topography of the Mediterranean Sea.

The geological structure and tectonic movements

The Mediterranean Sea is characterized by instability and great complexity because it is structurally located within the Alpine-Himalayan concave, representing an advanced stage in the development of concave plates. The instability is also due to the constant movement of the Arab-African base towards the north and northeast, pressing on the European continent, as shown in Figure (2). This intense pressure has put the mountainous areas overlooking the Mediterranean in the north in a state of continuous structural activity, and the Arab base is exposed to subsidence downward, submerged under the European base. These swallowing areas are characterized by instability, and this part of the crust is considered transitional towards the oceanic crust.

The Topography of the Mediterranean Sea

According to the topography of the Mediterranean Sea, the most fragile areas of the Mediterranean coast are the flat and low coastal plains (0-1 m above sea level), delta areas and plains formed at river mouths, and the sandy beaches characterized by their gentle slopes. Thus, the lower areas of the Mediterranean coast, such as sandy beaches, estuary plains, and deltas, will be exposed to more serious problems due to rising sea levels in places such as Egypt, the Arab Maghreb, and Northwest African countries. In contrast, the rise in sea level will have a lesser impact on European countries, and countries with higher coasts, such as Syria and Egypt in particular, will be the most affected, especially the Nile Delta in Egypt.

4.1.3. Reciprocal Water Movement

One of the causes of the difference in the level between the Mediterranean Sea and the Atlantic Ocean is the difference in the flow of water entering and exiting the sea, as the difference in the amounts of the flow of the Strait of Gibraltar is large and amounts to (0-2.6×10)6 m3/s. In contrast, the amount of difference between the water entering the sea is estimated at about (1020) km3, which is reflected in the sea level in general and locally. In addition to other factors like the changes resulting from the movement of the Mediterranean Sea waters which include Tsunamis and Tides, and the changes resulting from the accumulation of sediments on the bottoms of seas and oceans.

4.2. The Nature of the Change in the Level of the Mediterranean Sea between 1950 and 2022 AD

The change in the level of the Mediterranean Sea between 1955 and 2022 AD was determined by analyzing a set of sea level data through the Global Sea Level Observing System (GLOSS) which is one of the most important global systems for monitoring current sea level change through many of its stations in the Mediterranean Sea (Trieste, Marseille, Gibraltar, Antalya, Dubrovnik, Tarifa, Malaga, Alexandria, Trieste, Genova, Marseille) (Figure 3). The Mediterranean sea level rises were determined at the stations (Trieste in Italy, Marseille in France, and Gibraltar in the Strait of Gibraltar) from 1955 to 2022 AD and for a shorter period at some stations (Figure 4). Figure 4 shows a decrease in the level of the Mediterranean Sea at a rate ranging between -0.3 and - 0.5 mm/year between 1955 and 1991 AD. The reason for this is likely to be an abnormal increase in atmospheric pressure over the Mediterranean Sea, i.e. an increase in atmospheric pressure over the Mediterranean basin and conflicting atmospheric pressures, which pushed water out of the basin.

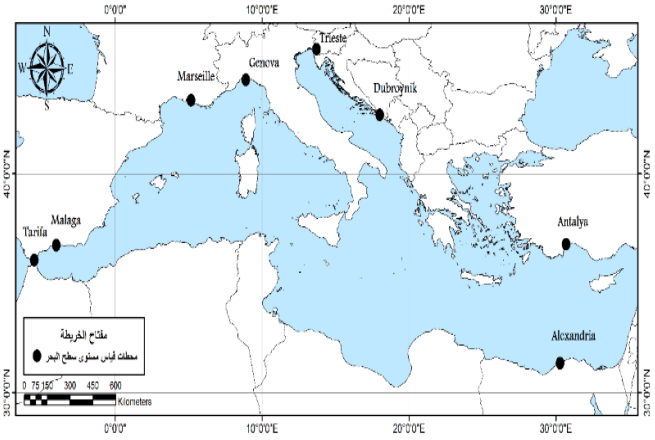

Fig. 3 Map of Mediterranean sea level measurement stations. Source: Prepared by the present study based on (GLOSS)

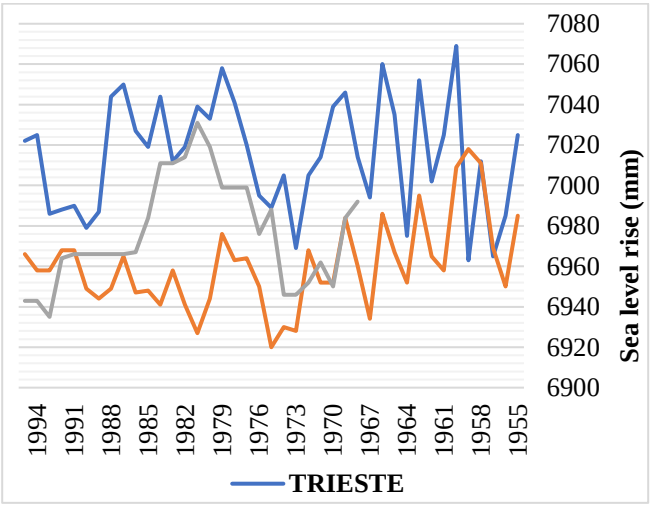

Fig. 4 Average sea level changes (mm) at selected stations between 1955 and 1995. Source: Prepared by the present study based on (GLOSS)

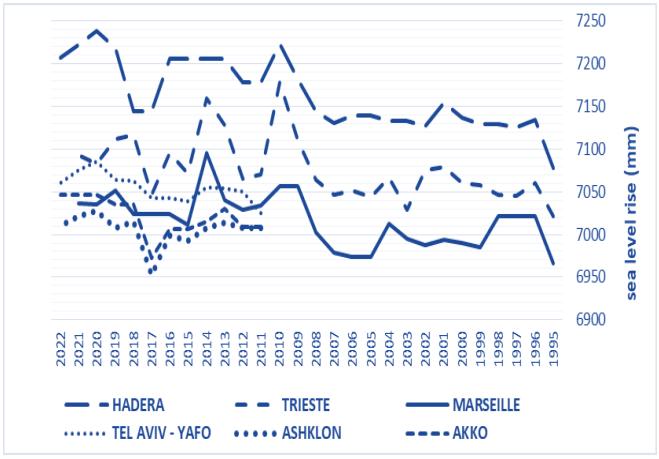

Fig. 5 Average sea level changes (mm) at selected stations between 1995 and 2022 AD. Source: Prepared by the present study based on (GLOSS)

Sea level elevations were determined at the following stations: Trieste in Italy, Akko, Ashklon, Hadera, and Yafo on the eastern coast of the Mediterranean, and Marseille in France, for a period of 28 years starting from 1955 to 2022 AD, and for a shorter period at some stations as shown in Figure (5). The Mediterranean Sea level began to accelerate after 1989, driven by dynamic changes and loss of land ice, reaching a rate of 3.6 ± 0.3 mm per year in the period 2000-2018 due to the general retreat of ice and the melting of ice in mountainous and coastal areas in cold latitudes.

The sea level has risen faster since the beginning of 2000 in the Aegean, Adriatic and Levant seas compared to other areas in the Mediterranean. The average rise in all the studied stations was about 180 mm over a period of 28 years (at a rate of 2.5 mm/ year (figure 5). These results are close to the results of many studies, such as the study of Wexler [3], who estimated the sea level rise at about (2) mm/year, and Wigley and Raper [4], who estimated the sea level rise at about 1.7 mm/year, and the study of Fairbridge [5] who indicated a rise in sea level at a rate of 1.12 mm/year.

4.3. Analysis of the Recession of the Syrian Coast and the Mediterranean Sea in 2023 AD

Contrary to what is commonly believed in studies that usually analyze the risks of rising sea levels in the Mediterranean resulting from the phenomenon of global warming, threatening many deltas, islands and coastal cities in the Mediterranean with drowning, an unusual phenomenon is occurring, which is the phenomenon of the recession of the Mediterranean coasts at a rate of 30-50 cm on many of its shores. This phenomenon appeared noticeably after the earthquake in Turkey and northern Syria, that is, on February 9, 2023, AD, on all shores of the Mediterranean simultaneously. The multiple hypothetical reasons for the decline in the Mediterranean Sea level following the earthquake in Turkey and northern Syria were revealed, some of which were due to climatic factors and some of which were due to geological or astronomical factors such as the tides, the high atmospheric pressure and the phenomenon of anticyclone, decrease in annual rainfall for that year, in addition to geological reasons.

4.3.1. The Tides

It is a positive movement of the waters of the seas and oceans, which occurs under the influence of the gravitational forces of both the moon and the sun. It has a regular or irregular periodic nature, as the gravitational relationships and connections between the Earth, the moon and the sun draw the nature of the tide movement, in addition to the influence of natural geographical factors. If the sun, moon and Earth are on the same straight line, this leads to the phenomenon of the great tide, which occurs on the Syrian coast on two consecutive days in December, according to a study by Kayali. But this reason is not sufficient to explain the sudden recession of all the Mediterranean coasts at the same time, as when the sea level rises due to the phenomenon of tides in a specific area, the water recedes in another area because the mass of water is fixed and does not change.

Table 1. Sea level rise rate in mm for the year 2100 AD

Source	Thermal expansion (mm)	Glacier melt (mm)	Greenland ice sheet melting (mm)	Antarctic ice sheet melting (mm)	Optimal estimate of sea level rise (mm)	Total height range (mm)	Until the year
IPCC90-A	43	18	10	5-	66	110-31	2100

Source: Prepared by the researcher based on the IPCC Second Assessment Synthesis Report [6]

Table 2. Sea level rise in the next century for the six scenarios proposed in the fourth report

climate trend			B1	B2	A1B	A1T	A2	A1F1
Sea level rise relative to 1990	Best report (mm)		0.28	0.32	0.35	0.33	0.37	0.43
	Range(mm)	%5	0.18	0.21	0.23	0.22	0.25	0.28
		%95	0.37	0.42	0.47	0.44	0.50	0.59

Source: Prepared by the researcher based on the IPCC Fourth Assessment Synthesis Report [8]

4.3.2. High Atmospheric Pressure and the Anticyclone Phenomenon

The anticyclone in meteorology is a climatic phenomenon that refers to areas of high atmospheric pressure where the wind moves in a vortex over those areas. The high atmospheric pressure of 1035 HPA over the Mediterranean Sea at the beginning of February led to a disturbance in the movement of seawater and a decline in sea level by several centimeters. Also, this reason is insufficient to explain the sudden decline in all the coasts of the Mediterranean Sea simultaneously, as the phenomenon of high atmospheric pressure occurs annually in the winter and has not previously caused any decline in sea level.

4.3.3. Decrease in Annual Rainfall

European countries witnessed a decrease in the amount of annual rainfall, accompanied by a decrease in the river flow that feeds the water supply to the Mediterranean Sea.

4.3.4. Geological Reasons

The most important geological reasons are the occurrence of a crack in the seabed as a result of the displacement of the Arabian plate and its collision with the Anatolian plate, which led to the earthquake in Turkey and northern Syria and the expansion of the Mediterranean basin floor, and the waters of the Mediterranean seeped in to fill it, resulting in a sudden decline in the water level from all the Mediterranean coasts at the same time. In this regard, it was noted after the accident that the water began to gradually return to its previous level due to the water compensation process as a result of the Mediterranean Sea's water connections with neighboring seas and oceans. Naturally, the Mediterranean Sea is characterized by a negative water balance, and the annual water deficit of the Mediterranean Sea is estimated at (1700) km3 according to the study Kayali [10]; this deficit is one of the causes of the annual decrease in sea level if it were not for the water compensation process as a result of the Mediterranean Sea's water connections with neighbouring seas and oceans.

4.4. The Future of Change in the Level of the Mediterranean Sea

The temperature will rise at a rate of 1.5 - 4.5 C° by the year 2050 AD, according to the report published by the National Center for Atmospheric Research in the United States (NCAR), considering all greenhouse gases.

This temperature rise will be accompanied by a rise in sea level between 20 - 140 cm. Therefore, two cases must occur in the future: the melting of all the ice and the continued rise in the general sea level, and thus the submersion of large parts of the land surface underwater, in addition to the time in which we live, represents a greenhouse phase, and the surface of the Earth will be exposed again in the future to a period of severe cold, which will lead to an increase in ice and a decrease in sea level. By 2100 AD, the sea level will rise by about 66 cm, according to the second report submitted by the Intergovernmental Panel on Climate Change (IPCC), as shown in Table (1). The third report stated that climate change will lead to a rise in seawater temperature, a rise in sea level, and a decrease in sea ice cover [7].

The fourth report [8] and the fifth report indicated that sea level will rise in the next century by about 18-59 cm due to the thermal expansion of warm oceans and the increased rate of melting of icebergs (Table 2).

The Intergovernmental Panel on Climate Change recommended that about 0.2 m should also be added to the upper limits of the expectations as a precaution against what might be involved in the melting of ice in Greenland and Antarctica, which were not fully included in the proposed models. Accordingly, the total of the proposed expectations for sea level in (2095) becomes the equivalent of 0.18 and 0.79 m relative to 1990 [8].

4.5. Identifying Areas Exposed to Flooding on the Syrian Coast

The Syrian coasts suffer from the impact of climate change factors, especially the rise in sea level and the accompanying physical, chemical and biological changes. The Syrian coastal and marine areas differ in their impact on sea level change according to various factors, including topographic and geological factors. The coastal plain is one of the areas most affected by sea level change, especially coastal lakes, salt marshes, and low-lying areas.

4.5.1. The Coastal Plain

Most areas of the Syrian coastal strip extend at elevations below 50m above sea level, directly affecting these areas by current and future marine phenomena resulting from climate change, especially sea level rise and marginal marine phenomena.

4.5.2. Coastal Lagoons (Lagoons) and Salt Marshes (Ramat) in the Syrian Coastal Plain

Coastal lagoons have disappeared from the Syrian coast. In contrast, a large lagoon called Ramat al-Lahha was found, which belongs to the Al-Hamidiyah region, about 25 km south of the city of Tartous, directly south of the Abrash River and represents a wet coastal area with an area of more than 50 hectares. The ground level in Ramat al-Lahha is low, which makes it vulnerable to direct submergence due to rising sea levels. It used to be a lagoon or a coastal lake connected to the sea via a waterway or strait. However, currently, the waterways have been turned into natural drains for the sea due to sedimentation processes.

4.5.3. Low-Lying Areas on the Syrian Coast

The flat areas with low elevations relative to sea level are the most vulnerable to flooding on the Syrian coast. They are often within the range of 1-2 m or less, in addition to river mouths and sloping sandy beaches.

4.5.4. Sandy Beaches

There are about 90.91 km of sandy beaches along the Syrian coast.

5. Conclusion

The current level of the Mediterranean Sea is affected by the current global sea level, which is gradually rising at a rate of 1-2 mm/year and decreases at a rate ranging between -0.3 - 0.5 mm/year between 1960 and 1989 due to the increase in atmospheric pressure above the basin, which pushes water out of the basin. After the year 1989, the level of the Mediterranean Sea began to rise at a higher rate reaching to 3.6 - 0.3 mm/year between 2000-2018 due to the melting of land ice. It began to rise faster since 2000 in the Aegean Sea, the Levantine Sea and the Adriatic Sea in particular compared to anywhere else in the Mediterranean. The sea level has continuously risen over the past 28 years in all Mediterranean stations, as the average rise reached about 180 mm. According to IPCC reports, predicting the rise in sea level in the next century will be about (18-59) cm. On the other hand, the emergence of a crack in the Mediterranean Sea floor as a result of the displacement of the Arabian plate towards the Anatolian plate is the most acceptable reason for explaining the phenomenon of the sudden decline in the level of the Mediterranean Sea and the Syrian coast in 2023 AD.

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