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MODERNIZING WATER QUALITY MONITORING IN BANGLADESH: A CRITICAL REVIEW OF UV-VIS SPECTROPHOTOMETRY OVER TRADITIONAL METHODS

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ABSTRACT

Water quality parameters serve as vital benchmarks for determining the safety and usability of water across multiple sectors, such as drinking, irrigation, industry, and ecosystem. These indicators help to determine whether water meets the necessary standards for each purpose. Monitoring them is key to ensuring water quality, controlling pollution, and protecting aquatic ecosystems. In Bangladesh, water quality testing usually relies on traditional methods. These methods require the use of various chemicals, which not only increases the overall cost but also extends the time needed to obtain accurate results. The process can be resource-intensive which makes it less efficient for situations where quick, reliable outcomes are necessary. This is particularly problematic for assessing surface water quality affected by industrial effluents, where traditional methods are slow, and in-situ testing is nearly impossible. UV-vis spectrophotometers are gaining popularity in developed countries for monitoring water quality parameters using UV-vis sensors. UV-vis spectrophotometers are reagent-free and provide faster responses compared to conventional methods which makes them a more efficient solution for water quality monitoring. This review highlights the potential application of UV-vis spectrophotometry in Bangladesh and compares it to traditional water quality testing methods. Key parameters such as color, turbidity, nitrate nitrogen, chemical oxygen demand (COD), dissolved organic carbon (DOC), total organic carbon (TOC), and heavy metals, traditionally measured by conventional methods in Bangladesh, are compared with results obtained using UV-vis spectrophotometer technology. The paper also emphasizes the research opportunities for utilizing UV-vis spectrophotometers to measure these water quality parameters in Bangladesh.

Keywords: *Water Quality, UV-Vis Spectrophotometry, Quality Monitoring, Modernization, Sustainability*

INTRODUCTION

Water pollution is one of the major threats to public health in the world. According to the UNESCO 2021 World Water Development Report, about 829,000 people die every year from diarrhea due to unsafe drinking water, sanitation, and hand hygiene, including nearly 300,000 children under five years old (Lin et al., 2022). In Bangladesh, sewage, solid waste, industrial waste, and effluents are the primary causes of surface water pollution (M. K. Hasan et al., 2019). Not only surface water but also groundwater is polluted in Bangladesh. Arsenic (As) contamination in groundwater causes a severe health risk in Bangladesh (Ganguli et al., 2021). It was investigated that at present most of the waterbodies in Bangladesh are contaminated and unsafe for human consumption without proper treatment (M. K. Hasan et al., 2019). Therefore, water quality monitoring is an important part of preventing water pollution. Various conventional methods of water quality monitoring process are implemented in our country. As the water resource environment is deteriorating day by day, the present world has been focusing on advanced technology to modernize the water quality monitoring process for rapid and accurate determination of water quality parameters and process control (Guo et al., 2020). Ultraviolet-visible spectroscopy is such a modern promising technology that measures the absorption of Ultraviolet and visible light (wavelength ranging from approximately 200 to 800 nm) by a water sample and nowadays it is used to determine the different water quality parameters in many countries effectively. This review highlights the basic principle of UV-Vis spectroscopy, compares the potential application of UV-Vis spectroscopy to traditional water quality testing methods, some key parameters such as Chemical Oxygen Demand (COD), color, turbidity, nitrate, nitrite, Total Organic Carbon (TOC), Dissolve Organic Carbon (DOC), heavy metals are determined in Bangladesh in the conventional methods are compared with the results obtained using various model of UV-vis spectroscopy. A water quality detection model of online UV-Vis sensors for real-time monitoring of water quality and process control is proposed. At last, the research opportunities for utilizing UV-Vis spectrophotometer to determine the water quality parameter in Bangladesh is emphasized in this review.

Basic Principles

Lambert-Beer Law

The numerical assessment of water quality characteristics using a UV-Vis spectrophotometer is based on the Lambert-Beer law. Scientist Lambert (1760 AD) proposed that when a light of single wavelength is transmitted or refracted through a transparent medium, the degree of decrease of light intensity (di/dl) concerning the thickness of the medium (l) is proportional to the incident light intensity. According to scientist Beer (1852 AD), when a monochromatic light travels through a solution of a solute, the degree of decrease of intensity of transmitted light is exactly proportional to the solution's concentration. By combining these two principles the Lambert-Beer equation can be found.

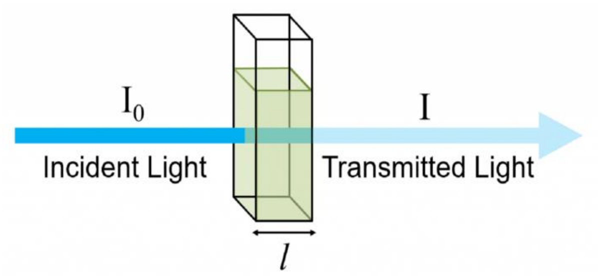

Figure 1 An illustration of the Lambert-Beer law

The measurement principle of Lambert-Beer law is based on a beam of monochromatic parallel light that illuminates the surface of the measured substance. After passing through a medium of a specific thickness, the medium absorbs some of the light energy, reducing the intensity of the transmitted light passing through it. The absorbance of the absorption medium is directly proportional to the thickness of the medium. Figure 1 depicts a visual representation of Lambert-Beer law. Lambert-Beer's equation is written as follows:

$$A = \log(1/T) = Ka\mathbf{l} \quad (1)$$

In Equation (1), A represents the absorbance, T stands for transmittance, and it represents the ratio of the intensity of outgoing light (**I**) to the intensity of the incident light (**Io**), The molar absorption coefficient (K) corresponds to the type of the absorbing substance, and 'λ' is the wavelength of the incident light, the concentration absorbing substance is represented by 'a' and its unit is mol/L, and '**l'** stands for the thickness of the absorbing layer in cm. The electrons of pollutant molecules in the water can absorb UV-Vis light of a specific wavelength, and then they shift from the ground state to the excited state by minimizing the amount of transmitted light. According to the Lambert-Beer law, there is a close relationship between the absorption spectrum and the concentration of the solution. Most of the pollutants absorb this monochromatic light in different wavelengths of the Ultraviolet-Visible region and provide various spectral curves. For this reason, this law is known as the mathematical basis through which the concentration of contaminants in water can be determined precisely.

METHODOLOGY

As there is a significant correlation between the absorbed spectra and concentration of the water quality parameters, a high-precision prediction model can be created (J. Li et al., 2018)**.** Different studies adopted the prediction model in different ways. Figure 2 depicts the steps necessary for developing a water quality prediction model.

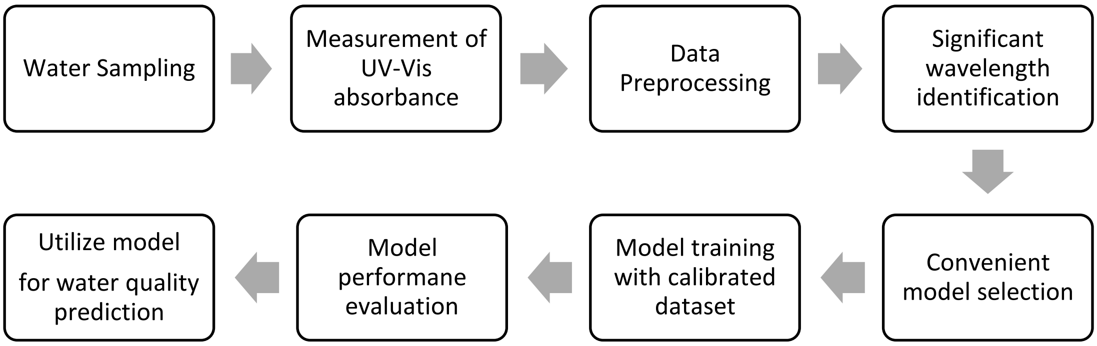

Figure 2 The steps required for developing a water quality prediction model (Guo et al., 2020)

Partial least squares regression (PLSR) and support vector machine regression (SVR) have become the two predominant techniques used in water quality prediction (Guo et al., 2020).

Water Sampling

In different studies, various water sampling methods were used to determine the chemical constituents of the sample water by using UV-Vis Spectroscopy. For example, UV-Vis spectroscopy was used to determine the concentration of nitrate and NPOC levels in groundwater from 75 wells in Linkoping municipality, Ostergötland, Sweden, and the water was collected in a polythene bottle after a 10-minute flush (Dahlén et al., 2000). Water samples were taken from two ombrotrophic peatlands in North Wales, UK, after collection, the samples were kept at 4°C in the dark and acidified with 1M hydrochloric acid (pH <3) before analysis, and filtration (Peacock et al., 2014). Samples were filtered using Whatman 0.45 mm Cellulose Nitrate filters and evaluated for dissolved organic carbon (DOC) using an Analytical Sciences Ltd Thermalox Total Carbon analyzer with a CO2 detector (Peacock et al., 2014). (Hu et al., 2016) sampled artificial seawater solution in the lab to determine the concentration of NO_3, COD, and turbidity by online UV-Vis Spectrophotometer. For example, the turbidity solution was made by diluting a 400 NTU Formazine Turbidity solution, the COD standard solution was made by dissolving potassium hydrogen phthalate, and the nitrate solution was made from potassium nitrate (Hu et al., 2016).

Data Preprocessing

Absorption spectrums in UV-Vis spectroscopy are commonly disrupted by power frequency interference from light sources, hydraulics fluctuation, suspended materials, and pollutants (Shen et al., 2013). Because of all this background noise, using UV-Vis spectroscopy to detect contaminants in water is very challenging or even impossible (Guan et al., 2018). So Pretreatment is very important before analysing water quality as it ensures accurate, reliable, and consistent results by minimizing interference and removing all types of disturbance.

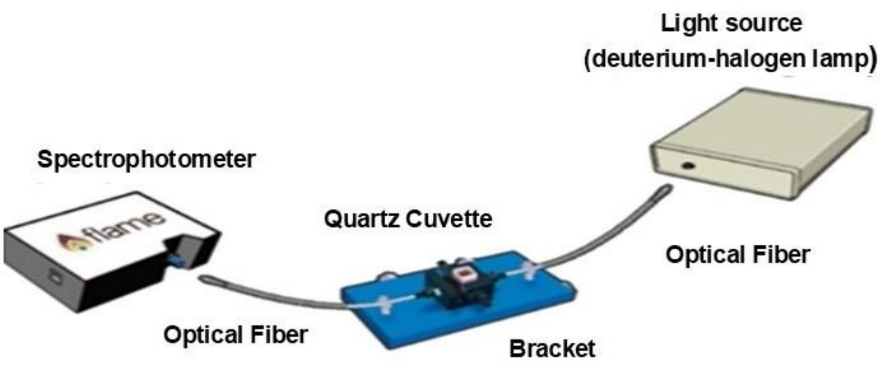

Figure 3 UV-Vis absorption spectrum acquisition method with equipment layout diagram (Guan et al., 2024)

Initially, using the instrument Guan et al. (2024) found high-frequency noise uniformly (194-699 nm) as shown in Figure 3. To remove disturbance and improve signal to noise ratio a filter named Discrete Wavelet Transform (DWT) was used (Guan et al., 2024). There are different types of pretreatment methods such as Savitzky-Golay (SG) smooth filter, Wavelet transform (WT), Standard Normal Variate (SNV), Multiple Scattering Correction (MSC), and so on (Guo et al., 2020). These preprocessing methods have various advantages, such as noise reduction, spectral data smoothing, etc. which are shown in Table 1 (Guo et al., 2020).

Table 1 Advantages of the pretreatment method

Pretreatment Method	Advantages	Related Literature
Savitzky–Golay (SG) smooth filter	Improve smoothness of spectrum to reduce noise interference.	(Savitzky & Golay, 1964)
Wavelet transform (WT)	The most effective, and practical approach to denoising UV–vis spectra as well as other spectra to improve the signal-to-noise ratio and decrease root mean square error. It is more efficient to analyze non-stationary process signals and broadband noise signals.	(Zhou et al., 2019), (Huang et al., 2017), (Guan et al., 2018)
Standard normal variate (SNV)	To eliminate the influence of the size of solid particles, surface scattering and the change of optical path on the spectrum.	(Guo et al., 2020)
Multiple scattering correction (MSC)	It can correct spectra by adjusting the scale and offset based on the reference spectrum, which is the average of the spectra.	(Preys et al., 2008)

Traditional Methods Used for Water Quality Monitoring

In different studies, various traditional methods were used to determine the concentration of chemical constituents of the sample waters in Bangladesh. COD refers to the oxygen consumed during the breakdown of organic matter and the oxidation of inorganic matter (Babatunde, 2024). Traditionally COD levels are determined in mg/l using micro-digestion, colorimetry, and reflux distillation with acid potassium dichromate, followed by titration (Verma & Singh, 2013). The COD level in the Buriganga River was detected using the Closed Reflux Colorimetric method, and the maximum value of COD was 212 mg/L in Sadarghat (Salman et al., 2018). Industrial wastewater samples were tested for COD using the Titrimetric technique and found to be 139.21 mg/L, 183.7 mg/L, and 26.90 mg/L in Buriganga, Turag, and Balu rivers respectively (Rahman et al., 2016).

The water samples were obtained from four points across the Buriganga River, all samples were filtered through filter paper with a pore size of 0.45μm, and then measured turbidity by a turbidity meter, nitrate by ion chromatography, color by spectrophotometer, chromium, and lead were determined by high-performance liquid chromatography (Pramanik & Sarker, 2013).The value of turbidity was found in the range of 6.8-28.7 NTU, and the maximum value of nitrate, color, chromium, and lead was 5.6 mg/L, 90.34 TCU, 0.02 mg/L, and 0.254 mg/L respectively (Pramanik & Sarker, 2013). Traditional methods for detecting nitrite nitrogen include chromatography, chemiluminescence, spectrophotometry, and electrochemical methods (Alahi & Mukhopadhyay, 2018). Ten types of water samples were collected from ten different locations in Buriganga River and an Atomic Absorption spectrometer (GBC sensAA) was used for the detection of heavy metals, after that the average concentration of Fe^{2+}, Mn^{2+}, Zn^{2+}, and Pb^{2+} was found 0.17 mg/l, 0.23 mg/l, 0.053 mg/l, 0.28 mg/l respectively (M. S. Islam et al., 2019). Atomic Absorption Spectrophotometer (AAS, AA-6800, Shimadzu) was used to determine the concentration of Arsenic (As) in the Ganges and Brahmaputra rivers and it was found that the average concentration of arsenic in the Ganges river was 1300 ng/l and the average concentration of arsenic in

Brahmaputra river was 908.3 ng/l (S. M. N. Islam et al., 2012). Mladenov et al. (2015) determined the concentration of Dissolve Organic Carbon (DOC) in the groundwater of Araihazar in the Ganges Brahmaputra Delta (GBD) study area using a variety of methods, including the TOC-V CSN Total Organic Carbon Analyzer (Shimadzu) with high-temperature catalytic oxidation and potassium hydrogen phthalate standards. The amounts of 10 heavy metals (Zn, Al, Cd, Pb, Cu, Ni, Fe, Mn, Cr, Co) in surface of the Meghna River near Narsingdi district were measured using an Atomic Absorption Spectrophotometer (Model-iCE 3300, Thermo Scientific, designed in the UK and manufactured in China) (Bhuyan et al., 2017). To determine Total Organic Carbon (TOC), a TOC analyzer (Aurora Model 1030, Autosampler Model 1088) combusted the sample and measured the evolved carbon dioxide using a non-dispersive infrared gas analyzer and found that the TOC levels in groundwater in Shirajdikhan and Srinagar Upazilla varied from 2.4 to 31.4 ppm (mean: 14.4 ppm) (M. Hasan, 2016). The benefits of the spectral method over conventional detection methods are continuous detection, ease of use, and pollution-free operation as the traditional method is a long-term process and creates environmental pollution (Zhang et al., 2023).

Advanced Models Used for Water Quality Monitoring

In different studies, various advanced models were utilized to determine the chemical contents of the sample waters in the world using UV-Vis spectroscopy. The quantity of oxygen needed to break down organic and inorganic substances in water is measured by chemical oxygen demand. Different studies used different methods to measure the COD value of water Samples. L. L. Wang et al. (2013) used partial regression method to obtain characteristics wavelength of UV-vis spectrum which can rapidly detect the COD content in seawater without any preprocessing and secondary pollution and found too much organic contamination in the range of wavelength 200 to 340 nm. J. Li et al. (2019) proposed a turbidity compensation method to detect COD in lake water and showed that the COD absorption region (200-400 nm) of the proposed model performs significantly better than Proportional Compensation (PC) and Multiplicative Scatter Correction (MSC) and after that Partial Least Square Model was used to create a COD prediction model from raw and compensated spectra.A single wavelength (SW) model was used to identify COD in the absorption wavelength of 350 nm for a groundwater sample (Wu et al., 2019). For the simulated water surface, 546 nm absorption wavelength was used to detect COD by using a Single wavelength model (SW) (Youquan et al., 2011). UVE-SPA (uninformative variable elimination- successive projections algorithm) variable selection algorithm was utilized to determine UV-Vis spectrum characteristic wavelength, which was then applied with LS-SVM (Least Squares-Support Vector Machine) modeling to properly estimate COD concentrations in aquaculture water (CAO et al., 2014). To characterize UV-VIS Wavelength Competitive Adaptive Reweighting Sampling method (CARS) was utilized to construct an ELM (Extreme Learning Machine) model that immediately detects aquaculture water COD (X. Wang et al., 2016).

Turbidity determines the cloudiness of a water sample produced by the presence of suspended particles, such as silt, clay, organic matter, microorganisms, or other fine elements. Various studies measured the turbidity of water samples using different methods. Carré et al. (2017) used a Partial Least Square Regression model in the wavelength range 243-400 nm with good predictivity and also found 373 nm from the absorbance as the most relevant wavelength to detect turbidity by the PLS-CCR (correlated component regression) algorithm in a wastewater treatment plant located in the south of France.

Dissolve Organic Carbon (DOC) measures the amount of organic carbon compounds dissolved in water. Different studies measured the DOC of water Samples. Peacock et al. (2014) looked at the suitability of using three distinct wavelengths—230, 254, and 263 nm—as substitutes for the concentration of DOC**.** Avagyan et al. (2014) used MSR (Multiple Stepwise Regression), PLS (Partial Least Squares Regression), and PCR (Principal Component Regression) methods with field data to detect DOC in surface water (bog, fen, and marginal swamp areas) in the range of 250-740 nm in case of online water quality monitoring process. Etheridge et al. (2014) used PLS, Lasso regression, and MSR to detect DOC in surface water in the range of full spectra in the water quality monitoring process. Zhu et al. (2021) used laboratory and field datatype and MSR model to detect DOC and Fe in the wavelength of 250, 290, 307.5, 437.5, 447.5, 630, and 645 nm in the case of online water quality monitoring process. As aromatic humic substances are the dominant source of DOC in natural water, in water treatment plants the absorbance of 254 nm is considered a proxy of DOC and these can absorb light in the ultraviolet range of the electromagnetic spectrum (Guo et al., 2020). Portable, regardless of in situ UV spectrophotometric sensor with high temporal resolution (every 30 seconds) which follows Spectral acquisition, Hybrid Linear Analysis (HLA) Curve fitting algorithm, is used to detect DOC in freshwater (Sandford et al., 2010). Compounds that contribute to the DOC pool typically absorb in the range of 200–380 nm and this method can give better prediction results than the Partial Least Square method (Sandford et al., 2010; Berger et al., 1998; Thomas et al., 1990).

Nitrite concentrations in source-separated urine were estimated using Principal Component Analysis (PCA) in the presence of high nitrate concentrations with UV spectrometry (Mašić et al., 2015). The characteristic wavelength of Nitrate in artificial sampled sea water with PLS (Partial Least Square Regression) was identified in the range of 220-230 nm by using an online UV-vis Spectrophotometer (Hu et al., 2016).

The Single wavelength (SW) particle compensating method is used to decrease the particle's impact over the spectra of raw surface water (Shi et al., 2022). Shi et al. (2022) plotted an absorbance vs wavelength graph and showed that the initial maximum absorbance of the raw surface water was 53 m^{-1} at the wavelength 220 nm, after the application of the SW method, the maximum absorbance of the compensated spectrum became 47 m^{-1} at the same wavelength, the minimum absorbance of the raw surface water was 5 m^{-1} at the wavelength 700 nm, but after the application of the SW method, the minimum absorbance of the compensated spectrum became zero at the same wavelength.

Continuous Projection Algorithm SPA was used to extract the characteristic wavelength associated with nitrite nitrogen and after that, a regression model for nitrite nitrogen was created by fitting the sample and characteristic wavelength using support vector regression (SVR) and it was found that the model was highly applicable to detect nitrite nitrogen (Zhang et al., 2023). By combining UV spectroscopy with the partial least squares support vector machine (LS-SVM) model, a quick quantitative prediction technique was proposed to ascertain the nitrate content in water, and the model's prediction accuracy was greatly increased (Chen et al.,2019). Maguire et al. (2022) showed that Random Forest and Gradient Boosting (GBM) Machine Learning (ML) application outperformed the Partial Least Squares Regression (PLSR), Lasso, and Stepwise Multivariate Linear Regression models in complicated environmental samples using UV-vis absorbance to detect the nitrate in surface water.

Different studies adopted various techniques to determine the heavy metal or metal ions in a water sample. The spectroscopic method applied such as wavelet transform (WT), Savitzky–Golay (SG), Fourier transform (FT), and Partial Least Square Regression (PLSR) to detect zinc, cobalt, and nickel in industrial wastewater by UV-Vis spectrometry where WT, SG, and FT were used to preprocess the spectral data to get the maximum amount of modeling wavelength and to maintain the uniformity of detected ion, and then PLSR was used to detect those ions simultaneously, and it was found that the absorption spectra of Zn (30mg/L), Co (1.2mg/L), Ni (3.0mg/L) at the wavelength of 250-600 nm, and the process is very much suitable for online detection of these polymetallic ions in industrial wastewater but difficult to use this process in wastewater solution (Zhou et al., 2021). Zhu et al. (2021) Collected stream water and used a portable spectrophotometer and estimated Fe^{3+} by Partial Least Square(PLS), Principal Component Regression (PCR), and Multiple Stepwise(MSR) regressions model effectively. The Ag-doped ZnO nanoparticles were synthesized using the preparation method, and after being exposed to ultraviolet light, they successfully detected the heavy metal ions Nickel(II), Copper(II), Chromium(III), Chromium(VI), Iron(II), and Iron(III) and determined the minimum concentration to be 100 μM (Ahmed et al., 2022).The industrial wastewater, biological and soil sample was collected, and Using chromogenic reagents, such as synthesized phenyl hydrazone and glutaraldehyde (GPH), it was discovered that the colourful metal-ligand dimethyl formamide (DMF) exhibited maximal absorbance in heavy metals under pH 6.5-7.5 (Echioda et al., 2021). The following maximum absorption wavelength was determined by applying the GPH method: Arsenic-GPH (395 nm), Lead-GPH (395 nm), Chromium-GPH (360 nm), and Cadmium-GPH (387 nm), and at the same working concentrations, the ligand glutaraldehyde phenyl hydrazone tends to decrease the maximum wavelength of the metal complexes' absorptions, which tends to provide better absorption for UV-Vis spectrophotometric determination of the above mentioned heavy metals with great accuracy (Echioda et al., 2021).

The amount of organic carbon in a water sample, which includes both dissolved and particulate forms, is measured by total organic carbon. Different studies adopted different models to detect TOC in water samples. The multiple linear regression model used 260,265,280,285 nm absorption wavelength to detect TOC in drinking water, seawater, and river water (Kim et al., 2016). The Classical Least Square Vector Machine (LSSVM) technique is a classical modeling method to detect TOC more precisely, with minimum structural risk and excellent robustness (Y. Li et al., 2023). From the above explanation, it becomes apparent that different models are utilized for different purposes due to their wide range of advantages. The advantages of some spectral data models are presented in Table 2.

Table 2 Advantages of some spectral data models

Name of Model	Advantages	Related Articles
Partial Least Square Regression	It can model many dependent and independent variables, can be used in small samples, and easily be calculated.It can also minimize the effect of particles on the water.	(Pirouz, 2006), (Shi et al., 2022)

Support Vector Machine Regression	It can tackle practical problems like short sample sizes, nonlinearity, and high dimensionality.	(Jiao et al., 2014) (Guo et al., 2020)
Multiple Linear Regression	MLR develops the linear correlation between a dependent variable (laboratory results) and an independent variable (raw spectra wavelengths). It reduces particles effect on the UV-Vis spectra of brackish water and accurately measures the water quality parameter.	(Shi et al., 2022), (Etheridge et al., 2014)
Single or Double Wavelength	It is a simple, Well-developed method, that relies on the numerical assessment of predetermined water-quality characteristics	(Hou et al., 2014)
Stepwise Regression	This model offers great prediction accuracy, is simple to use, and keeps significant variables.	(Guo et al., 2020)
Extreme Machine Learning	It contains good training speed and generalization capacity, and It converges much faster than typical algorithms as it trains without iteration	(J. Wang et al., 2022)
Principal Component Analysis	It can capture characteristics wavelength, reduce dimension and simplify the complex data structure.	(Hou et al., 2015), (Guo et al., 2020)

Many studies have tried to use different models to establish the linear relationship between absorbance and water quality parameters and found that Stepwise Regression, Extreme Machine Learning, and Multiple Linear Regression have such type of notable characteristics (Shi et al., 2022).

Water Quality Detection Model

A water quality model for real-time monitoring based on online UV-Vis sensors should be built to gather data continuously, analyze it quickly, and integrate it with automated systems. Figure 5 demonstrates how online UV-Vis sensors are used for real-time monitoring and process control in the treatment of water and wastewater. The untreated water from natural sources like rivers, lakes, sea, and so on or wastewater discharged from residential, industrial, or commercial purposes is collected. After sampling the raw water, single-wavelength monochromatic light is passed inside the UV-Vis sensor. The water quality is analyzed with the help of UV-Vis spectroscopy, which measures the absorption spectrum of the water. This technology is reagent-free and analyzes any data rapidly. The absorption spectra which are produced by UV-Vis sensors indicate the presence of various pollutants and compounds. Such as the absorption spectrum range of nitrate and nitrite is 200-220 nm, conjugated diene, unsaturated aldehyde, and ketone is 220-250 nm, organic matter is 250-380 nm, turbidity is 380-750 nm (Guo et al., 2020).

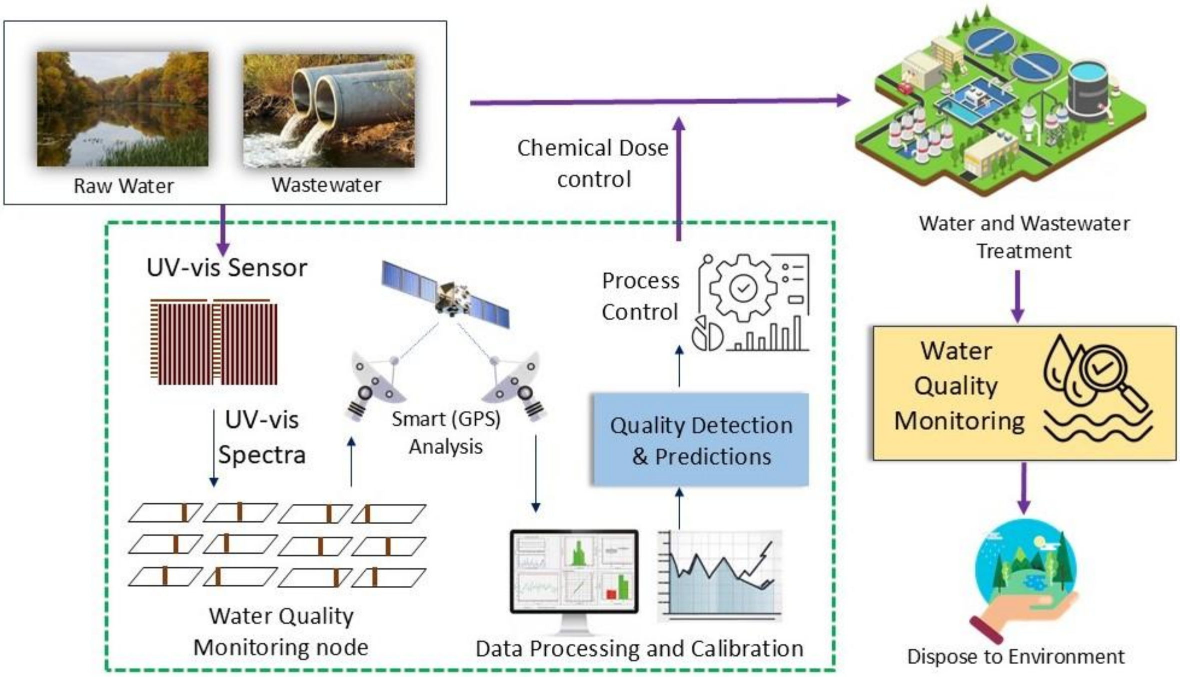

Figure 5 Application of Online UV-Vis Sensors for Real-Time Monitoring of Water Quality and Process Control

Various sensors are used for evaluating the quality of water. The summary of some online UV-Vis sensors is presented in Table 3. The collected data from sensors is analyzed by a monitoring node, which combines and transmits data for further analysis. When online UV-Vis spectrophotometers with inherent algorithms are difficult to use for continuous, accurate measurements, or when the instruments lack built-in algorithms, end users can create alternative particle compensation (calibration) methods like PLS, SVM, MSR, SW, and so on (Shi et al., 2022).

After the smart GPS analysis is completed, integrating spatial data has to allow for real-time geolocated monitoring. Data Processing and Calibration will ensure the accuracy and precision of the measurements. Quality detection and prediction is an algorithm that predicts the water quality parameters. Analysed data guide the treatment process adjustments including chemical dosage management to optimize purification and this is known as process control. Treated water is regularly monitored to ensure safety and environmental criteria before discharge. If the water can be monitored regularly then all sorts of risk can be effectively minimized. Three elements of an anomaly detection method are analysis of data, event detection, and evaluation of the performance that can analyze real-time water quality data to produce a trustworthy indicator of contamination (Zhao et al., 2014).

Treated water is safely disposed of in the environment, resulting in minimum ecological impact. This technology enables efficient, automated, and real-time monitoring, which enhances the quality of water treatment processes.

Table 3 Summary of the General Online UV-Vis Sensor for Evaluating Water Quality

Instrument Name	Producer	Measured Wavelength	obtained parameter	Advantage	Accuracy	Source
UV absorption sensor	Endress+Hauser, Switzerland	254 nm	SAC254	Data logger	±3% /m	(Page et al., 2017)
proPs-UV Photometer	Trios GmbH, Germany	200-385 nm	Nitrate, COD, TOC	Path length customizing	±.01% mg/L	(Sandford et al., 2007)
Real UV254 Probe	Real Tech, Germany	253.7 nm	UVT-254, SAC254	Different pathlength calibration	±5% /m	(De Das et al., 2020)

Spectro: lyser	s::can Messtechnik GmbH, Austria	200-720 nm 220-390 nm	A wide range of Parameters	Various paramet ers differ in length	±2% mg/L	(Lewis et al., 2013)

CONCLUSION

Water pollution is a major threat to public health worldwide. Bangladesh faces serious problems with contamination of surface and groundwater. UV-Vis spectroscopy is an advanced technology that provides fast and accurate measurement of water quality parameters like COD, turbidity, nitrate, and heavy metals. UV-Vis spectroscopy offers numerous advantages for water quality monitoring due to its efficiency and accuracy. One of its key benefits is the ability to provide continuous detection with ease of use and minimal environmental impact compared to traditional methods. Spectral methods effectively reduce the effects of particles in water, enabling better prediction results for parameters like COD and DOC. Advanced models such as Partial Least Square Regression (PLSR) excel in handling multiple variables and minimizing particle effects. Support Vector Machine Regression (SVR) addresses challenges like nonlinearity and high dimensionality, ensuring robust analysis even with limited samples. Multiple Linear Regression (MLR) establishes strong correlations between spectra and water quality metrics while reducing particle interference. Stepwise Regression simplifies variable selection and offers high prediction accuracy, making it a reliable choice for water quality studies. Extreme Machine Learning (ELM) is noted for its fast training speed and strong generalization ability, making it efficient for rapid analysis. Single and double wavelength models provide straightforward numerical assessments of specific water quality parameters. Principal Component Analysis (PCA) captures characteristic wavelengths and simplifies complex datasets by reducing dimensions. Techniques like UVE-SPA and CARS optimize variable selection for more accurate predictions. Portable UV-Vis spectrophotometers with high temporal resolution enable real-time monitoring, further enhancing their utility. These models provide a scalable and flexible approach for diverse applications, including detecting organic carbon, turbidity, heavy metals, and nutrients. Their adaptability across different water types and conditions underscores their significance in modern water quality monitoring. Consequently, UV-Vis spectroscopy, paired with advanced models, continues to be a cornerstone in sustainable and efficient water quality management. A real-time water quality monitoring model utilizing online UV-Vis sensors provides continuous data collection, rapid analysis, and integration with automated systems. These sensors analyze water using UV-Vis spectroscopy, a reagent-free method measuring absorption spectra to detect pollutants such as nitrates, organic matter, and turbidity across specific wavelength ranges. The collected data is processed through calibration techniques (e.g., PLS, SVM) and GPS integration for geolocated monitoring, enabling accurate quality prediction and treatment optimization. This technology ensures effective process control and environmental safety, minimizing contamination risks. A summary of online UV-Vis sensors highlights their ability to measure parameters like SAC254, nitrate, COD, and UVT-254 with high accuracy

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