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Water quality monitoring using wireless sensor network technology

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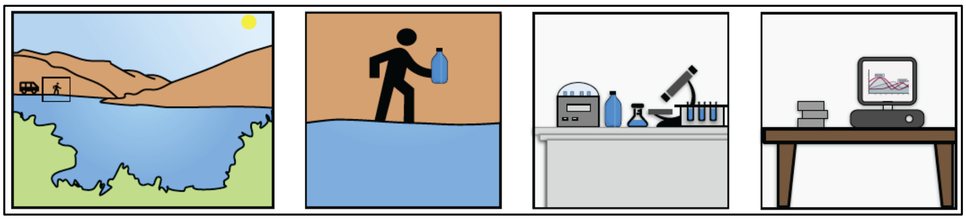
Abstract
Modernization in major areas in the world and urban cities with concentrated human activity are responsible for severe water pollution, which is considered one of the major problems affecting the environment. Water quality describes the general composition of water with reference to its chemical, physical and biological properties. Water Quality Monitoring (WQM) typically involves monitoring fresh water sources such as rivers, streams, lakes, ponds, reservoirs, shallow or deep ground waters, and wells in order to ensure that the water source is providing safe water for drinking and irrigation purposes. The use of (Wireless Sensor Networks) WSNs for WQM is particularly appealing due to the low cost of the sensor nodes and hence the cost-effectiveness of this solution, the ability to acquire and process data at a number of distributed sampling points, and the ability to communicate the data using low-power wireless communication techniques, which enables decision makers to receive data from multiple remote sensor devices in a timely manner. The sensors are classified into single and multiple parameter sensors. Energy harvesting is an issue of key concern in the design of a WSN-based WQM system. There have been many advances in water quality monitoring over the years. Energy harvesting techniques that can support the sensor network to make it operational for longer periods of time should also be researched. Data processing and aggregation algorithms should be developed to ensure proper data management in the development of WSNs for WQM. Addressing these issues will enhance the overall performance and utility of WSN-based WQM systems.

Keywords: Energy management, network communication, water quality, wireless sensor network

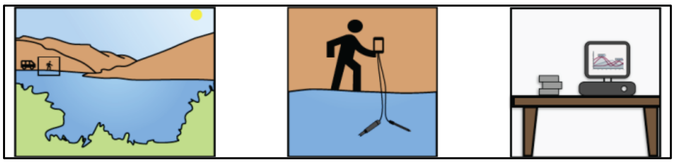
Introduction
Water is an essential commodity for human survival. While approximately 71% of the world is covered in water, only 2.5% of this is freshwater; hence fresh water is a valuable resource that must be carefully monitored and maintained. The burgeoning population is having a devastating impact on our environment, directly resulting in a cost to human health. [Panayiotou *et al.* 2005] [12]. It is also responsible for severe water pollution, which is considered one of the major problems affecting the environment [Derbew and Libsie, 2014] [1]. As a result, observing and detecting pollutants in water is vital. Effective monitoring of the system is critical for ensuring environmental sustainability and water quality monitoring is one of the key areas in environmental monitoring. Water quality describes the general composition of water with reference to its chemical, physical and biological properties based on specific use.
Water Quality Monitoring (WQM) can be described as a method for periodically sampling and analyzing water conditions and characteristics [Farrell-Poe, 2005] [3].

Evolution of WQM Systems
Beginning from the 1960's to 2000, WQM mainly relied on a manual approach for water sampling and analysis, where a human user would travel to a water source, take one or more samples of the water, and transport these samples to a laboratory for subsequent analysis.



Traditional Manual Lab-Based (TMLB) WQM approach

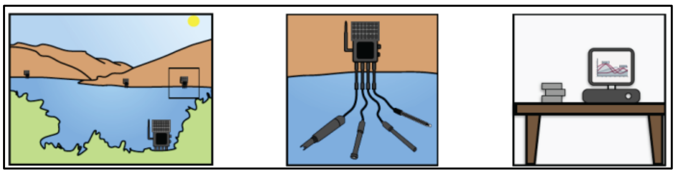
During this period, the focus of the research on WQM was related to the general framework, including identification of the objectives and strategies and specific techniques to be used for water analysis, as well as on the network design, including selecting the water quality variables to be measured, the sampling sites, and the sample frequencies. Further improvement in WQM system came with the advent of traditional manual in situ water quality monitoring.



Traditional Manual In-Situ (TMIS) WQM approach

These traditional WQM systems had several limitations due to the high spatiotemporal variability of the water physiochemical and/or microbial parameters [Katsriku *et al.* 2015] [7]. A modern approach (WSN- wireless sensor network based approach) to WQM was eventually developed in the beginning of twentieth century and this modern approach meets the following goals:

- Achieves high sensitivity and selectivity
- Enables to detect water quality parameters in real time and on site
- Provides distributed sensing of the water body and support local analysis of the data from the distributed sensors
- Provides a long operational lifetime



Moreover WSN based approach to WQM has been considered as an alternative solution to traditional WQM approach.

Water quality parameters

Soil and water quality are inherently linked; conserving or enhancing soil quality is a fundamental step towards improving water quality. The water quality can be evaluated by its aesthetic, physical, chemical and biological properties. Aesthetic properties include colour, smell, odour and appearance. Physical properties that influence water quality include turbidity and clarity, dissolved solids, sediment load and suspended organic and inorganic materials. The important chemical properties in relation to water quality include pH, salinity, alkalinity, dissolved oxygen, dissolved load of chemical constituents, especially nitrate, phosphorus, fluoride, arsenic, heavy metals, pesticides and other toxic compounds. Among biological properties, the presence and number of microorganisms and their biomass and the presence of pathogens, phytoplankton and zooplanktons are used to assess the impact of water quality. Some of the ion limits for irrigation water for agricultural use are given in Table no. 1.

Sodium hazard: High concentrations of sodium are undesirable in water because sodium adsorbs onto the soil cation exchange sites, causing soil aggregates to break-down, sealing the pores of the soil, and making it impermeable to water flow. The tendency for sodium to increase its proportion on the cation exchange sites at the expense of other types of cation is estimated by the ratio of sodium content to the content of calcium plus magnesium in the irrigation water, called sodium adsorption ratio (SAR).

The adjusted SAR is a value corrected to account for the removal of calcium and magnesium by their precipitation with bicarbonate and carbonate ions in the irrigation water.

Bicarbonate hazard: The bicarbonate (HCO_3^-) anion is an important parameter in irrigation water as regards calcium and to a lesser degree also of magnesium as their carbonates in the soil. This brings a change in the soluble sodium percentage (SSP) in the irrigation water and therefore, an increase in sodium hazard. The residual sodium carbonate (RSC) is used to evaluate the quality of irrigation water.

Table 1: Parameters for interpretations of water quality for irrigation

Parameters	Suitable	Moderately suitable	Not suitable
EC(dS/m)	0.25	0.25-0.75	>0.75
Sodium adsorption ratio (SAR)	<10	10-18	>18
Sodium (as adjusted SAR)	3	3-9	9
Residual sodium carbonate (RSC) (me/L)	<1.25	1.25-2.5	>2.5
HCO_3^- (me/L)	<1.5	1.5-8.5	>8.5
NO_3-N (me/L)	<5	5-30	>30
B (mg/L)	<0.75	0.75-2	>2
Cl (me/L)	<4	4-10	>10
F (me/L)	<1	1-15	>15
pH	6.5-8.4	8.5-9.5	>9.5

Salinity hazard: The concentration of soluble salts in irrigation water can be classified in terms of electrical conductivity (EC).

pH: It is defined as the logarithm of the reciprocal of the H^+ ion activity. Soil reaction can be measured by determining the pH.

Boron concentration: Boron is essential for normal growth of plants, but the amount required is very small. The occurrence of boron in toxic concentration in certain irrigation waters makes it necessary to consider this element in assessing the water quality.

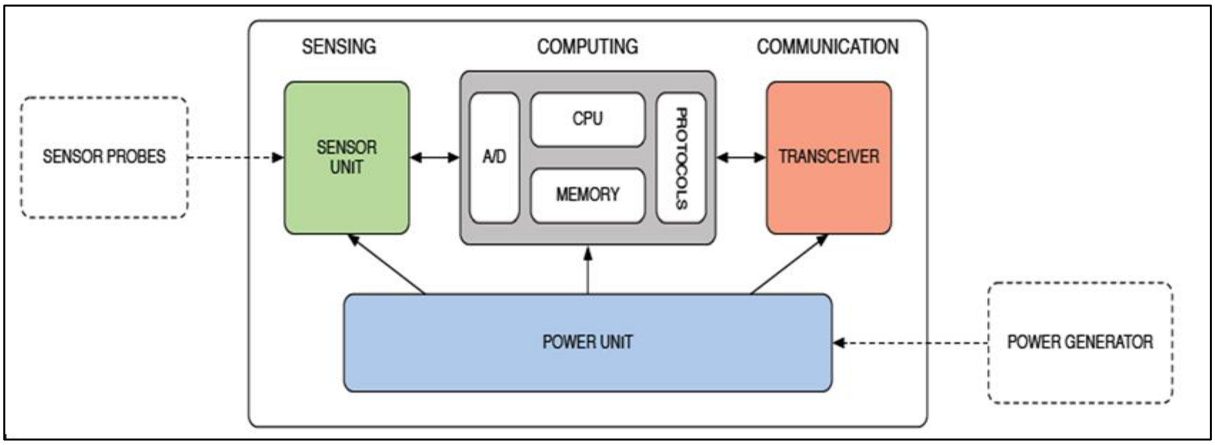
Nitrate concentration: Groundwater very frequently contain high amount of nitrate and when such type of irrigation water applied on soils continuously affects various physical properties very badly causing poor growth of plants.

Chloride and fluoride concentration: These can also be used as factors to assess the water quality.

Quality of irrigation water is one of the main factors that affect the physical and chemical properties of the soil and ultimately, the crop growth. The irrigation water must be free from excess soluble salts and from concentrations of specific chemical substances that may create soil quality problem such as salinity, Sodicity, permeability and specific ion toxicity. So periodical water quality assessment is must to evaluate the effectiveness of various land use practices that enhance plant, animal and human health and sustain biological diversity.

Wireless sensor networks

WSNs enable the automatic transfer of the data as well as providing a feedback mechanism in some instances, to refine the granularity of data collection. Typically, a wireless sensor node consists of the sensor unit, the interface circuitry, a processor, a transceiver system, and a power supply unit.



Generic wireless sensor node hardware architecture

The sensors are classified into single and multiple parameters, depending on the number of water quality parameters that the sensor is able to detect. Single parameter sensors can sense only a single parameter (Table no. 2) while multiple parameter sensors are capable of simultaneous sensing of several parameters with a single material and single read-out device (Table no. 3). Several specialized hardware devices have also been proposed for supporting the wireless sensor nodes for measuring the water quality parameters (Table no. 4).

Table 2: Single Parameter

Sensor model	Water quality parameter	Reference
Hach model A-15	Free/total chlorine	[Hall *et al*. 2007] [5].
Hach 1720 D, WQ730, WQ720	Turbidity	[Hall *et al*. 2007; Xylem Inc. 2015b] [5, 15].
GLI Model PHD, WQ201, WQ101	pH	[Hall *et al*. 2007; Xylem Inc. 2015b] [5, 15].
GLI Model 3422, WQ-Cond	Specific conductance	[Hall *et al*. 2007; Xylem Inc. 2015b] [5, 15].
WQ401	Dissolved oxygen	[Xylem Inc. 2015b] [15].
WQ600	Oxidation reduction potential (ORP)	[Xylem Inc. 2015b] [15].

Table 3: Multiple Parameter

	Water quality parameter	Reference
Hydrolab Data Sonde 4a	- Specific conductance, Dissolved oxygen, Oxidation reduction potential, pH, Temperature, Free chlorine, Ammonia-nitrogen, chloride, nitrate-oxygen, turbidity	[Hall *et al*., 2007] [5].
Smart Water (Libelium)	- Conductivity, Dissolved oxygen, Oxidation reduction potential, pH, temperature, turbidity, nitrates, dissolved ions	[Libelium , 2014] [9].

Table 4: Specialized hardware devices for supporting wireless sensor nodes

Device	Communication	Implementation	Advantages	Disadvantages	Reference
Digital videos	ZigBee and CDMA	Three monitoring points along a river	- Multihop, - Ability to monitor a large area, - Flexible and - Easy to extend three layer architecture	Data acquisition not clearly defined	[Peng 2009] [11]
Automatic Under-water Vehicles	GPRS (multi-hop routing)	3D grid of sensors	- Shows high performance	AUV navigates only in one direction	[Zhan *et al*. 2009] [16].

WSN framework

The framework comprises of the functions Data Acquisition, Processing and Transfer (DAPT). It is viewed as an unified process and the next stage is the Data Processing, Storage and Retrieval (DPSR) which is fully automated in WSN-based system.

- **Data acquisition:** It is the process of sampling signals that measure real world physical conditions and convert into digital numerical values that can be manipulated by computer. The spatially distributed wireless sensor nodes acquire samples and using multiple sensors increases the level of accuracy. Frequency of gathering the data can also be set.
- **Filtering/Processing:** The collected samples are processed computationally. Different algorithm techniques are implemented for detecting required water quality parameters. There are two main approaches for data processing – In-node and CTP (Collaborative Task Processing). In in-node processing a node processes its own samples and in collaborative task processing nearby nodes share the data with each other.
- **Data transfer:** It describes the way in which data is moved from the source to the final destination.
- **Data analysis/storage/reporting:** In this phase some additional computations are performed and the data is classified. Data can be stored using offline storage media, online storage media and cloud. The data is then presented to user in form of graphs, charts and tables.

Network communication: It is set of protocols that allows application programs to talk with each other without regard to the hardware and operating systems where they are run. Communication network design is an important aspect for WSN- based WQM system. The network architecture can be separated into two main parts

1. **Local Network Communication:** Transmission of the data from the sensor nodes to a local monitoring station (or base station) (Table no. 5)
   a. Direct communication
   b. Multi-hop communication
2. **Remote Network Communication:** Transmission of the data from the local monitoring station to a remote monitoring station that enables users to access the data (Table no. 6).

Table 5: Local Communication

Technology	Coverage	Frequency	Speed	Advantages	Disadvantages	References
ZigBee	50m	2.4-2.48 GHz	20/40/250 Kbps	- Low cost, - low power consumption, - ad hoc, - potential to support a large number of users	- Does not penetrate buildings well, - low speed	[Ho *et al*. 2013; Sidhu *et al*. 2007] [6, 14]
WiFi	200m	2.4 and 5 GHz	Upto 150 Mbps	- Low cost, - high speed, - wide distribution - common standard	- High power consumption - requires a central access point, - scalability	[Ho *et al*. 2013; Dhawan 2007] [6, 2]

Table 6: Remote Communication

Technology	Coverage	Frequency	Speed	Advantages	Disadvantages	References
RF Module	8 Km	2.4 GHz	250 Kbps	- Resilient to noise and variations in the signal strength	- Requires complex demodulator - low speed	[Laird Technologies 2012] [8]
GSM (Global System for Mobile communication)	10 Km	900-1800 GHz	9.6 Kbps	- Wide distribution, - 2-factor authentication, - support for roaming	- Low speed, high energy consumption - needs special processing to handle handoffs	[Rahnema 1993; Ho *et al*. 2013 [13, 6]

Energy management: Techniques to manage the power consumption over time and how to power the devices is an issue of key concern in design of WSN-based WQM system. So to support the continuous operation of a WSN based WQM system there are two main design approaches:

1. Energy available to the wireless sensor nodes can be increased through renewable energy sources, by harvesting energy from solar, wind and hydro energy.
2. Energy draw of the wireless sensor node can be reduced through techniques such as duty-cycling, power control, wake-up radios, etc.

Data processing, storage and retrieval

Data Processing: Processing is carried out in several places: locally on the wireless sensor node, at the local monitoring station or at the remote monitoring station. But WSN-based WQM systems does not focus on specific algorithms, rather it focuses on answering the following questions:

1. Why is the water quality parameter being collected?
2. What type of data is sensed and transmitted?
3. How often is the data sensed and transmitted, and when does this data require usage?
4. How do we process and secure the data?
5. Which data sensing techniques and algorithms are appropriate for the data collection for optimal performance?
6. Where do the data reside?

Data Storage and retrieval: It is the most important aspect of the WQM process .The amount of energy consumed by the devices greatly depends on the amount of data to be acquired and the frequency of data acquisition. Also the quality of the WQM process depends on the above factors. The remote monitoring centre relies on a database management system for storing the water quality data.

Advantages

- It achieves high sensitivity and selectivity.
- It is able to detect water quality parameters in real time and on-site.
- It provide distributed sensing of the water body and support local analysis of the data from the distributed sensors.
- It provides a long operational lifetime
- It does not require human presence or intervention to operate so the sensors can even be deployed in areas where human accessibility is difficult or inconvenient.

Issues/disadvantages

- **Data computation, analysis and reporting:** These are performed either at the local monitoring station or at the remote monitoring centre and computes different water quality parameters but it lacks specialized algorithms for combining the water quality parameters from different sampling points.
- **Security, privacy and data confidentiality:** Security is very important in preserving the reliability of a water quality monitoring system and it must ensure its high quality water is provided to the consumer. Physical security should also be implemented. As the data used to be obtained manually in traditional methods but now there has been a shift towards an unrestricted web-based data access which can be traced and hacked, so security measures need to be developed.
- **Biofouling:** It is also a key factor which determines the length of time water quality sensors can be deployed.
- **Sensor drift:** It is the temporal shift of sensor response due to aging of sensors or environmental changes such as

temperature and pressure variations.

- **Underwater propagation:** Communication in underwater is a challenging task due to limited availability of band width, signal failing, node failure, etc.

Conclusions

There have been many advances in water quality monitoring over the years but still number of open issues need further additional research to the use of WSN based WQM systems. Energy harvesting techniques supporting the sensor network should also be researched. The data processing and aggregation algorithms should be developed to ensure proper data management in the development of WSNs for WQM. Addressing these issues will enhance the overall performance and utility of WSN based WQM systems.

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