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Evaluation of The Impact of Climatic Changes on Sea Water Level at The Northern Egyptian Coastal Area

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Abstract

In the recent and coming decades, the climate change induced sea level rise (SLR), is considered a big challenge facing many countries especially coastal cities, islands, and deltas. The sea level rise has significant impacts on coastal systems included flood risks, coastal erosion, loss of coastal infrastructure, and danger of saltwater intrusion. This research aims to establish and observe the sea level fluctuation along the Mediterranean coast of Egypt. Two tide gauge stations were installed (Alexandria city and Port said city), to record the sea level each 30 minutes since 2010 till now. Acquiring and analysing the long-term datasets of the tide gauges were conducted in order to estimate the relative trend of sea level rise. A group of relationships of the sea level fluctuation on the basis of daily, monthly, and yearly, were produced. It can be concluded that the sea level rise within the period (2010 – 2020) was ranging from 2 to 5 mm/year, while the sea level was fluctuated from 65 mm to 650 mm. The obtained results were compared and matched with other study covered the period from year 1943 to year 2000.

Keywords: *Sea level rise, climate changes, tide gauge, Nile delta*

1. Background

Most of the countries have major effects of climate change. Global warming due to greenhouse gas emissions (GGE) and radiation forces are causing changes in the climate system. Millions of people in urban areas are likely to be affected by rising sea levels and more extreme heat and cold. Increasing warming amplifies the exposure of small islands, low-lying coastal areas and deltas to the risks associated with sea level rise for many human and ecological systems, including increased saltwater intrusion, flooding and damage to infrastructure. Risks associated with sea level rise are higher at 2°C compared to 1.5°C. The slower rate of sea level rise at global warming of 1.5°C reduces these risks, enabling greater opportunities for adaptation including managing and restoring natural coastal ecosystems and infrastructure reinforcement (Intergovernmental Panel on Climate Change, 2018)

More than 600 million people live in coastal areas that are less than ten meters above sea level and these areas are becoming increasingly urbanized, During this century, flooding from the rising sea level and storm surges will threaten the viability of some islands as well as some major deltas, such as the Nile and Mekong River deltas (Ponte, N., 2013).

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Model-based projections of global mean sea level rise (relative to 1986–2005) suggest a range of 0.26 to 0.77 m by 2100 for 1.5°C of global warming, 0.1 m (0.04 – 0.16 m) less than for a global warming of 2°C (medium confidence). By 2100, global mean sea level rise is projected to be around 0.1 meter lower with global warming of 1.5°C compared to 2°C (medium confidence). The sea level will continue to rise well beyond 2100 (high confidence) and the magnitude and rate of this rise are depending on the future emission pathways. From the climate models and based RCPs scenarios, the projections for mean sea level rise are presented in Table 1 and Fig. 1

Emission scenarios	**Representation concentration pathway (RCP)**	**2100, CO_2 concentration (ppm)**	**Mean sea level rise**	
			2046 - 2056	2100
Low	2.6	421	0.24 (0.17-0.32)	0.44(0.28-0.61)
Medium low	4.5	538	0.26 (0.19-0.33)	0.53(0.36-0.71)
Medium High	6.0	670	0.25 (0.18-0.32)	0.55(0.38-0.73)
High	8.5	936	0.29 (0.22-0.38)	0.74(0.52-0.98)

Table 1: mean sea level for varies emission scenario

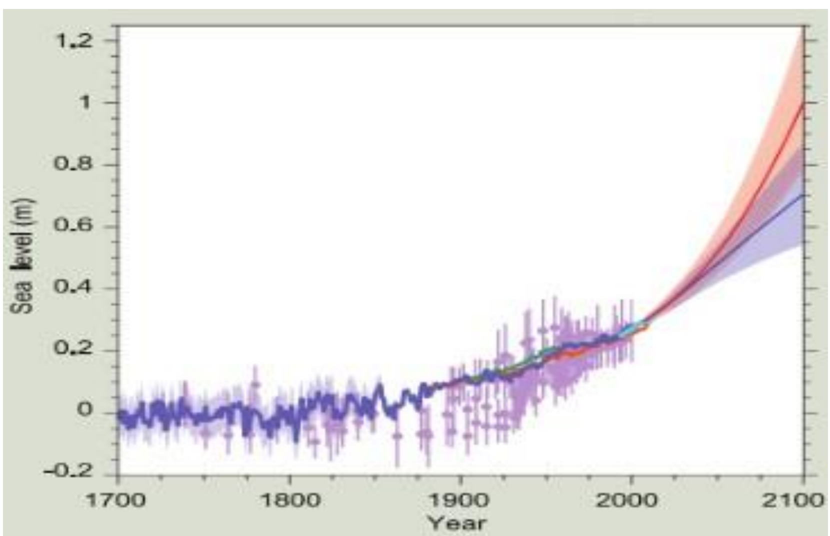


Figure 1, Global Mean Sea Level Rise

Worldwide tide measurements during the period from 1901 to 2010, indicated that the global average sea level rise is 19 cm as oceans expanded due to warming and ice melted. The average sea level rise is predicted as 24 – 30 cm by 2065 and 40-74 cm by 2100. In fact, many coastal ecosystems, including deltas and small islands, will have to face the threat of increased flooding and land loss due to sea level rise, changes in river flows and sediment transport, and severe storms (Nicholls, 2011)

With the study conducted by Hinkel et al (Hinkel et al. 2012) under the A1B scenario, the sea level rise by year 2100 is expected 1.26 m and the projected losses of 25 percent of the Nile Delta's land area, is expected with a 1-meter sea-level rise. Another study done by United Nations Development program, (Hassanein, M. 2012), estimated that 0.5 m sea-level rise by year 2070. As shown in Table 2, under the A1F1 scenario, the projected losses of 22.5 % of the Nile Delta's land area, is expected with 1.04 -meter sea-level rise. While under the Rahms and Pfeffer scenarios, the projected losses of 42.5% and 49.2% of the Nile Delta's land area, is expected with 1.85 m and 2.45 m sea-level rise respectively.

1. "Coastal flood damage and adaptation costs under 21st century sea-level rise".
2. United Nations Development program, 2013 "Potential Impacts of Climate Change on the Egyptian Economy" http//:

Study done by Hassanein (Hassanein, M. K, 2013), concluded that, under the A1F1 scenario, about 14.4 % of the Nile Delta would be at risk from inundation by 2100. Depending on the sea-level rise scenario and assuming no adaptation, about 22.5–29.2 % of the area was vulnerable to inundation. Some coastal low-lying land could be inundated in the Nile Delta. Figures 2a, 2b present the impact of sea level rise on Nile delta in case of 0.5 m and 1.0 m sea level rise.

Figure 2a, Impact of sea level rise of 0.5 m on Nile Delta

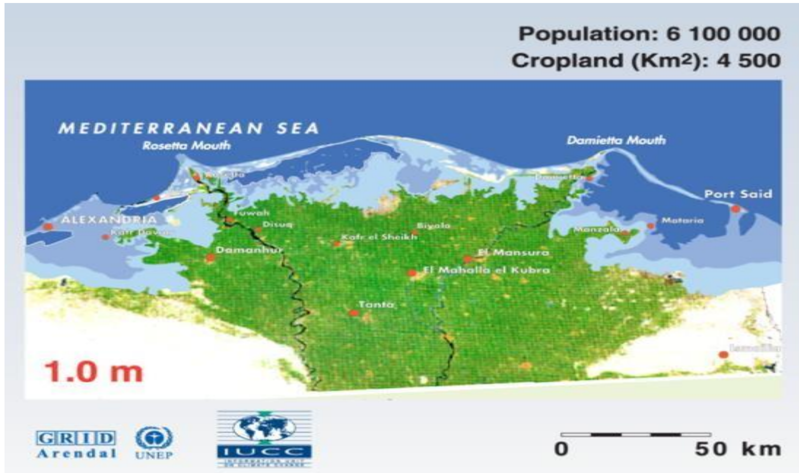


Figure 2b, Impact of sea level rise of 1.0 m on Nile Delta

scenario	projected relative SLR (m)	inundation delta area		distribution of inundation impact		
				built land	cultivated land	undeveloped land wetland
		Km2	%			
A1F1	1.04	4,006	22.5	4.4%	42%	53.6%
Rahms Torf	1.85	7,336	42.2	3.8%	60.7%	35.5%
Pfeffer	2.45	8,769	49.2	3.7%	64%	32.3%

Table 2, Result for three scenarios of sea level rise in the Nile Delta

The study done by Elshinnawy (Elshinnawy , 2012) , concluded that the tide data along the Northern Egyptian coast from year 1943 to year 2000 show that the annual rate of sea-level rise ranges between 1.6 and 5.3 mm/year included the land subsidence. In addition, the study conducted by Ali et al (Ali,2015) expected that the increase of sea level to year 2100 will ranges between 4 cm and 22 cm according to the different IPCC scenarios, , which will cause inundation of the lowland areas along the Nile Delta coast.

concluded that, the present sea-level rise can cause addition shoreline erosion with rate of 0.1 to 0.15 m/year. The Nile Delta coast will be accelerated lost under the effect of the sea-level rise, subsidence, and the presence of High Aswan Dam.

The study conducted by Moheb (Moheb,2020), clarified that the climate change within the Egyptian Mediterranean coastal zone, created severe shoreline erosion along the Northern coast and migration of the sand spit inland along the Rosetta Nile branch. Therefore, it was recommended that the coastal sand dune, as well as other nature resources of sediment, should be protected to eliminate the coastal erosion.

Based on population density, economy, biophysical characteristics, and effectiveness of safety measures, the risk assessment matrix indices were built and presented in Table 3 by Mimura (Mimura, 2012) He stated that the Risk areas in the Alexandria region are: Mandara and El Tarh (east of the city), while risk areas in the Nile Delta region are: the Manzala Lagoon barrier, east and west of the Rosetta City, Gamil, and the Tineh plain.

Sector index	NW Coast	Alexandria	Nile Delta	North Sinai
Population	L	M	M	L
Economy	M	H	H	M
Biophysical	L	M	H	L
Effectiveness of safety measures	L	M	M	L

L=low, M= Moderate, H= High [12]

This research present part of the observation system to monitor the sea level fluctuation along the Mediterranean coast of Egypt to cope with their consequence impact.

2. Materials and Methods

2.1 Vulnerability of Study Area

Egypt is located in northern Africa, bordering the Mediterranean Sea between Libya and Gaza strip, with a coastal strip extending for about 3,500 kilometers, overlooking the Mediterranean Sea in the north, and the Red Sea in the east. The main feature of the northern coastal zone is low lying delta of the River Nile. The climate is semi-desert characterized by hot dry summers, moderate winters and very little rainfall. The country is characterized by particularly good wind regimes with excellent sites along the Red Sea and Mediterranean coasts. There is some winter rain in the delta and along the Mediterranean coast, west of the delta. Most of the population and infrastructure are concentrated in the Nile Delta and along the Mediterranean coast, which makes the country vulnerable to the impacts of sea level rise and saltwater intrusion.

2.2 Tide Gauge Stations

Sea level variation is essentially in determining: the shore-line position, navigation channel depth and the crest elevation of protective measures as well as the optimum forces affecting. Moreover, most decision makers are not considered the effect of sea level rise in near future consequently, protection works could face many hazards. In order to know the water level variation in the sea, a recorder tide gauges are installed. Two Tide gauge stations were installed along the Mediterranean Sea at Alexandria and Port Said (see Fig. 3). These tide gauges work with float and counter weight (type delta manufactured by SEBA hydrometric, Germany). The sea level variation data is recorded by Strip chart recorder. These charts are weekly collected and analyzed to convert into digital form. The sea level was recorded each 30 minutes. A model sample of the long-term datasets for Alexandria tide gauge for April 2016, is presented in Table 4. A computer program has been prepared to calculate the average sea level (daily, monthly, yearly).

Figure 3, Locations of the Tide gauges stations at vulnerable study area

hour / Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0:00	40.3	35.7	32.6	31.0	32.6	35.7	41.9	49.6	54.3	55.8	55.8	51.2	46.5	41.9	37.2
0:30	41.1	36.4	32.6	30.2	30.2	32.6	37.2	44.2	49.6	52.7	54.3	51.2	47.3	43.4	38.8
1:000	41.9	37.2	32.6	29.5	27.9	29.5	32.6	38.8	45.0	49.6	52.7	51.2	48.1	45.0	40.3
1:300	43.4	39.5	34.1	30.2	27.9	27.9	29.5	34.9	41.1	46.5	50.4	50.4	48.8	46.5	41.9
2:000	45.0	41.9	35.7	31.0	27.9	26.4	26.4	31.0	37.2	43.4	48.1	49.6	49.6	48.1	43.4
2:300	46.5	44.2	38.8	34.1	30.2	27.1	26.4	29.5	34.1	40.3	45.7	48.8	49.6	48.8	45.7
3:000	48.1	46.5	41.9	37.2	32.6	27.9	26.4	27.9	31.0	37.2	43.4	48.1	49.6	49.6	48.1
3:300	49.6	48.8	45.7	41.9	36.4	31.8	28.7	28.7	30.2	35.7	41.1	46.5	49.6	50.4	49.6
4:000	51.2	51.2	49.6	46.5	40.3	35.7	31.0	29.5	29.5	34.1	38.8	45.0	49.6	51.2	51.2
4:300	51.2	52.7	52.7	50.4	45.7	40.3	34.9	32.6	31.0	34.1	38.0	43.4	48.8	51.2	52.7
5:000	51.2	54.3	55.8	54.3	51.2	45.0	38.8	35.7	32.6	34.1	37.2	41.9	48.1	51.2	54.3
5:300	51.2	55.0	57.4	57.4	55.0	50.4	44.2	40.3	36.4	35.7	38.0	41.9	47.3	51.2	54.3
6:000	51.2	55.8	58.9	60.5	58.9	55.8	49.6	45.0	40.3	37.2	38.8	41.9	46.5	51.2	54.3
6:300	50.4	55.0	58.9	62.0	62.0	59.7	55.0	49.6	44.2	40.3	40.3	41.9	45.7	50.4	53.5
7:000	49.6	54.3	58.9	63.6	65.1	63.6	60.5	54.3	48.1	43.4	41.9	41.9	45.0	49.6	52.7
7:300	48.8	52.7	57.4	62.8	65.9	65.9	63.6	58.9	52.7	47.3	44.2	43.4	45.0	48.1	51.2
8:000	48.1	51.2	55.8	62.0	66.7	68.2	66.7	63.6	57.4	51.2	46.5	45.0	45.0	46.5	49.6
8:300	46.5	48.8	53.5	58.9	64.3	67.4	67.4	65.9	60.5	54.3	49.6	46.5	45.0	45.7	48.1
9:000	45.0	46.5	51.2	55.8	62.0	66.7	68.2	68.2	63.6	57.4	52.7	48.1	45.0	45.0	46.5

Table 4, 30-minute raw data for Alexandria tide gauge, April 2016

3. Results and Discussions

The raw data was analyzed and the average fluctuated of sea level was calculated, daily, monthly, and yearly, starting from January 2008 to April 2017, as shown in Table 5. The mean of the maximum and minimum sea level was presented in Table 6.

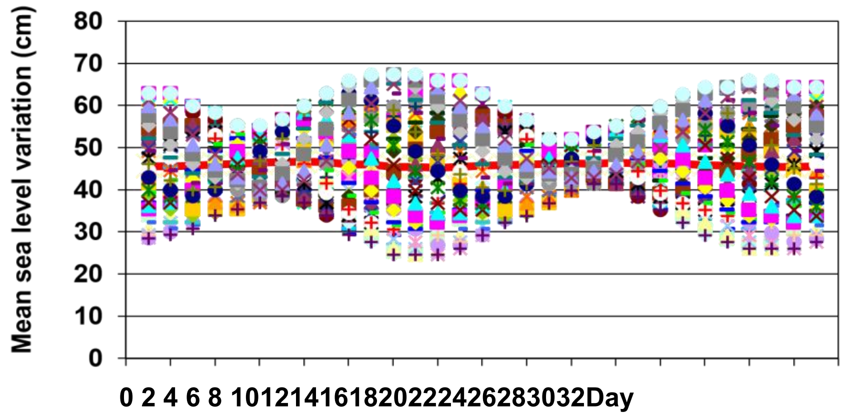
year	Alexandria Tide gauge			Port Said Tide gauge		
2008	Daily Mean (mm)	Monthly Mean (mm)	yearly Mean (mm)	Daily Mean (mm)	Monthly Mean (mm)	yearly Mean (mm)
2008	200-650	100	4 - 5	200-700	200	2 - 3
2009	200-650	140		200-700	70	
2010	200-650	80		200-700	90	
2011	200-650	80		200-700	80	
2012	200-650	80		200-700	80	
2013	200-650	60		200-700	80	
2014	200-650	60		200-700	80	
2015	200-650	60		200-700	80	
2016	200-650	65		200-700	80	
2017	200-650	30		300-700	50	

Table 5, the average sea level (daily, monthly, yearly)

year	Alexandria Tide gauge			Port Said Tide gauge		
	Mean SL (mm)	Mean of Max. SL (mm)	Mean of Min. SL (mm)	Mean SL (mm)	Mean of Max. SL (mm)	Mean of Min. SL (mm)
2008	415	467	363	439	562	315
2009	418	491	344	442	567	316
2010	442	493	391	440	564	316
2011	451	493	409	498	565	431
2012	453	489	416	465	523	406
2013	460	500	420	453	485	420
2014	456	484	428	458	496	420
2015	462	495	428	460	500	420
2016	462	494	429	461	501	421
2017	444	459	429	446	470	421
Average	446			456		

Table 6, the mean of the maximum and minimum sea level

A group of relationships of the sea level fluctuation on the basis of daily, monthly, and yearly, were developed as examples for both tide gauges and presented in Figs.4, 5, 6, 7.



Alexandria Tide_GuageJan 2017

Figure 4, Daily Sea level fluctuation for Alexandria tide gauge

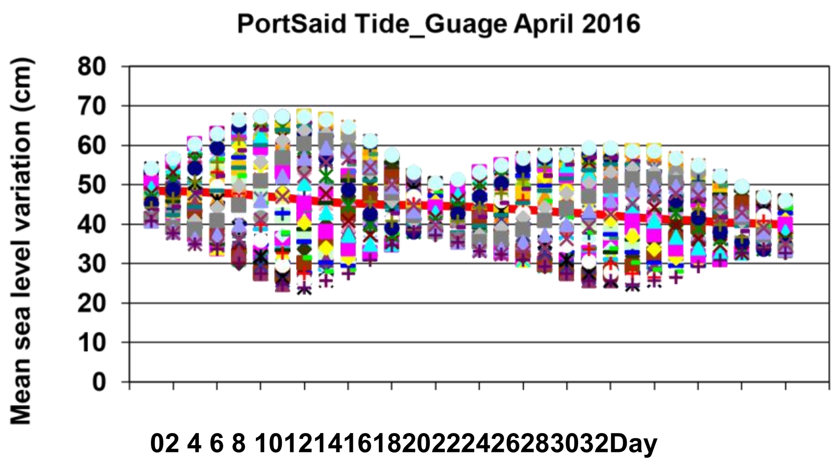


Figure 5, Daily Sea level fluctuation for Port Said tide gauge

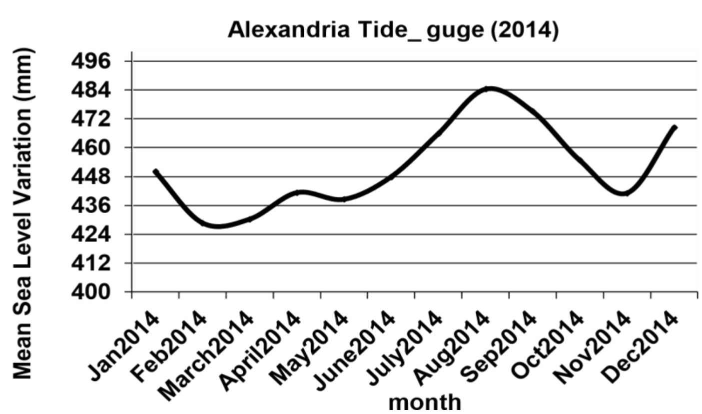


Figure 6, Monthly Sea level fluctuation for Alexandria tide gauge

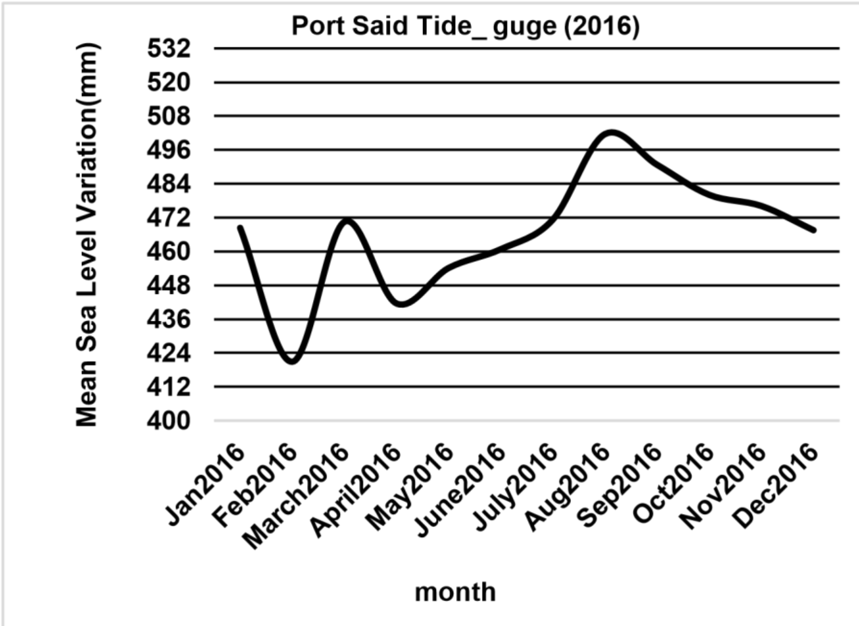


Figure 7, Monthly Sea level fluctuation For Port Said tide gauge

Starting from January 2008 to April 2017, it can be seen clearly that, the average daily of sea level at Alexandria and Port said stations, was ranging from 200 mm to 700 mm. At Alexandria station, the monthly mean of see level decreased from 100 mm at year 2008 to 30 mm at year 2017. While at Port Said station, the monthly mean of see level decreased from 200 mm at year 2008 to 50 mm at year 2017. The annual mean of see level was ranged between 4 – 5 mm and 2 – 3 mm at Alexandria and port Said stations respectively.

Furthermore, the mean of the maximum sea water level at Port Said station (52.45 mm) is more than that in Alexandria station (48.69 mm). It was noted that the mean sea level during the period from 2008 to 2017 ranged from 415 mm to 444 mm and from 439 mm to 446 mm for Alexandria and Port Said stations respectively. While the average mean sea level during that period were 446 mm and 456 mm for Alexandria and Port Said stations respectively. Hence, for the period of year 2008 up to year 2017, the annual trend of the sea water level rise is calculated and presented in Figs. 8 and 9 for both stations (Alexandria and Port Said).

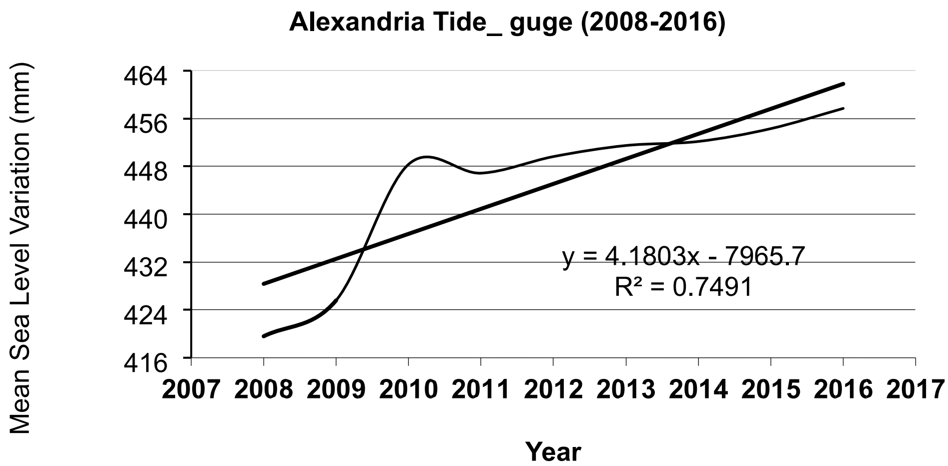


Figure 8, Mean rate of Sea level Rise for Alexandria tide gauge

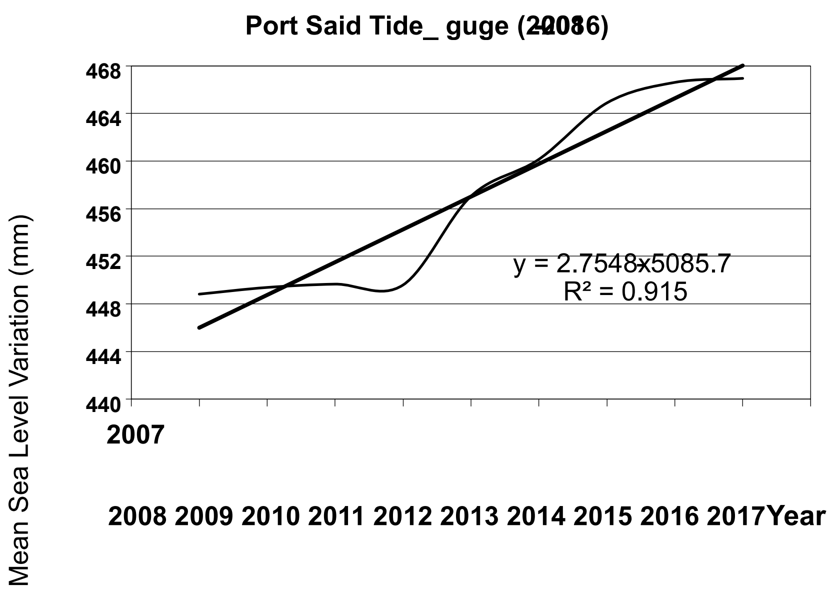


Figure 9, Mean rate of Sea level Rise for Port Said tide gauge

It can be seen that the slope of the line at Alexandria station is more than that at Port Said station, which mean that the trend for future increasing of the sea level at Alexandria station will be more risk than that in Port Said station. This sea level rise can be expressed by the equations; Y = 4.18 X – 8000 (R2 = 0.75) and Y = 2.75 X – 5000 (R2 = 0.91) for Alexandria and Port said gauges respectively. (where Y is the annually mean of the sea level, X is the year). Finally, the obtained results were compared with reviewed studies and found matched with the study done by Hassanein et al (2013). Generally, at the two stations, the water level increased during summer months due to the positive surge acting by wind action which cause drawl of water toward the shore. While it decreased during February that may be due to the negative surge which cause negative drawl of water away from the shore.

4. Adaptation Measures Towered Sea Level Rise

For controlling the impact of sea level rise (SLR), the Egyptian government implement National Strategy for Adaptation to Climate Change such as setting up regulations and guidelines for coastal development included; i) incorporating the effect of the SLR in the context of the environmental impact assessment (EIA) and strategic impact assessment (SEA), ii) setting limits and binding requirements when issuing permits to drill wells for the withdrawal of groundwater in the coastal zone, iii) designing engineering structures to protect high risk vulnerable areas, iv) introducing appropriate measures to mitigate penetration of seawater toward the cultivated delta soil, v) rehabilitating and strengthening the existed engineering coastal structures particularly on the low-lying lands, and vi) implementing sand dunes systems to be the first defensive line for the Nile Delta.

5. Conclusion

There is no doubt that the Nile Delta would be at risk from inundation by 2100 due to the sea level rise. Previous studies along the Northern Egyptian coast from 1943 to 2000 show that the annual rate of sea-level rise ranges between 1.6 and 5.3 mm/year included the land subsidence. In this research, a group of relationships of the sea level fluctuation on the basis of daily, monthly, and yearly, were produced. The increase rate of the sea surface in the period from 2008 to 2016 was ranged from 2 to 5 mm annually, which matched with the findings of previous studies. The obtained result was compared with other study conducted from 1943 to 2000, show that the annual rate of sea-level rise ranges between 1.6 and 5.3 mm/year included the land subsidence.

In fact, in case of assuming no adaptation, about 25% of the Nile delta area will be lost. Therefore, the government and the private sector must be proactive in establishing adaptation strategies to reduce the potential impacts. These could include establishing institutional for integrated coastal monitoring and management capabilities, enforcing laws and regulations, and raising awareness of climate risks and adaptation to build resilience.

6. Acknowledges

Thanks, and grateful to the Egyptian navy surveying Authority for great supporting and providing maintenance and security to the constructed tide gauge stations. The extended thanks and grateful also for the team of survey research institute (SRI)

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