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The Impacts of the Pacific Southern Oscillation and the Indian Ocean Dipole on the Mean Sea Level of the Arabian Gulf and the Arabian Sea

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Abstract. This study uncover the linear impact of both the Pacific El Nino–Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) on the mean sea level (MSL) in the coasts of the Arabian Gulf and the Arabian Sea in recent decades and identify the areas that might be affected by these changes in order to take the necessary precautions to avoid future threats of sea level rise on ports and coastal areas. The data of tide gauge stations were collected from the permanent service of MSL (PSMSL) and statistically analyzed using the linear regression method and Pearson correlation. Significant correlation coefficients were obtained for IOD and ENSO in some stations located on the Saudi and Iranian coasts of the Arabian Gulf as well as in some stations located on the coasts of India and Pakistan in the Arabian Sea. It was noted that ENSO was the weakest influence in the Arabian Gulf compared to the IOD and its linear effect was more pronounced in the Arabian Sea. Because global warming has been on the rise recently, the impact of IOD and ENSO events on MSL may increase and the situation may be more serious in the coming decades.

Keywords: El-Nino Southern Oscillation, Indian Ocean Dipole, Arabian Gulf, Arabian Sea.

1. Introduction

Mean Sea level (MSL) is a very important variable for studying the meteorological and oceanographic status at the study area. Sea level rise has an important relationship to global and regional climate changes (Beşel and Kayıkçı, 2020). Climate changes and the accompanying global warming are considered important drivers of current researches. Earth's climate change due to global warming has been proven to result from gases retaining in the atmosphere due to the burning of fossil fuels as well as due to deforestation. MSL in the world ocean may rise about 5-30 cm in the year 2050 as mentioned in the report of the Intergovernmental Panel on Climate Change (IPCC) (Church *et al.*, 2013, Alothman *et al.*, 2014). Global warming has led to many negative results, including a rise in the surface temperature of land, as well as a rise in the temperature of sea and ocean waters. These results cause water to expand and sea level to rise. It also led to melting the polar ice, which flows into the oceans and seas, leading to a rise in the sea level (Cazenave and Cozannet, 2014). On its part, sea level rise is a major threat to residents of the coastal areas (Bird et *al.*, 1987).

The Indian Ocean Dipole (IOD) and the Pacific El Niño–Southern Oscillation (ENSO) are two of the important factors that may affect the sea level rise in the context of climate change. On one hand, the IOD is the continuous change in the difference between the sea surface temperatures in the eastern half of the tropical Indian Ocean and those in the western half of it (Bom, 2013). It has three phases:

positive; negative and neutral ones affecting the weather in many places around the world (Saji and Yamagata, 2003). On the other hand, ENSO is considered as a cooling and fluctuating warming pattern that has a great impact on the weather and rainfall rate in many places around the world. It also has three phases: El Niño (positive phase); La Niña (negative phase) and neutral Phase (Allan *et al*., 1991, Können *et al*., 1998, Ropelewski and Jones, 1987). Many researchers have studied these phenomena due to their major effects on the global climate and hence the mean sea level changes. These impacts may be violent and catastrophic at some times. Climate parameters in the regions of the Northern Arabian Gulf have been increased by linking with ENSO and the IOD phenomena for a period of 40 years from 1973 to 2012 (Al Senafi and Anis, 2015). Analyzing the rainfall statistics in the Arabian Gulf and its relationship with ENSO has showed an increase in rainfall during ENSO years in the context of climate changes (Kumar *et al*., 2016). The increased relationship between the rainfall in the Arabian Gulf and the three phases of ENSO has been proved by (Sandeep and Ajayamohan, 2018).

The changes in the MSL of the Arabian Gulf revealed an increasing trend around 2.3 cm between 1980-1990 (Sultan *et al*., 1995). The sea level in the Arabian Gulf decreases in winter and rises during summer due to the difference in air pressure as shown by (Al-Subhi, 2010). The results of the climatic parameters could be adopted for comparison with the results of our study which is a first study to be conducted in the Arabian Gulf and Arabian Sea. These parameters could be considered as proxy data of MSL in our study. Al Othman *et al*., (2014), deduced the absolute sea level rise in the Arabian Gulf of about 1.5±0.8 mm/year in accordance with the global estimate of 1.9 ± 0.1 mm/year. However, the researchers did not mention the effects of ENSO and the IOD on MSL at the coasts of the Arabian Gulf and the Arabian Sea. Therefore, the conducted research will investigate these effects.

2. Study Area

The Arabian Gulf (Fig. 1) is a semi-enclosed shelf sea with shallow waters of an area of 226×10^3 km^2 and an average depth of 35 m (Emery, 1956). Its length is about 990 km. The source of fresh water of the Arabian Gulf is the Shatt Al-Arab river resulting from the confluence of Tigris and Euphrates rivers as well as the Karun river coming into Al-Basrah city at southern Iraq as shown in Fig. 3 (Reynolds, 1993).

The Arabian Sea (Fig. 2) is the northwestern part of the Indian Ocean, *i.e*., oceanic sea, connected to the Arabian Gulf from east by the Strait of Hormuz. It has a total area of 3,886,000 km^2 and an average depth of about 2990 m (Aleem, 2019).

The data of 24 coastal stations have been selected on the coasts of the Arabian Gulf and the Arabian Sea as shown in Fig. 1 and Fig. 2 in the form of time series representing the mean sea level fluctuation as a function of time and space. The MSL linear trend can be calculated as a function of time and space and can be removed (detrended) before the calculations of correlation and regression coefficients. Where, there is no guaranty for the existence of these linear changes at each studied station. Thus, the calculations of MSL linear trend are very important in which it represents the changes in vertical land movement of the sea floor and climate.

The observational mean sea level PSMSL “metadata” is the main source of information on long-term changes in global sea level during the last two centuries, it includes the datasets from almost 200 National Authorities distributed around the world, the datasets have been employed intensively in studies such as those of the Intergovernmental Panel on Climate Change (Mahmood, 2016).

Fig. 1. Tide gauge stations at the coast of Arabian Gulf.

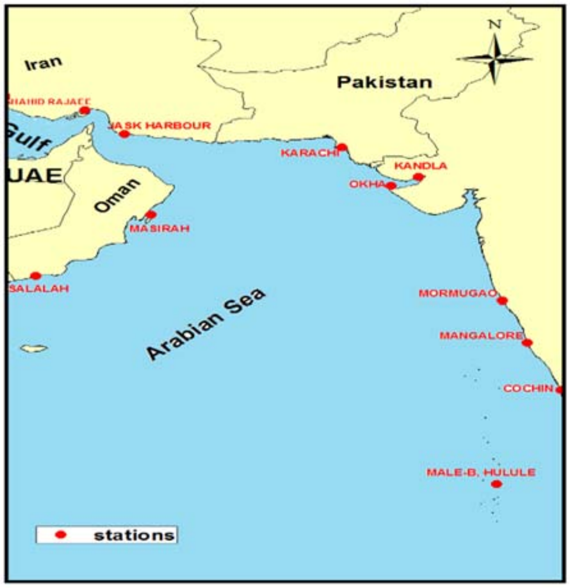


Fig. 2. Tide gauge stations at the coast of Arabian Sea.

Fig. 3. Positions of the Tigris; Euphrates; Karun and Shatt Al-Arab rivers (James, 1996).

3. Material and Methods

MSL can be measured by two methods: Tide gauges and satellite altimeter. Satellite altimetry is a worldwide modern technology mostly used in the last two decades. However, the tide gauges are the main source for throughout history. It is capable to show the changes that occur at sea level and its relationship to climate changes (Barbosa *et al.*, 2004). In the present research, the monthly average data series of tide gauges were collected from the permanent service of MSL (PSMSL) website which is a global mean sea level bank (Woodworth, 1991, Woodworth *et al.*, 2003). The 24 coastal stations have been selected along the coasts of the Arabian Gulf and the Arabian Sea as shown in Fig. 1 & 2.

In order to find the differences in the influences of the equal and different time periods, the studied time series, *i.e.*, MSL, ENSO & IOD, have been constructed into equal periods. The different periods were ranging from 1950 to 2013 as shown in Table 1. Equal time periods were extracted into 14 stations. These periods have extended for 9 years from 1986-1995 in the context of climate change. The mentioned time series of each station was divided into five types such as monthly and seasonal series (*i.e.*, Spring, Summer, Autumn & Winter series), where, they were constructed directly in the following study over the entire period of each tide gauge station listed in Table 1.

The statistical time series analysis technique has been done by using our MatLab codes for this study to constructing the regression prediction functions as well as to estimate Pearson correlations coefficients. The missing value of the time series were filled using the interpolation method as shown in Table 1. The missing data must be less than 30% of the time series length (Sturges, 1983). Figure 4 shows to the original monthly MSL time series of four tide gauge stations used in the present study, collected from PSMSL.

The linear correlation value between the X and Y variables is measured by the Pearson correlation coefficient (R) which is represented by the following relationship (Mahmood, 2016):

$$R = \frac{n\sum_i x_i y_i - \sum_i x_i \sum_i y_i}{\sqrt{[n\ \sum_i x_i^2 - (\sum_i x_i)^2][n\ \sum_i y_i^2 - (\sum_i y_i)^2]}} \qquad (1)$$

Where, the n represents the number of X and Y values, and the R ranges between -1 and 1. At first, the detected linear trend resulting from the various effects at sea level should be detrended. Next, the Pearson correlation coefficients should be estimated. Later, for the significant result, the new series should be created as a function of ENSO or the IOD by using the OLS - Ordinary Least Square standard bivariate linear regression method (Isobe *et al.*, 1990), as clarified in the following equations:-

$$\text{OLS } (Y = a + b\ X) \qquad (2)$$

$$b = \frac{\sum(x_i - \bar{X})(y_i - \bar{Y})}{\sum(x_i - \bar{X})^2} \qquad (3)$$

$$\text{OLS } (Y = a + T\ \text{time}) \qquad (4)$$

Where OLS: is Ordinary Least Square, (a) is the intercept regression coefficient and b is the linear regression slop coefficient, T is the linear trend, $\boldsymbol{x_i}$ is the independent variable (*i.e.*, ENSO & IOD) and $\boldsymbol{y_i}$ is the dependent variable (*i.e.*, MSL). Next, $\bar{X}$ is the mean of X and $\bar{\mathbf{Y}}$ is the mean of Y.

Coastal mean sea level station series = a + b (station-based of the IOD or ENSO series) (5)

$$\text{MSL} = a + b\ (\text{IOD or ENSO}) \qquad (6)$$

The linear trend T as a function of IOD or ENSO could clarify as following:

Coastal mean sea level station series = a + T (time) (7)

$$\text{MSL} = a + T\ (\text{time}) \qquad (8)$$

The Pearson correlation coefficient has calculated between each of the resulting sea level time series with the IOD once and with ENSO again and tested if they were statistically significant. The P-value was found to be less than 0.05. That means, the correlation result is statistically significant and there is an impact of these phenomena on the mean sea level.

4. Results

4.1 For Different Periods

Table 2 shows the total linear trends of the MSL time series, that were estimated from the tide gauge stations, including all the affecting factors (*i.e.*, meteorological, climatic, oceanographic as well as isostatic factors). Moreover, this linear trend includes all the variables that affect the MSL, that is: The long-term Oceanic-Atmospheric circulation such as: ENSO and the IOD as well as the other short-term phenomena. Emam Hassan linear trend was the highest value, it could be indicates to the influences of all affecting factors in the context of local; regional and global drivers that affect the MSL. Moreover, the influence of IOD was more pronounced at this station over the monthly average time scale. The positive and negative trends indicate to the vertical land movement (*i.e.*, subsidence or rising) at the Arabian Gulf-Arabian Sea.

The five types of time series were correlated with both ENSO and IOD; only the significant correlation coefficients are listed in Table 3 and characterized in Fig. 5.

Figure 3 shows the significant correlation coefficients between MSL and IOD, ENSO in tide gauge stations. The linear trends of IOD and ENSO on MSL were estimated at each measurement station for which significant correlation coefficients appeared in Table 4. From Tables 3 and 4, the following results were obtained:

The monthly mean results have shown a dominance of the linear influence of IOD on the MSL, especially the monthly effects at the stations: Emam Hassan, Marjan, Zuluf, Lawhah, Safaniya Pier, Juaymah Pier, Ras Tanura, Qurayyah Pier, Karachi, Male-B, Hulule and Salalah. The linear effect of ENSO on the MSL was detected on the stations: Karachi, Kandla and Cochin. In winter season, the influences of IOD on the MSL were detected at the stations: Emam Hassan, Safaniya Pier, Qurayyah Pier, Karachi and Male-B, Hulule. While, the ENSO effects were detected at the tide gauge stations: Karachi, Kandla, Mormugao, Mangalore and Cochin. The spring season showed the impact of IOD on the MSL at the stations: Abu Ali Pier, Juaymah Pier, Ras Tanura (North Pier), Karachi, Okha and Mormugao. However, the ENSO impacts were more pronounced at the station: Emam Hassan. Next, the influence of IOD on MSL in summer season were recognized at the stations: Shahid Rajaee, Cochin (Willingdon Is.) and Salalah. Nevertheless, the ENSO showed its impact on the MSL at the stations: Zuluf and Abu Ali Pier. In the autumn season, the impact of IOD was more pronounced than the influence of ENSO, especially, at the stations: Emam Hassan, Marjan, Lawhah, Safaniya Pier, Tanajib Pier, Juaymah Pier, Shahid Rajaee, Karachi, Male-B, Hulule and Salalah. However, the ENSO impact was more dominance at Karachi and Okha only.

4.2 For Equal Periods (1986-1995)

In order to compare the effect of the ENSO and the IOD phenomena on MSL for different and equal period lengths, the period (1986-1995) has been extracted, in which 14 tide gauge stations are involved such as: Marjan, Zuluf, Safaniyah, Lawhah, Safaniya Pier, Tanajib Pier, Abu Ali Pier, Juaymah Pier, Abu Safah, Ras Tanura, Qurayyah Pier, Kandla, Okha and Cochin. The total linear trend values for monthly averages have been estimated, which includes all factors (including the IOD and ENSO phenomena) that affect MSL as shown in Table 5. Marjan and Zuluf linear trends were the highest values, indicating to the influences of all affecting factors. Moreover, the influence of IOD was more pronounced at these stations over the monthly average time scale.

Depending on Pearson correlation coefficients, the results indicate that some stations showed significant P-values as shown in Table 6 which also shows that coefficients were estimated for each station. That reflected the influence of the negative or positive phase according to the signs of the corresponding coefficients, while the linear trends of the MSL as a function of IOD and ENSO were detected as well (Table 7) at each station has a significant correlation coefficient.

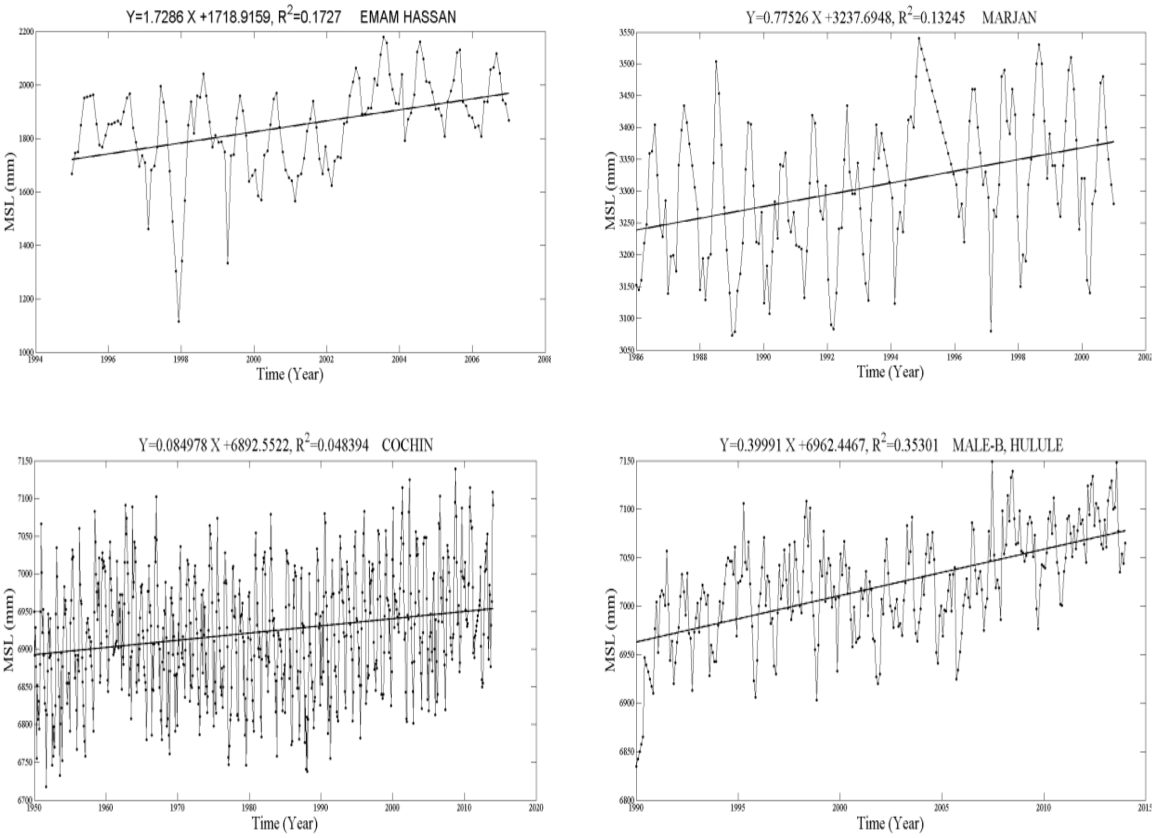
In monthly time scale, the positive phase of IOD can be observed in stations: Marjan, Zuluf, Safaniyah, Lawhah, Safaniya Pier, Juaymah Pier and Ras Tanura at the Saudi coast of the Arabian Gulf. The positive phase of ENSO can be observed in Zuluf and Abu Safah stations at the Saudi coast of the Arabian Gulf as well. In winter, the effect of the positive phase of the IOD was observed in the stations: Marjan, Zuluf, Lawhah, Safaniya Pier and Qurayyah Pier at the Saudi coast of the Arabian Gulf. While, there was no effect of ENSO in winter. In spring, the effect of the positive phase of IOD was observed on the stations: Abu Ali Pier, Juaymah Pier and Ras Tanura at the Saudi coast in the Arabian Gulf. The positive phase of ENSO was more pronounced on station: Tanajib Pier at the Saudi coast of the Arabian Gulf as well. In summer, the effect of the positive phase of IOD was noticed on Marjan station at the Saudi coast of the Arabian Gulf, while, ENSO had no effect. In the autumn, the influence of the positive phase of IOD appeared on stations: Marjan, Lawhah, Safaniyah and Safaniya Pier at the Arabian Gulf. The influence of the positive phase of ENSO was on Kandla station which is located on the coasts of the Arabian Sea at India coast.

Table 1. General characterizations of the Arabian Gulf-Arabian Sea Mean Sea Level Stations Selected for the Conducted Research.

No.	Station Names	Location	Long.	Lat.	Period	Missing Period
1	EMAM HASSAN	Arabian Gulf	50.250000	29.833333	1995-2006	1997-1998
2	MARJAN	Arabian Gulf	49.633333	28.450000	1986-2000	1994-1996
3	ZULUF	Arabian Gulf	49.266667	28.400000	1986-2000	1994-1996
4	SAFANIYAH	Arabian Gulf	48.900000	28.400000	1986-2000	1994-1996
5	LAWHAH	Arabian Gulf	49.616667	28.250000	1986-1997	1991-1993
6	SAFANIYA PIER	Arabian Gulf	48.766667	28.0	1980-1997	Non
7	TANAJIB PIER	Arabian Gulf	48.883333	27.783333	1985-2000	1994-1996
8	ABU ALI PIER	Arabian Gulf	49.650000	27.300000	1980-2000	1994-1996
9	KANGAN	Arabian Gulf	52.050000	27.833333	1995-2006	Non
10	JUAYMAH PIER	Arabian Gulf	49.900000	26.866667	1981-2000	1995-1996
11	ABU SAFAH	Arabian Gulf	50.500000	26.950000	1986-1997	1992-1993
12	RAS TANURA (NORTH PIER)	Arabian Gulf	50.166667	26.650000	1980-2000	Non
13	QURAYYAH PIER	Arabian Gulf	50.116667	25.883333	1980-1997	1993-1994
14	SHAHID RAJAEE	Arabian Gulf	27.100000	56.066667	1995-2006	Non
15	JASK HARBOUR	Arabian Sea	57.766667	25.650000	1998-2006	Non
16	KARACHI	Arabian Sea	66.975000	24.811667	1960-2013	1992-1994
17	KANDLA	Arabian Sea	70.217000	23.017000	1950-2009	1986-1987

18	OKHA	Arabian Sea	69.083000	22.467000	1975-2013	1999-2001
19	MORMUGAO	Arabian Sea	73.800000	15.417000	1969-2013	1979-1980
20	MANGALORE	Arabian Sea	74.833000	12.850000	1977-2013	1994-1996
21	COCHIN (WILLINGDON IS.)	Arabian Sea	76.266667	9.966667	1950-2013	1991-1992
22	MALE-B, HULULE	Arabian Sea	73.533000	4.183000	1990-2013	Non
23	MASIRAH	Arabian Sea	58.867000	20.683000	1997-2013	Non
24	SALALAH	Arabian Sea	54.000000	16.933000	2001-2013	2005-2006

STATION (1) STATION (2)



STATION (21) STATION (22)

Fig. 4. Samples of monthly averages of Mean Sea Level (MSL) time series collected from PSMSL for the stations (Emam Hassan, Marjan, Cochin & Male-B, Hulule).

Table 2. Total Linear Trends of Mean Sea Level Averages for the Different Periods.

No.	**Station Names**	**Monthly linear trends (mm/year)**
1	EMAM HASSAN	1.7286
2	MARJAN	0.7753
3	ZULUF	0.2565
4	SAFANIYAH	- 0.0881
5	LAWHAH	0.2442
6	SAFANIYA PIER	0.206
7	TANAJIB PIER	0.2805
8	ABU ALI PIER	0.0965
9	KANGAN	0.3762
10	JUAYMAH PIER	0.1568
11	ABU SAFAH	0.386
12	RAS TANURA (NORTH PIER)	0.1571
13	QURAYYAH PIER	0.2766
14	SHAHID RAJAEE	0.0226
15	JASK HARBOUR	0.0561
16	KARACHI	0.1531
17	KANDLA	0.2111
18	OKHA	0.0843
19	MORMUGAO	0.3719
20	MANGALORE	0.1208
21	COCHIN (WILLINGDON IS.)	0.1821
22	MALE-B, HULULE	0.3999
23	MASIRAH	0.172
24	SALALAH	0.237

Table 3. Pearson Correlation Coefficients with Statisticaly Significant P-values for the Different Periods.

	Monthly Means		Winter Season		Spring Season		Summer Season		Autumn Season	
No.	IOD	ENSO	IOD	ENSO	IOD	ENSO	IOD	ENSO	IOD	ENSO
1	-0.2261	Insig.	-0.466	Insig.	Insig.	-0.385	Insig.	Insig.	-0.346	Insig.
2	0.1646	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	0.4247	Insig.
3	0.1499	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	0.4640	Insig.	Insig.
4	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.
5	0.1939	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	0.4265	Insig.
6	0.1917	Insig.	0.2693	Insig.	Insig.	Insig.	Insig.	Insig.	0.2813	Insig.
7	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	0.3481	Insig.
8	Insig.	Insig.	Insig.	Insig.	0.3943	Insig.	Insig.	0.2846	Insig.	Insig.
9	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.
10	0.1558	Insig.	Insig.	Insig.	0.3421	Insig.	Insig.	Insig.	0.2620	Insig.
11	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.
12	0.1533	Insig.	Insig.	Insig.	0.3044	Insig.	Insig.	Insig.	Insig.	Insig.
13	0.1414	Insig.	0.2744	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.

14	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	0.3544	Insig.	0.3373	Insig.
15	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.
16	0.2456	0.1958	0.4051	0.3441	0.3489	Insig.	Insig.	Insig.	0.2862	0.2687
17	Insig.	0.1005	Insig.	0.2358	Insig.	Insig.	Insig.	Insig.	Insig.	0.1758
18	Insig.	Insig.	Insig.	Insig.	0.2361	Insig.	Insig.	Insig.	Insig.	Insig.
19	Insig.	Insig.	Insig.	0.3607	0.3191	Insig.	Insig.	Insig.	Insig.	Insig.
20	Insig.	Insig.	Insig.	0.2198	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.
21	Insig.	0.1982	Insig.	0.2864	Insig.	Insig.	-0.152	Insig.	Insig.	Insig.
22	0.1936	Insig.	0.2909	Insig.	Insig.	Insig.	Insig.	Insig.	0.4543	Insig.
23	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	0.414
24	-0.3693	Insig.	Insig.	Insig.	Insig.	Insig.	-0.444	Insig.	-0.4625	Insig.

Insig. = Insignificant

Table 4. The linear Mean Sea Level Trends as Function of the IOD and the ENSO only Concerning the Different Periods.

	Monthly Means		Winter Season		Spring Season		Summer Season		Autumn Season	
No.	IOD	ENSO	IOD	ENSO	IOD	ENSO	IOD	ENSO	IOD	ENSO
1	-0.0004669	Insig.	-0.00078049	Insig.	Insig.	-0.0037536	Insig.	Insig.	-0.00126	Insig.
2	0.00056424	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	0.002872	Insig.
3	0.00038619	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	0.009871	Insig.	Insig.
4	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.
5	0.00066017	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	0.0032375	Insig.
6	0.00049026	Insig.	0.00054567	Insig.	Insig.	Insig.	Insig.	Insig.	0.0011455	Insig.
7	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	0.0024746	Insig.
8	Insig.	Insig.	Insig.	Insig.	0.001699	Insig.	Insig.	0.004308	Insig.	Insig.
9	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.
10	0.00057035	Insig.	Insig.	Insig.	0.001349	Insig.	Insig.	Insig.	0.0022091	Insig.
11	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.
12	0.00055698	Insig.	Insig.	Insig.	0.001329	Insig.	Insig.	Insig.	Insig.	Insig.
13	0.00055453	Insig.	0.0012936	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.
14	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	0.003106	Insig.	0.0031434	Insig.
15	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.
16	0.00080887	0.0022413	0.001188	0.0046836	0.001091	Insig.	Insig.	Insig.	0.0010732	0.003013
17	Insig.	0.0013995	Insig.	0.0041637	Insig.	Insig.	Insig.	Insig.	Insig.	0.002723
18	Insig.	Insig.	Insig.	Insig.	0.001254	Insig.	Insig.	Insig.	Insig.	Insig.
19	Insig.	Insig.	Insig.	0.0074963	0.0014137	Insig.	Insig.	Insig.	Insig.	Insig.
20	Insig.	Insig.	Insig.	0.0050722	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.
21	Insig.	0.0029912	Insig.	0.0060737	Insig.	Insig.	0.001193	Insig.	Insig.	Insig.
22	0.0013197	Insig.	0.0018662	Insig.	Insig.	Insig.	Insig.	Insig.	0.003582	Insig.
23	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	0.00751
24	0.0015567	Insig.	Insig.	Insig.	Insig.	Insig.	0.002137	Insig.	0.0022568	Insig.

Insig. = Insignificant

Fig. 5. The impacts of IOD and ENSO on the Arabian Gulf – Arabian Sea coasts (*i.e.*, A: Influence of IOD in monthly, B: Influence of IOD in winter, C: Influence of IOD in spring, D: Influence of IOD in summer, E: Influence of IOD in autumn, a: Influence of ENSO in monthly, b: Influence of ENSO in winter, c: Influence of ENSO in spring, d: Influence of ENSO in summer, e: Influence of ENSO in autumn), in terms of the different periods.

Table 5. Total Linear Trends of Mean Sea Level Averages for the Period 1986-1995.

No.	Station Names	Monthly linear trends (mm/year)
2	MARJAN	1.1419
3	ZULUF	1.301
4	SAFANIYAH	- 0.4184
5	LAWHAH	0.049
6	SAFANIYA PIER	0.0355
7	TANAJIB PIER	-0.1952
8	ABU ALI PIER	-0.4965
10	JUAYMAH PIER	-0.0172
11	ABU SAFAH	0.1077
12	RAS TANURA (NORTH PIER)	0.304
13	QURAYYAH PIER	0.3393
17	KANDLA	0.594
18	OKHA	0.8609
21	COCHIN (WILLINGDON IS.)	0.5922

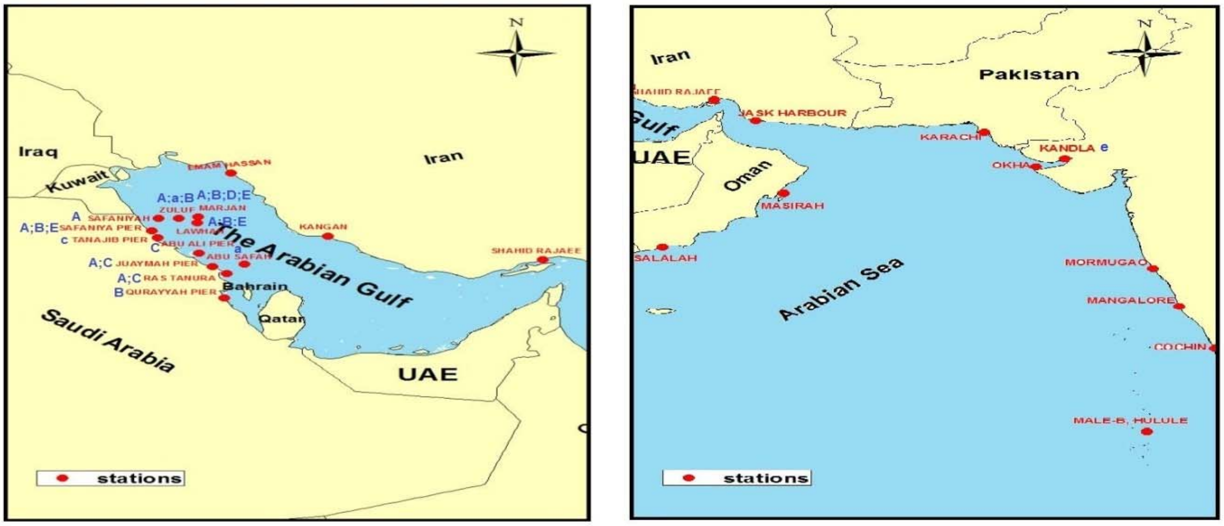


Fig. 6. The impacts of IOD and ENSO on the Arabian Gulf – Arabian Sea coasts (*i.e.*, A:Influence of IOD in monthly, B: Influence of IOD in winter, C: Influence of IOD in spring, D: Influence of IOD in summer, E: Influence of IOD in autumn, a:Influence of ENSO in monthly, b: Influence of ENSO in winter, c: Influence of ENSO in spring, d: Influence of ENSO in summer, e: Influence of ENSO in autumn), in terms of equal periods (1986-1995).

Table 6. Values of Pearson Correlation Coefficients for the Period 1986-1995.

	Monthly Means		Winter Season		Spring Season		Summer Season		Autumn Season	
No.	IOD	ENSO	IOD	ENSO	IOD	ENSO	IOD	ENSO	IOD	ENSO
2	0.2777	Insig.	0.4580	Insig.	Insig.	Insig.	0.3992	Insig.	0.5783	Insig.
3	0.2761	0.2168	0.6227	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.
4	0.2651	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	0.3770	Insig.
5	0.2548	Insig.	0.5363	Insig.	Insig.	Insig.	Insig.	Insig.	0.4231	Insig.
6	0.2455	Insig.	0.549	Insig.	Insig.	Insig.	Insig.	Insig.	0.5141	Insig.
7	Insig.	Insig.	Insig.	Insig.	Insig.	0.4942	Insig.	Insig.	Insig.	Insig.
8	Insig.	Insig.	Insig.	Insig.	0.3736	Insig.	Insig.	Insig.	Insig.	Insig.
10	0.192	Insig.	Insig.	Insig.	0.382	Insig.	Insig.	Insig.	Insig.	Insig.
11	Insig.	0.1917	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.
12	0.1990	Insig.	Insig.	Insig.	0.3711	Insig.	Insig.	Insig.	Insig.	Insig.
13	Insig.	Insig.	0.4126	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.
17	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	0.5065
18	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.
21	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.

Table 7. The linear Mean Sea Level Trends as Function of IOD and ENSO only Concerning the Equal Periods (1986-1995).

	Monthly Means		Winter Season		Spring Season		Summer Season		Autumn Season	
No.	IOD	ENSO	IOD	ENSO	IOD	ENSO	IOD	ENSO	IOD	ENSO
2	0.00086	Insig.	0.00085	Insig.	Insig.	Insig.	0.00270	Insig.	0.00290	Insig.
3	0.00066	0.00177	0.00067	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.
4	0.00080	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	0.00170	Insig.
5	0.00072	Insig.	0.00116	Insig.	Insig.	Insig.	Insig.	Insig.	0.00208	Insig.
6	0.00045	Insig.	0.00072	Insig.	Insig.	Insig.	Insig.	Insig.	0.00120	Insig.
7	Insig.	Insig.	Insig.	Insig.	Insig.	0.00805	Insig.	Insig.	Insig.	Insig.
8	Insig.	Insig.	Insig.	Insig.	0.00187	Insig.	Insig.	Insig.	Insig.	Insig.
10	0.00062	Insig.	Insig.	Insig.	0.00164	Insig.	Insig.	Insig.	Insig.	Insig.
11	Insig.	0.00093	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.

12	0.00069	Insig.	Insig.	Insig.	0.00189	Insig.	Insig.	Insig.	Insig.	Insig.
13	Insig.	Insig.	0.00143	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.
17	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	0.00016
18	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.
21	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.	Insig.

Insig.=Insignificant

5. Discussion

The linear influences of IOD and ENSO event were detected on MSL in both the Arabian Gulf and the Arabian Sea in the different and equal lengths of time series. The IOD and ENSO have contributed to MSL changes on the coasts of the Arabian Gulf and Sea in monthly and seasonal time scales. That contribution was specifically clear in the stations located within the Saudi and the Iranian territorial waters in the Arabian Gulf as well as on the coasts of Pakistan and India along the Arabian Sea. The calculated correlation coefficients with significant statistical ranged between 0.14 to 0.46, this correlation confirms that the MSL was affected by global climate changes (Mahmood, 2016). This is consistent with previous studies such as (Alawad *et al.*, 2019), where, they concluded the close relationship between sea level in the Arabian Sea and the positive phase of ENSO phenomenon between 1993 and 2017. Also the influences of ENSO and IOD on the sea surface temperature of the Arabian Gulf and the Arabian Sea could directly affect the MSL change as revealed by (Nandkeolyar *et al.*, 2013).

Alawad *et al.* (2017) also indicated that the influence of the ENSO on the Arabian Sea was stronger than the impact of IOD. This is consistent with the results of our current research where the impact of ENSO was more evident on the stations located on the coasts of the Arabian Sea in the time series of different lengths. In this regard, (Al Senafi and Anis, 2015) have stated a significant correlation between the patterns of ENSO and the IOD and climatic fluctuations in the Arabian Gulf. The effects of IOD events on the climate of many regions including some Asian regions as well as those around the Indian Ocean, were revealed by (Saji and Yamagata, 2003)

During the winter season, IOD showed a linear effect spread over several distributed tide gauge stations between the Arabian Gulf and the Arabian Sea while the linear effect of the ENSO was evident on the stations located on the coasts of India and Pakistan. This is consistent with what some researchers have reached, like (N N V *et al.*, 2016), Where found a great correlation between the ENSO and MSL on the western coasts of India (*i.e.,* at the Arabian Sea) in the winter season as well as they found a linear relationship between the IOD and the MSL on the same coasts.

Although the linear impact of the IOD was the strongest on the stations located on the coasts of the Arabian Gulf comparing with ENSO, the linear trend of the ENSO has appeared during the summer season in two stations (*i.e*., Zuluf and Abu Ali Pier) in the Arabian Gulf, this result is consistent with the study conducted by Al Senafi and Anis, (2015), where indicated that the effect of ENSO by increased precipitation during summer season on the coasts of the Arabian Gulf and the Arabian Sea. Hence, this increase is caused by the effect of ENSO on monsoons winds, where the highest rate of precipitation was observed in the summer of 1997 when recording the strongest event for ENSO. Therefore, that increases the precipitation which affects the MSL mentioned above.

Pourasghar *et al.*, (2012) indicated that the differences in the amount of annual rainfall from the years 1974 - 2005 in the southern parts of Iran coasts at the Arabian Sea in the autumn season was more strongly related with IOD more than ENSO. This contrast was caused by ENSO, and this contradiction is attributed to the fact that some of the IOD and positive ENSO events occur together, and the fact that the IOD events decompose in the winter. However, the ENSO events reach their climax in the winter and continue until the spring. This explains the appearance of the linear trends of the ENSO in different regions of the Arabian Sea coasts in the winter season.

6. Conclusion

The importance of this study lies in revealing the quantitative relationship between climate changes and sea level fluctuation in the Arabian Gulf and the Arabian Sea regions and identifying the areas that will be affected by these changes to take the necessary precautions to avoid future threats due to sea level rise on ports and coastal areas. This study confirmed that the change in sea level in the studied areas is a reaction to climate changes in those areas and these changes depend on many physical factors in the sea as well as within the atmosphere (N N V *et al.*, 2016). The Statistical time series analysis technique used for the 24 tide gauge records on the coasts of the Arabian Gulf and the Arabian Sea showed that there are linear effects of both ENSO and IOD on mean sea level in the different and equal periods. In the different periods, important correlation coefficients of the IOD with the MSL were found in both the Arabian Gulf and Sea for monthly and seasonal measurements, especially in autumn. As for ENSO significant correlation coefficients, there are limited effects on the stations located at the coasts of the Arabian Sea for monthly and seasonal measurements (winter and autumn), while significant correlation coefficients were more pronounced during the summer and spring seasons in some stations at the Arabian Gulf. In equal periods, the linear effect of ENSO was weak compared to the IOD, as few stations showed significant correlation coefficients while no correlation was seen of it in some seasons. These important impacts may have future impacts on sea level rise in the region.

In general, the ENSO was the weakest influence in the Arabian Gulf compared to the IOD and its linear effect was more pronounced in the Arabian Sea. However, the IOD linear effect was more pronounced in the Arabian Gulf.

Climate change is one of the significant challenges for coastal cities worldwide. Thus, necessary investments have been discussed around the world in order to adapt to these changes and prevent the occurrence of coastal floods in the coming decades (Dangendorf *et al.*, 2014)

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تأثيرات تذبذب المحيط الهادئ الجنوبي وثنائي القطب في المحيط الهندي على مستوى سطح البحر في سواحل الخليج العربي وبحر العرب

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المستخلص. تكشف هذه الدراسة عن التأثير الخطي لكل من تذبذب المحيط الهادي – النينو الجنوبي (ENSO) وثنائي القطب في المحيط الهندي (IOD) على متوسط مستوى سطح البحر (MSL) في سواحل الخليج العربي وبحر العرب في العقود الأخيرة، وتحديد المناطق التي قد تتأثر بهذه التغييرات، من أجل اتخاذ الاحتياطات اللازمة لتجنب التهديدات المستقبلية لارتفاع مستوى سطح البحر على الموانئ والمناطق الساحلية. تم جمع بيانات محطات قياس المد والجزر من الخدمة الحكومية الدائمة لـ (PSMSL MSL)، وتم استخدام تقنية التحليل الإحصائي للسلاسل الزمنية باستخدام طريقة الانحدار الخطي (ذات المتغير الواحد والمتغيرين) ومعامل ارتباط بيرسون. وتم الحصول على معاملات ارتباط كبيرة لـ IOD وENSO في بعض المحطات الواقعة على السواحل السعودية والإيرانية للخليج العربي، وكذلك في بعض المحطات الواقعة على سواحل الهند وباكستان في بحر العرب. ولوحظ أن ENSO كان أضعف تأثيرًا في الخليج العربي مقارنة مع تأثيرات IOD وأكثر وضوحًا في بحر العرب. ونظرًا لارتفاع درجة حرارة الاحتباس الحراري للأرض مؤخرًا، فقد يزداد تأثير كل من IOD وENSO على MSL من خلال زيادة تواتر تلك الظواهر، وقد يكون الوضع أكثر خطورة في العقود القادمة.

الكلمات المفتاحية: التذبذب الجنوبي في المحيط الهادئ، ثنائي القطب في المحيط الهندي، الخليج العربي، البحر العربي.