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Temporal Variability of Sea Surface Temperature in Iraq Marine Water, Northwest of Arabian Gulf

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Abstract

Understanding sea surface temperature (SST) change in coastal areas is crucial for many aspects of the coastal environment and maritime operations in these water systems. Although SST fluctuations have been frequently documented in various Arabian Gulf areas, such variations in Iraq's marine waters, situated northwest of the Arabian Gulf, are poorly understood. To determine the temporal variations of SST, we examined SST measurements taken off the coast of Iraq between 2017 and 2019. The results revealed that SST exhibited pronounced annual, semiannual, and seasonal fluctuations. The highest and lowest recorded SST values were 36.77 and 14. 68°C, respectively. The seasonal averages of SST reach their maximum value during the summer season at 32.38 C and then are reduced to their lowest range during winter at 17.23 C. Furthermore, the results revealed that the highest SST was recorded in August of all three study years, namely 2017, 2018, and 2019. Meanwhile, the lowest recorded SST was observed in December of 2017 and February of both 2018 and 2019. The results also revealed a negative correlation between SST and Shamal winds. A perceived decrease in SST occurs with Shamal wind events, where the average reduction of SST reaches 2-3 C. At the same time, our results show that SST increases when the southeast wind is predominant. The results obtained in this study could benefit several aspects of the environment and maritime at this significant part of the Arabian Gulf.

Keywords: *SST, Arabian Gulf, Iraq marine water, Shamal wind*

Introduction

Sea surface temperature (SST) is an important parameter and indicator of water quality, with several ecological and anthropogenic implications (Androulidakis and Krestenitis, 2022). SST is a critical parameter in coastal and oceanic systems. The sea surface represents a lower boundary of the atmosphere, and it directly responds to the regional and, perhaps global fluctuation of air temperature. Hence, any change in the climate regime directly impacts the SST in the oceanic system (Brierley and Kingsford, 2009). However, SST information can be useful for a wide range of operational applications, including climatic and seasonal monitoring/ forecasting, bleaching of coral reefs, coastal tourism, and coastal protection strategies (Lafta, 2021; Alawad *et al*., 2023). SST plays a fundamental role in the evolution of tropical cyclones during their formation, intensification, and dissipation stages (Dube *et al*., 2024). Furthermore, SST represents an indicator of the spread of marine organisms and a tracer of various oceanic processes (Cracknell and Hayes, 1991).

The primary factors influencing SST fluctuations include changes in the air-sea heat flow, vertical mixing, and horizontal heat advection (Skliris *et al*., 2011). Additional physical factors that affect the fluctuations in SST are wind speed, the thermal conductivity of the sediments, solar radiation, relative humidity, water depth, and groundwater influx (Pilgrim *et al*., 1998).

The SST characteristics in coastal areas can be studied using a variety of techniques. The first approach uses continuous field measurements, which are carried out by installing specialized equipment that records the water temperature changes over time. The second approach involves studying the physical characteristics of coastal systems using the numerical modeling technique. The third approach involves measuring the SST on a broad scale over a longer period using remote sensing and satellite imagery. Even though it necessitates expensive equipment and extended observation times, the in situ measurement method is the most accurate of the three methods mentioned for studying SST variations (O'Carroll *et al*., 2019).

Iraq's marine water is located at the northwest tip of the Arabian Gulf (Figure 1). According to Reynolds (1993), the Arabian Gulf is a semi-enclosed body of water of 990 km in length, 370 km in width, and 36 m in mean depth. The

Arabian Gulf is a major waterway for oil transport and industry in the world. As a result, it brings very high interest from researchers in numerous scientific areas, especially oceanic studies (Sadrinasab and Kämpf, 2004; Alothman and Ayhan, 2010; AlOsairi *et al*., 2011; Ranjbar *et al*., 2020; Al-Fartusi *et al*., 2023a, Al-Fartusi *et al*., 2023b). Meanwhile, studies that highlighted the characteristics of SST, in particular at the northwest tip of the gulf are very scarce, largely due to the scarceness of oceanographic measurements.

Nevertheless, the Arabian Gulf is close to the Arabian Peninsula's hottest desert region, where the high temperature reflects on the hot SST. So, every summer, the Arabian Gulf is the world's warmest sea (Riegl *et al*., 2011). The gulf's shallow depth, low water exchange with the Gulf of Oman, and the hyper-arid climate around it may cause summer SSTs to approach 35 ^{o} C (Sheppard *et al*., 1992; Coles, 2003), with temperatures surpassing 33^{o}C for several months (Riegl *et al*., 2012). According to Paparella *et al*. (2019), mean SSTs in the Arabian Gulf are rising during the last three decades as a consequence of climate change.

In Iraq's marine water, there is no sufficient information, especially those that depend on reasonably long-term observations, which are only available for a short time. As a result, and to address the gap, the current study is attempting to highlight variability in SST in this essential Arabian Gulf region. To achieve this goal, realistic SST observations, which had never been measured in this location before, were adopted. This examination will be essential for comprehending the nature of SST and could be vital for many applied purposes, such as environmental conversation, port construction, and coastal protection strategies.

Materials and Methods

Iraq's marine water is critical because it provides the country's only access to the sea. However, the region appears as an estuarine ecosystem in the northwestern portion of the Arabian Gulf (Lafta, 2022; Mahmood *et al*., 2022). The tidal forces of the Arabian Gulf govern the hydrodynamic behavior of the region. The study region has the greatest observed tidal range in the whole Arabian Gulf, exceeding 4 m (Al-Mahdi *et al*., 2009). Furthermore, the large tidal range produces powerful tidal currents of up to 1 m.s^{-1} during both ebb and flood phases of the tidal cycle (Lafta, 2023). This area has an arid desert environment that have two different seasons: summer with high temperatures and a cold winter (Zakaria *et al*., 2013). According to Reynolds (1993), rainfall falls throughout the winter season and typically is modest, contributing insignificantly to the Arabian Gulf's water budget. The Arabian Gulf experiences high air pressure in the winter. December and January had the greatest atmospheric pressure readings. On the other hand, the Arabian Gulf as a whole has low atmospheric pressure throughout the summer due to the high air temperatures, with July showing the lowest levels (Sharaf El-Din, 1990). The northwest wind, also known as the Shamal wind, is the dominant wind pattern in the Arabian Gulf's northwest region. Nonetheless, with noticeable seasonal fluctuations, this wind blows across the region for the majority of the year. The southeast wind, which can last from a few hours to many days, is the second significant wind pattern in the area (Reynolds, 1993).

There are inadequate oceanographic and atmospheric observations of Iraqi maritime water, and when they are available, they are only available for brief periods of time. Fortunately, the DAEWOO company and the general company of Iraq ports constructed an offshore monitoring platform around 655 meters away from the western breakwater of Faw Grand Port during its construction. This station continuously records a number of meteorological and oceanic variables. This information is maintained by General Acoustics, a German corporation (https://www.generalacoustics.com/). However, this collection of data is special since, to our competence, no other similar dataset in the vicinity has been identified earlier. The SST fluctuations over roughly three years were investigated using this dataset. A 10-minute record of both SST and meteorological parameters (air temperature and wind speed and direction) for three years (2017-2019) was acquired from the Al-Faw port station.

Results and Discussion

The time series of SST revealed a pronounced annual, semiannual, and seasonal fluctuations. Summer and winter exhibited the highest and lowest SST values, respectively (Figure 2A). Throughout the study interval, the highest recorded SST was 36.77 ^{o} C in summer 2017. Meanwhile, the highest SST recorded in 2018 was 34.32, and in 2019 was 34.33 ^{o} C (Table 1). Correspondingly, the minimum value of the recorded SST during the study period was observed in the winter of 2017 at 14.68 ^{o} C. However, the lowest SST recorded in 2018 was 14.67, and in 2019 was 15.24 ^{o} C (Table 1). The annual averages of SST indicated that the year 2017 exhibited the maximum average of SST during the study period at 26.44^{o}C. Correspondingly, the average of SST in 2018 was 26.26^{o}C, and in 2019

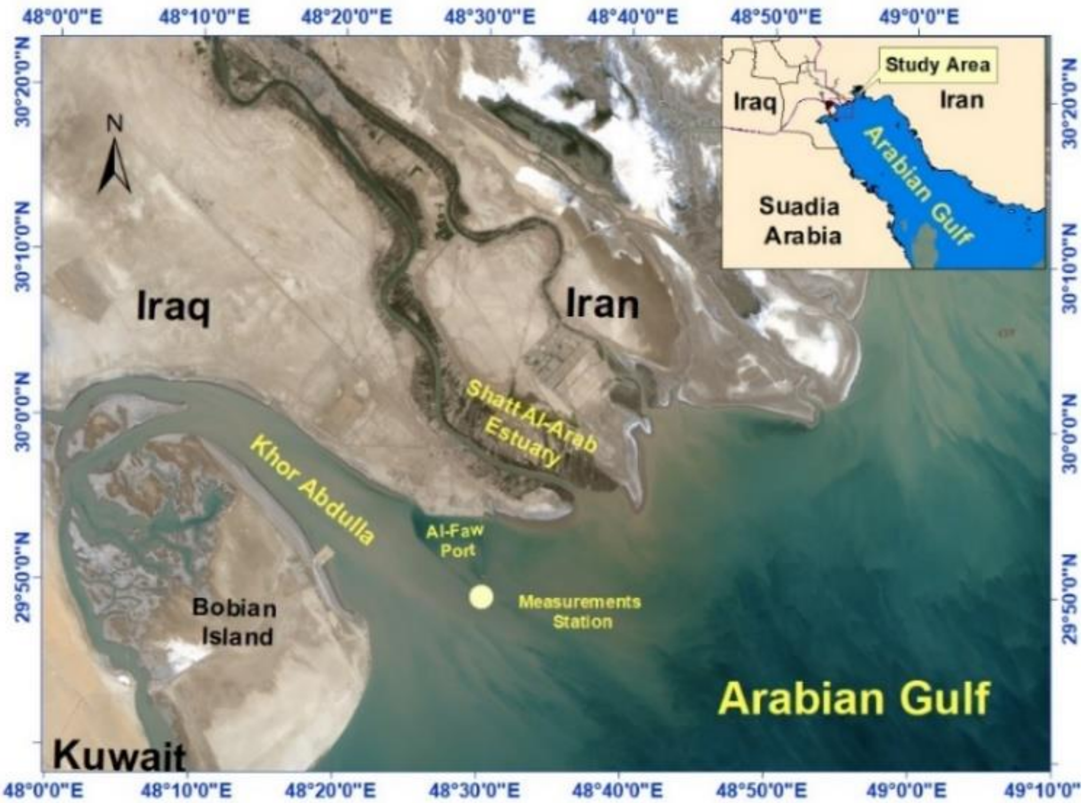

Figure 1. Geographical location of investigated area

was 25.75 °C (Table 1). The seasonal change in the SST begins in early spring and ends in early autumn. SST oscillation ranges were highest in autumn and spring and lowest in summer and winter, as demonstrated by standard deviation values (Table 2). The seasonal averages of SST reach their maximum value during the summer season at 32.38 °C and then are reduced to their lowest range during winter at 17.23°C.

Between July and December, there was no substantial temporal change in SST, which fluctuated between 34 and 36°C. Furthermore, there is a significant decrease in SST of 8-10°C between early October and November. At this period, the air temperature has dropped from 36 to 19°C. This is a transitional time from summer to winter, during which the cold Shamal wind dominates the area in addition to inter-seasonal temperature changes. Nevertheless, during the transition from winter to summer, from March to April, there was a significant temporal change in SST, which fluctuated between 19 and 25°C. During this time, the air temperature progressively rises as sun radiation serves as a heating source for the shallow water regions. Furthermore, the southeasterly warm wind begins to blow over the area, causing SST to rise further.

The time series SST revealed that extreme measurements were observed in August for the years 2017, 2018, and 2019, as shown in Table 1. However, Hereher (2020) previously reported the greatest SST in the Arabian Gulf occurs in August, demonstrating that the entire Gulf heats up to attain the highest possible temperature in August (33 to 35°C), making the gulf the world's warmest water. The lowest recorded SST, on the other hand, occurred in December of 2017 and February of both 2018 and 2019. Overall, the SST varied irregularly throughout the season and across the years. These data revealed that the arrival times of climatic heat waves differed between the seasons. In the northern Arabian Gulf, the SST is strongly affected by climatic heat waves, as Alosairi *et al*. (2020) demonstrated.

The highest SST observed throughout the study period was 36.77°C on August 17, 2017 at 4:10 PM. However, this value indicates one of the highest and most extreme water temperatures ever measured in the northwestern Arabian Gulf. On 23 July 2017, the approximate extreme water temperature of 36.9°C was measured near our study area, namely the Kuwait Bay (Alosairi *et al*., 2020). Accordingly, when the extreme SST was recorded, the tide was in the neap tide phase, the air temperature was 36°C, and the southeast wind was

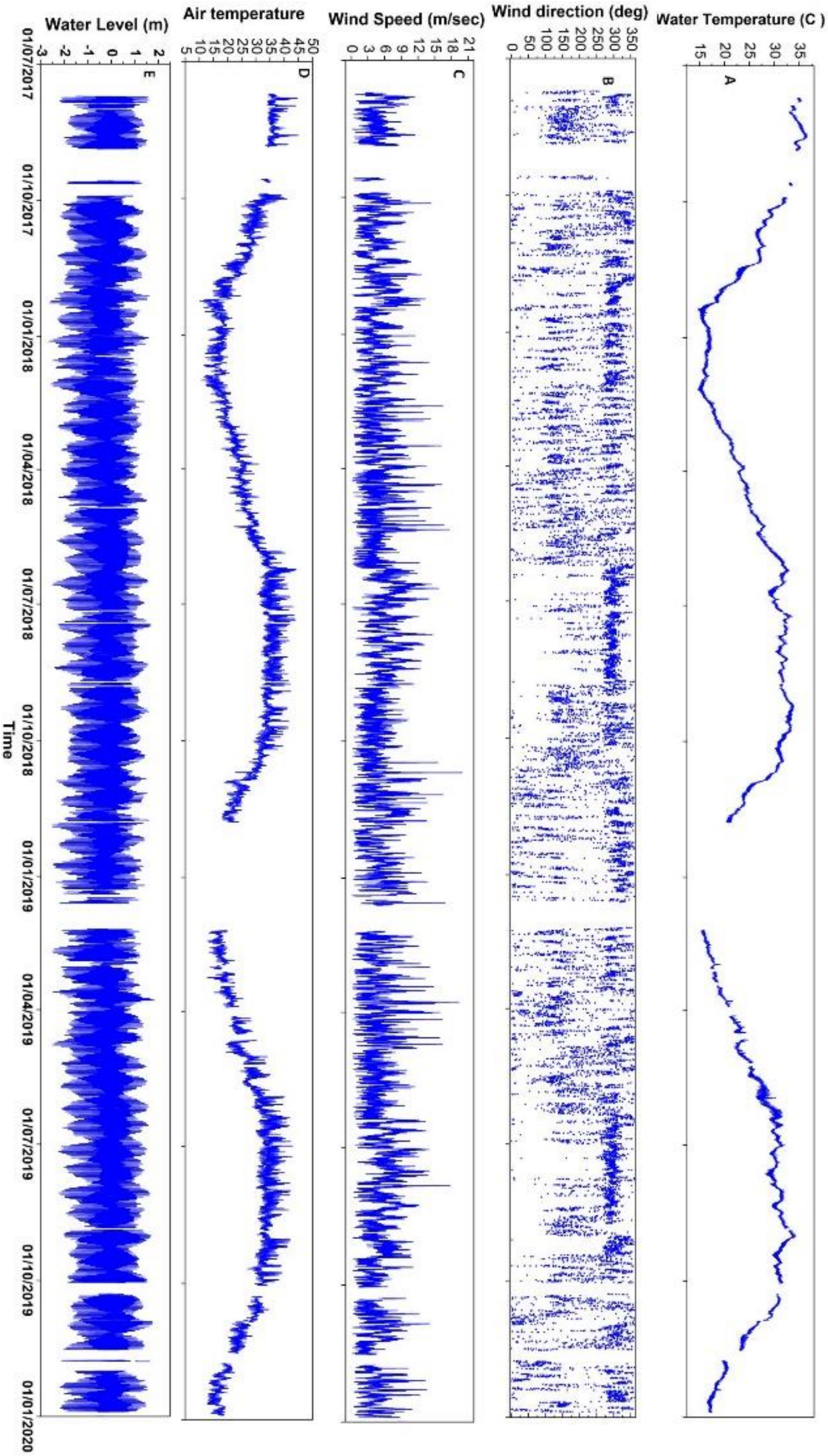

Figure 2. Time series data for the: A, SST, B, Wind Direction, C, Wind Speed, D, Air Temperature, E, Water leve

Table 1. Annual statics of SST in Iraq marine water during 2017-2019.

Year	SST °C)				
	Max		Min		Ave.
2017	17 Aug 16:10	36.77	12 Dec 11:00	14.68	26.44
2018	22 Aug 17:00	34.32	4 Feb 10:20	14.67	26.26
2019	21 Aug 13:10	34.72	6 Feb 5:20	15.24	25.75

Table 2. Seasonal statics of SST during 2017-2019.

Parameters	Statics	Season			
		Winter	Spring	Summer	Autumn
Water Temperature (^{O}C)	Max	24.15	33.02	36.77	32.268
	Min	14.67	19.28	28.21	15.173
	Mean	17.23	27.09	32.38	22.839
	Stdv	2.42	3.07	1.56	4.92

predominant, reaching 6.2 m.s^{-1}. However, in August 2017, the highest values of SST recordings were observed, from 4 August until 27 August, SST ranged between 34 to 36^{o}C. At this time, the prevailing wind pattern was the southeast wind that plays a fundamental role in the region's heat waves in summer season. However, the summer of 2017 was exceptionally warm compared to other years. It was remarkable in that it had an extended period of calm wind conditions, likely summer 2017 temperatures to surpass previous years' highest values, according to Paparella *et al*. (2019). Unfortunately, there is missing data throughout September 2017, but in late September, SST started to reduce coinciding with the dropping of air temperature and transition of wind regime to the Shamal wind.

To explore the role of winds in controlling the SST, observed wind speed and direction were plotted against the SST (Figure 2A, B, C). It is clear that a perceived decrease in SST occurs with Shamal wind events. The average reduction of SST during Shamal events reaches 2-3^{o}C.

Paparella *et al*. (2019) demonstrated that the summer season winds divide into two various patterns: breezes and Shamal wind. On days with summer breezes, the winds exhibit significant direction swings, frequently slowly turning clockwise from land to sea breezes and back over a 24-hour period (Figure 2B). Our results showed that the Shamal winds may stay for 2-6 days, during which the winds stop to swing and blow steadily from the northwest, with a daily average velocity that considerably more than 6 m.s^{-1} on the windiest day of the week. However, the negative correlation between SST and Shamal winds is more evident during summer days (Figure 2B). SST increases are often associated with a decrease in Shamal winds and a predominance of southeast winds. According to Alawad *et al*. (2023), a decrease in the Shamal wind, which blows from the north, results in reduced advection of comparatively cold air systems from Southern Europe across the Arabian Gulf. Then, if the Shamal wind diminishes, the surface wind speed is further reduced since there will be fewer evaporation and hence fewer surface cooling. Consequently, a reduction in the Shamal wind, particularly over shallow basins like the Arabian Gulf, enhances the stratification of the water masses, slows down the upwelling process, and maximizes the SST.

The impacts of the extreme SST on the Arabian Gulf environment were noticed in several aspects. However, many fish kill incidents were documented during these extreme SST events (Alosair *et al*., 2020). Correspondingly, several coral bleaching in different regions of the Arabian Gulf were reported throughout the extreme SST periods (in particular during 2017) (Burt *et al*., 2019; Paparella *et al*., 2019; Kavousi *et al*., 2021).

Conclusions

In this study, the temporal variability of SST was highlighted in the Iraq marine water. Realistic SST observations served as a basis for the investigation. However, the data used in this study is unique and has never been measured earlier in this location. The results demonstrated that the SST revealed pronounced annual, semiannual, and seasonal fluctuations. The highest and lowest values of SST occurred in summer and winter, respectively. During the study period, the maximum SST recorded was 36.77ºC in summer 2017 and the lowest was 14.68ºC in winter 2017. The yearly averages of SST showed that the year 2017 had the highest average of SST during the study period, at 26.44ºC. In general, and over the three study years, the summer of 2017 was the warmest, not just in our study location, but also in several other Arabian Gulf regions. Furthermore, the results demonstrated that wind patterns in the regions have significant effects on SST behavior. The influence of Shamal winds on controlling SST, with SST rising during light Shamal winds and decreasing during strong winds due to their cooling effect. In contrast, SST was observed to increase during the predominant of the summer southeast wind. It should be highlighted that these were the key findings, which concentrated on the temporal variability of SST in this critical region of the Arabian Gulf. However, the exploration of the effect of the extreme SST on the Iraq marine water environment is highly recommended.

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