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Research Article

Optical Wireless Communication System for Monitoring Underwater Floods and Water Quality

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ABSTRACT

An improved model for a UOWC system with real-time flood and water quality monitoring is implemented, taking into account the Arduino sensor modules, along with high precision of the optical channel simulation models developed with Opti and MATLAB environments, with the support of parameters like water turbidity, depth, temperature, transmission angle, reception angle, horizontal distance of transmission, and transmission angle and distance. Operating limits for the system were defined under various aquatic conditions and in different water environments. Key communication parameters, including signal-to-noise ratio (SNR) and bit error rate (BER), were analyzed. The results showed that the system is effective for use in different aquatic environments to detect floods and monitor environmental parameters and their changes in real time within defined operating limits. A graphical user interface was developed using MATLAB App Designer to ensure real-time monitoring and control, making the system suitable for intelligent underwater and flood monitoring applications.

Keywords: Underwater Optical Wireless Communication, Water Quality, Flooding, real-time monitoring and control.

INTRODUCTION

Water is one of the most essential natural resources for life on Earth, rivers, lakes, seas, and oceans make up more than 70% of the planet's surface. Ecosystems, industry, agriculture, and human survival all depend on it. However, infrastructure and human safety in aquatic environments can be significantly threatened by a number of environmental conditions and natural events, such as pollution, climate change, and natural disasters like floods [1][2].

One of the most frequent and devastating natural disasters, floods are brought on by heavy rainfall, overflowing rivers, or dam collapses. These disasters have the potential to cause significant property damage, deaths, and economic activity interruptions. Because of this, aquatic habitat management and monitoring have become more important in recent years [3][4].

Communication systems are widely used to facilitate data transmission and real-time monitoring of the aquatic environment to overcome these challenges. In particular, wireless communication is essential for transmitting environmental data from remote locations to monitoring facilities. Compared to wired systems, this technology offers flexibility, scalability, and ease of setup[5]. However, low data transmission rates, latency, signal attenuation in complex environments, and signal loss are some of the drawbacks of traditional wireless communication systems, especially those that rely on voice transmission. As a result of these limitations, real-time monitoring solutions become less reliable and efficient [6].

Therefore, optical wireless communication has emerged as an advanced alternative due to its faster data transmission speed, quicker response time, real-time detection of environmental disasters, and improved signal quality. Optical communication systems are characterized by their ability to transmit large amounts of data[7]. The study analyzes and verifies the integration of systems based on data collection through sensors, signal processing, and optical communications, with the aim of improving the performance of flood monitoring systems using environmentally related data and simulation.

The main contributions of this research can be summarized as follows:

- This research presents a comprehensive simulation framework for underwater wireless optical communication (UWOC) systems under non-line-of-sight (NLOS) conditions in realistic environments.
- Unlike previous studies, this work integrates several environmental variables into a unified model, including depth, horizontal distance, temperature, and salinity.
- The research focuses on real Iraqi aquatic environments (Mosul Dam and Kut Barrage), providing a practical analysis based on actual environmental conditions.
- The system's performance was analyzed under critical conditions, particularly when the error rate (BER) reached high values   1, thus highlighting the system's operational limitations.

LITERATURE REVIEW

Wireless communications are constantly evolving, particularly in recent years, as the need to study this topic has increased due to its importance in protecting human lives and infrastructure from disasters in the aquatic environment, whether in flood monitoring or collecting data on the aquatic environment. The following table illustrates the importance of studies related to the topic of study.

Table 1.1: Previous studies that addressed aspects relevant to the Current study

Title	Author	Year	Contribution
Improving the Hybrid FSO/LI-FI/UWOC Networks[8]	Satea H. Alnajjar	2025	* FSO (Air-to-Air Communications) * Li-Fi * UWOC (Underwater Communications) Objective: * Improve signal quality and reduce BER Used: * Opti System for simulation Key achievements: * Integration of multiple communication technologies into a single system * Improved performance using multiple optical technologies * Achieving higher data transmission efficiency between air and water
Effective Signal Transmission from Underwater to Air Utilizing Optical Communication[9]	Satea H. Alnajjar1, * , Amjed Razzaq Alabbas1 , Mahmood J. Ahmad1	2025	I focused on: * Transmitting signals from underwater to air I used: * An optical communication system (UWOC + FSO) Studying the effects of: * Water surface (reflections and refraction) * Signal loss during transmission * Improving transmission between the two mediums * Reducing noise and increasing reception efficiency

Underwater Wireless Optical Communication Channel Modeling and Performance Analysis[10]	Sermsak Jaruwatanadilok's	2008	I studied underwater optical communications (UWOC) I focused on the effect of: * Salinity * Temperature On: * SNR and BER I used: * MATLAB for modeling I proved: * Increased salinity and dispersion lead to signal quality degradation
Hybrid FSO/UWOC Communication System Performance Evaluation under Environmental Conditions[11]	Devendra Gurjar	2019	A hybrid system combining FSO and UWOC Studying the effect of: * Fog * Rain * Water properties on: * BER and Q-factor * Using MATLAB and Opti System
Performance Analysis of Visible Light Communication System for Free Space Optical Communication Link [12]	P. Shamsudheen E. Sureshkumar Job Chunkath	2020	* Li-Fi System Analysis Studying the Impact of: * Noise * Signal Strength * on SNR * Using MATLAB * Optimizing Performance Using Modulation Techniques
Analysis an optical communications system by using Optisystem program to transfer data over various distances	Hasan J. Hasan	2023	Optical System Analysis Using Opti System Study: * BER * Eye Diagram With Changes: * Distance * Power * Determining Optimal System Settings
Hybrid Terrestrial–Underwater Optical Communications Link[13]	Satea Hikmat Alnajjar1*, Mohammed K. Al-obaidi2, Mahmood J Ahmad1, Baraa Munqith Albaker2	2025	Proposed hybrid FSO-Fiber-UWOC system to improve signal transmission between air and underwater, with analysis of environmental effects and BER performance

METHODOLOGY

This section presents the proposed design model for this study. To ensure the system's effectiveness in practical applications, it was first logically simulated using simulation software according to internationally recognized standards, and then a hardware prototype was designed. This study utilizes MATLAB App Designer, the Arduino platform, and OptiSystem software.

OptiSystem is an innovative, rapidly evolving, and powerful software design tool that enables users to design, experiment with, and simulate all fiber optic link models at the transmission layer for a wide range of optical networks. It also facilitates the design and planning of optical communication systems at the transmission layer, from the component level to the system level, and visually presents analyses and scenarios.

The MATLAB user interface was developed using MATLAB App Designer within the MATLAB environment to create an interactive graphical user interface for the proposed system. This tool enables the development of object-oriented applications and the direct linking of user interface elements to computational algorithms and data processing. The user interface of the developed application communicates with OptiSystem for data transfer and simulation analysis. It also communicates with the Arduino platform to receive signals and execute control commands in a realistic environment. The integration of the user interface with OptiSystem and the Arduino platform creates a unified environment for simulating software and practical applications within a single environment.

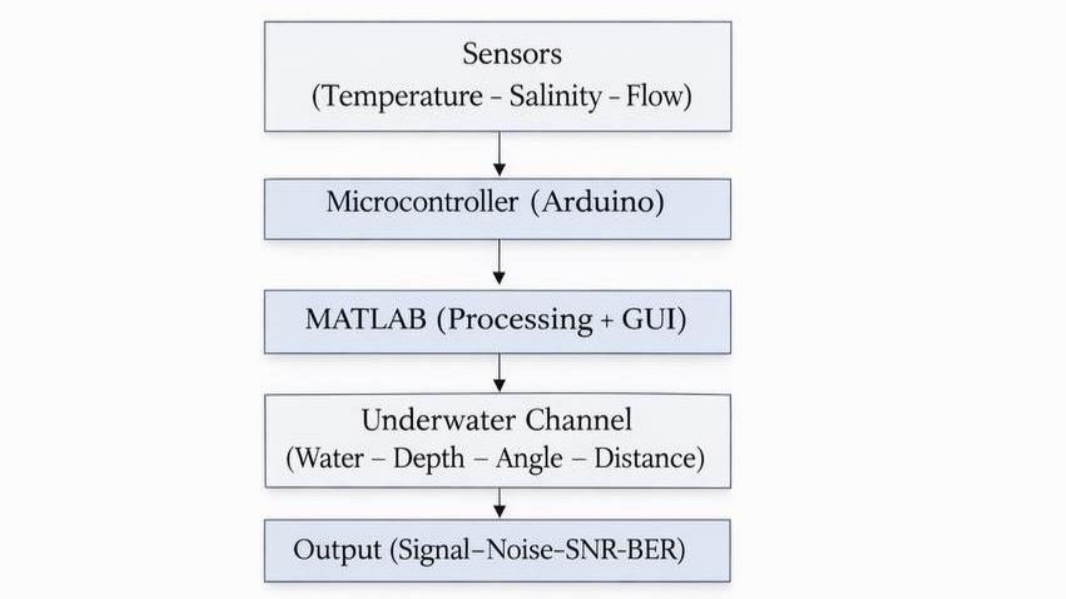

Figure 1: data sequence within the software system.

Actual sensors (such as Arduino sensors) were incorporated into the proposed system design to connect the model to practical applications. However, due to the difficulty of precisely controlling underwater environmental conditions such as temperature, turbidity, and aqueous properties, simulation was used to evaluate the system's performance under various scenarios in a controlled manner.

Simulation allows for the systematic and isolated study of the effects of variables, which is difficult to achieve in practice due to the random variations in the aqueous environment. Therefore, this approach combines practical design with theoretical analysis, providing a more comprehensive understanding of the system's performance. Future work is expected to include field tests to verify the simulation results.

Optical frequency and Underwater optical channel

The wavelength of 532 nanometers was chosen based on the optical characteristics of river water. Compared to ocean water, river water has larger amounts of dissolved organic matter and suspended silt. Scientifically, the green light spectrum falls inside the optical window of water, where the absorption coefficient is the lowest. This enables the laser beam to penetrate deeper and travel longer distances with minimal energy loss when compared to other wavelengths (such as red or infrared), which are rapidly absorbed by water molecules, and blue light, which is better suited to clear water than river water, given the nature of the riverine environment in Iraq.

The underwater optical channel is the most challenging component of the system due to its vulnerability to the high dispersion and attenuation coefficients in river water. In this study, an NLOS (Non-Line-of-Sight) channel was chosen for the system instead of the conventional LOS (Line-of-Sight) channel. An indirect communication method was chosen for this application in Iraq because of the environmental conditions along the rivers and dams created by suspended solids, salts, and complex hydraulic structures that inhibit direct visibility between the transmitter and receiver.

The NLOS configuration provides a method to receive signals at the receiver through obstructions associated with the direct channel due to the reflective nature of the surface of the water versus air or reflective structures being placed to reflect the transmitted signals.

The combination of these factors will increase the spatial diversity of the system, as well as improve the reliability of the flood warning signal, by using many propagation paths to ensure that a stable connection between the transmitter and receiver is provided.

The channel model in an underwater optical communication system also depends on several physical factors, the most important of which are attenuation, dispersion, and geometric loss, which directly affect the power of the received signal and the performance of the system.

Attenuation in underwater optical communication systems is defined as the gradual decrease in the intensity of the optical signal as it propagates through the aquatic medium, as a result of absorption and scattering processes, leading to the loss of part of the signal's energy before it reaches the receiver.

$$P(d) = P_0 e^{-cd}$$

Where:

P0: Transmitted power

P(d): Received power after a distance of d

c: Total attenuation factor

d: Distance between transmitter and receiver

$$c=a+b$$

Where:

a: Absorption coefficient

b: Dispersion coefficient

Scattering is defined as a physical phenomenon in which light rays are deviated from their original path as a result of their collision with particles suspended in water, such as salts and organic materials, leading to the signal spreading in multiple directions and reducing the amount of energy that reaches the receiver directly.

These mathematical relationships were used to model the behavior of light signal propagation within the aquatic medium and to evaluate the system's performance under the influence of different environmental conditions.

System Operation Steps

The logic of functionality in the developed system for the intelligent control of flooding is presented below divided in several blocks that describe sequentially the development of the system from the beginning in terms of collection of data until the complex analysis of communications.

The steps in systematic implementation follow several simple actions:

Initialization and Sensing: To start, the system is installed along with the sensors. The data is acquired from the undersea surrounding in real-time with the help of flow rate, temperature, and TDS sensors (TDS is salinity).

1. Data Integration (MATLAB): Collected data is transferred to the MATLAB environment for processing. At this point system calculates the primary communication parameters; Signal power, Noise power, first estimates of SNR and BER.
2. Smart Decision Layer: One of the crucial steps within this flowchart is the environmental conditions. Once they go outside of what is considered acceptable to have reliable communications, the system initiates an adjustment loop in order to re- calibrate its variables.
3. Site-Specific Evaluation: Finally, the UWOC efficiency was assessed using actual water data of two of the major sites: Mosul Dam and Kut Barrage. The purpose of using actual water data is to make sure that the simulation results correspond to the actual water problems in the Iraq water system, not theoretical solutions.

OptiSystem Simulation Software

The OptiSystem simulation system is an industry recognized tool for designing communication devices and testing the physical layering of optical networks. It has proven successful for submarine research and testing communication systems through a comprehensive library of realistic optical components; researchers have used OptiSystem to analyze communications and signal degradation. [51].

For this study, I chose to use OptiSystem as a "Dynamic Channel Emulator" vs. a standard static emulator. The primary objective of using OptiSystem as a dynamic channel emulator is to apply the environmental variables that were live analyzed in MATLAB to a virtual optical channel link. This is an important step of the process, as both the signal to noise ratio (SNR) and bit error rate (BER) can be determined.

This tool is unique in its ability to simulate aquatic environments in order to visually inspect the quality of optical communication, while simultaneously providing an analysis of how certain environmental and engineering variables impact the light signal using the eye chart within the simulator. Simply put, OptiSystem simulates, analyzes, and corroborates the reliability of communications underwater based on real world environmental variables.

These tools are extremely valuable for constructing complicated communication systems, such as undersea communications. The key benefit of using the OptiSystem program is its ability to realistically simulate complex physical conditions. This eliminates the time, effort, and monetary expense typically associated with conducting field studies. Conducting field studies and underwater testing in Iraqi rivers requires significant monetary resources for specialized equipment and substantial issues regarding environmental control. As a result of the simulation program's rapid environmental testing and quick results, researchers will be able to perform multiple environmental and engineering tests with a minimal amount of time and effort. They will also be able to diagnose problems, identify obstacles, and determine limits before the final deployment of the system. The design of the proposed system using the simulation platform is depicted in Figure 2.

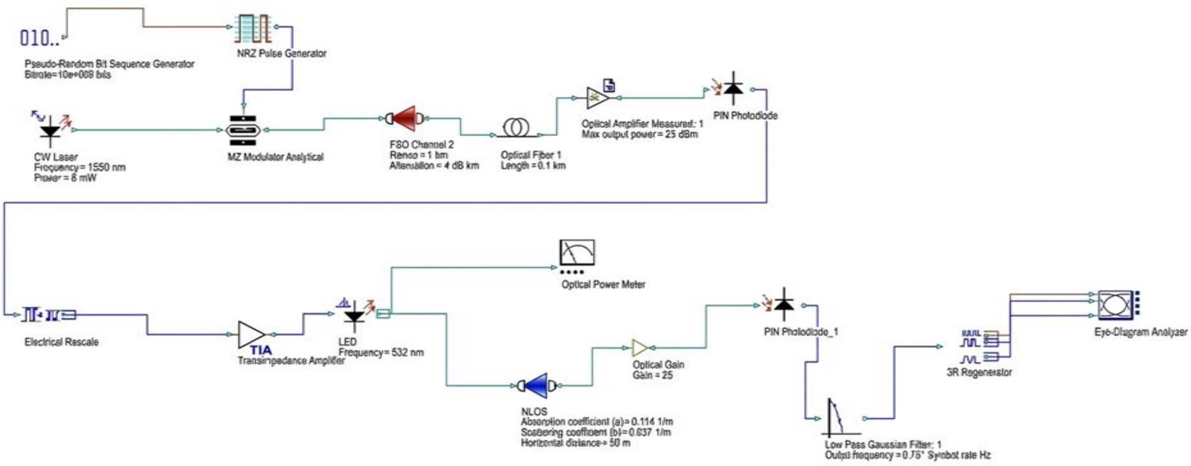

Figure 2: Simulating the proposed system in the OptiSystem version 23.0.

System Workflow

A key defining characteristic of any operating system's system structure or workflow is that it must ensure that no important flood data via sensor input, in this case, are lost through external factors or interference. This work naturally progresses from perception to analytical decision-making.

The work begins with a detailed analysis of the system ,as shown in Figure 3.The system then receives the water data provided by the sensor; specifically, TDS, flow and temperature via the combined MATLAB-OptiSystem environment. This work has a special feature known as "Intelligent Feedback Looping". Rather than simply failing when the water quality is determined to be "Highly Turbid", the system will first enter an adjustment (recalibration) phase to reset the optical connection settings. Therefore, the final performance(BER and SNR) will be valid for the environmental conditions.

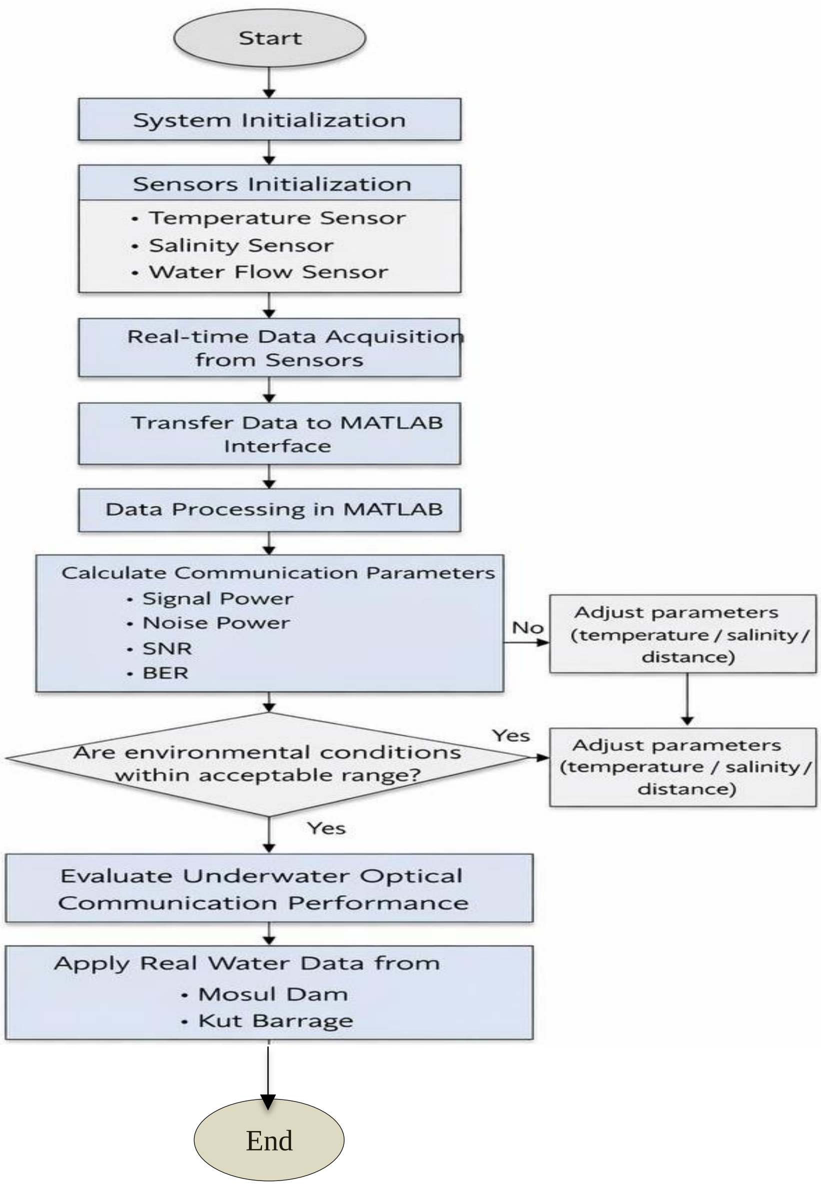

Figure 3: Operational Flowchart of the Smart Flood Control System and Decision-Making Logic.

Performance Analysis Metrics

Analysis of cause within wireless network technology involves investigating the underlying reasons for performance issues or failures. This addresses factors like signal interference, hardware defects, or system congestion that may affect network speed or reliable access. Analyzing these issues help to devise methods to improve stability and streamline system function. We do not simply quantify the results when evaluating the performance of the UWOC system. We must correlate results with established engineering specifications to confirm data accuracy.

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1. Bit Error Rate (BER) Thresholds

The BER (Beat Signal Processor) is the ultimate indicator of connection quality. In digital systems, performance is measured as follows[14]:

▪**Excellent Performance:** When the BER value is BER $\leq 10^{-9}$. In this case, the connection is very clear and there is no noticeable data loss.

▪**Forward Error Correction (FEC) Limit**: The internationally recognized standard value in UWOC research is 3.8×10^{-3}[15].

If the BER is below this value, software (such as MATLAB) can correct errors and recover all data.

If the BER is above this value, the system begins to crash, and "cubes" appear in videos or unintelligible symbols appear in text.

▪**Outage/Connection Loss:** When the BER reaches values such as 10^{-1} or 10^{-2}, the optical link is considered to be effectively broken (Link Failure), because the amount of noise and attenuation has completely covered up the transmitted optical pulses.

2. Signal-to-Noise Ratio (SNR) Analysis

The SNR value reflects the signal's strength relative to the noise level[15]:

▪**High Quality Signal:** SNR > 20 dB. This means the signal is much stronger than the noise, and data reception is easy.

▪**Acceptable Signal**: SNR between 10 dB and 20 dB. The connection is stable but may require correction techniques.

▪**Marginal/Critical Signal**: SNR < 7 dB. Here, the signal becomes overwhelmed by noise (noise floor), and it is difficult for the optical sensor to distinguish between the light pulse and the thermal noise caused by high temperatures.

RESULTS AND DISCUSSION

Beam Divergence Angle Calibration(Inner & Outer)

To account for the characteristics of underwater communication channels, which depend primarily on light propagation and correlation in the aquatic environment, an internal 0° angle was chosen for the purpose of the dedicated, non-specific communication. This choice helps concentrate light energy and minimizes unnecessary spacing within the medium. Consequently, the impact strength is improved and reduced, particularly in water spheres where absorption and correlation effects are significant.

Conversely, the external aspect accounts for the largest share of overall communication performance. Therefore, multiple external angle values were evaluated through simulation. Among the tested variables, as shown in Table 2, a 68° range performed best externally. Specifically, it achieved a bit error (BER) closest to the limit for the projected light values and a signal-to-noise ratio (SNR) near the maximum, ideally indicating a kitchen between the cooling and diffusion of the glass.

It also indicates that large throttling significantly increases radial correlation and burns out the photovoltaic batteries within the shared network, while very rapid throttling reduces radial interference and decreases communication path pulses. Accordingly, choosing a range close to 68 degrees provides the best level of outdoor coverage, ensuring improved underwater wireless communication systems under unspecified conditions.

Table 2: Effect of Inner and outer angles on BER (fixed Temperature and Salinity).

Outer angles(deg.)	BER
33	1
35.5	$1.99419e^{-36}$
40	$1.16467e^{-35}$
45	$5.61006e^{-35}$
55	$1.46925e^{-34}$
68	$8.0291e^{-38}$
75	$2.47234e^{-37}$
80	$1.04455e^{-35}$
85	$9.07278e^{-37}$

Simulation and analysis of depth, horizontal distance, and environmental conditions

Numerous experiments were conducted to measure and analyze the impact of spatial and environmental parameters on BER at different distances for each factor, given that communication is significantly affected by parameters relative to the distance between devices. Among the most important experiments conducted were:

In the first experiment, the transmitter and receiver depths were both fixed at 20 m, while a horizontal distance sweep was performed between 10 m and 100 m under the specified environmental conditions. The purpose of this experiment was to evaluate the effect of horizontal distance on the performance of the underwater optical wireless communication system and determine the maximum stable operating range for the proposed configuration. The results obtained are presented in the following Figure.

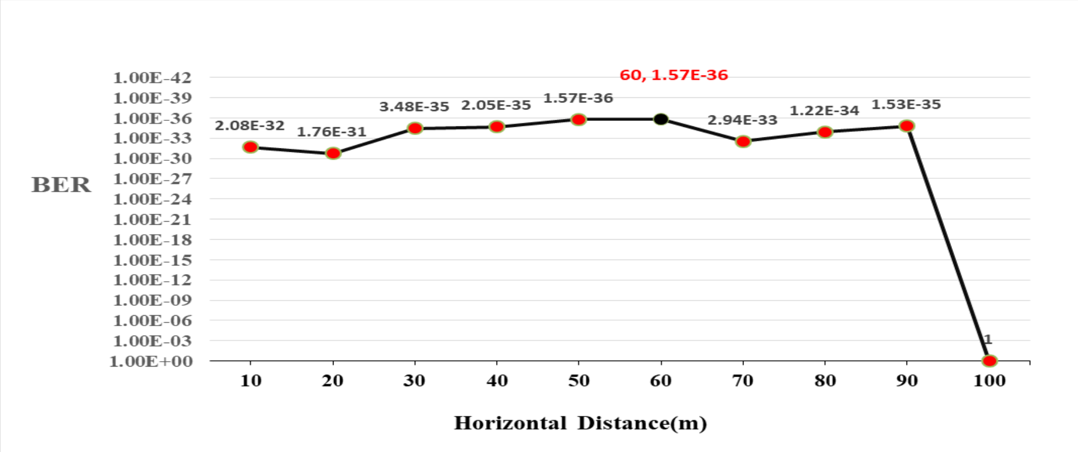


Figure 4 : Bit error rate performance under the influence of horizontal distance (m) on environmental conditions.

The results showed that the system maintained very good performance from a distance of 10 m to 90 m, with BER values remaining very low, approximately between 10^{-31} and 10^{-36}. This indicates that the optical signal was stable and that the effect of loss in the water channel was limited within this range. The best performance was observed at distances of approximately 50 m and 60 m, where the BER value reached 1.56989×10^{-36}, an excellent value indicating a very low probability of error.

However, at a distance of 100 m, the BER value increased to 1, indicating a failure of communication or system collapse at this point due to increased attenuation and dispersion with the length of the optical path. Therefore, A safe operating distance at a depth of 20 meters can be considered to be approximately 90 meters, while 100 meters represents an unsuitable limit for this setting, as shown in Figure 4.

Second experiment: In this experiment, the depth of the transmitter was fixed at 30 m while the depth of the receiver was increased to 70 m and 80 m, with the aim of studying the effect of the large increase in depth on the performance of the underwater optical communication system at different horizontal distances.

However, if the depth difference between the transmitting device is increased to a depth of 30 meters and the receiving device to a depth of 70 meters or 80 meters, the results are as shown in the following figure 5 .

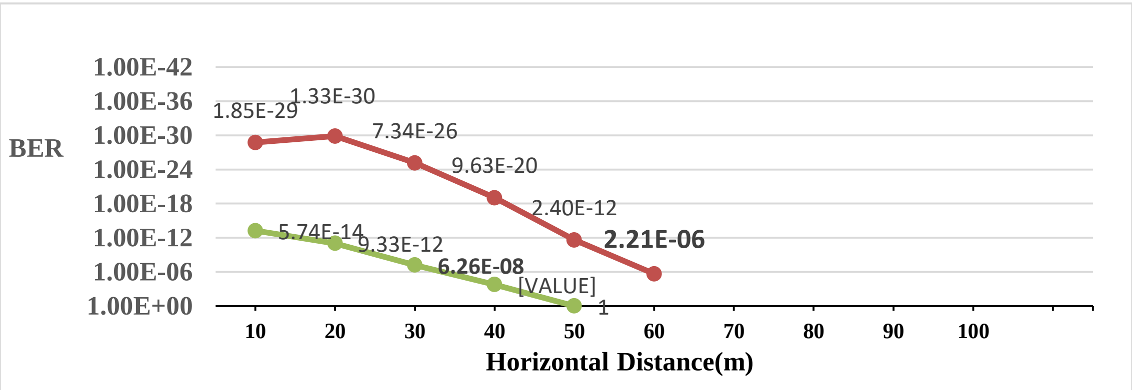


Figure 5: Bit error rate performance under the influence of horizontal distance and depth on environmental conditions.

The results showed that the system's performance began to deteriorate significantly with increasing receiver depth, with BER values gradually rising compared to previous experiment at shallower depths.

At a receiver depth of 70 m, the system maintained relatively acceptable performance at short distances, with the BER value at 10 m reaching 1.84674 × 10^{-29}, and remaining relatively low up to 40 m. However, performance began to decline noticeably after 50 m, with the BER value rising to 2.40 × 10^{-12}, and then to 2.21 × 10^{-6} at 60 m, indicating an increased effect of loss and scattering within the optical channel.

With the receiver depth increase to 80 meters, the performance of the system had been reduced. The BER values had rapidly risen with the increasing horizontal distances. At 40 meters, theBER value was 0.000170509 and at 50 and 60 meters, the BER had reached to 1, indicating a complete communication failure and also, that the system could not correctly decode the transmitted signal.

This is caused by the fact that underwater, the optical path length significantly increases with depth and the absorption and scattering effects are significantly increased due to the transmitter and receiver depth difference.

From these results, it can be clearly deduced that by increasing the receiver depth to larger values significantly impacts the reliability and efficiency of the system in longer horizontal distances. It means the system was highly sensitive toattenuation when depth difference had become bigger, therefore, large depths such as 80m can reduce the effective communication distance,as is clear in Figure 5. In Third experiment, transmitter and receiver depths were kept at 20m and 40m,horizontal distance between them was kept at 40m, temperaturewas maintained at 30°C. The variable salinity values ranging from 3.5 to 35, were used in order to identify its impacts on the system.

Table 3: Signal quality analysis at a horizontal distance of 40 m.

Salinity %	BER
3.5	3.21523E-35
7	1.74115E-32
10.5	9.40081E-33
14	3.35994E-34
17.5	3.16668E-35
21	4.95704E-33
24.5	1.12004E-32
28	1.3841E-32
31.5	2.24495E-33
35	1.33889E-30

The results, shown in Table 3, indicate that the system maintained stable performance at all salinity values in this experiment. The BER values were very low, ranging from 10^{-30} to 10^{-35}, demonstrating the system's ability to withstand saline conditions within this range.

The best value was recorded at a salinity of 3.5, with a BER of 3.21523 × 10^{-35}, indicating very high signal quality and a low probability of error.

With increasing salinity, a gradual fluctuation in BER values was observed. Values rose relatively at certain salinity levels, such as 7, 24.5, and 28, then reached 1.33889 × 10^{-30} at a salinity of 35, the highest value recorded in this experiment. This is because increasing salt concentration affects the propagation characteristics of light in water by increasing absorption and scattering and altering the refractive index, leading to a relative decrease in optical signal quality.

The previous experiment was repeated with the transmitter depth fixed at 20 m, the receiver depth at 40 m, and the temperature at 30°C, except that the horizontal distance between the two devices was increased to 80 m to study the effect of the long distance in conjunction with the change in salinity ratio.

The results, as shown in the following table, indicate that the BER values increased significantly compared to the previous experiment at a distance of 40 m, with the values falling within the range of 10^{-10} and 10^{-11}, indicating a decrease in signal quality due to the increased optical path length within the aqueous medium.

The results, indicate that the system has good tolerance to salinity variations within the studied range.

However, a gradual increase in salinity leads to a decrease in communication efficiency and an increase in the error rate, particularly at high salinity levels. Therefore, salinity is an important environmental factor that directly affects the performance of underwater optical communication systems.

Table 4: Analysis of signal quality at a horizontal distance of 80m and different salinity levels and their effect on BER

Salinity %	BER
3.5	1.14E-10
7	1.80E-11
10.5	9.58E-11
14	3.52E-12
17.5	1.37E-11
21	1.43E-11
24.5	3.92E-11
28	4.91E-11
31.5	1.13E-11
35	1.36E-11

The results also showed that the best performance was achieved at a salinity of 14, with a BER value of 3.52×10^{-12}, the lowest value in this experiment, while a salinity of 3.5 recorded the highest BER value of 1.14×10^{-10}. These results indicate that the effect of salinity becomes more pronounced at longer distances, as the interaction between increased salinity and increased distance enhances the absorption and scattering of light, directly impacting communication quality.

Overall, the results suggest that longer distances, namely 80 m, decreases stability. However the system did not collapse fully and remained functioning.

. The results also confirm that the impact of environmental factors, such as salinity, becomes more sensitive at longer distances due to increased loss in the underwater optical channel.

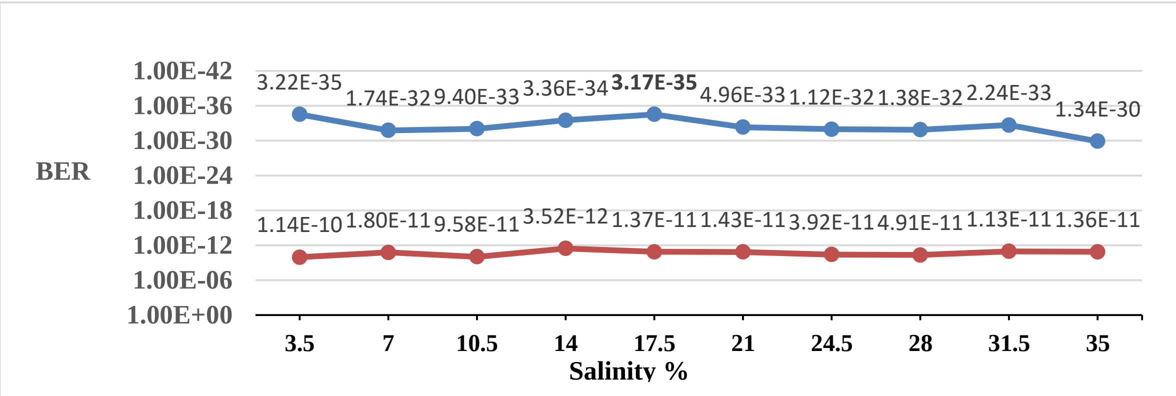


Figure 6: At depths of 40m, the comparison of salts at the receiving depth is shown, along with the effect of salts and their impact on BER.

In the fifth experiment, the effect of varying salinity on the performance of an underwater optical communication system was measured at different depths and horizontal distances, with a constant temperature of 30°C. Salinity values were varied within a range of 3.5 to 35 to study the system's response to environmental changes related to salt concentration in the aquatic medium.

In the first attempt of the fifth experiment, the effect of varying salinity on the performance of an underwater optical communication system was investigated. The transmitter depth was fixed at 30 m and the receiver depth at 40 m, with a horizontal distance of 70 m and a constant temperature of 30°C, e salinity was gradually increased over a range of 3.5 to 35.

The results shown in Figure 7 indicate that the system is stable at most salinity values, with the BER remaining low in the range of 10^{-17} to 10^{-19}. This demonstrates the system's stability and the efficiency of its optical transmission.

A high bit error rate was observed at a salinity of 35%, with a BER value of 1.10×10^{-13}. This indicates a signal decrease at high salinity levels due to the increased effect of salinity on the propagation characteristics of light in the aqueous medium, the higher salt concentration led to increased light absorption and scattering.

The results shown in Figure 7 confirm that the system works efficiently at different salinity levels at these depths and distances, but when salinity increases, the system's performance gradually declines, especially at high horizontal distances.

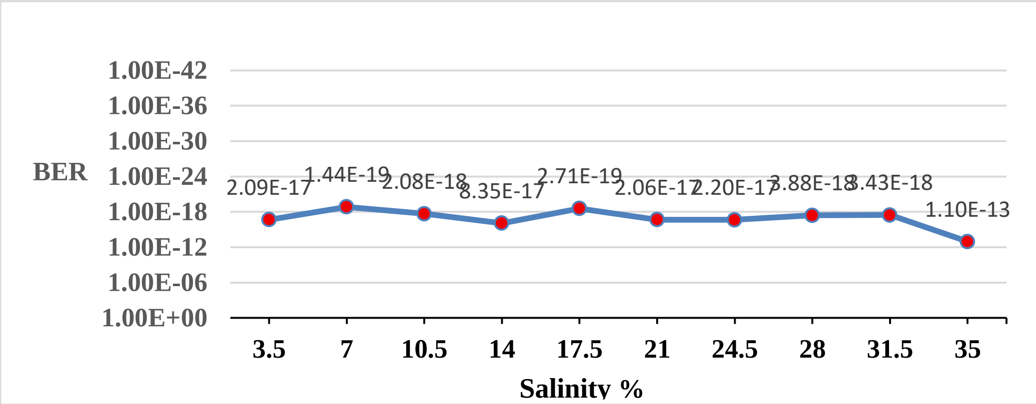


Figure 7: The effect of high salinity on system performance is shown over a horizontal distance of 70 meters and at different depths.

The other test studies the effect of salinity at a large depth difference between the two devices and a medium horizontal distance, where the transmitter was fixed at a depth of 30 meters while the receiver was fixed at 50 meters and at a horizontal distance of 50 meters between the two devices, at a temperature of 30 degrees Celsius and a salinity between 3.5 and 35 percent.

The result reveals that the performance of the system is relatively stable under most salinity values, and the BER is still quite low, which reflects the successful transmission of optical information at greater depth difference between transmitting and receiving sides.

Performance was also optimal at low and moderate salinity levels, while the BER gradually increased at higher salinity, particularly at 35 m. This suggests an increased effect of absorption and light scattering with rising salt concentration in the aqueous medium.

The results also indicate that reducing the horizontal distance to 50 m helped maintain system stability compared to cases with longer distances, despite the increased receiver depth. This indicates that horizontal distance plays an important role in reducing the impact of environmental factors on the performance of underwater optical communication systems, as illustrated in following Figure.

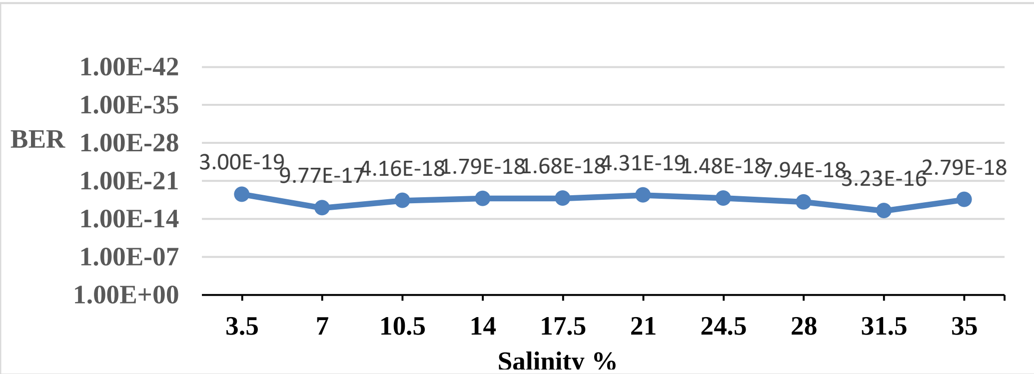


Figure 8: This figure illustrates the change in salinity at different depths over a horizontal distance of 50m.

In this test, the transmitter depth was fixed at 30 m and the receiver depth at 60 m, with a relatively short horizontal distance of 20 m. Salinity values were gradually varied across several levels, as shown in the figure, at a constant temperature of 30°C. This experiment aimed to study the effect of salinity when there was a large depth difference between the transmitter and receiver, while simultaneously reducing the horizontal distance to minimize signal loss in the water channel.

The results showed that the system maintained very good stability across all studied salinity values. BER values remained within low limits, ranging approximately between 10^{-15} and 10^{-17}, indicating that reducing the horizontal distance significantly helped maintain signal quality despite increasing the receiver depth to 60 m. The best value was recorded at a salinity of 35, with an BER value of approximately 3.76×10^{-17}, while the highest value was recorded at a salinity of 3.5, reaching 1.45×10^{-15}.

It means that, even when there's a large difference in depth, a short distance is also able to effectively weaken the salinity impact, owing to the decrease in optical path length, the attenuation in the water body, and the decrease in scattering in the water body. Therefore, it's very important to decrease the horizontal distance to enhance the stability of underwater optical wireless communication system with non-uniformity, as shown in Figure 9.

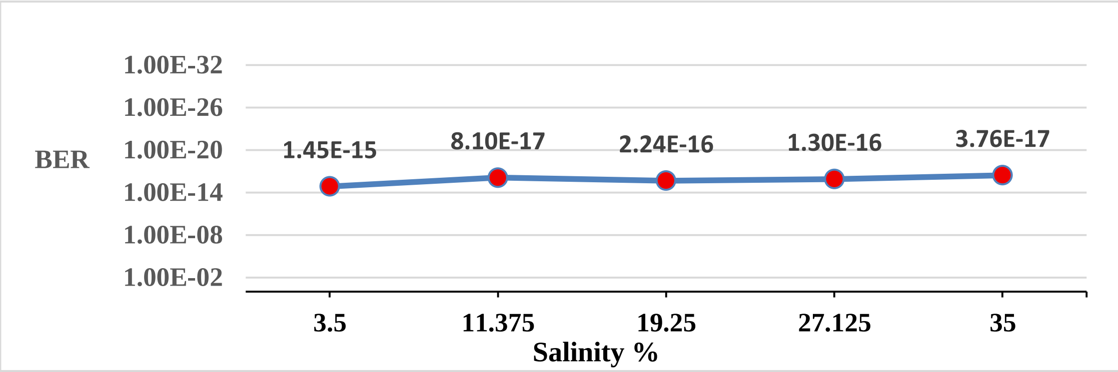


Figure 9: this figure presents salinity vs bit error rate in various depths with thehorizontal distance of 20m.

Ultimately, the communication breakdown observed in most experiments can be physically explained by the fact that, at large distances or elevated temperatures, a sharp degradation in system performance occurs, where the bit error rate (BER) rises to values indicating a complete loss of communication. This behavior is primarily attributed to the significant reduction in the received signal power due to increased attenuation within the underwater medium, which intensifies with propagation distance.

Moreover, scattering causes a considerable portion of photons to deviate from the direct path toward the receiver, thereby reducing the effective received power and degrading signal quality. In addition, thermal noise at the receiver, particularly at higher temperatures, further reduces the signal-to-noise ratio (SNR), increasing the probability of detection errors.

Therefore, the system failure observed under these conditions cannot be attributed to a single factor; rather, it results from the combined effects of attenuation, scattering, and noise, all of which become more pronounced under harsh operating conditions.

Simulating Iraqi aquatic environmental conditions

After completing the system configuration and design constraints analysis, we move to the current section, which involves simulating internal environmental conditions (the Iraqi water environment). The performance of an optical wireless communication system is not only affected by the location of the transmitter and receiver, but also by environmental conditions such as temperature, salinity, and distances between devices. Because the Iraqi environment varies greatly in salinity and temperature from place to place, a number of studies were carried out.

The effect of these factors on system performance was measured through a number of tests. In order to determine how each element affected the BER value, one factor was changed in each experiment and its impact was tested at various depths. This enables the device to function effectively without signal deterioration or breakdown by choosing the ideal depth and distance within the designated aquatic environment.

Experiments on the effect of salinity

With a horizontal distance of 24 meters, a temperature of 30°C, and a salinity range of 3.5% to 35%, the transmitter and receiver depths in the first experiments were set at 8 meters, representing the depths typical of the Iraqi environment. The purpose of this was to investigate and evaluate the system's performance in a shallow aquatic setting with water conditions similar to those seen in Iraqi waterways.

The BER value stayed low between 10^{-17} and 10^{-20}, indicating that the system was successful in maintaining outstanding stability at all salinity levels. With a BER value of 3.33×10^{-20}, the lowest bit loss was seen at a salinity of 24.5%, suggesting little bit error and acceptable signal quality.

Because of the shallow depth and short horizontal distance, which lessened the impacts of absorption and dispersion within the aquatic medium, the overall results indicate that the influence of salinity was restricted in this configuration.

Therefore, this setup can be considered suitable and stable for operation in a shallow Iraqi water environment with varying salinity.

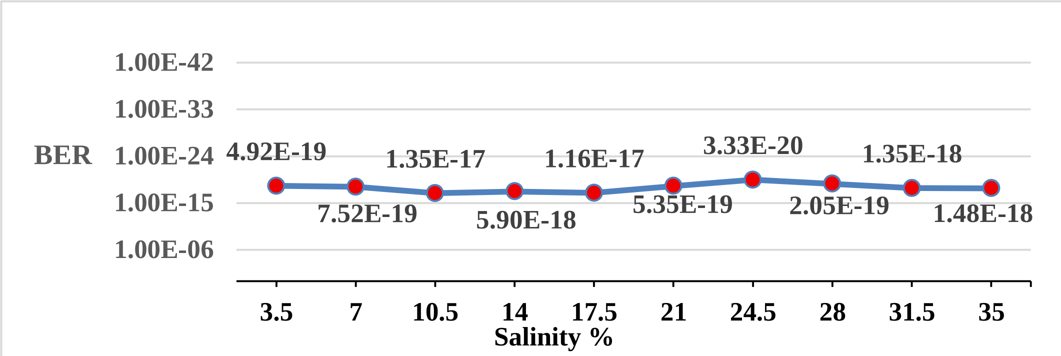


Figure 10: This figure illustrates the effect of salinity on the bit error rate at a horizontal distance of 24m and a constant depth of 8m, demonstrating the extent of salinity's impact on the signal.

Experiments on the effect of temperature

In this experiment, the effect of temperature on the performance of an underwater optical communication system was investigated in a shallow aquatic environment. The transmitter and receiver depths were fixed at 8 m, the horizontal distance at 24 m, and the salinity at a constant 3.5 **%**. The temperature was varied from 5°C to 30°C to determine the effect of temperature variation on the BER value.

The results in Figure 4.28 showed that the BER values remained very low in the range of 10^{-33} to 10^{-39}. This means that the system maintained excellent performance at all temperatures, and there was a gradual improvement in system performance with increasing temperatures, reaching its peak at 30°C, where there was the lowest bit error rate of 2.58×10^{-39}, meaning very high signal quality and a low probability of error.

These results suggest that increasing the temperature within the studied range did not negatively affect system performance; rather, it contributed to better stability of the optical signal under these conditions. This was due to limited effect of heat in comparison to distance and depth on distances and depths such as used in the current investigation.

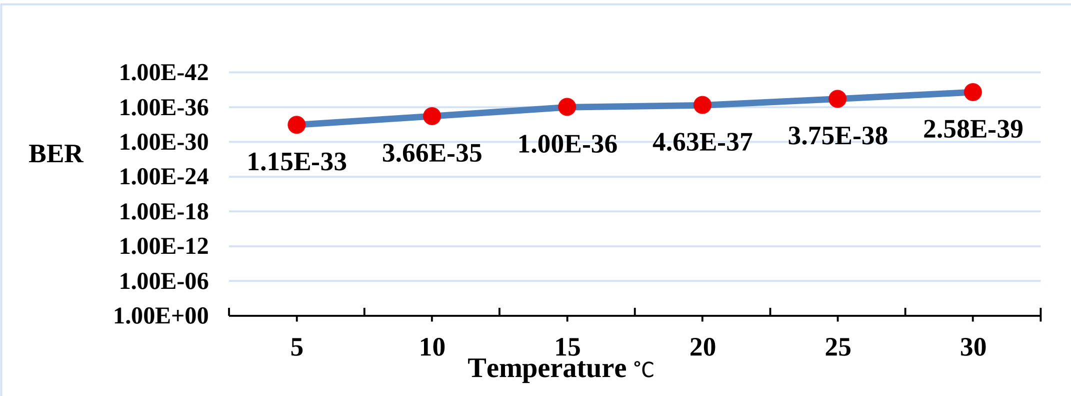


Figure 11: Effect of temperature on bit error rate at depths of 8m and horizontal distance of 24m for an indoor environment.

In this experiment, the effect of temperature on the performance of an underwater optical communication system was investigated by increasing the depth of both the transmitter and receiver to 20 m each, while maintaining a constant horizontal distance of 24 m and a salinity of 3.5. The temperature was varied within a range of 5°C to 30°C to analyze the impact of temperature variations on the BER value at greater depths compared to the previous experiment.

The results showed that the system maintained good performance across all studied temperatures, with BER values remaining very low, approximately between 10^{-30} and 10^{-39}. A gradual and significant improvement in system performance was observed with increasing temperature, as the BER values decreased steadily from 4.16×10^{-30} at 5°C to 2.30×10^{-39} at 30°C, the optimal value observed in this experiment.

These results demonstrate that within the range studied, higher temperatures resulted in higher signal quality and fewer opportunities for errors, even for depths as great as 20m. The results also suggest that the And also proven to be stable at those depths for those ranges and have the capability of operation under the changing thermal conditions in the water that could present in Iraq's aquatic environment

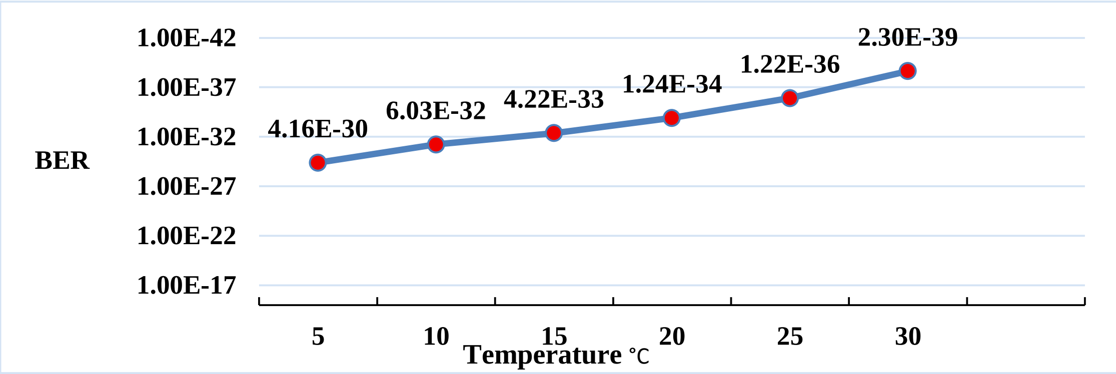


Figure 12: Effect of temperature on bit error rate at depths of 20m and horizontal distance of 24m for an indoor environment.

Experiments on the effect of horizontal distance

In this experiment, the Iraqi aquatic environment was simulated by fixing the transmitter and receiver depths at 8 m, with a constant temperature of 30°C and a salinity of 3.5, while varying the horizontal distance between the two devices within a range of 3 m to 30 m. The purpose of this experiment was to investigate the stability of an underwater optical communication system at shallow depths, which are representative of various local aquatic ecosystems, including rivers or places close to the surface. With BER values maintaining very low, roughly between 10^{-12} and 10^{-21}, suggesting great signal quality and a minimal likelihood of error, the results demonstrated that the system maintained very steady performance over all the examined distances. The experiment's lowest BER value of 5.57×10^{-21}, which indicates great data transmission efficiency at this distance, was obtained at a distance of 24 m, where the best performance was recorded

The findings also demonstrate that the effects of attenuation and dispersion inside the water were lessened by short and medium distances at shallow depths; as a consequence, no discernible decline in system performance was seen within the examined range. 13 indicates these results confirm the system had high operability in shallow Iraqi waters and provided robust communication links across a limited range and medium range.

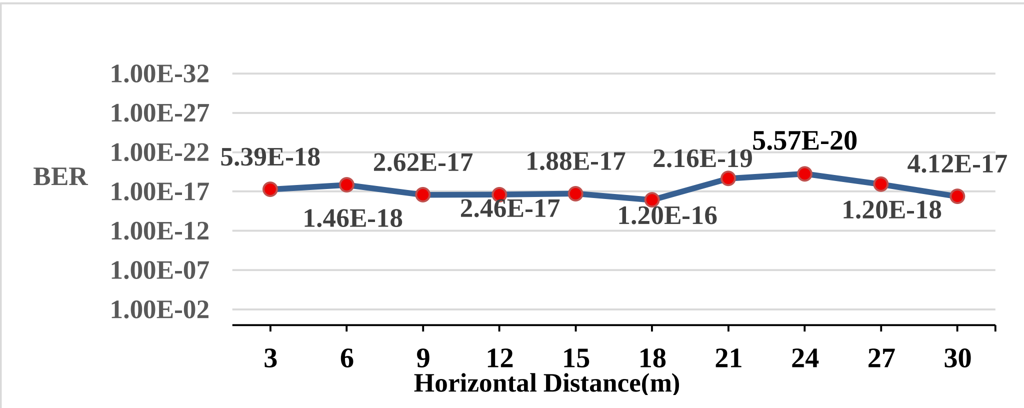


Figure 13: The effect of horizontal distance on bit error rate at a depth of 8 m in an indoor environment.

This test demonstrates the effect of increasing horizontal distance on the performance of an underwater optical communication system in an environment simulating the conditions of the Al-Kut Dam. The temperature was kept constant at 30°C, the salinity at 0.8%, and the depth of both the transmitter and receiver at 5 m. The horizontal distance between the two devices was increased from 2 m to 25 m to determine the system's actual operating limits in this environment.

The results indicate that the system's optimal performance is within the range of 10^{-28} to 10^{-36} bit error, reflecting the stability of the optical signal and its minimal impact from absorption and scattering at these distances. The system's performance remained stable even at higher horizontal distances, such as 20 m, demonstrating its ability to maintain communication quality within this range.

However, upon reaching a horizontal distance of 25 m, the bit error rate suddenly increased to 1, indicating a complete breakdown of the communication. This is attributed to the distance exceeding the optical channel's operational limit under the conditions of the Al-Kut Dam. In this case, propagation, absorption, and scattering losses become greater than the receiver's ability to correctly capture the optical signal.

It is clearly stated from these results that the functional operation of the system at this particular environment condition is less than 25 m. When this range is extended the signal is lost completely and this sets the limits for using the system at such marine conditions such as those at Al-Kut Dam.

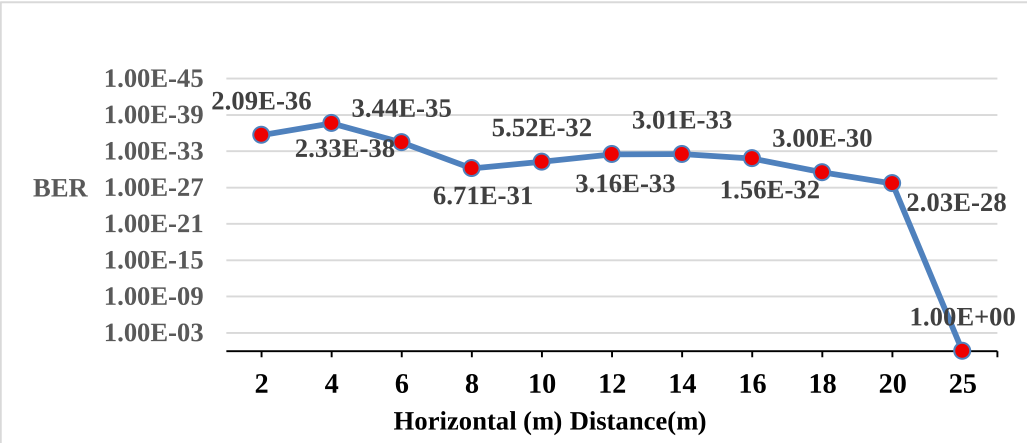


Figure 14: This illustrates the effect of horizontal distance on bit error rate at depths of 5m, temperatures of 30°C, and salinity of 0.8% under specific environmental conditions.

However, if the transmitter and receiver depth was fixed at 10 m within the Al-Kut Dam data, the horizontal distance was increased from 5 m to 50 m to study the system's stability at a greater depth compared to the previous case.

The results showed that the system maintained excellent performance from a distance of 5 m to 45 m, with BER values remaining very low, within an approximate range of 10^{-32} to 10^{-36}, indicating optical signal stability and high data transmission efficiency. The best value was recorded at a distance of approximately 30 m, with a BER value of 9.32×10^{-36}. At a distance of 50 m, the BER value increased to 1, indicating a breakdown of the connection at this point. Therefore, the safe operating distance at a depth of 10 m can be considered to be approximately 45 m, while 50 m represents an unsuitable limit for this setup.

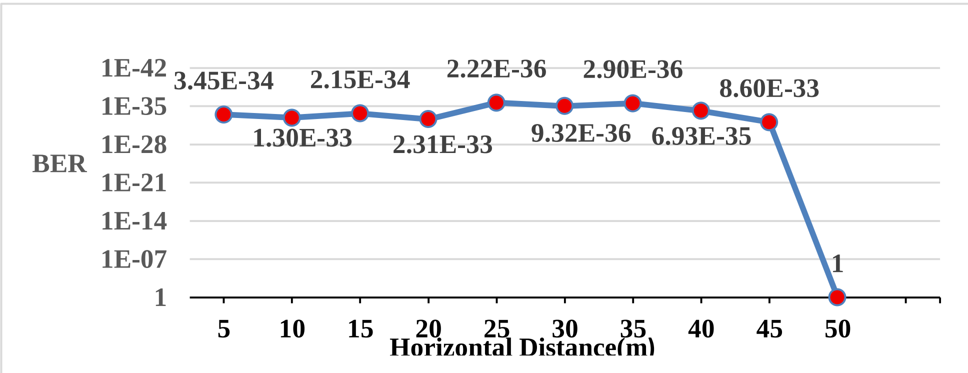


Figure 15: This illustrates the effect of horizontal distance on bit error rate at depths of 10m, temperatures of 30°C, and salinity of 0.8% under specific environmental conditions.

The results in Figure 16 illustrate the effect of increasing depth on the performance of an underwater optical communication system in an environment simulating the conditions of the Mosul Dam. The depth of both the transmitter and receiver was fixed at 20 m, with a constant temperature of 30°C and a salinity of 0.6%. We changed the distance between two devices ranging from 5 m to 50 m in order to see the performance behavior under the condition of this range. The shown curve reveals that the system performance maintained a quite stable level throughout most distance, BER values varied between about 10^{-34} and 10^{-26}. It can be considered that there is quite high efficiency in transmitting optical signal underwater environment. It also is demonstrated that there was no drastic break down occurring in this system even at longer distance while some other tests experienced so abrupt system performance decrease; instead it happened in a smooth way. Performance maintained rather consistent for increasing distance at long distance; it demonstrates that in Mosul Dam conditions deep water played the part of weakening impact of surface fluctuation. environmental fluctuations, which positively impacted the stability of the optical channel. In addition, the lesser saline nature of the environment was an influential factor towards lower absorption and scattering losses than what higher saline environment offers. In the latter distances, especially around 45m and 50m, a slow degradation of the quality of communication was perceived, caused by increased propagation loss as a function of distance. Nonetheless, the BER values stayed low and acceptable. Thus, the Mosul Dam surrounding represents a fairly well environment for UOC at intermediate and larger distances.

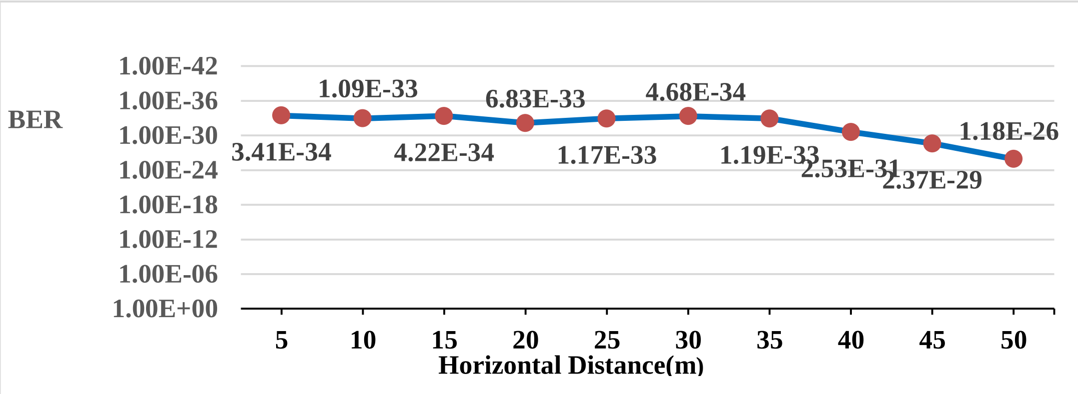
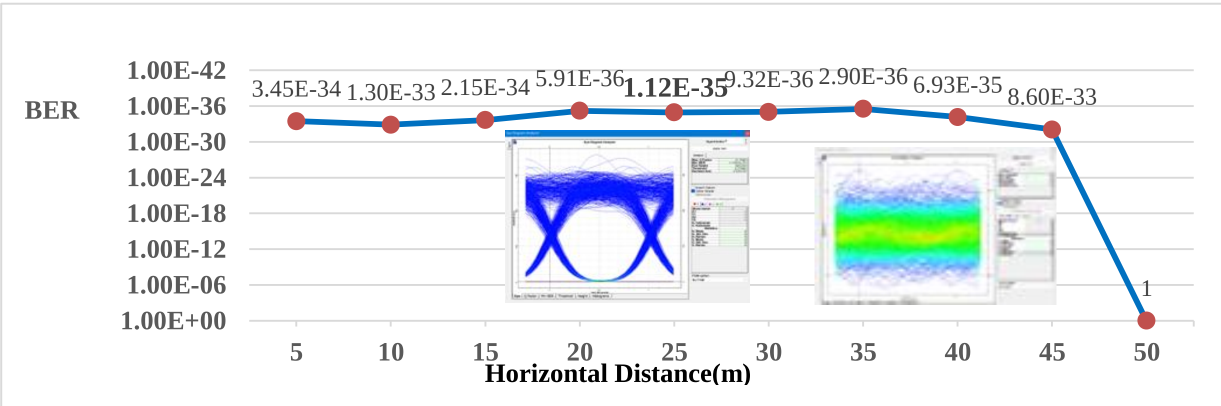


Figure 16: This illustrates the effect of horizontal distance on bit error rate at depths of 20m, temperatures of 30°C, and salinity of 0.6% under specific environmental conditions.

A shallower depth was simulated within the conductor dam data, with the transmitter and receiver depths fixed at 10 m and the same parameters (temperature 30°C and salinity 0.6) as before, while the horizontal distance was changed from 5 m to 50 m.

The results showed that the system maintained excellent performance from a distance of 5 m to 45 m, with BER values remaining very low, within an approximate range of 10^{-33} to 10^{-36}, indicating optical signal stability and communication efficiency within this range. The best value was recorded at a distance of approximately 35 m, with a BER of 2.90×10^{-36}.

At depth of 50m, the value of BER becomes 1 meaning the system was terminated due to breakdown at this depth. Therefore, safe working depth at depth of 10m can be taken to be approximately 45 m in this scenario and the system can not be operated beyond the 50 m level as can be seen from the Figures 17.



17: Effect of Horizontal Distance on Bit Error Rate in a water depth of 10 m, a water temperature of 30°C a nd salinity of 0.6% with specified environmental conditions.

Temperature Limits

System limitations with reference to thermal loads, were decided according to historic climatic variations of the Iraqi ambient temperature, Mosul Dam represents the relatively cooler region, while the Kut Dam represents the hottest, especially during the summer. Therefore, a wide thermal range was adopted in the simulation, starting from low temperatures around 5°C and reaching high temperatures up to 30°C in the current experiments.

In this test, environmental conditions were simulated to mimic those of the Kut Dam. The depth of both the transmitter and receiver was fixed at 10 meters, the horizontal distance between them at 30 meters, the salinity level at 0.8%, and the transmission angle at 68 degrees. To determine the effects of thermal conditions on system performance, temperatures were varied from 5°C to 46°C to ascertain the system's operating thermal limits within the Iraqi environment throughout the year.

The results indicate that the system worked efficiently and stably for almost all temperature variations. The bit error rate was very low for almost all temperatures and its value was from 10^{-38} to 10^{-23} showing the system's stable performance against temperature change without loss of communication.. The results in Figure 4.36 show that performance was relatively better at low and medium temperatures. The lowest BER values were recorded at the beginning of the temperature range, while BER values gradually increased with rising temperature, especially after exceeding 30°C. This is because rising temperature alters the physical properties of water, increasing the effects of scattering and turbulence within the optical channel, thus gradually increasing signal losses.

Despite this gradual deterioration, the system continued to operate within stable limits even at the maximum temperature of 46°C, without reaching a complete signal breakdown. This indicates that the system has good operational capacity under the relatively harsh thermal conditions that Iraqi aquatic environments may experience during the summer months.

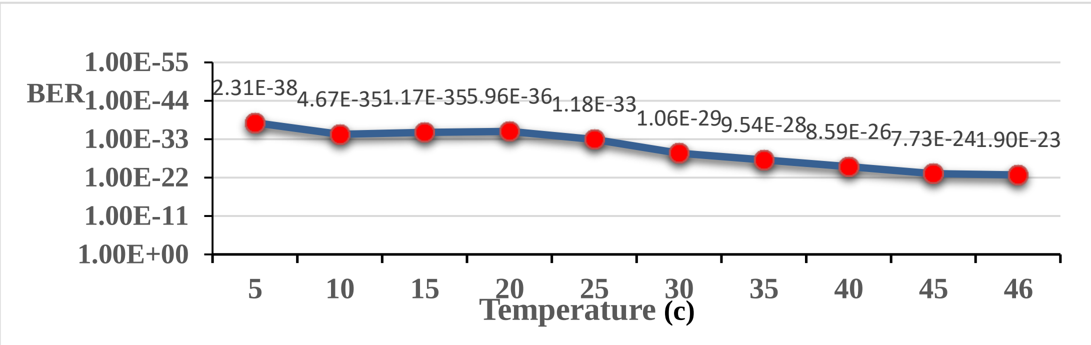


Figure 18: Effect of temperature limits on bit error rate under environmental conditions of 30m horizontal distance and 10m depth.

The results in Figure 19 illustrate the effect of increasing depth and horizontal distance on the thermal operating limits of an underwater optical communication system in an environment simulating the conditions of the Al-Kut Dam. In this simulation, the depth of both the transmitter and receiver was fixed at 20 m, the horizontal distance was increased to 50 m, the salinity was maintained at 0.8%, and the external transmission angle was kept at 68°. The temperature was varied within a range of 5°C to 46°C to study the system's ability to continue operating under more demanding conditions.

As shown in figure the BER values remained at very low levels at both low temperature and medium temperature that the stability of the system, especially under the condition with great depth and long distance from previous situations. However, the effect of temperature became more pronounced with increasing temperatures. BER values began to rise steadily after 25°C, and this effect increased even further at temperatures between 35°C and 46°C.

The reason behind this behavior is due to the fact that depth and horizontal distance enhance the optical loss over the water channel. At higher temperatures this further enhance the absorption, scattering, turbulence over the water channel which degrade the signal over a long distance.

It is noticed that even though of these more complex conditions the system did not experience total signal breakdown but BER is still within relatively good values which means the system is robust for temperature variation at a more complex condition i.e. At larger depth and distance over the Iraqi water sources.

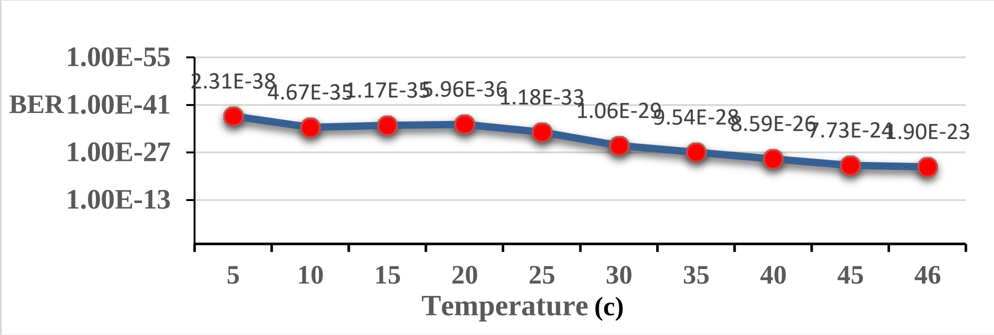


Figure 19: Effect of temperature limits on bit error rate under environmental conditions of 50m horizontal distance and 20 m depth.

In this test, we are going to calculate the thermal operation limits of a UWOC system that simulates the conditions inside the Mosul Dam. The transmitter and the receiver will be at the same depth (20 m) at 40 m distance and the external transmission angle and salinity will be 68° and 0.6% respectively. We will increase temperature from 5°C to 46°C to observe how it affect the system stability and the communication performance.

Shows that system had very stable performance at low and middle temperatures within very low limits ranging around 10^{-36} and 10^{-34} Optical signal could be transmit at high efficiency in the water channel at these temperatures. The performance was similar up to 30°C, this means that the condition in Mosul Dam would be proper for this system operation, due to low salinity and less loss compared to higher salinity water. While over 35°C, the shape of the curve changed dramatically. The BER values increase to a relatively high limit, i.e. 10^{-20} and 10^{-19}, the initial response of the system to higher temperature was obviously. This can be explained by the higher temperature would lead to a greater disturbance in the liquid and change of the physical properties. Consequently enhance the effect of scattering and optical loss in the optical channel. However, the system was still not collapsed even at the higher temperature. So it could maintain a good resistance to the variation of temperature in the conductor dam, while being comparatively better than the result obtained in higher salinity water or greater distance.

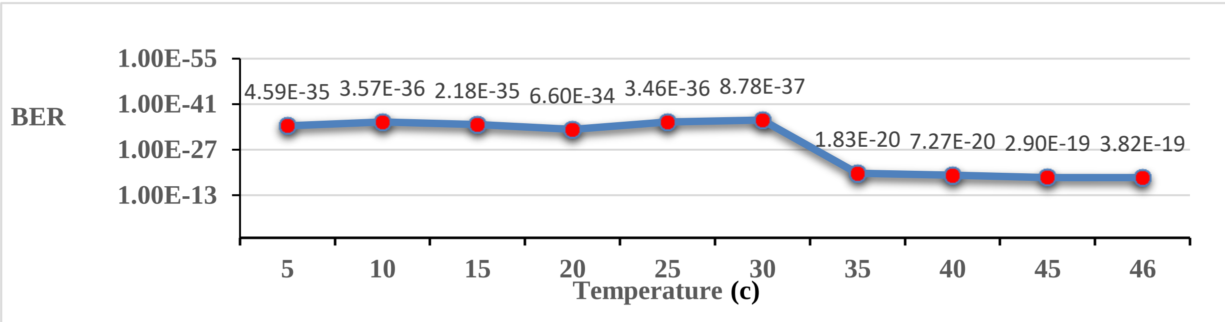


Figure 20: It explains the limits of indoor environmental temperatures and their impact on BER.

The graphs presented in Figure 20 demonstrate that greater depths and further horizontal distance can greatly affect the thermal limits of the system. Figure 21 shows the performance characteristics of the system with increased depth and horizontal distance for a channel setup mimicking the parameters for a dam in Mosul. For the tests in the figure, both the transmitter and the receiver depths were set at 30 m and the horizontal distance to 80 m. The salinity was kept constant at 0.6%, and the outer transmission angle remained at 68°

As you can see from the graph, the system still performed quite well at the lower and moderate temperature ranges; the BER stays very low all the way up until 30°C. This signifies that the system could perform even at the higher depth and distance settings. The graph takes a sudden and drastic turn as the temperature increases to 35°C, at which point the BER instantly rises to 1; this signifies complete loss of the optical signal and communication. This happens as the great depth and horizontal distance caused high levels of optical loss to occur in the water channel, which was then exacerbated at higher temperatures by absorption and scattering.

Added to this, the great distance of 80 m resulted in higher susceptibility of the signal to thermal variations with respect to shorter distances described above. Conclusions The conducted analysis showed that thermal limits of operations of the system are dependent not only on the temperature but strongly depend on a combination of parameters including depth, distance of propagation etc. As the temperature of system increase so is the possibility of communication break under these conditions of high temperature and pressure.

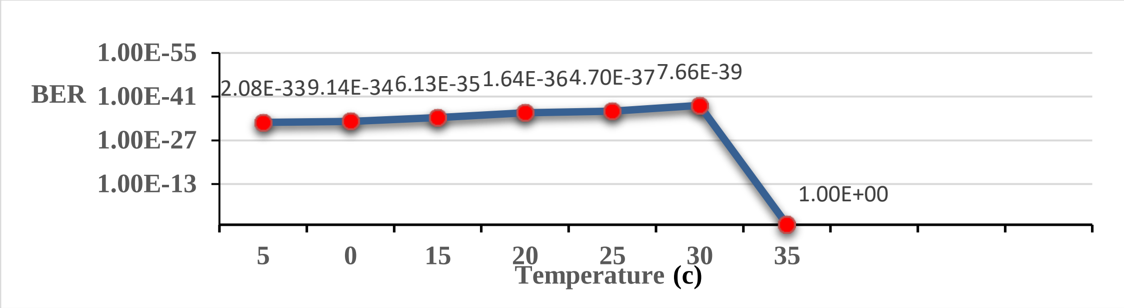


Figure 21: Impact of temperature limit to bit error rate under horizontal 80 m conditions distance and 30m depth.

To analytically calculate the system's thermal failure point, polynomial fitting method was applied to fit the temperature-BER curve.

A second-order polynomial function was used with the following formula:

P = polyfit(T, log(BER), 2);

Where T represents the temperature values and BER represents the error rate. The logarithm of the BER values was used to facilitate the analysis of large changes in values. The number 2 indicates that the fitting was performed using a second-order polynomial curve, which is more suitable for the data behavior than a straight line.

This method helped clarify the system's behavior with increasing temperature and identified the point at which performance begins to deteriorate or break down, especially in cases where the BER value increased suddenly at high temperatures.

Salinity Limits

The limits on the salinity was calculated with regard to the water characteristics of the dams in Mosul and Kut. The Mosul dam was found to have quite a low level of salinity in comparison to the Kut dam. As such, it was decided that a variety of salinity levels would be utilized throughout the simulation ranging from low levels such as 0.6 and 0.8 to highs up to 35 to identify how this would impact the underwater optical communication system.

In this test, operating ranges associated with the salinity was calculated for the conditions of the Al-Kut dam, as a temperature of 30°C,, both transmitter and receiver at a depth of 10 m, horizontal distance of 30 m, and an exterior angle of 68°.Salinity was tested from 0.5 to 1.5 to identify impact of varying salt concentrations on stability.

It was observed from the results that no variation could be noted from the system at the levels tested and that the system was operating exceptionally well. The Bit Error Rate (BER) was always incredibly low and was only between 10^{-33} and 10^{-39} It was also noted that the performance was actually the best when the salinity was 1.5 with the lowest value in this experiment occurring at this concentration and with a BER of $8.52{\times}10^{-39}$ the highest stability and lowest error possibility.

These results indicated that system performance did not break down or fail at any level of salinity tested and thus the acceptable limits of salinity for this system when set to these conditions in the Al-Kut Dam is within the 0.5 to 1.5 range.

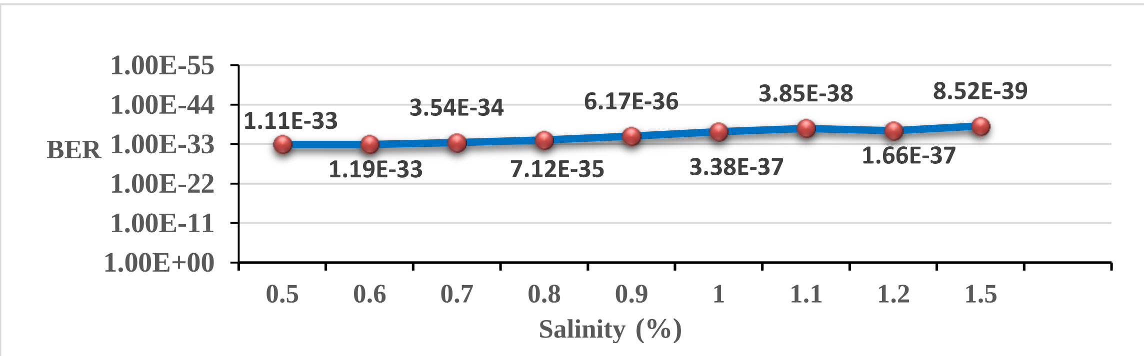


Figure 22: The figure illustrates the salinity limits at depths of 10m and horizontal distances of 30m under specific environmental conditions and their effect on BER.

However, when the horizontal distance was increased to 50 m and the transmitter and receiver depths increased to 20 m under the same conditions at the Al-Kut Dam, the results showed continued system stability across all tested salinity values from 0.5 to 1.5. BER values remained very low, within an approximate range of 10^{-33} to 10^{-43}, indicating the system's ability to maintain communication quality despite increased depth and distance.

The best performance was achieved at a salinity of 1.2, with a BER value of 3.72×10^{-43}, the lowest value recorded in this experiment. This indicates the highest signal stability and the lowest probability of error. All other values remained within a very low range without any system failure.

The results demonstrate that the system operated efficiently even with increased distance and depth, indicating that the salinity range used is not a critical factor under these conditions and that its impact remained limited compared to the effects of distance and depth.

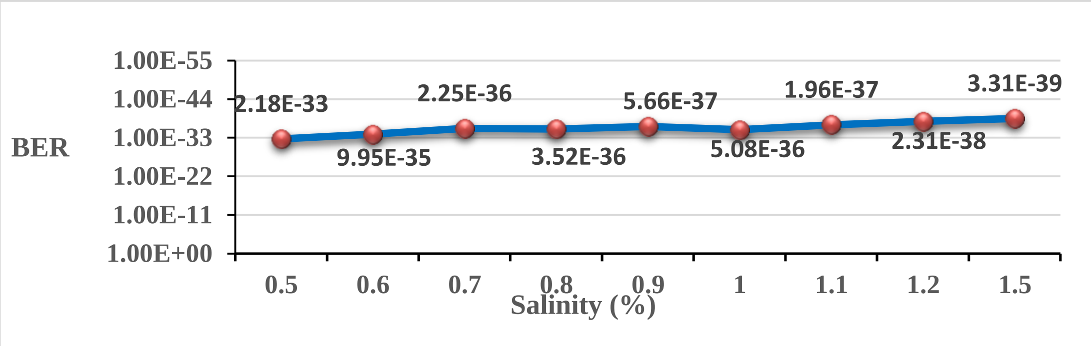


Figure 23: The figure illustrates the salinity limits at depths of 20m and horizontal distances of 50m under specific environmental conditions and their effect on BER.

The operating range for salinity was set in this test under the conditions of the Mosul Dam. Temperature was set to 25°Cbecause it is significantly lower than the temperatures experienced in southern locations, receiver/transmitter depths were fixed at 20 m, horizontal distance at 40 m, and outside angle at 68° . The salinity was altered over a range from 0.5 to 0.8 due to the Mosul Dam having low salinity water. The system operated at a very steady level for all salinity values and had a BER in a very good range. The bit error rate ranged from $10^{-}34$ and $10^{-}41$. The best performance was achieved at a salinity of 0.7, with a BER value of 1.13×10^{-41}, the lowest value in this experiment, indicating the highest signal stability and the lowest probability of error.

The results indicate that the salinity range used for the connector seal is within the safe operating limits of the system, as there was no breakdown in the connection or sharp rise in the BER value, confirming the system's ability to operate efficiently within this aqueous environment.

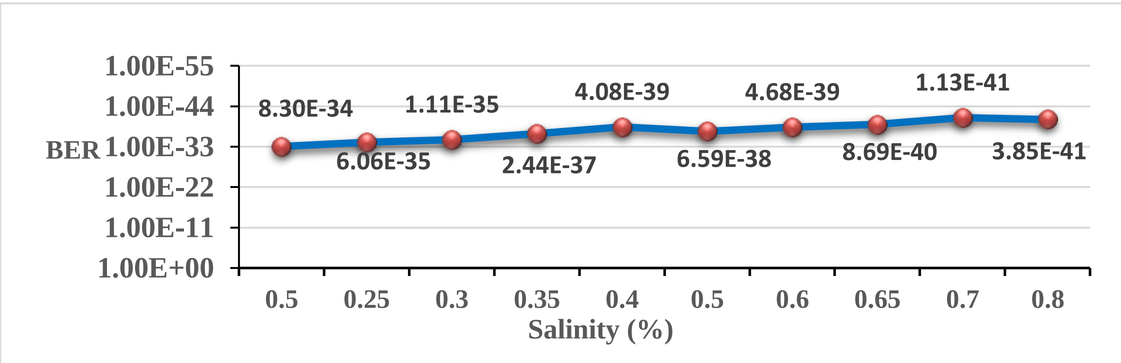


Figure 24: The diagram shows the salinity limit for depth of 20m at the horizontal distance of 40m under given ambient environment conditions and their impact on BER.

But, by extending the depth into 30 m and horizontal distance into 80 m in similar conditions of the conductor dam, we investigated the impact of salinity with salinity value of 0.5 to 0.8 while the temperature was set to be 25C and the external angle to be 68.

The results showed that the system maintained very good stability despite the increased depth and distance, with BER values remaining very low, within an approximate range of 10^{-33} to 10^{-41}.

The best performance was achieved at a salinity of 0.8, where the BER value reached 1.32×10^{-41}, and the lowest value in this test. This result indicates that the system did not experience failure or severe deterioration within the studied salinity range, even with the horizontal distance increased to 80 m.

Overall, the results suggest that the salinity of the conductor dam within this range is not a critical factor affecting system performance, while the effect of depth and distance remains the most important factor in determining the actual operating limits.

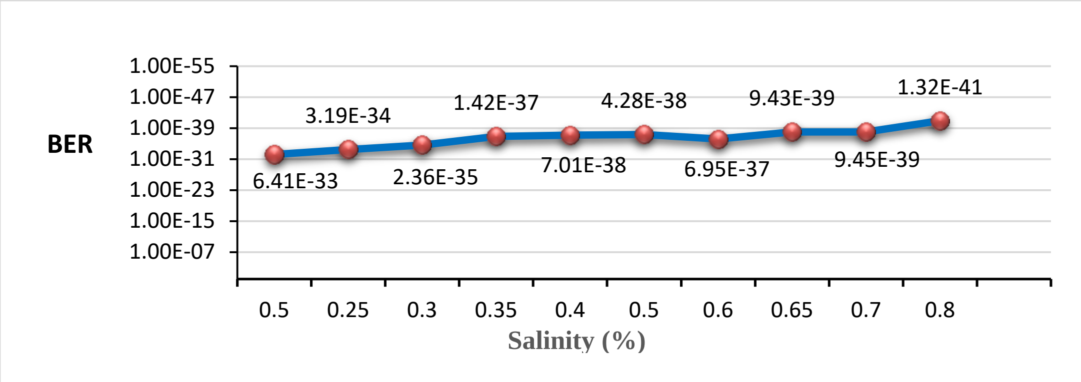


Figure 25: The figure illustrates the salinity limits at depths of 30m and horizontal distances of 80m under specific environmental conditions and their effect on BER.

Water flow limits

Having determined the boundaries for temperature and salinity for operation, the next variable studied was water flow, on the performance of the system of underwater optical communication. This is a significant variable because an increased flow rate or intensity will cause instability of the surrounding medium and stability of the optical path between receiver and transmitter. This aspect is very important in flood detection systems since increase in water flow is directly linked to the hydrological changes and chance of flooding. The impact of the variable water flow on the performance of system was measured against the BER value to establish the boundary at which communication was stable and the boundary where the system begins to fail or deteriorate. In the first test of water flow impact on Al-Kut Dam data, the transmitter and receiver were both placed at a depth of 10m and their horizontal separation at 30 m. Other factors were held constant at 30°C for temperature, 0.8 for salinity and the incident angle was 68°. The data for the flow of water were varied

From 300 m^3/s to 900 m^3/s to investigate the influence of the increasing water speed on the performance of underwater optical communication system. Results are showed that the system performed good quality under low speed, with the BER value of 10 at 300 m^3/s. Gradually, the BER value has been increasing with the speed from 10 at 400 m^3/s and approaching 1 at between 700 m^3/s and 900 m^3/s

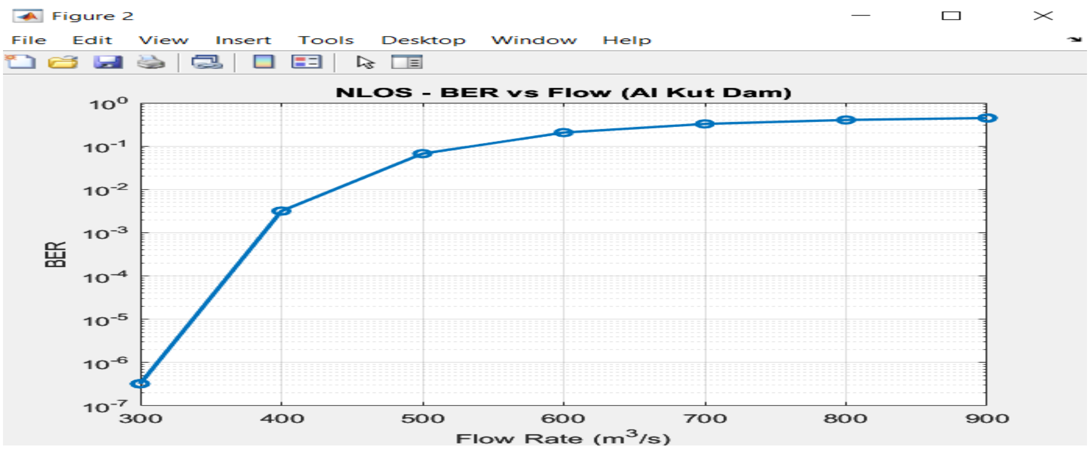


Figure 26: The diagram illustrates the impact of water current (flow) on the quality of communications at the Al-Kut Dam simulated using MATLAB (R2022b)

These results indicate that increased water flow leads to greater turbulence in the aqueous medium, causing increased scattering and loss of stability in the optical path between the transmitter and receiver. As can be concluded, the system can be considered stable at both low and medium flow values and its behavior starts deteriorating significantly at high flow values that might appear at flood or high runoffs at Al-Kut Dam.

In this test, the effect of water flow under conductor dam conditions was investigated. The depth of the transmitter and receiver was maintained at 20 m; horizontal distance was kept at 40 m; the temperature at25°C salinity at 0.6; external angle at 68. Flow rate was changed between 600 m^3/s and 2000 m^3/s in order to evaluate the system's capability at various flow rates.

Results: Excellent performance of the system at600 m^3/s BER is at around 10^{-12} and the connection is highly stable

. However, the BER value gradually increased with increasing flow rate, reaching approximately 10^{-3} at 900 m^3/s, then approximately 10^{-2} at 1000 m^3/s, and continuing to rise at higher flow rates, approaching 1 at rates exceeding 1500 m^3/s.

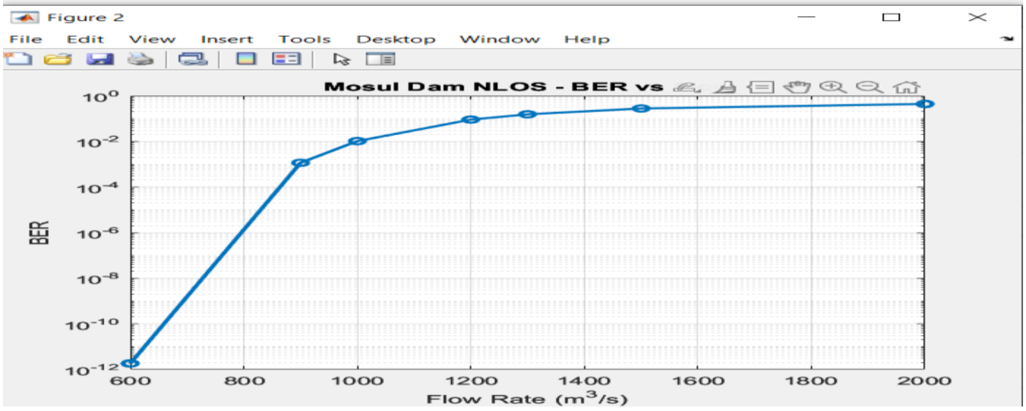


Figure 27: The diagram illustrates the impact of water current (flow) on the quality of communications at the Mosul Dam. simulated using MATLAB (R2022b)

These results indicate that increased water flow in the Mosul Dam leads to greater turbulence in the aqueous medium, increased scattering effects, and loss of photosystem stability, which directly impacts the BER value. Therefore, the system can be considered to operate efficiently at low and medium flow rates, while performance begins to gradually deteriorate at high flow rates associated with severe hydrological conditions or flooding.

System Performance Analysis under Different Water Types

The impact of absorption, scattering and optical attenuation on signal propagation through the water column were investigated by performing an analysis of system performance at various types of water, following an examination of: how design factors and environmental conditions influence the performance of underwater optical communications systems Factors that define the characteristics of aquatic environments such as suspended particulates, salinity, and turbidity have a large impact on the physical and optical characteristics of various aquatic environments and can create vastly different system performance and communication capabilities between various types of aquatic water. The different types of water chosen for this investigation are clear ocean water, harbor/coastal water, and are unique water types which provide each type with their own set of characteristics and also yield a unique level of system performance under specific conditions. Temperature, salinity, depth and distance between transmitter and receiver were given realistic values that would create realistic system performance for the particular type of water at its proper operating parameters.

Clear Ocean Water

A clean saltwater environment with little dispersion in water and small optical attenuation was simulated for the test. Temperature was maintained at 25°C and salinity at 0.5%. Transmitted and receiver depth were at 10m and horizontal distance at 40m. Optical attenuation was incremented from 0 to 18 dB. Because the BER values were extremely low, the results demonstrated that the system maintained great stability even with increasing attenuation. This suggests that clean water offers an ideal setting for the propagation of underwater optical signals. The reason for that lies in the reduced effect of absorption and dispersion of the described type of water on maintaining signal power throughout the optical channel.

Coastal Water

Similar as above example the coastal sea test used same range of optical attenuation, depths of transmitter and receiver were set to 10m, horizontal distance was 30m, temperature was20°C salinity was 1.0%.

BER performance start to decrease rapidly as optical attenuation goes up, which represents system performance decreased more comparing with clear water, and the reason why it is happened is because compared with clear water, plankton and dispersion in coastal water are both bigger and resulted in a higher degree of loss in the transmission..

Harbor Water

The case is within the environment of a port water area. It is one of the most challenging aquatic environments for underwater optical communications because of high turbidity, scattering and absorption. In this test, the depth of the transmitter and receiver were 8 m, the horizontal distance was 20 m, the temperature was 18°C, and the salinity was 1.5%.

The results showed rapid and clear degradation of the system performance as compared to the earlier cases. BER values increased significantly even for moderate attenuation levels, showing a clear loss of signal quality in the optical channel. The reason is that in this type of water there is a high concentration of suspended particles and turbidity which causes the increased absorption and scattering.

Comparative Analysis of Water Types

The comparison of different water types indicated that the system performance deteriorates gradually with the increase of turbidity and optical attenuation in the water medium. • Clear water system had the best performance and the lowest values of BER due to minimize optical absorption and dispersion while in contrast the port water has the worst performance due to the high value of optical loss on the optical channel. • The study result proved the importance of setting the correct values for both depth and horizontal distance parameters for every kind of water to perform an appropriate comparison between system performances due to the application of uniform values for all mediums may lead to loss of communication, errors or the failure of the system in some cases. • The BER analysis according to optical attenuation shows that the increase in the value of attenuation cause direct loss in the performance of the system since the receiving signal power decreases steadily leading to an increased in error rate and the stability of communication will be lost.

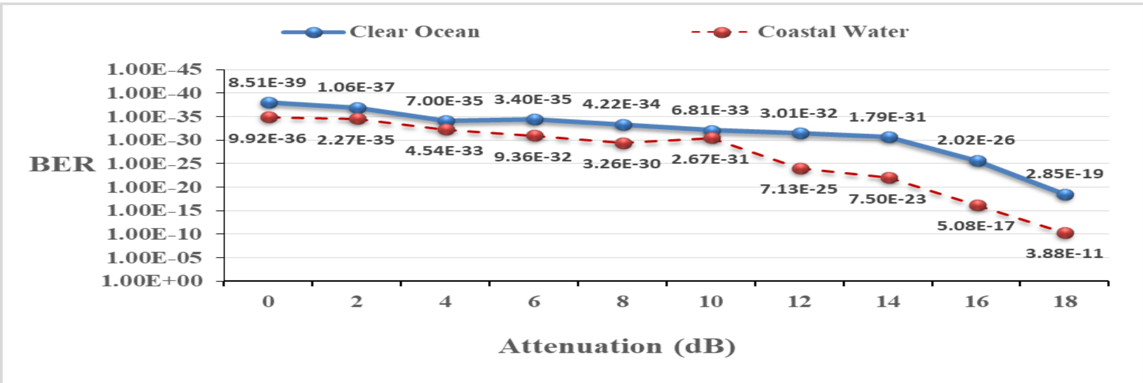


Figure 28 : Example demonstrating impact of attenuation over error rates with variation in media (type of water)

The obtained results show overall that water medium type strongly impact overall performance & application restrictions for UWOC systems.

This is because of the lower absorption and dispersion values in clear water, leading to better system performance and lower BER values. In high turbidity environments, the signal loss is higher and the quality of communication deteriorates significantly.

To further evaluate the robustness of the proposed system under varying environmental conditions, a comparative analysis was conducted between Mosul Dam and Al-Kut Barrage, as illustrated in Figure 29.

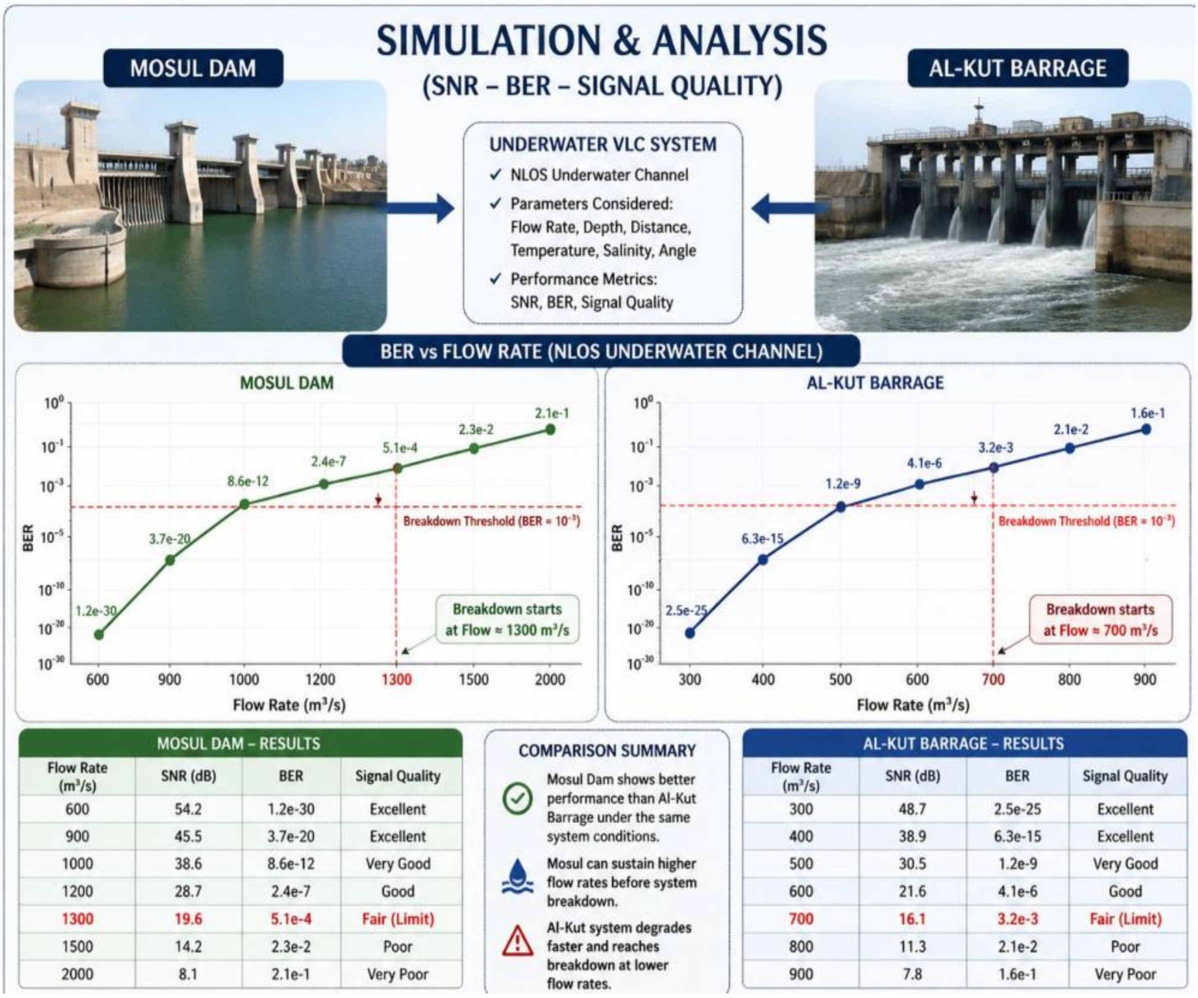


Figure 29 : presents a comprehensive comparison of system performance in terms of BER, SNR, and signal quality under different flow rate conditions for both locations.

COCLUSION

This study looked at the creation and assessment of an indirect communication channel-based underwater optical communication system (NLOS Underwater) for use in early flood detection and environmental monitoring. The system's performance was assessed using a range of simulations that considered design elements and environmental aspects that impact communication quality in an aquatic setting.

Simulation results showed that several factors directly affect the performance of underwater optical communication systems, most notably the depth of the transmitter and receiver, the horizontal distance between them, and the transmission angle, in addition to environmental conditions such as temperature, salinity, and water flow rate. It was found that any change in these variables causes a significant change in the bit error rate (BER) and the signal-to-noise ratio (SNR), thus affecting system stability and data transmission efficiency.

According to the study, maintaining communication stability depends on selecting the appropriate depth and horizontal distance. Over time, the aquatic environment's attenuation and dispersion values increase with depth or distance, weakening the signal and increasing the error rate. Nevertheless, up to a communication breakdown, the system was able to maintain steady performance within certain operating boundaries.

The results of the transmission angle calibration also showed that the outer angle of 68° worked better than the other angles tested, while the optimal interior angle for the NLOS channel was 0°. It was utilized for the remaining study experiments because it produced the highest SNR values and the lowest BER values.

Regarding environmental factors, the findings demonstrated that the effects of salinity and temperature varied according to the kind of aquatic habitat and the depth and distance values used. Due to lower salinity and more stable environmental conditions, which helped mitigate the effects of absorption and scattering inside the optical channel, the Mosul Dam environment performed marginally better than the Kut Dam environment.

Furthermore, the water flow study findings revealed that raising the flow rate causes a progressive decrease in system performance due to increased aquatic turbulence and instability of the optical signal channel. The system was discovered to approach its failure limit faster at the Kut Dam than at the Mosul Dam, indicating the major influence of water turbulence on the efficiency of underwater optical communication.

Analysis of the system's performance in various aquatic environments revealed that clear seawater performed best due to reduced light loss caused by low levels of suspended particles and other microorganisms. Conversely, in port waters, the system performed worst due to high turbidity, efflorescence, and absorption. This emphasizes how important aquatic environmental features are in establishing the stability and operational limitations of the system.

Overall, this study showed how beneficial it is to use optical communication systems underwater for flood detection and environmental monitoring applications, as long as the restrictions and operational parameters of the system are suitable for each environment.

ETHICAL DECLARATION

Conflict of interest: No declaration required. **Financing:** No reporting required. **Peer review:** Double anonymous peer review.

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