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Review Article

## Combination of GIS with Different Technologies for Water Quality: An Overview

Nada Jasim Habeeb <sup>a\*</sup> , Shireen Talib Weli <sup>a</sup>

<sup>a</sup> *Middle Technical University, Baghdad, Iraq.*

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### Abstract

Water is one of the most important requirements in daily life, which represents the largest part of the Earth. As a result, economic, industrial, and social development in most countries has led to increased pollution of water resources. It is, therefore, necessary to monitor water quality continuously to prevent a future catastrophe that adversely affects the quality and quantity of water wealth. A Geographic Information System (GIS) is used in various fields to monitor and analyze data collected from different geographical locations. Integration of GIS and other technologies has become an indispensable tool. This gives us direct control over solution expansion, cost reduction, powerful complex case analysis, as well as increased accuracy and efficiency of geospatial data. In recent years, many combinations of GIS with different technologies such as remote sensing, wireless sensor networks, and internet of things approaches have been proposed due to the rapid progress of technology development in many applications. However, in the last several years, no review articles have been published about water quality using the integration of GIS and other technologies. Therefore, this paper investigates the status of continuous search in the field of GIS and its integration with other technologies (Remote Sensing, Internet of Things, Web, etc.) for water quality management and monitoring to maintain the water resources in a proper way. Finally, the integration of GIS with these technologies creates a powerful platform for analyzing and processing big data and mapping geographic remotely in less time, at a lower cost, at a higher speed, with more accurate details, and in real time when compared to traditional geographic information systems. This paper also highlights future research trends on the cooperation of GIS with other technologies for matters that are related to water quality.

*Keywords:* GIS; IoT; Remote Sensing; Water Quality Management; Web-GIS.

### 1. Introduction

Water is one of the most essential necessities in day-by-day lifestyles, which includes major parts of the Earth's hydrosphere [1-3]. Scientific investigations concerning the lack of sufficient water resources, the increase of air pollution in water sources in a predominant part of the world, and the increase of man's destructive activities affecting water resources are going to cause a disaster in the near future. Figure 1 represents, depending on the selected country, the per capita consumption of water between the years 2015-2018. 1207 cubic meters is the amount of water consumed annually by the average American, which makes the United States one of the largest consumers of water worldwide. By 2050, industrial demand for freshwater is expected to increase, leading to a shortage of water for domestic and agricultural uses ([www.statista.com](http://www.statista.com)). Implement appropriate policies to evaluate the water resources through sound management and integrated planning consider as vital steps [4].

Water quality has become a major issue in the management of natural resources because of the problem of water pollution with chemicals or other polluting substances. This affects human health directly or indirectly [5]. Water Quality

\* Corresponding author: [nadaj2013@mtu.edu.iq](mailto:nadaj2013@mtu.edu.iq)

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means water quality assessment and concentration of components and additives. Then compare the results of this concentration with the purpose for which this water will be used. Used in homes for drinking and food preparation, they are different from those used for fish farming or irrigating crops. The parameters of water quality play an important role in making decisions regarding the use of water [6, 7]. Water quality management includes all processes related to water quality. Monitoring water quality includes checking water parameters and comparing them with specified standards. Water acceptability is determined by compliance with the required usage criteria [8-10]. Due to the spatial nature of water on Earth, Geographic Information System can be used to model water resources effectively, and it provides an effective tool in analysing and assessing the degree of water pollution. Therefore, this technique is important for decision-makers in land reclamation, groundwater management, and water quality control.

As a result of the development and technological progress in various fields, it is possible to obtain data abundantly, accurately, and quickly compared to the traditional methods through which it is difficult for some water resources to obtain accurate data. The integration of GIS and other technologies such as Remote Sensor, Internet of Things, web, and Cloud Computing facilitates the automation of the management and control of water quality such as data collection accurately, quickly, and adding high capacity in storage and processing. This paper provides an overview of the integration of GIS with other technologies to view the importance of the integration of these techniques in real-time for the importance and management of water quality.

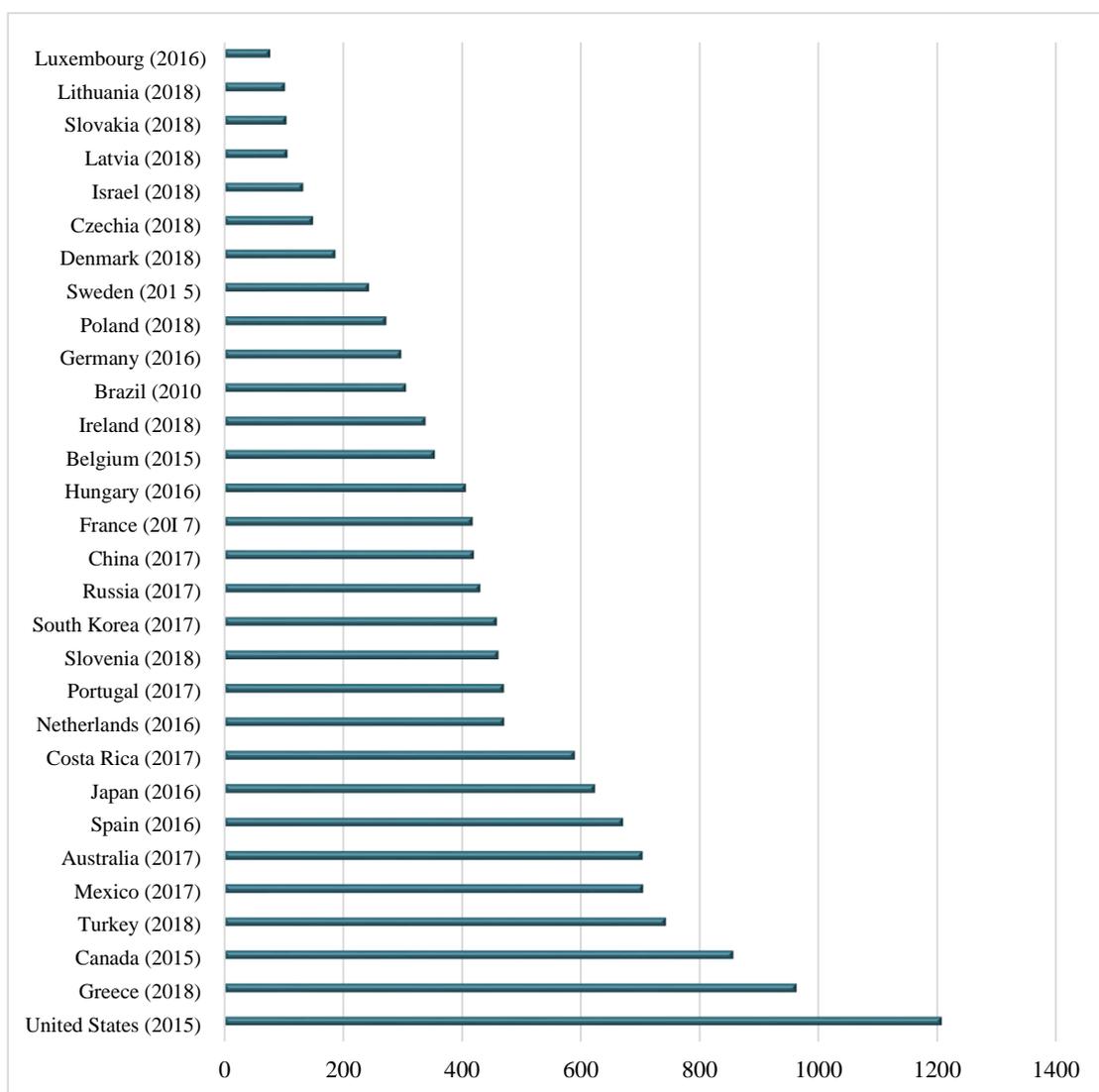


Figure 1. Water consumption per capita per cubic meter (www.statista.com, 2021)

## 2. Background and Literature Review

Geographic Information Systems (GIS) were created in 1963 in Canada by Roger Tomlinson, known as the GIS father. GIS can be described as a computer-based device that stores, analyses, controls, and visualizes geographic information, typically on a map [11-13]. In general, GIS is a computer system used for geographic information, manage, analyse this information, and show it as spatial data [14]. Spatial data means the data has positional x, y coordinate

values. GIS represents our world through digital maps. Recently, GIS is used in many applications that need analysis and management of spatial data such as GIS applications in the field of environment, in the areas of urban planning, in the military, Medical, water, and agriculture.

One of the important applications of GIS is an environmental data management. It can be used to supply managers and scientists with a range of scenarios for the spatial distribution of the data and predict future trends of the data to avoid a possible environmental crisis. Geo-spatial data mining can be used to assess the hidden relationships of disasters or crises, and environmental pollutions, sources, causes and the number of pollutions to take the necessary measures for environmental protection [4]. The current uses of the GIS are land use planning, utility management, ecosystems modelling, landscape evaluation, planning of transportation and infrastructure, facilities management, market analysis, analysis of visual impact, tax assessment, analysis of real estate, ..., etc. of GIS tasks can be organized as data input, data management, data display, information analysis and retrieval [15].

The geographic information is arranged as various layers or series of layers of thematic maps with their related attributes. Attributes are the items of data, which relate to the map, but are not a part of it, such as the names of rivers or the type of vegetation in an area. Figure 2 shows a group of maps of the same portion of the zone and each location has the same coordinates in all the maps contained in the system. This will help to analysis its structural and spatial characteristics to obtain a perfect knowledge of this zone [16, 17].

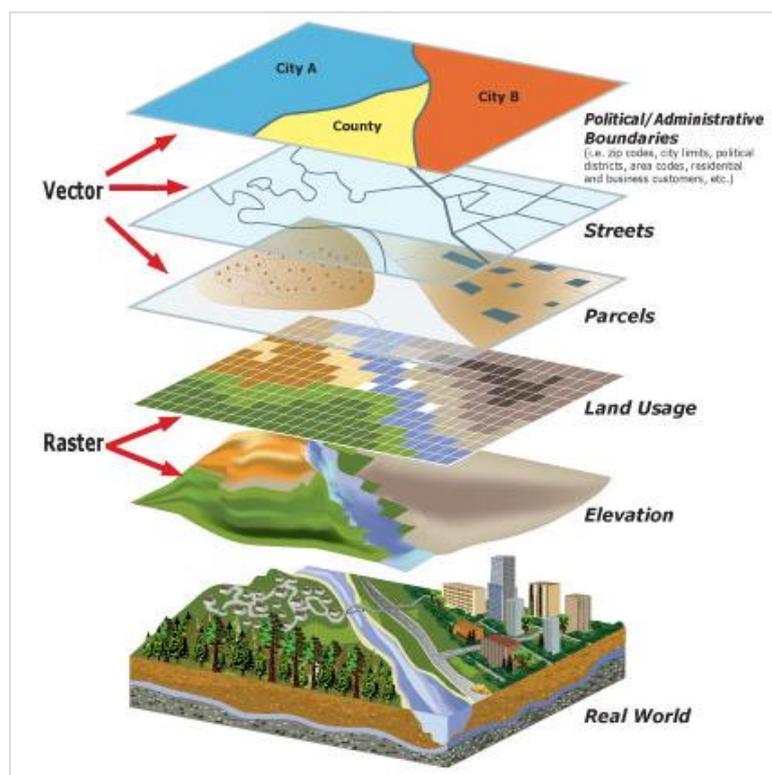


Figure 2. GIS model layers of the real world (<https://inyo-monowater.org>)

In Figure 2, GIS represents a model of the real world in the form of layers showing the geographical distribution and related data. GIS data are called geospatial data, which is based on big data with different functions [18, 19]. The GIS allows the integration of various information with geographic information such as digital maps, satellite images, aerial photographs, and GPS data. The GIS is a combination of digital mapping technology with database management systems in which spatial data is managed and analysed from various sources.

### 3. Data and Features

Data is the foremost imperative component of GIS and is considered the costliest part of the GIS components. They are collected and stored in GIS or in external databases [20]. In GIS, the spatial data are managed by either a vector data model or a raster data model. The vector data model constructs spatial features of a region, lines, and points using geographic points. The raster data model constructs the spatial features using grid cells in the form of rows and columns [21-23]. Data is entered into a GIS by many source technologies. Figure 3 shows the types of data entry. Analog data is converted to digital data and then converted into raster/vector data. The entered data that is collected by GPS is digitized and converted to vector data, which entered into a GIS, while raster data is generated from remote sensor data [24, 25].

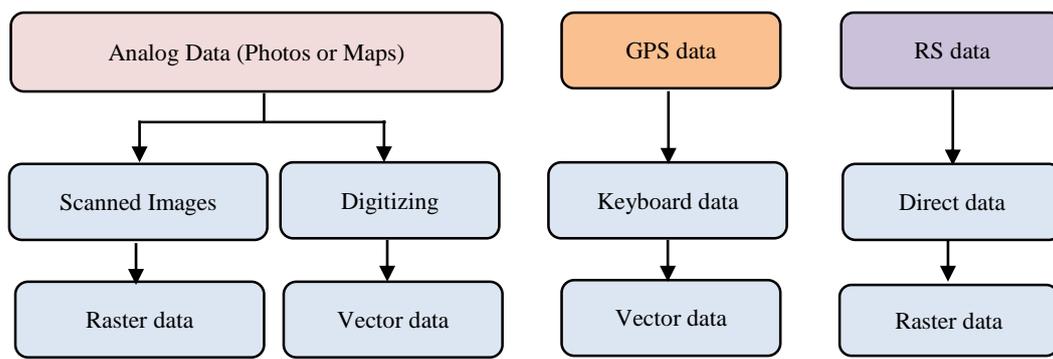


Figure 3. Data entry into GIS from different sources

### 4. Open-Source GIS Software

Open Source is a program that can be used and changed freely by anyone. ArcGIS is an integrated and comprehensive, scalable system designed to meet the needs of most GIS users. It can be defined as "a system of hardware, software, and procedures designed to facilitate the collection, management, manipulation, analysis, modelling, rendering and output of spatially referenced". ArcGIS contains alphanumeric and cartographic information. It is possible to know the exact location of each element in space as well as its relationship with other elements. It is also possible to create a database to store the information in the real world and link it dynamically to display it on the screen dynamically. Generally, GIS is used for several main purposes, namely: 1- Data creation. 2. Data visualization. 3- Data processing and Analysis. 4. Presentation [26].

### 5. Integration of GIS with other Technology for Water Quality

GIS has been used extensively for water quality. Table 1 includes the previous literature using GIS without integrating it with other technologies for the period between 2010 and 2021.

Table 1. The literature in GIS for water quality for the period between 2010 and 2021

Study	Application purpose	Water Usage	Researched area
Ma and Cui, 2011 [27]	Water quality information system	Usable water	Fuzhon city of Jiangxi-China
Li, 2010 [28]	Water quality information Management and monitoring of early warning	Urban drinking water quality	Some cities of China
Ferrer et al., 2012 [29]	Assess water quantity and quality	Surface water and groundwater	The Júcar River Basin District- Spain
Zhao et al., 2010 [30]	Water quality and water quantity	River water	The main canal of South-to-north Water Transfer East Route Project in Shandong province-China
Yan and Li, 2011 [31]	Spatial variability of groundwater quality	Groundwater	Xianyang City-China
Mu and Wu, 2010 [32]	Water source management and water environment protection	Urban Drinking Water	China
Gai et al., 2012 [33]	Evaluation in the form of pollution index, and the distribution map of water quality	Global water	Qing yang city-China
Arnatskaya et al., 2017 [34]	Water facilities evaluation hydro biological indicators	Freshwater	Gulf of Finland ecological state
Jayarathna et al., 2017 [35]	Managing water resources	Residential water	Australia
Abbasnia et al., 2018 [36]	Evaluate the groundwater quality and its suitability for irrigation purpose	Groundwater	Villages of Chabahr city, Sistan and Baluchistan province-Iran
Hashesh, and Ahmed, 2018 [37]	Measure the changes in the spectral reflectivity water quality, analysing seasonal difference	Marshes water	AL-Hawizah marshes, South of Iraq
Mir et al., 2017 [38]	Management of water resources	River water	Sistan- Iran
Oseke et al., 2021 [39]	Assessment of water quality	Drinking Water	Nigeria
Fang et al., 2020 [40]	Assessment of the hydrodynamics role	Groundwater	Dagu River, China
Bashir et al., 2020 [41]	Water quality assessment	Irrigation Water	Lower Jhelum canal in Pakistan
Lad et al., 2020 [42]	Assessment of water quality	River water	Tapi basin in central India
Rawat and Singh, 2018 [43]	Evaluation of water quality	Groundwater	Bay of Bengal in the East of Kanchipuram district of Tamil Nadu state
Williams et al, 2020 [44]	Water quality analysis	Lake water	Lakes in Linden
Batarseh et al., 2021 [45]	Assessing groundwater resources	Groundwater	Abu Dhabi Emirate, UAE
Bera et al., 2021 [46]	Groundwater vulnerability assessment	Groundwater	Nangasai River Basin, India

The integration of GIS with the other technologies such as Remote Sensing, Internet of Things, Web or Internet, Cloud Computing, etc. For the quality of water facilitates, the process of monitoring changes in water quality parameters across temporal and spatial scales that are not apparent in normal site measurements [47]. Recent studies have focused on the integration models, GIS with other technologies.

### 5.1. RS - GIS

Geographic information systems provide techniques for storing, processing, and controlling a large amount of information derived from Remote Sensing Devices. Remote Sensing (RS) can be defined as "the observation and measurement of an object without touching it" [48]. Another definition of RS is "the acquisition of physical of defining data of an object with a sensor that has no direct contact with the object itself" [49]. Bachiller-Jareno defined RS as "the science and art of collecting information about surface phenomena without direct physical contact with these phenomena" [50]. This information is collected by means of sensing and recording the reflected energy and emitted from those phenomena and recording them as data, as an initial step to the process and analyse these data and to convert it into information for use in different fields [51, 52]. RS uses satellites and aerial platforms to capture image data. Satellite images are obtained with different wavelengths. It is possible to distinguish aspects of the surface of the Earth through different image processing procedures.

The integration of GIS and RS technique is widely used in the planning, design, and practice of water resources engineering [53]. The integration of GIS and RS technologies helps automate the measurement of the physical and chemical parameters of the water area and helps to access and monitor water quality [54, 55]. Qurtas et al. [56] presented the integration of GIS and RS for spatial and temporal detection of water pond distribution in Iraqi Kurdistan. In addition, this combination is used to detect the sustainability of water ponds. The information was obtained using Remote Sensor methods, which are based on sensor data acquired by the cameras and radar. GIS was used for mapping and for calculating the pond area variations.

Nelly and Mutua (2016) determined the groundwater potential zones as well as the quality of groundwater using the integration of GIS and RS. From the Shuttle Radar Topography Mission data, the Model of Digital Elevation was extracted. A groundwater potential map was generated using ArcGIS software [57]. Kumar et al. [58] used the integration of GIS with RS to identify potential groundwater areas. This method has proven effective in terms of reducing cost, time and labor. Five different thematic layers were identified in the study area through satellite imagery and topographic maps. And then generate a potential groundwater map using GIS.

Drilling and stratigraphy methods are traditional and reliable methods for determining the location of aquifers, but these methods are expensive and take a long time. To solve these problems, the technique of integrating remote sensing with the GIS appeared as an important method for modeling potential areas of groundwater, especially in solid rocky terrain. Das et al. (2018) [59] attempted to identify potential areas of groundwater in the water areas of West Bengal, India by combining remote sensing with the GIS. This technique was applied in discovering the potential of aquifers by analysing the compositions of the various influencing factors.

### 5.2. IoT - GIS

The Internet of Things (IoT) is a system designed to connect many computers, digital and mechanical machines, or people, with the ability to send data over the Internet without the need for human intervention [60, 61]. IoT also refers to "a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual 'Things' have identities, physical features, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network" [62]. The Internet of Things represents a breakthrough in the world of communication technology, a technology that may dramatically change human life to make it easier, faster and more productive.

Modern geographic information systems that are fed with data in real-time using the IoT will be a powerful tool for carrying out operations that serve many companies' organizations at the speed of solving problems and making decisions. The integration of IoT and GIS provides a necessary means to address many infrastructure problems in real-time. GIS tracks data to find the area where the problem occurs. IoT identifies the fault based on thermal, acoustic, and electromagnetic sensors, thus quickly locating the problem and damaged infrastructure. The sensor data is integrated with GIS applications, which in turn build a digital map showing the location of the damaged section. This will save several efforts and time searching for the problem location [63].

Gopikumar et al. (2021) [64], designed an experimental model that improves the biological analysis potential of wastewater. The model works on samples identified by surveying the topographic wastewater site. Where the Internet of things was used for the purpose of collecting information in real-time.

Xiaocong et al. (2015) [65] introduced a system that provides water resources information accurately and comprehensively using GIS integration with the Internet of Things. The system consists of three basic steps. First: some

parameters were defended, which are a parameter of water quality, water level parameter, and water flow parameter. Second: designing a network of wireless sensors based on the Internet of Things that monitor the information about water resources. Third: design the file system for the management and interactive application based on Web-GIS.

### 5.3. Web - GIS

Recently, Web-GIS or Internet GIS is widely used in many applications. Web-GIS provides an easy user interface to implement GIS programs. The user only needs a web browser. Web-GIS is flexible, durable and accessible [66-68]. Web-GIS uses the Internet to facilitate access to geographic information, geo-analysis tools, geographic databases, and distributed GIS. The distributed GIS is a wider system than traditional GIS, which has helped to develop all comprehensive GIS programs and data models [69].

Internet-based GIS has many advantages over traditional GIS systems. It allows the user to access many different options by providing decision support tools and databases on the Internet. The user does not need to know how to use complex and expensive GIS programs. In addition, large databases are stored in a central server and this helps save time and money [70, 71].

Economic development and social changes in any country may lead to negative impacts on the marine and coastal environment. It is, therefore, necessary to have a permanent marine water-monitoring program for protecting and conserving water resources. Amiruddin (2016) [72] presented a project in which Wave Glider combined with Web-GIS technology. The GeoEvent processor expands the capabilities of the web GIS in providing real-time monitoring data with ease and speed. This helps to make decisions for natural resources.

### 5.4. GIS with other Technology

For sustainable development, groundwater quality is of great importance in this area, and it is considered a vital resource in urban and rural areas. Due to the excessive use of groundwater, saltwater intrusion may result in usable groundwater. Jeihouni et al. (2018) [73] presented a system to monitor the quality and quantity of groundwater regularly. Results showed that saltwater was detected through quality maps and regression analysis. This new approach for the quantitative assessment of groundwater balance is appropriate for countries that do not have hydrological characteristics databases. Nath et al. (2018) [74] conducted an analysis of potable groundwater using the integration of GIS and geochemical methods to determine the amount of water pollution in arsenic and other minerals. In addition, a chemical water assessment quality was performed to determine the sustainability of potable groundwater reserves.

Cloud Computing plays an important role in the water quality sector, it is a technology that relies on the transfer of processing and storage space of the computer to the so-called cloud that is accessed via the Internet. Cloud service providers have Internet-connected devices through which they provide applications and other services. The user takes advantage of these services over the web [75]. Integrated sensor nodes with cloud computing may help monitor water quality and also assist in decision-making inappropriate corrective actions [76]. The integration of GIS with cloud computing provides a fast platform for detecting changes occurring in the environment. Exploring these changes will require multiple servers simultaneous to process the data and the use of caching help in the process of improving performance [77].

Al-Karnaz (2017) [78] presented a system for water quality management using the integration of GIS and Cloud computing to evaluate water quality in the selected zone and identify its underground obtained from 2007 to 2015. It concluded that there is a strong relationship between the increase of population and the increase of pollution, and there is a relationship between water pollution by chemicals (Nitrate - Chloride - Sodium - Potassium - Magnesium - Hardness - Total dissolved solids - Calcium) and diseases (liver disease – kidney disease - nervous system disease) and other diseases. This study showed that the use of cloud computing for water quality management helps to raise awareness and make the community realize the magnitude of pollution. This will lead to creating a spirit of cooperation and positive participation in a try to decrease the problem by ensuring the optimal use of water and reduce the wasting of water in a spontaneous way, Moreover, the cloud technology service saves data from any damage, maintain it and make it easy to access.

Arulbalaji et al. (2019) [79] identified the potential groundwater areas using a combination of GIS and analytical hierarchical process techniques. Based on the final output of the groundwater map, the study classified five potential groundwater areas: areas with very high, high, moderate, low and poor density. Determining the groundwater map helps in decision making in order to reach better planning and management to provide groundwater for agriculture purposes, thus increasing agricultural production. RadFard et al. (2019) [80] used Artificial neural networks and Arc-GIS combinations for the purpose of assessing the quality of groundwater drinking and determining the water quality index in Bardaskan villages –Iran. The study took 18 parameters of water samples for the researched areas. These parameters were analyzed using the Arc-GIS system. The purpose of using the artificial neural network was to estimate the groundwater quality index.

Ben Brahim et al. (2021) [81] indicated that the Kebili region, in southwestern Tunisia, is an arid desert region. They proposed to apply water quality index models and Fuzzy Logic models using the geographic information systems environment for the purpose of addressing the spatial division of water and assessing the quality of drinking and irrigation water. Some studies have indicated that a GIS-based water quality assessment is a cost-effective tool for assessing water quality but is unable to deal with the uncertainties involved in assessing environmental problems. To solve this problem, Jha et al. proposed in (2020) [82] to merge fuzzy logic with water quality index based on the geographic information system in one of the regions of southern India.

Huang & Tian (2019) [83] designed a simulation program for three-dimensional hydrodynamic and analysis of lake water quality, based on a GIS. The system provides the necessary functions for building hydrodynamic modeling and provides a geo-user interface for displaying and manipulating the model. It also provides the necessary tools for mapping and modeling development. All these features of the proposed system facilitate the task of the hydrodynamic modeling and water quality process.

## 6. Challenge Issues in Water Quality in Iraq

Water resources are the main lifeblood of the arid and semi-arid environments where Iraq is located. In these areas, the water resources in Iraq have faced many threats and many damages, especially in the second half of the last century. Large areas of the marshes that make up half of the water bodies have dried up, as well as the water resources of lakes and running river water have diminished due to the establishment of dams and irrigation projects in each of Syria, Turkey, and Iran, where a large proportion of the population in the countryside suffers from the scarcity of potable water. In Iraq, there is a group of major rivers in which most of the water sources are from outside Iraq, and among the most important rivers in Iraq are: Tigris, Euphrates, Shatt al-Arab, and the Great Zab, Little Zab, and Diyala.

Water resources in Iraq suffer from many physical, chemical, or biological changes. These changes lead to water pollution, as a number of government institutions in Iraq conduct measurements to check the levels of dissolved salts and some mineral elements. These checks are considered one of the basic criteria for measuring the quality of surface water and the annual variables that take place in the Tigris and Euphrates rivers, and among these tests are Chlorides CL, Sulfates  $SO_4$ , Total Dissolved Salts S.D.T and other checks. Water resources in Iraq suffer from many sources of pollution, the most important of which is industrial pollution.

The main problem facing Iraq is the pollution of its water and the consequent economic and social effects that stand as one of the obstacles to achieving economic development and managing water quality. Pollution is defined as introducing a type of pollutant into the natural environment, damaging it and causing an imbalance in the ecosystem [64]. Pollution occurs in various forms of energy, such as noise pollution, thermal pollution, and others. It negatively affects life and makes the water unusable. The sources of water pollution in Iraq can be classified into two main types. The first is natural pollution. It appears in changing water temperature, increasing salinity, or increasing suspended substances, dry the marshes, etc. The second is chemical pollution, which includes agricultural drainage water, wastewater, industrial wastewater, and reservoirs and dams. Successful water quality management and access to a good level of water quality require the protection of the aquatic environment from all types of pollution. The interrelationship between Earth's ecosystems and human impact on the environment is a complex challenge for governments, institutions, and scientists. To improve water quality, integration of GIS with other modern technologies such as Remote Sensing, IoT, Web, and others is a powerful tool to improve water quality management, reduce energy costs, and prevent polluted events.

## 7. Conclusion

This paper presents a review of recent works for the integration of GIS applications with various technologies such as Remote Sensing, IoT, Web, cloud computing, etc., for water quality improvement. From the literature review, it was concluded that the integration of GIS with other modern technologies could produce a powerful tool to enhance water quality management, reduce cost and time, and prevent pollution from the water environment. It is difficult to provide these features in traditional water quality management using a single GIS, since the data collection is expensive and takes a long time. Combining GIS with one or more modern technologies will give great benefits for water quality control and management. In RS-GIS, the RS provides data for GIS at a distance in the shortest time and at a low cost compared to traditional GIS. It also contributes to the analysis and interpretation of geographic data. IoT-GIS helps to conduct real-time spatial analysis to generate real-time geographical insights. This will lead to lower costs and less time wasted in making decisions. Web-GIS offers data analysis, dynamic response, and flexible access to geographic data. This combination makes GIS a very powerful tool.

For some countries, like Iraq, the challenges in the water quality domain are: 1) to determine the ways in which GIS facilitates the management of water quality; 2) to develop new GIS-based methods to solve water resource and water quality problems; and 3) to train the next generation of engineers and scientists in water resources on the best use of GIS programs.

## 8. Declarations

### 8.1. Data Availability Statement

The numerical data in the manuscript were obtained from a statistical site ([www.statista.com](http://www.statista.com)), and most of them are freely available.

### 8.2. Funding

The author received no financial support for the research, authorship, and/or publication of this article.

### 8.3. Declaration of Competing Interest

The author declare that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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