Internet of Things for Water Quality Monitoring and Assessment: A Comprehensive Review

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Abstract The implementation of urbanisation and industrialisation plans lead to the proliferation of contaminants in water resources which is a severe public challenge. These have led to calls for innovative means of water quality monitoring and mitigation, as highlighted in the sustainable development goals. Environmental engineering researchers are now seeking more intricate techniques conducting real-time monitoring and assessing of the quality of surface and groundwater that is assessable to the human population across various locations. Numerous recent technologies now utilise the Internet of Things (IoT) as a platform in water quality monitoring and assessment. Wireless sensor network and IoT environments are currently being used more frequently in contemporary times. In this paper, the recent technologies harnessing the potentials and possibilities in the IoT for water quality monitoring and assessment is comprehensively discussed. The main contribution of this paper is to present the research progress, highlight recent innovations and identify interesting and challenging areas that can be explored in future studies.

Keywords Actuators · Environment · Internet of things · Sensors · Sustainable development · Water quality

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1 Introduction

Water is one of the most abundant natural resources in the biosphere and one that is important for the sustenance of life on earth [1]. The implementation of urbanisation and industrialisation plans lead to the proliferation of contaminants in water resources which is a severe public challenge [2–4]. About 250 million cases of diseases infections are annually reported world-wide due to water pollution-related causes [5]. Therefore, innovative means of monitoring and mitigation water pollution are required [6–8] so that environmental sustainability can be achieved as highlighted in the sustainable development goals (SDGs). Environmental engineering researchers are now developing more intricate techniques for conducting real-time monitoring and assessing of the quality of surface and groundwater that is assessable to the human population across various locations [9, 10]. The internet has powered a lot of technologies and applications which make possible in our time. The Internet of Things (IoT) is an integration of many newly developed digital/information technologies [11].

The IoT now has applications in diverse anthropogenic activities both in the domestic and industrial domain [13]. These include transportation and logistics, healthcare, smart homes and offices [2], water quality assessment [14], tourism, sports, climatology [15], aquaculture [16] and a host of others [17]. More discussion on the IoT can be found elsewhere [18, 19]. Numerous recent technologies now utilise the IoT as a platform in water quality monitoring and assessment [19]. Wireless sensor network and IoT environments are currently being used more frequently in contemporary times. The intricacies of the system require that aspects such as software programming, hardware configuration, data communication and automated data storage be catered for [20].

IoT-enabled AI for Water Quality Monitoring is quite relevant for sustainable development purposes. The presence of clean water to humans is a fundamental part of the sixth (6th) sustainable development goal. It would be difficult to assess which water body and sources is actually clean enough to drink without water quality monitoring. Furthermore, the utilisation of IoT-enabled AI means that any potential water pollution arising from a point or non-point source is quickly identified and mitigated. For 14th sustainable development which emphasises the need to protect life below water, IoT-enabled AI for Water Quality Monitoring would ensure that the quality of water do not go below threshold detrimental to the survival of aquatic flora and fauna.

Within the scope of the authors' exhaustive search, the last detailed review on the subject was published over 15 years ago by Glasgow et al. [21]. In that time frame, a lot has changed in the technology as much advancements and breakthroughs have been made. It would not be out of place to revisit the topic and evaluate recent findings.

In this chapter, the recent technologies harnessing the potentials and possibilities in the IoT for water quality monitoring and assessment is comprehensively discussed. The main contribution of this paper is to present the research progress, highlight recent innovations and identify interesting and challenging areas that can be explored in future studies. After the introduction, the first section discusses the fundamental reasons behind water quality assessment and defines the fundamental indices involved. The next section discusses the importance of IoT in water quality monitoring and assessment. The hardware and software designs for IoT enabled water quality monitoring and assessment for a smart city was discussed in the foregoing section. This is succeeded by an empirical evaluation on the subject matter based on published literature in the past decade and concluded by discussions on knowledge gap and future perspectives.

2 Water Quality Assessment in Environmental Technology

Water quality refers to the physical, chemical and biological characteristics of water [22]. Assessment and monitoring of water quality are essential because it helps in timely identification of potential environmental problems due to the proliferation of pollutants (from anthropogenic activities) [11]. These are usually done both in the short and long term [23]. Monitoring and assessment are also fundamental so that potential regulation offenders can be identified and punished [24]. Technical details as regards the methods for environmental monitoring is discussed by McDonald [25].

There are specific indices used in water quality. A water quality index (WQI) is a dimensionless number used in expressing the overall quality of a water sample based on measurable parameters [26]. Many indices have been developed (as much as 30), but only about seven (7) are quite popular in contemporary times [26]. In all these, the foundational information about the water is gotten from the measurable parameters [27]. The important measurable parameters of water quality are defined below [28].

1. ***Chemical oxygen demand (COD)***: This is the equivalent amount of oxygen consumed (measured in mg/l) in the chemical oxidation of all organic and oxidisable inorganic matter contained in a water sample.
2. ***Biochemical oxygen demand (BOD)***: This is the oxygen requirement of all the organic content in water during the stabilisation of organic matter usually over a 3 or 5 day.
3. ***pH***: This is the measure of the acidity or alkalinity of water. It is neutral (at 7) for clean water and ranges from 1 to 14.
4. ***Dissolved oxygen (DO)***: This is the amount of oxygen dissolved in a water sample (measured in mg/l).
5. ***Turbidity***: This is the scattering of light in water caused by the presence of suspended solids. It can also be referred to as the extent of cloudiness in water measured in nephelometric turbidity units (NTU).
6. ***Electrical conductivity (EC)***: This is the amount of electricity that can flow through water (measured in Siemens), and it is used to determine the extent of soluble salts in the water.

7. ***Temperature***: The is the degree of hotness or coldness of the water and usually measured in degrees Celsius (°C) or Kelvin (K).
8. ***Oxidation-reduction potential (ORP)***: This is the potential required to transfer electrons from the oxidant to the reductant, and it is used as a qualitative measure of the state of oxidation in water.
9. ***Salinity***: This is the salt content of the water (measured in parts per million).
10. ***Total Nitrogen (TN)***: This is the total amount of nitrogen in the water (in mg/l) and is a measure of its potential to sustain and eutrophication or algal bloom.
11. ***Total phosphorus (TP)***: This is the total amount of phosphorus in the water (in mg/l) and is a measure of its potential to sustain and eutrophication or algal bloom.

3 Internet of Things in Water Quality Assessment

Environmental engineering researchers are now seeking more intricate techniques for conducting real-time monitoring and assessing of the quality of surface and groundwater that is assessable to the human population across various locations. Digital communication technologies are now the bedrock of modern society [29] and IoT enabled water quality monitoring and assessment is a vital aspect of that. The traditional method of water quality monitoring requires human personnel taking the readings by instruments and logging the data [30] is considered inefficient, slow and expensive [20]. In this section, the importance of IoT in water quality monitoring and assessment is itemised in light of its advantages over the traditional methods of water sampling and analysis utilised by environmental engineers and scientists when conducting water quality monitoring.

1. The most significant advantage of IoT in water quality monitoring and assessment is the possibility of real-time monitoring. Here, the status of the water quality (based on the different indices) can be obtained at any given time. This is facilitated by the speed of internet communications where data can be transmitted from the sensors in fractions of a second. These incredible speeds are not achievable in traditional water quality monitoring.
2. IoT in water quality monitoring and assessment can be automated. This means that it does not require the presence of human personnel to take readings and log data [31]. Moreover, these IoT systems would require less human resources and eliminate human errors in data logging and computations. Automation is the foundational concept of smart cities and its associated technologies.
3. Alongside the advantage of automation, IoT has led to the use of adaptive and responsive systems in water quality monitoring. These smart-systems can alert authorities or personnel regarding impending danger (such as high water level of an impending flood) or non-optimal conditions (such as in aquaponic systems) [32].

4. IoT in water quality monitoring and assessment is cheaper than hands-on personnel conducting the monitoring and assessment. The cost of human resources is minimised, and an IoT based system would not require.

4 Water Quality Monitoring Systems

IoT aims to provide a continuous presence of distinct cyber-physical systems which incorporate and intelligence capabilities [33, 34]. On the one hand, IoT has changed people daily routine and is today included in most social activities and in particular regarding smart city concept [35]. On the other hand, IoT is a relevant architecture for the design and development of intelligent monitoring systems for water quality assessment.

IoT is currently applied in different kinds of monitoring activities such as thermal comfort [36–40], acoustic comfort [41] and air quality [42, 43]. Moreover, IoT is also applied in agricultural environments such as aquaponics and hydroponics [44–47]. Water quality is crucial in agricultural activities and significantly affect the productivity and efficiency of agricultural ecosystems. IoT systems for enhanced water quality allow to store and compare the water quality data to support the decision making of agricultural plant managers.

The smart city concept associated with multiple strategies which aim to address the most relevant cities challenges using computer science technologies [48]. Currently, cities face crucial challenges regarding their socio-economic goals and the best approaches to meet them and at the same time, improve public health [49]. Water resources are an integral element of cities and are also a crucial challenge regarding their management and quality assessment [50]. Water contamination significantly affects the health and well-being of citizens, and real-time supervisor systems can be used to detect possible contamination scenarios for enhanced public health early.

IoT systems can be located in multiple places and provide a continuous stream of real-time water quality data to various municipal authorities to improve water resources management. The data collected can also be used to plan interventions for enhanced public safety [51].

The technologies used in the design and development of IoT systems in the water management domain are presented in Sect. 4.1.

4.1 Hardware and Software Design

Currently, multiple technologies are available for the design and development of IoT systems. On the one hand, numerous open-source platforms for IoT development such as Arduino, Raspberry Pi, ESP8266 and BeagleBone [52]. These platforms support various short-range communication technologies such as Bluetooth and Wi-Fi but also long-range such as GPRS, UMTS, 3G/4G and LoRA that are efficient methods

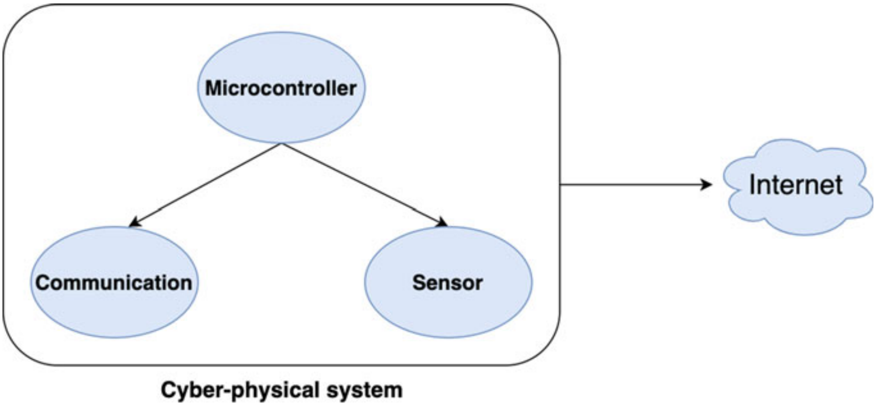

Fig. 1 IoT architecture

for data transmission. Moreover, IoT platforms also support multiple identification technologies, such as NFC and RFID identification technologies [53].

At the hardware level, IoT cyber-physical system can be divided into three elements: microcontroller, sensor and communication (Fig. 1). Commonly, an IoT system is composed by the processing unit, the sensing unit and the communication unit. The processing unit is the microcontroller which is responsible for the interface with the sensor part and can have integrated communication unit or be connected to the communication module for data transmission. The sensor unit is responsible for the physical data collection and is connected to the microcontroller using several interfaces such as analogue input, digital input and I2C. The communication unit is related to the communication technologies used for data transmission. These technologies can be wireless such as Wi-Fi or cabled such as Ethernet.

The data collected using the sensor unit is processed and transmitted to the Internet. These activities are handled using the microcontroller. The analysis, visualization and mineralization of the collected data are conducted using online services and carried by backend services which include more powerful processing units. Multiple low-cost sensors are available with different interface communication and support for numerous microcontrollers which can be applied in the water management domain [54–56].

4.2 Smart Water Quality Monitoring Solutions

Water quality assessment also plays a significant role in multiple agricultural domains such as hydroponics, aquaponics and aquaculture. In these environments water quality must be monitored; however, the main applications involve high priced solutions which cannot be incorporated in the developing countries. Therefore, the cost of water quality monitoring system is a relevant factor for their implementation.

On the one hand, hydroponic applications the nutrients in the water are a crucial factor to be monitored in real-time to provide high-quality products and avoid problems related to contaminations [57]. Therefore, water quality monitoring systems must be incorporated as long with advanced techniques of energy consumption monitoring since hydroponics is associated with high energy consumptions [58, 59]. Moreover, real-time monitoring is essential also in aquaponics since this approach combines the conventional aquaculture methods in the symbiotic environment of plants and depends on nutrient-generators. In aquaponic environments, the excrement produced by animals is used as nitrates that are used nutrient by plants [60]. On the other hand, smart cities require efficient and effective management of water resources [61].

Currently, the availability of low-cost sensors promotes the development of continuous monitoring systems for water monitoring [62]. Furthermore, numerous connectivity methods are available for data transmission of the collected data using wireless technologies [63]. Bluetooth and Zigbee communication technologies can be used to interface multiple IoT units to create short-range networks and be combined with Wi-Fi and mobile networks for Internet connection [64, 65].

Furthermore, smartphones currently have high computational capabilities and support NFC and Bluetooth, which can be used to interface external components such as IoT [66]. In particular, Bluetooth technologies can be used to configure and parametrize IoT water quality monitoring systems and retrieve the collected data in locations where Internet access are not available. On the one hand, mobile devices enable numerous daily activities and provide a high number of solutions associated with data visualization and analytics [67]. On the other hand, people commonly prefer to use their smartphones when compared with personal computers [68, 69].

The current water quality monitoring systems are high cost and do not support data consulting features in real-time. The data collected by these systems are limited since it is not related to the date of data collection and location. The professional solutions available in the literature can be compact and portable. However, that equipment does not provide a continuous data collection and sharing in real-time. Most of these systems only provide a display for data consulting or provide a memory card for data storage. Therefore, the user must extract the information and analyses the results using third-party software.

TDS and conductivity pens are quickly found in the market and are also widely used for water assessment. However, these portable devices do not incorporate data storage or data-sharing features. The user can only check the results using an LCD existent on the equipment. Moreover, this equipment commonly does not have any data storage method.

The development of smart water quality solutions using up to date technologies which provide real-time data access is crucial for the management of water resources (Fig. 2). It is necessary to design architectures which are portable, modular, scalable, and which can be easily installed by the user. The real-time notifications are also a relevant part of this kind of solutions. The real-time notification feature can enable intervention in useful time and consequently address the contamination scenarios in an early phase of development.

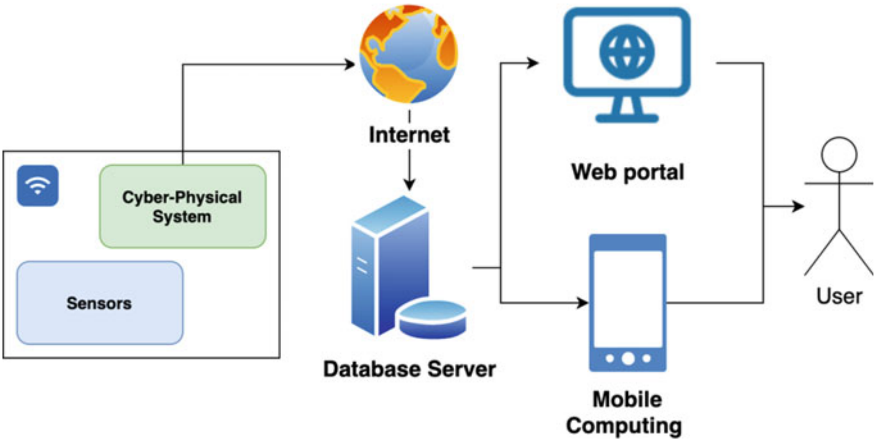

Fig. 2 Smart water monitoring system

5 An Empirical Evaluation of IoT Applications in Water Quality Assessment

In this section, a brief chronological evaluation is made of some of the interesting empirical investigations where IoT enabled technology was utilised in water quality monitoring and assessment. The focus will be not just on studies where an IoT-enabled system was designed for water quality monitoring and assessment but for studies where this technology was applied to specific water bodies within the past decade.

Wang et al. [70] monitored the water quality in the scenic river, Xinglin Bay in Xiamen, China. Their system was divided into three subsystems. There was the data acquisition subsystem, the digital data transmission subsystem and data processing subsystem. The indices monitored were pH, dissolved oxygen (DO), turbidity, conductivity, oxidation-reduction potential (ORP), chlorophyll, temperature, salinity, chemical oxygen demand (COD), NH_4^+, total phosphorus (TP) and total nitrogen (TN). The results of the study were positive as the design was adequate in achieving the set objectives. Furthermore, the water quality was of a good standard as the water had a powerful self-purification ability.

Shafi et al. [71] investigated the pH, turbidity and temperature of surface water across 11 locations in Pakistan, using an IoT enabled system that in-cooperated machine learning algorithms. The four algorithms considered were Support Vector Machine (SVM), k Nearest Neighbour (kNN), single-layer neural network and deep neural network. It was observed from the learning process on the 667 lines of data that deep neural network had the highest accuracy (at about 93%). The model could accurately predict water quality in the future six months.

Saravanan et al. [72] monitored the turbidity, temperature and colour at water pumping in Tamilnadu, India using a Supervisory Control and Data Acquisition

(SCADA) system that is enabled by IoT. The technology was usable in real-time and employed a GSM module for wireless data transfer.

In a quite interesting study, Esakki et al. [73] designed an unmanned amphibious vehicle for pH, DO, EC, temperature, and turbidity of water bodies. The device could function both in air and in water. Part of the mechanical design considerations was in its power requirements, propulsion, hull and skirt material, hovercraft design and overall weight. It was designed for military and civil applications with a mission of time of 25 min, a maximum payload of 7 kg and utilised an IoT based technology.

Liu et al. [74] monitored the drinking water quality at a water pumping station along the Yangtze river in Yangzhou, China. The technology was IoT enabled but incorporated a Long Short-Term Memory (LSTM) deep learning neural network. The parameters assessed were Temperature, pH, DO, Conductivity, Turbidity, COD and NH_3.

Zin et al. [75] utilised wireless sensor network enabled by IoT for the monitoring of water quality in real-time. The system they utilised consisted of Zigbee wireless communication, protocol, Field Programmable Gate Array (FPGA) and a personal computer. They utilised the technology to monitor the pH, turbidity, temperature, water level and carbon dioxide on the surface of the water at Curtin Lake, northern Sarawak in the Borneo island. The system was able to minimise cost and had lesser power requirements. Empirical investigations of IoT applications in water quality monitoring and assessment is summarised in Table 1.

Due to the nature of the sensors, parameters like TDS, turbidity, electrical conductivity, pH and water level are the more popularly studied indices. This was quite apparent from Table 1. It would require a major breakthrough in sensor technology to have portable and cheap sensors that can detect other parameters like heavy metals and other ions. The future of research in this area is likely to be investigations on alternative sensor technologies to determine the wide range of parameters that can adequately describe the quality of water. If this is achievable, then water quality monitoring and assessment would be able to apply correlations of Water Quality Index (WQI) to get quick-WQI values. This would enable rapid determination of the suitability of water sources for drinking.

The current water quality monitoring systems are relatively expensive and do not support data consulting features in real-time. It is predicted that researchers will gradually shift focus from portability in design to affordability. Furthermore, the development of smart water quality solutions using up to date technologies which provide real-time data access is crucial for the management of water resources. It is necessary to design architectures which are portable, modular, scalable, and which can be easily installed by the user. Researchers in the future will likely delve into better real-time monitoring technologies that would incorporate notifications and social media alerts.

Table 1 Summary of IoT applications in water quality monitoring and assessment

Year	Location	Parameters monitored	Ref
2019	Curtin Lake, Borneo island	pH, turbidity, temperature, water level and CO_2	[75]
2019	Pumping station, Yangtze river, Yangzhou, China	Temperature, pH, DO, EC, turbidity, COD and NH_3	[74]
2019	Unspecified location in Bangladesh	pH, turbidity, ORP and temperature	[76]
2018	Pumping station, Tamilnadu, India	Turbidity, temperature and colour	[72]
2018	Unspecified location	pH, DO, EC, temperature, and turbidity	[73]
2018	11 locations in Pakistan	pH, turbidity and temperature	[71]
2018	Unspecified location in India	pH, water level, temperature and CO_2	[13]
2017	Lab setup, India	pH and EC	[1]
2017	Aquaponics system, Manchay, near Lima, Peru	pH, DO and temperature	[77]
2017	Aquaponic system, Chennai, India	pH, water level, temperature and ammonia	[78]
2017	Unspecified location in India	pH, turbidity and EC	[55]
2017	Unspecified location in India	pH, turbidity and water level	[15]
2017	Nibong Tebal, Malaysia	pH and temperature	[79]
2015	Unspecified location in Malaysia	Water level	[12]
2013	Scenic river, Xiamen, China	pH, DO, turbidity, EC, ORP, chlorophyll, temperature, salinity, COD, NH_4^+, TP and TN	[70]
2006	7 locations in South Africa	Unspecified	[80]
2002	Tagus estuary, near Lisbon, Portugal	pH, turbidity and temperature	[81]

6 Conclusions

Urbanisation and industrialisation plans have led to the proliferation of contaminants in water resources which is now a severe environmental challenge. These have led to calls for innovative means of water quality monitoring and mitigation, as highlighted in the SDGs. The recent technologies harnessing the potentials and possibilities in the IoT for water quality monitoring and assessment is comprehensively discussed in this paper. Advantages of IoT in water quality monitoring and assessment are in the possibility of real-time monitoring, automation for smart solutions, adaptive and responsive systems and in a reduction of water quality monitoring costs. A brief chronological evaluation is made of some of the interesting empirical investigations where IoT enabled technology was utilised in water quality monitoring and assessment in the last decade. It was observed that IoT in water quality monitoring and assessment had not been applied to some more sophisticated parameters like heavy metals and other ions. The future of research in this area is likely to be investigations on alternative sensor technologies to determine the wide range of parameters that can adequately describe the quality of water. Cost considerations in the design and real-time data management are also areas of future research interest on the subject matter. The paper was successfully able to present the research progress, highlight recent innovations and identify interesting and challenging areas that can be explored in future studies.

References

1. B. Das, P. Jain, Real-time water quality monitoring system using internet of things, in *2017 International Conference on Computer, Communications and Electronics (Comptelix)*, Jaipur, Rajasthan India, 1–2 July 2017. IEEE
2. J. Shah, An internet of things based model for smart water distribution with quality monitoring. Int. J. Innov. Res. Sci. Eng. Technol. **6**(3), 3446–3451 (2017). http://dx.doi.org/10.15680/IJIRSET.2017.0603074
3. A.G. Adeniyi, J.O. Ighalo, Biosorption of pollutants by plant leaves: an empirical review. J. Environ. Chem. Eng. **7**(3), 103100 (2019). https://doi.org/10.1016/j.jece.2019.103100
4. J.O. Ighalo, A.G. Adeniyi, Mitigation of diclofenac pollution in aqueous media by adsorption. Chem. Bio. Eng. Rev. **7**(2), 50–64 (2020). https://doi.org/10.1002/cben.201900020
5. S.O. Olatinwo, T.H. Joubert, Efficient energy resource utilization in a wireless sensor system for monitoring water quality. EURASIP J. Wireless Commun. Netw. **2019**(1), 6 (2019). https://doi.org/10.1186/s13638-018-1316-x
6. P. Cianchi, S. Marsili-Libelli, A. Burchi, S. Burchielli, Integrated river quality management using internet technologies, in *5th International Symposium on Systems Analysis and Computing in Water Quality Management*, Gent, Belgium, 18–20 Sept 2000
7. J.O. Ighalo, A.G. Adeniyi, Adsorption of pollutants by plant bark derived adsorbents: an empirical review. J Water Process Eng. **35**, 101228 (2020). https://doi.org/10.1016/j.jwpe.2020.101228
8. O.A.A. Eletta, A.G. Adeniyi, J.O. Ighalo, D.V. Onifade, F.O. Ayandele, Valorisation of cocoa (theobroma cacao) Pod husk as precursors for the production of adsorbents for water treatment. Environ. Technol. Rev. **9**(1), 20–36 (2020). https://doi.org/10.1080/21622515.2020.1730983
9. R.G. Lathrop Jr., L. Auermuller, S. Haag, W. Im, The storm water management and planning tool: coastal water quality enhancement through the use of an internet-based geospatial tool. Coastal Manag. **40**(4), 339–354 (2012). https://doi.org/10.1080/08920753.2012.692309
10. J.H. Hoover, P.C. Sutton, S.J. Anderson, A.C. Keller, Designing and evaluating a groundwater quality Internet GIS. Appl. Geogr. **53**, 55–65 (2014). https://doi.org/10.1016/j.apgeog.2014.06.005
11. X. Su, G. Shao, J. Vause, L. Tang, An integrated system for urban environmental monitoring and management based on the environmental internet of things. Int. J. Sustain. Dev. World Ecol. **20**(3), 205–209 (2013). https://doi.org/10.1080/13504509.2013.782580
12. T. Perumal, M.N. Sulaiman, C.Y. Leong, Internet of things (IoT) enabled water monitoring system, in *2015 IEEE 4th Global Conference on Consumer Electronics (GCCE)*, Osaka, Japan, 27–30 Oct 2015. IEEE
13. K. Spandana, V.S. Rao, Internet of things (Iot) based smart water quality monitoring system. Int. J. Eng. Technol. **7**(6), 259–262 (2017)
14. P. Jankowski, M.H. Tsou, R.D. Wright, Applying internet geographic information system for water quality monitoring. Geography Compass. **1**(6), 1315–1337 (2007). https://doi.org/10.1111/j.1749-8198.2007.00065.x

15. P. Salunke, J. Kate, Advanced smart sensor interface in internet of things for water quality monitoring, in *2017 International Conference on Data Management, Analytics and Innovation (ICDMAI)*, Pune, India (24 Feb 2017. IEEE
16. D. Ma, Q. Ding, Z. Li, D. Li, Y. Wei, Prototype of an aquacultural information system based on internet of things E-Nose. Intell. Autom. Soft Comput. **18**(5), 569–579 (2012). https://doi.org/10.1080/10798587.2012.10643266
17. J.J. Caeiro, J.C. Martins, Water Management for Rural Environments and IoT, in *Harnessing the Internet of Everything (IoE) for Accelerated Innovation Opportunities* IGI Global 2019. pp. 83–99. http://dx.doi.org/10.4018/978-1-5225-7332-6.ch004
18. P. Smutný, Different perspectives on classification of the Internet of Things, in *2016 17th International Carpathian Control Conference (ICCC)*, High Tatras, Slovakia, 29 May–1 June 2016. IEEE
19. M.U. Farooq, M. Waseem, S. Mazhar, A. Khairi, T. Kamal, A review on internet of things (IoT). Int. J. Comput. Appl. **113**(1), 1–7 (2015)
20. L. Wiliem, P. Yarlagadda, S. Zhou, Development of Internet based real-time water condition monitoring system, in *Proceedings of the 19th International Congress and Exhibition on Condition Monitoring and Diagnostic Engineering Management*, Lulea, Sweden (12–15 June 2006). Lulea University of Technology Lulea
21. H.B. Glasgow, J.M. Burkholder, R.E. Reed, A.J. Lewitus, J.E. Kleinman, Real-time remote monitoring of water quality: a review of current applications, and advancements in sensor, telemetry, and computing technologies. J. Exp. Mar. Biol. Ecol. **300**(1–2), 409–448 (2004). https://doi.org/10.1016/j.jembe.2004.02.022
22. S.O. Olatinwo, T.-H. Joubert, Energy efficient solutions in wireless sensor system for monitoring the quality of water: a review. IEEE Sens. J. **19**(5), 1596–1625 (2019)
23. K.E. Ellingsen, N.G. Yoccoz, T. Tveraa, J.E. Hewitt, S.F. Thrush, Long-term environmental monitoring for assessment of change: measurement inconsistencies over time and potential solutions. Environ. Monit. Assess. **189**(11), 595 (2017)
24. W.B. Gray, J.P. Shimshack, The effectiveness of environmental monitoring and enforcement: a review of the empirical evidence. Rev. Environ. Econ. Policy. **5**(1), 3–24 (2011). https://doi.org/10.1093/reep/req017
25. T.L. McDonald, Review of environmental monitoring methods: survey designs. Environ. Monit. Assess. **85**(3), 277–292 (2003)
26. A.D. Sutadian, N. Muttil, A.G. Yilmaz, B. Perera, Development of river water quality indices—a review. Environ. Monit. Assess. **188**(1), 58 (2016)
27. X. Yu, Y. Li, X. Gu, J. Bao, H. Yang, L. Sun, Laser-induced breakdown spectroscopy application in environmental monitoring of water quality: a review. Environ. Monit. Assess. **186**(12), 8969–8980 (2014). https://doi.org/10.1007/s10661-014-4058-1
28. A. Bahadori, S.T. Smith, Dictionary of environmental engineering and wastewater treatment. Springer (2016). https://doi.org/10.1007/978-3-319-26261-1_1
29. D. Diamond, *Internet-scale sensing*, ACS Publications (2004)
30. F. Toran, D. Ramırez, A. Navarro, S. Casans, J. Pelegrı, J. Espı, Design of a virtual instrument for water quality monitoring across the Internet. Sensors Actuators B Chem. **76**(1–3), 281–285 (2001). https://doi.org/10.1016/S0925-4005(01)00584-6
31. F. Toran, D. Ramirez, S. Casans, A. Navarro, J. Pelegri, Distributed virtual instrument for water quality monitoring across the internet, in *Proceedings of the 17th IEEE Instrumentation and Measurement Technology Conference* [Cat. No. 00CH37066], Baltimore, MD, USA 1–4 May 2000. IEEE http://dx.doi.org/10.1109/IMTC.2000.848817
32. E.M. Dogo, A.F. Salami, N.I Nwulu, C.O. Aigbavboa, Blockchain and internet of things-based technologies for intelligent water management system, in *Artificial Intelligence in IoT* (Springer 2019), pp. 129–150. http://dx.doi.org/10.1007/978-3-030-04110-6_7
33. D. Giusto, A. Iera, G. Morabito, L. Atzori, *The Internet of things* (Springer, New York, New York, NY, 2010)
34. G. Marques, Ambient assisted living and Internet of things, in *Harnessing the Internet of everything (IoE) for accelerated innovation opportunities*, ed. by P.J.S. Cardoso, et al. (IGI Global, Hershey, PA, USA, 2019), pp. 100–115

35. J. Gubbi, R. Buyya, S. Marusic, M. Palaniswami, Internet of things (IoT): a vision, architectural elements, and future directions. Future Gener. Comput. Syst. **29**(7), 1645–1660 (2013). https://doi.org/10.1016/j.future.2013.01.010
36. G. Marques, R. Pitarma, Non-contact infrared temperature acquisition system based on Internet of things for laboratory activities monitoring. Procedia Comput. Sci. **155**, 487–494 (2019). https://doi.org/10.1016/j.procs.2019.08.068
37. G. Marques, I. Pires, N. Miranda, R. Pitarma, Air quality monitoring using assistive robots for ambient assisted living and enhanced living environments through Internet of things. Electronics **8**(12), 1375 (2019). https://doi.org/10.3390/electronics8121375
38. G. Marques, R. Pitarma, Smartwatch-Based Application for Enhanced Healthy Lifestyle in Indoor Environments, in *Computational Intelligence in Information Systems*, ed. by, S. Omar, W.S. Haji Suhaili, S. Phon-Amnuaisuk, (Springer International Publishing, Cham), pp. 168–177
39. G. Marques, R. Pitarma, Monitoring and control of the indoor environment, in *2017 12th Iberian Conference on Information Systems and Technologies (CISTI)*, Lisbon, Portugal, 14–17 June 2017. IEEE http://dx.doi.org/10.23919/CISTI.2017.7975737
40. G. Marques, R. Pitarma, Environmental quality monitoring system based on internet of things for laboratory conditions supervision, in *New Knowledge in Information Systems and Technologies*, ed. by Á. Rocha, et al. (Springer International Publishing, Cham, 2019), pp. 34–44
41. G. Marques, R. Pitarma, Noise monitoring for enhanced living environments based on Internet of things, in *New Knowledge in Information Systems and Technologies*, ed. by Á. Rocha, et al. (Springer International Publishing, Cham, 2019), pp. 45–54
42. G. Marques, R. Pitarma, Using IoT and social networks for enhanced healthy practices in buildings, in *Information Systems and Technologies to Support Learning*, ed. by Á. Rocha, M. Serrhini (Springer International Publishing, Cham, 2019), pp. 424–432
43. G. Marques, R. Pitarma, An Internet of things-based environmental quality management system to supervise the indoor laboratory conditions. Appl. Sci. **9**(3), 438 (2019). https://doi.org/10.3390/app9030438
44. M. Mehra, S. Saxena, S. Sankaranarayanan, R.J. Tom, M. Veeramanikandan, IoT based hydroponics system using deep neural networks. Comput. Electron. Agric. **155**, 473–486 (2018). https://doi.org/10.1016/j.compag.2018.10.015
45. V. Palande, A. Zaheer, K. George, Fully automated hydroponic system for indoor plant growth. Procedia Comput. Sci. **129**, 482–488 (2018). https://doi.org/10.1016/j.procs.2018.03.028
46. G. Marques, D. Aleixo, R. Pitarma, Enhanced hydroponic agriculture environmental monitoring: an internet of things approach, in *Computational Science—ICCS 2019*, ed. by J.M.F. Rodrigues, et al. (Springer International Publishing, Cham, 2019), pp. 658–669
47. S. Ruengittinun, S. Phongsamsuan, P. Sureeratanakorn P, Applied internet of thing for smart hydroponic farming ecosystem (HFE), in *2017 10th International Conference on Ubi-media Computing and Workshops*, Pattaya, Thailand, 1–4 Aug 2017. IEEE http://dx.doi.org/10.1109/UMEDIA.2017.8074148
48. A. Caragliu, C. Del Bo, P. Nijkamp, Smart cities in Europe. J. Urban Technol. **18**, 65–82 (2011). https://doi.org/10.1080/10630732.2011.601117
49. H. Schaffers, N. Komninos, M. Pallot, B. Trousse, M. Nilsson, A. Oliveira, Smart cities and the future Internet: towards cooperation frameworks for open innovation, in *The Future Internet*, ed. by J. Domingue, et al., (Springer Berlin Heidelberg, 2011). http://dx.doi.org/10.1007/978–3-642-20898-0_31
50. H. Chourabi, T. Nam, S. Walker, J.R. Gil-Garcia, S. Mellouli, K. Nahon, T.A. Pardo, H.J. Scholl, Understanding smart cities: an integrative framework, in *2012 45th Hawaii International Conference on System Sciences (HICSS)*, Maui, Hawaii USA 4–7 July 2012. IEEE http://dx.doi.org/10.1109/HICSS.2012.615
51. S. Talari, M. Shafie-khah, P. Siano, V. Loia, A. Tommasetti, J. Catalão, A review of smart cities based on the internet of things concept. Energies **10**(4), 421 (2017). https://doi.org/10.3390/en10040421
52. K.J. Singh, D.S. Kapoor, Create your own internet of things: a survey of IoT platforms. IEEE Consum. Electron. Mag. **6**(2), 57–68 (2017). https://doi.org/10.1109/MCE.2016.2640718

53. G. Marques, R. Pitarma, M. Garcia, N. Pombo, Internet of things architectures, technologies, applications, challenges, and future directions for enhanced living environments and healthcare systems: a review. Electronics **8**(10), 1081 (2019). https://doi.org/10.3390/electronics8101081
54. A.S. Rao, S. Marshall, J. Gubbi, M. Palaniswami, R. Sinnott, V. Pettigrovet V, Design of low-cost autonomous water quality monitoring system, in *2013 International Conference on Advances in Computing, Communications and Informatics (ICACCI)*, Mysore, India, 22–25 Aug 2013. IEEE http://dx.doi.org/10.1109/ICACCI.2013.6637139
55. S. Geetha, S. Gouthami, Internet of things enabled real time water quality monitoring system. Smart Water. **2**(1), 1 (2016). https://doi.org/10.1186/s40713-017-0005-y
56. N.A. Cloete, R. Malekian, L. Nair, Design of smart sensors for real-time water quality monitoring. IEEE Access. **4**, 3975–3990 (2016). https://doi.org/10.1109/ACCESS.2016.2592958
57. D.-H. Jung, H.-J. Kim, W.-J. Cho, S.H. Park, S.-H. Yang, Validation testing of an ion-specific sensing and control system for precision hydroponic macronutrient management. Comput. Electron. Agric. **156**, 660–668 (2019). https://doi.org/10.1016/j.compag.2018.12.025
58. T. Gomiero, Food quality assessment in organic vs. conventional agricultural produce: findings and issues. Appl. Soil Ecology. **123**, 714–728 (2018). https://doi.org/10.1016/j.apsoil.2017.10.014
59. A. Zanella, S. Geisen, J.-F. Ponge, G. Jagers, C. Benbrook, T. Dilli, A. Vacca, J. Kwiatkowska-Malina, M. Aubert, S. Fusaro, M.D. Nobili, G. Lomolino, T. Gomiero, Humusica 2, article 17: techno humus systems and global change—three crucial questions. Appl Soil Ecology. **122**, 237–253 (2018). https://doi.org/10.1016/j.apsoil.2017.10.010
60. C. Maucieri, Z. Schmautz, M. Borin, P. Sambo, R. Junge, C. Nicoletto, Hydroponic systems and water management in aquaponics: a review. Italian J Agron. **13**(1), 1012 (2018). http://dx.doi.org/10.21256/zhaw-3671
61. S. Pellicer, G. Santa, A.L. Bleda, R. Maestre, A.J. Jara, A.G. Skarmeta (2013) A global perspective of smart cities: a survey, in *2013 Seventh International Conference on Innovative Mobile and Internet Services in Ubiquitous Computing (IMIS)*, Massachusetts Ave., NW Washington, DCUnited States: IEEE. http://dx.doi.org/10.1109/IMIS.2013.79
62. L. Parra, S. Sendra, J. Lloret, I. Bosch, Development of a conductivity sensor for monitoring groundwater resources to optimize water management in smart city environments. Sensors **15**(9), 20990–21015 (2015). https://doi.org/10.3390/s150920990
63. I. Ganchev, M.G. Nuno, D. Ciprian, C. Mavromoustakis, R. Goleva, Enhanced living environments: algorithms, architectures, platforms, and systems, in *Lecture Notes in Computer Science*. vol. 11369 (Springer International Publishing, Cham)
64. C. Dobre, Constandinos Mavromoustakis, Nuno Garcia, Rossitza Ivanova Goleva, G. Mastorakis, *Ambient assisted living and enhanced living environments: principles, technologies and control* (Butterworth-Heinemann, Amsterdam; Boston, 2017), p. 499
65. A. Anjum, M.U Ilyas, Activity recognition using smartphone sensors, in *Consumer Communications and Networking Conference (CCNC)*, IEEE: Las Vegas, Nevada, USA 12–13 Jan 2013, pp. 914–919. http://dx.doi.org/10.1109/CCNC.2013.6488584
66. I. Bisio, F. Lavagetto, M. Marchese, A. Sciarrone, Smartphone-centric ambient assisted living platform for patients suffering from co-morbidities monitoring. Commun. Mag. IEEE **53**, 34–41 (2015). https://doi.org/10.1109/MCOM.2015.7010513
67. S. Haug, R.P. Castro, M. Kwon, A. Filler, T. Kowatsch, M.P. Schaub, Smartphone use and smartphone addiction among young people in Switzerland. J. Behav. Addictions **4**(4), 299–307 (2015). https://doi.org/10.1556/2006.4.2015.037
68. D. Kuss, L. Harkin, E. Kanjo, J. Billieux, Problematic smartphone Use: investigating contemporary experiences using a convergent design. Int. J. Environ. Res. Public Health. **15**(1), 142 (2018). https://doi.org/10.3390/ijerph15010142
69. D. Wang, Z. Xiang, D.R. Fesenmaier, Smartphone Use in everyday life and travel. J. Travel Res. **55**(1), 52–63 (2016). https://doi.org/10.1177/0047287514535847
70. S. Wang, Z. Zhang, Z. Ye, X. Wang, X. Lin, S. Chen, Application of environmental internet of things on water quality management of urban scenic river. Int. J. Sustain. Dev. World Ecology. **20**(3), 216–222 (2013). https://doi.org/10.1080/13504509.2013.785040

71. U. Shafi, R. Mumtaz, H. Anwar, A.M.Qamar, H. Khurshid, Surface water pollution detection using internet of things, in *2018 15th International Conference on Smart Cities: Improving Quality of Life Using ICT & IoT (HONET-ICT)*, Islamabad, Pakistan, 8–10h Oct 2018). IEEE
72. K. Saravanan, E. Anusuya, R. Kumar, Real-time water quality monitoring using Internet of Things in SCADA. Environ. Monit. Assess. **190**(9), 556 (2018). https://doi.org/10.1007/s10661-018-6914-x
73. B. Esakki, S. Ganesan, S. Mathiyazhagan, K. Ramasubramanian, B. Gnanasekaran, B. Son, S.W. Park, J.S. Choi, Design of amphibious vehicle for unmanned mission in water quality monitoring using internet of things. Sensors **18**(10), 3318 (2018). https://doi.org/10.3390/s18103318
74. P. Liu, J. Wang, A.K. Sangaiah, Y. Xie, X. Yin, Analysis and prediction of water quality using LSTM deep neural networks in IoT environment. Sustainability **11**(7), 2058 (2019). https://doi.org/10.3390/su11072058
75. M.C. Zin, G. Lenin, L.H.Chong, M. Prassana, Real-time water quality system in internet of things, in *IOP Conference Series: Materials Science and Engineering*, vol 495, no 1, p. 012021 (2019). http://dx.doi.org/10.1088/1757-899X/495/1/012021
76. M.S.U. Chowdury, T.B. Emran, S. Ghosh, A. Pathak, M.M. Alam, N. Absar, K. Andersson, M.S. Hossain, IoT based real-time river water quality monitoring system. Procedia Comput. Sci. **155**, 161–168 (2019). https://doi.org/10.1016/j.procs.2019.08.025
77. S Abraham, A. Shahbazian, K. Dao, H. Tran, P Thompson, An Internet of things (IoT)-based aquaponics facility, in *2017 IEEE Global Humanitarian Technology Conference (GHTC)*, San Jose, California, USA, 2017. IEEE
78. M. Manju, V. Karthik, S. Hariharan, B. Sreekar, Real time monitoring of the environmental parameters of an aquaponic system based on Internet of Things, in *2017 Third International Conference on Science Technology Engineering and Management (ICONSTEM)*, Chennai, India, 23–24 Mar 2017. IEEE
79. K.H. Kamaludin, W. Ismail, Water quality monitoring with internet of things (IoT), in *2017 IEEE Conference on Systems, Process and Control (ICSPC)*, Malacca, Malaysia, 15–17h Dec 2017. IEEE
80. P. De Souza, M. Ramba, Wensley A, E. Delport, Implementation of an internet accessible water quality management system for ensuring the quality of water services in South Africa, in *WISA Conference*, Durban, South Africa. Citeseer (2006)
81. O. Postolache, P. Girao, M. Pereira, H. Ramos, An internet and microcontroller-based remote operation multi-sensor system for water quality monitoring. Sensors **2**, 1532–1536 (2002)