# Salinity and Turbidity in the Red Sea

Subjects: Engineering, Marine
Contributor: Ayshah S. Alatawi

Several industrial and scientific underwater applications require high-speed wireless connectivity. Acoustic communications have low data rates and high latency, whereas attenuation in seawater severely limits radio frequency communications. Optical wireless communication is a promising solution, with high transmission rates (up to Gb/s) and little attenuation in water at visible wavelengths.

Keywords: underwater optical wireless communication (UWOC) ; light emitting diodes (LEDs) ; Red Sea ; salinity ; turbidity

## 1. Introduction

The Red Sea is one of the world's busiest shipping waterways, connecting the Mediterranean, Africa, and Asia through the Suez Canal, and providing an alternative route via the Cape of Good Hope. It is a vital link in the political and economic stability of many countries in that region [1]. The Red Sea coast of the Kingdom of Saudi Arabia is approximately 2000 km in length. Saudi Arabia is working to develop its Red Sea coastline, most notably through megaprojects such as NEOM, LINE, and the Red Sea Project, all of which are part of Saudi Vision 2030 efforts [2][3][4]. These projects will incorporate smart city technologies such as the Internet of Things (IoT), augmented reality (AR), virtual reality (VR), autonomous vehicles, hyperloops, and many other applications. The key to enabling and implementing these technologies is wireless communication infrastructure [5][6].

The use of wireless communications in terrestrial devices should be explained, whereas underwater wireless communication has become an area of interest. It is receiving more attention as research on marine-related challenges progresses rapidly and has become a critical concern for all countries worldwide. This technology has vast potential for various applications, such as oceanography studies, oil and gas exploration, and military applications. The Red Sea is the world's most intriguing area for hydrocarbon exploration and mineral discovery, but it has been underexplored. Saudi Arabia is the world's most significant producer and exporter of oil, with a quarter of the world's proven oil reserves [7]. Aramco, a Saudi oil company, aims to employ various cutting-edge technologies, ranging from artificial intelligence (AI) to unmanned vehicles (UVs), to boost efficiency, productivity, and sustainability. Underwater wireless communication (UWC) technology plays a vital role in enabling these technologies. In addition, the strategic and economic importance of the Red Sea requires advanced security technology. The UWC plays a vital role in military applications to conduct underwater surveillance, detect intrusion, and plan attacks, if needed. Another military application is to prevent any rival state from sabotaging the waters by laying a communication system in the water.

Furthermore, autonomous submarines capable of sending real-time messages through a UWC are being used to control drug traffickers. Moreover, unmanned underwater vehicles (UUVs) and autonomous underwater vehicles (AUVs) are increasing rapidly. Therefore, the amount of data to be transferred and the associated data rates continue to increase to fulfil the demands of the aforementioned applications [8]. Employing underwater cables or tethers to provide data links is expensive, requires additional maintenance, and its installation is restricted or difficult in many areas. In the current situation, underwater wireless connection is inevitable.

Acoustic waves are the most commonly used underwater communication system, with a range of several kilometers. Acoustic communication is characterized by extremely low bandwidth (only 100 bps), with high latency owing to the reflections, and relatively low throughput, owing to the speed of sound. Consequently, real-time communication for dynamically managing underwater vehicles and operations is impractical. Radio communication can provide a higher data rate; however, its high conductivity in seawater restricts it to a shorter distance. Considering the abovementioned factors, underwater optical wireless communication (UWOC) is a possible alternative or complementary solution. UWOC offers many technical advantages, including high data rates and secure connectivity. It also provides economic benefits such as reduced installation and operating expenses. UWOC systems can be classified into two types based on the transmitter light source: laser-based (LDs) and light-emitting-diode-based (LEDs). Although LDs have a larger modulation bandwidth than LEDs, LEDs are more suitable for medium-bit-rate applications due to their lower cost, higher power efficiency, and longer lifetime.

LEDs were first employed for underwater illumination in the 2000s and are currently the industry standard. They are now found in a wide range of applications, from indicator lights to solid-state illumination, and are available in various shapes and sizes. Owing to their high optical power density, they have been used in underwater white light illumination to extend the underwater lighting distance. LEDs have gained considerable attention in recent years for data transmission applications, where LED luminaires are used to provide both general-purpose lighting and Mb/s or Gb/s optical wireless connectivity. If this technology is successfully implemented, every light bulb can be used to transmit wireless data, similar to a Wi-Fi hotspot, and significantly contribute to a greener, more cost-effective, and brighter future.

## 2. Salinity and Turbidity in the Red Sea on White-LED-Based Underwater Wireless Communication

Many recent studies have explored higher data rates and extended transmission ranges using LED-based systems. Using five primary-colored LEDs, Zhou et al. [9] showed a transmission of 15.17 Gb/s over 1.2 m of clear tap water. Wang et al. [10] demonstrated a transmission of 2.175 Gb/s over 1.2 m of clean tap water using a single green LED, operating at 521 nm. Tian et al. [11] experimentally verified a 200 Mb/s data rate with a BER of $3.0 \times 10^6$, through a tap water tank of 5.4 m. Kumar et al. [12] investigated the performance of white, blue, and green LED arrays in transmitting voice in real time, through a 50 cm tap water tank. The findings show that blue light has the lowest attenuation and exhibited the best performance.

Significant progress has been made in research on underwater LED-based systems, both theoretically and experimentally. However, most of these studies were performed using tap water and did not consider the effect of real water channel parameters, such as salinity, turbidity, and temperature, on system performance. The fundamental characteristics of various water bodies, from shallow to deep oceans, vary widely, making the propagation of underwater optical beams very challenging. Therefore, a complete understanding of the effect of water parameters on the light beam propagation for UWOC is required.

Over the past few years, great and valuable studies have been conducted to investigate the effect of different real water channel parameters on both LED and LD UWOC systems. Swathis et al. [13] calculated the received power for various wavelengths such as 470 nm, 525 nm, and 660 nm based on the attenuation coefficients for pure sea, clear ocean, coastal water, and harbor water types. They concluded that the blue spectrum has a better communication window than the red and green spectrums for pure sea, clear ocean, and coastal water types. However, the green spectrum performs better in harbor water than the blue and red spectrums. Therefore, the type of water and chlorophyll content affects the wavelength choice.

Hassan et al. [14] used three types of water channels including clear, sea, and cloud water to test the received light intensity from LED and laser diodes at different transmitting distances up to 50 cm. Seawater was collected from Mengabang Telipot beach in Kuala Terengganu. In the seawater, they found that the received power from red laser light is approximately 35% higher than the power from green LED light.

Experimental studies were performed by Kumar et al. [15][16] using a 450 nm LD transmitter to investigate the effect of salinity on a transmission distance of up to 2 m. The results showed that at less than 40 cm, salinity of 35 g/L can block more than 90% of the laser's power [15]. It was also determined that the transmission depth of the saline water channel is only about 60 cm [16].

Another water channel parameter that may affect the UWOC system performance is air bubbles. Hagem et al. [17] demonstrated a UWOC system for swimming applications using a 520 nm LED transmitter and an integrated detector–preamplifier. The system achieved a communications range of more than 1 m in all three scenarios under consideration: still pool water, still spa water, and bubbles spa water. The effect of bubbles produced by a spa jet is quite noticeable and significantly exceeds the effect of the bubble density and size expected by a swimmer. Oubei et al. [18] experimentally investigated the performance of green-LD-based UWOC links in the presence of different air bubble sizes. The received signal intensity was measured at five different beam sizes and under four bubble sizes. Large bubbles with a size comparable to the beamwidth can result in a deep fade or complete communication loss.

## 3. Characteristics of Red Sea

The Red Sea has a total length of approximately 2100 km and is enclosed by deserts. It is connected to the Indian Ocean through the Bab-el-Mandeb and Gulf of Aden.

### 3.1. Red Sea Salinity

Salinity is defined as a measure of salt concentration in water. Chloride and sodium account for over 85% of the ions in seawater, which is the same as table salt. The salinity in seawater is expressed in parts per thousand (ppt). Parts per thousand is the number of parts, or grams, of salt present in a kilogram (1000 g) of seawater. In normal seawater, an average of 35 parts of dissolved salt are typically present per thousand parts of water (35 ppt). This is equivalent to 35 g of dissolved salt per kilogram of seawater.

Owing to high rates of evaporation (up to ~2 m/yr), low mean annual rainfall from 3 mm/yr (N) to 150 mm/yr (S), and a lack of river intake, the Red Sea has a high salt concentration. The saltiness increases towards the north, as shown in **Figure 1** [19]. It increases along its axes, reaching 3.8% by about 17° N, 3.9% by about 22° N, and 4.0% by about 26° N.

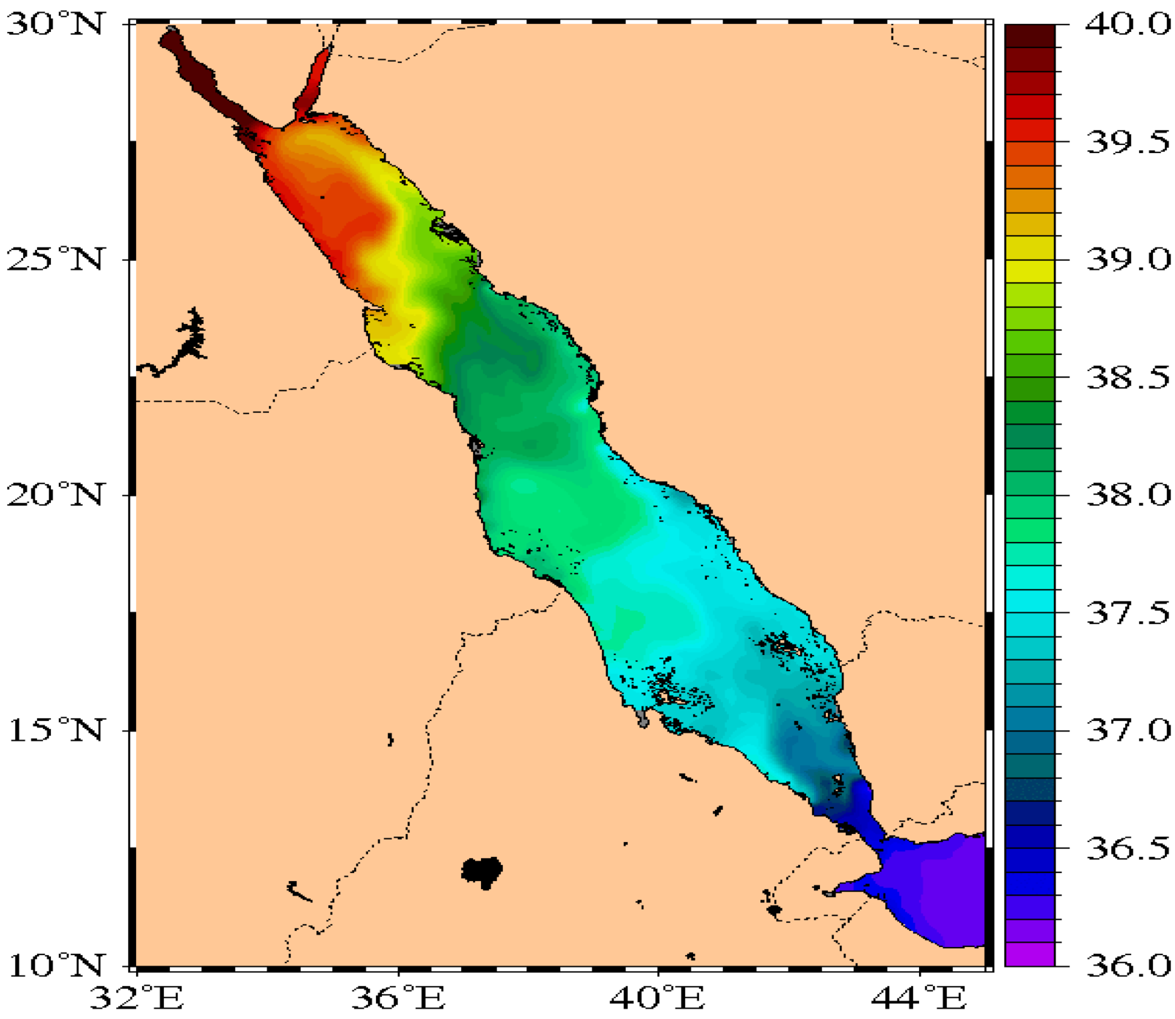


**Figure 1.** Salinity map.

### 3.2. Red Sea Turbidity

Another significant parameter that affects the LED-based UWOC link is water turbidity, which can block wave propagation between the transmitter and receiver. Turbidity is a measure of the cloudiness of water. Several materials can cause turbidity, including clay, silt, mud, plankton, and chemicals in the water.

The name of the unit of turbidity is referred to as the Formazin nephelometric unit (FNU). Turbidity in the high sea ranges from 1 to 3 FNU. The outermost parts of the coastal waters are usually 2–6 FNU. Turbidity in some estuaries can peak at up to 80 FNU [20]. To the best of my knowledge, the only reported data for Red Sea turbidity is found in [21], where the turbidity of water from the Thuwal, coastal area, is 2.34 ± 0.12 NTU. However, turbidity varies according to location, season, and weather. In open sea areas, algal abundance mainly affects the water turbidity.

## References


1. Edwards, A.J. Red Sea, 1st ed.; Elsevier: Amsterdam, The Netherlands, 2013; p. 1.
2. Farag, A.A. The story of NEOM city: Opportunities and challenges. In New Cities and Community Extensions in Egypt and the Middle East; Attia, S., Shafik, Z., Ibrahim, A., Eds.; Springer: Cham, Switzerland, 2019; pp. 35–49.
3. Al-sayed, A.; Al-shammari, F.; Alshutayri, A.; Aljojo, N.; Aldhahri, E.; Abouola, O. The Smart City-Line in Saudi Arabia: Issue and Challenges. Postmod. Open. 2022, 13 (Suppl. 1), 15–37.
4. Chalastani, V.I.; Manetos, P.; Al-Suwailem, A.M.; Hale, J.A.; Vijayan, A.P.; Pagano, J.; Williamson, I.; Henshaw, S.D.; Albaseet, R. Reconciling tourism development and conservation outcomes through marine spatial planning for a Saudi Giga-Project in the Red Sea (The Red Sea Project, Vision 2030). Front. Mar. Sci. 2020, 7, 16.
5. Boubakri, W.; Abdallah, W.; Boudriga, N. An optical wireless communication based 5G architecture to enable smart city applications. In Proceedings of the 2018 20th International Conference on Transparent Optical Networks (ICTON), Bucharest, Romania, 1–5 July 2018.
6. Miladić-Tešić, S.D.; Marković, G.Z.; Nonković, N. Optical technologies in support of the smart city concept. Tehnika 2020, 75, 209–215.
7. These 15 Countries, as Home to Largest Reserves, Control the World's Oil. Available online: https://www.usatoday.com/story/money/2019/05/22/largest-oil-reserves-in-world-15-countries-that-control-the-worlds-oil/39497945/ (accessed on 30 May 2022).
8. N'doye, I.; Zhang, D.; Alouini, M.-S.; Laleg-Kirati, T.-M. Establishing and maintaining a reliable optical wireless communication in underwater environment. IEEE Access 2021, 9, 62519–62531.
9. Zhou, Y.; Zhu, X.; Hu, F.; Shi, J.; Wang, F.; Zou, P.; Liu, J.; Jiang, F.; Chi, N. Common-anode LED on Si substrate for beyond 15 Gbit/s underwater visible light communication. Photon. Res. 2019, 7, 1019–1029.
10. Wang, F.; Liu, Y.; Jiang, F.; Chi, N. High speed underwater visible light communication system based on LED employing maximum ratio combination with multi-PIN reception. Opt. Commun. 2018, 425, 106–112.
11. Tian, P.; Liu, X.; Yi, S.; Huang, Y.; Zhang, S.; Zhou, X.; Hu, L.; Zheng, L.; Liu, R. High-speed underwater optical wireless communication using a blue GaN-based micro-LED. Opt. Express 2017, 25, 1193–1201.
12. Das, A.K.; Ghosh, A.; Vibin, A.M.; Prince, S. Underwater Communication System for Deep Sea Divers Using Visible Light. In Proceedings of the 2012 Photonics Global Conference (PGC), Singapore, 13–16 December 2012.
13. Swathi, P.; Prince, S. Designing Issues in Design of Underwater Wireless Optical Communication System. In Proceedings of the 2014 International Conference on Communication and Signal Processing, Melmaruvathur, India, 3–5 April 2014.
14. Hassan, W. Experimental Study of Light Wave Propagation for Underwater Optical Wireless Commu-Nication (UOWC). J. Commun 2022, 17, 23–29.
15. Kumar, S.; Prince, S.; Venkata Aravind, J.; Kumar G, S. Analysis on the effect of salinity in underwater wireless optical communication. Mar. Georesources Geotechnol. 2020, 38, 291–301.
16. Kumar, S.; Prince, S.; Kumar, G.S. Investigation on Effects of System Parameters on Transmission Depth in Underwater Wireless Optical Communication. Photonic Netw. Commun. 2021, 41, 163–176.
17. Hagem, R.M. The Effect of Air Bubbles on an Underwater Optical Communications System for Wireless Sensor Net-Work Applications. Microw. Opt. Technol. Lett. 2012, 54, 729–732.
18. Oubei, H.M.; ElAfandy, R.T.; Park, K.-H.; Ng, T.K.; Alouini, M.-S.; Ooi, B.S. Performance Evaluation of Underwater Wireless Optical Communications Links in the Presence of Different Air Bubble Populations. IEEE Photonics J. 2017, 9, 1–9.
19. Mezger, E.M.; de Nooijer, L.J.; Boer, W.; Brummer, G.J.A.; Reichart, G.J. Salinity controls on Na incorporation in Red Sea planktonic foraminifera. Paleoceanography 2016, 31, 1562–1582.
20. Seawater is Most Turbid Close to the Shoreline. Available online: https://www.marinefinland.fi/en-US/The_Baltic_Sea_now/Water_quality/Turbidity (accessed on 30 May 2022).
21. Hamad, J.Z.; Ha, C.; Kennedy, M.D.; Amy, G.L. Application of ceramic membranes for seawater reverse osmosis (SWRO) pre-treatment. Desalination Water Treat. 2013, 51, 4881–4891.