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ARTICLE

Hydro-environmental Characteristics of Seawater around Boubyan Island, Kuwait Using Annual Variations of Seawater Temperature, Salinity and Tide Fluctuations

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ABSTRACT

The temporal and spatial variations of seawater temperature, salinity, and tidal fluctuations are important parameters for understanding the hydrodynamic, water quality, and marine biological activity in the seawater. It is also important to study and understand the probability and statistical aspects of these parameters for the planning and implementation of different types of marine projects. These parameters were measured at five different locations around Boubyan Island, Kuwait, for a span of almost one year during 2015-16. Based on the analysis of the measured data, it is found that the seawater salinity has varied from 34.14 to 48.31 ppt. The seawater temperature is also found to vary from 10.83 oC to 35.67 oC. The seawater level has varied from -2.694 m to 2.378 m with respect to the mean sea level. It is found that the peak of the probability density of seawater level is flat valued, whereas the probability density of salinity and seawater temperature is multimodal. A comparison of present and past measured seawater temperatures revealed that in Khor Al-Sabiya, the seawater temperature is increasing at the rate of 0.034 oC/year, which clearly indicates the effect of global warming. A similar study reveals that the annual average increase in salinity at Khor Al-Sabiya is 0.38 ppt, which clearly indicates a significant reduction of freshwater flow from Shatt Al-Arab into the Arabian Gulf. Since Kuwait is investing in many projects around the Boubyan Island, the results of this study will be useful for the integrated and sustainable development of Boubyan and Failaka Islands in Kuwait.

1. Introduction

Seawater temperature, salinity, and tidal fluctuations are important parameters, especially for the studies on seawater quality and development of marine life. Increase in seawater temperature due to increased air temperature would reduce the density of seawater and increase the thermal expansion of the seawater. According to http://sciencefairwater.com/physical-water-quality-parameters/water-temperature/water-temperature-effects-on-fish-and-aquatic-life/, higher temperatures diminish the solubility of dissolved oxygen and decrease the availability of this essential gas; elevated temperatures increase the metab-

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olism, respiration and oxygen demand of fish and other aquatic life, approximately doubling the respiration for a 10° C rise in temperature. Hence, the demand for oxygen is increased under conditions where oxygen supply is lowered. The solubility of many toxic substances is increased as the temperature rises [1]; higher temperatures militate against desirable fish life by favoring the growth of sewage fungus and the putrification of sludge deposits, and finally even with adequate dissolved oxygen, there is a maximum temperature that each species of fish or other organism can tolerate. Higher temperatures produce death. The maximum temperatures that adult fish can tolerate vary with the species of fish, prior acclimatization, oxygen availability and the synergistic effects of other pollutants". Similarly, increase in the salinity of seawater due to high evaporation would result in an increase in the density of seawater and lead to the less solubility of oxygen, which is detrimental for marine life. Many studies have reported the influence of seawater salinity on fish development and growth. In most species, egg fertilization and incubation, yolk sac resorption, early embryogenesis, swim bladder inflation, and larval growth are dependent on salinity. In larger fish, salinity is also a key factor in controlling growth [2]. It is shown in the literature that there is an optimal salinity for the better growth of each fish species. Some marine animals are described as stenohaline, which means that they can't cope with large salinity fluctuations; others are euryhaline and can tolerate a wide range of salinities. For example, blue crabs (callinectes sapidus) can live in a wide range of salinity from nearly freshwater to ocean salt water. Increase in seawater salinity would increase the osmotic pressure in the fish species. Some of the fishes may not tolerate such increased osmotic pressures. Boeuf and Bail [3] revealed that seawater temperature and light are important parameters for fish growth. Buckel et al. [4] also revealed that temperature and salinity affect the fish growth significantly. There are many published literatures dealing with the effect of salinity on the growth of marine life; some promising works are Conides et al. [5]; Canagaratman [6]; Fielder and Bardsley [7]; Morgan and Iwama [8, 9]; Nordlie et al.[10]; Otto [11]; Peterson et al. [12]; Smith et al. [13]; Swanson [14, 15]; Tandler et al. [16]; and Watanabe et al. [17]. Similarly, there are many studies on the effect of both salinity and temperature on fish growth; some of the promising works are Hart and Purser [18]; Imsland et al. [19]; Parker and Specker [20]; and Peterson et al. [21]. It is clear from these literatures that both seawater temperature and salinity affect the fish growth significantly.

Higher tidal fluctuation is expected to increase the current velocity, which in turn will increase the carrying capacity of the suspended sediments, fish eggs, nutrients, and fish larvae from one place to other far-off places. Higher tidal fluctuations result in a much bigger tidal flat and may increase the biological activity of mud skippers in the tidal flats, which has a bearing on the population of migrating birds [22]. Also, in a place where the tidal fluctuation is higher, it is required to select a higher deck level of marine structures such as marine terminals, and a higher top level of breakwater or coastal protection structures such as offshore breakwaters, groins, and seawalls. A thorough understanding of these parameters for any marine space is hence important for planning and managing different types of marine projects. These three parameters were measured at five different locations around the Boubyan Island, Kuwait, for a duration of about one year. Probability and statistical analysis is carried out and the results are presented in this paper. The present measured values are compared with the earlier values and the trend of change is also reported.

2. Study Location and Basic Oceanographic Information

Kuwait is located at the northwestern corner of the Arabian Gulf (Figure 1) and is surrounded by Iraq and Saudi Arabia. The Kuwaiti government has plans to develop Boubyan, Warba, and Failaka Islands, which are located at the northwestern part of the Arabian Gulf within the territorial waters of Kuwait. Site wise, these islands are located near the estuary of Shatt Al-Arab (Figure1),which is considered to be the main supplier of freshwater, including fine sediment, to the Arabian Gulf [23]. Consequently, this would have various effects on the hydro-environmental characteristics of this region, where various projects are intended to be undertaken [23]. The effects include water dynamics, water quality and marine ecology. The measured annual seawater turbidity in this site ranged from 7 to 58,008 ppm in a year [24]. The seawater velocity around these locations varied up to 90 cm/s over the same one-year period [25].

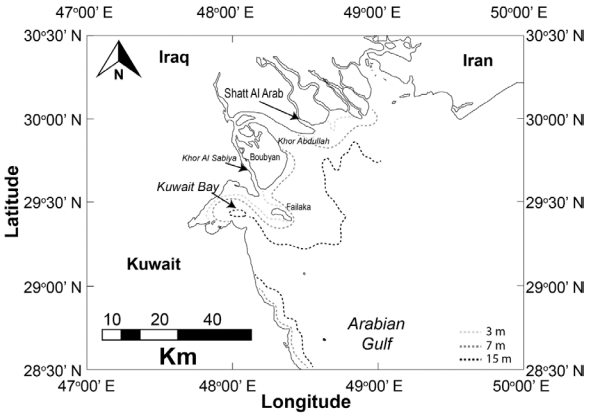

Figure 1. Gulf including The Kuwait Bay, Boubyan Island and Shatt Al-Arab; the field survey stations are in black circles and letters

3. Objectives of The Study

The main aim of this research study is to define the hydro-environmental characteristics around Boubyan Island, using annual variations of seawater temperature, salinity and tidal variation parameters. The hydro-environmental characteristics are visualized in the probability domain based on the analysis of these field data for its probability distribution, probability of non-exceedance of temperature, minimum, maximum, mean, median, mode, standard deviation, skewness, and kurtosis of these parameters.

4. Methodology

The objectives were executed through the following tasks: collection of data on seawater temperature, salinity, and tidal variation using accurate instruments; probability and statistical analysis of the measured data, and comparison of the present study with previous publications. The details of the work carried out in each task are subsequently explained.

4.1 Collection of Data on Seawater Temperature, Salinity and, Water Level Variation

INFINITY-CTW is the name of the instrument used for measuring the sea water temperature and electrical conductivity in the field. The specification of the instrument is provided in Table 1.

Table 1. Specification of INFINITY-CTW

Parameter	Temperature	Electric Conductivity
Principle	Thermistor	7-electrode type
Range	-3 to 45 °C	2 to 70 mS/cm
Resolution	0.001 °C	0.001 mS/cm
Accuracy	+/- 0.01 °C (0 to 35 °C)	+/- 0.01 mS/cm (2 to 65 mS/cm)

Infinity-CTW is an autonomously deployable data logger for highly accurate temperature and salinity measurements during long-term periods. The instrument has a mechanical wiper that periodically sweeps the sensing surface of the seven-electrode conductivity cell to keep the initial accuracy, avoiding bio-fouling without chemical materials and frequent maintenances. Infinity-CTW allows for accurate and stable salinity measurements for several months without cleaning maintenances. Infinity-CTW performance was evaluated and reported by Alliance for Coastal Technologies, ACT code: VS09-06. The instrument also provides the seawater salinity in ppt by the standard conversion formula using the electrical conductivity value.

HOBO Water Level Logger is used to measure the water level variations. The specification of the instrument is provided in Table 2. The HOBO U20 Water Level Logger is used for monitoring changing water levels in a wide range of applications including streams, lakes, wetlands, tidal areas, and groundwater. The loggers are typically deployed near the seabed specifically for deploying the loggers. This logger features high accuracy with no cumbersome vent tubes or desiccants to maintain. The logger uses a maintenance-free absolute pressure sensor and features a durable stainless steel or titanium housing (depending on model) and ceramic pressure sensor. The HOBO Water Level Titanium is recommended for saltwater deployment for recording water levels and temperatures in wetlands and tidal areas. The logger uses precision electronics to measure pressure and temperature and has enough memory to record over 21,700 combined pressure and temperature measurements.

Table 2. Specification of HOBO WLL

Parameter	Water level	Temperature
Range	0 to 9 m	-20 to 50 °C
Resolution	0.21 cm	0.1° at 20 °C
Accuracy	+/- 0.5 cm (+/- 0.05% FS)	+/- 0.37° at 20°C

The station's name, its longitude and latitude, and dates of deployment and retrieval are provided in Table 3.

Table 3. The station's name, longitude and latitude, and dates of deployment and retrieval

Station Name	Longitude (East)	Latitude (North)	Date of Deployment	Date of Retrieval
Location A (Boubiyan port)	48°19'29.46"	29° 52'36.06"	26.03.2015	31.12.2015
Location B (Sabiya military camp)	48°01'22.74"	29° 55'3.84"	25.03.2015	17.02.2016
Location C (Warba Island)	48°08'15.48"	29° 59'57.72"	25.03.2015	31.12.2015
Location D (Failaka Island)	48°16'0.12"	29° 26'4.38"	25.03.2015	15.02.2016
Location E (Sabiya coast guard)	48°19'29.46"	29° 52'36.06"	26.03.2015	17.02.2016

The instruments are fixed using a bottom mounted frame and the sensors are located about 15 cm from the seabed. The burst time of INFINITY-CTW is selected as 20 minutes. The instruments acquire 10 samples at a sampling speed of 1 sample/s and the average of these 10 samples is stored once in every 20 minutes. Hence, for a day, the instrument stores 72seawater temperature and salinity values, and for a year, each instrument stores 26,280 numbers of data at each location.

The burst time of HOBO Water Level Logger is select-

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ed as 30 minutes. The instruments acquire 10 samples at a sampling speed of 1 sample/s and the average of these 10 samples is stored every 30 minutes. Hence, for a day, the instrument stores 48 velocity values, and for a year, each HOBO Water Level Logger stores 17,520 numbers of water level data. It is clear from the table 3 that the data are available for almost a year to cover all of the four seasons in Kuwai, such as summer, spring, winter and autumn.

4.2 Data Analysis

The time series of the data collected from each station are plotted and verified for their quality. Then, the data are analyzed for probability density and probability of non-exccedance. Microsoft excel is used for probability density and probability of non-exccedance values. The standard statistical formula is used to find out the mean (first moment), median, mode, standard deviation (second moment), Skewness (third moment) and Kurtosis (fourth moment) of the probability density of sea water temperature, salinity and tidal variations.

5. Results and Discussion

Around Boubyan Island, the wave heights are smaller with the height ranging up to 1.0 m, and the wave period in the range of 3.0 to 6.0 s. The predominant wave direction near Failaka is to the northwest and southeast. The water depth is also shallow, with a depth varies up to 8.0 to 9.0 m at the middle of Khor Abdullah.

5.1 Seawater Temperature

The measured seawater temperature values are divided into a number of bins as shown in Table 4. The probability of the seawater temperature value for each bin width is estimated. For example, the probability of measured seawater temperature at Boubyan port area for the range of 20.001 to 22 °C is 0.126 or 12.6%. Similarly, it is possible to get the probability of seawater temperature for other stations and for any range from 10.001 to 36 °C. In all of the locations, the probability of seawater temperature in the range 0 to 10 °C is 0.0%. It means that there is no seawater temperature value less than 10 °C at these locations. For Boubyan port area, the highest probability value of 0.234 (23.4% of the time) has occurred for the seawater temperature of 29 °C (Figure 2). For other sites, the highest probability density values are indicated in bold letters. The corresponding seawater temperature values are the mode for that location. It is interesting to note that the mode for Failaka area is at 15 °C and 29 °C, since the highest probability density value is the same for these two temperatures.

Table 4. Probability of measured seawater temperature at five different stations around the Boubyan Island

Temperature Range (°C)		Mid Value (°C)	Probability of Temperature				
From	To		Boubyan Port	Failaka	Sabiya-Coast Guard	Sabiya-Military	Warba
0	2	1	0.000	0.000	0.000	0.000	0.000
2.001	4	3	0.000	0.000	0.000	0.000	0.000
4.001	6	5	0.000	0.000	0.000	0.000	0.000
6.001	8	7	0.000	0.000	0.000	0.000	0.000
8.001	10	9	0.000	0.000	0.000	0.000	0.000
10.001	12	11	0.000	0.002	0.018	0.003	0.000
12.001	14	13	0.005	0.035	0.126	0.128	0.006
14.001	16	15	0.072	**0.166**	0.077	0.084	0.067
16.001	18	17	0.017	0.017	0.008	0.010	0.015
18.001	20	19	0.044	0.018	0.054	0.055	0.064
20.001	22	21	0.126	0.100	0.108	0.116	0.142
22.001	24	23	0.067	0.068	0.050	0.047	0.045
24.001	26	25	0.078	0.050	0.091	0.063	0.078
26.001	28	27	0.101	0.090	**0.187**	**0.194**	**0.218**
28.001	30	29	**0.234**	**0.164**	0.110	0.115	0.134
30.001	32	31	0.102	0.122	0.126	0.140	0.150
32.001	34	33	0.150	0.130	0.044	0.044	0.079
34.001	36	35	0.003	0.039	0.000	0.000	0.000

The probability density plots (Figure 2) for seawater temperature show multiple peaks for almost all of the stations. The winter temperatures for all of the stations peak around12 to 14 °C and the summer temperatures for all of the stations peak between 27 and 29 °C. This is a unique plot for the seawater temperatures around the Boubyan Island in Kuwait.

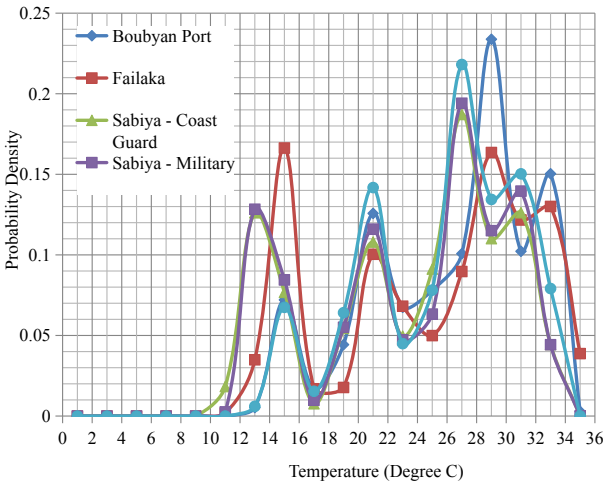

Figure 2. Probability density of seawater temperature around the Boubyan Island

The probability of non-exceedance of seawater tem-

perature for each location is provided in Table 5. Figure 3 shows the probability of non-exceedance of seawater temperature. For example, in Boubyan port area, 84.7% of the time, the seawater temperature will not exceed 31 °C. That is, the seawater temperature at Boubyan port exceeds 31 °C for 15.3% of the time in a year. Similar interpretation and information can be extracted for different values of temperature and for different locations. It is to be noted that for Failaka area, 83.1% of the time in a year, the temperature will not exceed 31 °C. That means, the temperature value exceeds 31 °C in Failaka area for 16.9% of the time in a year. For Sabiya coast guard, Sabiya military camp area, and Warba, 95.5%, 95.6% and 92.1% of the time in a year, the temperature value does not exceed 31 °C. It is an indication that seawater temperatures in these three locations are cooler compared to eastern part of Boubyan Island and Failaka Island areas. The probable reason is that the eastern part of Boubyan Island and Failaka Island area has almost flat sea bed and is shallow and hence the sunlight and its heat can reach the water near the seabed most of the time. Whereas on the Khor Al-Sabiya and Warba area, the channel is deep near the centre and the sunlight cannot reach most of the time and keeping the seawater temperature relatively cooler. It is to be remembered that with a high seawater temperatures, the oxygen holding capacity of the sea water reduces. Under such circumstances, if the water is polluted with nitrates and phosphates, it would result in a harmful algal bloom due to eutrophication, which in turn reduces the oxygen level in seawater to an anoxic condition and subsequently leads to a massive fish kill. The presentation of seawater temperature plots (Figure 3) in this paper will be useful for such type of further study.

Table 5. Probability of non-exceedance of the measured temperature at five different stations around the Boubyan Island

Temperature Range (°C)		Mid Value (°C)	Probability of Non-Exceedance of Temperature				
From	To		Boubyan Port	Failaka	Sabiya-Coast Guard	Sabiya-Military	Warba
0	2	1	0.000	0.000	0.000	0.000	0.000
2.001	4	3	0.000	0.000	0.000	0.000	0.000
4.001	6	5	0.000	0.000	0.000	0.000	0.000
6.001	8	7	0.000	0.000	0.000	0.000	0.000
8.001	10	9	0.000	0.000	0.000	0.000	0.000
10.001	12	11	0.000	0.002	0.018	0.003	0.000
12.001	14	13	0.005	0.037	0.144	0.131	0.006
14.001	16	15	0.077	0.203	0.221	0.215	0.073
16.001	18	17	0.094	0.220	0.229	0.225	0.089
18.001	20	19	0.139	0.238	0.283	0.280	0.153
20.001	22	21	0.265	0.338	0.391	0.396	0.295
22.001	24	23	0.332	0.406	0.441	0.444	0.340
24.001	26	25	0.410	0.456	0.532	0.507	0.418
26.001	28	27	0.511	0.546	0.719	0.701	0.636
28.001	30	29	0.745	0.710	0.829	0.816	0.770
30.001	32	31	0.847	0.831	0.955	0.956	0.921
32.001	34	33	0.997	0.961	1.000	1.000	1.000
34.001	36	35	1.000	1.000	1.000	1.000	1.000

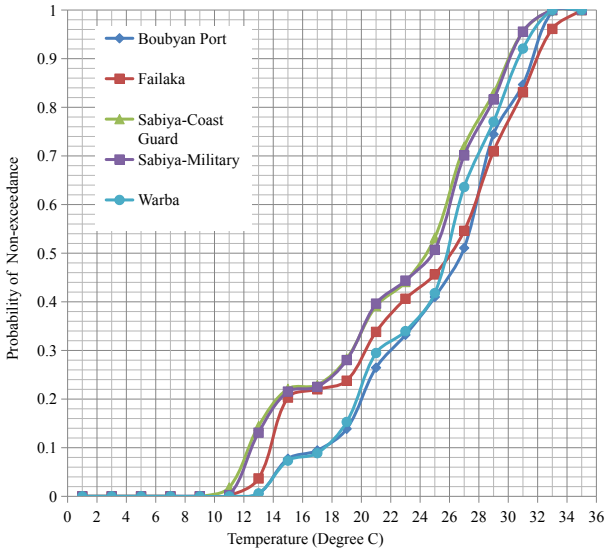

Figure 3. Probability of non-exceedance of seawater temperature around the Boubyan Island

Table 6 provides the observed minimum, maximum, mean, median, mode, standard deviation, skewness, and kurtosis of the seawater temperature for all of the five locations. The maximum value of the temperature recorded is 35.67 °C at Failaka area. The minimum value of temperature is at the Sabiya coast guard area and is 10.77 °C. The information is useful for numerical modeling and to study the effect of seawater temperature variation on marine life.

Table 6. Observed minimum, maximum, mean, median, mode, standard deviation, skewness, and kurtosis of the seawater temperature for all of the five locations

Statistical Properties of Temperature (°C)	Boubyan Port	Failaka	Sabiya-Coast Guard	Sabiya-Military	Warba
Minimum	12.77	10.83	10.77	11.31	13.24
Maximum	34.55	35.67	34.15	34.01	34.17

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Mean	26.14	25.09	23.50	23.71	25.67
Median	26.85	26.15	24.50	24.90	25.80
Mode	29.0	15.0 and 29.0	27.0	27.0	27.0
Standard Deviation	5.33	6.72	6.39	6.34	5.11
Skewness	-0.59	-0.42	-0.42	-0.41	-0.55
Kurtosis	-0.61	-1.17	-1.12	-1.13	-0.64

Seawater temperature is fairly symmetrical for Failaka, Sabiya-coast guard and Sabiya military area since the skewness value is between -0.5 and 0.5. For Boubyan port and Warba, it is moderately negatively skewed, since the skewness is between -1 and – 0.5. The value of Kurtosis is negative for all of the locations. It means that it has less weightage in the tail compared to the normal distribution.

5.2 Seawater Salinity

The measured seawater salinity values are divided into a number of bins as shown in Table 7. The probability of the seawater salinity value for each bin width is estimated. For example, the probability of the measured seawater salinity at Boubyan port area for the range of 40.01 to 41 ppt is 0.122 or 12.2%. Similarly, it is possible to get the probability of seawater salinity for other stations and for any range from 34.01 to 49 ppt. For all of the locations, the probability of seawater salinity in the range 34.01 to 39 ppt is 0.0%. It means that there is no seawater salinity value less than 39 ppt at these locations. In the open sea and oceans, the salinity is mostly in the range of 30 to 32 ppt. For Boubyan port area, for the highest probability value of 0.252 (25.2% of the time), the seawater salinity is 41.5 ppt. For other sites, the highest probability values are indicated in bold letters. The corresponding seawater salinity values are the mode for that location.

Table 7. Probability of measured seawater salinity at five different stations around the Boubyan Island

Salinity Range (ppt)		Mid Value (ppt)	Probability of Salinity				
From	To		Boubyan Port	Failaka	Sabiya-Coast Guard	Sabiya-Military	Warba
34.01	35	34.5	0.000	0.000	0.000	0.000	0.000
35.01	36	35.5	0.000	0.000	0.000	0.000	0.000
36.01	37	36.5	0.000	0.000	0.000	0.000	0.000
37.01	38	37.5	0.000	0.000	0.000	0.000	0.000
38.01	39	38.5	0.000	0.000	0.000	0.000	0.000
39.01	40	39.5	0.002	0.000	0.011	0.020	0.000
40.01	41	40.5	0.122	0.071	0.150	0.162	0.213
41.01	42	41.5	**0.252**	**0.517**	0.064	0.061	0.071
42.01	43	42.5	0.209	0.190	0.126	0.149	0.105
43.01	44	43.5	0.182	0.184	0.124	0.133	**0.214**
44.01	45	44.5	0.114	0.037	**0.188**	**0.180**	0.156
45.01	46	45.5	0.118	0.000	0.154	0.168	0.189
46.01	47	46.5	0.000	0.000	0.125	0.126	0.051
47.01	48	47.5	0.000	0.000	0.057	0.001	0.000
48.01	49	48.5	0.000	0.000	0.000	0.000	0.000

The probability density plots (Figure4) for seawater salinity show multiple peaks for almost all of the stations. For Failaka, 51% of the salinity is with 41.5 ppt. Multiple peaks indicate most probably the effect of low saline water mixing for a certain span and high evaporation of seawater for a certain span of time.

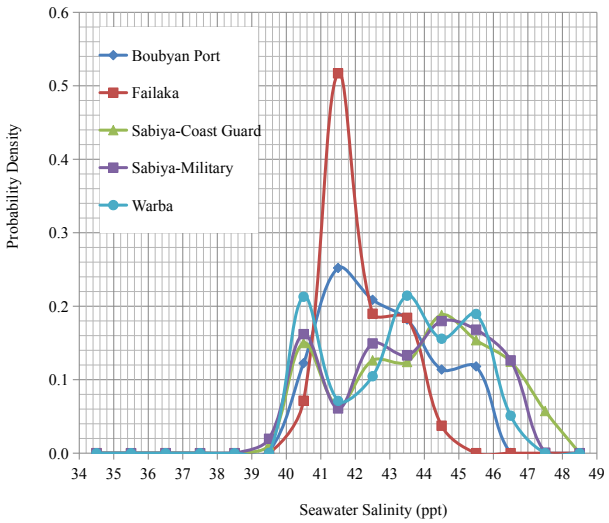

Figure 4. Probability density of seawater salinity around the Boubyan Island

The probability of non-exceedance of seawater salinity for each location is provided in Table 8. For example, in Boubyan port area, 88.1% of the time, the seawater salinity is not expected to exceed 44.5 ppt. This means that the seawater salinity at Boubyan port is expected to exceed 44.5 ppt for 11.9% of the time in a year. Similar interpretation and information can be extracted for different values of salinity and for different locations. It is to be noted that for Sabiya coast guard, 66.4% of the time in a year, the salinity is not expected to exceed 44.5 ppt. That means, the salinity value is expected to exceed 44.5 ppt in Sabiya coast guard area for 33.6% of the time in a year. For Sabiya military camp area, 70.5% of the time in a year, the salinity value is not expected to exceed 44.5 ppt. It is an indication that salinity in Khor Sabiya is higher than the eastern part of Boubyan Island.

For the other two stations (Failaka and Warba), the probabilities of exceedance of salinity by a value of 44.5 ppt are 0.0% and 24.1% respectively. One reason why Failaka area has a low probability of exceedance is possi-

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bly due to the freshwater mixing from Shatt Al-Arab, but this fact needs to be explored further.

Table 8. Probability of non-exceedance of the measured salinity at five different stations around Boubyan Island

Salinity Range (ppt)		Mid Value (ppt)	Probability of Non-Exceedance of Salinity				
From	To		Boubyan Port	Failaka	Sabiya-Coast Guard	Sabiya-Military	Warba
34.01	35	34.5	0.000	0.000	0.000	0.000	0.000
35.01	36	35.5	0.000	0.000	0.000	0.000	0.000
36.01	37	36.5	0.000	0.000	0.000	0.000	0.000
37.01	38	37.5	0.000	0.000	0.000	0.000	0.000
38.01	39	38.5	0.000	0.000	0.000	0.000	0.000
39.01	40	39.5	0.002	0.000	0.011	0.020	0.000
40.01	41	40.5	0.125	0.072	0.161	0.182	0.213
41.01	42	41.5	0.377	0.589	0.226	0.243	0.285
42.01	43	42.5	0.586	0.778	0.352	0.392	0.389
43.01	44	43.5	0.768	0.963	0.476	0.525	0.604
44.01	45	44.5	0.881	1.000	0.664	0.705	0.759
45.01	46	45.5	1.000	1.000	0.818	0.873	0.949
46.01	47	46.5	1.000	1.000	0.943	0.999	1.000
47.01	48	47.5	1.000	1.000	1.000	1.000	1.000
48.01	49	48.5	1.000	1.000	1.000	1.000	1.000

The probability of non-exceedance of seawater salinity around the Boubyan Island is shown in Figure 5. For a salinity value greater than 41 ppt, among the five stations, the probability of non-exceedance is highest for Failaka area and the lowest for Sabiya coast guard area. For example, for 44 ppt, the probability of non-exceedance is 99% for Failaka and is 57% for Sabiya coast guard, proving a very high salinity at Sabiya coast guard area.

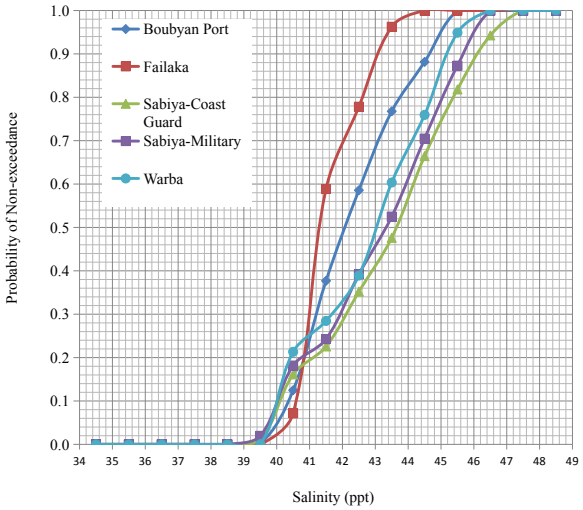

Figure 5. Probability of non-exceedance of seawater salinity around, the Boubyan Island

Table 9 provides the observed minimum, maximum, mean, median, mode, standard deviation, skewness, and kurtosis of the seawater salinity for all of the five locations. The maximum value of the salinity recorded is 48.31 ppt at Sabiya military area. The minimum value of salinity is at the Failaka area and is 34.14 ppt. The information is useful for numerical modeling and to study the effect of turbidity on marine life.

Table 9. Observed minimum, maximum, mean, median, mode, standard deviation, skewness, and kurtosis of the seawater salinity for all the five locations

Statistical Properties of Salinity (ppt)	Boubyan Port	Failaka	Sabiya-Coast Guard	Sabiya-Military	Warba
Minimum	39.15	34.14	36.53	38.72	39.11
Maximum	46.16	45.06	47.37	48.31	47.05
Mean	42.77	42.16	43.85	43.56	43.28
Median	42.70	41.3	43.65	43.33	43.03
Mode	41.50	41.50	44.50	44.50	43.50
Standard Deviation	1.47	0.91	2.12	2.06	1.90
Skewness	0.33	0.57	-0.24	-0.20	-0.22
Kurtosis	-0.82	-0.04	-1.07	-1.10	-1.21

Salinity is fairly symmetrical, except for Failaka. For Failaka, it is moderately positively skewed. The value of kurtosis is negative for all of the locations. It means that it has less weightage in the tail compared to the normal distribution unlike turbidity measurements.

5.3 Seawater Level

The seawater level instruments measure the instantaneous water depth, which varies with respect to time due to tidal variation. The average water depth is estimated from the measurements and is used to estimate the seawater level with respect to the mean sea level and is used for the probability analysis. These seawater level values are divided into a number of bins as shown in Table 10. The probability of the seawater level value for each bin width is estimated. For example, the probability of the measured seawater level at Boubyan port area for the range of -0.1 to 0.1m is 0.066 or 6.6%. Similarly, it is possible to get the probability of seawater level for other stations and for any range from-2.7 to 2.5 m. For Boubyan port area, at the highest probability value of 0.08 (8.0% of the time), the seawater level is 0.8 m. For other sites, the highest probability values are indicated in bold letters. The corresponding seawater level values are the mode for that location. It is interesting to note that the mode for Failaka area is 0.0 m.

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Table 10. Probability of measured seawater level at five different stations around the Boubyan Island

Level Range (m)		Mid Value (m)	Probability of Level				
From	To		Boubyan Port	Failaka	Sabiya-Coast Guard	Sabiya-Military	Warba
-2.7	-2.501	-2.6	0.000	0.000	0.001	0.001	0.000
-2.5	-2.301	-2.4	0.000	0.000	0.003	0.003	0.003
-2.3	-2.101	-2.2	0.001	0.000	0.009	0.009	0.009
-2.1	-1.901	-2	0.010	0.000	0.021	0.019	0.018
-1.9	-1.701	-1.8	0.018	0.001	0.028	0.028	0.029
-1.7	-1.501	-1.6	0.026	0.005	0.034	0.037	0.039
-1.5	-1.301	-1.4	0.032	0.019	0.041	0.042	0.042
-1.3	-1.101	-1.2	0.044	0.036	0.048	0.051	0.047
-1.1	-0.901	-1	0.054	0.052	0.053	0.058	0.053
-0.9	-0.701	-0.8	0.061	0.064	0.056	0.056	0.055
-0.7	-0.501	-0.6	0.070	0.074	0.054	0.053	0.055
-0.5	-0.301	-0.4	0.069	0.084	0.055	0.051	0.054
-0.3	-0.101	-0.2	0.066	0.100	0.053	0.052	0.053
-0.1	0.1	0	0.066	**0.101**	0.056	0.054	0.054
0.101	0.3	0.2	0.070	0.096	0.057	0.055	0.054
0.301	0.5	0.4	0.072	0.099	0.060	0.057	0.058
0.501	0.7	0.6	0.075	0.100	0.060	0.061	0.061
0.701	0.9	0.8	**0.080**	0.083	0.062	**0.063**	0.066
0.901	1.1	1	0.068	0.048	**0.066**	0.061	**0.068**
1.101	1.3	1.2	0.054	0.025	0.063	0.059	0.065
1.301	1.5	1.4	0.036	0.009	0.050	0.051	0.050
1.501	1.7	1.6	0.018	0.002	0.036	0.037	0.034
1.701	1.9	1.8	0.009	0.000	0.022	0.024	0.020
1.901	2.1	2	0.000	0.000	0.010	0.015	0.010
2.101	2.3	2.2	0.000	0.000	0.003	0.003	0.001
2.301	2.5	2.4	0.000	0.000	0.001	0.000	0.000

The probability of seawater level for all of the five locations is provided in Figure 6. The probability is high for water levels in the range of -1.1 m to 1.0 m.

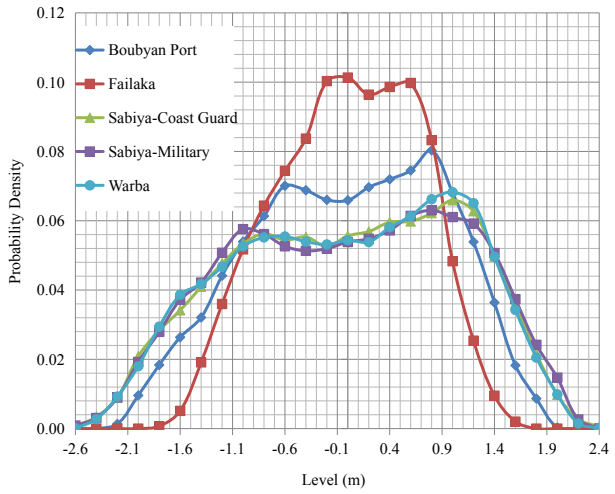

Figure 6. Probability density of seawater level around the Boubyan Island

The probability of non-exceedance of seawater level for each location is provided in Table 11 and the plot for the probability of non-exceedance of water level is provided in Figure 7. For example, in Boubyan port area, 88.3% of the time, the seawater level is not expected to exceed 1.0 m. It means, the seawater level at Boubyan port is expected to exceed 1.0 m from the mean water level for 11.7% of the time in a year. Similar interpretation and information can be extracted for different values of the water level and for different locations. It is to be noted that for Failaka area, 96.3% of the time in a year, the water level from the mean water level is not expected to exceed 1.0 m. That means, the water level value is expected to exceed 1.0 m in the Failaka area for 3.7% of the time in a year. For Sabiya coast guard area, Sabiya military camp area, and Warba, 81.7%, 81.1% and 81.9% of the time in a year, respectively the seawater level is not expected to exceed 1.0 m from the mean sea level. It is an indication that sea water level in these three locations are higher, than the other two locations. This is due to the funneling effect when the tide is rising.

Table 11. Probability of non-exceedance of the measured level at five different stations around Boubyan Island

Level Range (m)		Mid Value (m)	Probability of Non-Exceedance of Level				
From	To		Boubyan Port	Failaka	Sabiya-Coast Guard	Sabiya-Military	Warba
-2.7	-2.501	-2.6	0.000	0.000	0.001	0.001	0.000
-2.5	-2.301	-2.4	0.000	0.000	0.004	0.004	0.003
-2.3	-2.101	-2.2	0.001	0.000	0.013	0.013	0.012
-2.1	-1.901	-2	0.011	0.000	0.034	0.032	0.030
-1.9	-1.701	-1.8	0.029	0.001	0.062	0.060	0.060
-1.7	-1.501	-1.6	0.056	0.006	0.096	0.097	0.098
-1.5	-1.301	-1.4	0.088	0.025	0.137	0.139	0.140
-1.3	-1.101	-1.2	0.132	0.061	0.185	0.190	0.187
-1.1	-0.901	-1	0.186	0.113	0.238	0.248	0.239
-0.9	-0.701	-0.8	0.247	0.177	0.295	0.304	0.294
-0.7	-0.501	-0.6	0.317	0.251	0.349	0.357	0.350
-0.5	-0.301	-0.4	0.386	0.335	0.404	0.408	0.404
-0.3	-0.101	-0.2	0.452	0.435	0.457	0.460	0.457
-0.1	0.1	0	0.518	0.537	0.512	0.514	0.511
0.101	0.3	0.2	0.588	0.633	0.569	0.569	0.565
0.301	0.5	0.4	0.660	0.732	0.629	0.626	0.623
0.501	0.7	0.6	0.734	0.832	0.689	0.687	0.685
0.701	0.9	0.8	0.814	0.915	0.751	0.750	0.751
0.901	1.1	1	0.883	0.963	0.817	0.811	0.819
1.101	1.3	1.2	0.936	0.988	0.880	0.870	0.884
1.301	1.5	1.4	0.973	0.998	0.929	0.921	0.934
1.501	1.7	1.6	0.991	1.000	0.965	0.958	0.968
1.701	1.9	1.8	1.000	1.000	0.987	0.983	0.989
1.901	2.1	2	1.000	1.000	0.997	0.997	0.998
2.101	2.3	2.2	1.000	1.000	0.999	1.000	1.000
2.301	2.5	2.4	1.000	1.000	1.000	1.000	1.000

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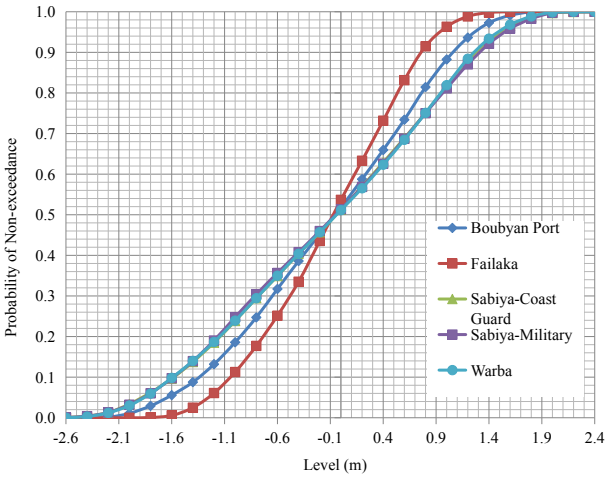

Figure 7. Probability of non-exceedance of seawater level around Boubyan Island

Table 12 provides the observed minimum, maximum, mean, median, mode, standard deviation, skewness, and kurtosis of the seawater level for all of the five locations. The maximum value of the level recorded is 2.378 m with respect to the mean sea level at Sabiya coast guard area. The minimum seawater level is -2.694 m, with respect to the mean sea level at the same station. This location is hence ideal for tidal a power plant.

Table 12. Observed minimum, maximum, mean, median, mode, standard deviation, skewness, and kurtosis of the seawater level for all of the five locations

Statistical Properties of Level (m)	Boubyan Port	Failaka	Sabiya-Coast Guard	Sabiya-Military	Warba
Minimum	-2.190	-1.854	-2.694	-2.657	-2.576
Maximum	2.096	1.699	2.378	2.300	2.314
Mean	0.000	0.000	0.000	0.000	0.000
Median	-0.05	-0.075	-0.05	-0.05	-0.05
Mode	0.8	0.0	1.0	0.8	1.0
Standard Deviation	0.902	0.676	1.068	1.083	1.063
Skewness	-0.168	-0.158	-0.141	-0.107	-0.150
Kurtosis	-0.851	-0.740	-0.961	-0.998	-1.002

Seawater level is fairly symmetrical for all of the stations since the skewness value is between -0.5 and 0.5. The value of kurtosis is negative for all of the locations, which means that it has less in the tail compared to the normal distribution.

5.4 Comparison of the Result of the Present Study with Earlier Field Measurements

Anderlini et al. [26] has reported a salinity range of 37 to 50 ppt in the Kuwait Bay during 1981 based on a 12-month study. Shunbo et al. [27] recorded a salinity value of 33 ppt at Khor Al-Sabiya. During 1995-96, the mean salinity of Kuwait's water dropped to 34.7 ppt due to the forced man-made freshwater discharge from Mesopotamian marsh land, and during 1996-97, the mean salinity in Khor Al-Sabiya was 36.6 ppt (Al-Yamani et al., [28, 29].The mean salinity of 41.6 ppt was recorded during 1999-2002 in Khor Al-Sabiya. Extensive measurements of seawater salinity was carried out by Al-Yamani et al. [30] at one location closer to the locations selected for the present study (Location E, Sabiya coast guard). According to Al-Yamani et al. [30], the average value of seawater salinity from 1996 to 2005 near the Sabiya coast guard station was 32.3 ppt. The minimum and maximum recorded seawater salinity values were 18.2 and 44.9 ppt, respectively. Based on the present study, the average annual seawater salinity for the same location is 43.85 ppt. The minimum and maximum recorded seawater salinity value during 26.3.2015 to 17.2.2016 was 36.53 and 47.37ppt, respectively. This means, the mean water salinity values has increased by 11.55 ppt during 1996-2005 to 2015-2016. If the mean salinity of 36.6 ppt at Khor Al-Sabiya is compared between 1996 and 97 measured by Al-Yamani et al., [28] to the present field study result of 43.85 ppt, it is clear that the annual average increase in salinity at Khor Al-Sabiya is 0.38 ppt. There are two possible reasons for this increase in sea water salinity; 1. The significant reduction of fresh water flow from Shatt Al-Arab into Arabian Gulf. 2. Slow increase in the atmospheric temperature and increased sea water evaporation rate. It is also clear that the value of minimum seawater salinity also increased by 18.33 ppt during 1996-2005 to 2015-2016. However, the value of maximum sea water salinity has increased by 2.47 ppt during 1996-2005 and 2015-2016. It is clear from this comparison that freshwater discharge from Iraq has reduced significantly between 1996 - 2005 to 2015 - 2016. This information will be useful for further investigation on change in marine biodiversity in this area. It is to be noted that increase in the salinity of seawater due to high evaporation would result in an increase in the density of the seawater and lead to the less solubility of oxygen, which is detrimental for marine life.

Al-Yamani et al. [31] also reported about the seawater temperature and salinity in the Kuwaiti territorial waters. According to Al-Yamani et al. [31], the mean annual temperature of Kuwait's seawater was 23.8 ^{o}C. The minimum seawater temperature recorded in Khor Al-Sabiya was 10 ^{o}C in December 1984 (Shunbo et al., [27]). According to the present study, the minimum seawater temperature recorded at Khor Al-Sabiya is 10.77 ^{o}C in the south and 11.31 ^{o}C in the northern part. Hence, the mean minimum seawater

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temperature in Khor Al-Sabiya during 2015-16 is 11.04 °C. Hence, the minimum temperature value has increased to 1.04 °C by 31 years. Hence, there is an annual increase of about 0.034 °C in the minimum seawater temperature. This could be due to an increase in the air temperature. The average mean seawater temperature from the five stations is 24.82 °C. When compared to the average seawater temperature of Kuwait, measured by Al-Yamani et al. [31], it is 1.02 °C higher. Hence, it is clear that the seawater temperature is increasing at the rate of 0.034 °C/year.

6. Conclusion

In this study, an attempt is made to understand the hydro-environmental characteristics of the seawater around Boubyan Island in Kuwait, using annual variations of seawater temperature, salinity, and tide fluctuations. These parameters are measured for a year at five different locations. The following important conclusions are obtained:

(1) The salinity of the seawater has varied from 34.14 to 48.31 ppt in a year around Boubyan Island.

The seawater temperature varied from 10.83 °C to 35.67 °C in a year around Boubyan Island.

(2) The seawater level ranged from -2.694 m to 2.378 m with respect to the mean sea level.

(3) The probability density of seawater level is single peaked, whereas the probability density of salinity and seawater temperatures are multimodal. The peak of the probability density of surface water fluctuations is flat.

(4) In Boubyan port area, seawater salinity is expected to exceed 44.5 ppt for 11.9% of the time in a year.

(5) It is found that the salinity in Khor Sabiya is higher than the eastern part of the Boubyan island. The seawater temperature at Boubyan port area is expected to exceed 31 °C for 15.3% of the time in a year.

(6) The seawater temperature in Khor Al-Sabiya is increasing at the rate of 0.034 °C/year. The annual average increase in salinity at Khor Al-Sabiya is 0.38 ppt.

(7) It is suggested that the parameters should be measured continuously to understand the annual change in the seawater temperature and salinity, which will help to understand the global warming trend and the reduced freshwater flow from Shatt Al-Arab. Such continuous measurement will help understand the effect and change on marine biodiversity in this area.

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