Optical properties of Iraqi waters

Samar al dubagh **Ziad al dahan** **Asmahan asaad**

Baghdad university **Nahrain university** **Baghdad university**

Abstract:

The optical properties of Tigris, Euphrates, and Shat al Arab studied in this research. The optical properties of water studied in this research are absorption, transmission, reflection, refractive index, absorption coefficient, scattering coefficient, and the attenuation of optical beam passing through the water samples. The optical properties were measured in the visible range (470-600) nm by using the spectrophotometer. Results of research show that there are differences in the values between the samples and there are two area of maximum and two area of minimum in all properties value.

Key words: optical properties, water, spectrophotometer

الخلاصة

تم في هذا البحث دراسة الخواص البصرية لنهر دجلة والفرات وشط العرب . الخواص البصرية للماء تضمنت فحص الامتصاصية، الانعكاسية، معامل الانكسار، معامل الامتصاص، معامل الاستطارة والتوهين للحزمة الضوئية المارة من خلال عينات الماء. تم قياس الخواص البصرية ضمن المدى المرئي للطيف البصري (470-600) نانو متر بواسطة جهاز المطياف البصري. أظهرت النتائج اختلاف في القيم للنماذج المفحوصة وهناك منطقتان للقيمة العظمى ومنطقتان للقيمة الصغرى لكل خواص الماء للنماذج المفحوصة.

الكلمات المفتاحية : الخواص البصرية ، الماء ، المطياف البصري

1- Introduction :

Water is one of the most important molecules on Earth, which makes our planet different from other known celestial bodies. Water covers about 70% of the surface of Earth, mostly as saltwater in the ocean (97%). Some is fresh water in rivers and lakes; some is in the form of ice or vapor.
Natural waters can be of great purity, e.g. deep sea waters. Natural waters have dissolved organic or inorganic materials as well as suspended particles. These materials have their own characteristic absorption and scattering properties. [1]

2- theory

2-1 Optical properties of water:

In order to estimate the attenuation of light, we need to understand the nature of the optical properties of the medium. Optical Properties of natural waters are broadly classified into Inherent Optical Properties (IOP) and Apparent Properties (AOP) .Inherent properties are those that are dependent only on the medium, while Apparent Optical properties depend on both the medium as well as the ambient light [2]. The two main Inherent Optical Properties are spectral absorption coefficient a(λ) and spectral scattering coefficient b(λ). Beam attenuation coefficient and single-scattering albedo are other IOPs.

Inherent properties of water like scattering and absorption are motivated by the water and its constituents. Natural waters contain particles with sizes ranging from water molecules of size ~0.1nm to small organic molecules ~1 nm, large organic molecules of size ~10nm to viruses of size ~100nm, bacteria of size ~1μm, phytoplankton size range between 1μ to 200 μm etc. Traditionally natural waters are divided into dissolved and particulate matter which is either has organic or inorganic origins. Every particle in water contributes in some way to it optical properties.[4]

Seawater is a complex mixture of dissolved substances, organic matter, living organisms, and water molecules themselves all of which contribute to its optical properties.[5]

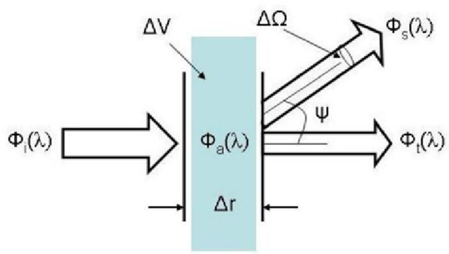

Fig. 1 geometry used to define inherent optical properties [3]

Our interest revolves around the spectral absorption coefficient a(λ) and spectral scattering coefficient b(λ), since these are the main sources responsible for attenuation of light. The illustration in Figure (1) will give a good start to our approach.

This case is considered under the assumption that the inelastic scattering occurs for monochromatic light. The spectral absorptance A(λ) is the fraction of the incident power that is absorbed within the water volume [3].

$$A(\lambda) = \frac{\phi_a}{\phi_i} \ldots\ldots\ldots\ldots (1)$$

Likewise the spectral scatterance B(λ) is the fraction of the incident power that is scattered.

$$B(\lambda) = \frac{\phi_s}{\phi_i} \text{..................} \quad (2)$$

The volume of water considered is of thickness Δr, hence the spectral absorption coefficient a(λ) is defined as:

$$a(\lambda) = \lim_{\Delta r \to 0} \frac{A(\lambda)}{\Delta r} \ldots\ldots \quad (3)$$

And the spectral scattering coefficient b(λ) is:

$$b(\lambda) = \lim_{\Delta r \to 0} \frac{B(\lambda)}{\Delta r} \text{..........} \quad (4)$$

2-2 Absorption:

The absorption coefficient of natural water is the fundamental IOP. It is important to understand and quantify the value of the absorption coefficient that would enable us to estimate the light absorbed by the medium.

The absorption by water itself is known, however the absorption due to various dissolved particles need to found. The concentration of these dissolved particles is variable. The spectral absorption of water is a combination of the absorption by pure sea water, phytoplankton, detritus and Colored Dissolved Organic Matter (CDOM).

$a(\lambda)=a_w(\lambda)+a_{chl}(\lambda)+a_{CDOM}(\lambda)+a_{detritus}(\lambda)$ ….. (5)

1 Absorption by pure sea water $a_w(\lambda)$
2 Absorption by phytoplankton $a_{chl}(\lambda)$
3 Absorption by CDOM $a_{CDOM}(\lambda)$
4 Absorption by Organic Detritus $a_{detritus}(\lambda)$

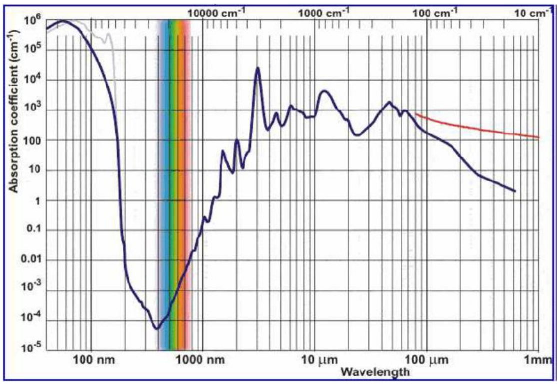

Fig. 2 Absorption coefficient of water.

2-3 Scattering:

Scattering is the process in which light energy in the form of a photon is redirected spatially from the forward propagating path due to interaction with molecules or particles.

Unlike absorption, the photon is not converted to another form of energy in a scattering event. Scattering can be divided into two types: Rayleigh scattering, which occurs for small particles with radius r <<λ, and Mie scattering, which occurs for larger particles with radius r ≈ λ and larger. A fundamental difference between these two types of scattering is that Rayleigh scattering tends to scatter uniformly in all directions while Mie scattering is biased in the forward direction. The scattering of light is primarily caused by water molecules, sea salt, and particulate matter such as phytoplankton and detritus [6].

Light scattering is due to photon interactions with the water molecules, particulate matter, and other dissolved substances in the water.[7]

The isotropic part of the Rayleigh ratio intensity of the scattered radiation is given by:[8]

$$R_{iso} = \frac{\pi^2}{2\lambda^4} k_B T \beta_T \frac{(n^2-1)^2(n^2+2)^2}{9} \ldots. (6)$$

where K_B is the Boltzmann constant, T is the absolute temperature, β_T is isothermal compressibility, and n is the refractive index at wavelength . This leads to the expression for the scattering coefficient b:

$$b = \frac{8\pi^3}{27\lambda^4} k_B T \beta_T (n^2-1)^2(n^2+2)^2 \ldots. (7)$$

The reasons behind scattering are :

1 Scattering by pure seawater
2 Scattering by particles
3 Turbulence

The passage of a coherent electromagnetic beam through a pure medium in turbulence results in a change of light velocity which in turn causes distortion in intensity and phase of the beam .[10]

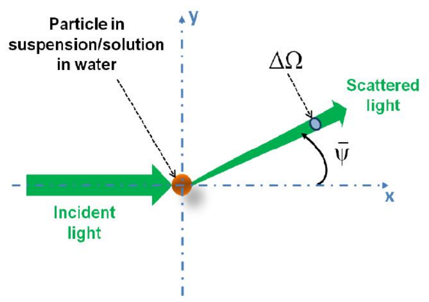

Fig. 3 Light scattering when encountering a particle in water. Part of the incident light flux is absorbed by the particle and the remaining flux is scattered through an angle ψ. The scattering direction ψ is within a solid angle Δψ around ψ [12]

2-4 Refractive Index:

A fundamental optical parameter of a material relates to how fast light travels in it. Upon entering a dielectric or nonconducting medium, a light wave slows down and now travels at a speed (s), which is characteristic of the material and is less than (c). The ratio of the speed of light in a vacuum to that in matter is known as the refractive index or index of refraction n of the material and is given by:

$$n = \frac{c}{s} \ldots\ldots\ldots\ldots (8)$$

Typical values of n to two decimal places are 1.00 for air, 1.33 for water, 1.45 for silica glass, and 2.42 for diamond.[11]

Another way to calculate the refractive index of water samples is by using the reflection law:

$$R= [(n2 - n1)/(n2 + n1)]^2 \ldots\ldots\ldots (9)$$

2-5 Attenuation

Attenuation of an optical signal transmitted through water is primarily caused by absorption and scattering. [5]

In accordance with Beer's Law, the reduction in radiant flux, Φ, with distance r from a source is proportional to the initial radiant flux, the distance traversed and the coefficients governing extinction by absorption and scattering. The attenuation of light propagating in an aquatic medium is wavelength dependant and a result of the cumulative effects of absorption and scattering, governed by the absorption and scattering coefficients a (λ) and b (λ) respectively. The total attenuation is described by the extinction coefficient c (λ) , which is related to a (λ) and b (λ) by the simple relation [13]

$$c(\lambda) = a(\lambda) + b(\lambda) \ldots (10)$$

The beam attenuation coefficient is defined as a measure of the decay of the unscattered light and is described as:

$$P_r(\lambda) = P_o(\lambda)e^{-a(\lambda)r} \ldots\ldots (11)$$

where $P_o(\lambda)$ is the radiated optical power; $Pr(\lambda)$ is the received optical power; and r is the water path length.

the single–scattering albedo (= probability of elastic scattering),is :

The proportion of light which is scattered versus absorbed is characterized by ω (λ); that is, if scattering prevails then ω (λ); approaches a value of (1) and if absorption dominates, ω (λ); approaches (0). [14]

$$\omega_0 = \frac{b}{c} \equiv \frac{b}{a+b} \ldots (12)$$

Parameters ω_0 is dimensionless and vary in the following range for any possible type of absorbing and scattering media in natural water:

$0 \leq \omega_0 \leq 1$ [15].

In general, inorganic tripton particles such as clays and carbonate minerals increase the albedo of water in a density dependent manner, due to strong scattering efficiency and comparatively low absorption. In contrast, absorption by organic tripton often resembles CDOM, with a strongly inverse correlation between wavelength and concentration. [16]

3- Experimental part :

The optical properties of water samples (Tigris, Euphrates, and Shat Al Arab) were measured by using UV/VIS spectrophotometer in the visible range (470-600) nm.

A spectrophotometer is commonly used for the measurement of transmittance or reflectance of solutions, transparent or opaque solids, such as polished glass, or gases.

When making transmission measurements, the spectrophotometer quantitatively compares the fraction of light that passes through a reference water sample (distilled water) and a test water sample (Tigris, Euphrates, and Shat Al Arab). Light from the source lamp is passed through a monochromator, which diffracts the light into a "rainbow" of wavelengths and outputs narrow bandwidths of this diffracted spectrum. Discrete frequencies are transmitted through the test sample. Then the photon flux density (watts per metre squared usually) of the transmitted or reflected light is measured with a photodiode or other light sensor. The transmittance or reflectance value for each wavelength of the test water sample is then compared with the transmission (or reflectance) values from the reference sample which is the distilled water.

The absorbance of the water was measured in a 10-cm quartz cuvette between 470 and 600 nm with 1-nm increments using a dual beam spectrophotometer (UV/VIS SP 8001 spectrophotometer Metertech).
Light from the source (a xenon lamp) is passed through a grating monochromator to select the incident wavelength. The samples

are held in quartz cuvettes with 1-cm path lengths. Variable slits in the light path before and after the sample are used to alter the bandpass. The scattered light from the sample then passes through another grating monochromator that measures the emission spectrum over a selected wavelength region.

4- Results and discussion:

The two main processes affecting light propagation in water are absorption and scattering, which both depend on wavelength (λ). Absorption is the irreversible loss of intensity and depends on the water's index of refraction. The spectral absorption coefficient a(λ) is the main intrinsic optical property (IOP) to model water absorption. Scattering, on the other hand, refers to the deflection of light from the original path, which can be caused by particles of size comparable to (diffraction), or by particulate matters with refraction index different from that of the water (refraction).

Light can be lost from a beam by absorption as well as scattering. Absorption of light takes place on electrons bound in atoms or molecules, and on free electrons in metals. The atoms may promptly re-emit the radiation or promptly emit radiation at a longer wavelength. This radiation is known as fluorescence. In denser materials the absorption occurs over broad bands of wavelength rather than narrow lines, and of course some materials absorb all the light. The energy absorbed is generally converted through atomic processses and collisions to heat. [17]

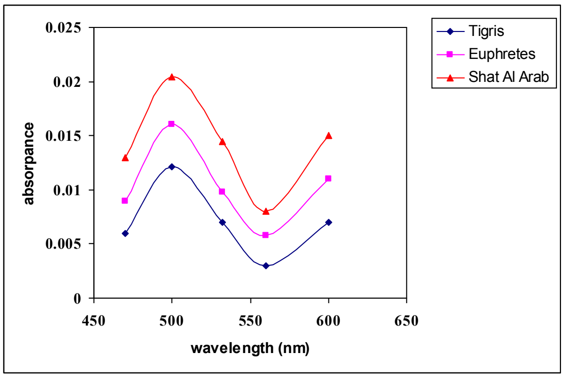

Fig (4) the absorbance of water samples vs wavelength

Figure (4) show the absorption of three water samples plotted as a function of the wavelength. In this fig. there is the less absorption value in the 560 nm and the maximum value in 500 nm for all samples and can be noticed that the absorption of Shat Al Arab have the higher value of a absorption and Tigris have the minimum value that is because Tigris river have less salts and mud, the water in Shat al Arab is more turbidity than Tigris river so it absorb more . The absorption in Euphrates River has moderate value of absorption because it has moderate salts and mud.

Transmittance is the fraction of radiation transmitted by a material, and falls below unity because there is absorption in the body of material and reflection at the entry and exit surface. Internal transmittance is defined as the light intensity reaching the exit surface divided by that which entered the material.
The behaves of transmittance is the oppose behave of absorption that is the high absorption is less transmittance as shown in fig. (5)

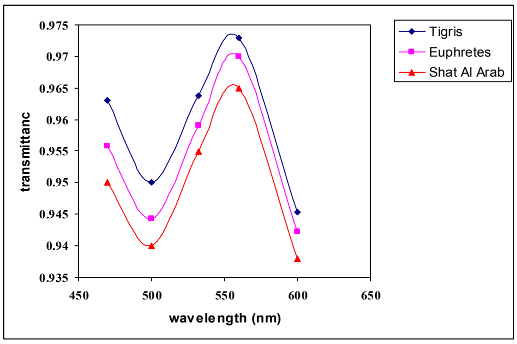

Fig. (5) transmittance of water samples vs wavelength

The fact water is quite transparent to visible light while it absorbs microwaves strongly. Materials transparent to light have refractive indices ranging from near unity for gases up to 2.47 for diamond. The variation of the velocity of electromagnetic radiation with wavelength is known as dispersion and gives rise to effects such as the dispersion of light by a prism. For most materials that are transparent to light the refractive index falls smoothly with wavelength across the visible spectrum. A few materials show anomalous dispersion and for these the refractive index rises from the blue end to the red end of the spectrum.

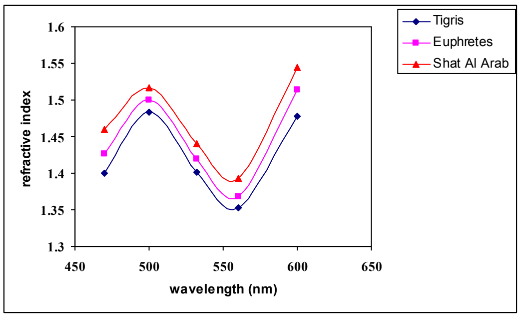

Fig (6) refractive index of water samples vs wavelength

By using eq. (9) the refractive index of water samples were calculated and plotted as a function of wavelength. In fig (6), the water of shat al arab has the highest value of refractive index because it is the highest absorbing of light which make the light pass more slow than Tigris and Euphrates river water.

In fig (7), the scattering coefficient of water samples were calculated by using eq. (7) and by substance the values of refractive index getting from eq. (9) for all water samples. The fig. shows that the water in shat al Arab has the highest value for scattering coefficient.

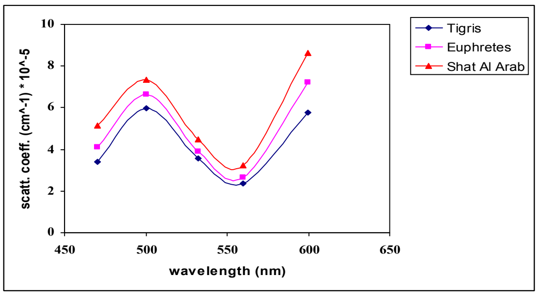

Fig (7) scattering coefficient of water samples vs wavelength

The absorption coefficient of water samples calculated by Beer – Lampart low according to eq. () is clear in fig. (9). As expected from recent sesults, shat al arab water has the highest values of the absorption coefficient for the same seasons .

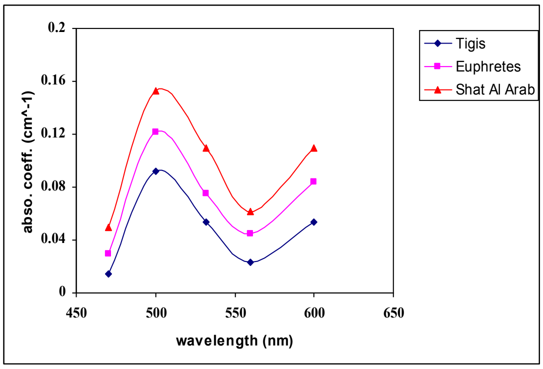

Fig (8) absorption coefficient of water samples vs wavelength

5- Scattering albedo:

Scattering albedo, ω_0, is another useful metric derived from the scattering and absorption IOPs.

In high albedo waters, a photon is more likely to be scattered. Naturally, in low albedo waters, absorption plays a larger role in overall attenuation.

Table (1) shows representative values of the scattering albedo for a three samples of water in the range (470-600) nm .

wavelength nm	scattering albedo(Tigris)	scattering albedo(Euphrates)	scattering albedo(shat al Arab)
470	0.0023	0.00136	0.00101
500	0.00064	0.00054	0.00048
532	0.00067	0.000519	0.000411
560	0.00102	0.000599	0.000524
600	0.00108	0.000858	0.000784

The table illustrates the differences in the scattering albedo that could be expected in deferent water types. Naturally in clear waters (Tigris water), the overall scattering albedo is low, meaning that the majority of attenuation is due to absorption. In contrast, for turbid waters (shat al arab water), the scattering albedo can be quite high. Additionally, turbid waters often have higher scattering albedos, meaning that the overall attenuation is dominated by scattering.

6- Conclusions :

- There are varying in the optical properties of Iraqi rivers (tigris, Euphrates, and shat al arab)
- Tigris water has the minimum value of absorption, absorption coefficient, refractive index, scattering index, scattering – albedo ,and maximum value in transmittance .
- Shat al arabe water has the maximum value of absorption, absorption coefficient, refractive index, scattering index, scattering – albedo ,and minimum value in transmittance .
- Euphrares water has moderate values in absorption, absorption coefficient, refractive index, scattering index, scattering – albedo ,and transmittance between tigris and shat al arab.
- In the optical range of measured properties of water samples, there are two values of minimum absorption(560 nm) and maximum absorption(500 nm) .
- in order to study the optical properties of Iraqi water , a light of 560 nm should be used in order to have the minimum loss in the optical beam that passes through the water sample.

References:

[1] Ling Wang, Measuring Optical Absorption Coefficient of Pure Water in UV Using The Intgrating Cavity Absorption Meter, Doctorate thesis, Texas A&M University, 2008.

[2] W. Scott Pegau, Deric Gray, and J. Ronald V. Zaneveld, Absorption and attenuation of visible and near-infrared light in water: dependence on temperature and salinity, APPLIED OPTICS, 20 August 1997 y Vol. 36, No. 24 y .

[3] C. D. Mobley, Light and Water- Radiative Transfer in Natural Waters. California: Academic Press Inc., 1994.
[4] Yash Jagdishlal Gawdi, Underwater Free Space ptics, Master thesis, Raleigh, North Carolina, 2006.

[5] Jared Scott Everett, Forward-Error Correction Coding for Underwater Free-Space Optical Communication, Master thesis, North Carolina State University, 2009.
[6] Eric Y.S. Young, Audra M. Bullock, Underwater-airborne laser communication system: Characterization of the channel, Proceedings of SPIE Vol. 4975 (2003).
[7]William Charles Cox, Jr., Simulation, Modeling, and Design of Underwater Optical Communication Systems. 2012 .
[8] A.T. Reghunath; V. Venkataramanan, D. Victor Suviseshamuthu,R. Krishnamohan, B: Raghavendra Prasad, S, Raghuveer ,C.K. Subramanian, P. Chandrasekhar and P .S. Narayanan and M. Ravisankar, V .P .N .c Nampoori and K. Sathianandan, Radiation in Ocean Waters, Def Sci J, Vo141, No 1, January 1991, pp 1-20.
[9] Charles H. Mazel , Jody Kalata-Olson, and Chuong Pham, The inherent visible light signature of an intense underwater ultraviolet light source due to combined Raman and fluorescence effects, Society of Photo-Optical Instrumentation Engineers, 2000.
[10] D. Bogucki, A. Domaradzki, R. Zaneveld, T. Dickey, Light Scattering Induced by Turbulent Flow , SPIE Vol. 2258 Ocean Optics XII (1994) / 247.
[11] Michael Bass, Handbook of optics Fundamentals, Techniques, and Design, Volume I, Second Edition, McGraw-HILL, INC., 1995.
[12] Chadi Gabriel1, Mohammad-Ali Khalighi1, Salah Bourennane, Pierre Léon, and Vincent Rigaud, Monte-Carlo-Based Channel Characterization for Underwater Optical Communication Systems, Journal of Optical Communications and Networking, Volume 5, Issue 1, Pages 1-12, January 2013.
[13] Shlomi Arnon & Debbie Kedar , UV solar-blind FSO sub-sea video communication: link budget study Unmanned/Unattended Sensors and Sensor Networks V, Proc. of SPIE Vol. 7112, 711207 , 2008 .
[14] T. D. Dickey, INHERENT OPTICAL PROPERTIES AND IRRADIANCE, University of California, Santa Barbara,CA, USA ,Academic Press, 2001.
[15] Alexander A. Kokhanovsky, Light Scattering Reviews Single and Multiple Light Scattering, Praxis Publishing Ltd, Chichester, UK, 2006.
[16] J. F. Schalles, L.L. Richardson and E.F. Le Drew, Optical remote sensing techniques to estimate Phytoplankton Chlorophyll a concentrations in coastal waters with varying suspended matter and CDOM concentrations , (eds.), Remote Sensing of Aquatic Coastal Ecosystem Processes: Science and Management Applications,27-79. 2006 Springer.
[17] I. R. Kenyon, The Light Fantastic a Modern Introduction to Classical and Quantum Optics, School of Physics and Astronomy, University of Birmingham, Oxford university press, 2008.