Water Quality Monitoring Systems

Subjects: Water Resources

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Water quality monitoring (WQM) refers to the collection of representative information on the physical, chemical, and biological characteristics of various water bodies in both spatial and temporal scales. Water quality monitoring systems are being developed and deployed to monitor changes in the aquatic environment. With technological progress, traditional sampling-based water monitoring has been supplemented with sensors and automated data acquisition and transmission devices, resulting in the automation of water quality monitoring systems.

Keywords: seawater intrusion ; water monitoring system ; salinity

1. Introduction

According to the international organization for standardization (ISO), monitoring is defined as the programmed process of sampling, measuring, and recording or signaling, or both, of various water properties, often with the aim of assessing compliance with established objectives [1]. Water quality monitoring (WQM) refers to the collection of representative information on the physical (temperature, turbidity, color, electrical conductivity (EC), suspended solids, sediment), chemical (pH, dissolved oxygen (DO), biological oxygen demand (BOD), nutrients, organic and inorganic compounds), and biological (algae, bacteria, viruses) characteristics of various water bodies in both spatial and temporal scales [2] and can effectively guide water resource protection for safe and clean water [3]. WQM is of both local and global interest and is usually regulated by legislation [4], such as the Water Framework Directive [5] in the European Union. To understand the process dynamics and changes of a watershed, a well-designed WQM network is essential [2]. The design of WQM systems is a complex field and requires specialized knowledge [6], which has recently evolved to include specific and focused topics such as eutrophication [7], acidification, salinization, and various types of contaminations [2]. When designing a monitoring network, several things, such as the number and spatial distribution of WQM stations, the objective of monitoring, as well as sampling frequency and variables selection [2], should be carefully considered. There are two different approaches to water quality monitoring. The traditional approach to water quality monitoring using water samples and costly laboratory analysis is still the most commonly used in both researchers and established water quality programs. On the other hand, automated devices such as sensors, water quality probes, and even remote sensing techniques have recently been used to reduce costs and labor and collect data at a high frequency.

2. Development of Automated Continuous WQM Systems

As water resources were recognized as a national priority in the first half of the 20th century, water quality surveys, the precursor to WQM, were used to characterize water suitability for a variety of purposes [8]. The traditional approach to water quality monitoring based on grab sampling, typically taking a relatively small volume of water, usually once a month, can be quite challenging and is even unlikely to obtain reliable and representative results on water quality status [9]. In addition, it is labor intensive and can be financially challenging as it includes both on-site sampling and laboratory analysis costs. Over the next 50 years, advances in technology led to the development of the first continuous WQMs, which can be described as in situ monitoring with a higher temporal frequency. In the early 1950s, one of the first prototypes of continuous WQM, which measured and recorded water temperature and EC on a strip chart, was installed at a monitoring station at the Delaware Estuary near Philadelphia (United States) in 1955 [8][10]. Since then, continuous WQM has evolved, and today WQM is conducted using automated techniques such as sensors or multiparameter probes that typically measure a number of different parameters such as temperature, pH, DO, EC, turbidity, as well as concentrations of various ions using ion-selective electrodes (ISE) [11] (**Figure 1**). To adequately describe a variety of different natural and anthropogenic processes that vary on smaller time scales, the sub-daily time step would usually be appropriate for continuous WQM [8]. In addition to spot field or laboratory measurements, multiparameter probes can be used for long-term monitoring, and when combined with some types of telemetry solutions such as modems, data collection, and transmission, can be conducted remotely via GPRS, 3G, 4G, etc., without the need for frequent site visits [8]. Telemetry solutions provide efficiencies and improve the reliability of WQM because data and stations can be managed remotely, and the time between field maintenance trips can be extended [8], reducing labor and costs.

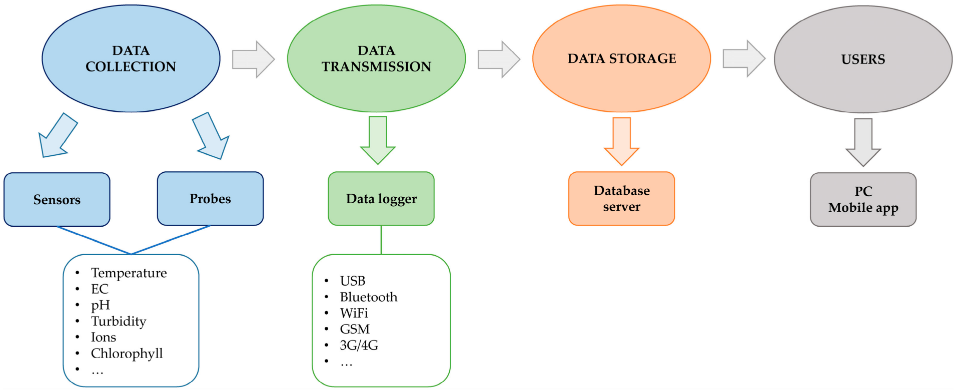

Figure 1. Scheme of automated continuous WQM.

Automatic monitoring devices nowadays produce relatively reliable, high-frequency data, provided that some sort of quality assurance is performed [9], and many countries, such as the U.S. and Germany, have already started to transform their monitoring programs by using automatic sensors [12]. There are many commercially available technologies and instruments for monitoring water quality parameters such as pH, EC, temperature, and DO in (near) real-time that provide reliable data [13]. Over the past 20 years, many researchers, although addressing different problems in different areas [14][15][16], have used some type of multiparameter probe that has measured different parameters.

Recently, several continuous autonomous WQM systems/platforms have been developed worldwide. When developing WQM systems with sensors for continuous measurements, it is important to consider the objective of the research and the type of water body and to select the variables of interest accordingly [17]. An example is the research of [18], which investigated the effects of drought on ecosystem metabolism (gross primary production and ecosystem respiration) using high-frequency in situ data on DO from the Connecticut River watershed (U.S.). The DO, water level, temperature, and EC were measured using Eureka Manta 2 multiparameter probes at 15 min intervals over a 2-year period, with on-site calibration performed at least once a month to ensure proper functioning. Similarly, [19] investigated ways to improve chlorophyll-a estimation in the Krishnagiri Reservoir, a major source of irrigation water in Tamil Nadu, India, by using remote sensing and in situ measurements. For the in-situ measurements, the Aquaread 2000 multiparameter sonde was used to measure temperature, salinity, EC, TDS, and chlorophyll-a in sampling campaigns during 2019–2020, and the results were used to develop time-series forecasting models.

A more complex and advanced system for monitoring and collecting hydrometry, water quality, suspended sediments, and bedload data has been developed and implemented by a group of authors [17]. The multi-instrument platform RIPLE (River Platform for Monitoring Erosion) was developed using commercially available sensors (except for the fiber optic turbidity meter) to measure discharge, water quality, and sediment flux variables, and with a user interface that allows the visualization of data and remote configuration of the platform. All sensors are controlled by a data logger with a 10 min measurement interval and data transmission via 3G/GPRS. The system has been implemented on two rivers in the French Alps, the Romanache in Bourg d'Oisans (September 2016–October 2018) and the Galabre in La Robine sur Galabre (since October 2018), to demonstrate the proper functioning of the system.

On a larger scale, ref. [20] a wireless sensor network called SoilWeather has been developed as an operational in situ network for river basins that provides (near) real-time information on weather, soil moisture, and water quality with high temporal resolution. The established network covers the entire 2000 km^2 Karjaanjoki River basin (Finland) with a total of 70 sensor nodes: 55 weather stations, four nutrient monitoring stations, and 11 turbidity monitoring stations. Data are collected at high frequency, once per hour for nutrient measurements and at 15 min for all the other sensors. Real-time data are made available in the form of graphs and tables in two different internet-based data services provided by the sensor vendors and are accessible only to project participants. Due to the large number of sensors collecting data with high temporal frequency, relatively high maintenance resources and effective data quality control must be ensured. Although the system is still under development, it was concluded that sensors collecting water quality data require more fieldwork than meteorological and terrestrial data collections, so no reduction in the fieldwork is expected compared to traditional sampling-based monitoring.

In addition to commercially available systems, which still require significant financial investment [21], much recent research has focused on the development of low-cost prototypes for water quality monitoring, many of which are based on Arudino platforms [22][23]: an open-source electronics platform based on easy-to-use hardware and software. Ref. [24] developed a prototype river water quality monitoring system consisting of commercially available individual sensors that measure the pH, temperature, light, EC, DO, and oxidation-reduction potential (ORP). The sensors were coupled with the Arduino Mega 2560 to collect and process the data. After testing, preliminary results showed that, with proper calibration, the sensors could provide accurate results over extended periods of time and may be suitable for continuous long-term water quality monitoring. [25] made the prototype more suitable for field and long-term deployment, especially in coastal areas where temperature and salinity were important parameters affecting the coastal environment. They designed a probe with sensors for temperature and conductivity (Atlas Scientific) based on an Arduino platform with a data logging attachment. Measurements were compared to a commercially available YSI 6600 probe, and it was found that the RMSE was 1.35 ppt for salinity and 0.154 °C, indicating that this type of device may be used as a low-cost alternative to more expensive instruments.

Two different approaches can be taken in designing and developing continuous WQM systems:

- The use of commercially available and reliable sensors in conjunction with data acquisition instruments.

- The development of low-cost prototypes based on open-source hardware (OSH).

While the latter is less expensive, they require additional expertise, especially with regard to calibration and validation. In addition, these systems are not yet suitable for long-term deployment in diverse environments such as rivers, streams, and coastal areas, but it is hoped that future development will enable the use of low-cost platforms for continuous water quality monitoring. Both commercially available and developed WQM sensor systems generally measure a similar set of water parameters such as temperature, pH, EC, and DO, with pH and EC in addition to TDS and salinity (which can be derived from EC), most of which are essential for monitoring SWI into the coastal surface and groundwater resources.

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