Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2022, 9(5):85-100**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Variations of Sea Levels and Atmospheric Parameters along the Egyptian Coasts Over 2008-2020

Gomaa M. Dawod*, Ahmed M. Amin, Ghada G. Haggag

Survey Research Institute, National Water Research Center, Giza, Egypt
* dawod_gomaa@yahoo.com, ORCID = 0000-0002-4426-8231

Abstract Recently, the climate changes and global warming phenomena have resulted in a significant Sea Level Rise (SRL) worldwide. The objectives of the current study include defining the recent Mean Sea Level (MSL) datum of Egypt, estimating SRL trends, and investigating the correlation between sea level and meteorological elements, principally air temperature and atmospheric pressure, and to give general indications about sea level and atmospheric elements' variations at four locations over the Egyptian coasts along both the Mediterranean and Red seas. It utilizes the most-recent heterogeneous hourly datasets from 2008 to 2020. Even though it is a relatively medium period, the achieved findings are significant for coastal management and risk assessment of environmental hazards. The attained results, as previous researches, reveal sea level is increasing as going east over the Mediterranean Sea and it decreases as going south over the Red Sea. In addition, it has been shown that sea level has a strong positive correlation with air temperature and a strong negative correlation at Alexandria, Port Said, and Suez sites. Concerning the spatiotemporal variations of sea level in Egypt, it has been noticed that the relative rising rate of the Mediterranean Sea range from 1.8 mm/year at Port Said to 3.1 mm/year at Alexandria. Regarding the Red Sea, the relative SRL varies between 2.7 mm/year at Suez and 4.3 mm/year at Safaga. Generally, the accomplished findings necessitate developing a national plan for dealing with the SLR phenomenon and its consequence hazardous environmental impacts. From a geodetic and surveying perspective, such reality should be significantly considered in the realization of a recent Egyptian vertical datum for mapping and surveying applications.

Keywords Environmental Changes, Global Warming, Sea Level Rise, Metrological Elements, Egyptian Costs

1. Introduction

Nowadays, it becomes a fact that the Earth suffered a global warming phenomenon, in the last couple of centuries, with serious environmental and economic hazards. One such crucial hazard is the accelerating Sea Level Rise (SRL) worldwide that causes sea flooding, particularly for low-elevation lands and coasts. According to the Intergovernmental Panel on Climate Change (IPCC), three chief remarks should be considered: (1) the global SRL has increased from 1.4 mm/year over the period 1901-1990 to 2.1 mm/year over 1970-2015 to 3.2 mm/year over 1993-2015 to 3.6 mm/year over 2006-2015, (2) under some specific scenarios, the global SRL could likely reach 0.84 m (0.61-1.10 m) by 2100 over the 1986-2005 level, and (3) if global warming is fast accelerating and the global air temperature is kept rising over the next three centuries, a global SRL could be over few meters by 2300 [1]. On another hand, it has been found that atmospheric pressure affects the sea level changes on a global basis over a long time [2-3]. Moreover, warm air temperature could contribute significantly to the generation of severe sea level changes and storm surges in coastal regions [4-5].

Global variations of sea levels are attributed to several factors such as thermal expansion, glaciers melting, and land water storage changes [6] (Oppenheimer et al. 2019). Moreover, Local or regional SLR are mostly due to land subsidence, ocean dynamics, and climate changes (ibid). Global Sea Level Rise (GSLR) is a mean estimate of SLR worldwide, which varies from one specific region to another. Thus, many studies have been carried out to estimate SLR over different spatial areas. For example, Parker and Ollier [7] have reported that SLR in India, computed from datasets of 11 TG over 51 years, equals 1.06 mm/year. Similarly, the SLR in the north-western part of the Arabian Gulf was found to be 2.2 mm/year [8]. In Poland, the SLR over the period 1951-2017 was estimated as 2.99 mm/year [9].

Projecting SLR over future time comprises a vital research activity for estimating the vulnerability of such significant environmental hazards. An example of such projection reported by Mengel et al. [10] where sea level in 2100 could rise by 0.28-0.56 m, 0.37-0.77 m, and 0.57-1.31 m for different greenhouse gas concentration scenarios. Other studies have projected the SLR in the 21st century on a regional scale. For example, Edwards [11] has reported that in the United Kingdom there are three scenarios of sea level rise from 1990 to 2100 based on the expected rise in global temperature: (a) the low-to-medium case of possible SLR of 0.30 m, (b) the high scenario of possible 0.60 m of SLR, and (c) the extreme situation of SLR of 2.5 m. Similarly, Dawod et al. [12] have projected sea level at four TG stations along the Delta coastlines and estimated the risks of SLR and storm surges by 2025.

In Egypt, evaluating SLR has become a major concern not only to the government but also to the research community in the last few decades. For example, Dawod [13] (2001) has utilized datasets at Alexandria over 1944-1999 and at Port Said over 1926-1987 to estimate a long-term SRL over the Nile delta along the Mediterranean sea. He found that SRL equals 1.7 mm/year and 2.4 mm/year at Alexandria and Port Said respectively. Moreover, Dawod et al. [14] have utilized hourly tide datasets and Global Navigation Satellite Systems (GNSS) covering 2008-2016 to estimate relative SRL, land subsidence rates, and absolute SRL at both Alexandria and Port said. It has been found that the relative SRL in the Nile delta region varies from 2.6 mm/year to 4.3 mm/year, and the vertical land movements rates at the tide gauge sites range between +0.09 mm/year and -4.3mm/year, and hence the absolute SRL differ between 5.0 mm/year at Alexandria to 6.9 mm/year at Port Said. Recently, Radwan et al. [15] have utilized different datasets with variable time resolution (over the period 2009-2015) at Alexandria, Damietta, and Port Said along the Mediterranean sea to investigate the variations of sea level in the Nile delta region. They estimated the Mean Sea Level (MSL) relative to the 1906-based national datum equal 0.172 m, 0.601 m, and 0.513 m at Alexandria, Damietta, and Port Said respectively. Using a three-year tide dataset (covering 2012-2014), El-Geziry et al. [16] have inspected the general pattern of sea level in Safaga and Qussier harbors on the Egyptian Red sea costs, and they found that the MSL at those two sites equal 0.56 m and 0.50 m respectively.

The metrological elements that influence sea level variations comprise a wide range of factors as utilized in many research studies worldwide. For example, Zubier and Eyouni [17] have analyzed the relation between sea levels and air temperature, atmospheric pressure, wind speed and wind near Jeddah harbor, Saudi Arabia. Other researchers [18] have focused on the relationship between wind and air pressure on the variability of sea levels. Other studies have analyzed the influence of both air temperature and precipitation on sea level variations [19]. Moreover, Han et al. [20] have studied the impacts of only atmospheric pressure on sea levels in the Asian marginal seas. In Iraq and Egypt, Both Latfa [21] and El-Geziry et al. [22] have investigated sea level variations with air temperature, atmospheric pressure, and wind speed.

The relationship between sea level and metrological factors has been investigated extensively in the last few years in Egypt. Mohamed [23] and Dawod et al. [24] have investigated the inter-relationship between the MSL and meteorological variations at Alexandria. Based on the monthly tide and metrological records from 1985 to 2003, it has been concluded that the most-critical metrological elements are the air temperature that has a 60% positive correlation impact on the recorded tide, and the air pressure which has a negative correlation of 40%. Thus, the current research highlights the correlation between sea level and only air temperature and atmospheric pressure. Furthermore, Sharaf El Din [25] has investigated the relationship between sea level changes and metrological factors over three tide gauges in Egypt along both Mediterranean and Red seas over 1956-1966. Freshly, Ibrahim [26] has investigated the variability of sea level at Mersa Matruh along the Mediterranean sea and their relationship to pressure, air temperature, and wind speed. She concluded that air temperature and wind speed significantly affect the observed sea level at this site.

This paper aims to fulfill three objectives: (1) defining the recent MSL datum, (2) estimating SRL trends, and (3) investigating the correlation between sea level and meteorological factors, and (4) to give general indications about sea level and atmospheric elements' variations at four sites over the Egyptian coasts along both the Mediterranean and Red seas using most-recent heterogeneous datasets over the period 2008-2020.

2. Methodology

There are several approaches for analyzing the trend of sea level variations and their relationship to metrological elements, with a wide range of variability in mathematical formulation, flexibilities, and characteristics [27]. Some of such techniques are harmonic analysis [28], machine learning [29], and Artificial Neural Network: ANN [17]. However, the regression statistical analysis has been extensively utilized in modelling and predicting sea level variability worldwide. For example, Jamali et al. [30] have utilized regression to predict monthly variations of sea level in Malaysia. Moreover, Kumar [31] has investigated the variations of sea levels in the western South Pacific islands using the multiple regression approach with a selection of some oceanic and atmospheric parameters as input. Also, the regression approach has been applied to statistically reconstruct sea levels in the Baltic sea from tide gauge datasets [32].

Simply, the correlation coefficient quantifies the correlation between two or more variables. It is a unitless value that varies between +1, expresses strong positive agreement, and -1, describing a strange negative agreement, where 0 means no correlation between the investigated variables. The sample correlation coefficient, r_{xy}, between two variables x and y can be estimated as:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}} \qquad (1)$$

where,

n is the sample size,

x_i, y_i are the individual i^{th} sample point, and

$\bar{x}$ and $\bar{y}$ are the sample mean for both variables x and y.

Moreover, linear regression modelling has been performed to model the temporal variations of sea level and metrological elements over the period 2008-2020. A linear regression model can be estimated as:

$$Y = a + bX \qquad (2)$$

where,

Y is a set of observed values of the dependent variable,

X is a set of predicted values of the independent variable, and

a and b are two unknowns to be estimated as:

$$a = \frac{(\sum y)(\sum x^2) - (\sum x)(\sum xy)}{n(\sum x^2) - (\sum x)^2} \qquad (3)$$

$$b = \frac{n(\sum xy) - (\sum x)(\sum y)}{n(\sum x^2) - (\sum x)^2} \qquad (4)$$

To judge the goodness of the attained linear regression model, a statistical measure called the coefficient of determination, R^2, is applied. Simply, it represents the proportion of the variation in the dependent variable that is estimated from the independent variable. Thus, its value ranges from zero to +1 and the higher this value the better the regression model. The coefficient of determination could be estimated as:

$$R^2 = \frac{\sum(\hat{y} - \bar{y})^2}{\sum(y - \bar{y})^2} \quad (5)$$

where,

$\hat{y}$ and $\bar{y}$ represent the estimated and average values of the dependent variable respectively.

3. Study Area and Available Data

The study has utilized two integrated datasets: sea level data and metrological data, particularly air temperature and atmospheric pressure. Such datasets have been collected over along Egypt's Mediterranean coasts between Alexandria (31.13^{0}N, 29.88^{0}E) and Port Said (31.20^{0}N, 32.31^{0}E) and the Red sea cost from Suez (29.91^{0}N, 32.59^{0}E) to Safaga (26.71^{0}N, 33.95^{0}E) as depicted in Fig. 1.

The four Tide Gauges (TG) have been installed and operated by the Survey Research Institute (SRI) of the National Water Research Center (NWRC) under the umbrella of the Ministry of Water Resources and Irrigation. At Alexandria and Port Said, the installed (TG) are microwave devices (Fig. 2) while pressure devices are installed at Suez and Safaga sites. The collected Sea Level (SL) datasets comprise bi-hourly measurements from 2008 to 2020 for three TG, while the fourth one, namely Suez, has data since 2016. No gaps exist for the three sites, but Port Said TG did not have SL data in 2018 (Table 1). It is worth mentioning that the utilized TG data at all locations have an accuracy level of less than one centimeter. Moreover, the normality of the utilized datasets has been analyzed and proved and, thus, parametric modelling techniques, such as the regression analysis, could be carried out. Also, it should be stated that SL data at Alexandria are relative to the vertical national Egyptian datum as defined in 1906, while the other three TG have data tied to the nearest benchmark, where a datum shift of 0.18 m exists between those two vertical frames. It is worth mentioning that there are no hourly 30-years TG datasets available in Egypt to extremely analyze climate changes and global warming. Thus, the current available dataset have been utilized to give general indications about sea level and atmospheric elements' variations in Egypt.

Figure 1: The Study Area

Figure 2: A Utilized Tide Gauge

Normally, the investigation of long-term variations of sea level and metrological elements require long-span datasets of at least 30 years. However, the importance of that environmental issue and the lack of long-term data, in many situations, force several researchers to utilize data covering only fewer years. For example, Latfa [21] has analyzed the influence of atmospheric forces on sea-surface fluctuations in Iraq using hourly datasets covering the entire year of 2017. Also, El-Geziry et al. [22] have utilized datasets of two years (2012-2013) to investigate the variability of sea-level in Safaga harbor, Egypt in relation to metrological conditions and tidal characteristics. Also, Tur et al. [29] have utilized sea level and metrological datasets over 2014-2015 in investigating sea level prediction in Antalya harbor, Turkey.

The second dataset contains hourly metrological data at the four investigated sites over the period 2008-2020 with no gaps. Such dataset has been collected from several online sources, particularly the Automated Surface Observing System (ASOS) and the Automated Weather Observing System (AWOS) projects [33].

Table 1: Available Datasets

(a) Sea Level Data

Site	Data Span	Gaps
Alexandria	2008-2020	None
Port Said	2008-2020	2018
Suez	2016-2020	None
Safaga	2008-2020	None

(B) Metrological Data

Site	Data Span	Gaps
Alexandria Port Said Suez Safaga	2008-2020	None

4. Results and Discussions

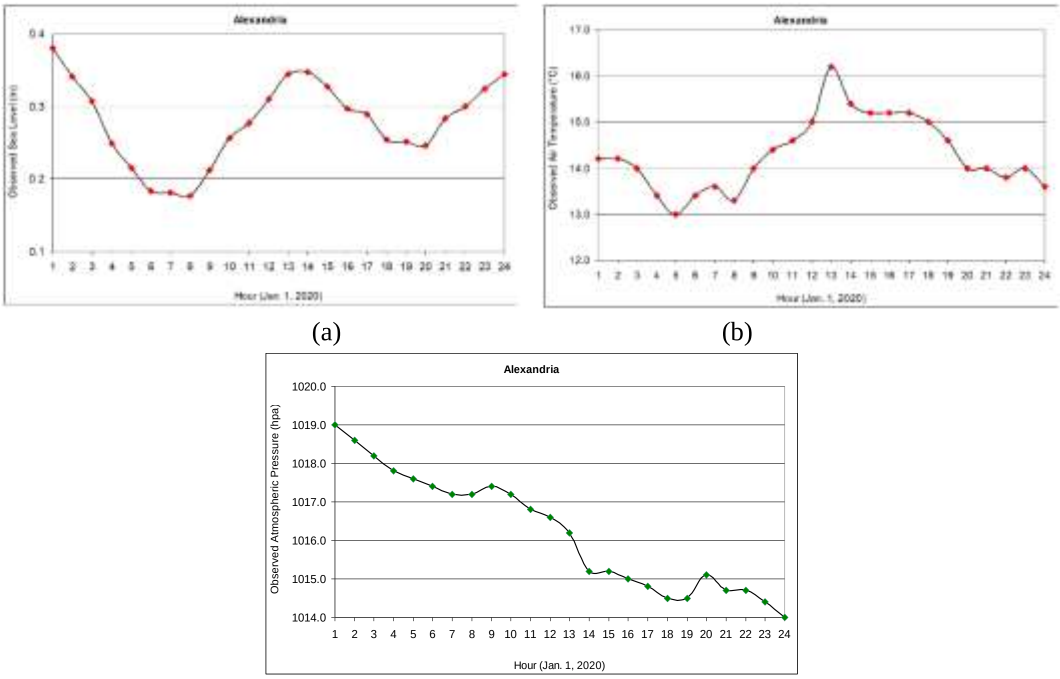
The accomplished results have been presented and analyzed in the next four sub-sections.

4.1 Daily Variations

The hourly datasets of sea levels, air temperature, and atmospheric pressures at the utilized four TG have been investigated. The first of January 2020 (as the most-recent dataset) has been selected as a typical day for inspecting the daily patterns of sea level and metrological factors. Starting by studying the variations over the Mediterranean sea at both Alexandria and Port Said, Table 2 summarize the daily variations. It can be noticed that the sea level at Alexandria varies between 0.177 m and 0.380 m with an average equals 0.279 m. While at Port Said, it ranges from 0.288 m to 0.510 m with a mean of 0.403 m. Regarding air temperature at Alexandria, it changes daily from 13.0 ^{o}C to 16.2 ^{o}C with a mean equals 14.3 ^{o}C. At Port Said, the air temperature varies between 12.0 ^{o}C and 17.9 ^{o}C with an average of 14.9 ^{o}C. The atmospheric pressure at Alexandria ranges from 1014.0 hpa to 1019.0 hpa with an average of 1016.2 hpa. At Port Said, it varies between 1017.2 hpa and 1020.8 hpa with a mean of 1019.0 hpa. Fig. 3 and 4 depict the daily variations of such factors at Alexandria and Port Said respectively. It can be noticed that the sea level daily patterns at both sites are semi-diurnal (two maximum and two minimum values) in nature. As expected, the daily patterns of air temperature are diurnal at both sites. However, the atmospheric pressure does not possess a daily pattern.

Table 2: Variations Over the Mediterranean Sea on January 1st, 2020

Item	Minimum	Maximum	Mean
(A) At Alexandria			
Sea Level (m)	0.177	0.380	0.279
Air Temperature (^{o}C)	13.0	16.2	14.3
Atmospherics Pressure (hpa)	1014.0	1019.0	1016.2
(B) At Port Said			
Sea Level (m)	0.288	0.510	0.403
Air Temperature (^{o}C)	12.0	17.9	14.9
Atmospherics Pressure (hpa)	1017.2	1020.8	1019.0

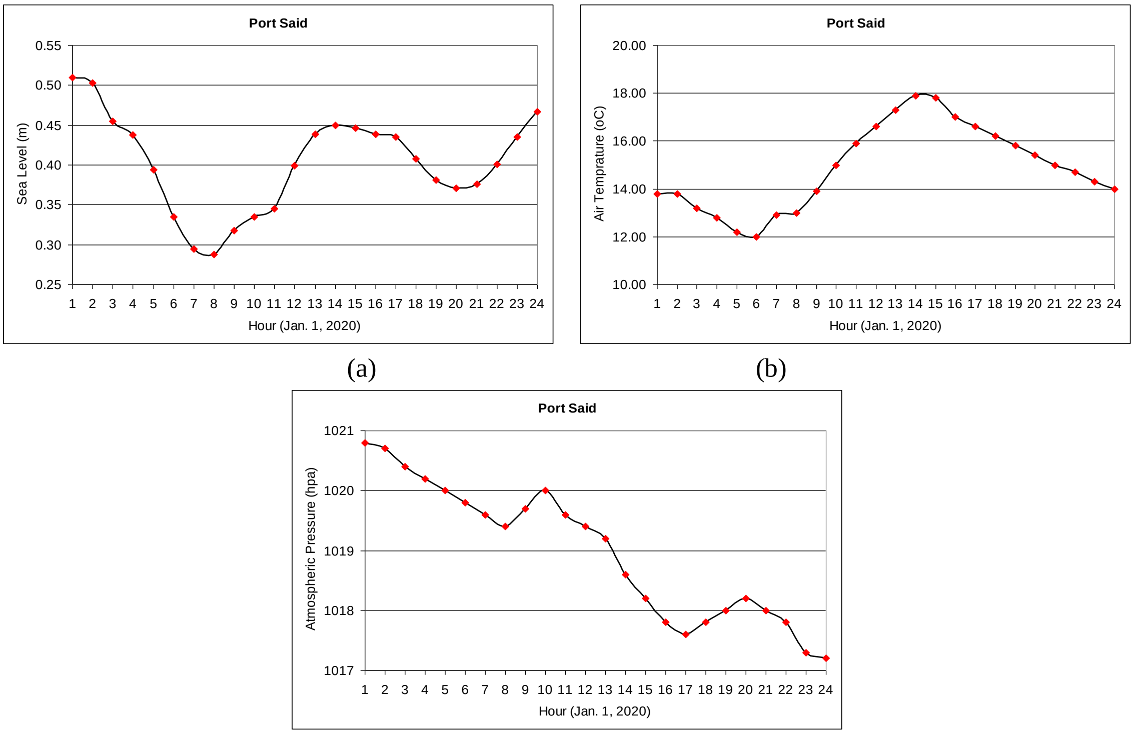


(a) (b)

(c)

(a) Sea Level, (b) Air temperature, (c) Atmospheric Pressure

Figure 3: Variations Over Alexandria on January 1st, 2020



(a) (b)

(c)

(a) Sea Level, (b) Air temperature, (c) Atmospheric Pressure

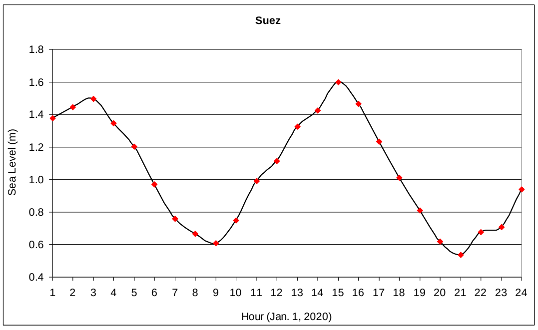
Figure 4: Variations Over Port Said on January 1st, 2020

Next, the variations over the Red sea at both Suez and Safaga have been inspected. Table 3 summarize the accomplished daily variations. It can be recognized that the sea level at Suez varies between 0.536 m and 1.597 m with an average equals 1.044 m. While at Safaga, it ranges from 0.361 m to 1.048 m with a mean of 0.733 m. On the other hand, the air temperature at Suez changes daily between 12.8 ºC and 18.4 ºC with a mean equal 15.2

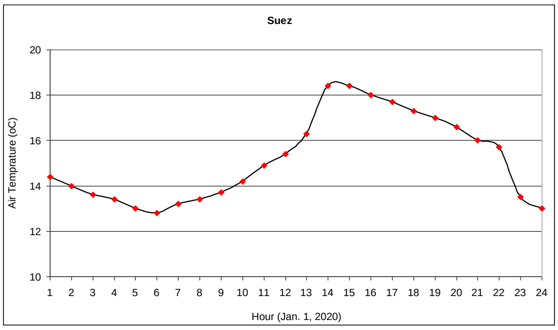
°C. At Safaga, the air temperature varies from 13.7 °C to 21.4 °C with an average of 17.6 °C. The atmospheric pressure at Suez ranges from 1017.7 hpa to 1021.3 hpa with an average of 1019.6 hpa. At Safaga, it varies between 1014.3 hpa and 1017.8 hpa with a mean of 1016.1 hpa. Fig. 5 and 6 depict the daily variations of such factors at Suez and Safaga respectively. It can be noticed that the sea level daily patterns at both sites are also semi-diurnal in nature. Additionally, the daily patterns of both air temperature and atmospheric pressure are generally diurnal at both sites.

Table 3: Variations Over the Red Sea on January 1st, 2020

Item	Minimum	Maximum	Mean
(A) At Suez			
Sea Level (m)	0.536	1.597	1.044
Air Temperature (°C)	12.8	18.4	15.2
Atmospherics Pressure (hpa)	1017.7	1021.3	1019.6
(B) At Safaga			
Sea Level (m)	0.361	1.048	0.733
Air Temperature (°C)	13.7	21.4	17.6
Atmospherics Pressure (hpa)	1014.3	1017.8	1016.1



(a)

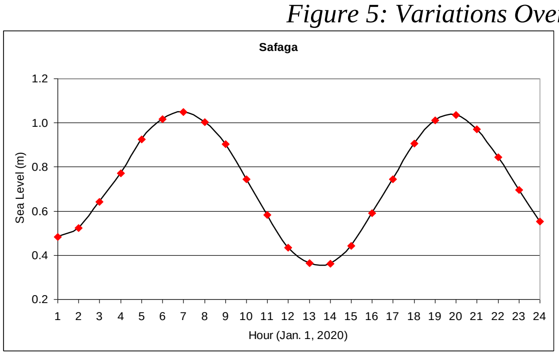


(b)

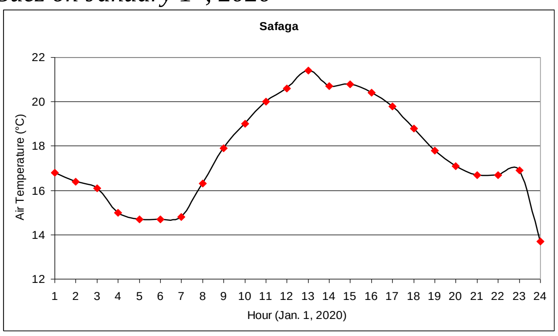
(c)

(a) Sea Level, (b) Air temperature, (c) Atmospheric Pressure

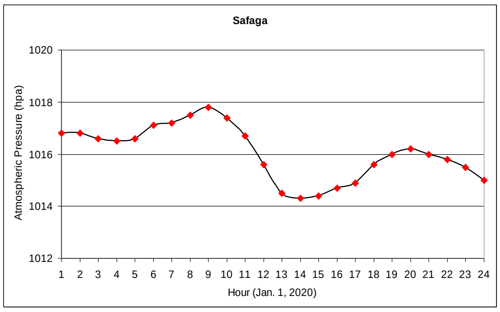
Figure 5: Variations Over Suez on January 1st, 2020



(a)



(b)



(c)

(a) Sea Level, (b) Air temperature, (c) Atmospheric Pressure

Figure 6: Variations Over Safaga on January 1st, 2020

4.2 Monthly Variations

The hourly data have been averaged to produce the daily values which have been averaged again to obtain the monthly means of sea level, air temperature, and atmospheric pressure at the four investigated locations in 2020. Tables 4, 5, and 6 presented the attained results. Regarding sea level, it can be noticed that it reached the minimum values in February for both Alexandria and Port Said and attained its maximum values in August-September. Over the Red sea, the minimum sea level occurred in January and June for Suez and Safaga respectively and attained the maximum in August and October. Similar results have been reported for other sites on the Mediterranean coasts of Egypt [34]. Furthermore, the air temperature almost follows the same patterns at the investigated sites, while the atmospheric pressure has a slightly different scheme.

A significant remark could be concluded from those tables, particularly concerning the spatial variations of sea level and metrological factors over both the Mediterranean and Red seas. First, from Table 4 and Fig. 7 it can be noticed that the mean annual value of sea level at Alexandria and Port said equal 0.284 m and 0.344 m respectively. That means that the sea level is increasing as going east over the Mediterranean sea. The mean sea level in 2020 at Suez equals 1.161 m. Thus, the sea level of the Red sea is higher than that of the Mediterranean sea at Port Said. Also, it is realized that the annual mean sea level at Suez and Safaga equals 1.161 m and 0.533 m respectively. Similar results have been reported by other studies [16, 32]. El-Geziry and Said [34] have reported the existence of spatial variations of sea level along the Egyptian Mediterranean coast where the mean sea level increase from the west (at Marsa Matruh) to the east (at Port Said) with a difference of 0.35 m.

In addition, comparing the sea level at Suez and Safaga reveals that the Red sea is decreasing as going south. Such an observation has been recognized by other researchers too. For example, regarding the MSL at both Safaga (1.4 m) and Qusseir (0.67 m) on the Red sea, as reported by El-Geziry et al. [16], it can be noticed that it decreases as going south. Also, Shirman and Nelzer [35] have reported the difference in sea level magnitudes and trends between the Mediterranean and Red seas using tide gauge records over 1958-2008. Moreover, comparing the MSL at Safaga on the Red Sea [28] and that of Alexandria on the Mediterranean sea [32] concluded that variations of sea levels between both seas. Also, comparable results have been reported by Alam El-Din and Abdelrahman [36]. Similarly, it can be concluded that the air temperature is increasing as going south while the atmospheric pressure is decreasing.

Table 4: Sea Level Monthly Variations in 2020 (m)

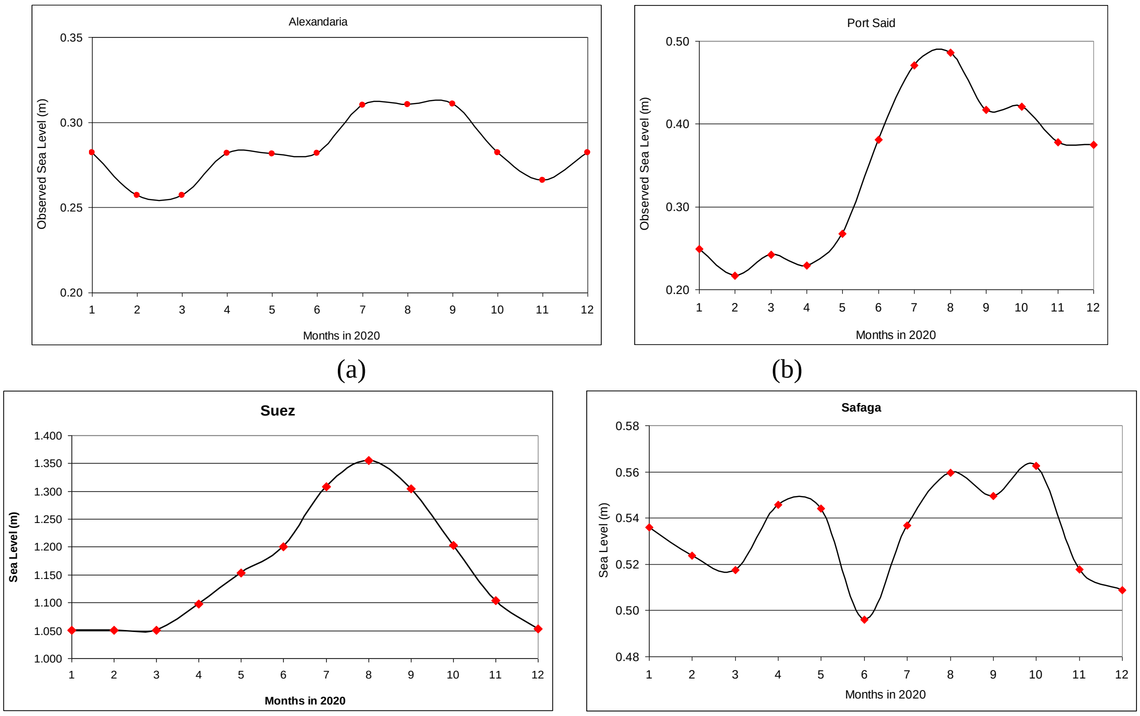
Site	Minimum	Maximum	Mean
Alexandria	0.257 (February)	0.311 (September)	0.284
Port Said	0.217 (February)	0.486 (August)	0.344
Suez	1.050 (January)	1.355 (August)	1.161
Safaga	0.496 (June)	0.563 (October)	0.533

Table 5: Air Temperature Monthly Variations in 2020 (ºC)

Site	Minimum	Maximum	Mean
Alexandria	15.8 (February)	28.2 (August)	22.3
Port Said	14.2 (January)	28.7 (September)	22.1
Suez	15.3 (January)	31.2 (August)	24.1
Safaga	17.4 (January)	32.6 (August)	26.0

Table 6: Atmospheric Pressure Monthly Variations in 2020 (hpa)

Site	Minimum	Maximum	Mean
Alexandria	1007.4 (July)	1018.0 (December)	1013.0
Port Said	1008.2 (July)	1021.6 (January)	1014.9
Suez	1005.4 (January)	1020.9 (August)	1012.9
Safaga	1003.3 (July)	1020.0 (January)	1011.3



(a) (b) (c) (d)

(a) Alexandria, (b) Port Said, (c) Suez, (d) Safaga

Figure 7: Sea Level Monthly Variations in 2020

4.3 Annual Variations

Furthermore, the monthly datasets of sea levels, air temperature, and atmospheric pressure have been investigated to reveal the correlation between sea levels and metrological elements. The accomplished findings are tabulated in Table 7. It can be concluded that sea levels have a strong positive correlation with air temperature and a strong negative correlation at Alexandria, Port Said, and Suez sites. At those sites, comparable correlation estimates have been reported by Dawood [37]. However, the estimated correlation at Safaga is moderate, which might need further deep investigation. In this regard, El-Geziry et al. [28] have concluded that the astronomical tides have a higher influence (1.5 times) on the observed sea levels at Safaga than the metrological circumstances.

Table 7: Correlation Between Sea Level and Atmospheric Elements in 2020

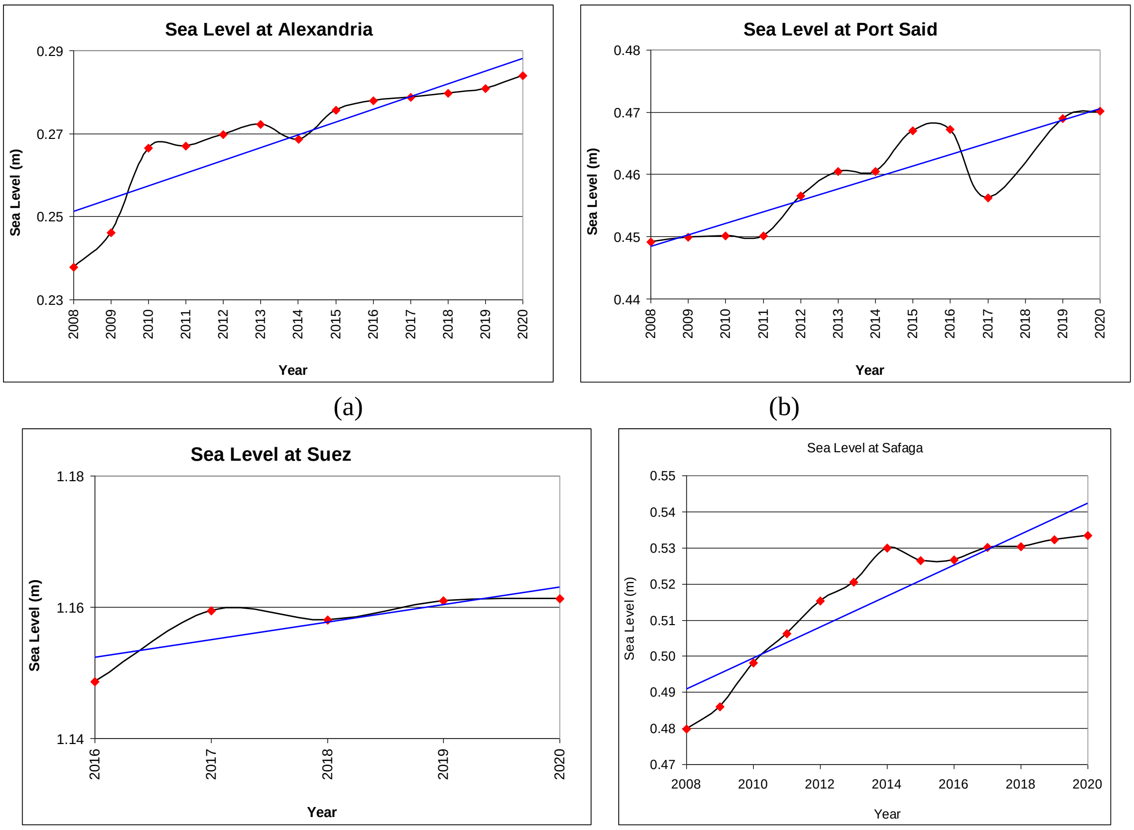
Site	Correlation to Air Temperature	Correlation to Atmospheric Pressure
Alexandria	0.80	-0.63
Port Said	0.85	-0.68
Suez	0.94	-0.87
Safaga	0.39	-0.31

4.4 Long-Term Variations

It is worth mentioning that the utilized hourly datasets, particularly sea level, might be considered the most-recent high-frequency data over a long period span in the 21st century from 2008 to 2020 in Egypt. Table 8 and Fig. 8 presented the spatiotemporal variations of sea level in Egypt. From that table, it can be noticed that the Mean Sea Level (MSL) over 2008-2020 equals 0.270 m, 0.459 m, 1.158 m, and 0.517 m at Alexandria, Port Said, Suez, and Safaga respectively. This is a critical fact that the global warming phenomena have significantly raised MSL in Egypt in the last years over the MSL national Egyptian vertical datum at Alexandria defined in 1906. Additionally, this fact necessitates developing a national plan for dealing with the SLR phenomenon and its consequence hazardous environmental impacts. From a geodetic and surveying perspective, such reality should be taken into consideration in the realization of a recent Egyptian vertical datum for mapping and surveying applications.

Table 8: Long-Term Sea Level Annual Variations Over 2008-2020 (m)

Site	Minimum	Maximum	Mean
Alexandria	0.238	0.284	0.270
Port Said	0.449	0.470	0.459
Suez	1.149	1.161	1.158
Safaga	0.480	0.533	0.517



(a) (b)

(c) (d)

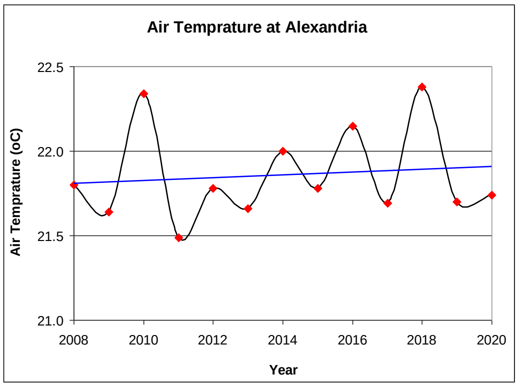
(a) Alexandria, (b) Port Said, (c) Suez, (d) Safaga

Figure 8: Long-Term Sea Level Variations over 2008-2020

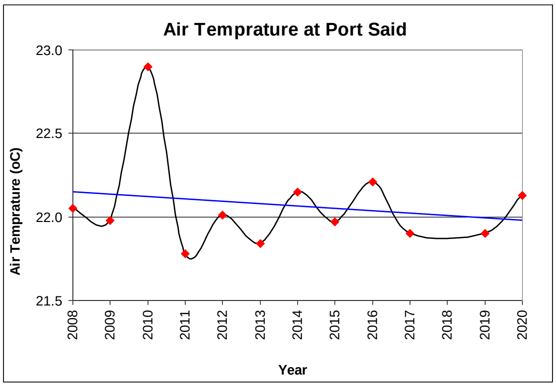
Table 9 and Fig. 9 describe the annual variations of air temperature over the period 2008-2020 at the four investigated locations in Egypt. A common trend of increasing temperature, except at Port Said, could be noticed from this figure. Additionally, Table 10 and Fig. 10 describe the annual variations of atmospheric pressure over 2008-2020 at the examined sites. A common trend of decreasing pressure at Alexandria and Suez and increasing schemes at Port Said and Safaga could be realized from this figure. The utilization of a medium span of metrological data, herein, just gives overall indications about the metrological variations. In this context, it should be mentioned that long-term metrological datasets, of at least 30-year, might be necessary to precisely investigate the climate changes over Egypt.

Table 9: Long-Term Air Temperature Annual Variations Over 2008-2020 (ºC)

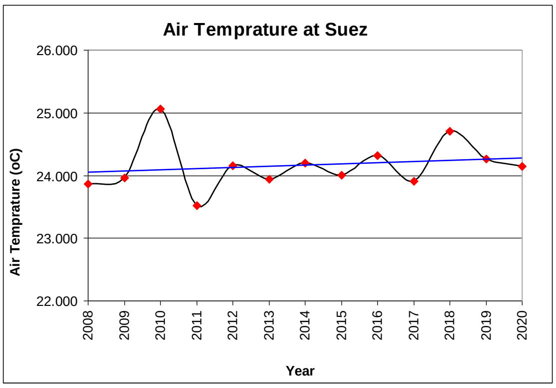
Site	Minimum	Maximum	Mean
Alexandria	21.5	22.4	21.9
Port Said	21.8	22.9	22.1
Suez	23.5	25.1	24.2
Safaga	25.4	27.0	26.1



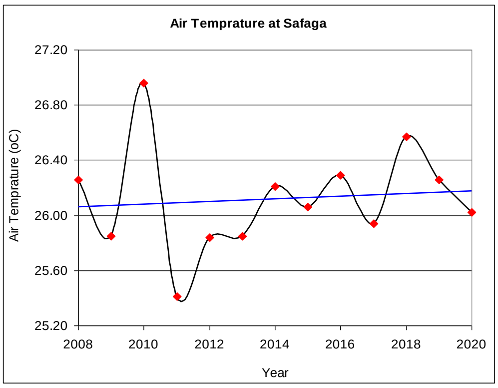
(a)



(b)



(c)



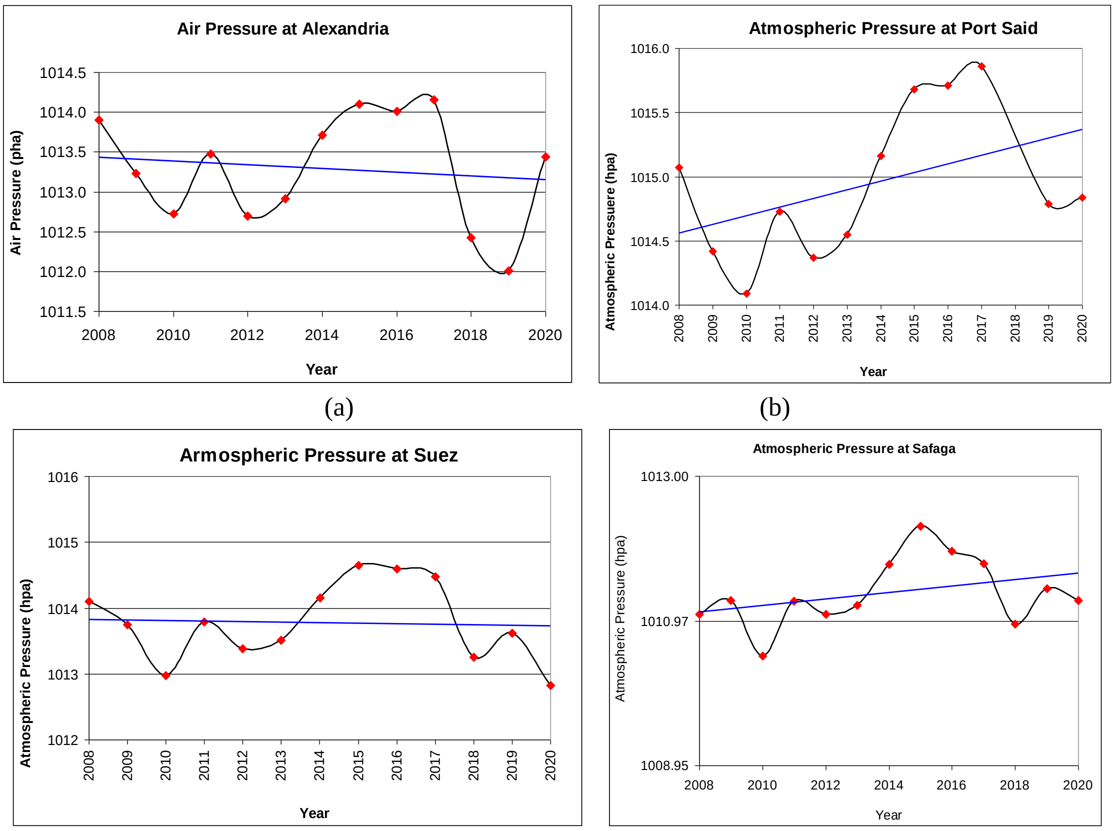
(d)

(a) Alexandria, (b) Port Said, (c) Suez, (d) Safaga

Figure 9: Long-Term Variations of Air Temperature over 2008-2020

Table 10: Long-Term Atmospheric Pressure Annual Variations Over 2008-2020 (hpa)

Site	Minimum	Maximum	Mean
Alexandria	1012.0	1014.2	1013.3
Port Said	1014.1	1015.9	1014.9
Suez	1012.8	1014.7	1013.8
Safaga	1010.5	1012.3	1011.4



(a) (b) (c) (d)

(a) Alexandria, (b) Port Said, (c) Suez, (d) Safaga

Figure 10: Long-Term Variations of Atmospheric Pressure over 2008-2020

Modelling the relative SLR is the next processing step where a linear regression model has been applied for the 2008-2020 collected data over the four tide gauges in Egypt. Table 11 presents the accomplished findings. First, it can be noticed the coefficient of determination (R^2) is generally high which concludes that the linear regression produces reliable results. Second, the computed annual rates of relative SRL indicated that sea level is rising over the Egyptian coasts, with variable rates, as a consequence of the global warming phenomena. The rising rate of the Mediterranean sea range from 1.8 mm/year at Port Said to 3.1 mm/year at Alexandria. Regarding the Red sea, the relative SRL varies between 2.7 mm/year at Suez and 4.3 mm/year at Safaga.

Concerning air temperature regression analysis (Table 12), it shows a rising trend at Alexandria, Suez, and Safaga but a decreasing rate at Port Said. Although the R^2 values are very weak, the overall trend is positive at the three sites. In addition, Table 13 presents the results of regression modelling of the atmospheric pressure. It can be noticed that the annual rate is positive at both Port Said and Safaga while it is negative at Alexandria and Suez. Alike, lower R^2 values for regression of both air temperature and atmospheric pressure have been reported for Alexandria over 2007-2018 [38]. These two findings might be attributed to the short time of the utilized metrological data that could not describe such a global phenomenon.

Table 11: Regression of Sea Level Variations Over 2008-2020

Site	Equation	Annual Rate (mm/year)	R^2
Alexandria	SL = 0.0031 Y – 5.9054	+ 3.1	0.77
Port Said	SL = 0.0018 Y – 3.2482	+ 1.8	0.78
Suez	SL = 0.0027 Y – 4.2734	+ 2.7	0.67
Safaga	SL = 0.0043 Y – 8.1382	+ 4.3	0.83

Table 12: Regression of Air Temperature Variations Over 2008-2020

Site	Equation	Annual Rate (ºC/year)	R^2
Alexandria	T = 0.0086 Y + 4.5948	+ 0.0086	0.01
Port Said	T = -0.143 Y + 50.887	- 0.0143	0.04
Suez	T = 0.0187 Y – 13.466	+ 0.0187	0.04
Safaga	T = 0.0096 Y + 6.7515	+ 0.0096	0.01

Table 13: Regression of Atmospheric Pressure Variations Over 2008-2020

Site	Equation	Annual Rate (hpa/year)	R^2
Alexandria	P = -0.0231 Y + 1059.9	- 0.0231	0.02
Port Said	P = 0.0672 Y + 879.61	+0.0672	0.21
Suez	P = -0.0086 Y + 1031	- 0.0086	0.01
Safaga	P = 0.0453 Y + 920.07	+ 0.0453	0.14

5. Conclusions

The global warming phenomenon has caused a significant rise of sea level worldwide in the last century. Since the rate of SLR changes spatially and over time, this paper focuses on giving general signals about sea level and atmospheric elements' variations at four locations in Egypt along with both the Mediterranean and the Red seas over the period 2008-2020. Correlation and relationships between SL and metrological elements, mainly air temperature and atmospheric pressure, have been, also, investigated. It is worth mentioning that, to the best of the authors' knowledge, no previous research have been published using such precise hourly datasets of sea levels and metrological elements covering almost thirteen years at four different sites on the Egyptian coasts. The accomplished findings reveal several important remarks. First, it has been noticed that the sea level daily patterns at the four investigated sites are semi-diurnal in nature. As expected, the daily patterns of air temperature is diurnal and the atmospheric pressure does not possess a daily pattern. Second, it has been concluded that the mean annual value of SL at Alexandria and Port said equal 0.284 m and 0.344 m respectively, which means, similar to results of previous studies, that sea level is increasing as going east over the Mediterranean sea. On the other hand, the mean SL at Suez equals 1.161 m, which indicates that the sea level of the Red sea is higher than that of the Mediterranean sea at Port Said, as other researchers have reported. In addition, it has been realized that the annual mean sea level at Suez and Safaga equals 1.161 m and 0.533 m respectively, which concluded that it decreases as going south. Third, it has been concluded that sea level has a strong positive correlation with air temperature and a strong negative correlation at Alexandria, Port Said, and Suez sites. However, that correlation at Safaga is moderate, which might need further deep investigation.

Although the utilized datasets cover a relatively medium period, the accomplished findings are considered important for coastal management and risk assessment of environmental hazards. Concerning the spatiotemporal variations of sea level in Egypt, it has been noticed that the MSL over 2008-2020 equals 0.270 m, 0.459 m, 1.158 m, and 0.517 m at Alexandria, Port Said, Suez, and Safaga respectively over the Alexandria defined national vertical datum in 1906. Such rises could be attributed to the global warming phenomena in the last years. The rising rate of the Mediterranean sea range from 1.8 mm/year at Port Said to 3.1 mm/year at Alexandria. Regarding the Red sea, the relative SRL varies between 2.7 mm/year at Suez and 4.3 mm/year at Safaga. Concerning air temperature regression analysis, it shows a rising trend at Alexandria, Suez, and Safaga but a decreasing rate at Port Said. Although the estimated values of the coefficient of determination are very weak, as formerly documented by other studies, the overall trend is positive at the three sites. Regarding the pressure trend over the period 2008-2020, it has been noticed that the annual rate is positive at both Port Said and Safaga while it is negative at Alexandria and Suez. Such findings might be attributed to the short time span of the utilized metrological data that could not describe such a global phenomenon.

Overall, the attained findings impose developing a national plan for dealing with the SLR phenomenon and its consequence hazardous environmental impacts. From a geodetic and surveying perspective, such reality should be significantly considered in the realization of a recent Egyptian vertical datum for mapping and surveying applications.

References

[1]. Oppenheimer, M., Glavovic, B., Hinkel, J. , van de Wal, R., Magnan, A., Abd-Elgawad, A., Cai, R., Cifuentes-Jara, M., DeConto, R., Ghosh, T., Hay, J., Isla, F., Marzeion, B., B., Meyssignac, B. and Sebesvari, Z. (2019) *Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities*. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

[2]. Piecuch, C. G., P. R. Thompson, and K. A. Donohue (2016), Air pressure effects on sea level changes during the twentieth century, *Journal of Geophysical Research: Oceans*, (121):7917–7930, https://doi.org/10.1002/ 2016JC012131.

[3]. Oddo, P., Bonaduce, A., Pinardi, N. and Guarnieri, A. (2014) Sensitivity of the Mediterranean sea level to atmospheric pressure and free surface elevation numerical formulation in NEMO, *Geoscientific Model Development*, (7):3001–3015, https://doi.prg/10.5194/gmd-7-3001-2014.

[4]. El-Geziry, T. Dabbous, A. and Abdallah, A. (2020) General pattern of sea level in Safaga and Qussier harbors on the Egyptian Red sea coast, *Arabian Journal of Geosciences*, 13:436, https://doi.org./10.1007/s12517-020-05447-y

[5]. Huang, J., Liu, H. and Yin, K. (2018) Effects of meteorological factors on the temporal distribution of red tides in Tolo harbour, Hong Kong, *Marine Pollution Bulletin*, (126): 419-427, https://doi.prg/10.1016/j.marpolbul.2017.11.035.

[6]. Oppenheimer, M., B.C. Glavovic , J. Hinkel, R. van de Wal, A.K. Magnan, A. Abd-Elgawad, R. Cai, M. Cifuentes-Jara, R.M. DeConto, T. Ghosh, J. Hay, F. Isla, B. Marzeion, B. Meyssignac, and Z. Sebesvari, 2019: *Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities*. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

[7]. Parker, A. and Ollier, C. (2015) Sea level rise for India since the start of tide gauge records, *Arabian Journal of Geosciences*, (8):6483-6495.

[8]. Alothman, A., Bos, M., Ferenandes, R., and Ayhan, M. (2014) Sea level rise in the north-western part of the Arabian Gulf. *Journal of Geodynamics*, http://dx.doi.org/10.1016/j.jog.2014.09.002

[9]. Lyszkowicz, A. and Bernatowicz, A. (2018) Geocentric sea level changes at tide gauge station in Wladyslawowo, Presented at the *FIG Working Congress*, Istanbul, Turkey, May 6-11.

[10]. Mengel, M., Levermann, A., Frieler, K., Robinson, A. and Marzeion, B. (2016) Future sea level rise constrained by observations long-term commitment, *PNAS*, 113(10):2597-2602, https://doi.org/10.1073/pnas.1500515113

[11]. Edwards, T. (2017) *Current and future impacts of sea level rise on the UK*, A report to the UK government office for science, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/663885/Future_of_the_sea_-_sea_level_rise.pdf, accessed January 2022.

[12]. Dawod, G., Ebaid, H., Haggag, G. and Al-Krargy, E. (2021) An integrated geomatics approach for projecting sea level variations and risks: A case study in the Nile Delta, Egypt, *Journal of Architecture and Civil Engineering*, 6(8):24-38.

[13]. Dawod, G. (2001) The magnitude and significance of long-term sea level rise in Egypt from a geodetic perspective, Proceedings of the *Eleventh International Conference on Environmental Protection*, Alexandria University, Alexandria, May 8-10, 2001, pp. 207-215.

[14]. Dawod, G., Mohamed, H. and Haggag, G. (2019) Relative and absolute sea level rise based on recent heterogeneous geospatial data: A case study in the Nile delta, Egypt, *Journal of Scientific and Engineering Research*, 6(6):55-64.

[15]. Radwan, A., Magdy, M., Rabah, M., Saber, A. and Zaki, A. (2021) Sea level analysis using tide gauge observations at the northern delta coast, Egypt, *NRIAG Journal of Astronomy and Geophysics*, 10:1, 361-371, https://doi.prg/10.1080/20909977.2021.1940742.

[16]. El-Geziry, T., Dabbous, A. and Abdallah, A. (2020) General pattern of sea level in Safaga and Qusseir harbours on the Egyptian Red Sea coast, *Arabian Journal of Geosciences*, 13: 436, https://doi.prg/10.1007/s12517-020-05447-y.

[17]. Zubiera, K. and Eyouni, L. (2020) Investigating the role of atmospheric variables on sea level variations in the eastern central Red Sea using an artificial neural network approach, *Oceanlogia*, (62):267-290, https://doi.org/10.1016/j.oceano.2020.02.002

[18]. Gao, Z., Zhang, Q., Wang, H., Zou, T., Liu, K. and Wu, S. (2016) The impacts of wind and air pressure on fluctuations of the mean Bohai sea level, *Journal of Coastal Research*, (74):13-21.

[19]. Hunicke, B. and Zorita, E. (2006) Influence of temperature and precipitation on decadal Baltic sea level variations in the 20th century, Tellus A: Dynamic Meteorology and *Oceanography*, (58A):141-153.

[20]. Han, M., Cho, Y., Kang, H., Nam, S., Byun, D., Jeong, K. and Lee, E. (2020) Impacts of atmospheric pressure on the annual maximum of monthly sea-levels in the northeast Asian Marginal seas, *Journal of Marine Science and Engineering*, 8, 425, https://doi.org/10.3390/jmse8060425

[21]. Latfa, A. (2021) Influence of atmospheric forces on sea-surface fluctuations in Iraq marine water, northwest of Arabian Gulf, *Arabian Journal of Geosciences*, 14:1639, https://doi.org/10.1007/s12517-021-07874-x

[22]. El-Geziry, T., Dabbous, A., Abdallah, A., and Eid, F. (2021) Temporal variability of sea-level in Safaga harbor, Egypt in relation with metrological conditions and tidal characteristics, *Arabian Journal of Geosciences*, 14:1206, https://doi.org/10.1007/s12517-021-07561-z

[23]. Mohamed, H. (2005) *Realization and redefinition of the Egyptian vertical datum based on recent heterogeneous observations*, PhD dissertation, Department of Surveying Engineering, Shoubra faculty of Engineering, Zagazig University, Egypt.

[24]. Dawod, G., Meligy, M. and Mohamed, H. (2005) Assessment and modelling of sea level rise and metrological changes in Egypt, Proceedings of *Ain Shams first International Conference on Environmental Engineering*, Cairo, Egypt, April 11-12, pp. 573-582.

[25]. Sharaf el Din, S. H. (2015). Variation of sea level on the Egyptian Mediterranean and Red sea coasts, *The International Hydrographic Review*, 52(1):63-73.

[26]. Ibrahim, O. (2021) Study of the sea level variability and storm surges at Mersa Matruh, Egypt, *Arabian Journal of Geosciences*, 14: 1678, https://doi.prg/10.1007/s12517-021-07907-5.

[27]. Visser, H., Dangendorf, S. and Petersen, A. (2015), A review of trend models applied to sea level data with reference to the ‘‘accelerationdeceleration debate’’, *Journal of Geophysical Research: Oceans*, 120, 3873–3895, https://doi.org/10.1002/2015JC010716

[28]. El-Geziry, T. and Dabbous, A. (2021) Behavior of surges in Alexandria eastern harbor, Egypt, *Egyptian Journal of Aquatic Research*, (47):171-178, https://doi.prg/10.1016/j.ejar.2021.02.001.

[29]. Tur, R., Tas, E., Haghighi, A. and Mehr, A. (2021) Sea level prediction using machine learning, *Water*, 13, 3566. https://doi.org/10.3390/w13243566

[30]. Jamali, A., Mustapha, A., and Mostafa, S. (2021) Prediction of sea level oscillations: comparison of regression-based approach, *Engineering Letters*, 29(3):23-29.

[31]. Kumar, V. (2020) *Statistical downscaling of island sea levels in the southwest Pacific: a multiple linear regression approach*, PhD Dissertation, Université Paul Sabatier, Toulouse, France.

[32]. Madsen, K., Høyer, J., Suursaar, Ü., She, J. and Knudsen, P. (2019) Sea level trends and variability of the Baltic sea from 2D statistical reconstruction and altimetry, *Frontiers in Earth Science*, 7:243, https://doi.org/10.3389/feart.2019.00243

[33]. NOAA (U.S National Oceanic and Atmospheric Administration) (2021) https://www.ncei.noaa.gov/products/land-based-station/automated-surface-weather-observing-systems, Accessed 12 November, 2021.

[34]. El-Geziry, T. and Said, M. (2019) Sea level variations in El-Burullus new harbor, Egypt, Arabian Journal of Geosciences, 12:460, https://doi.org/10.1007/s12517-019-4620-9
[35]. Shirman, B. and Melzer, Y. (2009) Long term monitoring of the Mediterranean and Red sea levels in Israel, Presented at the *FIG Working Week 2009 Conference*, Eilat, Israel, May 3-8.
[36]. Alam El-Din, K. and Abdelrahman, S (2010) Is the rate of sea level rise accelerating along the Egyptian coasts?, Presented at the *International Conference on Coastal Zone Management of River Deltas and Low Land Coastlines*, Alexandria, Egypt, March 6-10.
[37]. Dawood, A. (2017) The effect of sea level rise on Egyptian economy, *Journal of Environmental Science and Engineering*, (6):188-199, https://doi.org/10.17265/2162-5298/2017.04.003
[38]. Mahfouz, B., Osman, A., Saber, S. and Kanhalaf-Allah, H. (2020) Assessment of weather and climate variability over western harbor of Alexandria, Egypt, *Egyptian Journal of Aquatic Biology and Fisheries*, 24(5):323-339.