RESEARCH ARTICLE OPEN ACCESS

A Critical Review of IoT Based low-cost Quality Sensors for Freshwater management in Smart Cities

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ABSTRACT

Safety, Reliability and Traceability of potable drinking water is first priority for developed Nations and a contrasting luxury for Third World countries. Increasing Natural and man-made pollution forces civic Authorities to monitor and take precautionary and preventive measures to ensure safety of drinking water on continuous basis. Municipal Authorities/ Governments have been using manual methods to track and trace quality and quantity of freshwater for ages. Introduction of Information and Communication Technology (ICT) and further developments in Internet of Things (IoT) sensor-based technology has eased the real time evaluation and of various quality and quantity parameters of drinking water . These low-cost sensors have eased financial burden of basic infrastructure cost to a considerable extent. This paper takes a detailed stock of various low cost IoT sensors in the field of freshwater management from a techno-social perspective.

Keywords: - *Water Quality Management, IoT, Oxidation Reduction Potential, Contamination, MQTT, Arduino*

1. Introduction

1.1 Why do we need to check for quality of water ? - As per World Health Organization (WHO), any ground or surface water source which is free of heavy metals, minerals, chemicals, pollutants, faeces, harmful bacteria, algae, fungi and pathogens, microplastics may be considered as potable/ drinking water. By drinking this water one can keep away from communicable health hazards such as dysentery, diarrhea, cholera, typhoid, hepatitis A etc. Organizations like Environmental Protection Agency in USA (EPA), European Union Drinking Water Directive (EU-DWD) and Bureau of Indian Standards (BIS) define drinking water standards called ***Water Quality Index***. Every Municipal Corporation is required to abide by these standards and ensure delivery of potable water to the citizens at all times.

1.2 What qualities are checked to ensure safety of potable water ? - As per these standards various chemical, physical and biological water quality parameters must be in the given range to consider it as "safe for drinking". The physical characteristics like taste, odor, color, temperature, pH, Turbidity (Total Dissolved Solids (TDS) and Total Suspended Solids (TSS)) ; chemical characteristics measuring Dissolved Oxygen (OD), Biological Oxygen Demand (BOD) , levels of Chlorine, Nitrogen, Phosphorus, Ammonia, Calcium and metals like Lead, Iron, Cadmium, Arsenic, Mercury , further to that Biological characteristics such as presence of Pathogens (Bacteria, Viruses, Fecal coliforms) and microplastics are measured to ensure water safety.

1.3 What is Internet of things ? - "Internet of Things" is essentially an Internet based ecosystem where in "***sensors***" are placed at various points or "***Things***" in network under consideration. These sensors are RFID chips customized to collect certain type of data. Due to its miniature size, a sensor can be placed in wearables at close proximity or at remote, far-off places. They are connected to micro-controllers which collect, process and standardize this raw data, (***edge computing***) its wireless unit sends it further to internet (***Cloud computing***) website, network storage, database which processes this information for further use. User can collect this information either from internet-based application or through mobile app. Decisions taken (either human or machine) by analyzing the information are further communicated to "***Actuators***" for further action.

1.4 What is the role of IoT in ensuring water quality – As mentioned, IoT sensor technology uses RFID tags and can be placed anywhere, this is majorly advantageous in situations and places where access is limited, dangerous or laborious. IoT sensors are extremely useful where continuous real-time monitoring is required. In particular, right from source, like Dam, lake, river to treatment facility (WTP) to storage reservoirs (ESR/ GSR) further to consumer taps, these sensors can be installed to monitor water quality every now and then. These sensors are connected to small dedicated micro-controllers which process data partially (edge / fog) and send to centralized server (Cloud)

1.5 What are various IoT sensors used to measure these parameters – Depending on the characteristic (physical/ chemical/ biological) to be examined there are analog/ digital sensors available. These sensors are customized to measure temperature, pH, Turbidity, Dissolved Oxygen (Physical), levels of gases (Chlorine/ Ammonia), metals and minerals (Chemical) or traces of pathogens and microplastics (Biological) . Sensors can be analytical or digital types

2. Literature Review

This section discusses articles and papers already published and resonate with the topic under consideration. The order of discussion is purposely matched with list of references and evaluated in same sequence in next section.

2.1 Authors Miller, Kisiel et.al.[1] from Poland have discussed IoT technology and its use in Water Quality Management. sensors are proposed to be placed at sources and smart meters at Consumer end generalized view of IoT application takes a stock of Sensors, Actuators, Gateways, Smart Meters. Here a Gateway is Raspberry Pi programmed (in Python/Julia) to collect Sensor Data and transmit to Cloud. Challenges discussed – Unbiased Analysis of Volume of Data generated, Security, Lack of Standardization, Interoperability, Cost of implementation and Maintenance.

2.2 Authors S. Geetha and S. Gauthami [2] from India have surveyed existing literature on IoT based water quality analysis. Their low-cost sensor system essentially uses built-in wi-fi module for edge-processing which is highly secure and low on energy consumption. Three physical properties viz. conductivity -pH -Turbidity along with water level discussed. Their system focuses on domestic water quality and essentially focuses on stored water where sensor probes are hung in container.

2.3 Authors Rahman, Bepery et.al.[3] from Bangladesh have proposed an IoT based system for determining Water Quality Index(WQI). Various sensor (pH , Turbidity, Temperature, Dissolved Oxygen and Salinity) connected to Arduino send data to NodeMCU that converts and processes analytical data to digital and sends to Firebase server that holds the database for further processing by webserver and notifications displayed on webpage. WQI of various samples compared and arrived at the conclusion.

2.4 Authors Murti, Saputra, and Alinursafa [4] from Indonesia have proposed IoT based pH and Turbidity sensor (DFRobot) based system for River water quality testing that employes ATmege328P-AU controller to send signals to LoRa LPWAN gateway that connects further to Antares for cloud storage and results displayed on Android. The river sources are evaluated for pH and turbidity and level of pollution determined.

2.5 Author Geeta N [5] from Tirupur, (Coimbatore, India) has particularly highlighted about the extreme pollution of Noyyal river due to textile industry's effluent discharge. PIC16f877a along with GMS modem used to detect pH of river water and alerts (SMS) are generated for off range (<6.5 and >9.5) values.

2.6 Author E. T. de Camargo et. al. [6] from Brazil have done a systematic literature review (SLR) for low cost water quality sensors. They have evaluated almost 127 articles to arrive at the low-cost sensor data. DFRobot, Atlas Scientific and Vernier were the most preferred brands among researchers. pH, Turbidity and Temperature are the most assessed water quality parameters. The Authors have confirmed that low cost IoT sensors are as accurate, durable and cost effective as traditional means and reference sensors. Majority of studies used rivers, lakes and Aquacultures as source. Wi-fi/802.11 was most popular technology for signal transmission followed by GSM-mobile and LoRa WAN. Arduino (and its variants Arduino + ESP32 / Arduino + Raspberry Pi/ Arduino + ESP8266) were the most preferred open source platforms to implement IoT sensors. India followed by Bangladesh, Malaysia, China are the top countries where research in this field is highest. Most of the papers considered were lacking information about precision, calibration, accuracy, durability, and reliability of IoT sensors .

2.7 Authors Laxmikantha et.al. [7] from Mysuru, India have come up with cost effective IoT based water quality sensors to monitor pH, Turbidity, Conductivity, Carbon Dioxide, Humidity and Temperature. The system employes Arduino AT-MEGA328 (with built-in ADC and Wi-Fi modules) The wired sensor transmit data (via Arduino) to LCD.

2.8 Authors N.K. Velayudhan. et.al.[8] from India have evaluated all aspects of water distribution network and have come up with an IoT Architecture - IoTA4IWNet, for real-time monitoring and control. The Author has particularly reviewed literature for water sources, intake structure, treatment, conveyance and distribution systems, sensor technology, Edge-Fog-Cloud technology, Communication protocols and IoT Architecture in great details. The paper not only discusses the water quality monitoring applications, but also their positioning in distribution network to maximize operational excellence and minimize water stress and loss.

2.9 Authors Yaroshenko, Kirsanov et. Al [9] evaluated historical approach to water quality monitoring system w.r.t. electro-chemical, optical and bio - sensors, microwave spectroscopy etc. Essentially, these multi-sensor, stand-alone systems were used to collect data from Rivers or WTP/STP, were connected to wireless sensor network (but not having RFID tags) collected real-time data and connected to internet through a GSM- GPRS system. Even though the paper was published recently, it has no explicit mention of IoT technology, but is still considered as it evaluates latest sensor technology for water quality monitoring.

2.10 Authors Deshmukh, Lokhande et.al.[10] have proposed an IoT sensor-based system implemented within the Water filter at end-user premises. The system has pH, Turbidity, Temperature and UV radiation sensors which are connected to Raspberry Pi and is used to monitor real-time values and generate alerts. As the setup- is installed in Consumer premises, it assumes that basic filteration and chlorination is done. It can be further enhanced to monitor residual chlorine and send this data to Authorities to adjust and ensure quality of water at the consumer tap. Also integrating the quality sensor with Smart meter can track for leaks and detect theft in longer run.

2.11 Authors Vasudevan et.al.[11] have presented sensor probe with both pH and ORP. Data is collected by LPC 2148 32-bit microcontroller and further transmitted through SIM 900 GSM module. The correlation of pH and ORP established using different water samples. Pre- established fact that higher ORP ensures negligent or no coliforms was validated through IoT based online monitoring.

3. Discussion

Almost all Cities, towns, Villages and local area governance in India have their own infrastructure for supply of drinking water. These age-old infrastructures have traditional (mostly manual) methods of water purification and quality management. With the advent of Third Industrial Evolution (Digital Evolution) there has been a partial upgrade in terms of Process Automation (SCADA and ICT, Resource management and Billing), but the core processes of Water Treatment and Distribution for a City is still mostly dependent on old technologies. It is imperative to systematically upgrade the infrastructure for proactive management and quick turn-around time as the world is already into Industry 4.0, the Fourth Industrial Revolution !

It is observed that most of the literature focuses on Academic Research of IoT sensor technology, cloud connect/ website and storage management and Application / Interface management. The research has been limited to laboratory implementation of sensors, information gathering and interfacing with Apps. Very few researchers [2,8,11] have evaluated the possibilities of IoT integration with the entire Supply Chain of freshwater for Smart City.

Components of Water Quality Management in Freshwater Supply Chain for Smart Cities is assimilated briefly herewith**:-** Basic ***IoT Architecture*** comprises of sensors and actuators placed at or with things. In Water Distribution Systems (WDS) or Water Management Systems (WMS) There are variety of (IoT) Water Quality Sensors offered by DFRobot, Atlas Scientific, Robu (for academic purpose) Commercial sensors offered by Hanna, Horiba, Renke, Synox etc. The sensors feed data to IDE comprising of microcontrollers (Arduino/ Raspberry Pi/ ESP32/ ESP8266) and Wi-fi/ Bluetooth onboard. There are application-level communication protocols viz. MQTT/ COAP/ HTTP/ OPC-UA. Wi-Fi/ Bluetooth/ ZigBee are short range wireless , GSM/LTE/5G are long range wireless network protocols for cloud communication connecting sensors to internet. There are Various IoT platforms like Amazon Web-services (AWS). Microsoft Azure, Insight Hub (Siemens) IBM Watson (Legacy), Oracle IoT Cloud are some of the commercial and ThingsBoard, ThingSpeak, Thinger are some open-source platforms that integrate Storage, Data Analytics and Web hosting capabilities. These platforms further connect to standalone applications or mobile apps which offer constant monitoring capabilities to end-users.

4. Conclusion

In India, Bureau of Investigation Standards (BIS) has set-up Water Quality Index (WQI) and the water sample adhering to these standards is considered as “Potable Drinking Water “. There are strong corelations among water qualities like pH, ORP, OD, TSS, Temperature. Lower ORP,DO or pH indicates presence of pathogens (E.coli, Salmonella, Campylobacter and Listeria) which are common cause of infections and diseases worldwide. Manual evaluation of water samples is laborious, time-consuming and costly, in contrast placement of IoT sensors across Water Distribution Network right from Source to treatment facility, further to storage reservoirs, down-stream distribution network right up to user tap is particularly helpful in continuously tracking incidences of contamination and degraded water quality in real-time. It is further helpful in tracking leakages, and apparent losses. Comparatively low investments and accuracy of the results make IoT based water management systems a must have for India. Being the topper in the charts for non-revenue water (NRW), it is need of the hour !

5. Limitations and Future Scope

It is observed that due to multiple options in communication protocols, and IoT technology inter-operability and technology adaptability is a challenge in IoT scenario. Even though the sensors are low cost, their integration requires upgradation of existing systems. Data Analytics and Decision-making with the help of Machine Learning

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