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Groundwater quality parameters for irrigation utilization: A review

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ABSTRACT

Groundwater is a critical natural resource. Unfortunately, owing to indiscriminate withdrawals due to increased water demand, this essential resource is under intense pressure. Groundwater tables are depleting at an accelerated rate and the groundwater quality is turning inferior due to exaggerated natural processes and inappropriate artificial activities. This review gives insight into the numerous irrigation water quality measures as well as describes the effects of poor quality groundwater on crop yield and soil characteristics. Water quality is measured and assessed in accordance with the water's intended use. Salinity hazards, sodium hazards, salt levels, alkalinity hazards, permeability hazards, and ion-specific toxicity hazards are all indicators for water quality evaluation. Improper irrigation water use has messed up soil and water quality. Low water quality must be managed carefully in salt-affected soil. The important elements that determine crop output and soil quality are also depicted in this review. The aim is to help better understand the effects of water quality on soil and crops, as well as to assist in the selection of appropriate alternative solutions to address potential water quality issues that could reduce yield under current use conditions.

Keywords: Crop yield, Irrigation water quality, Salinity, Sodium hazard

Groundwater plays an essential environmental role. It is a large source of freshwater on Earth (UNESCO 2018). It is vital to meet water demand for different uses, such as irrigation, industries, and drinking sectors. Recent studies have shown that almost 20% of worldwide groundwater is utilized for irrigation (Adimalla and Venkatayogi 2018, Dimple *et al.* 2022). Approximately 80% of wastewater worldwide is disposed into the environment without proper treatment (UNESCO 2018). Rainfall quality and amount, aquifer characteristics, and geological properties are the significant variables that can chemically affect groundwater quality (Dimple *et al.* 2022).

Currently, groundwater is decreasing at a rate of 800 km^3 per year worldwide. A significant source of depletion of groundwater is irrigated agricultural lands (Burek *et al.* 2016, Dimple *et al.* 2022). The calculated annual groundwater usage is approximately 230 km^3, and the largest user of groundwater worldwide is India. Additionally, over 60% of the groundwater is used for irrigation, and 85% is used for India's drinking supplies. Because of this, groundwater levels have declined by more than 4 m in many parts of the country (CGWB 2014). According to a report, the groundwater used for irrigation is approximately 245 $\times 10^9$ m^3 (CGWB 2014). Food crop production has to be increased by about 60% by 2050 to secure worldwide food security and irrigation will eventually fulfil this requirement. In the race to boost agricultural productivity, irrigation will become reliant on poor-quality water sources. Accessing our current level of information and investigating the influence of irrigation water quality on plants is crucial. This will ensure sufficient agricultural production to match elevated demand and retain adequate food and soil quality. Groundwater exploration (irrigation withdrawal) can expel naturally generated geogenic pollutants such as arsenic from solid-state to groundwater.

In developing nations, about 80–90% of wastewater flows out untreated and deteriorates freshwater sources. The review highlights the significance of numerous water quality parameters in the context of crop yield and soil health. The findings may be useful for agricultural sustainability research studies and to policymakers developing policies and action programs related to water resource management and agricultural activity in arid and semi-arid environments.

Groundwater quality assessment parameters

Irrigation water quality assessment criteria usually include salinity, sodicity, and ion toxicity. However, the same standards may not be applicable if the water is utilized with the intent of domestic use and industrial supply. Physical,

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chemical, and bacteriological qualities ascertain groundwater adequacy for agriculture use (Yadav *et al.* 2021). As reported by different researchers, groundwater suitability criteria are attributed to the effects of total dissolved solids (TDS), Electrical Conductivity (EC), sodium salts, and bicarbonate concentration. Ratnagiri district of Maharashtra is defined by shoreline and creeks, and agricultural land is said to be saline as a result of sea water incursion along the coastline, the quality of ground water has deteriorated as a result it is unsuitable for irrigation (Bhange *et al.* 2018). Table 1 shows literature focused on irrigation indices.

Varieties of measures have been followed to guarantee a high-quality review on groundwater quality parameters for irrigation utilization. The bibliometric analysis method has been used. This technique checks on bibliographical material which is needful in a way to use, analyze and organize the information in a specific area (Merigó *et al.* 2015).

Scopus and the Web of Science (WoS) are two databases that were worked for bibliometric analysis. The search was exercised in January 2021; the elected study period was from 1990 to 2020. We have considered papers up to 2020 in order to compare the whole 12-month juncture. Fig 1 shows comparative patterns in the groundwater and irrigation water quality work.

Effects of contaminated groundwater on crops and soils

The suitability of irrigation water depends on TDS (salinity), sodium, and SAR for crops. Poor quality irrigation water has many adverse impacts on both soil and crop production. Salt collection within the root zone causes insufficient soil water, increasing plant stress and lowering crop production (Shakoor 2015). Heavy metals will have several harmful effects in irrigation water on soil quality and outputs. Also, the plant nutrients available in the soil may be diluted by the elevated concentration of salts. In contrast, certain salts may not adversely impact the plants (Shakoor 2015). Ayers and Westcot (1985) also investigated the impact of poor-quality irrigation water use, including extra nutrients, lowered infiltration rates, and the harm caused by specific ions. Over time, soil salinity effects and trace elements' development on crop development have become more evident.

Boron in water impacted the growth of apricots and prunes around Hollister, California. In later years, the United States Department of Agriculture (USDA) conducted further research. It concluded that the most important indicators for assessing water suitability for irrigation are sodium, boron, and EC.

Indices for water quality suitability

The concentration of hydrogen ion (*p*H): The flocculation process and coagulation efficiency are highly affected by *p*H. Taylor *et al.* (1934) found that irrigation water's *p*H was the main factor for wheat growth in Punjab, India.

SAR: This parameter is used for assessing water quality for irrigation. Also, it is used in the measurement of sodium-affected soils. Singh *et al.* (1992) irrigated pearl millet and wheat with various EC and SAR values for eight years and reported reduced crop yield. The primary

Table 1 Focus on water quality parameters

Author	Focus
Roy *et al.* (2018)	SAR, EC, %Na, RSC, PI, MR, RSBC, SH, PS, SSP, TDS
Chaudhary and Kumar (2018)	The authors assessed the groundwater quality for irrigation and drinking purposes. They analyzed; EC, *p*H, TDS, TH, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-}, NO_3^-, F^-, SAR, %Na, RSC, PI, MR, RSBC, PS, KI, MH, Mg/Ca ratio, and HCO_3^-
Kumar *et al.* (2019)	*p*H, EC, TDS, MH, RSC, SAR, TH, major ions (Ca^{2+}, Mg^{2+}, Na^+, K^+,Cl^-, F^-, HCO_3^-, NO_3^-, PO_4^-, SO_4^-), MH, PI, KI, CAI, and heavy metals (Fe, Cr, Mn)
Ramamoorthy *et al.* (2018)	The authors studied groundwater quality suitability for drinking and irrigation purposes. *p*H, EC, TDS, %Na, RSC, SAR, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl
Vijai and Khan (2018)	The authors analyzed groundwater quality for irrigation purposes. %Na, RSC, KR, SAR, PI, MR, salinity index and sodicity index, CAI I, CAI II, PS
Shakoor *et al.* (2015)	SAR, EC, *p*H, RSC, TDS
Atta-Darkwa *et al.* (2016)	%Na, MH, KR, TDS, EC, SAR
Alaya *et al.* (2014)	SAR, RSC, PI, %Na, *p*H, EC, TDS
Dhaiphale *et al.* (2019)	Study was conducted at Jaisamand Lake catchment located in Udaipur district of Rajasthan, India. In this study they had collected 109 groundwater samples for analysis of water quality parameters for the irrigation purpose.

SAR (Sodium Adsorption Ratio), RSC (Residual Sodium Carbonate), RSBC (Residual Sodium Bicarbonate), KR (Kelly's Ratio), MR/MH/MHR (Magnesium Ratio/Magnesium Hazard, Magnesium Hazard Ratio), PI (Permeability Index), %Na (percent sodium), SH (Salinity Hazard), PS (Potential Salinity), SSP (Soluble Sodium Percentage), TH (Total Hardness), Ca^{2+} (calcium), Mg2+ (magnesium), Na+ (sodium), SO_4^-/SO_4^{2-} (sulfate), K+ (potassium), Cl^- (chloride), NO_3^- (nitrate), F^- (fluoride), WQI (water quality index), MAR (magnesium adsorption ratio), PO_4^- (phosphate), HCO_3^- (bicarbonate), CAI (chloro alkaline indices), Fe (iron), Mn (manganese), Cr (chromium), T (temperature), CO_3^- (carbonate), SI (saturation index), LDP (Lime deposition potential), and O_2 (dissolved oxygen).

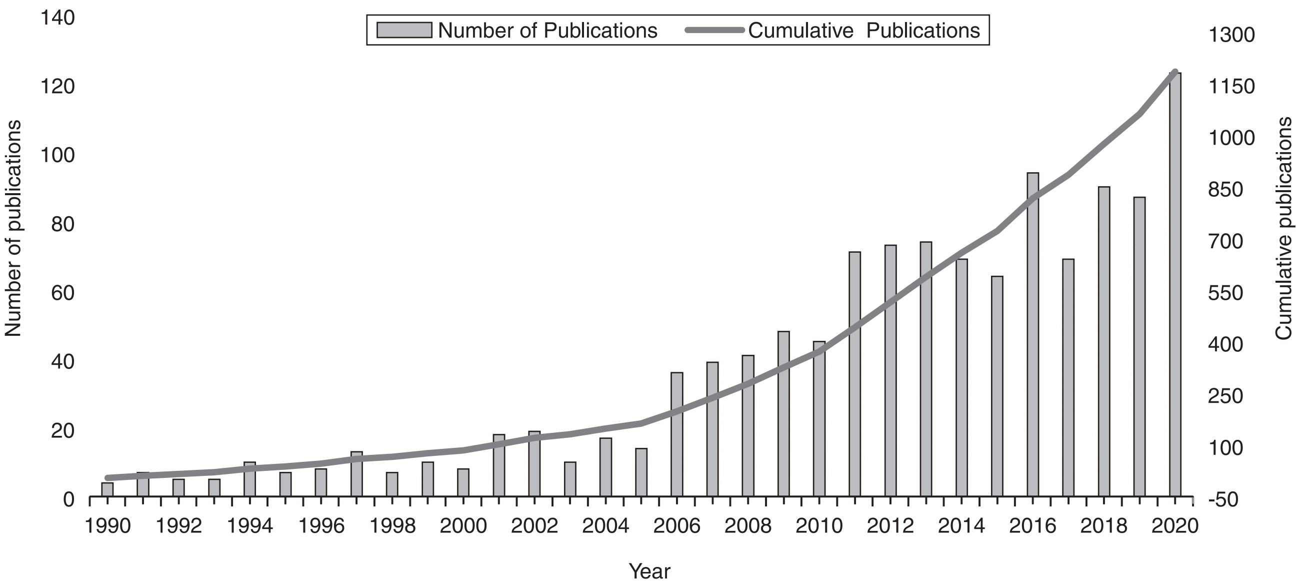

Fig 1 Comparative patterns in the groundwater and irrigation water quality work areas from 1990–2020.

reason for decreased yield was the quality of the irrigation water. SAR also tends to affect time water availability in the soil. Consequently, the minimum irrigation water SAR value is optimal.

$$SAR = \frac{Na^{+}}{\sqrt{\left(Ca^{2+} + Mg^{2+}\right)/2}} \quad (1)$$

where Na^+, soluble sodium concentration; Ca^{2+}, soluble calcium concentration; Mg^{2+}, soluble magnesium concentration. Richards (1954) introduced SAR Equation 1.

MH/Magnesium adsorption ratio (MAR): In assessing water quality for irrigation, the magnesium level in water is perceived to be one of the most relevant qualitative parameters. Elevated magnesium level is typically due to the presence of exchangeable sodium in irrigated soils. Paliwal (1972) coined MH, and it is estimated as per Equation 2. Excess of Mg within water reduced the crop yield and affected the soil's quality by increasing its alkalinity. Raghunath (1987) introduced a magnesium hazard indicator for the MR. According to the study by (Choudhary and Kumar 2018), Mg abundance in water negatively impacts crop yield because soils turn more alkaline; also, Kumar *et al.* (2017) found that equilibrium excesses in Mg^{2+} in the groundwater adversely affects the quality of soil by increasing its alkalinity, resulting in reduced crop yield. Additionally, Singh and Kumar (2015) showed that the adverse effect of Mg^{2+} abundance in irrigation water might reduce soil quality because of the release of Ca^{2+} on the disintegration of $CaCO_3$ if present in the soil.

$$MHR = \frac{Mg^{2+}}{\left(Ca^{2+} + Mg^{2+}\right)} \times 100 \quad (2)$$

EC: The total salt content of soil solutions or irrigation waters is usually expressed as electrical conductivity (EC) at 25°C. Excess amounts of EC and Na^+ decrease plants' osmotic pressure by restricting the nutritional intake available in the water for their proper growth. Excessive salinity can impair crop development and induce osmotic consequences and nutritional distortion (Raghunath 1987, Adimalla and Venkatayogi 2018). The first effect of more EC_w on crop productivity is that the plants are no longer capable of fighting ions present in the soil mixture for water.

KR: Kelly's ratio is also taken into account to evaluate irrigation water quality. It is calculated by the given formula.

$$KR = \frac{Na^{+}}{\left(Ca^{2+} + Mg^{2+}\right)} \quad (3)$$

PI: Prolonged long-period groundwater utilization to irrigate crops influences groundwater permeability index (Roy *et al.* 2018). PI is defined as:

$$PI = \frac{Na^{+} + \sqrt{HCO_3^{-}}}{Ca^{2+} + Mg^{2+} + Na^{+}} \times 100 \quad (4)$$

Na^+ (sodicity): A sodic soil consists of extremely high concentration of sodium (Na^+). The additional sodium level in irrigation water and subsequent storage in the soil causes an escalation in salt contents in alkaline and saline soils. Karanth (1987) indicated that a higher sodium percentage might degrade soil tilth, lower soil permeability, and trigger soil deflocculating. With an increased sodium ions concentration in water, Na^+ may be taken on by clay particles, having replaced Mg^{2+} and Ca^{2+} ions. This transfer phenomenon of sodium in water for Ca^{2+} and Mg^{2+} in soil lowers permeability and, in the end, results in a decreased inner drainage rate (Singh and Kumar 2015). A greater quantity of sodium ions and EC causes a reduction in the plant's osmotic pressure, restricting nutrients entry into the soil and affecting the growth. More Na^+ can have an impact on plants in three ways:

- A crust is formed because of a soil structure deterioration after each rainfall and irrigation, decreasing water speed (permeability) and soil aeration.

- When leaves and roots absorb these ions, they show the harmful effect.
- Potassium and calcium ions can be deficient when soil or water irrigation has high sodium ions.

Per cent Na or sodium hazard: The percentage of Na is utilized to classify irrigation water. Na^+ is a crucial parameter and helps organize any irrigation water source. Irrigation water with a low risk of water infiltration problems is excellent for crop production. Moderate-risk waters may or may not cause a significant water penetration problem. Management interventions to prevent loss of soil structure are necessary when the risk is high. The following equations are utilized to quantify the Na% parameter:

$$\%Na = \frac{\left(Na^+ + K^+\right)}{\left(Ca^{2+} + Mg^{2+} + K^+ + Na^+\right)} \times 100 \quad (5)$$

$$\%Na = (Na^+ + K^+) \times (Cu^{2+} + Mg^{2+} + Nu^+ + K^+) \quad (6)$$

Eq. 6 by Wilcox (1948). %Na is also calculated by employing the Eq. 7 by Todd (1995), expressed as:

$$\%Na = \frac{\left(Na^+ + K^+\right) \div \left(Ca^{2+} + Mg^{2+} + Na^+ + K^+\right)}{100} \quad (7)$$

RSC/residual alkalinity (RAC): RSC is a vital criterion for ascertaining irrigation water acceptability and is computed by equation eight below**.** Adimalla and Venkatayogi (2018) reported that residual sodium carbonate minus values show insufficient calcium and magnesium ions precipitation. Furthermore, the greater availability of calcium and magnesium ions in groundwater degrades soil properties, decreasing crop production. RSC was quantified (Singh and Kumar 2015) to ascertain the harmful impact of the carbonate and bicarbonate concentrations present during crops irrigation. Frequent and continuous use of irrigation water with an RSC value greater than 2.5 meq/L results in salt development and restricts air and water soil pores' movement that leads to deterioration of physical properties of soil (Singh and Kumar 2015) Eq. 8 is by Eaton (1950).

$$RSC = \left(HCO_3^- + CO_3^{2-}\right) - \left(Ca^{2+} + Mg^{2+}\right) \quad (8)$$

RSBC: RSBC is equally a responsible factor as RSC to determine water quality according to bicarbonate ion concentration. RSBC is calculated by Eq. 9.

$$RSBC = \left(HCO_3^- - Ca^{2+}\right) \quad (9)$$

PS: Doneen (1962) expressed it as:

$$PS = Cl^- + \frac{1}{2}SO_4^{2-} \quad (10)$$

Soluble sodium percentage: This is a crucial indicator for ascertaining the risk of sodium hazard from irrigation. It is calculated as per Todd (1960).

$$SSP = \frac{Na}{Ca + Mg + Na} \times 100 \quad (11)$$

All the Equations (1 to 11) expressed in milli equivalents/litre.

Arsenic (As): In groundwaters around the world, arsenic (As) is typically found in amounts varying between 0.01 mg/l to 2,100 mg/l according to area and location. As-rich waters are harmful to plants, which lead to improper germination and lowered biomass boom in the aerial and root systems and yields. In extreme cases, this results in plant death (Rahman et al. 2007). The Bangladesh Agricultural Development Corporation has performed many studies that have mainly assessed the impacts of As-abundant irrigation water on the soil, crop production, and food chain systems.

Fluoride (F): F concentration is more extensive than arsenic in the Earth's crust and existed in the ocean in quantities around 0.1 mg/l to 250 mg/l in all regions (Rahman *et al.* 2007). As per WHO (1984) rich F content water (>1.5 mg/L) affects more than 260 million people in the sector. The elevated level of F in groundwater, which impacts a massive proportion of Indian semi-arid areas, is one of the most common groundwater quality problems (Kumar and Singh 2015, Machiwal and Jha 2015). Because of geological and climatic conditions, India's risk of fluoride contamination is high (Brindha *et al.* 2016).

TDS: The excessive presence of TDS may affect water clarity, cause a reduction in photosynthesis, and be integrated with toxic compounds and heavy metals. This phenomenon causes an increase in water temperature. A bland, insipid taste due to a deficient TDS level was not suitable for irrigation use (Kahlown *et al.* 2006). Irrigation water with a TDS of lower than 450 mg/l is usually assumed to be fair. A concentration above 2000 mg/l is not suitable for irrigation activities. Greater TDS levels in groundwater suggest groundwater unreliability for irrigation purposes (Alaya *et al.* 2014).

TH: Total hardness (TH) is a measurement in a water sample of the mineral content irreversible via boiling. Total hardness, therefore, can be compared to the total hardness of calcium and magnesium. Hard water is not acceptable for agriculture or domestic use. The hardness of water is primarily due to the excessive availability of Ca^{2+} and Mg^{2+} salts, such as carbonates, chlorides, and sulfates (Singh and Kumar 2015). The main problem is that Ca and Mg can react with bicarbonate to turn into insoluble Ca and Mg carbonate salts, which are unsuitable. Presence of these salts has a marked effect on media *p*H. It causes a reduction in sodium availability for plants. USDA method specified that 200 mg/l is a safe limit for water used for irrigation (Alaya *et al.* 2014). Total hardness is calculated according to the given formula. Table 2 shows suitability of groundwater for irrigation with their limits/ranges.

$$TH = 2.497Ca^{2+} + 4115\ Mg^{2+} \quad (12)$$

Formula, methods, techniques, and tools for the determination and assessment of water quality

Several investigators have often used several typical methods and techniques, from graphics to statistics, to describe groundwater quality. Researchers now believe it is essential to implement emerging technologies, such as time-series modeling (e.g. trend identification), geostatistical simulation modeling, and multivariate statistics for effective groundwater quality management and conservation of groundwater sources, and so on. Furthermore, (Maskooni *et al.* 2020) employed a new revolutionary approach (entropy weighted index) to scrutinize groundwater feasibility for drinking and irrigation use. Supplementary Table 1 has been provided showing different water quality assessment methods and others listed by Machiwal *et al.* (2018).

Causes and sources of groundwater pollution

Water remains a vital natural resource used by human beings. It is not only a survival mechanism for people; it is a live ecosystem of large quantities of Earth's animals and plants. The contamination of water and the subsequent degradation of groundwater quality result from various human activities that change water's physicochemical properties. Sources of groundwater pollution can indeed be classified according to multiple criteria (origin, source geometry and transmission rate). Sources of emissions from natural or anthropogenic sources, the source configuration may be a point (landfills, waste sumps, and septic filler tanks), linear (roads), and diffused (nitro-pollution, acid rain, and uranium decay). At the same time, the rate of transmission is constant.

Remedial measures for contaminated water

Various efforts have recently been made to identify water quality changes by including measurements of new types of contaminants like arsenic, fluoride. Nonetheless, tracking irrigation water quality encompassing different kinds of geogenic and evolving contaminants is challenging. In future years, climate change consequences are likely to exacerbate the problem because water scarcity and drought can raise water pollution. The real cost of regulation, alongside sampling and lab assessment of newly detected contaminants, is one rationale for introducing more realistic approaches for monitoring irrigation water quality. For human beings, iron (Fe) and manganese (Mn) are two significant life elements. Excessive Fe and Mn consumption, however, is much detrimental to the health of the human body. Even abundant manganese in the water source often causes tremendous losses in production. While several treatment techniques have been used to extract soluble Fe (II) and Mn (II) from water, conventional physicochemical reduction approaches are more sophisticated, versatile, and efficient for smaller capacity water treatment plants or under emerging conditions, such as sharp rises in Fe and Mn concentrations in water source during the hot season.

Plants tissue must be carefully inspected for contaminant absorption to ensure adequate production quality. Applying groundwater for non-treatment irrigation to any research area would damage plants and reduce production. Growing primarily saline or salt-tolerant crops with superior irrigation facilities can inhibit soil salinity, allowing crops to flourish in places where salinisation problems occur. A lime or gypsum strategy can lower soil permeability.

Crop selection: Semi-tolerant crops such as barley, cotton, sugar beet, mustard and wheat, including those with small water demand, are suggested for saltwater's profitable utilization. Crops that involve broad water usage, including rice, sugarcane, and berseem, should be discouraged. Crop selection or harvesting practices are based on the water quality; for example, if salinity is high in water, then use the salinity-tolerant crop or using a system of drip irrigation. Given that the utilization of sodium water demands repetitive use of gypsum, it is suggested to choose only tolerant, semi tolerant plants and their cultivars with fewer water needs: for example, barley, wheat, mustard, oats, basil, and sorghum. Usage of amendments: Traditional irrigation methods such as basin irrigation can be adopted to manage alkaline water.

It may be beneficial to introduce the following remediation steps: (1) trickle irrigation should be favoured rather than conventional irrigation methods like flooding, to avoid runoff and leaching loss and to minimize water intake and evaporation; (2) calcium chloride, gypsum, and organic manures should be used to disintegrate and deflocculate and create a more porous soil supply; (3) sodium salt-tolerant crop culture and sodium fertilizer use should be according to crop requirements and soil characteristics to achieve higher crop yields.

Table 2 Irrigation suitability of groundwater

Parameter	Water type	Quality	Suitability for irrigation
SAR alkalinity hazard/ sodicity, Richards (1954)	(S1) <10	*** Range/valve (0.53 to 6.02)	Suitable for all crop kinds and all soil kinds except crops sensitive to sodium
	(S2) 10–18	*	Feasible for coarse soils or organic soils having a good permeability
	(S3) 18–26	Doubtful	Hazardous to nearly all soil types, needs proper drainage, high leaching gypsum addition
	(S4) >26	Unsuitable	Unsuitable for irrigation
Salinity/EC(μs/cm) at 25°C	(C1) <250	***	Ideal for all crops and soil types
	(C2) 250–750	* Range/valve (350–750)	Can be utilized when there is moderate leaching possible. Essential salt-tolerant crops can be cultivated without many monitors of salinity
	(C3) 750–2250	Doubtful. Range/valve (768–2120)	Inappropriate for soils with insufficient drainage

Contd.

Table 2 (*Concluded*)

Parameter	Water type	Quality	Suitability for irrigation
	(C4) >2250	Unsuitable. (2380–2390)	Unsuitable for irrigation
EC (μs/cm), Richards (1954)	<250	***	
	250–750	*	
	750–2000	**	
	2000–3000	Doubtful	
	>3000	Unsuitable	
RSC, Eaton (1950)	<1.25	*	
	1.25–2.5	Doubtful	
	>2.5	Not suitable	
RSC, Raghunath (1987)		* (<1.25)	
		Doubtful. (1.25–2.5)	
		Not suitable. (>2.5)	
SH (EC values in μs/cm), Richards (1954)	100–250	Excellent	
	250–750	Good	
	750–2250	Doubtful	
	>2250	Unsuitable	
RSBC	<5	Satisfactory	
	5–10	Marginal	
	>10	Unsatisfactory	
PS, Doneen (1962)	<5	*** to *	
	5–10	* to danger	
	>10	Injurious to Satisfactory	
SSP, Todd (1960)	0–20	***	
	20–40	*	
	40–60	**	
	60–80	Doubtful	
	>80	Unsuitable	
%Na		*** (<20)	
		* (20–40)	
		** (40–60)	
		Doubtful (60–80)	
		Not suitable (>80)	
%Na, Eaton (1950)		Acceptable (<60)	
		Not acceptable (>60)	
MHR, Raghunath (1987)		Suitable (<50)	
		Unsuitable (>50)	
KI		Suitable (<1)	
		Marginal Suitable (1–2)	
		Unsuitable (>2)	
Mg/Ca ratio, Chaudhary and Kumar (2018)	<1.5	Safe	
	1.5–3.0	Moderate	
	>3.0	Unsafe	

C1, C2, C3, and C4 refer to low, medium, high, and very high water salinity. S1, S2, S3, and S4 refer to the low, medium, high, and very high sodium adsorption ratio of the water, respectively. *Good, **Permissible, ***Excellent.

Conclusion and future recommendations

Irrigation water of low standard has lowered crop production and deteriorated the soil's infiltration properties. Testing the quality of water from irrigation water sources is needed to suggest a proper cropping system. Technology implications eliminate undesirable results from improper groundwater quality, such as groundwater causing sodicity increase in soils, reducing water productivity and crop production in semi-arid and arid geographical regions globally. This review paper summarises the significance of various water quality parameters to classify the water into distinct classes according to individual factors or by combining multiple factors. The groundwater feasibility assessment for irrigation should evaluate all quality parameters expressed mainly regarding physical, chemical, and biological quality criteria. Because groundwater quality is dependent on the type of pollutant, it is thus highly recommended to determine the kind of pollutants so that proper mitigation measures can be addressed to utilize water for irrigating crops. The benefits of physicochemical and heavy-metal material accounted for the novel entropy-weighted groundwater quality indices enable objectivity in the compilation of weights and minimize error induced by subjectivity. Thus, groundwater management teams and decision-makers can use the unique index to ascertain water quality appropriateness for utilization effectively. Model optimization and data management should be emphasised in further studies of non-point source pollution. Researchers can also benefit from RS, GIS, and global positioning systems (GPS), which will provide numerical models with comprehensive data, increasing water pollution prediction accuracy. Water supplies entering the distribution network should also be adequately handled until they are used for drinking purposes**.**

Finally, based on these review studies, recommendations were made to local bodies to implement groundwater-surface water's conjunctive use to strictly track and regulate low groundwater quality regions to ensure that the resource is used sustainably and securely. During land and water management planning and field investigations and analysis, groundwater and surface water need to be treated as a single resource. This review will assist in better planning for future remediation steps. In addition to remediation measures, regulatory processes, especially in the developing world, are essential to developing. The investigation outcomes are beneficial for researchers, students, and policymakers since they provide a detailed description of the global research practices on irrigation water suitability. Several water quality indices have been established to evaluate water quality so the future emphasis has to be on assessing quantity as well as quality to conserve groundwater. Effective mitigation techniques should be developed at the smallest administrative unit to the regional scale. The exploitation of modeling and geo-spatial technology is necessary to establish sustainable groundwater use that requires comprehensive research. A structural indicator, which analyses the relationships between publications, authors, and areas of expertise using sociograms, may also be used in a future study. Hence, this review paper may be used as a basis for future management strategies in the field.

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REFERENCES

Adimalla N and Venkatayogi S. 2018. Geochemical characterization and evaluation of groundwater suitability for domestic and agricultural utility in the semi-arid region of Basara, Telangana state, South India. *Applied Water Science.* **8**(44). https://doi.org/10.1007/s13201-018-0682-1.

Alaya M B, Saidi S, Zemni T and Zargouni F. 2014. Suitability assessment of deep groundwater for drinking and irrigation use in the Djeffara aquifers (Northern Gabes, south-eastern Tunisia). *Environmental Earth Sciences.* **71**: 3387–21.

Atta-Darkwa T, Kabo-bah A T, Akolgo G A and Kotei R. 2016. Amo-Boateng, M. Assessment of groundwater quality for irrigation in the oda river basin, Ejisu-Besease, Ghana. *International Journal of Current Research.* **8**: 30994–31001.

Ayers R S and Westcot D W. 1985. Water quality for agriculture, FAO Irrigation, and Drainage, Paper; 29 Rev.1.

Bhange H N, Mahale D M, Ingle P M and Singh P K. 2018. Prediction of water quality parameters for irrigation in Konkan region using Artificial Neural Network Technique. *Journal of the Indian Society of Coastal Agricultural Research* **36**(2): 122–27.

Brindha K, Jagadeshan G, Kalpana L and Elango L. 2016. Fluoride in weathered rock aquifers of southern India: Managed aquifer recharge for mitigation. *Environmental Science and Pollution Research* **23**: 8302–16.

Burek P, Satoh Y, Fischer G, Kahil M T, Scherzer A and Tramberend S. 2016. Water futures and solution: fast track initiative (Final Report). Laxenburg, Austria: IIASA Working Paper, International Institute for Applied Systems Analysis (IIASA).

CGWB, Groundwater yearbook, Central Ground Water Board (CGWB). 2014. Ministry of Water Resources, Government of India, p. 76.

Chaudhary V and Kumar S S. 2018**.** Assessment of groundwater quality for drinking and irrigation purposes in arid areas of Rajasthan, India. *Applied Water Science* **8**: 218.

Dahiphale P, Singh P K and Yadav K K. 2019. Assessment of groundwater quality for irrigation and drinking purpose in Jaisamand catchment using geographical information system. *Indian Journal of Soil Conservation* **47**(3): 213–221.

Dimple, Rajput J, Al-Ansari N, Elbeltagi A, Zerouali B and Santos C A G. 2022. Determining the hydrological behaviour of catchment based on quantitative morphometric analysis in the hard rock area of nand samand catchment, Rajasthan, India. *Hydrology* **9**(31)**.** https://doi.org/10.3390/hydrology9020031

Dimple, Singh P K, Bhakar S R, Kothari M and Yadav K K. 2022. Identification of artificial recharge sites for Nand Samand Catchment. *International Journal for Research in Applied Science & Engineering Technology* **10**(1).

Dimple, Singh P K, Bhakar S R, Kothari M and Yadav K K. 2022. Determination of aquifer parameters by using Aqtesolv-software. *Ecology, Environment and Conservation* **28**: 294–99.

Doneen L D. 1962. The influence of crop and soil on percolating water. *(In) Proceedings 11961 biennial conference on groundwater recharge*, pp. 156–63.

Eaton E M. 1950. Significance of carbonates in irrigation waters. *Soil Science*. **69**: 123–33.

Karanth K R. 1987. *Ground Water Assessment: Development and Management*. Tata McGraw-Hill Publishing Company Limited, New Delhi, p.720.

Kumar B, Singh U K and Mukherjee I. 2017. Hydrogeological influence on the transport and fate of contaminants in the groundwater, India. *JSM Biology* **2**: 1–11.

Kumar R, Chaudhary S and Yadav S. 2019. Anthropogenic influences on the hydrogeochemistry and water quality of ground water in Singrauli Power Belt Region, Central India. (*In*) *Proceedings of the Indian National Science Academy* **85**: 637–58.

Machiwal D, Cloutier V, Güler C and Kazakis N. 2018. Review: GIS-integrated statistical techniques for groundwater quality evaluation and protection. *Environmental Earth Sciences* **77**: 681.

Machiwal D and Jha M K. 2015. Identifying sources of groundwater contamination in a hard-rock aquifer system using multivariate statistical analyses and GIS-based geostatistical modeling techniques. *Journal of Hydrology: Regional Studies* **4**: 80–110.

Maskooni E K, Rad M N, Berndtsson R and Nakagawa K. 2020. Use of heavy metal content and modified water quality index to assess groundwater quality in a semiarid area. *Water* **12**: 1115.

Merigó J M, Gil-Lafuente A M, Yager R R. 2015. An overview of fuzzy research with bibliometric indicators. *Applied Soft Computing* **27**: 420–33.

Mongeon P and Paul-Hus A. 2016. The journal coverage of Web of Science and Scopus: A comparative analysis. *Scientometrics* **106**: 213–28.

Paliwal K V. 1972. Irrigation with saline water. Monogram no. 2, new series 198, IARI, New Delhi.

Raghunath H M. 1987. *Groundwater*, p. 563. Wiley Eastern Ltd, New Delhi.

Rahman M A, Hasegawa H, Rahman M M, Islam M N, Miah M A M and Tasmin A. 2007. Effect of arsenic on photosynthesis, growth and yield of five widely cultivated rice (*Oryza sativa* L.) varieties in Bangladesh. *Chemosphere.* **67**: 1072–79.

Ramamoorthy P, Backiaraj S and Ajithkumar R. 2018. Evaluation of ground water quality for drinking and irrigation suitability: A case study in Marakkanam block, Villupuram district, Tamilnadu, India. *Journal of Industrial Pollution Control.* **34**: 2159–63.

Richards L A. 1954. Diagnosis and improvement of saline and alkali soils. *Agricultural Handbook* 60. USDA and IBH Pub. Coy Ltd, New Delhi, 98–99.

Roy A, Keesari T, Mohokar H, Sinha U K and Bitra S. 2018. Assessment of groundwater quality in hard rock aquifer of central Telangana state for drinking and agriculture purposes. *Applied Water Science* **8**: 124.

Shakoor A, Arshad M, Bakhsh A and Ahmed R. 2015. GIS based assessment and delineation of groundwater quality zones and its impact on agricultural productivity. Pak. *Journal of Agricultural Sciences* **52**: 1–7.

Singh A K and Kumar S R. 2015. Quality assessment of groundwater for drinking and irrigation use in semi-urban area of Tripura, India. *Ecology Environment & Conservation* **21**: 97–108.

Singh R B, Minhas P S, Chauhan C P S and Gupta R K. 1992. Effect of high salinity and SAR waters on salinisation, sodication and yields of pearl millet-wheat. *Agricultural Water Management* **21**: 93–105.

Taylor E M, Puri A N and Asghar A G. 1934.Soil deterioration in the canal-irrigated areas of the Punjab. I. Equilibrium between calcium and sodium ions in base-exchange reactions. *Research Publications*. **4**: 7.

Todd.1995. *Groundwater Hydrology,* 3rd edn. John Wiley and Sons Publications, New York.

Todd. 1960. Salt water intrusion of coastal aquifers in the United States. *International Association of Scientific Hydrology (Gentbrugge Belgium) Pub* **52**: 452–61.

UNESCO, 2018. Nature-based solutions for water. The United Nations World Water Development Report (WWDR), World Water Assessment Program, UNESCO, Paris, France,

Vijai K and Khan S M M N. 2018. Assessment of groundwater quality for irrigation purpose in Pennagaram block, Dharmapuri district, Tamilnadu, India. International *Journal of Life Sciences Research* **6:** 358–65.

WHO. 1984. Guidelines for drinking-water quality, fourth edn. World Health Organization.

Yadav K K, Dimple, Singh M and Singh P K 2021. Temporal variations of groundwater quality parameters. *Soil and Water Conservation and Management*, 1st edn. ISBN: 987-93-90647-86-6.