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Temperature Influence on the Optical Properties, Attenuation Coefficient, and Total Molecular Cross Section of Dhunge Dhara Drinking Water

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Abstract

This work aims to measure the different parameters of Dhunge Dhara water (DDW) such as absorbance, transmittance, mass attenuation coefficient (MAC), and molecular cross section (MCS) and experimentally compare the obtained values with those of pure water (PW) at various temperatures (5 °C to 90 °C) using a theremino spectrometer. Observation shows that the parameters vary with temperature and wavelength. The transmittance of DDW ranges from 18% to 85% and absorbance of the same ranges from 0.09 Au to 0.7 Au. Meanwhile, the transmittance of PW ranges from 40% to 98% and the absorbance of the same ranges from 0.09 Au to 0.39 Au. The MAC of PW ranges from 0.02 cm^2g^{-1} to 0.6 cm^2g^{-1}, and that for DDW ranges from 0.2 cm^2g^{-1} to 1.1 cm^2g^{-1} at 30 °C. The MCS of PW ranges from $0.1 \times 10^{-23} cm^2$ to $2.7 \times 10^{-23} cm^2$, and that of DDW ranges from $0.9 \times 10^{-23} cm^2$ to $5.5 \times 10^{-23} cm^2$ at 30 °C. In conclusion, DDW has an extremely high amount of impurities and total dissolved solids and is recommended to be filtered prior to use (drinking and cooking).

Keywords: absorbance, Dhunge Dhara, mass attenuation coefficient, molecular cross section, temperature, transmittance

Introduction

Organic substances are toxic to humans when they enter the body [1]. One of the most difficult challenges is to identify organic substances using photonic technology to eliminate them. Water pollution caused by natural and human activities is a major environmental and health concern. Insecticides/pesticides, heavy metals, sewage, pharmaceuticals, personal care products, etc. are some examples of human contaminants. A variety of methods, including chromatography, electrode potentiometry, mass spectrometry, UV–Vis spectrometry, and Raman scattering, are used to detect pollutants in water. The use of resistivity, temperature, pH, total suspended solids, absorbance at 254 nm (UV-254), and total organic content to monitor water quality is gaining popularity. In the range of 250 nm to 350 nm, pure water (PW) has a scattering-independent absorption coefficient of less than 0.1 m^{-1} and a minimum of less than 10^{-3} m^{-1} at the upper end of this range [2].

According to Singh and Pandey, the world's urban population is expected to reach 68% by 2050. This prediction has implications for Himalayan regions. Water governance in such regions remains a blind spot, and challenges related to urban water resilience are poorly understood. Kumar *et al*. in 1997 investigated the physicochemical properties of water from 12 springs within the municipal limits of Almora, a Himalayan town in central India reported in [3]. According to Merz *et al*. (2004) [4], 79% of the interviewed households in Jhikhu Khola have a female member of the household fetching water. Many residents in the upper reaches of the watershed get their water from natural springs.

Siwalik zone with an elevation of 900–1200 meters comprises 8% of the land area and is found south of the middle mountain. Middle hills with an elevation of 1200–3000 meters comprise 30% of the land area. High mountains with an elevation of 3000–5000 meters comprise 20% of the land area. Nepal has a high Himalayan elevation of more than 5000 meters and a land area of 9%. One of the main water sources in Bahun Khola is the stream. During the dry season, the stream completely dries out because any available water is collected for domestic water supply. People reuse domestic water because the water for irrigation is insufficient. Water consumption has been fairly consistent over the last 5 years, but the increasing population has resulted in increased water consumption [5]. The main water source is groundwater seepages and springs in the Baad Khola area. A small amount of water is also used for irrigation. During the post-monsoon season, the downstream flow of the spring is estimated to be 10 l/s [5].

Despite the global goal of universal access by 2030, billions of people worldwide are continuously deprived of access to safe drinking water, safe sanitation, and basic hygiene services, particularly those residing in rural areas. Approximately 44% of all wastewater flows generated by households worldwide are not safely treated. Although 60% of the world's monitored water bodies have good ambient water quality, one-fifth of the world's river basins are experiencing rapid changes in surface water coverage, indicating that climate change has caused flooding and drought events. In 2020, approximately 2 billion people or 26% of the world's population do not have access to on-premise drinking water services that are available when needed and free of contamination [6].

In developing countries, 90% of sewage is discharged into the water untreated. Every year, 730 million tons of sewage and other effluents are dumped into bodies of water, and industries release 300–400 megatons of waste into the environment. More than 30% of global biodiversity has been lost as a result of freshwater ecosystem degradation caused by the pollution of water resources and aquatic ecosystems [7]. Wastewater recycling in agriculture, which is critical for livelihoods, poses substantial health risks. Water pollution has worsened over the last three decades, affecting nearly every river in Africa, Asia, and Latin America. Currently, 80% of industrial and municipal wastewater is discharged without pretreatment. By 2050, global fertilizer consumption is expected to rise from around 90 million tons to more than 150 million tons. By 2050, the levels of nitrogen and phosphorus effluents will have increased by 180% and 150%, respectively. Global agricultural chemical use is currently at 2 million tons per year, with herbicides accounting for 47.5%, insecticides accounting for 29.5%, fungicides accounting for 17.5%, and other chemicals accounting for 5.5%. By 2050, water demand will rise but water availability will decrease [7].

From approximately 10,000 BC to 5000 BC, the global population remained relatively constant at less than 5 million people. It began to grow in the Bronze Age, reaching 50 million by the end and 190 million in the year 200 AD. The increase in the following years was minimal, with 265 million in 1000 AD and 350 million in 1400 AD. The global population steadily increased after 1500 AD, reaching 1 billion people 200 years ago. However, the increase between 1900 and 2000 was dramatic from 1.5 to 6.1 billion in just 100 years and from 2.50 billion in 1950 to 7.55 billion today [8]. According to the World Health Organization (WHO), 2.6 billion people do not have access to basic hygiene, and 1.8 million people die each year as a result of water-related diseases. Diarrheal diseases killed 499,000 children under 5 years old in 2015, accounting for 8.6% of all deaths in this age group [9].

Diarrhea is one of the most common water-borne diseases in Nepal and is caused by poor sanitation, hygiene, and water quality. Its incidence rate was 131 per 1,000 children under 5 years old in 1995/96. The diarrhea mortality rate was 0.34 per 1000 children under 5 years old, and the case fatality rate was 2.56 per 1,000 (CBS, 2001). Diarrhea is becoming common in Nepal at an alarming rate. According to a report obtained from Teku Hospital in Kathmandu, the water-borne disease was responsible for 16.5% of all deaths (Metcalf, 2000). Salmonella typhi, the organism that causes typhoid fever, and Vibrio cholera, the organism that causes cholera, are the most important pathogenic bacteria transmitted by water (Madigan *et al*., 1997) [10]. The government's investments in water supply and sanitation are primarily guided by the Water Plan (2002–27), which aims to achieve universal coverage of the basic levels of water supply and sanitation by 2017 and raise the basic level of water supply for 27% of the population to medium to high by 2017 and for 50% of the population by 2027. However, the Plan did not set targets for improved sanitation services [11].

Spectrophotometric analysis is used to investigate the common ingredients dissolved in beverages (soft and energy drinks) and various medicines. Monitoring the ingredient concentration of any drink is critical because of the possible physiological disorders inflicted on those who consume it. Furthermore, spectrophotometric methods are used in the analysis of pharmaceutical products, soft and energy drinks, tea, coffee, and other beverages. [12]. The water molecule has vibrational and rotational motions. The symmetric stretch mode frequency (v_1) is 3657.05 cm^{-1} (2.73444 μm), the asymmetric stretch mode frequency mode (v_3) is 3755.93 cm^{-1} (2.66246 μm), and the bend mode frequency (v_2) is 1594.75cm^{-1} (6.27058μm). In combined vibrational rotational spectra, the water molecule has a small moment of inertia on rotation [13]. The absorption spectra of ethanol and water measured with a halogen lamp-based photothermal lens spectrophotometer are in the range of 430–700 nm [14].

According to the United Nations and the World Water Development Report, clean water scarcity is a major issue in today's world of 7.7 billion people. The strain on the water system will increase by 2050 when the world population increases by 22% to 34% between 9.4 and 10.2 billion. At present, slightly less than half of the world's population, or 3.6 billion people (47%), live in areas where water is scarce for at least 1 month out of the year. By 2050, more than half of the world's population (57%) will live in areas where water is scarce for at least 1 month of the year. Currently, 12% of the world's population drinks water from unimproved and dangerous sources. More than a third of the world's population, or 2.4 billion people, does not have access to basic sanitation. In this work, Dhunge Dhara water (DDW) and PW samples were collected to compare their optical properties, attenuation coefficient, and total cross section. Clean technology was used to study the optical properties and purity of the water samples. Analysis of the attenuation coefficient and total molecular cross section (MCS) of DDW can aid in its use for radiation shielding. This study is necessary because DDW is used by locals for a variety of purposes, including drinking, cooking, and other household tasks.

Researchers use a theremino spectrometer to examine the optical properties of solidified water, soybean oil, and saltwater. In one study, transmittance properties were found to decrease with the increase in wavelength and were greater in PW than in saltwater and soybean oil; however, the absorbance and reflectance values increased with the wavelength [15]. Another work used the theremino spectrometer to analyze the transmittance and absorbance of drinking water, organic honey solution, sunflower oil, mustard oil, and a mixture of all and found a decrease in transmittance and an increase in absorbance increase with the increasing wavelength of the photon [16]. Comparison among the samples showed that the drinking water has high transmittance and the mixture has low transmittance. Investigation of the optical properties of samples from two water supplies, Kathmandu Upatyaka Khanepani Limited (KUKL) and Kathmandu Valley Water Supply Improvement Project (KVWSIP) in the Kupondole Area, Lalitpur, Nepal using theremino spectrometer showed higher transmittance for KVWSIP sample water than for KUKL. The transmittance of spring drinking water (420–700 nm) in a hilly region near Nisi Khola Area Baglung, Nepal was studied using theremino spectrometer, and the results showed that the transmittance of bas khola was higher than that of the other eight source samples [17, 18].

Many researchers tested the purities of different samples of drinking water from different sources using chemical methods; however, the optical properties of DDW in our country, particularly in the research area, have not been examined. After comparing the optical properties of PW and DDW, the authors can recommend nearby DDW resources and how people can use DDW in their daily life. In testing the impurities of water, the proposed technology is better, less time-consuming, and less expensive than reverse osmosis, UV treatment, and ozonation. These techniques do not provide any information about the transmittance coefficient or temperature for testing the purity of water.

Materials and Methods

An experimental method was used to investigate the absorbance and transmittance of water. The intensity of visible light was measured using theremino spectrometer software and a diffracting grating in the experiment. The experiment was conducted at Patandhoka's DDW source in Lalitpur, Nepal. The absorbance and transmittance coefficients of DDW were studied and compared with those of PW to identify the contaminations present in DDW and determine the properties of the dissolved particles (organic, inorganic, and total dissolve solute) in drinking water with interaction. This testing method is less expensive and does not pose any serious risks. Total dissolved solids (TDS) quantity in water was represented by transmittance, and the optical properties of TDS were represented by absorbance.

According to the block diagram in Figure 1, the source white LED emitted white light that contains seven different visible colors as it passed through the drinking water sample (sample at 24 °C as cold and 34 °C as hot). A portion of the light was absorbed, and others were transmitted through the sample (represented by a thin blue arrowhead). The transmitted light from the samples struck the theremino spectrometer sensor, which generated data that were recorded in a computer. Origin software was used to arrange and plot the recorded data. The experiment was carried out in a darkroom to avoid interference from outside sources that changes the intensity of incident light on the sample. Except for the temperature, the experimental conditions for both samples were ideal.

The Lambert–Beer law is based on the passage of a monochromatic parallel light beam that irradiates the tested substance's surface [19, 20] as shown in Figure 1. Obtaining a reliable formulation of the Beer–Lambert law in photochemistry requires knowledge of the role that the space–time dependence of the absorbance plays on the system. Spatial memory due to the correlation between obstacles can be modeled using a fractional calculus

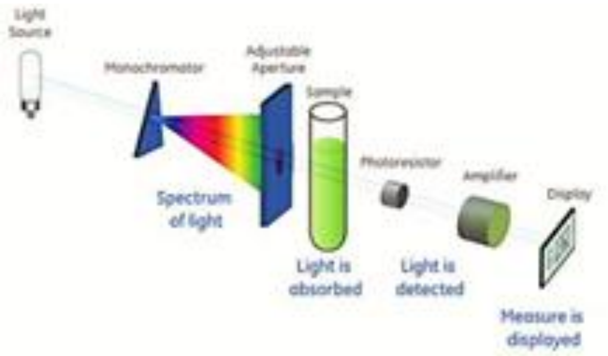


Figure 1. Block Diagram of an Experiment on the Transmittance and Absorption Coefficient of Samples

approach. Here, a generalized Beer–Lambert law based on Mittag–Leffler extinction of radiation was derived through probabilistic arguments under the assumption that the number of extinction events follows a fractional Poisson distribution [21].

Mechanism of observation of data and related formula. When visible photons passed through the samples (at different temperatures), some were absorbed into the sample and others passed through the sample transmittance. The same sample was used at different temperatures to investigate the transmittance of a photon through a sample. Absorbance A was defined as $\{2 - \log(T[\%])\}$, and transmittance was defined as $T\,\% = \left(\frac{I}{I_0}\right) \times 100\ \%$, where I is the intensity of light after passing through the sample and I0 is the intensity of light before passing the sample. $I = I_0 e^{-\left(\frac{\mu}{\rho}\right)x}$ was used for mass attenuation coefficient (MAC) [22, 23] and $\sigma_{t,m} = \left(\frac{\mu}{\rho}\right)\frac{M}{N_A}$ for molar cross section, where M is the molecular weight and N_A is Avogadro's number.

Results and Discussion

Optical properties of DDW. Figures 2 (a) and (b) depict the transmittance coefficient and absorbance of DDW at various temperatures, respectively. The transmittance decreased with the wavelength at different degrees. The transmittance range was between 18% and 85%. In 2020, Prieto *et al*. [24] reported that the low transmittance of a water sample indicated its high contaminant level because of its high turbidity. They measured the transmittance and absorbance using wavelength (380–700 nm) and found that the graph followed a steep curve with the wavelength. The variation of the slope was due to the due organic matter interaction with light because, at low wavelengths (UV near–visible range), organic matter absorbs radiation but the visible transmission is maximum relative to that in UV. Similar findings were obtained by other authors [25, 26]. The steep slope with wavelength for PW was also obtained by the authors in [27].

Optical properties of the PW. The transmittance and absorbance at °C are shown in Figures 3(a) and (b). The transmittance decreased with the increasing wavelength, and the absorbance increased with the wavelength. In addition, the maximum transmittance was only observed for PW. The bump was observed with wavelength due to the molecular vibration of water (interaction of a photon with water molecules) [28]. The trend of the transmittance and absorbance of PW at 30 °C in (Figure 3) was similar to that in [15-18]. The standard transmittance of PW and DDW was compared with the standard data for PW calculated by Jerlov in 1968 (Table 1).

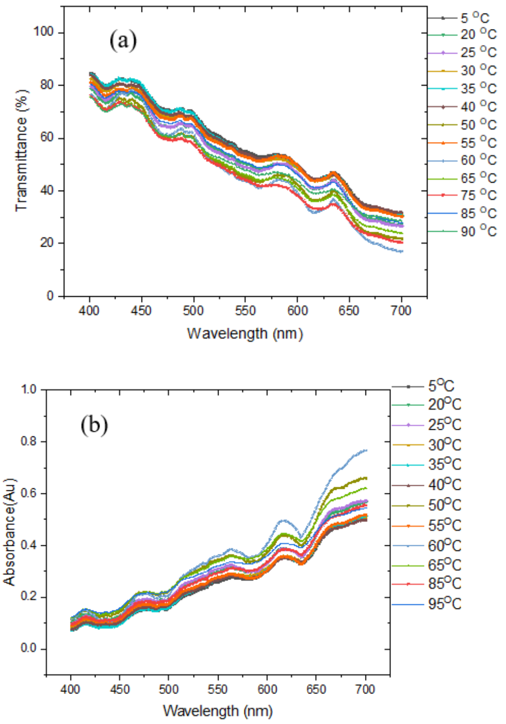
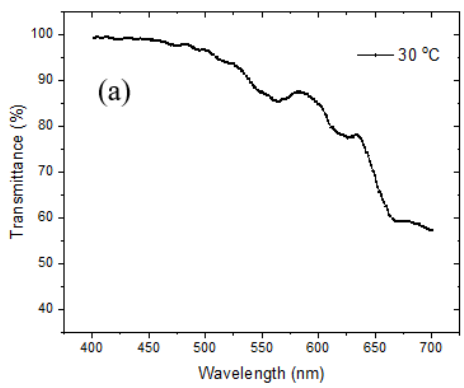


Figure 2. Variation of (a) Transmittance and (b) Absorbance of Dhunge Dhara Water at Different Temperatures



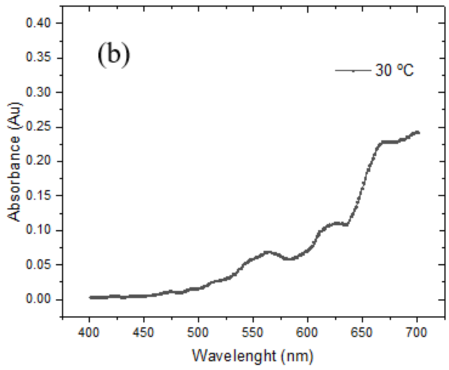


Figure 3. Variation of (a) Transmittance and (b) Absorbance of Pure Water at 30 °C

Table 1. Recent Progress in the Application of COS-based Nanomaterials for DDS

Wavelength	Transmittance (%)		
	Jerlov [29]	Present work	
		PW	DDW
400	95.8	99.3	84.2
450	98.1	98.9	79.9
500	96.5	96.4	66.2
550	93.3	87.4	53.1
600	83.3	84.8	48.5
650	75.0	67.8	39.6
700	60.7	57.3	30.9

Comparison of the optical properties of PW and DDW. The transmittance of absorbance and transmittance differed between DDW and PW as shown in Figure 4. The transmittance of DDW was lower than that of PW because of the presence of impurities and TDS. Dhunge Dhara was built in ancient and medieval Nepal by several kings. It consists of a complex network of ponds and canals that were built as a water supply during the dry season and to help reduce the water pressure brought on by the monsoon rains to support the system. The absorbance of DDW was high because the molecular and impurities interact with electromagnetic waves. This work only aimed to study the physical properties, not the chemical contamination. The observation showed that the transmittance of PW was 58% greater than that of DDW at 30 °C, and the absorbance of DDW was 140% greater than that of PW.

MAC of PW and DDW. Figures 5(a) and 5(b) show that the MAC of DDW and PW increased with the wavelength. The MAC of DDW was higher than that of PW of the same nature. MAC is the measurement of how strongly a chemical species or substance absorbs or scatters light at a given wavelength per unit of mass. A high MAC indicates a high interaction. The higher MAC for DDW than for PW revealed that the interaction of light with the presence of impurities and TDS was high.

Comparison of MAC between PW and DDW. The comparative study of the MAC of PW and DDW is shown in Figure 6. The MAC of DDW was greater than that of PW. Hence, the interaction of the electromagnetic wave with impurities and TDS was high.

MCS of PW and DDW. Figure 7 depicts the MCS of DDW and PW. The MCS increased with the wavelength for both samples. The MCS of PW varied from $0.1 \times 10^{-23} cm^2$ to$1.75 \times 10^{-23} cm^2$. At random temperatures, the MCS of water ranges from $0.9 \times 10^{-23} cm^2$ to $5.5 \times 10^{-23} cm^2$. The increase in MCS indicated that the size of particles present in water ranged from 400 nm to 700 nm because the electromagnetic wave interacts with particles of this size.

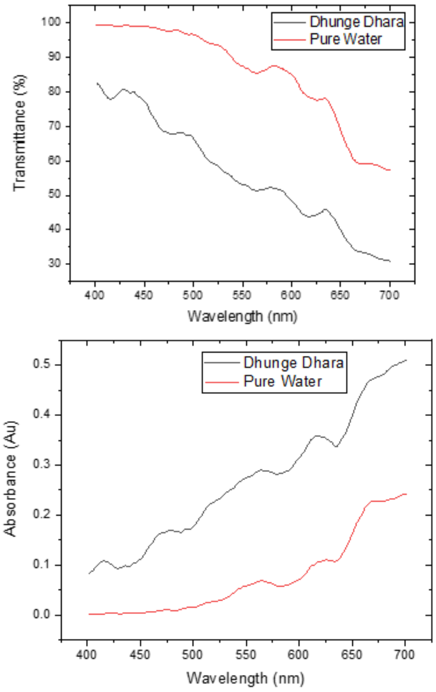
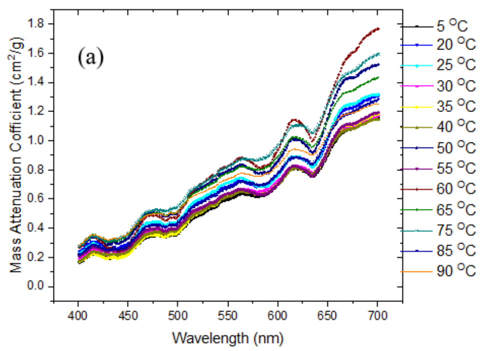


Figure 4. Comparison of Transmittance and Absorbance Between Pure Water and Dhunge Dhara Water at 30 °C



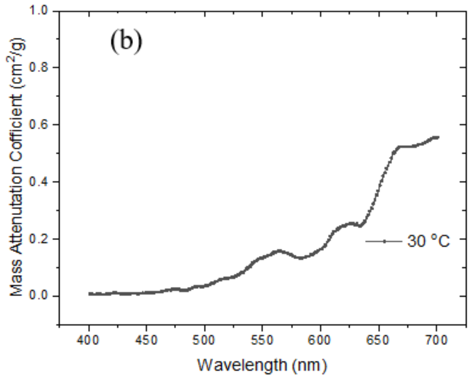


Figure 5. Mass Attenuation Coefficient of (a) Dhunge Dhara Water and (b) Pure Water

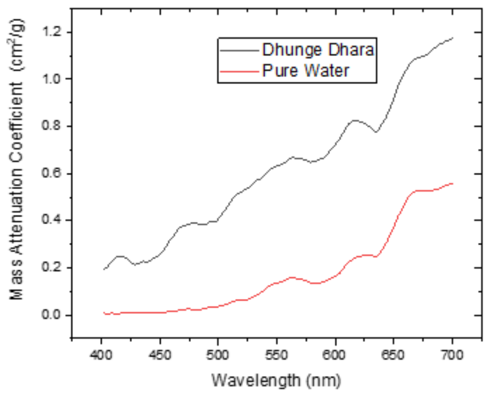


Figure 6. Comparison of MAC between Pure Water and Dhunge Dhara Water at 30 °C

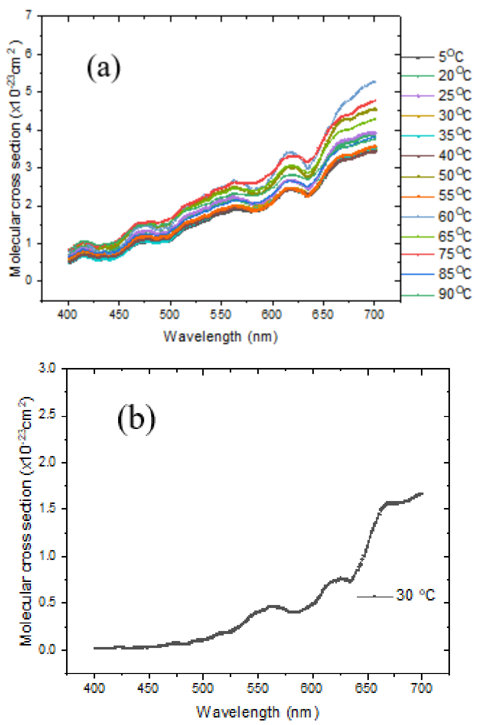


Figure 7. Molecular Cross Section of (a) Dhunge Dhara Water and (b) Pure Water

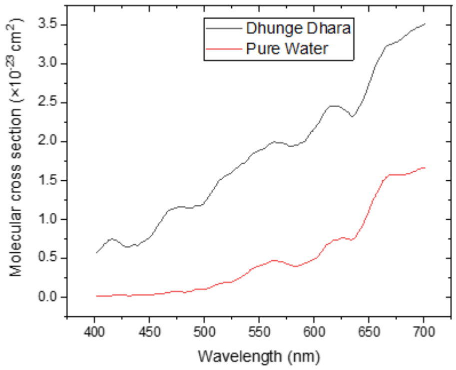


Figure 8. Comparison of Dhunge Dhara Water and Pure Water at 30 °C

Table 2. Correlation Between the Optical Parameters of DDW

Correlation	Transmittance	Absorbance	MAC	MCS
Transmittance	1	−0.99034	−0.99034	−0.99034
Absorbance	−0.99034	1	1	−0.99034
MAC	−0.99034	1	1	1
MCS	−0.99034	1	1	1

Comparison of MCS of PW and DDW. The comparative study of DDW and PW is shown in Figure 8. The MCS of PW was less than that of DDW because the impurities, TDS, and water molecules form a cluster in DDW. Such cluster was not observed in PW. The transmittance of DDW and PW decreased with the wavelength, and their absorbance increased with the wavelength. The transmittance of PW was greater than that of DDW because PW is free of contamination. Therefore, DDW contains impurities because the reservoir is under water. The effect of temperature on the transmittance, absorbance, MCS, and MAC of DDW was also observed. With the increase in temperature, the transmittance, MCS, and MAC of DDW also increased. The absorbance, MAC, and MCS of DDW were 33.3% greater than those of PW at 30 °C. Meanwhile, the transmittance of DDW was 33.3% less than that of PW.

Table 2 shows that transmittance has a negative correlation with absorbance, MAC, and MCS, that is, transmittance increases with decreasing absorbance, MAC, and MCS. Meanwhile, absorbance has a positive correlation with MAC and MCS, that is, absorbance increases with MAC and MCS.

Conclusion

This study showed that the transmittance coefficient and absorbance of PW and DDW decreased and increased with the increasing wavelength, respectively. The variation of different parameters such as transmittance, absorbance, MCS, and MAC of PW and DDW was also observed with the increasing wavelength at different temperatures. The transmittance of PW was greater than that of DDW, and the MCS and MAC of DDW were greater than those of PW because of the impurities and TDS. Therefore, the authors recommended the use of DDW after filtration and concluded that DDW contains impurities and TDS. The presence of impurities and TDS was concluded using an optical technique and with the help of transmittance, absorbance, MCS, and MAC. The high transmittance defines the cleanness of water, and the high MCS, MAC and absorbance define the presence of contamination (impurities and TDS) in water. The optical technique in this work helps determine impurities present in water according to transmittance, absorbance, MCS, and MAC. Among the parameters, MCS and MAC are the most suitable to determine the size of impurities present in a transparent liquid.

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