

Some Physical Oceanographic Aspects of Kuwait and Arabian Gulf Marine Environment



Subramaniam Neelamani, Yousef Al-Osairi, Khaled Al-Salem, and Karim Rakha

Abstract Arabian Gulf is one of the important marine water body. Arabian Gulf has more than 800 offshore oil and gas platforms, and it is increasing every year. About 25,000 tankers/year move out with oil from the Gulf. For cost-effective design of all type of marine facilities, a clear understanding of physical oceanographic parameters, such as waves, tides, currents, seawater turbidity, temperature, salinity, etc., is needed. Such critical physical oceanographic parameters of Arabian Gulf, Kuwait territorial waters, and some of the specific area within the Kuwaiti territorial water are reported in this manuscript. Such information is also essential for sustainable development and integrated management of coastal projects in this region. The Arabian Gulf is a shallow water body with maximum water depth of about 100 m, and the average water depth is about 35 m. The total surface area of the Arabian Gulf is about 226,000 km², and it holds about 8000 km³ of seawater. The wave climate is mild to moderate. The tidal variation can reach up to 4.0 m, especially in the northern part of the Gulf. Current velocity exceeds 0.7 m/s in few locations like Strait of Hormuz and the northern part of the gulf. The annual average wind speed is in the range of 3.0–7.0 m/s, and the dominant direction is from northwest. The seawater in the northern part of the Arabian Gulf has almost zero transparency, whereas the transparency reaches 100% within a distance of about 150 km towards south. The seawater salinity of the water varies from 35 to 50 ppt due to strong evaporation and less freshwater flow into the Gulf. The seawater temperature varies in between 10 and 35 °C and is the hottest sea on the earth.

Keywords Arabian Gulf · Waves · Currents · Tide · Seawater temperature and salinity · Turbidity · Extreme waves and winds

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1 Introduction

The Arabian Gulf (Fig. 1), a marginal sea in a typical arid zone, is an arm of the Indian Ocean. It lies between the latitude of 24° N to 30° N and longitude of 48° E to 57° E. It is relatively young and has formed during the last 3000–6000 years due to melting of polar ice sheets (Riegl and Purkis 2012). The gulf covers an area of $250,000 \text{ km}^2$. It is 990 km long, and its width ranges from 56 to 338 km. It has a total volume of $7000\text{--}8400 \text{ km}^3$ of seawater (Emery 1956; Purser and Seibold 1973; El-Gindy and Hegazi 1996). The entire basin of the Gulf lies upon the continental shelf. The average water depth of the Arabian Gulf is about 35.0 m. However, depths more than 107 m occur in some places near Iranian territorial waters. The gulf's water depth increases in the southeast direction. Very little freshwater enters into the Gulf from Shatt Al-Arab from Iraq and Karun rives due to dam construction across these rivers (Sheppard et al. 2010).

The Gulf is connected to the Gulf of Oman and the Arabian Sea through the Strait of Hormuz, which is about 56 km wide and with an average water depth of 107 m. Strait of Hormuz allows water exchange between the Arabian Gulf and Arabian Sea.

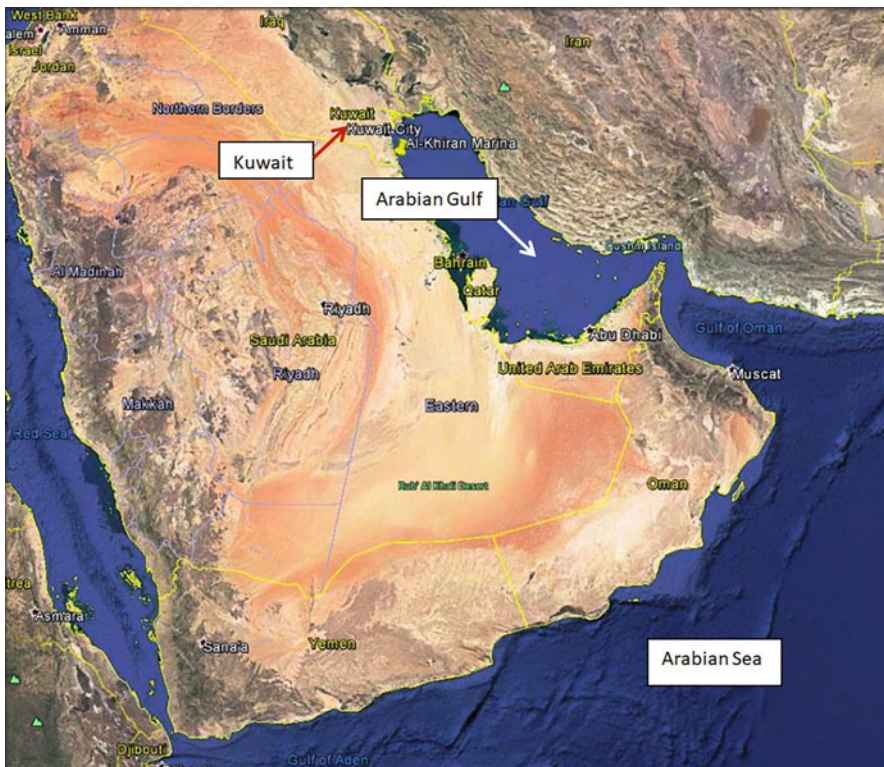


Fig. 1 Arabian Gulf (Source: Google map)

Significant information on the Arabian Gulf is reported in the book titled *Oceanographic Atlas of Arabian Gulf* by Al-Yamani et al. (2004). In the Arabian Gulf, in general the dominant wind direction is northwesterly (Elshorbagy et al. 2006). Arabian Gulf is a commercially active due to import of all type of goods from around the world and export of hydrocarbons. Most of the countries located around the Arabian Gulf use the seawater for desalination purposes and for cooling purposes of thermal power plants. Many high investment coastal and offshore projects are built (or being built) in the Arabian Gulf waters such as palm Jumeirah, palm Deira and world shaped water fronts in Dubai, Durrat Al-Bahrain—a jewelry shaped water front development; Hasabi and many water front projects in Bahrain, Qetaifan project in Qatar, Manifa oil field and Half moon bay in Saudi Arabia, Mubarak Al-Kabeer port, Sheikh Jaber Al-Ahmad Al-Sabah Causeway, Sabah Al-Ahmad sea city in Kuwait, a number of submarine pipeline and offshore oil and gas platforms, projects for development of tourism industries etc. The Arabian Gulf contains around 674 billion barrels of proven oil reserves, representing approximately two-thirds of proven, conventional world oil reserves and 1923 Tcf of natural gas reserves (35% of the world total). Oil and gas are the main economic source for the countries around Arabian Gulf (Kubursi 2015). Gulf already has more than 800 offshore oil and gas platforms and 25 major oil terminal (Sale et al. 2011), and it keeps increasing. About 53,000 ships pass the Straits of Hormuz into the Gulf every year (Al-Yamani et al. 2015). Safe and cost-effective design of offshore oil drilling platforms and other marine facilities are essential for sustainable growth of this region. Optimal design of marine facility depends on the design environmental parameters like wave, current, wind, cyclone, earthquake, tide, temperature, salinity, etc.

The sustainable and holistic development of the coastal and marine infrastructure for the countries surrounding the Arabian Gulf is challenging. The following are the main reasons:

- Arabian Gulf is surrounded by dense population, and the coastal population increases every year.
- The seawater temperature and salinity are high compared to other seas and ocean.
- The freshwater flow as well as the rainfall is very low.
- The natural oil seepage inside the Arabian Gulf is a hazardous phenomenon.
- Severe earthquakes of more than 9.0 in Richard scale is possible at Makran region outside the Arabian Gulf and the possible Tsunami.
- Uncertainty in the relative sea level rises.
- High natural and man-made turbidity level in the seawater at many locations.
- High toxin concentration of seabed materials due to industrial waste disposal.
- Periodic dust storm and dust fallout (and associated elements) into the gulf.
- Periodic oil spilling into the Gulf during loading/unloading, accidents, and ballast waste discharge.
- Periodic fish kill and red tides at many locations due to harmful algal bloom (HAB).

- Lack of enough research institutes to deal with Arabian Gulf issues and poor scientific co-operation between the countries surrounding the Gulf.
- Lack of good quality measured field data and exchange mechanism.
- High water consumption (400–550 L/day/head).
- High volume of seawater utilization for desalination and power plant cooling.
- Increased heat input from power plants into the Gulf.
- Over exploitation of living organisms and decrease in commercial fish stock.
- Many high volume dredging activities for development of new living space.
- Deteriorating water quality due to partially treated waste water from industries and houses.
- Solid waste dumping especially plastics.
- Lack of awareness of the effect of ocean pollution on human and marine health.
- Proposals for construction of nuclear power plants.
- Significant coastal morphological changes experience by the construction of many coastal and marine infrastructures.
- Slow dispersion of pollutants due to lack of accelerated dynamics of seawater at many parts within the Gulf due to less wave and currents.

Most of the countries around Arabian Gulf have master plans for the year 2030 in which proposals for many coastal and marine infrastructures are planned. Kuwait is planning for developing Boubyan and Failaka Island, and construction activities are in progress for Silk City on the coast. A clear understanding of the met ocean parameters and especially physical oceanographic parameters of the Arabian Gulf is needed for holistic and sustainable development of marine projects. This chapter is prepared by keeping these aspects in mind. Details of the physical parameters of the Arabian Gulf are provided. More focus is given for such information for the Kuwaiti territorial waters.

2 Some Physical Oceanographic Aspects of Arabian Gulf

2.1 Precipitation, Evaporation, and Flow of Seawater in and out of Arabian Gulf

The average annual precipitation into the Arabian Gulf is about 34 km^3 . The annual average river discharge into the Arabian Gulf is about 110 km^3 (Reynolds 2002). The average annual evaporation from the Gulf is estimated as 360 to 1250 km^3 (Reynolds 1993). The water flowing from the Arabian Sea into the Arabian Gulf neutralizes these net losses of seawater due to evaporation, precipitation, and river flow.

2.2 General Topography of the Countries Around Arabian Gulf

The general topographic feature of the Arabian Gulf region is as shown in Fig. 2. The eastern side of the Gulf is Iran with Zagros Mountains. The western part of the Arabian Gulf is covered with Saudi Arabia, Bahrain, Qatar, and UAE. The Northern side of the Gulf is covered with Iraq and the North West by Kuwait. These countries are generally arid or semi-arid and covered with desert type lands with average annual precipitation ranging from 80 to 130 mm. The change in land topography of the countries in the western part of the Arabian Gulf is mild and moderate unlike the eastern part with Zagros Mountains.

2.3 Bathymetry of Arabian Gulf

The bathymetry map of Arabian Gulf is provided in Fig. 3. The water depth is in general shallow on the western side of the Gulf. The water depth reaches to 100 m on the Iranian side of the Gulf, especially on the southeastern part of Iran. The water depth becomes deeper at the entrance to the Arabian Gulf. The water depth in the northern part of the Arabian Gulf is very shallow. For example, with respect to low

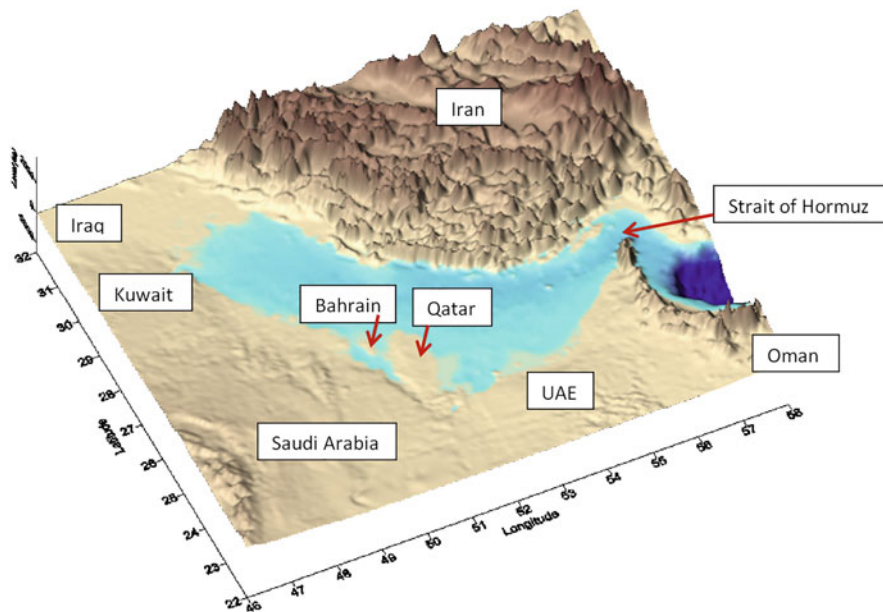


Fig. 2 Topographic and bathymetric map of the Arabian Gulf Region

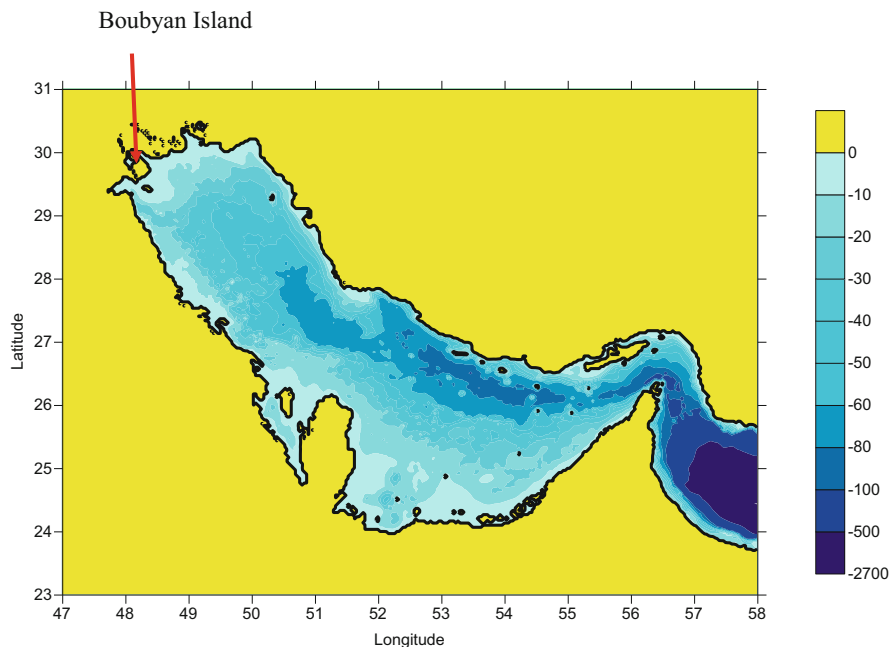


Fig. 3 Bathymetric map of the Arabian Gulf (Rakha et al. 2006)

water level, the water depth around Boubyan and Failaka Islands are about 2.0–3.0 m only.

2.4 Tidal Variation in the Arabian Gulf

Rakha et al. (2007a, b, 2009) have carried out a detailed hydrodynamic study for the Arabian Gulf and Kuwaiti territorial waters. The maximum range of the water level in the Arabian Gulf is shown in Fig. 4. The highest tidal variation in the Arabian Gulf occurs at the northern part of the gulf. The highest tide is about 4.0–4.5 m around Boubyan Island in Kuwait.

2.5 Wind Speed and Direction

In the Arabian Gulf, the dominant wind speed occurs from northwest. The wind speed and direction in Kuwait is represented using a typical rose diagram (Fig. 5) by using the measured wind data from 1.1.2012 to 31.12.2012 by Kuwait National

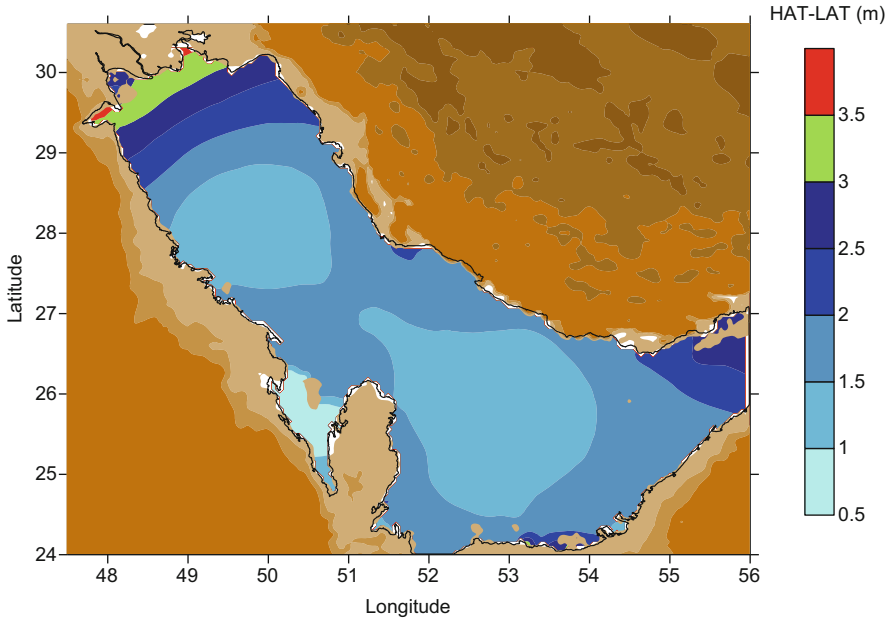


Fig. 4 Maximum range in water level for the Arabian Gulf (Rakha et al. 2006)

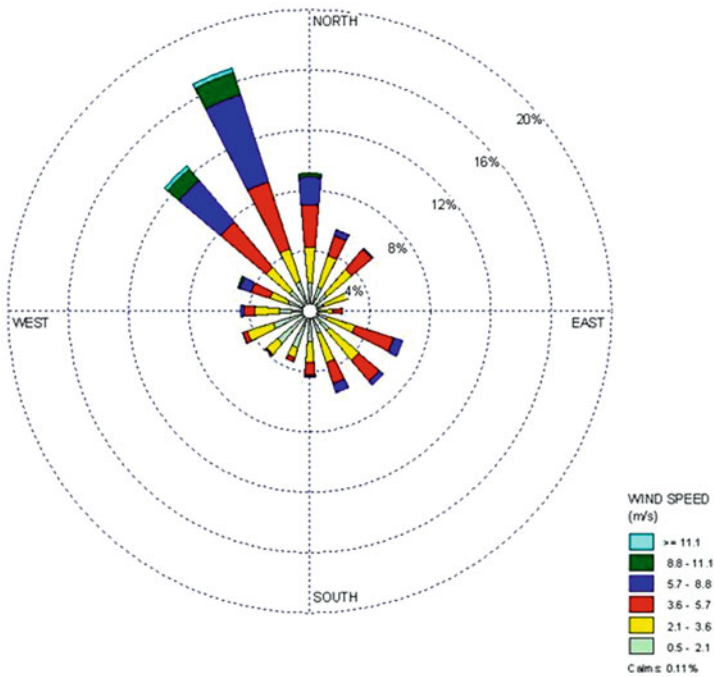


Fig. 5 Annual wind rose for Kuwait

Metrological Network. The second dominant wind direction is from Southeast. The extreme 10-min average wind speed for 100-year return periods can exceed 30–35 m/s (Neelamani et al. 2013).

2.6 *Maximum Tidal Current in the Arabian Gulf*

The magnitude of tidal current inside the Arabian Gulf is shown in Fig. 6 (Al-Salem 2006; Rakha et al. 2006). The tidal current is mainly due to tidal fluctuation within the Gulf. Current speed at the entry point of the gulf, Strait of Hormuz, can exceed 0.7 m/s. Similarly, the tide-induced current exceeds 0.9 m/s in the northwestern part of the Arabian Gulf, especially around Boubyan Island.

2.7 *Maximum Wave Heights and Periods Inside the Arabian Gulf*

The hindcasted wave heights validated with measured wave heights at some locations of Kuwaiti territorial waters are used for the estimation of the 100-year return

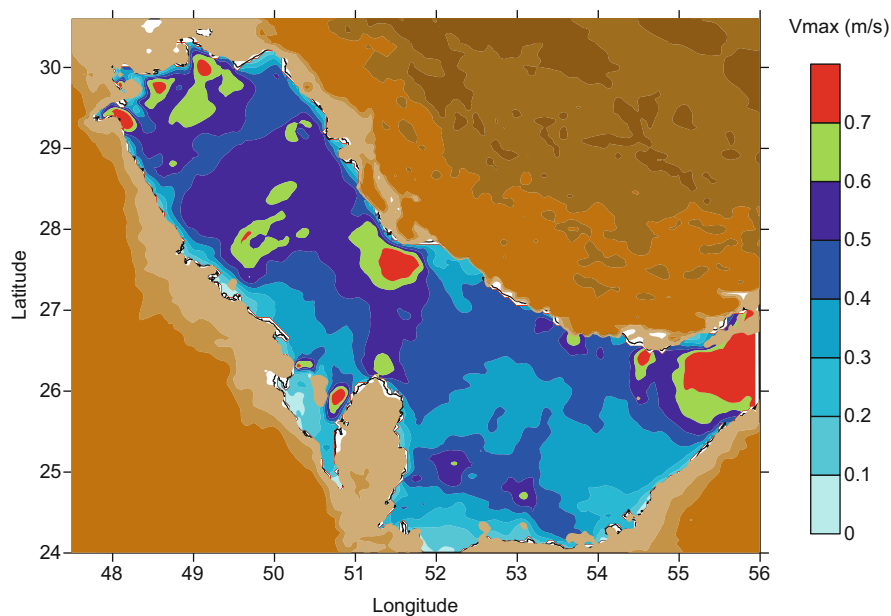


Fig. 6 Maximum tidal currents for the Arabian Gulf (Rakha et al. 2006)

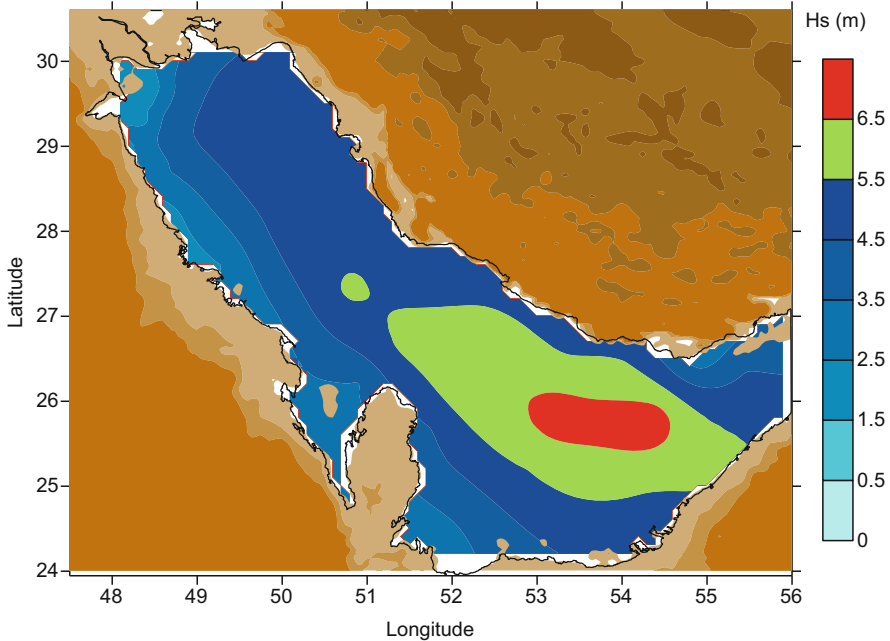


Fig. 7 Contour plot of the 100 Year significant wave heights in the Arabian Gulf based on Weibull distribution (Rakha et al. 2006)

period wave heights for the whole Arabian Gulf (Al-Salem and Rakha 2005). Figure 7 shows the contour plot of the 100 Year Significant Wave Heights in the Arabian Gulf. This assessment is based on Weibull distribution. Off the coast of UAE, 100-year return wave heights can exceed 6.5 m.

Figure 8 provides the 100-year return wave periods for many locations within the Arabian Gulf. Off UAE coast, the wave period can exceed 7.0 s. The wave periods are bit shorter (3.0–7.0 s) for the northern part of the Arabian Gulf.

3 Some Physical Oceanographic Aspects of Kuwaiti Territorial Waters

Kuwait is developing many coastal and marine projects in the near future, and a detailed knowledge on the physical oceanographic parameters are important. The details on tidal variation, current velocity, wave height and wave period, and other information off Kuwaiti coastal area are provided in this section.

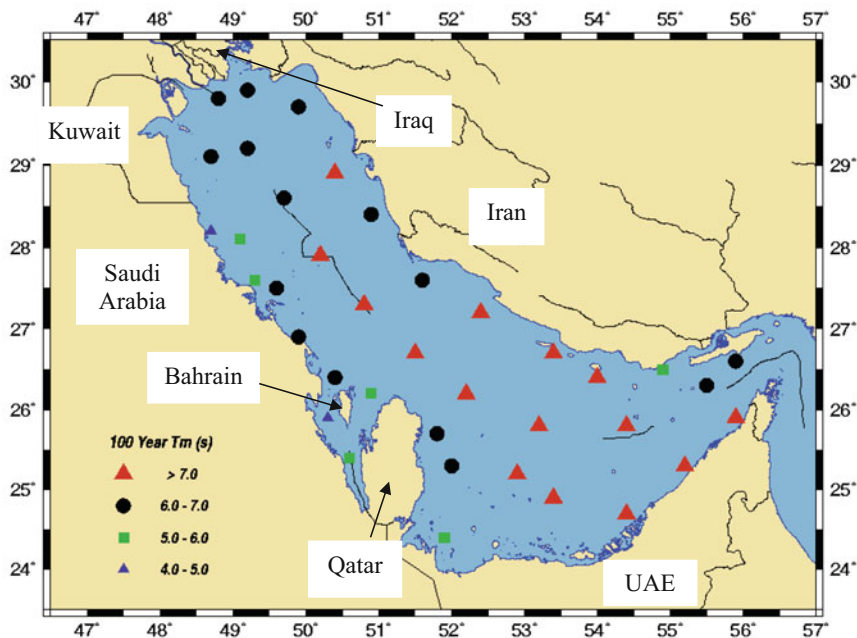


Fig. 8 Mean wave period in the Arabian Gulf for 100-year return period (Rakha et al. 2006)

3.1 Tidal Variation off Kuwaiti Territorial Waters

The difference between the magnitude of the high astronomical tide and low astronomical tide for Kuwaiti territorial water is provided in Fig. 9. Inside Kuwait bay, the value can exceed 3.5 m. The tides in Kuwait are semi diurnal and mixed.

3.2 Tide-Induced Current in the Kuwaiti Territorial Waters

Figure 10 reveals the maximum tide-induced currents within the Kuwaiti territorial waters. The entrance into Kuwait bay has current speed exceeding 0.7 m/s. Around Boubyan Islands, during spring tide, the current velocity exceeds 0.9 m/s.

3.3 Maximum Significant Wave Heights in the Kuwaiti Territorial Waters

Figure 11 provides the details of maximum significant wave heights in the territorial waters of Kuwait. This information is based on 12 years of hindcasted data

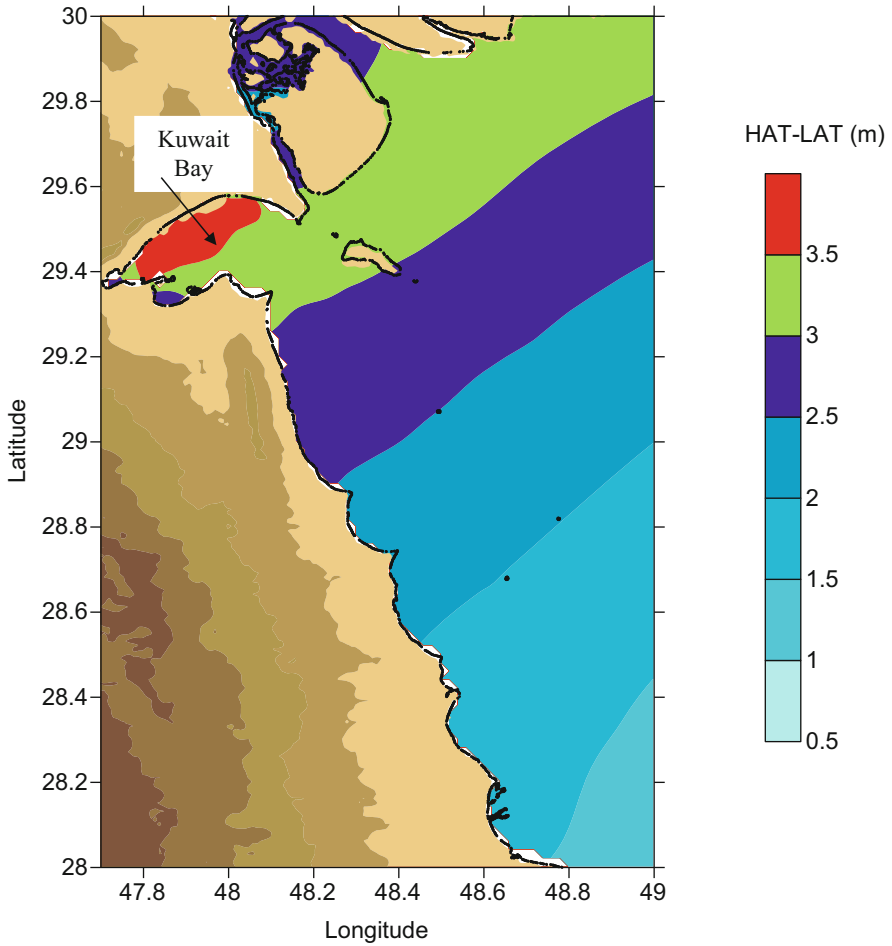


Fig. 9 Maximum range in water level for northern part of the Arabian Gulf (Rakha et al. 2006)

(Al-Salem 2006). The wave heights were hindcasted based on the marine wind speed data during the period 1.1.1993 to 31.12.2004. The source of wind speed data was European Center of Mean Weather Forecast (ECMWF). The measured wind speed data and the ECMWF data are compared, and the ECMWF data is upgraded before using it for hindcasting. Waves of more than 3.5 exist only in the offshore region of the Kuwaiti territorial waters. Around Boubyan and Failaka Island, the wave heights are much less than 1.0 m for more than 10 months in a year.

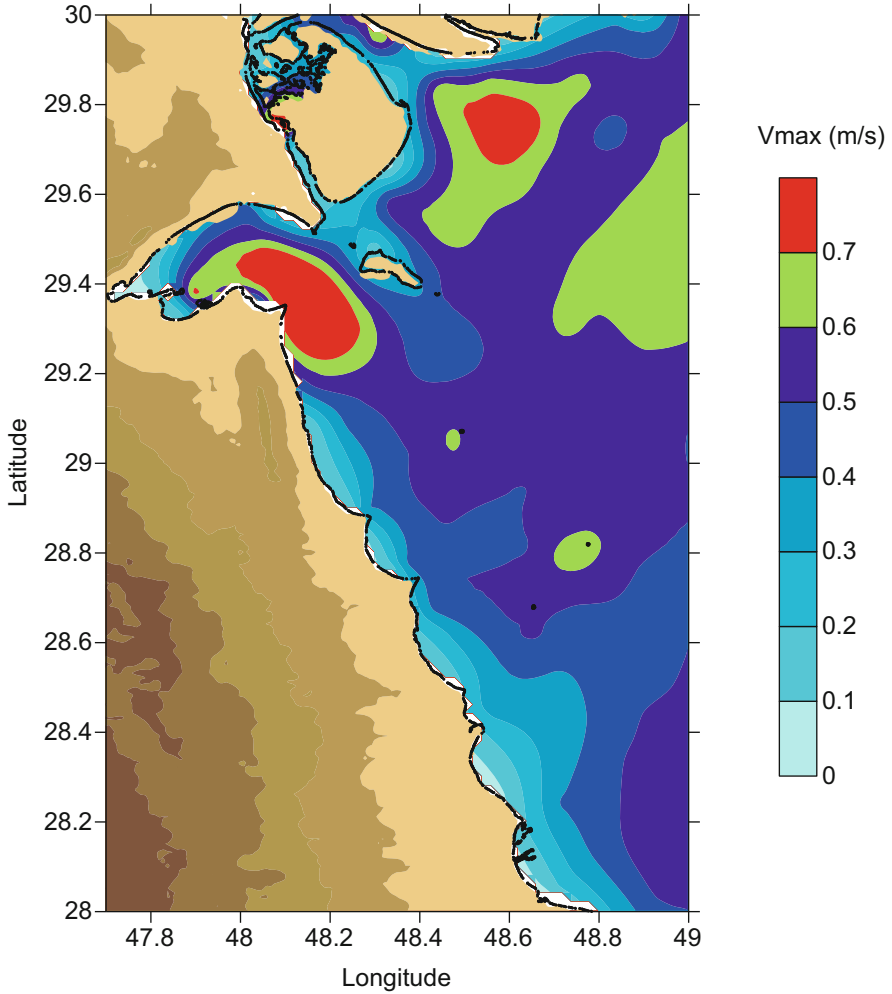


Fig. 10 Maximum tidal currents for northern part of the Arabian Gulf (Rakha et al. 2006)

3.4 Wave Period in Kuwaiti Territorial Waters

Figure 12 shows the wave period in Kuwaiti territorial waters. Wave periods more than 6.5 s exist only in the offshore region. Closer to the coastal area, the wave periods are in the range of 2.5–5.5 s only.

More data and information on waves, currents, tides, etc. can be obtained from Al-Salem and Al-Rashed (2016).

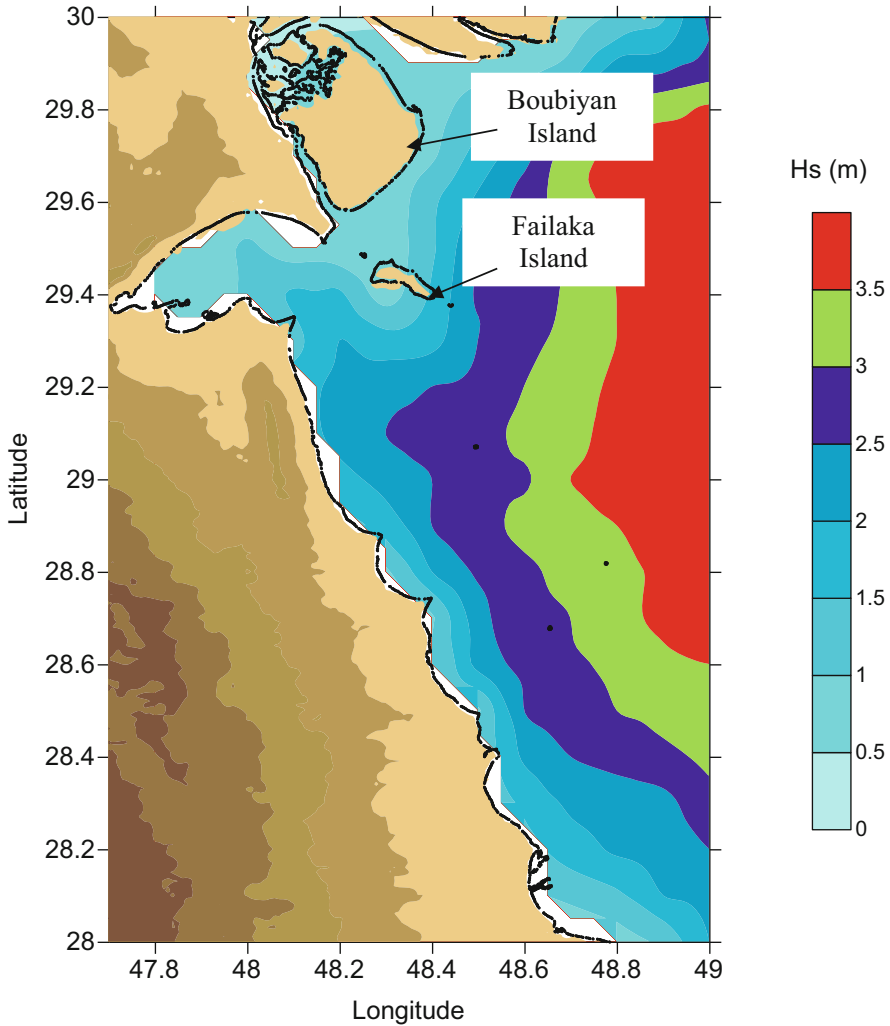


Fig. 11 Maximum significant wave heights over 12 Years (Northern part of Arabian Gulf) (Rakha et al. 2006)

3.5 Water Transparency in Kuwaiti Territorial Waters

Though the distance between the northern and southern coastal area of Kuwaiti territorial water is less than 170 km, the transparency of water varies from 0 to 100% from north to south. Figure 13 shows the transparency of water on the eastern side of Boubyan Island. Boubyan Island is within 30 km from the Shatt Al-Arab estuary. For the past many hundreds of years, the Tigris and Euphrates rivers have discharged sediments into this estuary and are drifting towards Kuwaiti territorial waters due to

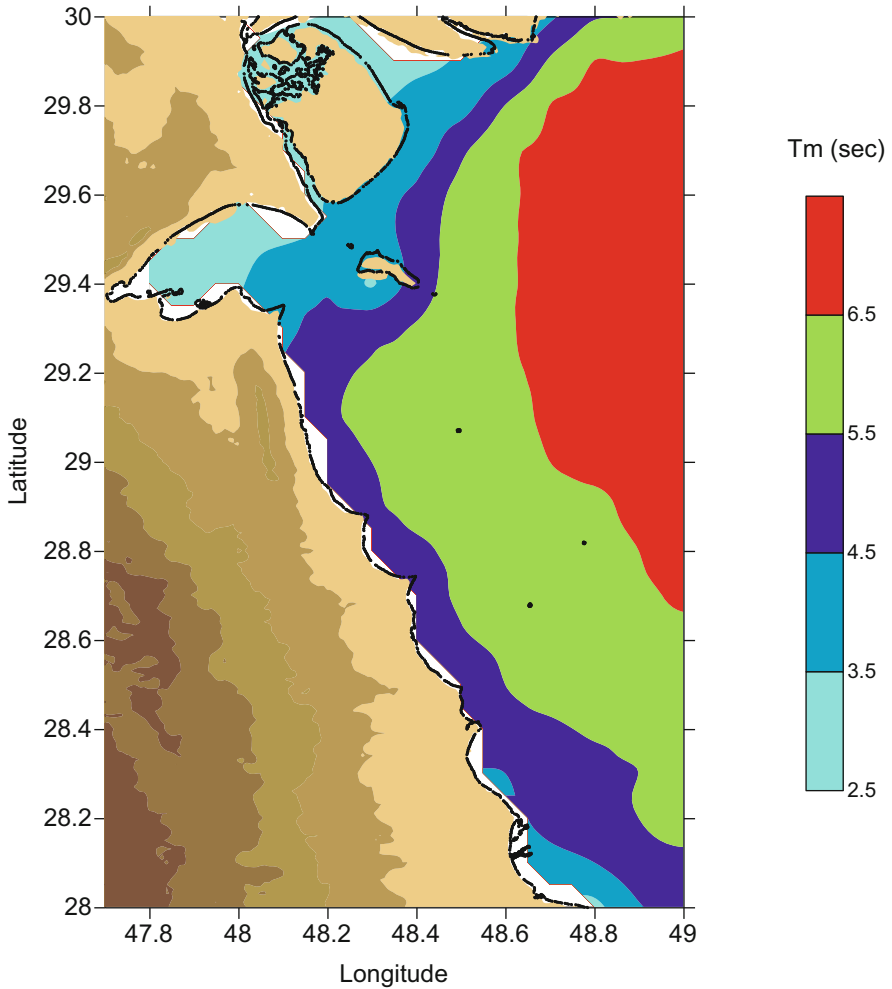


Fig. 12 Maximum average wave period over 12 years (for northern part of Arabian Gulf) (Rakha et al. 2006)

anticlockwise global rotation of the seawater. Hence, the northern part of Kuwaiti territorial water is always turbid.

Figure 14 is a typical picture of the seawater in the southern coastal area of the Kuwaiti coast. The total suspended sediments in the southern seawater body are less than 10–20 ppm.



Fig. 13 Seawater transparency in the Boubyan coast, northern part of Kuwait

3.6 Seawater Turbidity Around Boubyan Island in Kuwait Based on Field Measurements

Measurements of seawater turbidity for five different locations around Boubyan Island were carried out for about 12 months, from March 2015 to February 2016. All these five locations are around the Boubyan Island. The instruments are deployed for the measurements, and the locations are shown in Fig. 15. The turbidity data (as well as other data for salinity, seawater temperature) gathered were analyzed, and the outcomes are reported by Neelamani and Al-Osairi (2017a, b, c).

Some vital information on the seawater turbidity is provided here. A typical measured medium density turbidity time series near the Port area is shown in Fig. 16. During spring tide (when the currents are high, of the order of 0.8 m/s), the maximum medium density turbidity reached about 1300 FTU.

The probability density analysis is carried out on the turbidity time series for all the locations using 1-year measured data. Figure 17 shows the probability density of measured turbidity. It is found that near Warba Island area the turbidity peaks near 275 FTU, whereas near Sabiya coast guard are it peaks near 160 FTU.

The probability of non-exceedance of the measured turbidity is revealed in Fig. 18. Near Sabiya coast guard area, almost 90% in a year, the turbidity is less than 250 FTU. Whereas near Warba Island, this level of turbidity occurs for less than



Fig. 14 Seawater transparency in the South coast of Kuwait

38% of the time in a year. For other locations, it is in between 56% and 74% in a year for turbidity level of 250 FTU. This information will be useful for designing different marine structures such as marina, port, and harbor in this area for sedimentation analysis as well as for marine life-related studies, which depend on sediment concentrations for their growing and multiplication.



Fig. 15 Locations around Boubyan Island for deployment of instruments

Table 1 shows the minimum, maximum, mean, median, mode, and standard deviation of the measured seawater turbidity for all the five locations.

Turbidity of more than 58,000 ppm is recorded near Warba Island, which could be due to the disposal of the dredging materials by the ports near Warba island area as well as ship propeller agitations. The lowest value of the maximum turbidity value is recorded around Sabiya coast guard area due to coast guard restrictions for boat movement and related lesser agitation of the seawater.

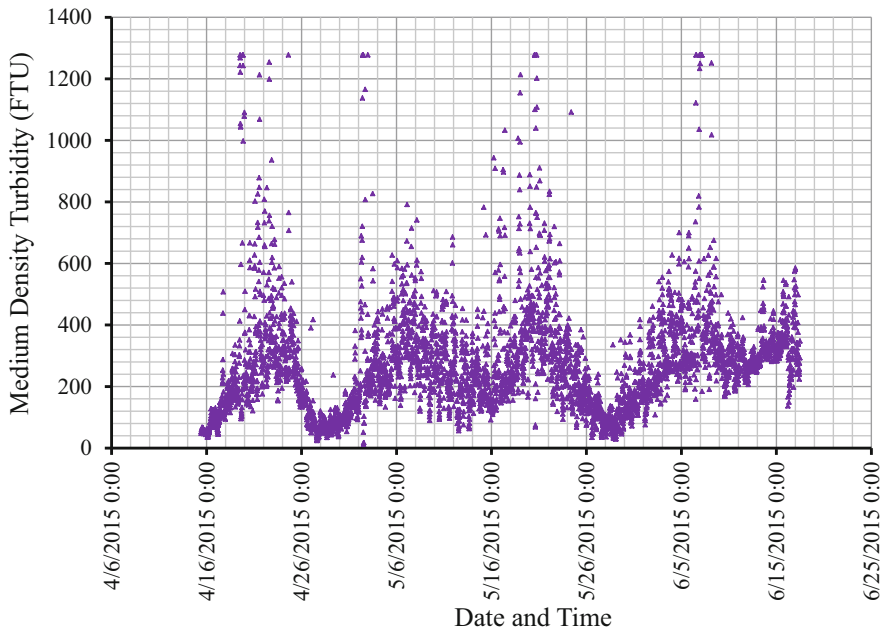


Fig. 16 Variation of medium density turbidity at Boubyan port area (Location A) from 15th April 2015 to 17th June 2015

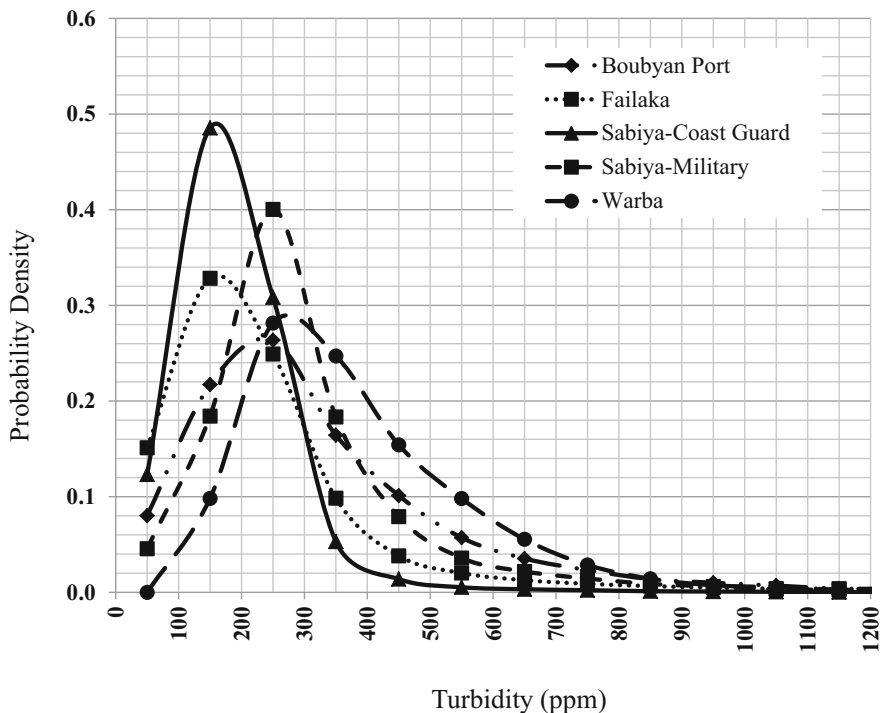


Fig. 17 Probability density of seawater turbidity at five different locations around Boubyan Island

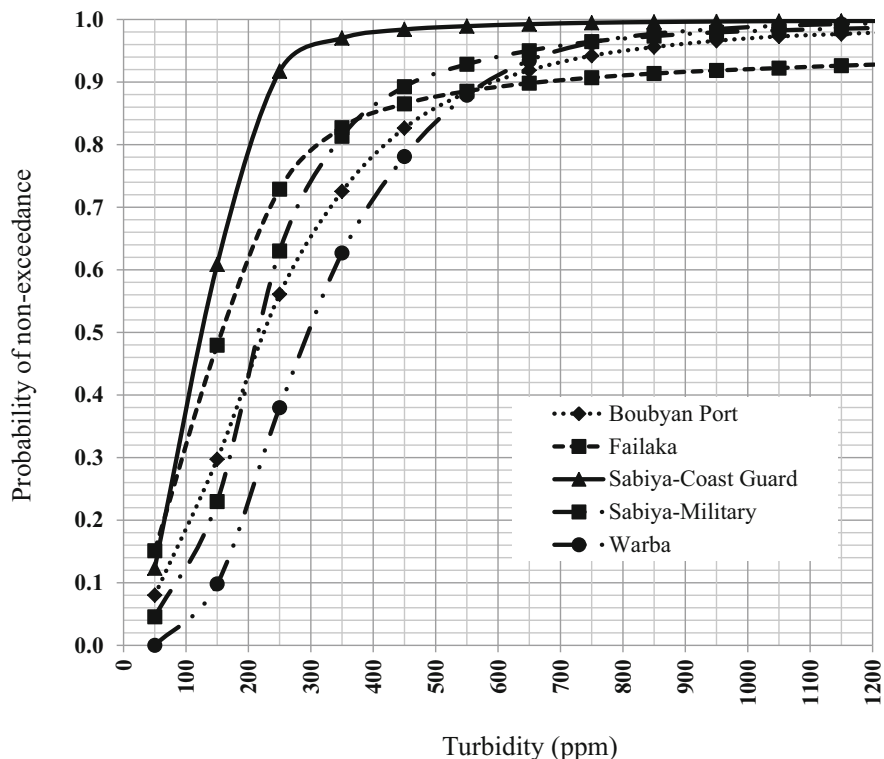


Fig. 18 Probability of non-exceedance of seawater turbidity at five different locations around Boubyan Island

Table 1 Observed minimum, maximum, mean, median, mode, and standard deviation of the seawater turbidity for all the five locations

Statistical properties of seawater turbidity (ppm)	Boubyan Port	Failaka	Sabiya coast guard	Sabiya military	Warba
Minimum	7	8	14	35	102
Maximum	43,098	48,069	10,293	20,887	58,008
Mean	404	708	199	331	412
Median	224	157	125	215	295
Mode	250	150	150	250	250
Standard deviation	1192	2431	231	440	745

4 Conclusions

A clear knowledge of the physical oceanographic parameter is essential for sustainable development of coastal projects. Such information for Arabian Gulf, Kuwait territorial waters, and some of the specific area within the Kuwaiti territorial water is

provided in this book chapter. The data for this analysis is gathered through different research projects carried out in Kuwait Institute for Scientific Research, Kuwait, during the past 35 years.

The Arabian Gulf is relatively a shallow water body with maximum water depth of about 100 m near Iran side. The wave climate is mild to moderate. The tidal variation can reach up to 4.0 m, especially in the northern western part of the Arabian Gulf. Current velocity exceeds 0.7 m in few locations like Strait of Hormuz and the northwestern part of the gulf. The main wind direction is northwest. The annual average wind speed is in the range of 3.0–7.0 m/s. The 10-minute average extreme wind speed for 100-year return periods is in the range of 30–45 m/s in Kuwait. Gust speeds exceed 60 m/s during certain season. The seawater in the northern part of the Arabian Gulf has zero transparency, whereas the transparency reaches 100% within a distance of about 150 km towards south. The seawater salinity of the water in this Gulf varies from 35 to 50 ppt due to strong evaporation and less freshwater flow into the Gulf. In a year, the seawater temperature varies in between 10 and 35 °C. The turbidity of the seawater can cross 50,000 ppm near Warba Islands, and care should be taken while designing ports, harbors, and marinas around this area.

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