Developing Low-Cost In-Situ Water Pollution Sensors

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Abstract:
Water is currently regarded as one of the planet's most limited natural resources. Plants, animals, and humans all value it. The need for researchers to investigate the detrimental effects of environmental degradation, particularly on water sources, which is increased by the expanding environmental degradation that has been caused in recent years by development, population growth, and climate change. More sophisticated techniques in environmental monitoring systems, particularly in the area of water quality monitoring, are required due to the global increase in water pollution in lakes, rivers, and oceans. Therefore, Wireless Sensor Network (WSN) for monitoring physical and chemical water parameters along with machine learning and the Internet of Things (IoT) are promising alternative technologies that could be utilized as an alternative to address the abovementioned water quality issues. Furthermore, several sensors were developed for deployment in different regions connected directly to lab to view the current situation in every region. This review sheds light on several attempts for low-cost in-situ water sensors which gives full long-term information on the situation in areas under study which would be further a good idea to implement them and distribute to have continuous data.

Key words: environmental crimes, pollution, in-situ water sensors, internet of things (IOT), SMS data notification, faecal contamination, phosphate contamination, single peptide sensor.

Introduction:

Green criminologists have long referred to water pollution as a general example of a green crime[(1)], yet, little attention has been devoted to the study of water pollution and its consequences[(2-4)], leaving this research area open for further analysis of the scope, consequences, regulation and punishment of water pollution crimes.

Environmental law infractions (civil, criminal and regulatory violations) intended to safeguard the health, safety, vitality of people, natural resources and ecosystems are included in the green criminological study of the causes of environmental crime and harm. This is referred to as the legal-procedural approach and it may take into account potential Clean Air Act, Clean Water Act, or Endangered Species Act infractions [(5,6)].

Environmental scientists have used complex residual variable models to estimate violations of water quality standards[(7)]. Agricultural economists have modelled factors that affect the punishment of water pollution violators[(8)] and water pollution permit compliance[(9)].

Water is currently regarded as one of the planet's most limited natural resources[(10)]. Plants, animals, and humans all value it [(11)]. A water's ability to sustain life and promote health or to cause illness and death depends on its quality. The need for researchers to investigate the detrimental effects of environmental degradation, particularly on water

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sources, is increased by the expanding environmental degradation that has been caused in recent years by development, population growth, and climate change. More sophisticated techniques in environmental monitoring systems, particularly in the area of water quality monitoring, are required due to the global increase in water pollution in lakes, rivers, and oceans.

The 2016 survey on water crime in European countries conducted by The Water Crimes Project revealed that criminal groups have found an ideal business in which to make an easy profit. This is mainly due to various loopholes in national environmental protection legislation and considerable discrepancies between countries[(12)]. Water management is viewed as a developing environmental crime and crime against water as an emerging worldwide issue[(13;14)]. As nation-states and law enforcement agencies increasingly recognize the breadth and nature of the issue, these subjects are becoming more and more important[(14)]; nevertheless, intelligence is limited and information is dispersed.

The Water Quality Index, or WQI for short, was developed to assess water quality since multiple biological, chemical, and physical elements affect its quality. No single factor can properly characterize what makes for healthy water. Furthermore, achieving certain water quality requirements comes at a higher cost than others. These criteria are investigated and established using samples taken from the area, either for the purpose of analyzing the local situation or to find out if any agricultural or industrial plant violations have occurred.

However, the process is labor-intensive, time-consuming, and labor-intensive in addition to being unable to quickly disseminate the information gathered or acquire and analyze data in real-time, all of which are essential for any successful effort at tracking the quality of the water and will cause a delay in identifying any water crimes committed[(15)].

The collection of data at predetermined locations and on a regular basis to provide information that could be used to characterize the current state of the water is known as water quality monitoring. The goals of the intelligent water quality monitoring system are as follows: measuring metrics related to dangerous quality, such as chemical, physical, and microbiological characteristics; identifying deviations in these metrics and promptly alerting users to potential threats or hazards; providing real-time analysis of sensor data and recommending appropriate corrective actions. In order to preserve the quality of water bodies, users must be involved in sustaining the quality of the water and paying attention to other factors including cleanliness, environmental sanitation, disposal, and storage [(16)].

Remote places can benefit from the decreased costs and reduced labor requirements associated with this Wireless Sensor Network (WSN) for monitoring physical and chemical water parameters [(17)]. It has several benefits, including portability, near real-time data collecting, and data logging capabilities, when used for water quality monitoring [(18-20)]. It has become more well-liked in the scientific community, which includes embedded systems researchers as well as environmentalists [21; 22]. Yet, thanks to their electrical component, which is completely insensitive to moisture or even water infiltration, WSN applications for aquatic environments are significantly more difficult to implement than those for land-based networks [23]. Water quality, hydrodynamic performance, agriculture, and irrigation are just a few of the uses for WSN-based environmental monitoring applications that have been put into practice[18; 24; 25;26; 22; 23; 27;28].

Additional research focuses on improving the environment's flexibility, power harvesting and management, and gearbox in the last few years of usage. The system's primary objective is to monitor the temperature, pH, and DO of the water. Its design and implementation took into account the system's suitability for a sizable aquatic area, its ability to measure and store data in a database in real time, and its mechanism for promptly notifying managers, authorities, and system users [29]. The system's primary responsibility is to make sure that the sensor-collected data accurately depicts the aquatic environment and that the data is transmitted and delivered in a timely way as an informational web display or as an SMS, or short message service, addressed to designated key users. This aims to offer an interface that enables quick information sharing and prompt development of a suitable and timely response. The key user, for instance, can quickly detect unexpected variations in values of the monitored parameters related to water quality when they receive a timely report by SMS. This allows the user to give themselves enough time to consider and possibly adopt actions to reduce if not completely eliminate, risks and damages.

Consequently, the system was built to offer the following features: power management for extended measurement durations [30]; datasheets, charts, and graphs for data dissemination and display [31; 32]; maintenance interface for administrators [33]; and data collecting and storage.

As of now, machine learning and the Internet of Things (IoT) are promising alternative technologies that could be utilized as an alternative to address the abovementioned water quality issues [34]. Furthermore, several sensors were developed for deployment in different regions connected directly to lab to view the present situation in every region[35].

In this review, we outline numerous productive attempts at web-connected, extremely accurate, labor-intensive and pricey sensor projects currently employed or awaiting patency approval for potential future use. They could all offer accurate and timely information about the degree of water contamination in the research sites. All of these sensors would aid developed countries in better safeguarding their irreplaceable water resources and urge companies and manufacturers to maintain high standards for wastewater treatment.

1- Fecal contamination detecting sensor

More than two billion people throughout the world utilize drinking water sources, including surface water, that are fecally contaminated, according to a number of recent UNICEF and WHO reports[36; 37].

Drinking such fecally polluted water is linked to a number of major health issues, including diarrhea, which is particularly prevalent in young children in low- and middle-income nations[38; 39], Additionally, a number of outbreaks of diarrhea have been reported in high-income nations[40].

Escherichia coli (E. coli) is the leading indicator of faecal contamination in drinking water according to the WHO[41]. E. coli or other faecal indicator bacteria (FIB), quantified in the lab on retrieved water samples after a bacterial culture for 18–24 hours, are used to estimate the health risk associated with faecal pollution. However, because to the expense, effort, time and equipment requirements of this approach, both water service providers and water users would miss contamination episodes[42; 43].

Despite the fact that multiple studies have demonstrated that high risk spikes of faecal contamination pose the greatest damage to human health when compared to consistent low relative risks, there is presently no way to identify them in real time[44; 45].

The UNICEF released a call for a low-cost Target product for quick, precise E. coli testing in 2016[41], It led to the development of fluorescence spectroscopy as a powerful water quality monitoring method that can identify microbial contamination[43;46-48]. Tryptophan-like fluorescence (TLF), also known as Peak T1, is a unique fluorescence characteristic that resulted from this procedure[49; 50]; Tryptophan either is present as a free molecule or attached to any proteins or peptides when microbial activity is present, according to any resultant TLF [51].

There are now several delicate, mobile TLF sensors available, but they are not designed for autonomous, in-place, continuous operation. Initially implemented sensors have shown a number of difficulties, such as tryptophan values were either in arbitrary units (AU) or ppb, water temperature, pH, water turbidity, background fluorescence noise in aquatic environments, dissolved organic matter (DOM) in drinking water, sediments and soil, biofouling and mineral scaling[52- 55].

Machine learning (ML) based synthetic calibration to implement noise-reduction and anomaly detection that enables alarm-threshold detection is one method to lessen or overcome the aforementioned difficulties [56].

An in-situ, near-time, remotely reporting TLF sensor system was created to distinguish between the danger categories that the WHO has recognized and are associated to the concentration of FIB[55]. The goal design limit of detection was established to 1 ppb dissolved tryptophan since it was previously suggested that low risk sources (1–9 CFU/100mL) be classified using a threshold of 1.3 ppb tryptophan concentration[54].

The sensor hardware was built using high power ultraviolet light emitting diodes (UV LEDs) to excite tryptophan-like fluorophores at 275 nm and a UV photodiode combined with a band-pass filter centered at 357 nm to detect faecal contamination in drinking water for a reasonably low price [57].

Boulder Creek, originating in the foothills and flows through Boulder, Colorado, has been monitored by a team from Colorado University using a TLF sensor [58]. The creek, a tributary of the South Platte River, receives the majority of its flow from tiny springs and snowmelt west of the city. Boulder's climate is semi-arid, with annual rainfall averaging 21 inches [59]. During the time of field deployment as shown in figure (1), four sensors were deployed, the examined portion of Boulder Creek typically has a pH between 6.8 and 8.5, turbidity 10 NTUs, hardness between 30 and 1130 mg/l, temperature between 10 and 25 °C and DOC between 2 and 8 mg/l. The primary sources of faeces in the creek include people who live nearby, people who participate in instream activities, leaky sanitary sewage lines, malfunctioning septic systems and animals[59; 60].

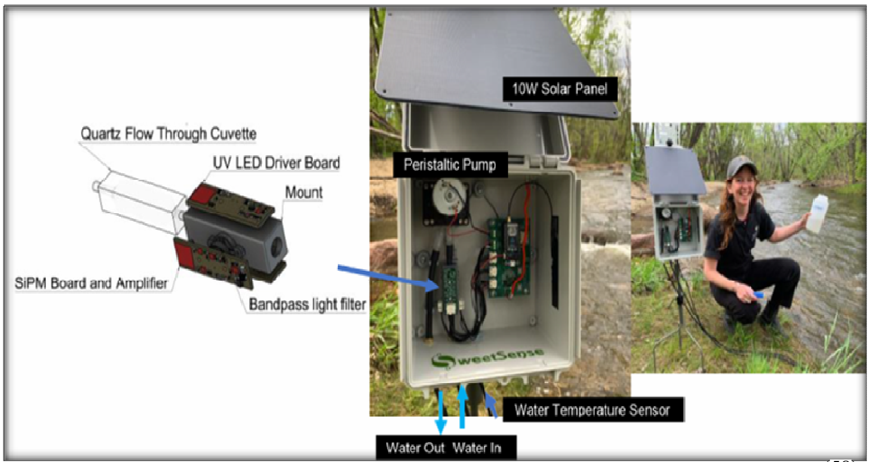

Figure 1: Prototype of tryptophan detection sensor for faecal contamination[58]

When the sensor is given a variety of current inputs to the LEDs, it may create a signal that differs noticeably between DI and 0.05 ppb tryptophan. So, the 1 ppb tryptophan design objective was accomplished. Tryptophan is more sensitive at low concentrations as the current to the LEDs increases; when the current declines, a wider range of tryptophan concentrations is observable.

TLF sensors were suggested to help distinguish between naturalized E. coli and contamination episodes in addition to sanitary inspections and conventional water quality monitoring[61].

The technology's usability and capacity to fit into current water management procedures are equally crucial to its success. To inform water service providers or customers of potential contamination in a way that is understandable to them, a web-based data interpretation platform must be developed. The sensor's ultimate objective is to be integrated into a drinking water system to increase the ability of the service provider or consumer to identify, control and reduce the risk levels associated with faecal contamination. To maximize the return on the investment, significant ongoing technical and planning support is needed for water quality improvement based on sensor data. In collaboration with end users, the sensor feedback mechanism's design should be designed. It is important to evaluate and prioritize their information needs regarding water quality. Depending on the sensor's use case, these requirements may change[(62)]. An action should always be taken in response to a TLF sensor alarm. The alarm would start more comprehensive, conventional testing to identify the scope and source of pollution if the sensor was being utilized in a water distribution or treatment system. The alarm would cause maintenance or filter replacement on the treatment technology if the sensor were installed in a home system together with treatment technology.

The technology is now being designed to move from the prototype stage to the final product stage as a home treatment system. People who use well water for drinking are the intended users of this design. Well water is especially prone to pollution from septic system problems and close proximity to livestock. Private groundwater supplies are not subject to US EPA regulation, thus homeowners are responsible for water testing and treatment[(63)]. The at-home sensor system will be combined with a medical innovation. The sensor will feature a cleaning function that allows a user to inject cleaning solution via the sensor when significant fouling has taken place. It will be a smaller sensor positioned in line with home's main water line and have a miniaturized design. Data from the sensor will be transmitted over the user's Wi-Fi to a database online, where the ML model will be used to forecast the risk level. A mobile app will be developed to notify the user if contamination is found. The treatment technology will need to undergo maintenance or replacement once contamination is found.

2- Phosphate contamination detection sensor

Agricultural runoff (fertilizers, animal manure), treated and untreated municipal wastewater discharges and industrial sources are examples of anthropogenic causes of phosphate pollution[(64)]. Currently, monitoring for phosphate levels in natural waters is done manually, entailing the collection of a sample and returning it to a lab for standard methods like the molybdenum blue method[(65)].

Phosphate in situ monitoring has demonstrated that high temporal resolution monitoring is necessary and that this type of manual monitoring is insufficient to determine risk or classify a specific waterway[(66;67)].

A sensor for phosphate in aqueous samples has been developed, evaluated and successfully used to monitor phosphate levels in water coming from an Irish wastewater treatment facility in Co. Kildare[(68-70)].

The sensor is based on the ammonium molybdate and ammonium metavanadate-containing reagent used in the molybdenum yellow method for phosphate detection, which involves mixing a phosphate-containing sample with the reagent in an acidic medium. Vanadomolybdophosphoric acid, a yellow substance with significant absorption below 400 nm, is produced. With the aid of a photodiode detector and a 370 nm LED, the compound's absorbance is determined. Within a specially created and manufactured microfluidic chip, mixing, reaction and detection take place. The system also includes the parts needed for power supply, data storage, wireless connection, sampling, calibrating, storing and pumping different solutions. The sensor was then employed to track phosphate levels in an estuary in County Dublin, Ireland, throughout the course of two distinct deployment periods in September-October and October-November 2009[71].

The system includes a sample port for collecting and filtering the water sample to be studied, polyethylene bags for keeping the reagent, calibration solutions and cleaning, as well as a number of solenoid pumps for pushing the necessary liquids through the microfluidic chip. Particulate matter is kept out of the microfluidic system using a polyethersulfone membrane filter with 0.45 m pore size that is housed in the sample port. The reagent and sample can be mixed using the microfluidic chip. For an absorbance measurement, the chip additionally feeds the reacted sample to an LED and photodiode. Following analysis, the sample is pumped to the waste storage. A microcontroller, which also handles data collecting and saves the collected data in a flash memory unit, is responsible for managing all of the fluid handling and analytical components. The data is sent to a laptop computer using the SMS protocol via a GSM (Global System for Mobile communications) modem.

The complete integrated system is shown in Figure 2

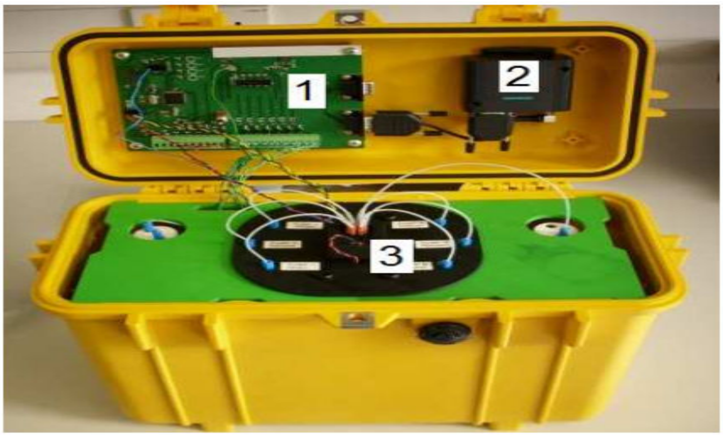

Figure 2: The prototype phosphate-analyzer system. (1) Electronics board. (2) GSM modem. (3) Microfluidic chip / detector assembly. The battery, storage bottles and solenoid pumps are contained within the lower part of the case

The sensor was installed in Broadmeadow Water in Co. Dublin, Ireland, after calibrated in a lab. This estuarine body of water has well-documented dramatically high nitrogen levels resulting from a combination of inputs from agricultural sources and outflows from wastewater treatment plants. A steel anchoring mechanism was used to secure the sensor to a small islet in one of the estuary channels. The sensor enclosure itself was entirely submerged at high tide because this was a tidal environment, thus the GSM modem antennae were placed outside the box and elevated above high water to assure continuous network coverage. The sensor functioned on an hourly sample frequency and data was sent in SMS (Short Message Service) mode at 5-hour intervals to a laptop computer stationed in the lab. Daily manual samples were taken for validation purposes at intervals that matched the sensor's sampling time, as closely as possible to the sample inlet of the sensor. Samples promptly filtered, analyzed using the appropriate reagent pack and a portable Hach-Lange DR890 colorimeter (amino acid method for high range phosphate).

A specific daily pattern of change was observed in the sensor's 236 readings taken during the relevant time period, attributed to tidal influences in the estuary. The sensor was placed 100 meters from an outfall of a wastewater treatment plant and shifting tidal levels had a big impact on how much dilution the wastewater discharges were experiencing at any one time. A hurdle to the widespread adoption of sensor technology is the disparity between traditional sampling-based ways to monitoring water quality and sensor-based approaches. Despite these factors, the data clearly demonstrates a major benefit of the deployable monitoring system. During the testing period, the more frequent sensor data revealed regular fluctuations in phosphate levels that were missed by manual sampling (even with daily manual sampling, which is not likely to be practicable in larger-scale monitoring procedures). As a result, sensor-based monitoring is more likely to detect transient pollution episodes while also giving long-term, high-resolution data that can reveal important insights on the analyte's long-term trends. The initial trial was terminated after 8 days of successful operation because dirt that had gathered near the sample port clogged the membrane filter. The sensor was installed near to the original site but in a place with lesser sensitivity to silt build-up on the channel bed in order to prevent this problem from happening again. During this second testing period, about 480 measurements were completed.

2- Single peptide sensor to identify water-soluble polymers

Plastics, microplastics and water-soluble polymers are currently the main contributors to marine pollution, which is a growing global issue. Alternative approaches must be used in place of conventional filtration techniques to overcome the difficulty to recover these polymers.

To identify water-soluble polymer contaminants in wastewater, Tokyo Tech researchers created a novel peptide sensor that classifies polymers using supervised machine learning[(72)].

This method resembles mammalian odor and taste judgement, is based on machine learning pattern analysis. Similar to how our noses and tongues use receptors to distinguish between various tastes and scents, this single peptide sensor can be used to identify and detect various compounds and polymers.

This cutting-edge technique functions by forming bonds between the chosen peptide and other polymers, followed by the training of a machine learning algorithm to enable it to identify and measure a huge number of contaminants in each sample.

The fluorescent tag N-(1-anilinonaphthyl-4) maleimide (ANM) is added to the peptide N-isopropylacrylamide (PNIPAM), that upon any connection between this molecule and any polymer, a separate fluorescent signal will be achieved according to the varied interactions.

In order to train the "linear discriminant analysis" algorithm to develop monitored machine learning, ANM signals were quantified in well-known solution concentrations of different polymers. This peptide sensor was then validated with various unknown samples, and it has proven its exceptional determination and quantification of polymers in mixed solutions.

Further evidence comes from the sensor's demonstration of its capacity to distinguish between polymers with related properties following the addition of ethanol and sodium chloride in trace amounts to test solutions. Finally, the developed peptide sensor's potential for detection was validated by testing it on actual wastewater.

This novel peptide sensor can identify and analyze how polymers entered the environment in addition to detecting them when they dissolve in water. Future developments will allow the expansion of the sensor's detection range to include more polymers and peptides that could protect and restore marine habitats.

Conclusions:

Any nation faces serious risks from water pollution since it destroys biodiversity, the economy, and public health. Even with the abundance of superb smart water quality monitoring devices, there are still many unanswered questions in the field. This study provides an overview of the most recent research conducted by the researchers to create intelligent, low-power, and highly effective water quality monitoring systems that would enable continuous monitoring and send alerts or notifications to the relevant authorities for additional handling.

Future recommendations include using the newest sensors to detect a variety of additional quality metrics, utilizing wireless communication standards to improve communication, and utilizing the Internet of Things to create a better system for monitoring water quality and ensuring that water resources are safe through prompt action.

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تطوير أجهزة استشعار منخفضة التكلفة لتلوث المياه فى الموقع

ماهيتاب فرغلى

تعتبر المياه حاليًا واحدة من الموارد الطبيعية الأكثر محدودية على كوكب الأرض، ومن ثم تزداد حاجة الباحثين إلى دراسة الآثار الضارة للتدهور البيئى، خاصة على مصادر المياه، ذلك التدهور المتزايد الذى نتج فى السنوات الأخيرة عن التنمية والنمو السكانى وتغير المناخ. وقد زادت الحاجة إلى تقنيات أكثر تطورًا فى أنظمة المراقبة البيئية، وخاصة فى مجال مراقبة جودة المياه، بسبب الزيادة العالمية فى تلوث المياه فى البحيرات والأنهار والمحيطات. لذلك، تعد شبكة الاستشعار اللاسلكية (WSN) لرصد معلمات المياه الفيزيائية والكيميائية إلى جانب التعلم الآلى وإنترنت الأشياء (IoT) من التقنيات البديلة الواعدة التى يمكن استخدامها كبديل لمعالجة مشكلات جودة المياه المذكورة أعلاه. علاوة على ذلك، تم تطوير العديد من أجهزة الاستشعار لنشرها فى مناطق مختلفة مرتبطة مباشرة بالمختبر للتعرف على الوضع الحالى فى كل منطقة. فى هذا المقال، تم إلقاء الضوء على عدة محاولات لإنشاء أجهزة استشعار للمياه منخفضة التكلفة فى الموقع، والتى توفر معلومات كاملة طويلة المدى عن الوضع فى المناطق قيد الدراسة والتى ستُعد – أيضًا – فكرة جيدة لتنفيذها وتوزيعها للحصول على بيانات مستمرة.

الكلمات المفتاحية: الجرائم البيئية، التلوث، أجهزة استشعار المياه فى الموقع، إنترنت الأشياء (IOT)، إشعار بيانات الرسائل النصية القصيرة، التلوث البرازى، التلوث بالفوسفات، مستشعر الببتيد الفردى.