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Detection of Chemical Contaminants in Water for Irrigation Systems: A Systematic Review

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ABSTRACT

Water pollution is a detrimental issue that occurs when there are bad changes in water quality parameters. It directly disrupts water usage and poses a danger to society, environment, economy, and agriculture. Water quality should be monitored to alert authorities on water pollution, so that action can be taken quickly. Improper water management pollutes rivers and lakes in Malaysia such as Klang River, Semenyih River, Kim Kim River, Slim River, and others. Various techniques are introduced to detect contaminants in water such as electronic sensors, biosensor approaches, laboratory analysis, and optical techniques. The functionality tool varies depending on the specific contaminants or parameters that are targeted, and the resources allocated. Several common contaminant types are found in polluted water including heavy metals, organic and inorganic chemicals, industrial pollutants, suspended solids, and others. The objective of the review is to study various non-optical and optical contaminant detection methods in water to identify the strengths and weaknesses of the methods. In this review, water pollution problems mainly due to the agricultural sector in several countries are discussed. Besides, conventional, and modern methods are compared in terms of parameters, complexity, and reliability. We believe that conventional methods are costly and complex, whereas modern methods are also expensive but simpler with real-time detection. Recent contaminant detection methods in water are also reviewed to study any loopholes in the latest methods. We found that the spectroscopy method based on light propagation theory is suitable and one of the promising methods for chemical contaminants detection for water quality analysis. This method offers fast analysis time, high sensitivity detection, non-invasive analysis, provides reliable data, and others. Undoubtedly, some contaminants in water can be challenging to be identified rapidly and confidently even though there are numerous tools and techniques available for water quality analysis. Thus, the review is important to compare previous methods and to improve current chemical contaminants detection analysis in terms of reliability with a minimum operating system and cost effectiveness.

Keywords:
Water pollution; chemical contaminants; agriculture; sensing methods; spectroscopy

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1. Introduction

Water is a crucial resource for the entire human population [1]. In Malaysia, the primary water source comprises of 99% surface water for domestic usage and 1% groundwater [2]. Despite our country has abundant water resource, the accelerating pace of industrialization, agricultural expansion, urban development, and population growth recently has impacted the water quality. States with large numbers of industrial areas and factories such as Selangor, Johor, Penang, and Perak, exhibit elevated levels of river pollution compared to others. During the Covid-19 pandemic, 160 cases of river pollution were reported and enforcement was taken during the Movement Control Order (MCO) period from March 18 to May 4, 2020 [3]. The imposed restrictions on business operations, human mobility, and anthropogenic activities have directly manifested positive impacts on the water quality index [4]. The foremost anthropogenic contributors encompass industrial operations, sewage disposal, agricultural practices, and animal husbandry activities.

In Malaysia, we are endowed with ample and sufficient water resources that act as a catalyst for socio-economic country development and environmental well-being. Due to high-rate population growth, expansion of urban areas, industrialization, and irrigated agriculture expansion, the demands of water resources increase and concurrently contribute to the water disruption and deterioration of water quality [5]. Without adequate awareness of the importance of quality water management, hydrologists have cautioned that Malaysia is at risk of encountering a water crisis by 2025 [2]. Water pollution in Malaysia gives severe problem and we need a practical solution to tackle this issue. It harms the sustainability of water resources and causes degradation of water quality. Physical, chemical, and biological contaminants contaminate the water supply can be detected in the water samples. As an example, Kim Kim River in Johor faces a toxic chemical pollution issue that give adverse disruptions to the water supply for around 20,000 households [2]. Semenyih River in Selangor also has been contaminated due to deliberate discharging of wastewater into the river and causing water supply disruptions to 463 areas in Selangor and Putrajaya [6]. A water supply disruption due to river pollution incidents has impacted 309,687 consumers across four districts in the Klang Valley [7]. Additionally, Malaysia has 25 rivers categorized under Classes 4 and 5, where the rivers are highly polluted and unsuitable for sustaining aquatic life [8].

2. Water Quality Effect from Agricultural Activities

2.1 Other Countries

Approximately 40% of the total land area in the United States is dedicated to agricultural activities, primarily dependent on water resources for irrigation [9]. Annually, around half a million tons of pesticides, 12 million tons of nitrogen, and 4 million tons of phosphorus fertilizer are applied to crops in the United States [10]. Besides that, the US Geological Survey (USGS) identified several pesticides in over 90% of water and fish samples collected from US streams [11]. According to the National Water Quality Assessment in the United States, agricultural runoff is acknowledged as the primary contributor to water quality impacts on rivers and streams [10]. In addition to nutrients and chemical pollutants, emerging contaminants such as heavy metals show an increasing trend in soil and water bodies [12]. The impact of excessive use of metal salts in agricultural soils from unproperly treated irrigation water is severe and can cause crop losses. Inversely, the runoff and infiltration transport of these chemical contaminants into local streams, rivers, and groundwater causing water pollution. In terms of phototoxicity, the toxicity of chemicals can give a negative effect on the structure and function of cellular components of crop plants while impeding various metabolic and developmental processes [13,14].

Moreover, Mexico stands as a prominent economic force in Latin America, grappling with environmental challenges such as excessive utilization of pesticides due to high availability and convenient cost of agrochemicals, flexible environmental laws, and attempt to fulfil the global demand for agricultural commodities [15]. Agricultural activities which are not well-monitored and managed such as the excessive use of pesticides, fertilizers, nutrients, heavy metals, metalloids, sewage irrigation, and improper waste management can contribute to the contamination of surface water and groundwater sources [16,17,13]. Besides that, in Mexico, water resources contain pesticides that ultimately contaminate lakes or rivers, exposing residents of multiple villages to harmful leachate [15]. Pesticide contamination also had been reported in the surface water in the Bohai Sea and the Yong-ding River of China [11]. The Yangtze or Chang Jiang, ranked among the three largest rivers globally, faces significant pollution issues due to the discharge of industrial wastes and the extensive use of fertilizers in farming [18].

Next, continuous agricultural irrigation using wastewater increases the chemical metals concentration in water, soil, and plants, and thus imposes risks in bioaccumulation in foods in Kandahar, Afghanistan [19]. A major industrial site in Punjab, Pakistan faces potentially harmful metals groundwater contamination as 748 industries in that area produce huge amounts of waste and effluent which contaminate the environment with harmful and toxic materials [20]. Arsenic-contaminated groundwater used for irrigation has been reported in many countries across the world and countries like Bangladesh, India, Vietnam, and China [21]. Consequently, excessive, and long-term usage can contribute to health risks. It can give harmful effects on human health from daily contaminated food consumption such as cancer, hormone imbalance, respiratory and cardiac disorders, and other serious diseases [22,23]. This is because chemical metals can enter food chain in different forms. Therefore, monitoring and detecting chemical contaminants in water from agriculture resources are needed to preserve water quality.

2.2 Malaysia

The correlation between land utilization and the deterioration of water quality in Malaysia has been studied. The findings indicate that primary contributors to water pollution are urban and agricultural land uses, as well as forest land use and other types of land [24]. Agricultural pollutants comprise pesticides, heavy metals, sediments, nutrients, and organic substances that impact the physical and chemical characteristics of water. n Malaysia, farmers, particularly those engaged in paddy cultivation, commonly employ pesticides for pest control [25]. It also directly harms the health of agricultural workers [26]. The Malaysian government subsidizes pesticides to promote agricultural productivity and income. The substantial use of pesticides in Malaysia is linked to the ongoing agricultural advancements in the country, where farming practices involve the application of pesticides across various crops such as vegetables, fruits, paddy, rubber, and palm oil plantations [27]. Nevertheless, extensive and unrestrained use of pesticides raises health concerns, as over 95% of applied pesticides disperse into the environment, adversely affecting non-target organisms [28]. Chemical pesticides are preferred, effective, and regularly utilized in agricultural fields [28].

Paddy is one of the most significant crops in Malaysia in the food subsector after rubber and oil palm plantations [28]. Due to excessive fertilizer usage in the paddy field, the water analysis conducted by FELCRA Seberang Perak, Malaysia shows that phosphate, aluminium, and iron concentration exceed the National Water Quality Standard Class IV [29]. The clean irrigation water used in rice fields also decreases due to planting activities. Typically, water from paddy fields is released directly into the drainage system, where residues from the applied agrochemicals can contaminate drains and receiving waterways. Other than that, paddy plants also tend to accumulate heavy metals from both natural and anthropogenic sources. There is an investigation of metal contaminations in paddy plants in Kelantan, Malaysia [30]. The levels of arsenic, cadmium, lead, copper, and chromium in both paddy soils and plants, gathered from three distinct regions within the paddy field (Kota Bharu, Pasir Mas, and Pasir Puteh), remain within the permissible limits established by applicable standards. Consequently, the soils and rice grain were safe for agriculture and consumption respectively. However, the accumulation of certain heavy metals in the rice grain may potentially lead to adverse health effects.

The impact of chemical pesticides is also associated directly with the farmer's health and the environment for a long period based on a cross-sectional study in 19 palm oil plantations Sabah, Malaysia to evaluate the perception of farmers towards pesticides and health effects [31]. Pesticide Action Network Asia Pacific (PANAP) urges the Malaysia Ministry of Agriculture and Food Industries (MAFI) to give paddy farmers support for safer, non-chemical alternatives to pesticides [26]. A recent study also shows that worldwide crop yields decline in farming areas that are highly dependent on pesticides due to soil and biodiversity degradation and destruction of natural resources [26]. However, pesticides are widely used, and the demand is increasing due to current method of crop production, which prioritises high agricultural yields [32]. Overall, pollutants are originated from various sources and adversely drive negative consequences mainly to human health, ecosystems, agriculture, and others. The severity of water pollution can vary depending on the concentration of pollutant, the location of pollution, and the sensitivity of the affected ecosystems.

3. Chemical Contaminant Types

Various types of pollutants have contributed to water pollution which comes from multiple sources. Globally, around 40% of deaths occur due to contaminated water [33]. The contaminant can be detected through chemical, physical and biological properties [34]. Chemical contaminants are elements or compounds that are not naturally found in water. Despite the release of high amounts of untreated wastewater and industrial compounds, agriculture remains the main source of chemical contamination [35]. Water near agricultural areas contains harmful material from pesticide and fertilizer applications. Anthropogenic activities include industrial production, agricultural sector, domestic activities, and sewage discharge contribute the most to the increasing amounts of chemical contaminants found in aquatic environments [36,37]. Sources of metals in the agricultural sector are fertilizers, pesticides, biosolids, manure, wastewater, and others [38,39]. The toxic and not biodegradable contaminant can induce multiple organ damage and diseases even at very low concentrations.

Furthermore, pesticides and fertilizers are agrochemicals that have become an integral part of modern agriculture to boost agricultural productivity and yields with relatively less effort [40]. Fertilizer typically provides various proportion of main macronutrients, secondary macronutrients, and micronutrients [41]. The main macronutrients which is chemically inorganic synthesized compounds used in fertilizer are nitrogen (N), phosphorus (P), and potassium (K) [42]. While the secondary macronutrients consist of Calcium (Ca), Magnesium (Mg), and Sulphur (S). Example of micronutrients are Copper (Cu), Chlorine (Cl), Iron (Fe), Manganese (Mn), Zinc (Zn), Molybdenum (Mo), Boron (B), Silicon (Si) and others that needed by plants in relatively smaller quantities than the macronutrients. The macronutrients are consumed in larger quantities and present in plant tissue to promote plant and root growth, increase plant size, reproduction, regulate water balance, enhance disease resistance and others. Asia is the largest consumer of nitrogen, phosphorus, and potassium from inorganic fertilizers, while Oceania and Africa consume the least [43]. Meanwhile, the major functions in plants of micronutrients are enzyme activity and pigmentations, chlorophyll formation, enzyme activations, and cellular development [44-46].

For pesticide contributions, herbicides account for 47.5%, followed by 29.5% of insecticides, 17.5% of fungicides, and others [47]. All pesticides include substances to control pests. There is a study of the concentration of trace heavy metals in various pesticide formulations (solid, liquid, and gaseous) determined by spectrometry [48]. Types of metals that can be found in pesticides and fertilizers are arsenic (As), Cadmium (Cd), Lead (Pb), Nickel (Ni), Chromium (Cr), Zn, Cu, Fe, and others [49,50]. Cu, Zn, and Cd have higher accumulation potential in agriculture soil due to the long-term use of fertilizer [51]. Agrochemicals used to boost the crop productivity but have significantly negative effects on plant growth, soils and waters if used in excessive amounts and lack of sustainable agricultural practices [52,40]. Systematic monitoring to detect chemical contamination concentrations due to the usage of fertilizers and pesticides in environmental compartments such as air, surface water, groundwater, and soil is only conducted in some parts of the world [43]. The monitoring of adverse effects on non-target organisms or human is virtually absent in low-income and medium-income countries and is rare even in high-income economies. Therefore, there is a need for better farming practices and regular monitoring of chemical-based contaminants from agrochemical sources that can adversely influence the agricultural ecosystem (plant, soil, and water) and human health [53].

4. Water Contaminant Detection Techniques

4.1 Non-Optical Techniques

The water treatment plant and water distribution system possess specific tools for monitoring water quality. To develop robust and efficient techniques, extensive research has been conducted over the past decades, focusing on detection and monitoring analyses [54]. Until now, there are limitations in existing tools to detect pollutants, necessitating enhancements in water quality assessments with regard to sensitivity, both quantitatively and qualitatively. The availability of in-situ measurements and multiple detection analysis has broadened the monitoring applications in various cutting-edge techniques to produce hand-held sensing devices that improve the portability on a real-time basis for pollutant detection. Hence, it is crucial to ensure a safe water supply, especially in areas that constituted a wide array of human activities. In aquaculture, the economic constraints and high costs of human resources have presented a longstanding challenge for farmers in achieving real-time intelligent monitoring for pollutant detection [33].

Thus, finding comprehensive solutions with rapid response, reliable, sensitive, robust, selective, inexpensive, easy to operate, portable, and miniature detection methods to monitor the quality of water has become authorities' concern and a topic of high interest to researchers [55,56]. The development of new techniques that allow real-time measurement of more advanced contaminants detection remains a subject of future study and requirements for further development even though there are several advanced options available [57]. Other than that, challenges still exist in practical applications especially when facing unknown contaminants.

Here, we categorize water contaminant detection into two sections which are non-optical and optical techniques. For non-optical techniques, various detection methods are conducted practically including laboratory-based analysis, electronic sensors, biosensors, toxicity tests, adenosine triphosphate (ATP) measurement, polymerase chain reaction (PCR), and others [58,56,55]. Meanwhile, optical sensors and spectroscopic approaches are examples of optical water contaminant detection techniques. Generally, selecting suitable detection techniques following the purpose of intended detection analysis requires quantitative, qualitative, or hybrid measurement.

4.1.1 Laboratory-based analytical methods

Conventionally, laboratory-based analytical methods are often conducted manually to detect water pollution [58]. The assessment of water quality has traditionally involved the manual collection of samples, which are then dispatched to a laboratory for thorough analysis [33]. This analytical process, conducted by a proficient individual, yields precise parameter detection results, however, the approach does not offer real-time data. Conversely, this technique is more time-consuming, and expensive, required analytical equipment, involves chemical materials, can be labour intensive, prone to data inaccuracies, and is inefficient for on-site monitoring applications [59,60,57]. Undoubtedly, conventional methods provide high sensitivity, good accuracy, and high specificity results with lengthy analysis [55]. Despite having many advantages, the lab-based method also involves complex early steps for sample preparation, required sterile laboratory conditions, and needs to be handled by highly qualified individuals for equipment operations [61]. Hence, manual standard laboratory analysis prohibits the integration into continuous or on-site monitoring systems. In recent years, automatic detection of water pollutants systems is well-developed and become more common as numerous basic measurements can be carried out by online instrumentation due to information technology. The low-cost sensor has increased the feasibility of monitoring via wireless sensor networks (WSN).

4.1.2 Electronics Sensors

Electronics sensing is an important alternative to conventional detection technique which allows rapid and real-time analysis with reproducible results. Electronics sensors especially for biological and chemical contaminants detection receive great demand as they are promising feasible device for integration and commercialization. Subsequently, deploying the water quality electronics sensor devices can improve the level of detection sensitivity in the water distribution systems by allowing several parameters measurement [54]. Examples of common water quality parameters measured are temperature, pH level, turbidity, conductivity, oxidation-reduction potential (ORP), and others. Sensors also have low production costs, real-time and continuous monitoring, and portability [62]. There is a case of intentional sabotage of raw water in Sungai Selangor with the diesel spillage causing major water disruption in the Klang Valley [63]. This issue triggers awareness for fast response detection to determine the presence of contamination in the water and the need for installing high-accuracy sensors with the water distribution system. Yet, it seems not very practical for numerous sensors because of high-cost installations. However, to obtain early irregularities of water quality with optimal time response from sensing mechanisms, multiple sensor data station on-site is more beneficial compared to the data from a single site.

The advancement of sensor and wireless communication technologies is fostering the widespread adoption of the Internet of Things (IoT) across diverse applications [64]. Over the last decades, the continuous development of IoT smart solutions allows real-time measurement of the quality of water for many applications and getting more significant nowadays [65,66]. The integration of digital and IoT technologies has the potential to revolutionize traditional farming practices into smart farming systems that capable in terms of controlling irrigation systems, remote sensing, monitoring soils and crop, managing water, and others [67]. Moreover, the efforts to develop monitoring systems by using different WNS and IoT technologies have received significant attention [68]. As a result, various recent non-optical water quality methods monitor and detect common water quality parameters which integrate multiples electronics sensors with IoT for real-time detection [59,64-74]. For example, Bogdan has devised an economical IoT water testing solution employing Arduino and Bluetooth modules to measure multiple water parameters from different sources in rural areas. This system is overseen and controlled through a mobile application, providing real-time status updates on water sources and issuing warning messages in the event of contamination [65]. Fast methods for measuring conductivity, dissolved oxygen, and temperature. Next, a recent investigation has been conducted to assess the pH, temperature, turbidity, electrical conductivity, and oxidation-reduction potential of river water, lake water, and tap water in Malaysia [75]. This study utilized Arduino as the primary controller, employing five sensors to measure various physical parameters. Another water quality monitoring system to analyze water from multiple sources including rivers, lakes, tap water, and filtered machine has been developed by integrating a sensing framework with a decision support method applicable in the agricultural sector [76]. The system incorporates four sensors; pH, temperature, ORP, and EC—controlled by an Arduino. It employs fuzzy logic to facilitate decision-making processes related to water quality assessment. pH, turbidity, total dissolved solid (TDS), and other common parameters are already implemented in many systems, and they are continuously becoming more robust and reliable. Nevertheless, this approach is better suited for monitoring water quality as it lacks the capability to identify particular water pollutants.

4.2 Optical Techniques

Another known method that is widely used for accessing water quality is optical detection technique. Optical detection technique is a system that manipulates the characteristics of light such as transmission, absorption, and fluorescence spectrum for measuring and identifying the concentration or properties of substances [77]. Concentration of suspended solids, size or properties of pollutants, presence of chemicals, and other matters are the characteristics of water that can be assessed by employing optical sensing devices [62]. Optical sensors and spectroscopy can be used to detect contaminants in water.

Spectroscopy is an example of optical techniques that is still used in many applications and evolves throughout the years. The level of complexity and sophistication of optical instrumentations can range from full-complex spectrometers with various types of light source and dispersion detection that can record full optical absorption profiles to low-cost devices that can measure the transmission of water at specific wavelengths and access common parameters such as colour change or cloudiness. Spectroscopy is suitable for water quality detection since the technique is highly reliable, precise, sensitive, quick-response, accurate, and non-intrusive technology [77]. However, the lab-based spectrometer has some drawbacks such as complicated to use, bulky equipment, expensive, requires an expert to handle, and takes time to read and analyze data. Lack of real-time monitoring is the main limitation of the lab-based spectrometer leading to the innovation of the portable spectrometer that still maintains high quality parameter detection but relatively simple and reliable instruments.

4.2.1 Optical sensors

The principle of optical sensors involves sensing of light propagation through a medium and the light is detected by a photometer [78]. There are some advantages of using the optical sensing technique such as high resolution, accuracy, free chemical, high throughput, fast response time, small footprint, and provide additional optical information in spectra. Despite that, it can be expensive for some devices, with high maintenance costs, and susceptible to interference from environmental effects. Optical density-probes, optical biosensors, fiber-optic sensors, in-situ microscopes, near-infrared sensors, fluorescence sensors, refractometers, and ultra-violet sensors are a few examples of optical water sensors [79]. Optical sensors rely on the absorbance, transmittance, fluorescence, or scattering properties of materials that are dissolved or suspended in water. Furthermore, an optical colorimetric sensor (OCS) is employed for assessing qualitative variations in water quality attributed to opacity or color alterations resulting from pollution. This is achieved through the measurement of transmission using different colored LEDs [80]. The OCS can measure the change in optical signal along two different optical paths which are transmitted and scattered. The result shows a strong linear correlation between the optical signal response and turbidity concentration. The changes in solid suspended scattering of algae blooms can also be detected using this device. Besides that, the optical methods including the colorimetric, scattering, and fluorimetric can detect inorganic arsenic contaminants based on the coupling of organic or biological molecules with inorganic nanomaterials [81]. Table 1 lists recent methods of water contaminants detection based on optical sensing technology.

Table 1
Previous research of optical sensors for water contamination detection

Authors	Research descriptions	Parameters measured	Methods/ Devices	Real-time monitoring
[79]	Review of optical biosensors and the applications for water pollution detections. The most useful biosensor is an SPR-based biosensor which computed the SPR principle and has an advantage over fluorescence biosensors as it can reach lower detection limits. The challenges to develop optical biosensors are device miniaturization, biological recognition elements stability, and device reusability. This paper delineated 67 articles discussing the utilization of optical biosensors for the identification of various environmental water contaminants.	Biological elements such as enzymes, antibodies, DNA/RNA, cells, proteins, and others.	SPR-based biosensors, optical transducers used for biosensors are SPR, fluorescence, interferometer, optical resonators, fiber optics, gratings, and others.	-
[81]	Review of recent advancements in colorimetric, scattering, and fluorimetric analysis of inorganic arsenite, and arsenate. Colorimetric methods offer benefit of easy visual observation, yet there is a necessity for enhanced selectivity and stability. The scattering methods usually involve high sensitivity with limited stability, and the fluorescence assays always depend on smart probe design and complex signal manipulation. Prospective research in arsenic detection should focus on achieving simpler manipulation, faster response times, increased sensitivity, and improved selectivity.	Inorganic arsenic (arsenite and arsenate)	Colorimetric, scattering, and fluorimetric strategies	No
[82]	An optical real-time bacteria sensor detection of contaminated drinking water from four different pollution events. The applied sensor utilizes 3D image analysis of each suspended particle, and the result is comparable to laboratory-based tests. For non-coloured samples, the number of particles detected by the sensor correlated with the turbidity value. The value of particle total concentrations and turbidity has shown a good correlation.	Bacteria and abiotic particle, turbidity, total direct cell count (TDCC)	Optical bacteria sensor, abiotic particle sensor, (Adenosine triphosphate) ATP for bacteria measurement	Yes

[83]	A cost-effective and energy-efficient planar interdigital phosphate sensor designed for smart agriculture utilizes Multi-Walled Carbon Nanotubes (MWCNTs) for electrodes and Polydimethylsiloxane (PDMS) for substrate formation. This sensor is capable of distinguishing concentrations of phosphate solutions within the range of 0.01 to 40 ppm. The system, based on Arduino, incorporates a machine learning model trained to predict phosphate concentrations in real water samples. With minimal training, farmers can employ the system to regularly monitor water nutrient levels.	Phosphate	AD5933 impedance analyser, phosphate sensor, Arduino Uno, Thingspeak	Yes

4.2.2 Spectroscopy methods

Nowadays, spectroscopic techniques have continuously upgraded the detection sensitivity, quantitatively and qualitatively for detecting contaminant. Many spectroscopy methods have been analyzed for water monitoring technology such as vibrational spectroscopy, light emission or luminescence spectroscopy, raman spectroscopy, infrared (IR) spectroscopy, near-infrared (NIR) spectroscopy, fluorescence spectroscopy, UV-Visible (UV-Vis) absorption spectroscopy, atomic absorption spectroscopy (AAS), and others [81]. Generally, optical spectroscopy methods can detect even the smallest traces of certain chemical elements in a sample [84]. In other words, it can be used to determine chemical composition through propagation of light. This method is suitable for contaminant detection. Valuable information can be acquired based on the amount of light absorption and its wavelength absorbed by the sample [85]. Light absorption can be used for characterizing and quantitatively determining substances. As a result, each substance exhibits distinct light absorption patterns, establishing a distinctive and specific correlation between the substances and the light spectrum [85]. Hence, the spectrum can be used to identify or quantify substances. The profile of the absorption peaks also allows specific compounds to be identified [85]. In fact, the concentration of certain substance in solution can be determined by measuring the absorbance at the specific wavelength [85]. Each chemical compound capable to absorb, transmit, or reflect electromagnetic radiation within a specific wavelength range [86]. To elaborate, the spectrometer enables the identification of particle composition and size distribution in samples through their optical properties [87]. Figure 1 illustrates a fundamental spectroscopy diagram, incorporating components such as the light source or laser as an emitter, samples, detector, and spectrometer for spectral analysis [86].

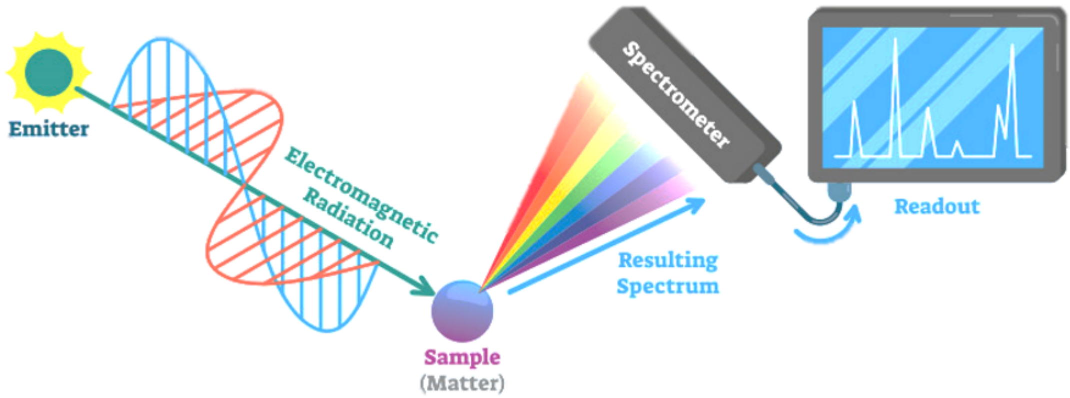

Fig. 1. Spectroscopy diagram [86]

Near-infrared (NIR) spectroscopy with a 1.0– 2.5 µm wavelength range is an alternative method that can determine total dissolved solids (TDS) parameter with several advantages such as simple sample preparation, non-invasive sampling, rapid detection, and pollution-free since no chemical materials involved [88]. Within IR spectroscopy, the middle infrared (MIR) spectroscopy with a 2.5–16 µm wavelength range is the most advanced method for analyzing molecular structures, primarily because most fundamental transitions occur within the MIR spectrum. However, due to the strong light absorption of water in MIR, special care is usually taken when conducting measurements on liquid samples. Even though MIR spectroscopy is well-established compared to NIR spectroscopy, it is a well-known technique to detect inorganic materials. NIR is more suitable for direct measurement of the liquid sample because water absorption in the NIR is weaker than in MIR.

Another research on irregularities water quality has been done based on UV-Visible (UV-Vis) spectroscopy to study the natural matrices and pollutants. Analyzed contaminants from water distribution through UV spectroscopy have rapid, direct, good sensitivity, wide availability, and low application cost. This technique can determine parameters such as total suspended solids (TSS), dissolved organic carbon (DOC), chemical oxygen demand (COD), biochemical oxygen demand (BOD), detergents, and nitrogen, this is because the materials are able to absorb electromagnetic radiation at a different wavelength [89]. High amounts of organic compounds and suspended solids are found in the washing water and wastewater in the on-farm packhouse from the extraction of UV-Vis absorbance spectra. Size of suspended particles can be obtained by integrating UV-Vis spectroscopy with laser granulometry analysis for a better physical absorption [90]. Fluorescence spectra in three dimensions (3D) can provide more complete spectral information and thus, better performance in a lower detection limit. Spectroscopy method depicts low-cost, rapid response, and acceptable data quality standard which shows that it is a reliable contaminant detection technique that can be easily integrated into water flow systems. It can complement the conventional method which are expensive, time-consuming, and unfriendly tools that require special laboratory conditions and equipment. Indeed, water pollutant detection needs to have a fast-paced innovation from conventional methods to emerging advanced technologies for tackling the water quality issue since it is highly correlated and influenced by human activities. Table 2 summarizes the developed spectrometer projects that have been conducted in previous studies.

Table 2
The spectrometer that has been discussed in the previous studies.

Year & Author	Research descriptions / Methods	Contaminant measured	Research gaps
2023 [91]	Designed a portable spectrometer utilizing ESP32 technology for the identification of chemical contaminants in irrigation water through the observation of light absorbance. The primary components employed include ESP32 as the main controller and a photodiode as the detector. The research demonstrates that different contaminants exhibit light absorption exclusively within specific wavelength ranges, dependent on the concentration of the samples.	Ammonium nitrate, organic pesticide, zinc oxide and two different reservoirs used for irrigation	*Not vary samples concentrations. *Only covers visible spectra. *Do not have spectrometer modeling.
2022 [92]	Designed a wireless spectrometer employing Arduino technology, adapted from an old Raman spectrometer. The Arduino program controls the stepper motor to regulate the rotational movements of the mirror and grating turret within the spectrometer. This configuration facilitated the	Silicon wafer, 4-nitrobenzenethiol, and rhodamine 6G (Raman probe molecule)	*Not vary samples concentrations. *Only covers Raman spectra.

	measurement of Raman spectra, with the prominent peak in the Raman spectrum of a silicon wafer identified at 519 cm−1.		*Customized the commercial spectrometer to construct wireless device. *Do not have spectrometer modeling.
2021 [93]	Developed spectrometer for metal concentration prediction uses white LED and commercially imported 6 channel spectral sensor (AS7262) for visible radiation reception. This system demonstrates good accuracy to predict heavy metal concentration in water samples. The incorporated spectral sensor captures the visible spectrum within the 400 to 700nm range, featuring a resolution of 30nm. It also used Atmega-328P based controller unit and enabled Android application for data visualization. The highest average transmittance peak is at 550nm. Validated of developed spectrometer system with commercial system for unknown concentration of samples.	0.001 to 5 ppm of copper and iron metals.	*Used commercial spectrometer sensor, not study on slit or any dispersion element. *Available for visible spectrum only. *Do not have spectrometer modeling. *Validate the result with commercial spectrometer. *Has battery status monitoring. *Not refer to any water quality standard for water samples.
2021 [94]	A cost-effective and portable 2-in-1 UV–Vis spectrophotometer, utilizing Arduino technology, has been created for the quantification of proteins and nucleic acids. The device is seamlessly integrated with an Android smartphone application via Bluetooth. The system is designed to detect light wavelengths within the range of 190–1100 nm, with UV and visible LEDs, as well as a photodiode, being utilized. The sensitivity and limit of detection of this system were evaluated by comparing them with a commercially available spectrometer.	Protein and nucleic acid.	*Available for UV and visible spectrum. *Do not have spectrometer modeling. *Not include slit and grating in the developed spectrometer.
2021 [95]	Investigates the quality of milk samples, both freshly opened and after being stored at room temperature for a few days using commercial spectrometer and applying scattering theory. The optical properties such as absorption, reflectance and transmission were observed using VIS and NIR spectrometers. The modelling using MATLAB based on Mie scattering theory was done to compare the light propagation in milk, water, and air. The results of the modeling indicate that milk scatters light more significantly than water and air due to the presence of fat globules, proteins, and minerals.	Milk samples	*Used wavelength ranges of NIR and VIS-NIR. *Not develop hardware-based spectrometers. *Not specifically spectrometer system modelling. The modelling part is used to determine the characteristics of light in a disordered medium.
2020 [96]	A cost-effective imaging spectrophotometer system is employed, comprising a halogen lamp for visible light, a CMOS camera as the detector, a collimator slit for parallel light, and monochromatic filters as a wavelength selector. The intensity of light transmission after passing through the sugar solution sample was measured based on the grey values in the sample images. The maximum absorbance for various sugar types is identified with violet light at 475.02nm. The analysis utilizes image analysis to determine the absorbance information of the molecule, which correlates with the concentration changes in the solution. The wavelength of the filter output is	Three types of sugar solutions (glucose, fructose, sucrose) with varied concentrations.	*Radiation source used is only visible light. *Do not have spectrometer modeling. *Not validate and compare the output from commercial lab-based spectrometer. *Not discuss the optimum distance or location of each component used for better design optimization. *No smartphone integration.

	determined using a conventional lab-based spectrometer.		
2020 [97]	A low-cost standalone customizable and portable spectrophotometer is capable of assessing absorption within the wavelength spectrum spanning 450 to 740 nm and employing a single warm light LED from Nichia Optisolis. The open-source mini spectrophotometer (OSMS) device is based on the Hamamatsu C12880MA spectrometer chip, used in a transmission configuration. 3D casing model was created in Autodesk Fusion 360 software. Opting for a black color enhances performance outcomes and diminishes reflectivity from internal surfaces. Android application was integrated and can display full absorbance spectrum mode and single wavelength mode.	Vitamin B_{12}, phosphate, horseradish peroxidase (HRP)	*Data displayed and easily viewed via smartphone or computer interface. *The spectrometer chip used only cover for visible range. *Do comparison with commercial spectrometer. *Do not have spectrometer modeling.
2019 [98]	A simple spectrophotometer design using LED as light source and Light Dependent Resistor (LDR) sensors based on Arduino. The light-detecting sensor can accurately measure light intensity within the wavelength span of 380 to 750nm. The Arduino-controlled stepper motor and motor driver facilitate the rotation of the light source, allowing the selection of specific color spectrums transmitted through the sample. To configure the stepper motor's movement or rotation for color selection, a 4x4 matrix keypad is utilized in this system. The dye solutions used to test the developed spectrometer.	Varies copper sulfate concentration, green and red food dye solutions.	*Visible light spectrum range. *Not integrate with smartphone. *Not validate the result based on the commercial spectrometer. *Not measure and calibrate the light wavelength passes through samples accurately.
2018 [99]	A simple Arduino-based spectrophotometer features a white LED as a light source for analyzing solution concentrations. The system utilizes a continuous light spectrum extending up to 620nm. Commercial standard UV-Vis spectrophotometers encounter limitations when analyzing concentration less than 50 ppm, but the developed system surpasses such constraints because the measurement is based on the LED light being penetrated. Use glass cuvette and BH1750FVI light sensor. The concentration of curcumin is directly linked to color and turbidity, with distinct absorption patterns identified. The main peak was detected at wavelength of 280nm. The primary peak is discerned at a wavelength of 280nm. To increase spectral resolution, the sensor is strategically positioned directly behind the cuvette.	0 to 100 ppm of curcumin solutions (Filtered turmeric suspension)	*Not suitable for real-time and on-site contaminants detection. (No smartphone integration) *Available for visible spectrum only. *Do not have spectrometer modeling. *Use photosensor as detector, has created 2cm small hole to promote the focus of light beam, and not use dispersion elements. *Validate the result with commercial spectrometer.
2016 [100]	A UV spectrophotometry-based optical technique is employed for determining the concentration of organic compounds in water. The measurement of the UV (ultraviolet) strong absorption at a wavelength of 250 - 300 nm. The UV absorbance is assessed using a multiple linear regression (MLR) model to estimate the total organic carbon content in water. The system utilizes a deuterium lamp emitting light within the 200-900 nm range, which is then transmitted through optical fiber to an optic spectrometer. This study compared the KHP concentration calculated by MLR analysis based in UV absorbance with conventional TOC analyzer using UV-persulfate oxidation method.	Organic compounds (potassium hydrogen phthalate (KHP)) with varied concentration, TOC	*Available for UV and visible spectrum. *Performed experiment with different real samples (tap, sea, and river water). *Used commercial UV spectrophotometry.

5. Conclusions

In this review, we focused on methods of chemical contaminant detection in water because most of the water sources are contaminated by these agrochemicals globally and not suitable for drinking or other domestic usages. We also discussed non-optical and optical methods to assess and monitor the presence of various contaminants in water sources. Every technique has specific characteristics and capabilities to detect pollutants in water based on physical, chemical, or biological properties. The methods offer different approaches to ensure accurate and reliable detection. The non-optical methods rely on physical or chemical measurements to assess water quality parameters whereas the optical method relies on the interaction of light with water to measure the properties by measuring the light absorbance and transmittance. A spectrometer is a promising method to measure the light interaction at specific wavelengths to determine the concentration of target contaminants based on light propagation theory. This technique may offer rapid detection, real-time and wide-range detection, non-destructive analysis, and high sensitivity. Therefore, it can complement the conventional methods which are expensive, time-consuming, and unfriendly tools that require special laboratory conditions and equipment. Overall, the choice of method depends on the specific contaminants of interest and the desired level of sensitivity and accuracy.

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