ASSESSMENT OF GROUNDWATER SUITABILITY FOR DRINKING AND IRRIGATION PURPOSE USING STATISTICAL AND GEOSPATIAL TECHNIQUES: A REVIEW

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ABSTRACT

Water is a vital source for all living individuals on earth. The consumption of fresh water has increased rapidly in recent years. Industrialization, urbanization, and population growth have resulted in deterioration of surface and groundwater quality. It is very important to manage groundwater resources and protect them from anthropogenic activities in order to sustain life on earth. This paper discusses methods for assessing the quality of groundwater using statistical and geospatial techniques. In addition, geographic information system (GIS)-integrated statistical methods are also discussed. Statistical methods, including quality indices, irrigation water quality parameter, and geospatial methods, including inverse distance weighted (IDW) and kriging strategies for evaluating groundwater quality and assessing aquifer susceptibility are also explained. In addition, the paper provides an overview of key groundwater quality indices (GWQI) and irrigation water quality indices (IWQI) that have developed over time and used for groundwater quality evaluation around the world. It is revealed that the use of GIS-integrated advanced statistical approaches is not common in assessments of groundwater quality. The constraints and research gaps of previous studies, as well as the prospects for future research needs have been examined.

Keywords: *groundwater, water quality index, GWQI, IWQI, irrigation water quality parameters, GIS*

INTRODUCTION

Water is a fundamental resource for life. Groundwater is crucial for human consumption, habitat sustenance, and maintaining the quality of base flow of rivers. Groundwater is generally of excellent quality and is substantially much cleaner than surface water [1]. It is filtered naturally as it passes through the earth surface. It is usually clear, colourless, and free of microbes and therefore requires little treatment. Unfortunately, it appears that high-quality groundwater is no longer available. The increasing amount of soluble chemicals from industrial, urban, and modern agricultural operations is a concern today. Moreover, landslides, fires, and other surface events that change infiltration, expose, or cover the surfaces of rocks and soil, and interact with water flowing downstream can also have an impact on the quality of shallow groundwater [2]. As the world's population and urbanization grows, industrial units and land irrigation have resulted in a degradation of groundwater and surface water quality, as well as a large loss of groundwater resources, which are the main sources of water to supply population [3].

The demand for water has grown intensively in recent years, resulting in water scarcity in several regions of the world [4]. Groundwater has gradually grown to become India’s security backbone for drinking water and agriculture. Groundwater contributes about 62 % to irrigation, 85 % to rural water supply, and 50 % to urban water supply in India [5].

According to the 2020 evaluation of dynamic groundwater resources, the total annual groundwater recharge in India has been estimated at 436.15 billion cubic meters (bcm), with total natural discharges of 38.51 bcm. As a result, the country’s total annual extractable groundwater resource is 397.62 bcm. Rainfall as the primary source and other secondary sources (such as applied irrigation water, surface water bodies, and water conservation buildings) recharge groundwater every year. Monsoon rainfall is the key source of groundwater recharge with 249.65 bcm, which is approximately 57 % of total annual groundwater recharge. Groundwater is the sole alternative supply of good quality water in rural areas because of the scarceness of surface water in several places. Annual groundwater extraction in India has been assessed at 244.92 bcm in 2020 and the degree of groundwater extraction was 61.6 %.

Groundwater pollution is an imperative worldwide issue. Groundwater quality is deteriorating due to increased water withdrawals and consumption, widespread urbanization, industrial growth, overuse of fertilizers and pesticides in agricultural regions, human and animal waste, and uncontrolled drainage systems [6]. Stopping the contaminants at the source will not restore the quality of the groundwater once it has been contaminated [7]. Because of their slow movement, contamination of groundwater in aquifers can last for hundreds of years [1]. However, this is not entirely true because it may depend on the type of pollutant and geology of soil strata.

According to the WHO (World Health Organization), water is responsible for about 80 % of all human diseases. It is estimated that waterborne diseases create a financial burden of approximately USD 600 million annually in India. At least 2 billion people worldwide drink water that has been contaminated with faeces [8]. Diarrhoea, dysentery, cholera, typhoid, and polio can be spread by contaminated water. It is estimated that contaminated drinking water causes 485 000 fatalities due to diarrhoea each year [8].

Water availability for irrigation has both quantitative and qualitative implications. Furthermore, the importance of irrigation water quality is often overlooked. Irrigation water quality can be evaluated through adequate monitoring and evaluation based on experience and judgement of water suitability. The soil and the crops grown on it are directly affected by the quality of irrigation water. Good irrigation water quality will result in optimal crop yield under normal soil and water management practices [9]. The main cause of the deterioration of soil quality and the agricultural crops grown on such soils is the use of poor quality water for irrigation [1]. Groundwater quality is determined by underlying geology and climate, but also depends on contamination from industry and agriculture [10].

Fresh water supplies are becoming increasingly scarce as the global demand for it grows. As a result, knowledge of hydrochemical properties and water quality is becoming increasingly important for groundwater planning and management in order to maintain sustainable usage of the resources for agriculture, drinking and industry [11]. Groundwater quality evaluation is a complicated process that involves a number of variables that can cause a variety of stressors on overall groundwater quality. It is complicated to assess the quality of water from a vast number of samples, each of which has concentrations for different parameters [12]. Water quality evaluation comprises evaluating the physical, chemical, and biological parameters of water in relation to natural quality, human effects, and anticipated usage, especially those that can have an impact on human health and the health of the aquatic system [13].

For the purpose of analysing groundwater quality, several researchers have used various traditional tools and methodologies ranging from graphical to statistical [14]. Calculating quality indices is one technique to analyse its applicability. Data on water quality are included in the quality indices, which summarize most of the information into a single number in order to present data in a logical and simplified manner. It compiles data from various sources to create a complete picture of the state of the water system. Making judgments about water acceptability would be simpler if the entire consequence of the water quality deviation could be articulated in a combined way, taking into account both the importance of each component and the magnitude of its exceeded concentration [15].

WATER QUALITY INDEX

The term water quality index (WQI) denotes to a scoring system that estimates the overall impact of several water quality criteria on the overall quality of water suitable for human consumption [3]. WQI is a ranking that replicates the combined influence of many water quality factors. The WQI is determined from the point of view of suitability of groundwater for human consumption [7]. The water quality for a specific application can be expressed by a single number called the “water quality index”, which is derived from the individual values of a number of factors, as well as the relative importance of each variable [15]. The water quality index (WQI) is a single-digit number that measures the overall water quality at a given time, based on an analysis of the value of various water quality criteria. The main goal of determining the WQI is to transform complicated water quality data into understandable information that can be used for other purposes, such as planning and decision making [16]. Table 1 shows the several water quality indices developed over time for assessing quality of surface water.

GROUNDWATER QUALITY INDEX

Several researchers have developed various quality indices to assess suitability of groundwater for drinking purpose based on physicochemical parameters. These quality indices are called groundwater quality indices (GWQI). Table 2 shows different GWQIs developed over time. During the last two decades, many studies have been conducted regarding vulnerability assessment of the groundwater quality for various uses. Babiker et al. 2007 [2] studied the groundwater quality of Nasuno basin, Japan, and proposed a GWQI by integrating physicochemical analysis with GIS using raster data and performing the kriging technique. Babiker et al. 2007 [2] also used GIS to assess the sensitivity of the proposed model. Ramakrishnaiah et al. 2009 [9] proposed a GWQI to assess suitability of groundwater by using statistical methods. He proposed the weighted arithmetic mean method and weighted the selected parameter according to its relative importance in the drinking water. Statistical method for groundwater quality assessment is also proposed by Ramesh et al. 2010 [19] and Sethy et al. 2017 [20]. Ramesh et al. 2010 [19] proposed GWQI by distributing various physicochemical parameters into 5 groups based on opinion of experts and their relative importance in accordance to drinking water quality and considered biological parameter which is also an important parameter in relation to drinking purpose. Khan et al. 2011 [21] studied a watershed near Hyderabad, India and assessed the influence of rapid urbanization on water quality based on land use patterns by proposing GWQI. GIS-integrated technique was used to create groundwater sustainability map with regard to water quality. Machiwal et al. 2011 [22] performed a map removal sensitivity analysis to identify the most important water quality indicators and suggested which ones should be monitored most closely.

Table 1. Studies that used water quality indices models for assessing quality of surface water

WQI model	Assessed parameter	Technique	Parameter weighting		Classification		Reference
Horton index	Sewage treatment, dissolved oxygen (DO), pH, coliforms, chlorides, alkalinity, specific conductivity	Weighted arithmetic mean	Sewage treatment DO pH Coliforms Alkalinity Specific conductivity	4 4 4 2 1 1	Very good Good Poor Bad Very bad	91 - 100 71 - 90 51 - 70 31 - 50 0 - 30	[17]
National Sanitation Foundation (NSF) index	Nitrate, faecal, coliforms, pH, dissolved oxygen, 5-day biochemical oxygen demand (BOD), phosphate, turbidity, pesticides, total solids, temperature, toxic elements	Two mathematical functions were used - additive formula and multiplicative formula	According to judgement of expert panel and sum of weight value is equal to 1		Excellent Good Medium Bad Very bad	90 - 100 70 - 89 50 - 69 25 - 49 0 - 24	[18]
Bhargava index	Parameters divided into 4 groups Group 1 - coliform bacteria, Group 2 - toxicants and heavy metal, Group 3 - physically affecting variables, Group 4 - organic and inorganic nontoxic variables	Geometric mean method	Sensitivity value function for each group based on plotted curve		Unacceptable Acceptable	0 - 90 90 - 100	[15]

Table 2. Studies that used groundwater quality index to assess groundwater quality

Year	Assessed parameters	Technique	Basis of categorization of water quality	Categorization		Reference
				Colour / GWQI value	Water quality	
2007	Ca^{+2}, Mg^{+2}, total dissolved solids (TDS), Na^{+}, SO_4^{2-}, Cl^{-}, NO_3^{-}	GIS-integrated technique using kriging interpolation	Colour coded	Shades of blue	Maximum	[2]
				Shades of green	Medium	
				Shades of red	Minimum	
2009	TDS, pH, hardness, Cl^{-}, SO_4^{2-}, HCO_3^{-}, F^{-}, NO_3^{-}, Ca^{+2}, Mg^{+2}, Mn, Fe	Weighted arithmetic mean method	GWQI values	< 50	Excellent	[7]
				50 - 100	Good	
				100 - 200	Poor	
				200 - 300	Very poor	
				> 300	Unsuitable	
2010	pH, electrical conductivity (EC), hardness, Ca^{+2}, Na^{+}, Mg^{+2}, Cl^{-}, SO_4^{2-}, alkalinity, NO_3^{-}, F^{-}, NO_2^{-}, Cr, Cu, Zn, Fe, Cd, Mn, Ni, Pb, total coliform, salmonella	Weighted geometric mean	GWQI values	97.5 - 100	Excellent	[19]
				92.5 - 97.5	Good	
				85.0 - 92.5	Fair	
				75.0 - 85.0	Marginal	
				60.0 - 75.0	Poor	
				< 60	Very poor	
2011	Mg^{+2}, Ca^{+2}, Na^{+2}, TDS, Cl^{-}, SO_4^{2-}	GIS-integrated technique using ordinary kriging	GWQI value	Close to 100	High	[21]
				Close to 1	Low	
2011	EC, pH, TDS, hardness, Na^{+}, Ca^{+2}, Mg^{+2}, Cl^{-}, SO_4^{2-}, NO_3^{-}, HCO_3^{-}	GIS-integrated technique using IDW interpolation	Colour coded	Shades of blue	Maximum	[20]
				Shades of green	Medium	
				Shades of red	Minimum	
2017	pH, TDS, Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, NO_3^{-}, HCO_3^{-},	Weighted arithmetic mean method	GWQI value	< 50	Excellent	[22]
				50 - 100	Good	
				100 - 200	Poor	
				200 - 300	Very poor	
				> 300	Unsuitable	

IRRIGATION WATER QUALITY INDEX

The quality and quantity of dissolved salts in irrigation water has a significant impact on the water quality. These salts originate from both geogenic (rock and soil weathering) and anthropogenic (home and industrial discharges) sources [23]. These salts follow the path of water after being introduced into it. This results in the difficulties associated with soil salt content, which includes salinity hazard, permeability hazard, infiltration hazard and many more. When salts accumulate in the root zone of a crop, the amount of water available to the crop is reduced, posing a salinity risk. The rate at which irrigation water flows through lower soil layers is slowed by the high sodium ions content, leading to permeability and infiltration problems. When water cannot reach the roots of the crop to the extent necessary for crop, the reduced infiltration rate begins to have negative consequences. As a result, these salts begin to accumulate on the soil surface. It is impossible to maintain an adequate yield when the crop cannot collect enough water from the soil, which leads to a decrease in agricultural production [23]. An irrigation water quality index (IWQI) enables the conversion of huge data sets specifying the suitability of irrigation water sources into a single numerical score, which facilitates the assessment of water quality. Irrigation managers, site engineers, and decision makers find an IWQI very useful in monitoring, evaluating, and controlling irrigation water. Table 3 shows various IWQI developed over time by different researchers.

Table 3. Studies that used irrigation water quality index models to assess irrigation water quality

Assessed parameter	Technique	Parameter weighting		Classification		Reference
		Parameter	Weight	IWQI	Water quality	
Salinity hazard (EC), Permeability hazard (SAR), Specific ion toxicity (Cl, B), Trace element toxicity (heavy metals), Miscellaneous effects (pH, nitrate nitrogen)	Weighted and rating average method	Salinity hazard	5	< 22	Low	[23]
		Permeability hazard	4	22 - 37	Medium	
		Specific ion toxicity	3	> 37	High	
		Trace element toxicity	2			
		Miscellaneous effects	1			
pH, EC, Ca^{+2}, Mg^{+2}, K^+, Na^+, Cl^-, SO_4^{-2}, PO_4^{-3}, HCO_3^-, NH_4^+, NO_3^-, SAR	Using principal components and factor analysis (PC/FA), the parameters that contribute the most variability in irrigation water quality were identified, and a specification of quality measurement values (qi) and aggregate weights (wi) was produced.	Electrical conductivity (EC)	0.211	85 - 100	No restrictions	[24]
		Sodium (Na)	0.204	70 - 85	Low restriction	
		Bicarbonate (HCO_3)	0.202	55 - 70	Moderate restriction	
		Chloride (Cl)	0.194	40 - 55	High restriction	
		Sodium Adsorption Ratio (SAR)	0.189	0 - 40	Severe restriction	
EC, pH, Mg^{+2}, Ca^{+2}, K^+, Na^+, HCO_3^-, CO_3^{-2}, Cl^- and SO_4^{-2}	Arithmetic mean of quality indices	Mean values and corresponding standard deviation of reference population		≤ 1.96	Excellent	[25]
				1.96 - 5.88	Good	
				5.88 - 9.80	Average	
				> 9.80	Poor	
pH, Na %, F^-, SAR, Residual sodium carbonate (RSC), EC, B, Fe, Cd, As, Cl^-, NO_3-N	Weighted average aggregation	pH	0.013	0 - 25	Very bad	[9]
		As	0.183	25 - 50	Bad	
		Na %	0.048	50 - 75	Medium	
		F	0.117	75 - 95	Good	
		RSC	0.030	95 - 100	Excellent	
		EC	0.064			
		B	0.132			
		SAR	0.041			
		Fe	0.084			
		Cl	0.023			
		NO_3 -N	0.018			
		Cd	0.248			
F, Cl^-, NO, PO_4^{-3}, SO_4^{2-}, Na^+, K^+, Ca^{+2}, Mg^{+2}, HCO_3^-	Multivariate statistics	Product of the relative eigenvalues and relative loading values		0 - 25	Excellent	[26]
				25 - 50	Very good	
				50 - 75	Average	
				> 75	Poor	

IRRIGATION WATER QUALITY PARAMETERS

It has been known for years that the structure of the soil and the crops grown on it are directly affected by the quality of irrigation water. Suitability of groundwater for irrigation is determined by the mineralization of water and its impact on plants and soil. When irrigation water has a high salt content, sodium ions are absorbed into clay particles, displacing Mg^{2+} and Ca^{2+} ions and limiting soil permeability, resulting in soil with poor internal drainage. As a result, while the soil is wet, air and water circulation is difficult, and such soils are often hard when dry [27]. The soil permeability is changed by continuing usage of irrigation water that has high salt concentration, as well as the concentration of Na^+, Ca^{2+}, Mg^{2+}, and $HCO_3{}^-$ ions in the soil. In irrigated soils, high Mg levels can usually be attributed to the presence of exchangeable Na^+. Higher Mg^{2+} in water will have a detrimental effect on soil quality, making it alkaline, leading to lower agricultural production. The phrase "index of magnesium hazard" was coined by Palliwal 1972 [28]. As soils become more alkaline, a magnesium hazard value greater than 50 % would have a negative effect on crop productivity [27]. Because SAR is directly related to sodium adsorption in soil and affects soil permeability, it is a better indicator of salt (alkali) hazard in irrigation. The suitability of groundwater appropriateness for irrigation is further affected by the excess sum of carbonate and bicarbonate in the water over the total of calcium and magnesium. As the water in the soil becomes more concentrated, calcium and magnesium tend to precipitate in fluids with high bicarbonate concentrations. It has been established that the excess of sodium bicarbonate and carbonate affects soil physical properties because it causes the dissolution of organic matter in the soil, resulting in a black stain on the surface of the soil as it dries. Consequently, the amount of sodium in the water increases in the form of sodium carbonate, which is called residual sodium carbonate [24]. Many researchers have classified quality of water according to different parameters and ratios for assessing its suitability for irrigation purpose. Table 4 shows various irrigation water quality parameters calculated by different researchers over the time and classification of irrigation water quality according to them.

GEOSPATIAL TECHNIQUES

The visualisation, presentation, and interpretation of quality of groundwater ratings at wide spatial scales have greatly improved since the emergence of GIS technology, particularly after the 1990s [14]. Until the end of the 1990s, the use of geostatistical modelling tools in groundwater quality assessments was quite limited. Because of the advantages of spectral, temporal and geographical availability of data covering large and inaccessible areas in a short time, remote sensing has become a very valuable tool in research, analysis, and management of vital groundwater resources [35, 36]. Groundwater quality evaluation studies benefit from GIS applications, which are particularly useful for mapping geographic changes in water quality, modelling subsurface flow and pollution, and groundwater monitoring network design, among other things [14, 36]. GIS can be useful for a variety of tasks, including water quality analysis, determining water availability, flood control, understanding the natural environment, and improving water quality at regional and local levels [37]. Researchers have effectively linked advanced statistical tools with GIS to illustrate the chemical composition of groundwater spatially distributed over large areas, usually up to regional scales. Furthermore, some studies have used GIS-integrated statistical techniques and approaches to analyse the hydrochemical regime and propose strategies for managing groundwater resources, despite the complexity of natural processes and anthropogenic practices that affect groundwater quality. The use of geostatistical-modelling techniques in groundwater quality assessment has increased dramatically after its integration with GIS [14]. Remote sensing and geographic information systems (GIS) are useful techniques for mapping water quality and land cover, which are essential for monitoring, modelling, and detecting environmental change [37]. Table 5 shows various studies which have used geospatial technique to assess groundwater quality for drinking and irrigation purpose.

Anbazhagan and Nair 2004 [38] mapped the Panvel basin of Maharashtra, India to show groundwater zones which are suitable and unsuitable for drinking and irrigation purpose using triangulation and interpolation technique. Shukla et al. 2021 [16] described inverse distance weighted technique in his work as one of the interpolation technique in which the point to be measured is given a weight. The amount of this weight is determined by the distance between two unknown points [16]. Asadi et al. 2007 [37] assess groundwater quality in Hyderabad and correlate it with land use / land cover map of that area using remote sensing and GIS. Spatial distribution maps were created using Arc GIS software and WQI is calculated to assess groundwater suitability for drinking. Balakrishnan et al. 2011 [13] and Azlaoui et al. 2021 [3] analyse groundwater and show potential groundwater zones in Karnataka and Algeria using IDW technique in Arc GIS software.

Kriging was developed by Matheron in 1965. Kriging includes simple and ordinary kriging, co-kriging, universal kriging, and disjunctive kriging as well as other approaches to local estimation. Co-kriging is used when two or more variables are geographically interconnected and the one whose values must be anticipated is not sampled as completely as the others with which it is related [39]. Davies and Crosbie 2018 [40] modelled a relationship between chloride concentration and distance from the coast across Australia using kriging. Spatial trend and spatial correlation of the data can be modelled using kriging to describe spatial variability at the major and minor level [39].

Table 4. Categorization of water according to several parameters of water quality for irrigation

Irrigation water quality parameter	Formula / method of assessing irrigation water quality parameter	Categorization / suitability of water		Reference
		Value of parameter	Class / suitability of water	
% Na	$\%Na = \frac{Na^+ + K^+}{Na^+ + K^+ + Mg^{+2} + Ca^{+2}} \cdot 100$	< 20 % 20 % - 40 % 40 % - 60 % 60 % - 80 % > 80 %	Excellent Good Permissible Doubtful Unsuitable	[29]
		< 60 % > 60 %	Safe Unsafe	[30]
Kelly's ratio	$KR = \frac{Na^+}{Mg^{+2} + Ca^{+2}}$	< 1 > 1	Safe Unsafe	[31]
Permeability index	$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Na^+ + Ca^{+2} + Mg^{+2}} \cdot 100$	< 25 % 25 % - 75 % > 75 %	Suitable Marginal Unsuitable	[32]
Residual sodium carbonate	$RSC = [CO_3^{2-} + HCO_3^-] - [Ca^{+2} + Mg^{+2}]$	< 1.25 1.25 - 2.5 > 2.5	Safe Permissible Unsuitable	[30]
Sodium adsorption ratio	$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{+2} + Mg^{+2}}{2}}}$	< 10 10 - 18 18 - 26 > 26	Low Medium High Very high	[33]
Magnesium hazard	$MH = \frac{Mg^{+2}}{Ca^{+2} + Mg^{+2}} \cdot 100$	< 50 % > 50 %	Suitable unsuitable	[28]
Soluble sodium percentage	$SSP = \frac{Na^+}{Na^+ + Mg^{+2} + Ca^{+2}} \cdot 100$	< 20 20 - 40 40 - 60 60 - 80 > 80	Excellent Good Permissible Doubtful Unsuitable	[34]

Table 5. Studies that used geospatial technique to assess groundwater quality

Studied area	Parameters for which map was generated	Software used	Technique used	Reference
Panvel Basin, Maharashtra, India	Chloride, TDS, hardness, salinity hazard, integrated groundwater quality map	Idrisi 32 GIS	Triangulation and interpolation technique	[38]
Hyderabad, India	TDS, fluoride, WQI	Arc View GIS	Curve fitting method	[37]
Ain Oussera plain, Algeria	pH, EC, TDS, magnesium, calcium, potassium, sodium, sulphate, bicarbonate, chloride, nitrate, SAR, WQI	Arc GIS	Inverse distance weighted interpolation technique	[3]
Gulbarga City, Karnataka, India	Chloride, nitrate, TDS, hardness, groundwater quality zone map	Arc GIS	Inverse distance weighted interpolation technique and spatial analyst extension	[13]
Delhi, India	pH, total hardness, total alkalinity, calcium, chloride, nitrate, WQI	QGIS	Inverse distance weighted interpolation technique	[41]
Gorakhpur, India	pH, chloride, turbidity, EC, total alkalinity, TDS, WQI	QGIS	Inverse distance weighted interpolation technique	[16]
Australia	chloride	Arc GIS	Ordinary kriging	[40]
Horonobe, Japan	chloride	-	Ordinary kriging and co-kriging	[42]
Italy	nitrate	-	Disjunctive kriging	[43]

Passarella et al. 2002 [43] described disjunctive kriging as a reliable computational approach that enables the description of the spatial distribution of conditional probability. Passarella et al. 2002 [43] use disjunctive kriging to assess the probability of nitrate concentration exceeding a given concentration in Modena plain in Italy which serves as a basis for management decision.

LIMITATIONS AND GAPS IN RESEARCH

As revealed by literature review, statistical techniques have been used to assess water quality for a long time. However, their integration along with the GIS has rapidly increased for the last few decades. It is also seen from the literature that various researchers have incorporated statistical and geospatial techniques to assess the suitability of groundwater for its beneficial use, but some work is still needed to overcome some limitations. Some of the limitations of the existing work are highlighted below:

- Different researchers have used different models of water quality index for the quality assessment. Universally accepted quality index is not available in the existing literature. There is a need for a versatile and consistent quality index that can be globally accepted.

- It is evident from the literature that for the mapping of groundwater quality or for the calculation of water quality indices, samples were taken from various locations in the studied area. Some groundwater sources may be susceptible to contamination due to poor drainage, non-complying sanitary conditions or any unwanted untreated discharge. Nearby conditions and neighbouring environment of the source must also be considered for the quality assessment.
- Researchers have used various interpolation techniques to create spatial distribution maps for water quality in an area, such as IDW and kriging. These techniques can show spatial variation of the water quality data, but not the temporal variation. There is a need for some techniques that provide data on the temporal variation of water quality.
- Groundwater sources studied by the authors may be subjected to pollution or contamination after the research is done. Therefore, there is a requirement for real-time monitoring systems in the sensitive area or any degradation model must also be included in the study.
- Very few studies included uncertainty analysis in the study, and the error variance was also not calculated. There is a need for the cross-validation of the interpolation techniques and the calculation of error generated in the mapping.
- According to the reviewed literature, approaches to groundwater vulnerability assessment are mainly based on qualitative analysis. In order to determine the most appropriate strategy, a wider discussion and comparison of quantitative and qualitative approaches will be needed in the future.
- The calculation of quality indices is a very subjective method. In order to eliminate subjectivity from the selection of parameter and weight attribution processes, a realistic approach needs to be created.
- Many quality indices models are based on the guidelines issued by different institutions / governments / agencies for the acceptable and permissible limit of the various physico-chemical parameters for different area. This leads to difficulties in interpreting water quality when quality maps are linked at the regional level. Not only that, but it is also possible that water quality guidelines may change over time. So, it is necessary to update the previously generated maps.

CONCLUSION

It has been proven that water quality assessment is always a matter of concern for hydrologists. Effective and efficient management of water resources has attracted the researchers for the last 5 decades. The application of statistical and geospatial methodologies in assessing the suitability of groundwater for irrigation and drinking was clearly visible in the literature used in this paper. Since the introduction of the geographic information system (GIS) in the 1990s, advanced statistical and artificial intelligence approaches, combined with their GIS-based integration, have become a more effective tool for groundwater quality assessment. Furthermore, the integration of statistical technique with GIS platform for the water quality analysis attracts researchers today. However, there are also some limitations or shortcomings, as explained in the previous section, which could be a challenge for the future studies. It can be seen from the literature that many quality indices have been modelled for the suitability assessment of water for irrigation and drinking purposes. The importance of various parameters and ratios related to the quality of irrigation water is also explained. It is evident from the literature that the number of studies dealing with the quality of irrigation water has increased in the last few decades and they have become as important as the quality of drinking water. Thus, statistical and geospatial techniques, individually or integrated, can be successfully used to assess the suitability of groundwater, not only for drinking purpose but also for irrigation purpose.

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