PotableWater Quality Monitoring: A Survey of Intelligent Techniques

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***Abstract*—Water quality is of immense importance to the general health and safe livelihoods of citizens. This paper presents a survey of various water monitoring techniques with a view to check the quality of potable water available to the general public. The study analyses water quality monitoring methods with emphasis on the use of artificial intelligence that has become part of society. This technological advancement has provided a tool for potable water quality to be monitored by consumers themselves. The study concludes with providing gaps that may exist in literature as it affects the monitoring of water quality both in the household and in industry.**

***Keywords*—water quality, artificial intelligence, monitoring, wireless sensors, and water contaminants.**

I. INTRODUCTION

Water is a natural vital asset that needs to be protected at all times, artificial intelligence (AI) on the other hand could be an important tool towards achieving this. Tap water is often contaminated with contaminants which is bad for human consumption. Several techniques may exist to address this problem. However, the use of artificial intelligence and wireless sensors remains scarce.

Over the past decade, complex IT systems have been built to support urban development, i.e. the construction of so-called smart cities. Such systems provide modules dedicated to specific local economy industries, such as urban transport, heating systems, energy systems, telecommunications and, eventually, water and wastewater management. As far as the latter division is concerned, IT systems are being built that enable the management of water supply and wastewater networks and sewage treatment plants [1]. AI is an Intelligence human-computer information interacting system, which offers help and makes decision that are reasonable for manager by means of providing background information, providing assistance for defining Problems, completing model and amending, listing possible plans, doing comparison and analysis and prediction [2,3].

In the 1990's, a researcher Walley [4] initiated a technique that uses Artificial Intelligence (AI) in Britain with the help of H.A. Hawkes, the river ecology expert. Walley found two approaches having scope in the river health problem, namely: Expert System and Pattern Recognition while he was trying to model the human ways of solving the problem [4]. The application of AI in water resources could increase the rate of allocation of water resources to the scientific and utilization of water resources to the rational development [5].

Water is a very crucial requirement for a number of applications. Currently, important efforts have been applied in the development of the automatic monitoring and control methods to ensure a uniform level and high quality of drinking water [6]. A good motivation for the use of AI is that the technology has grown rapidly in recent times and has been widely used in medicine, business, engineering, science and other fields [5,6].

II. WATER QUALITY

Geographic Information Systems (GIS) are adopted to inaugurate a water quality standard syntaxes and water quality forecast system. The system carries about syntaxes between industrial release standard and water quality standard; Water quality is visually displayed and water quality forecast function is accomplished in order to deliver reliable basis for decision making on water resources security and utilization [6,7]. The multilayer feed forward neural network (BP network) method was applied to assess water quality in order to define the water quality in Fen river of Yuncheng section. Training sample was produced based on classification standard, and then the water quality was assessed by BP network that could be trained in Fen river of Yuncheng area [7,8]. There is no time to delay the employment of pollution gross control. The increasing worldwide urban population has put considerable pressure on the quality of urban water, and this strain is expected to raise in the foreseeable future. The hydrological and physic-chemical impacts of urbanization on stream habitats have been provided considerable attention. However, long-term water quality analyses in urban streams are scarce owing to the relative infancy of the urban ecology sector [9].

III. USE OF AI IN POTABLE WATER MONITORING

World Economic Forum classified drinking water crisis as one of the worldwide risks, due to which about 200 children are

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dying per day. Drinking unsafe water alone causes around 3.4 million deaths per year. Despite the developments in technology, sufficient quality measures are not present to measure the quality of drinking water. By concentrating on the above issue, what was suggested is a low cost water quality monitoring system using developing technologies such as IoT, Machine Learning and Cloud Computing, which can substitute traditional way of quality monitoring [10]. The monitoring system will evolve with the growth of the Internet of Things (IoT), because with the presence of technology as specific as appropriate such as low-power wide-area network (LPWAN), brief information can be transmitted using reduced power [11]. Water resources quality valuation is a very complicated topic, as it demands a great diversity of parameters to be analysed. The grey clustering technique, which is based on grey systems theory, provides an interesting substitute to assess water quality using artificial intelligence criteria. The grey clustering method presented interesting results and could be applied to others studies on water quality or environmental quality in general [12].

A. *Use of IoTs*

Internet of Things (IoT) technology has been widely utilized in water traffic research. Many critical waterways in the world are becoming more crowded due to many aspects in waterway environments, such as variability, invisibility, and uncertainty [13]. Regulation processes and water supervision that incorporate projected hydrological changes with correlated uncertainties become extremely significant in order to avoid degradation of water ecosystems. Ensuring real time water supervision and optimization becomes mandatory for resolving the limitations of water demand/supply and to comply with biodiversity requirements [13,14].

B. *Use of Neural Network*

The recent research was an exertion to mimic landfill leachate penetration into groundwater using fuzzy logic and neural network modelling methodologies. The attained models were used as effective tools for forecasting leachate penetration and valuation of its environmental effects, one of the models looks like the one in figure 1 below. The training processes were fruitful for both neural networks and fuzzy models. The train and test models revealed over 70% matches between the observed and the simulated values [15]. Artificial neural networks can be used in optimization problems to approximate the objective function so that other methods can be applied to solve the issue. A non-linear regression that can be used to solve an optimization issue approximates the objective function. The fresh objective function derivative should be polynomial in order to calculate the optimization problem solution [16]. A big quantity of experimental information was analysed using an artificial neural network (ANN) program for more precise pollutant identification and concentration estimation. The findings are encouraging to develop an easy and cost-effective bio-sensing technology for the existence of environmental pollutants for preliminary in-field assessment (screening) of water samples [17].

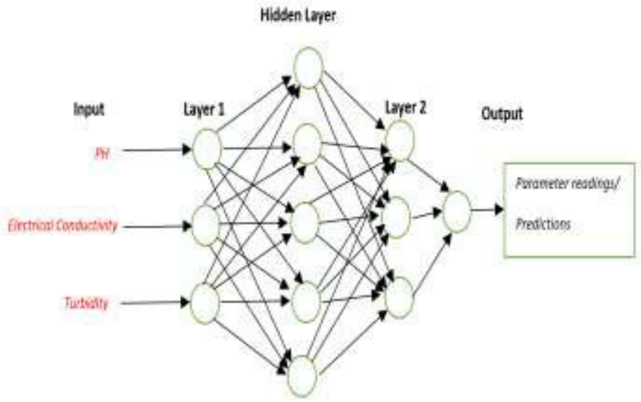

Fig. 1. Adaptive Artificial Neural Network based system (Reproduced from [16]).

C. *Smartphone-based water monitoring*

The computerized identification of colours and their strength from sensor pictures is an important interest in field deployable and cost-effective smartphone-based water monitoring solutions like the one in figure 2 below [18]. An embedded system based on a low-cost battery-operated smartphone was designed to evaluate distinct parameters of water quality in distinct distant places. Developed system measures pH, total dissolved salt (TDS) and water sample temperature using off the shelf available sensors. Using conventional mathematical relationships such as salinity, oxygen reduction potential and conductivity, measured pH and TDS data set were used to obtain other water quality parameters [19]. On the other hand, Artificial Intelligence (AI) has been widely used in automated image processing applications specifically when there is no familiar pattern in the image data. AI substantially outperforms conventional recognition methods using image examination in such situations. In the current work, Artificial Intelligence (AI) based mobile application platform has been developed, that can capture the sensor picture using an inbuilt smartphone camera, detect the existence of identifying parameters and categorize the level of the same based on colour intensity recognized in the training collections of the captured image using deep convolutional neural networks (CNN) [18,19]. The front-end read interface circuit has been designed and interfaced with the 8-bit microcontroller for measurement, data acquisition and logging purposes along with the classical Bluetooth module. A dedicated smartphone-based application provides opportunities for analysing and cloud data storage possibilities. It also offers the facility for fast judgement and simple comprehension to evaluate water quality data with location information on Google Map [19].

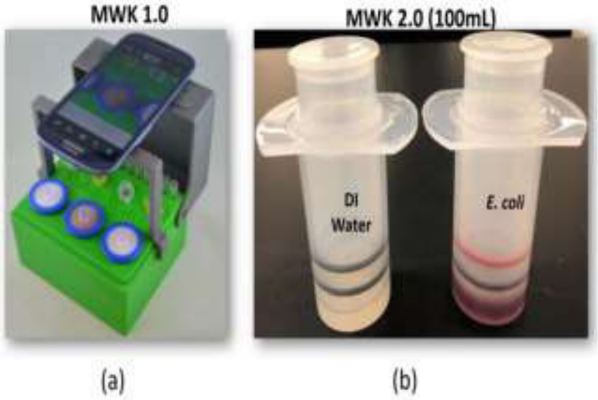

Fig. 2 Mobile water kit: (a) MWK 1.0; (b) MWK 2.0 (Reproduced from [18]).

D. Neural Network types

Salinity is one of the key aspects in groundwater quality monitoring. The core objectives of some current studies is to examine and compare the precision of three different neural computing methods, radial basis function neural network (RBFNN), multi-layer perceptron neural network (MLP) check figure 3 below, and generalized regression neural network (GRNN), in forecast of groundwater salinity of the Tabriz plain confined aquifer, articulated by electrical conductivity [EC (lS/cm)], and to employ a unified technique to combine the advantages of neural network models applying the idea of committee machine [20]. A new class of deep convolutional neural networks (CNN) PDE-interpretation has been created, frequently used to know from speech, picture, and video information. The interpretation involves convolution residual neural networks (ResNet), which are among the most promising solutions to assignments such as classifying images that have enhanced state-of - the-art efficiency in prestigious benchmark challenges [21]. ANN provides an effective tool of analysis and diagnosis to model the efficiency of the nonlinear plant. The research indicates that the ANN can predict the plant's performance with a correlation coefficient (R) between the anticipated and observed yield factors that would exceed 0.96 [22].

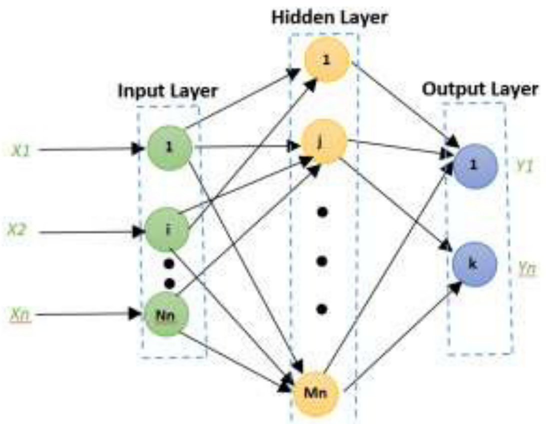

Fig. 3 Schematic diagram of feed-forward MLP Neural Network (Reproduced from: [21]).

IV. WATER POLLUTION MONITORING & CONTROL

Water pollution is the impurity of water bodies, which arises when pollutants are discharged directly or indirectly into water forms, which is a main problem in the global setting, and it leads to hazardous water-borne diseases and physical malformations. The impurity content in the water can be examined and indicated by a microprocessor-controlled instrument [23]. The potential and prevailing problem of local water resources growth can be directly mirrored by the quantification of water resources carrying capacity assessment index according to the common inverse and interactive relationship between optimum allocation of water resources and water resources carrying capacity evaluation [24].

Furthermore, many techniques have been developed to solve water pollution problems and one of them is 3s technique. The Use of 3s techniques can deliver a firm basis for the dynamic monitoring and forecasting of water contamination and cause operative control of water environment, as it has no boundary to space-time and area, and can provide a well-timed, accurate and fast access to water pollution monitoring, so it will be a countless revolution in application of water resources [24,25]. The developed forecasting system is intended to predict water impurity variables using remote sensing information. The other technique used is GIS Network Analysis technology. It is applied to water pollution tracing under water projects guideline, which initiate digital river network model and integrate and manage water projects regulating related data resource [26]. The relevant measures and countermeasures have been put onward to prevent water body contamination, such as enhancing farmers' consciousness of environmental protection, adopting ecological economic means, forming monitoring and evaluation system of AGNPS (agricultural non-point source) and refining related policies and laws [27]. Due to the growth of mining industry, there have been many mining sinking areas in Yangzhou. Waters around these regions have been congregated in the subsidence basin, producing serious problems of water contamination and water quality deterioration [28].

Chemical dosing is an important process of water treatment method because it influences water quality and effective cost. It is presented that a biochemical dosing pH control using time-based logic technique for ultrafiltration water treatment system, in order to authenticate and analyse a suitable control approach [29]. A technique of climbing picture nudged elastic band (cNEB) was used to explore the diffusion mechanism of water molecules within the interlayer gallery of graphene oxide (GO) laminates. The hydrogen bonding between water molecules and hydroxyl groups restricted the diffusion of water molecules; hence, a partly decreased hybrid GO membrane can demonstrate better water permeability and higher heavy metal ion rejection [30].

V. DISCUSSION OF FINDINGS

Table 1 presents a summary of the findings of this survey. Based on the in-depth study, it is determined that water quality is of predominate importance to water researchers. Of all the literature studied, only a couple of results are given on the utilization of AI and wireless sensors for water observation. GIS Network analysis is one among the other techniques used for checking water pollution, though it appears like it does not

TABLE I. SUMMARY OF KEY APPROACHES AND CHALLENGES IN WATER MONITORING.

Ref.	Monitoring technique	Parameters checked	Water type	Approach used	Water quality	Key challenges
[31]	GIS network	nitrate and nitrogen (in the form of ammonium nitrate), water flow	Ground water	A task-oriented approach was adopted to integrate GIS and water resource applications within a GIS environment. Tasks required to create and process the network model were implemented and embedded in a GIS using GIS data processing routines and external programs.	Enhanced	More complex, time-variant simulation computation procedures are not well suited for direct implementation within GIS systems.
[7]	BP Network	DO, COD, BOD5, NH3-N, Volatile Phenol, TP, Oil	Ground water	Training sample was generated based on classification standard, then the water quality was evaluated by BP network that could be trained in Fen river of Yuncheng section.	Not Enhanced	N/A
[24]	Grey Clustering System	pH, Coliforms, DBO5, DQO, Cadmium, Iron	Ground Water	The grey clustering method was used to assess the water quality of twenty-one monitoring points from Santa river watershed, in order to study the most important points of the area.	Not Enhanced	A limitation could be that the methods based on grey systems theory are not widely diffused compared to approaches based on multi-criteria analysis or statistics models.
[13]	ANN	river depth, river flow, rainfall rate	Ground and Portable water	The input of the prediction is obtained from real-time station readings and demonstrate that prediction can provide the means to improve the status of a water ecosystem and ensure direct environment benefits.	Enhanced	N/A
[17]	CNN	E. coli	Ground and Portable water	Using Artificial Intelligence based mobile application platform, which can capture the sensor image using an inbuilt smartphone camera, identify the presence of sensing parameters and classify the level of the same based on color intensity recognized in the training sets of the captured image using deep convolutional neural networks (CNN).	Enhanced	The color intensity of the pinkish red color represents the level of E. coli bacteria in water samples. Determining such color intensity for each concentration level is very difficult, especially because these are different shades of pinkish red for MWK.
[32]	LSSVR, GP, PCA	Na+, K+, Mg2+, SO42-, Cl-, pH, EC, and TDS	Ground water	Model inputs to the LSSVR algorithm and GP were determined using principal component analysis (PCA).	Enhanced	N/A
[24]	3s Technique	CDOM, water temperature, thermal pollution of water, DOC, BODS, TN, TP	Ground water	Predicting water pollution variables using remote sensing data.	Enhanced	N/A

report the findings in real time. Therefore, it may be of bigger use only if it had been ready to report in real time. The utilization of DSS (Decision Support System) in pollution monitoring has brought about some hope. This is attributable to its ability to spot the pollution causes, sort and propose measures for improving the water quality.

With the era of the fourth industrial revolution, and at the rate that technology is evolving fast, there is the urgent need for researchers and industry to move quickly to utilize these technologies for the good of humanity. One challenge however, could be that people do not feel that they are ready to use a number of the most recent technological advancements, reason being that they still making an attempt to understand them. However, an advantage of the speed at which technology is rising is that a lot of problems are solved quicker and the disadvantage is that with this rate, individuals may struggle to use this technology to unravel their issues because of the fast changes in this technology.

Among the evolutional technological innovations of our time, AI is one that has the ability of assisting in finding solutions to complex problems. A concern for humans is that the world will be dominated by machines in the near future. However, this would facilitate us in solving the more complex issues or decisions.

Unsafe potable water is reaching a crisis levels and is admittedly one among the worldwide risks. With the rate of young people dying per day, how are we going to have a more robust future because these are the future? Hence there is a need to develop, initiate and implement techniques like AI and machine learning which will facilitate in protecting our future. The internet of things and cloud computing may play a very important role in insuring a good quality of water monitoring to alleviate this tragedy. Implementation of this technological advancements will save several lives and conjointly improve our commonplace of living.

VI. VIII. CONCLUSION

This paper has presented and discussed a survey of intelligent techniques used for potable water quality monitoring. From the literature studied, it can be concluded that AI could be deployed in resolving the complex problem of maintaining the quality of potable water that is consumed every day. This is achieved by mimicking the knowledge from past and present data of water parameters. However most of the research done has focused on groundwater systems where a lot of quality issues lie. Further study seeks to pay a closer attention to how intelligent techniques could be applied for surface and potable water monitoring especially in developing countries like South Africa.

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