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Study on Transmission of Visible Light in Selected Water Bodies of Southwest Nigeria for Underwater Wireless Optical Communication

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ABSTRACT

A study on the transmission of visible light (400 nm-800 nm) in some selected natural water bodies of Southwest Nigeria was carried out via spectroscopy, and their salinity, total dissolved solids, and electrical conductivity were obtained. Samples of ten selected water bodies comprising rivers, lagoons, and the Atlantic Ocean were taken namely: River Ala, River Ogbese, River Kinira, River Apake, River Odo-Oru, River Odo-Eran, Epe Lagoon, Lagos Lagoon (Lekki Phase 1), Lagos Lagoon (Victoria Island) and the Atlantic Ocean. The absorption of light in them was measured using a spectrophotometer. From the results of the measurements, the rivers showed less conductivity, total dissolved solids, and salinity compared to the lagoons, and the Atlantic Ocean. The Atlantic Ocean gave the highest value. Also, there is varying optical attenuation with different wavelengths. At shorter wavelengths (blue light), there is higher absorbance with an increase in salinity compared to longer wavelengths (red light). At the infra-red end (750 nm – 800 nm), all the samples showed increased absorbance compared to the absorbance at red wavelength (700 nm). From the measurements, an optical beam of a wavelength of 650 nm was found most suitable for optical communication across these water bodies. The transmission was simulated at this wavelength for the water bodies using OptiSystem software linked with MATLAB at different data rates, and their performance was investigated in terms of received quality factor and bit error rate. The quality factor reduces with an increase in salinity, while the bit error rate increases with an increase in salinity.

Keywords: Absorbance, Salinity, Electrical Conductivity, Underwater Wireless Optical Communication, Quality Factor.

1 Introduction

Underwater Wireless Optical Communication (UWOC) has assumed great significance due to its wide application including research, and military operations. It is useful in communication in water (which is a difficult terrain for human beings), security, surveillance, and environmental monitoring for disaster prevention.

Water is an important necessity and a vital resource to man, animals, and plants. Water is used for several purposes: domestic use such as drinking, cooking, and washing, and for agricultural purposes [1]. There are various sources of water in the world. Some of these include rivers, lakes, oceans, streams, and lagoons. About two-thirds of the earth's surface is made up of water [2]. All the bodies of water on earth, such as oceans, lakes, rivers, etc., contain salt of varying concentrations which cause attenuation of light signals. Sea water contains about 35 parts per thousand of salts and is denser than freshwater. One of the most abundant salts in seawater is sodium chloride [3].

In UWOC, absorption and scattering affect the transmission of optical signals, which reduces the power and the effective communication range in the medium. Most water bodies are saline in nature with the limitations of absorption and scattering due to dissolved salts. The preferred range of wavelengths for transmission in particle-free sea water is the blue-green region (450 nm - 570 nm) because of low attenuation at these wavelengths [4]. However, when dissolved salt is present in the water, the attenuation increases at shorter wavelengths (blue-green) than at longer wavelengths (red). Over the years, researchers have been investigating factors that affect the performance of UWOC links.

In literature, some researchers have studied the transmission of optical signals in saline water and some natural water bodies. Authors of [5] measured the absorption coefficient of pure and saltwater in the visible and infra-red range at 15 discrete wavelengths. The temperature and salinity of the water were varied to study their effect on the absorption coefficient of liquid water. Their study revealed that the absorption coefficient of water is highly dependent on temperature in the near infra-red region than in the visible region except around 610 nm. The saltwater solution gave similar results for temperature dependence. An increase in salinity increases the absorption coefficient.

Authors of [6] studied the capability of UWOC links in the Bay of Bengal. Water samples were collected at different locations in the Bay of Bengal (harbor, coastal, and deep-water). The optical attenuation for the different types of water was determined. A numerical model was developed, and simulations of the seawater samples were done to obtain a communication range of 0.5m, 14m, and 35m in harbor, coastal, and deep-water locations respectively. Increasing the transmit power increases the communication range in the water.

Authors of [7] determined the extinction coefficient and transmittance of ocean water and shallow well water in Mombasa Kenya. The transmitted light intensities decrease exponentially with concentration in the two water bodies.

Authors of [8] showed how a message communicated with UWOC can be eavesdropped using a diffraction grating in municipal fresh water. It also showed that UWOC transmission is possible in the ultra-salty water of the Dead Sea.

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The authors of [9],[10] studied the effect of common table salt in water on the transmission of visible light in the wavelength range of 400 nm – 800 nm in different salt solutions of different concentrations ranging from 1g/100ml – 28g/100ml. The absorbance, conductivity, and total dissolved solids of the samples were measured. There is an increase in absorbance and conductivity with increased salt concentration. The absorbance is wavelength dependent with higher values at the blue end than at the red end of the spectrum with increased salt concentration. The performance of UWOC in the samples was also evaluated by simulation using OptiSystem software and showed that the achievable link distance reduced with increased salinity.

The author of [11] investigated the effect of salinity and turbidity in different salt concentrations (10 g/L - 40 g/L (representing the Red Sea salinity) via a white-LED transmitter. The received power decreased with link length and increase in salinity. The transmitted signals are more affected by turbidity than salinity. The transmission distance was limited to 60 cm due to turbidity. The white LED was able to send data at a maximum salinity value of 40 g/L.

Authors of [12] transmitted texts by Pulse Width Modulation (PWM) in an optical communication channel underwater at a wavelength of 532 nm. The salt concentrations were varied from 0 - 90% w/v ranging from clear water to turbid water. Results indicate that the attenuation coefficient is lower in a low concentration of sodium chloride like pure seawater while in turbid harbour water, a higher attenuation coefficient was obtained. The received power and signal-to-noise ratio was lower in the turbid harbour water compared to pure seawater.

Southwestern Nigeria falls within the rain forest belt of Nigeria with great fauna and flora. The people in this region are mainly of the Yoruba tribe and deal mainly in agriculture. In the northern part of this region are the western uplands, and in the southern part are lagoons and the Atlantic Ocean. Because of the uplands on the northern side, many rivers flow from the uplands towards the Atlantic Ocean. Most of these rivers are used mainly for agricultural, industrial, and commercial purposes.

The authors of [13] measured some water quality parameters of Ogbese River in Ondo State which is part of Southwest Nigeria such as electrical conductivity, pH values, total dissolved solids, etc., both during the dry season and wet season. The authors of [14] studied the pollution of Ogbese River in Ovia Northeast local government area of Edo State, Nigeria; and parameters such as pH, temperature, electrical conductivity, total dissolved solids, etc., were measured and analysed.

The authors of [1] assessed the seasonal surface water quality of the Ala River upstream in Akure, Ondo State of Nigeria. Some physicochemical parameters including pH, and total dissolved solids were measured and analysed. Authors of [15] studied the impact of environmental variables and processes of nutrient enrichment on the phytoplankton community at Epe Lagoon. Some physicochemical parameters including pH, total dissolved solids, and salinity were measured and analysed.

In this paper, the transmission of visible light in the waters of some selected rivers, lagoons, and the Atlantic Ocean in Southwest Nigeria was studied via spectroscopy. This kind of study via spectroscopy on these selected water bodies has not been carried out before in Nigeria. While measurements of salinity, electrical conductivity, and some other physiochemical properties of some of these water bodies have been done by some researchers for other purposes, however, the study of absorbance of these selected water bodies to visible light spectrum for optical communication purposes is still lacking. In this work, salinity, electrical conductivity, and total dissolved solids of these water bodies were also measured. Based on the absorbance measurements, this study helps to determine the most suitable wavelength for visible light communication across these selected natural water bodies of Southwest Nigeria at minimal attenuation. The performance of UWOC in them at this wavelength for different data rates was also investigated by simulation using OptiSystem software.

2 Properties of Water

2.1 Optical Properties

The two main optical properties of water which are inherent are absorption and scattering, and they are both dependent on wavelength. The irreversible loss of light intensity in water based on the refractive index of water and the spectral absorption coefficient is absorption [16]. Absorption of light in water is caused by the excitation of the water molecules and other dissolved particles when they are hit with photons of light [17]. The photons lose energy, which is converted into other forms [18].

Scattering is the deflection of light from its main path due to water molecules and suspended particles but with no change in energy [19],[20]. The particles might be comparable in size to the light wavelength leading to diffraction, or the particles might have a refractive index that varies from that of the water leading to refraction [21].

The attenuation coefficient c(λ) is the linear combination of the absorption coefficient, a(λ), and the scattering coefficient b(λ), as expressed in Eq. (1) [4].

$$c(\lambda) = a(\lambda) + b(\lambda) \tag{1}$$

2.1.1 Spectroscopy

A spectrophotometer measures the intensity of light relative to wavelength. It measures the absorbance and/or transmittance of light through a substance [22]. Absorbance (A) is expressed in Eq. (2) from Beer's law as,

$$A(\lambda) = \varepsilon(\lambda) l C \tag{2}$$

where ε is the molar absorptivity which depends on wavelength, l is the length of the path of light through the substance, and C is the concentration.

From [23], the transmittance is related to the absorbance by Eq. (3)

$$T(\lambda) = 10^{-A(\lambda)} \tag{3}$$

Absorption coefficient α(λ) is related to absorbance by Eq. (4) [24]

$$a(\lambda) = (\ln(10)) A(\lambda) \tag{4}$$

2.1.2 Underwater Wireless Optical Communication

(A) Underwater Optical Channel

Beer Lambert's law relates the transmitted optical power with respect to distance and attenuation in the medium which is wavelength dependent as expressed in Eq. (5).

$$P_r(d,\lambda) = P_o e^{-c(\lambda)d} \tag{5}$$

where P_o is the initial optical transmit power, and $P_r(d,\lambda)$ is the received optical power in the medium at distance d, λ is the wavelength, and c(λ) is the attenuation coefficient expressed in Eq. (1) [2].

(B) Quality (Q) Factor

Quality Factor (Q) is a function of the optical signal-to-noise ratio (OSNR) which provides a description of the receiver performance. The quality factor is a measure of how noisy a pulse signal is, and the eye pattern helps to evaluate the Q factor. A large Q factor means that the pulse is relatively free from noise. The Q factor is expressed in Eq. (6)

$$Q = \frac{I_1 - I_o}{\sigma_1 - \sigma_2} \tag{6}$$

I_1 is the 1-bit current value, I_o is the 0-bit current value, σ_1 is the standard deviation of the 1-bit current and σ_2 is the standard deviation of the 0-bit current [25],[26].

The logarithmic value of Q (in dB) is related to the OSNR by Eq. (7):

$$Q_{dB} = 20 \log \sqrt{OSNR} \sqrt{\frac{B_O}{B_E}} \tag{7}$$

where Q is the Q factor, B_O is the optical bandwidth of the receiver photodetector, and B_E is the electrical bandwidth of the receiver filter [26].

2.2 Physiochemical Properties

2.2.1 Salinity

The dissolved salt content in a body of water is salinity which is measured in kilogram of salt per liter of water equal to parts per thousand (ppt). Salinity is important in determining the chemistry of natural waters. Conductivity measures the ability of water to conduct electricity. Dissolved salts conduct electricity hence, conductivity increases as salinity increases [10]. Total dissolved solids (TDS) measure the organic and inorganic substances in a liquid often reported in parts per million. It is applied in the study of water quality for rivers, lagoons, and oceans.

The values of the salinity of some rivers in Southwest Nigeria are Osun River: 0.06 - 0.17 ppt [27]; Ogun River: 50 - 280 mg/L TDS [28]; Osse River: 0.13 – 0.37 ppt [29]. Seawater has average salinity of about 33 - 38 ppt [30].

2.2.2 Different Types of Open Water

There are four main types of open water. They are pure sea water, clear ocean water, coastal ocean water and turbid harbor. In pure sea water, absorption is the major limiting factor, which is the sum of absorption in pure water and absorption by salts like NaCl, $MgCl_2$, Na_2O_4, and KCl. The absorption in pure sea water is increased in the presence of salts and increases with increase in wavelength. Clear ocean water has a higher concentration of salts, mineral components, and organic matter that cause absorption and scattering [31].

Coastal ocean water has more dissolved particles such as water molecules, suspended particles, dissolved salts, mineral and organic matter, phytoplankton, chlorophyll, etc., which increased its turbidity, absorption, and scattering. Turbid harbor has the highest concentration of particles (both dissolved and in-suspension) and hence, the transmission of visible light in it is highly limited by absorption and scattering [3],[31].

3 Materials and Method

3.1 The Study Areas

The selected water bodies in Southwest Nigeria were taken from three different states: Ondo State, Oyo State and Lagos State. The water bodies are Rivers Ala and Ogbese in Ondo State; Rivers Kinira, Apake, Odo-Oru and Odo-Eran in Ogbomoso, Oyo State; and Epe Lagoon, Lagos Lagoon (Lekki Phase 1), Lagos Lagoon (Victoria Island), and the Atlantic Ocean in Lagos State.

One of the important rivers in the central and northern parts of Ondo State, Nigeria is Ogbese River. The source of the river is from Ayede-Ekiti in the western uplands of northern part of Ekiti State, flowing through Ayede-Ogbese town in Ondo State and empties into Ose River in the western part of Edo State. Ogbese town is about 10 km east of Akure which is Ondo State's Capital [13],[32]. River Ogbese is used for agricultural, industrial, and commercial purposes. Wood processing and food processing companies utilize water from the river daily. Ogbese community depends on the river for some other activities such as laundry and disposal of wastes. The use of fertilizers around the farmlands in the areas results in chemical substances in the river. Industrial wastes also flow into the river [13],[14].

Ala River flows from the Northwestern part of Akure to the Southeastern part. It is one of the main tributaries of Ogbese River. The length of the river is about 58 km, with about 14.8 km of it flowing through Akure township [1]. It flows through areas such as Obanla, Awule, Adegbola, Araromi, Oke-Ijebu, Alagbaka and Oba-Ile in Akure town. It also flows downstream to rural towns like Ajegunle, Owode, Ayetoro, Araromi and Ilado [1]. The river is used for irrigation, domestic use, and religious use.

Ogbomoso town is blessed with many rivers such as rivers Kinira, Apake, Odo-Oru and Odo-Eran (Animal River). Poor waste management results to the dumping of wastes along the river course causing great risk to public health. These rivers contain industrial wastes and domestic wastes. Kinira River contains detergents, sewage, and organic chemicals; Odo-Oru River contains plastics, garbage, detergents, sewage, and herbicides; Apake River contains detergents, plastics, garbage, pesticides, oil and cleaning solvents, and sewage while Odo-Eran River has a cow abattoir and both the blood and the animal dung are discharged into the river without treatment. Along the riverbanks, farmers plant maize, yam, and vegetables, and the fertilizers applied to the plants run off into the rivers [33].

Epe Lagoon is between Lekki Lagoon in the east and Lagos Lagoon in the west [34]. River Osun flows into the lagoon. The major source of livelihood for the people is fishing by making use of canoes and boats. Varieties of fish species such as croaker, bonga, catfish, sardine, shiny-nose, and tilapia are caught and taken to the Epe market (which is the biggest seafood market in Lagos) for sale. Aquatic species like crabs, prawns, shrimps, crayfish, turtles, lobsters, and snails are found in the lagoon. The vegetation surrounding the lagoon is swampy mangrove. The lagoon contains domestic wastes and industrial wastes [35].

Lagos Lagoon (Lekki Phase 1) is a large expanse of water between the Atlantic Ocean and Lagos State. The lagoon is utilized for fishing (which is the main occupation of the people living around the lagoon), washing cars, and other domestic uses. Domestic wastes are also being deposited at the shore. Sand-filling companies pack sand for plastering at the bank of the lagoon.

Lagos Lagoon (Victoria Island) lies between the Atlantic Ocean and Lagos State. The lagoon contains different species of fish and aquatic organisms that provide income and food for the people. These are caught with the aid of boats. It is in between two Islands: Victoria Island and Lagos Island. A channel links the northeast of the lagoon to the Lekki Lagoon passing by south of Epe town. Lagos Lagoon empties into the Atlantic Ocean at the Lagos Harbour [36]. There is urban and industrial waste in the lagoon due to wastewater entering the lagoon daily. River Ogun and a tributary of River Osun flow into it and contribute to the waste [37].

The Atlantic Ocean is the second largest among the world's five oceans: Pacific, Atlantic, Indian, Southern Antarctic, and Artic. It covers about 20% of the Earth's surface. The Ocean is bounded on the east by Africa and Europe, and on the west by the Americas. The salinity is between 33 ppt and 38 ppt varying with season and latitude. It is considered the saltiest major ocean. The effects of river inflow, evaporation and precipitation affect the salinity value. The electrical conductivity (EC) is between 3 - 6 S/m. The Atlantic Ocean provides lots of fish (various species) annually for human consumption and the industries [30]. The Atlantic Ocean in Nigeria is part of the North Atlantic and is a route for international trade in Nigeria. It is utilized for exportation and importation of goods and mineral resources (crude oil, cocoa, rubber, palm oil, groundnut, coal, timber) in Nigeria [38]. There are many beaches at the shore of the Atlantic Ocean in Nigeria, some are: Oniru beach, Eleko beach, Alpha beach, Bar beach, Elegushi beach and Kuramo beach. Table 1 shows the selected water bodies, their coordinates, and length. For some bodies, surface area is provided.

Table 1 Location coordinate, and length (or surface area) of the selected water bodies

River	**Coordinate**	**Length (or surface area)**
Ogbese	6.72° N, 5.43° E to 7.28° N, 6.57° E [32]	180 km [32]
Ala	7.26° N, 5.26° E [1]	58 km [1]
Kinira	8.15° N, 4.20° E [33]	4.8 km [33]
Odo-Eran	8.15° N, 4.24° E [33]	
Apake	8.13° N, 4.24° E [33]	
Odo-Oru	8.13° N, 4.27° E [33]	
Epe Lagoon	6.58° N, 3.98° E [34]	(243 km^2) [34],[15]
Lagos Lagoon (Lekki Phase 1)	6.50° N, 3.52° E [36]	Over 50 km [39], (6,354.7 km^2, combined) [36],[39]
Lagos Lagoon (Victoria Island)	6.45° N, 3.47° E [36]	
Atlantic Ocean (Elegushi Beach)	6.42° N, 3.61° E [40]	(85,133,000 km^2, worldwide) [30]

3.2 Collection of Water Samples

Samples of the ten water bodies were collected at Ayede-Ogbese (for River Ogbese), Oba-Ile Housing Estate (for River Ala), Kinira (Kinira River), Ori-Oke Grammar School (for Odo-Eran River), Oke-Elerin Baptist School (for Apake River), Ifeoluwa Baptist Church (for Odo-Oru River), Epe town (for Epe Lagoon), Lekki Phase 1 (for Lagos Lagoon), Victoria Island (for Lagos Lagoon), and Elegushi Beach (for Atlantic Ocean). Fig. 1 shows part of the Atlantic Ocean at Elegushi beach.

Collection of the water samples from the rivers, lagoons and the ocean were done during the rainy season. The water samples were taken with the aid of plastic bottles properly rinsed with clean water prior to being filled with water from the river, lagoon, or ocean. The samples were collected at about 30 cm below the water surface in the direction of the current flow and covered with a cap immediately. The samples were labeled to avoid the error of mixing up the samples during measurements and analysis.

Fig. 1 The Atlantic Ocean at Elegushi beach in Lagos

3.3 Measurement of the Physiochemical Parameters and Absorbance of the Water Bodies

3.3.1 Physiochemical Parameters

The measurements of the physiochemical parameters of the ten water bodies were carried out by utilizing an electronic water quality tester, EZ-9909SP. Some of the measured parameters are salinity, electrical conductivity, pH, and total dissolved solids (TDS).

For the measurements, the cap of the water quality tester was removed, and the device was turned on. The meter was calibrated prior to taking the measurements. The probe was rinsed with distilled water and dipped into the sample of the saline water for a few seconds. The water level covered the probe and the temperature sensor point making sure there was no air bubble trapped on the probe. The sample was stirred gently utilizing the probe to have a homogenous sample. The knob on the meter was pressed to change the mode of the readings (salinity, electrical conductivity, pH, total dissolved solids (TDS) and temperature). The result of the stable readings for each parameter was taken. After each reading, the probe of the water quality tester was rinsed with distilled water prior to taking a new measurement from another sample. When the readings were completed, the probe of the water quality tester was rinsed with distilled water and dried with clean cotton wool.

3.3.2 Measurement of Absorbance

The absorption spectra of the different water samples in the visible light range were determined using a VIS-721 Visible Light Spectrophotometer which is shown in Fig. 2 The measurement of each water sample was done with the aid of a pipette and placed in a cuvette-length of 10 mm. A reference cuvette contained distilled water while the sample cuvette contained the water samples. Each water sample's absorption spectrum in the wavelength range of 400 nm – 800 nm was obtained at intervals of 50 nm and recorded.

Fig. 2 The VIS-721 Spectrophotometer

3.4 Underwater Optical Communication Simulation

From the absorbance measurements, the most frequent wavelength with the least absorbance among the ten water bodies was determined. This wavelength was used in the simulation of underwater optical communication by OPTISYSTEM software linked with MATLAB. The absorption coefficients at this wavelength from the measured absorbance values for the ten water bodies were determined and used in the simulation for the ten water bodies. Simulation was performed at 10 kb/s, 100 kb/s, 1 Mb/s, 10 Mb/s, and 1 Gb/s data rates for transmit power of 30 mW and transmission distance of 100 cm. The results were assessed in terms of the received quality factor (Q) and the bit error rate (BER). The simulation parameters are shown in Table 2, and the design layout of the UWOC in OptiSystem is shown in Fig. 3.

Table 2 Parameters for the underwater optical communication simulation at 650 nm for the ten water bodies

Parameters	Values
Operating wavelength of Laser	650 nm
Power of Laser	30 mW
Bit rate of bit sequence generator	10 kb/s, 100 kb/s, 1 Mb/s, 10 Mb/s, and 1 Gb/s
Modulation	Non return to zero on-off keying (NRZ OOK)
Amplitude of NRZ pulse generator	1a.u.
Modulation index of amplitude modulator	1
Responsivity of photodetector	1 A/W
Dark current of photodetector	10 nA
Cutoff frequency of filter	0.75 x Bit rate
Transmission distance	100 cm

A continuous wave laser produces the light at the specified wavelength and then passes to a Mach-Zender optical modulator. A pseudo-random bit sequence (PRBS) is passed into an NRZ Pulse Generator whose electrical output is passed to the Mach-Zender modulator to optically modulate the light. The modulated light passes through the water body represented by the MATLAB component, and a PIN photodiode receives the light signals at the receiver which converts it to electrical signals. The signals are passed through a Gaussian filter, and then through a 3R regenerator for analysis by the Eye Diagram Analyzer.

4 Results and Discussion

4.1 The Results from the Salinity Measurement

The measured physiochemical parameters of the ten water bodies of Southwest Nigeria are shown in Table 3. From Table 3, the electrical conductivity, salinity, and TDS of the rivers and lagoons increase as the water bodies get closer to the Atlantic Ocean (which has the highest salinity). The rivers sampled in Ondo State, and Oyo State are in the hinterland, far away from the Atlantic Ocean; hence their salinity is lower than those of Lagos Lagoon and the Atlantic Ocean.

The TDS, pH, salinity, and electrical conductivity of River Ogbese obtained from this study lies within the range obtained by [13] for wet season, and by [14]. The domestic and industrial wastes contribute to the total dissolved solids in the water hence increasing the salinity and the conductivity. The electrical conductivity, pH, salinity, TDS, and temperature of River Ala conform to the results obtained by [1]. Akure is an urban city and has a larger population than Ogbese. This increases human activities (and attendant industrial wastes) along the river; hence, the TDS and salinity are higher than River Ogbese. Oba-Ile is at the downstream of the river hence will have a higher TDS value than the upstream.

Kinira River is at the outskirts of the city of Ogbomosho with less human activities hence the conductivity, TDS, and salinity are lower than the other rivers sampled in the city. Apake, Odo-Oru and Odo-Eran are in the city with lots of human and industrial wastes hence, their TDS, conductivity, and salinity increases.

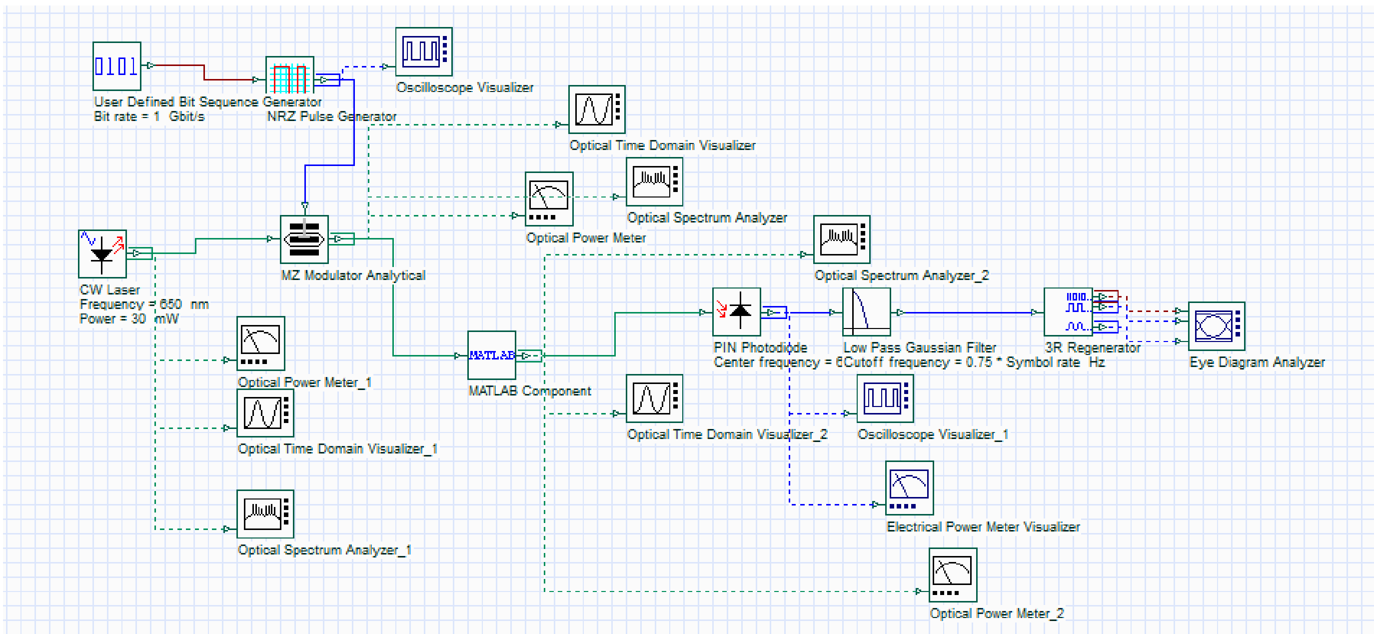

Fig. 3 Design layout of the UWOC in OptiSystem

Table 3 Measured parameters of the selected ten water bodies of Southwest Nigeria

State	Name of Water Body	Conductivity (μS/cm)	Temperature (°C)	TD Salt (ppt)	TDS (ppt)	Salt (%)	pH
Ondo	Ogbese River	185	23.8	0.093	0.094	0.00	5.86
	Ala River	297	23.1	0.149	0.150	0.01	5.90
Oyo	Kinira River	243	23.9	0.120	0.120	0.01	5.90
	Odo-Oru River	674	23.8	0.338	0.338	0.03	5.92
	Odo-Eran River	779	23.9	0.387	0.387	0.03	5.91
	Apake River	907	24.1	0.452	0.453	0.04	5.92
Lagos	Epe Lagoon	258	23.7	0.128	0.128	0.01	5.87
	Lagos Lagoon (Lekki Phase 1)	8090	23.8	4.050	4.130	0.41	5.89
	Lagos Lagoon (Victoria Island)	19750	23.9	9.920	11.30	1.08	5.87
	Atlantic Ocean	59400	23.7	30.00	37.00	3.70	5.96

Epe Lagoon has a somewhat low salinity, conductivity and TDS compared to those of some rivers in the hinterland despite having human activities such as fishing, farming and wastes from domestic use; and lying between Lagos Lagoon and Lekki Lagoon which are both close to the Atlantic Ocean. The values obtained in this study are close to the range of values obtained by [15]. This might be due to Osun River that empties into it which has low salinity, thereby diluting the Epe River and lowering its salinity and conductivity. The obtained salinity of the Atlantic Ocean is 37 ppt and electrical conductivity of 5.9 S/m which agrees with literature [30].

The variation of the electrical conductivity of the water bodies with the total dissolved salt and total dissolved solids is shown in Fig. 4.

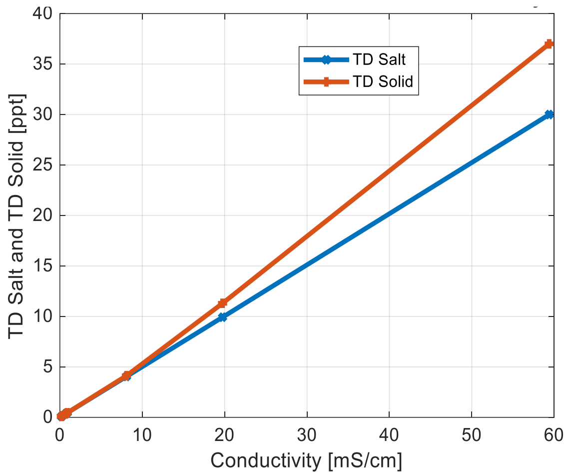

Fig. 4 Conductivity with TD salt and TD solid of the water bodies

There is a linear variation of the electrical conductivity of the water bodies with their total dissolved salts. This shows that any water body with high salinity will have high electrical conductivity and vice versa.

4.2 The Results of the Absorbance Measurement

The results of the measured absorbance within the visible wavelengths of 400 nm – 800 nm for the ten water samples are shown in Fig. 5 and Fig. 6. The rivers (Odo-Eran, Odo-Oru, Apake and Kinira in Oyo State; and Ala and Ogbese in Ondo State) have lower absorbance between 400 nm – 800 nm than the lagoons and the Atlantic Ocean in Lagos State, except Epe Lagoon.

In Fig. 5, River Apake has the highest absorbance, while the absorbance values of Odo-Eran, Odo-Oru, Ala, Epe, and Kinira reduces in this order with River Ogbese in Ondo State having the least absorbance which conforms to their salinity values.

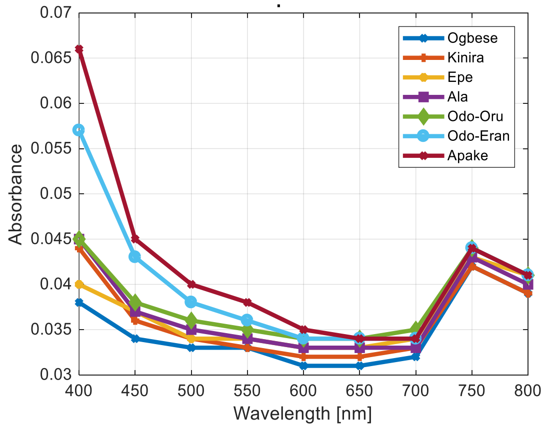

Fig. 5 Plot of the absorbance of the water bodies of Ogbese, Kinira, Epe, Ala, Odo-Oru, Odo-Eran, and Apake between 400 nm – 800 nm

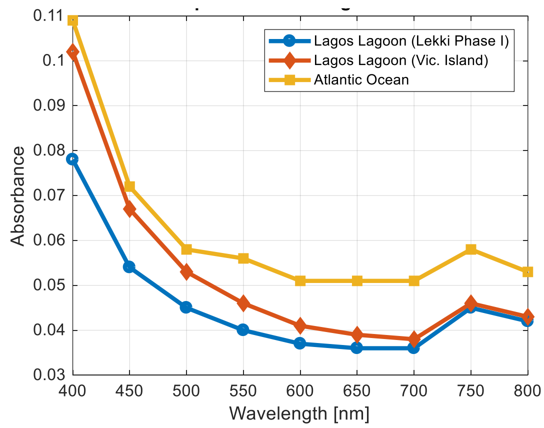

Fig. 6 Plot of the absorbance of Lagos Lagoon (Lekki Phase I and Victoria Island), and the Atlantic Ocean between 400 nm – 800 nm

For the lagoons and the Atlantic Ocean in Lagos State (Fig. 6), Epe Lagoon has the least absorbance, followed by Lagos Lagoon (Lekki Phase 1, Victoria Island) while the Atlantic Ocean has the highest absorbance with the corresponding highest salinity.

The absorbance of all the water bodies is higher at the shorter wavelengths of 400 nm –500 nm (violet–blue light) and decreases towards the longer wavelengths of 700 nm (red light). Between 700 nm – 750 nm (towards infra-red), the absorbance increases and then reduces between 750 nm – 800 nm. This implies that a lot of information would be lost if the shorter wavelengths are utilized for the transmission of signals in these water bodies unless there is an improvement in the transmission. Signal transmission using red light through the rivers, lagoons, and the ocean in the study will yield better reception at the receiver.

Fig. 7 shows the average absorbance with electrical conductivity of the water bodies. The average absorbance values for the water bodies were taken over the entire light spectrum of measurement (400 nm – 800 nm). The horizontal axis is in logarithmic scale. The rivers have lower average absorbance compared to the lagoons, and the highest is Atlantic Ocean.

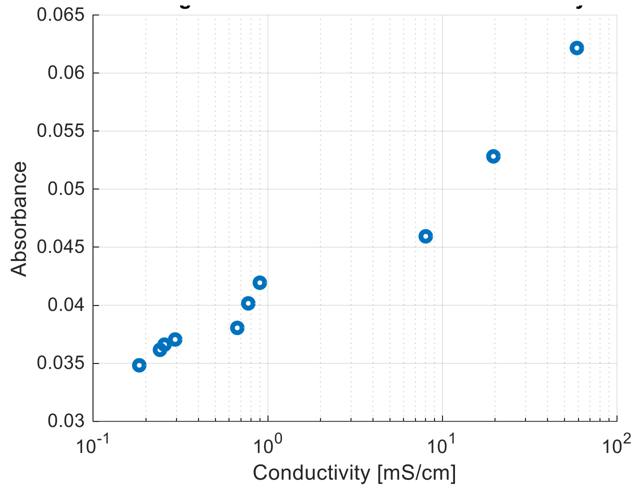

Fig. 7 Average absorbance with electrical conductivity of the ten water bodies. The horizontal axis is in logarithmic scale

4.3 Performance of the Underwater Visible Light Communication Simulation

Considering Fig. 5 and Fig. 6, all the water bodies have minimum absorbance between wavelengths of 600 nm and 700 nm. Four of them have from 600 nm – 650 nm, two of them have from 650 nm – 700 nm, and three of them have from 600 nm – 700 nm, while one of them has from 700 nm. Considering the wavelength with the least absorbance that is most frequently common among all the ten water bodies, it is found to be 650 nm which is away from green light but close to red light. Therefore, an optical beam of a wavelength of 650 nm would be suitable to use for optical communication in all the ten water bodies studied. This value was then used in the underwater visible light communication simulation described in Section 3.4.

Fig. 8 shows the pseudo-random bit sequence (PRBS) from the NRZ Pulse Generator in time domain at the transmitter side for Lagos Lagoon (Victoria Island) at 10 Mb/s, while Fig. 9 shows the same PBRS in time domain from the PIN photodiode receiver after covering 100 cm in the water. The figure shows that noise has been added to the signal with a reduction in signal amplitude. Fig. 10 shows the eye diagram of the detected PBRS signal after reception with a quality factor of 52.354.

Results of the simulation for the ten water bodies in terms of received quality factor (Q) and bit error rate (BER) at 10 kb/s, 100 kb/s, 1 Mb/s, 10 Mb/s, and 1 Gb/s data rate for transmit power of 30 mW and transmission distance of 100 cm are shown in Table 4 and Table 5.

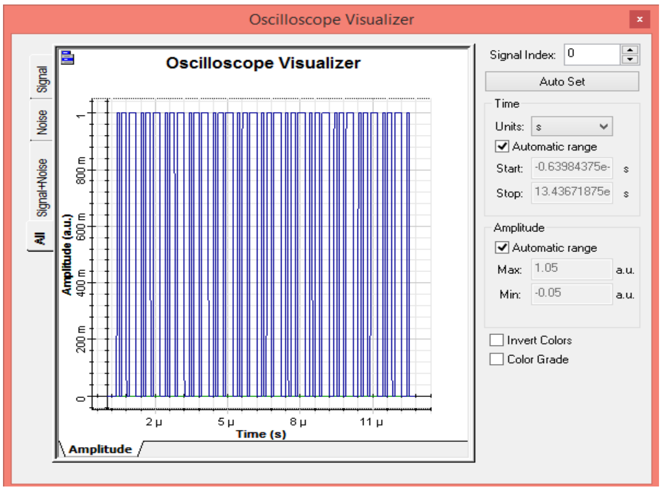

Fig. 8 The PRBS from the NRZ Pulse Generator in time domain at the transmitter side for Lagos Lagoon (Victoria Island) at 10 Mb/s

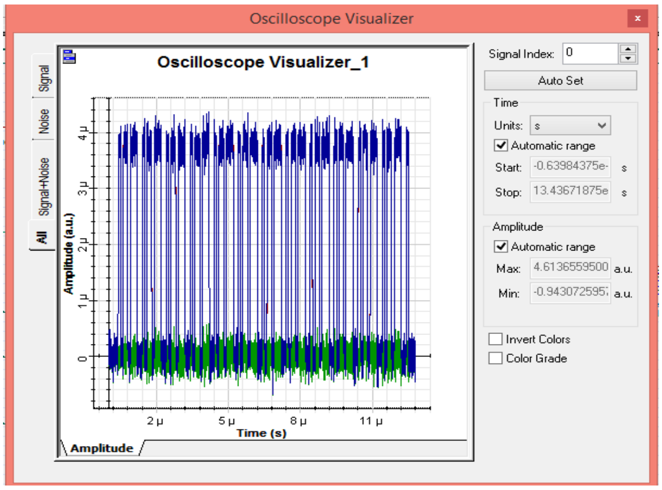

Fig. 9 The PBRS of Fig. 8 in time domain after the PIN photodiode receiver

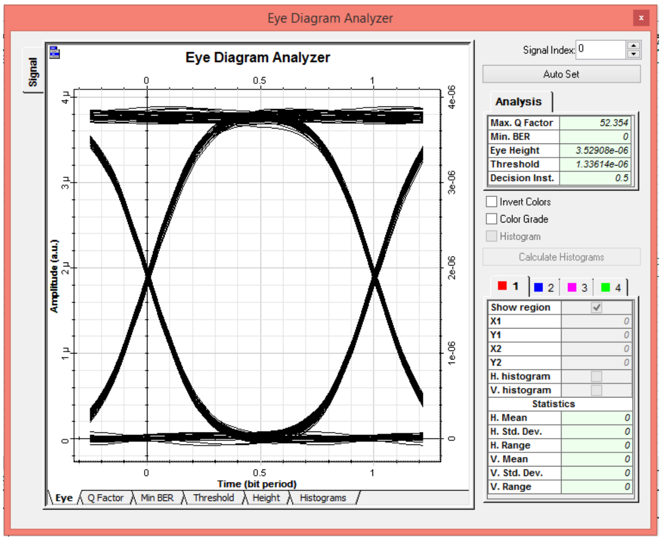

Fig. 10 Eye diagram of the detected PRBS of Fig. 8 after reception

Table 4 UWOC Simulation results at 650 nm for the ten water bodies (10kb/s – 1Mb/s)

Water Body	10 kb/s		100 kb/s		1 Mb/s	
	Q	BER	Q	BER	Q	BER
Ogbese River	341.546	0	333.212	0	326.364	0
Kinira River	342.058	0	334.731	0	292.057	0
Epe River	340.078	0	327.185	0	294.617	0
Ala River	342.796	0	324.474	0	277.686	0
Odo-Oru River	340.96	0	323.34	0	266.794	0
Odo-Eran River	342.158	0	321.479	0	262.932	0
Apake River	340.594	0	314.167	0	266.679	0
Lagos Lagoon (Lekki Phase 1)	341.124	0	313.763	0	232.961	0
Lagos Lagoon (Victoria Island)	339.687	0	262.48	0	143.773	0
Atlantic Ocean	89.745	0	30.742	7.78×10^{-208}	10.282	4.23×10^{-25}

Table 5 UWOC Simulation results at 650 nm for the ten water bodies (10 Mb/s & 1 Gb/s)

Water Body	10 Mb/s		1 Gb/s	
	Q	BER	Q	BER
Ogbese River	189.625	0	32.33	1.33×10^{-229}
Kinira River	172.527	0	24.115	8.57×10^{-129}
Epe River	164.186	0	18.446	2.72×10^{-76}
Ala River	176.746	0	18.263	8.00×10^{-75}
Odo-Oru River	152.512	0	14.928	1.07×10^{-50}
Odo-Eran River	161.209	0	15.365	1.41×10^{-53}
Apake River	134.805	0	14.114	1.55×10^{-45}
Lagos Lagoon (Lekki Phase 1)	92.182	0	9.056	6.71×10^{-20}
Lagos Lagoon (Victoria Island)	52.354	0	5.035	2.37×10^{-7}
Atlantic Ocean	3.055	1.1×10^{-3}	0	1

For each water body, the quality factor of the received data reduces at higher data rates than at lower data rates. Also, the quality factor reduces with an increase in absorbance which depends on salinity. For all the water bodies at 10 kb/s – 10 Mb/s, the BER is zero except for the Atlantic Ocean. At 1 Gb/s, the BER increases with an increase in salinity, and for the Atlantic Ocean at this rate, the quality factor is zero and the BER is 1 indicating no received data. The quality factor and BER suffer more in the ocean and the lagoons than in the rivers due to the relatively higher absorbance of the ocean and the lagoons even at the 650 nm wavelength. It will be difficult to transmit at relatively low power in the Lagos lagoons for a data rate of 1 Gb/s and above, and extremely difficult to transmit at relatively low power in the Atlantic Ocean for a data rate of 10 Mb/s and above.

5 Conclusions

This paper investigated the transmission of visible light (400 nm – 800 nm range) in ten selected water bodies (rivers, lagoons, and the Atlantic Ocean) of Southwest Nigeria via spectroscopy for underwater wireless optical communication. Only attenuation due to absorption was considered. From previous studies, in pure water, blue light (having the least attenuation) is ideal for transmission. However, this study revealed that the absorbance of these water bodies to visible light is wavelength-dependent. It increases at shorter wavelengths (blue-green) than at longer wavelengths (red). The rivers have lower electrical conductivity, salinity, and absorbance compared to the lagoons and the Atlantic Ocean. As the salinity of the water bodies increases, their electrical conductivity increases; and the absorbance is more pronounced on the blue light than the red light. This implies that in the water bodies, blue light is not ideal for optical signal transmission but rather light of longer wavelengths. The study also helped to determine the most suitable wavelength for transmission of visible light signals for underwater optical communication purposes across these selected water bodies of Southwest Nigeria. From the absorbance measurements, an optical beam of a wavelength of 650 nm was found most suitable. Transmission was simulated at this wavelength for the water bodies and their performance was investigated in terms of received quality factor and bit error rate. The results obtained from this work will be useful in setting up UWOC links in these selected water bodies.

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Conflict of Interest

The authors declare that there is no conflict of interest.

References

[1] Ayeni, A.O., Balogun, I.I. and Soneye, A.S.O., 2011. Seasonal assessment of physico-chemical concentration of polluted urban river: a case of Ala River in Southwestern-Nigeria. *Research Journal of Environmental Sciences*, *5*(1), p.22.

[2] Shen, C., Guo, Y., Oubei, H.M., Ng, T.K., Liu, G., Park, K.H., Ho, K.T., Alouini, M.S. and Ooi, B.S., 2016. 20-meter underwater wireless optical communication link with 1.5 Gbps data rate. *Optics express*, *24*(22), pp.25502-25509.

[3] Gabriel, C., Khalighi, M.A., Bourennane, S., Léon, P. and Rigaud, V., 2012, October. Investigation of suitable modulation techniques for underwater wireless optical communication. In *2012 International Workshop on Optical Wireless Communications (IWOW)* (pp. 1-3). IEEE.

[4] Han, X., Peng, Y., Zhang, Y., Ma, Z. and Wang, J., 2015. Research on the attenuation characteristics of some inorganic salts in seawater. *Journal of the European Optical Society-Rapid publications*, *10*, pp. 15045-1-5.

[5] Pegau, W.S., Gray, D. and Zaneveld, J.R.V., 1997. Absorption and attenuation of visible and near-infrared light in water: dependence on temperature and salinity. *Applied optics*, *36*(24), pp.6035-6046.

[6] Sathyaram, V., Prince, S. and Vedachalam, N., 2018. A study on underwater optical wireless communication link capability in the Bay of Bengal. *Ocean systems engineering*, *8*(1), pp.33-39.

[7] Mogunde, C. and Mosiori, C.O., 2018. Transmittance and Extinction Coefficient of Sea and Well-Water in Mombasa County, Kenya. *Traektoriâ Nauki= Path of Science*, *4*(10), pp.3001-3005.

[8] Shaboy, D., Rockban, D. and Handelman, A., 2018. Tapping underwater wireless optical communication in pure water and natural Dead-Sea ultra-high-salinity water by diffraction grating. *Optics Express*, *26*(23), pp.29700-29711.

[9] Ojediran O.A., Ponnle A.A. and Oyetunji S.A., 2021, October. Attenuation effect of saline water on performance of underwater wireless optical communication within the visible light range, In 2021 *SEET Annual Conference of Federal University of Technology*, Akure, Nigeria, (pp. 472 – 489).

[10] Ojediran, O.A., Ponnle, A.A. and Oyetunji, S.A., 2022. Experimental study on transmission of visible light in table salt water and effect on underwater wireless optical communication. *European Journal of Electrical Engineering and Computer Science*, *6*(2), pp.25-32.

[11] Alatawi, A.S., 2022. A Testbed for Investigating the Effect of Salinity and Turbidity in the Red Sea on White-LED-Based Underwater Wireless Communication. *Applied Sciences*, *12*(18), p.9266.

[12] Adnan, S.A., Hassan, H.A., Alchalaby, A. and Kadhim, A.C., 2021. Experimental study of underwater wireless optical communication from clean water to turbid harbor under various conditions. *International Journal of Design & Nature and Ecodynamics*, *16*(2), pp.219-226.

[13] Akinbile, C.O. and Omoniyi, O., 2018. Quality assessment and classification of Ogbese river using water quality index (WQI) tool. *Sustainable Water Resources Management*, *4*, pp.1023-1030.

[14] Orjiekwe, C.L., Dumo, D.T. and Chinedu, N.B., 2013. Assessment of water quality of Ogbese River in Ovia North-East Local Government area of Edo State, Nigeria. *International Journal of Biological and Chemical Sciences*, *7*(6), pp.2581-2590.

[15] Akagha, S.C., Nwankwo, D.I. and Yin, K., 2020. Dynamics of nutrient and phytoplankton in Epe Lagoon, Nigeria: possible causes and consequences of reoccurring cyanobacterial blooms. *Applied Water Science*, *10*(5), pp.1-16.

[16] Gabriel, C., Khalighi, M.A., Bourennane, S., Léon, P. and Rigaud, V., 2013. Monte-Carlo-based channel characterization for underwater optical communication systems. *Journal of Optical Communications and Networking*, *5*(1), pp.1-12.

[17] Sui, M., Yu, X. and Zhang, F., 2009, February. The evaluation of modulation techniques for underwater wireless optical communications. In *2009 International Conference on Communication Software and Networks* (pp. 138-142). IEEE.

[18] Elamassie, M., Miramirkhani, F. and Uysal, M., 2018, May. Channel modeling and performance characterization of underwater visible light communications. In *2018 IEEE International Conference on Communications Workshops (ICC Workshops)* (pp. 1-5). IEEE.

[19] Jamali, M.V., Khorramshahi, P., Tashakori, A., Chizari, A., Shahsavari, S., AbdollahRamezani, S., Fazelian, M., Bahrani, S. and Salehi, J.A., 2016, May. Statistical distribution of intensity fluctuations for underwater wireless optical channels in the presence of air bubbles. In *2016 Iran Workshop on Communication and Information Theory (IWCIT)* (pp. 1-6). IEEE.

[20] Jasman, F. and Green, R.J., 2013, October. Monte Carlo simulation for underwater optical wireless communications. In *2013 2nd International Workshop on Optical Wireless Communications (IWOW)* (pp. 113-117). IEEE.

[21] Kumar S., Prince S., Aravind J.V., and Kumar S.G., 2019. Analysis on the effect of salinity in underwater wireless optical communication. *Marine Geo-resources and Geo-technology*, *38*(3), pp.1-11.

[22] Atascientific (2020) *Understanding spectrometry and Spectroscopy*, *ATA Scientific*. Available at: https://www.atascientific.com.au/spectrometry/ (Accessed: 29 August 2023).

[23] Al-Azzawi, Z.M., Abdulzahra, N.Z. and Hammood, I.H., 2014. Optical Properties of Tap Water Purity using He-Ne Laser with Different Power Density. *Al-Nahrain Journal of Science*, *17*(3), pp.99-107.

[24] Hu, C., Muller-Karger, F.E. and Zepp, R.G., 2002. Absorbance, absorption coefficient, and apparent quantum yield: A comment on common ambiguity in the use of these optical concepts. *Limnology and Oceanography*, *47*(4), pp.1261-1267.

[25] Stotts, L.B., 2017. Eye diagram and its interpretation. John Wiley and Sons Inc., New Jersey, USA.

[26] Antony, T. and Gumaste, A., 2002. *DWDM network designs and engineering solutions*. Cisco Press, USA.

[27] Anifowose, A.J. and Oyebode, A.W., 2019. Studies on heavy metals contents of Osun River at the pre-urban settlement and across Osogbo City, Nigeria. *Journal of Taibah University for Science*, *13*(1), pp.318-323.

[28] Oketola, A.A., Osibanjo, O., Ejelonu, B.C., Oladimeji, Y.B. and Damazio, O.A., 2006. Water quality assessment of River Ogun around the cattle market of Isheri, Nigeria. *Journal of Applied Sciences*, *6*(3), pp.511-517.

[29] Osagie, E. and Fidelia, A., 2014. Water Quality Assessment of Osse River, Edo State, Nigeria, Using Some Physico-Chemical Parameters. *Nigerian Journal of Life Sciences (ISSN: 2276-7029)*, *4*(1), pp.153-174.

[30] Britannica, T., 2021. Editors of Encyclopedia. Atlantic Ocean. *Encyclopedia Britannica*.

[31] Ponnle, A.A., Ojediran, O.A. and Oyetunji, S.A., 2022. An alternative experimental method for determination of light beam attenuation coefficient in underwater wireless optical communication. *European Journal of Electrical Engineering and Computer Science*, *6*(3), pp.19-26.

[32] Okoli, C.S., Ojo, S.I.A. and Oguntuase, A.M., 2009. Modelling of Sediment Transport Capacities of Ogbese and Owena Rivers in SW Nigeria. *Advanced Materials Research*, *62*, pp.786-796.

[33] Oladeji, O. and Adelowo, F., 2016. The impacts of human activities of Ogbomosho river–causes, effects and role of

an individual (Ogbomosho residents) in prevention of water pollution. *Environmental Science*, *12*(8), pp.1-8.

[34] Olukolajo, S.O. and Hillary, E.C., 2012. Species diversity and growth pattern of the fish fauna of Epe Lagoon, Nigeria. *Journal of Fisheries and Aquatic Science*, *7*(6), pp.392-401.

[35] Travelwaka (2021) *Epe Fish Market – the biggest fish market in Lagos*, *TravelWaka*. Available at: https://www.travelwaka.com/epe-fish-market-the-biggest-fish-market-in-lagos/ (Accessed: 29 August 2023).

[36] Okusipe, O.M., 2003. Lagos Lagoon coastal profile: Information database for planning theory. Department of Urban and Regional Planning, University of Lagos, Lagos, Nigeria.

[37] Aina Adeogun, Professor of Aquatic Toxicology (2020) *How we learnt more about dangerous pollutants in lagos lagoon*, *The Conversation*. Available at: https://theconversation.com/how-we-learnt-more-about-dangerous-pollutants-in-lagos-lagoon-139987 (Accessed: 29 August 2020).

[38] Abuta, C.M.-A. (2018) *The Atlantic Ocean as a nigerian trade route*, *Make Heritage Fun!* Available at: http://www.makeheritagefun.com/atlantic-ocean-nigerian/?amp=1 (Accessed: 29 August 2023).

[39] Tata, H., Nzelibe, I.O., and Faneye, A.J., 2019. Bathymetric mapping for safe navigation: A case study of part of Lagos Lagoon. *Afr. Sch. J. Environ. Des. Constr. Mgt.(AJECM)*, *14*, pp.1-13.

[40] (No date a) *Elegushi beach, postal code, GPS coordinates, Lekki, Lagos 550104 Nigeria - tripexpress.com*. Available at: https://www.tripexpress.org/attraction-elegushi-beach-10081994/ (Accessed: 29 August 2023)