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Comparison between Microwave Radar Gauge and Pressure Gauge in Monitoring Sea Level Surface at Alexandria Naval Port

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Abstract

The importance of knowing the sea level stems from the full awareness of the danger this elevation poses to many people living in coastal cities which are sometimes located at elevations less than 1 meter. The Pressure Gauge (PG) is the oldest tool for measuring changes in sea level. In recent years, the microwave Radar Gauge (RG) device has emerged, which measures sea level using remote radar waves and records the rise and fall of the sea level.

In this study, a comparison between the observations of the PG and RG were conducted by collecting data from both devices over a period of fourteen months from January 2020 to February 2021.

A sea level monitoring station was established in the Alexandria Naval Port by the National Water Research Centre (NWRC) in collaboration with the Egyptian Military Survey Department of the Ministry of Defense. The microwave radar device was installed next to the previously installed pressure gauge, and data were collected from both devices. By analyzing 20,400 observations collected every 30 minutes over a period of 14 months and conducting T-test and F-test statistical analysis after applying 3σ rule filter, as well as representing graphical plots of the observations of both devices at different time periods, the results indicated a somewhat close accuracy between the two devices over long periods of the year. However, the pressure gauge remained stable, and its observations were more consistent than those of the microwave radar device.

Keywords

Tide Gauge; Microwave Radar Gauge; Pressure Gauge; Mean sea level

Introduction

The changing sea level is considered one of the challenges facing coastal cities, as this rise leads to the submergence of many of them, especially those located over the coast line. In addition, changes in sea level lead to changes in the vertical geodetic reference of Egypt, to which the elevations of benchmarks in the vertical measurement network are referenced. Given that the coasts of Egypt extend for more than 3500 km along the Mediterranean Sea and Red Sea, the efforts of various sectors are combined to prepare accurate data on sea level rise. Therefore, the Survey Research Institute in Egypt, in collaboration with the Military Survey Department of the Ministry of Defence, has conducted studies on the completion, monitoring, and tracking of sea level rise and its impact on the Egyptian coasts (Dawood G. et. al. 2022). This was done through monitoring and tracking the tide gauge network, which the Survey Research Institute (SRI) established using pressure theory devices in Alexandria, Port Said, Safaga, and Suez, as well as microwave radar devices in Alexandria and Port Said (SRI, 2019). These studies were conducted based on several mandates from the General Egyptian Authority for Coastal Protection since October 2010.

Two commonly used methods for measuring sea level are microwave radar and subsurface pressure gauge. Microwave radar measures the sea surface height using reflected electromagnetic waves, while subsurface pressure gauge measures the water pressure at a fixed depth beneath the surface.

Several studies have compared the accuracy and precision of sea-level measurements obtained through microwave radar and subsurface pressure gauge. A study by Cipollini et al. (2002) compared the performance of the two methods in the Mediterranean Sea. The study found that microwave radar measurements were generally more accurate than subsurface pressure gauge measurements, but that the accuracy of both methods was affected by local environmental conditions such as wind speed and wave height.

A study by Foden et al. (2016) compared sea-level measurements obtained through microwave radar and subsurface pressure gauge in the Pacific Ocean. The study found that the two methods produced comparable measurements, with microwave radar being slightly more accurate in calm conditions and subsurface pressure gauge being more accurate in rough conditions.

A more recent study by Passaro et al. (2020) compared the performance of the two methods in the North Atlantic Ocean. The study found that microwave radar measurements were generally more accurate than subsurface pressure gauge measurements, but that the accuracy of both methods was affected by the presence of waves and other environmental factors.

Overall, these studies suggest that microwave radar is generally more accurate than subsurface pressure gauge for measuring sea level, but that both methods are subject to error due to environmental conditions. Researchers should carefully consider the advantages and limitations of each method when choosing a measurement technique for their specific research question.

This paper presents a comparative analysis study between measurements taken by a subsurface pressure gauge and radar microwave at the same location, specifically Alexandria station. The aim is to determine the accuracy of each method and identify which one is more reliable.

Subsurface Pressure Gauge (PG)

The principle of PG Instrument is based on the measurement the atmospheric pressure at a particular location, which is then used to calculate the altitude or height above sea level. Atmospheric pressure decreases as altitude increases, meaning that the pressure at sea level is higher than at higher altitudes.

To measure atmospheric pressure, a barometer or a similar device is used, which typically consists of a sealed tube filled with mercury or other liquid. The liquid is supported by atmospheric pressure, and the height of the liquid column is measured to determine the pressure. This pressure measurement is then used to calculate the altitude or height above sea level using mathematical formulas.

The accuracy of the sea level pressure gauge measuring instrument depends on the accuracy of the atmospheric pressure measurement and the accuracy of the altitude calculation (Balogun et. al. 2021). Numerous factors can affect atmospheric pressure, such as temperature, humidity, and weather conditions, which can lead to fluctuations in the pressure readings. Therefore, it is important to calibrate the instrument regularly and account for these factors to obtain accurate altitude measurements.

The barometric formula, also known as the International Standard Atmosphere (ISA) model, is a mathematical formula that describes how atmospheric pressure changes with altitude. The formula takes into account the decrease in air density with altitude, which causes a corresponding decrease in pressure (Bolanakis et. al. 2015). The barometric formula is expressed as:

$$P = P_b * \left(\frac{T_b - (h - h_b) * L_b}{T_b}\right)^{\frac{g*M}{R*L_b}}$$

Where:
P_b is Reference Pressure
T_b is Reference temperature
L_b is the temperature lapse rate (the rate at which temperature changes with altitude)
h is the height at sea level
h_b is the height of reference level
g is the acceleration due to gravity
M is the molar mass of air
R is the universal gas constant

The barometric formula assumes a standard temperature lapse rate of 6.5°C per kilometre and a standard sea-level temperature of 15°C. The formula also assumes a value of 9.80665 m/s^2 for the acceleration due to gravity and a molar mass of 0.0289644 kg/mol for air.

Radar Gauge microwave (RG)

Sea level measurements using radar microwave technique involve using radar waves to measure the distance between the radar instrument and the surface of the ocean. The instrument sends out a radar pulse, which bounces off the water surface and returns to the instrument. By measuring the time it takes for the radar pulse to make the round trip, the distance between the instrument and the water surface can be calculated. This technique can be used to measure sea level changes over time, providing valuable information about changes in oceanographic processes, such as sea level rise and ocean circulation. Radar microwave measurements are also useful for monitoring coastal regions, where changes in sea level can have significant impacts on ecosystems and human populations.

The technique of RG allows for continuous monitoring of sea level changes over time, which is important for understanding long-term trends and changes in oceanographic processes. Unlike other techniques, such as tidal gauges, radar microwave measurements are non-invasive and do not require instrumentation to be placed directly in the water.

The equipment required for radar microwave measurements is expensive, making it a costly technique to implement on a large scale. Also the resolution of radar microwave measurements is limited by the wavelength of the radar pulse, which can result in a loss of detail in the measurement of small-scale features. Radar microwave measurements can be affected by interference from other sources, such as waves and weather conditions, which can impact the accuracy of the measurements.

Case Study: Alex. Monitoring station

In the early 21st century, the Egyptian Naval Hydrographic Department (ENHD) constructed a new tide gauge station, Navy TG, at the location 31° 11' 55" N, 29° 52' 12" E, within the Alexandria Naval Port as shown in Figure (1). ENHD signed an agreement with the Survey Research Institute (SRI) of the National Water Research Centre (NWRC) to commence scientific cooperation regarding sea level variations and environmental monitoring. Consequently, figure (2) shows a modern subsurface pressure tide gauge measurement device model (PASLTRP-122) with a fixed Global Positioning System (GPS) receiver was installed there (Mohamed, 2005). As a result, digital sea level observations of the Navy TG have been recorded since 2001 and continue to be recorded. Recently, a microwave type TG model (CS475A) has been installed at that TG as a precise backup system as shown in figure (3) (SRI, 2019).

The SMARTAQU Ver.F252 is the device responsible for recording sea level data for the subsurface pressure gauge, and the CS475A is responsible for the microwave observations (Dawood G. et. al., 2022). Two types of observations were recorded every half an hour for a period of 14 months, from January 2020 to February 2021.

Figure 1. Tide gauge station at Alexandria naval port

Figure 2. Alex. Station sub surface pressure tide gage PG (CS475A)

Figure 3. Alex. Microwave Tide Gauge RG Model (PASLTRP-122)

Statistics analysis and results

Sea level data were collected from Alex. During the period from 1 January 2020 up to end of February 2021, Naval Port Tide Gauge station was using the PG and RG. The observed data were recorded automatically by the attached recording unit of the PG & RG Measuring instruments periodically each half an hour. Data that collected are referenced to the first order bench mark to obtain sea level height data from the two techniques.

Approximately 20,400 observations were analyzed from both instruments, PG and RG. So, it was found that some of records was missing from RG recorded Data. So, about 180 records from PG were excluded in order to standardize the two data sets per time. By Appling 3σ rule filter, About 440 record was eliminated from each data set to be 19778 observations as a final number. The number of filtered records are about 2.2% of total observations, it means that they fall outside the range of (mean ± 3 * standard deviation (3σ) as determined by the 3 sigma rule. Typically, the 3 sigma rule suggests that approximately 99.7% of the data should fall within the range of three standard deviations from the mean. This implies that around 0.3% of the data would be expected to fall outside this range and be considered outliers. Therefore, if the filter data is 2.2% of excluded data, it suggests a higher percentage of outliers than what would be expected under the 3 sigma rule. Whether this is acceptable or not depends on the specific context and requirements of the data analysis. In some cases, a higher percentage of outliers may be expected or tolerated. It's important to consider the nature of data set, the goals of our analysis, and the potential impact of the excluded data on our results which will be subjected to many statistical tests and analyses as follows.

By looking at the observations and performing some mathematical calculations on them to derive the standard deviation and the arithmetic mean as shown in table (1). By examining the preliminary results, it turns out that the arithmetic mean in RG is better than PG. However, the standard deviation of the RG has worst results than PG.

When comparing two observation datasets by calculating the standard deviation for each, a higher standard deviation indicates a greater amount of variability or dispersion in the data. Conversely, a lower standard deviation suggests that the data points are closer to the mean and exhibit less variability. In terms of accuracy, neither a higher nor a lower standard deviation alone indicates the accuracy of the observations. The standard deviation measures the spread or dispersion of the data points around the mean, but it does not directly reflect the accuracy or correctness of the observations.

Accuracy refers to how close the observed values are to the true or expected values. It is possible to have accurate observations with a high or low standard deviation, depending on the nature of the data and the context of the observations. So, to assess the accuracy of the observations, conducting further analysis and validation are required.

Table 1. PG and RG data sets statistics.

Item	PG	RG
Data set	20400	20400
Filtered observation	2.2%	2.2%
Max.	0.645	0.785
Min.	0.194	-0.098
Mean	0.458	0.34312
St. Dev.	0.0890	0.146743

The results have been studied to some tests and statistical analyses such as T-test and F-test where, The F-test vs. t-test: The t-test and the F-test are two separate tests. The T-test compares two populations' means, whereas the other compares two populations' variances.

T-Test

When comparing two observations of PG and RG data sets, it is possible to hypothesize that their means are equal, and you determine an acceptable probability for incorrectly concluding the existence of a difference. Subsequently, a test statistic is calculated using the data and compared to a theoretical value obtained from a t-distribution. Based on the result, you either reject the null hypothesis or fail to do so.

T-test is the final statistical measure for determining differences between two means that may or may not be related i.e. whether there is a significant difference in the two techniques measurements. The null hypothesis (H_0) states that there is no significant difference between the means of the two data sets.

The alternative hypothesis (H_a) states that there is a significant difference between the means of the two data sets.

First; calculate the pooled standard deviation (Sp) using the formula:

$$Sp = \sqrt{\frac{n1-1*S1^2+n2-1*S2^2}{n1+n2-2}}$$

Where S_1 and S_2 are the standard deviations of the two data sets, n_1 and n_2 are the numbers of observations.

Then calculate the t-value using the formula:

$$t\text{- Value} = \frac{X1-X2}{Sp*\sqrt{\frac{1}{n1}+\frac{1}{n2}}}$$

Where, x_1 and x_2 are the means of the two data sets.

Determine the degrees of freedom (df) using the formula:

$$df = n_1 + n_2 - 2$$

Comparing the critical t-value corresponding to significance level 95% (e.g., 0.05) and degrees of freedom (df) in the t-distribution table with the calculated t-value: table (2) shows the input and output data results of t-test.

Table 2. Statistics of T-test applied for the PG and RG observations.

Item	PG	RG
Mean	0.4580002	0.34312
St. Dev.	0.08903473	0.146743
Data set number	19778	19778
Difference	0.11488341	
Pooled Standard Deviation	0.121368444	
Standard Error	0.00122047699	
95% CI	0.112491246 to 0.117275574	
Test statistic t	94.130	
T-Table	1.96	
DF	39554	
Significance level	P < 0.0001	

From calculated t-value which is greater than the critical t-value. So, the results reject the null hypothesis (H0) and conclude that there is a significant difference between the means of the two data sets. As t-test results confirms that one of the two techniques is better than other whereas amount of data that analyzed are huge. So, F-test is essential to proceed in our comparison.

F-test

F test is a statistics test that is performed to check whether the variances of the two given samples (or observations) are equal or not. However, F-test checks whether one data set variance is either greater than or smaller than the other, it becomes a one-tailed hypothesis F- test.
For the two data sets, the variance was calculated S12 and S22. Then F- value computed using the following formula:

$$F = S1^2 / S2^2$$

The degree of freedom for each data set (df_1, df_2) equal:

$$df_1 = n_1 - 1 \quad \text{and} \quad df_2 = n_2 - 1$$

Where n_1, n_2 are the number of the observation for each data set
Comparing the critical F-value corresponding to significance level 95% (e.g., 0.05), degrees of freedom for the numerator (df_1), and degrees of freedom for the denominator (df_2) in the F-distribution table with the F- calculated. Table (3) shows the input and output data results of F-test.

Table 1. Statistics of F-test applied for the PG and RG observations.

Item	PG	RG
Mean	0.4580002	0.34312
St. Dev.	0.08903473	0.146743
Data set number	19778	19778
F statistic	2.7164	
F critical	1	
Significance level	P < 0.001	

The obtained p-value (the probability value) is highly statistically significant. The convention is to consider a p-value less than the significance level (usually 0.05 or 0.01) suggests strong evidence to reject the null hypothesis and support the alternative hypothesis. In this case, since the p-value is less than 0.001, which is smaller than the typical significance levels, you would reject the null hypothesis with a high level of confidence.
In other words, a significance level result of $P < 0.001$ indicates strong evidence against the null hypothesis. It is important to note that accuracy assessment can be a complex task and may require a combination of approaches to reach a reliable conclusion. Careful consideration of the graphs that show the behaviors and the relation between the Tide Gauge and the time will help in making a more informed judgment about the accuracy of the datasets.
The available two data sets were represented graphically over the course of the year, once, and for specific times of the year at different periods, such as month, week, and even days. Throughout the year 2020 and two months of year 2021, tide gauges instruments PG and RG recorded measurements every half hour, and the observations were graphically represented as shown in Figure (4).

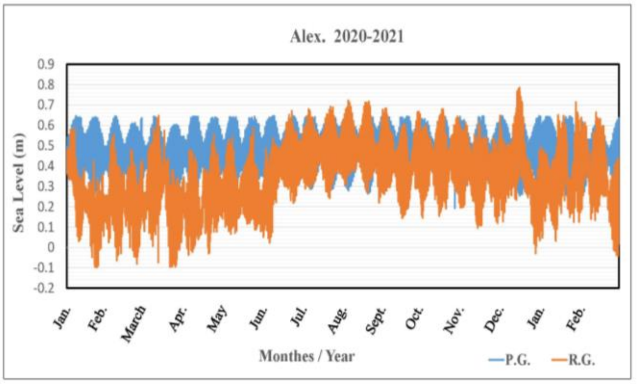

Figure 4. Sea level measurements at Alex.Tidal station using PG and RG techniques over more than one year.

In the first half of the year 2020, there was a significant discrepancy between the pressure gauge and the radar device. Radar observations being closer to the average sea level than those of the PG. Throughout the summer and until nearing the end of 2020, there was a convergence observed between the observations of the two devices. However, with the onset of winter again, the gap between the observations of both devices started to reappear. By examining the graphical representation of the observations of each device, it becomes evident that the pressure gauge follows a relatively consistent trend throughout the year, with no unexplained jumps. As for the radar device, its observations are not stable and exhibit noticeable fluctuations during months with wind activity, such as the winter months, while the observations calm down again during the summer months. Naturally, winter months always witness fluctuations in wind patterns. This observation supports the nature of radar waves suspended in the air, which are easily affected by wind, while the pressure

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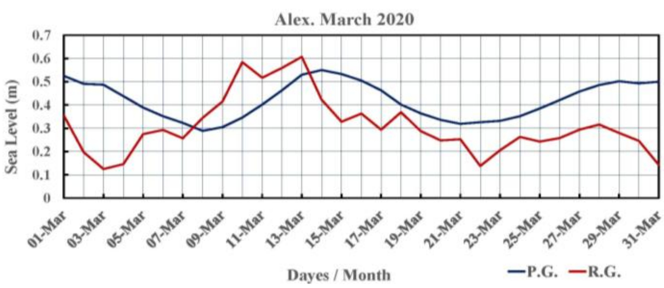
gauge is submerged underwater, explaining the stability of its readings.

Based on the observations, three distinct months were selected over the course of the 14-month observation period see figure (5). These months were March 2020, representing the end of winter, July 2020, known for high temperatures, and January 2021, the coldest month in winter. Thus, the selection of these months was based on climatic conditions.

Through graphical representation of these three months, it became evident that in March, the observations of the pressure gauge were good and somewhat aligned with the radar device. The RG observations appeared as jagged lines rather than smooth waves, indicating irregularity.

The observations of July were consistent and exemplary for both devices, showing harmony in their behaviour, ranging from 0.35 cm to 0.65 cm above sea level. This confirms that stable weather conditions provide accurate readings for the RG device compared to the PG.

With the onset of winter, weather fluctuations returned, and this was reflected in the radar device's observations in March 2021, resulting in the same irregular behaviour and gap compared to the PG. The consistent behaviour of the pressure gauge makes it more stable and reliable.



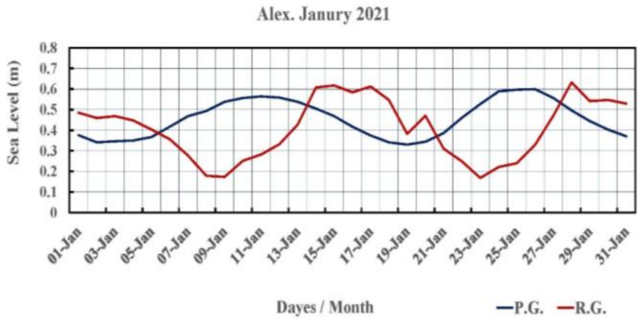
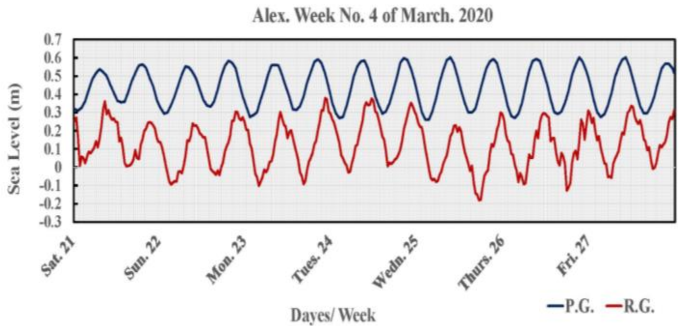


Figure 5. PG and RG observations during March 2020, July 2020, and January 2021.

To study the behaviour of both the PG and the RG devices in more detail, it was necessary to observe the behaviour of these observations over a shorter timeframe, such as a week or less. Figure (6) show the last week of March and the last week of October 2020 were selected to observe the graphical representation of both devices.



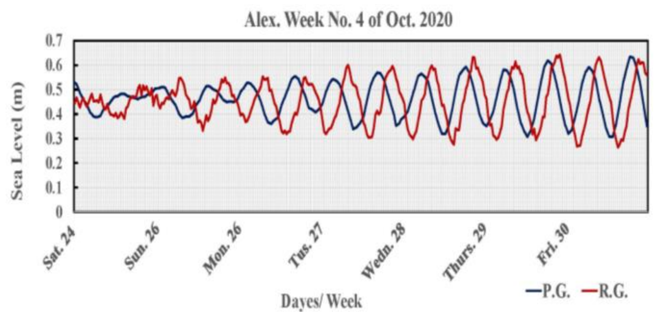
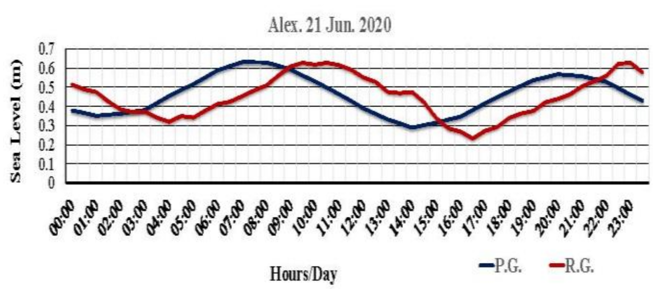


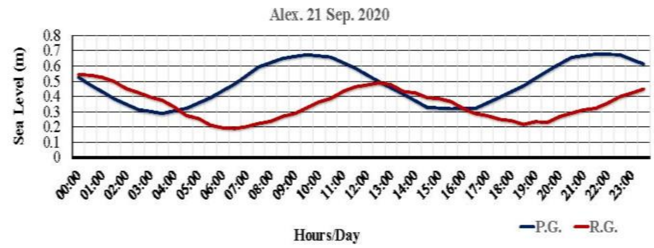
Figure 6. PG and RG Mean Sea Level during a week on March and October.

There is a weak convergence between the observations of the PG and the RG in the last week of March, which represents the end of winter. As for the last week of October, which represents mid-autumn when weather conditions appear relatively stable, the observations appeared intertwined, with small Up and Down from 0.35 cm to 0.65 cm above sea level. All of this supports the hypothesis that the radar device's observations are of lower quality and less reliable compared to the observations of the pressure gauge.

Figure (7) illustrates the graphical representation of the observations throughout a full day. The days selected were the 21st of each season's end and the beginning of the next season, as these specific days represent the transitional period between seasons when weather conditions tend to be relatively stable.

The chosen days were March 21st, June 21st, September 21st, and December 21st. The observations on these days further reinforce the hypothesis of the relative stability of the radar device's observations in accordance with stable weather conditions.





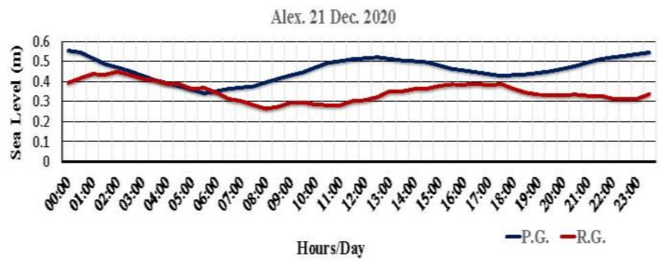


Figure 7. PG and RG graphical representation of the observations throughout a full day

In June, September, and December, the behaviour of the observations showed good convergence throughout the day. The observations for both devices ranged from 0.30 cm to 0.70 cm above sea level, despite these days being scattered throughout the year and far apart from each other. Although the observations on March 21st differed somewhat, they still fell within the same range."

Conclusion

In this research, we investigated the superiority of measuring sea level using microwave radar and subsurface pressure gauge. The comparisons were based on analytical and statistical tests supported by graphical representations. The results we obtained indicated that both devices perform closely and provide good and similar results regarding tide. However, the analyses revealed differences between the two devices, and the T-test and F-test confirmed that the null hypothesis of their symmetry is rejected. There is indeed a distinction between the observations of the two devices, especially considering that each device has its distinct technology. Therefore, through the graphical representations, the measurements of the RG appeared occasionally unstable, with unexplained and irregular jumps, particularly in changing weather conditions, especially during the winter months. In these

months specifically, the curve of the RG measurements showed fluctuations and breakpoints. On the other hand, the PG remained stable, and the curve of its measurements was smooth and consistent throughout the study period.
Hence, we recommend studying the microwave radar measurements over a longer period and under controlled conditions. It may be possible to create a specific enclosure around the microwave radar device to separate it from the influence of air currents. Additionally, we also recommend studying the observations of the subsurface gauge under the influence of changes in seawater density affected by rainfall, temperature variations, and relative will enable us to make a definitive judgment between the two devices.

References

Balogun, A. L., &Adebisi, N., 2021. Sea level prediction using ARIMA, SVR and LSTM neural network: assessing the impact of ensemble Ocean-Atmospheric processes on models accuracy. Geomatics, Natural Hazards and Risk, 12(1), 653-674.

Bolanakis, D. E., Kotsis, K. T., &Laopoulos, T., 2015. Temperature influence on differential barometric altitude measurements. In 2015 IEEE 8th International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS) (Vol. 1, pp. 120-124), IEEE.

Cipollini, P., Leuliette, E., Beckley, B., &Gasparini, G., 2002. Accuracy assessment of the TOPEX/POSEIDON and Jason-1 radar altimeters for oceanography. Marine Geodesy, 25(1-2), 3-18.

Dawod, G. M., Mohamed, H. F., &Haggag, G. G., 2022. Mean Sea Level and Tides Variations at Alexandria, Egypt over 1906-2020. JES Journal of Engineering Sciences, 50(4), 175-188.

Foden, P. R., Watson, C. S., &Foden, J., 2016. Comparison of in situ and remotely sensed sea level data from the Pacific Ocean. Journal of Geophysical Research: Oceans, 121(8), 5987-5996.

Mohamed, H., 2005. Realization and redefinition of the Egyptian vertical datum based on recent heterogeneous observations. Unpublished PhD thesis. Zagazig University.

Passaro, M., Pascual, A., Quartly, G. D., &Snaith, H. M., 2020. Comparison of Sea Level Measured by Microwave Radar Altimetry and Subsurface Pressure Gauges in the North Atlantic Ocean. Remote Sensing, 12(16), 2520.

SRI, 2019. Observing the variations and effects of sea level on the Egyptian coasts over 2008-2018. A technical Report, SRI, Giza, Egypt, 2019.