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Multi-criteria decision analysis-based irrigation water quality index for the Noyyal river basin, Tamil Nadu

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Abstract

The study aims to develop an irrigation water quality index (IWQI) for the semi-arid region of the Noyyal river basin. The groundwater samples were collected from the basin, and its physico-chemical and trace element characteristics were analysed in the laboratory. The samples were classified depending on their hazardous nature to crops through a Multi-Criteria Decision Analysis (MCDA) with the aid of the Geographic Information System (GIS). The result indicates that the lower basin is affected by excessive electrical conductivity, total dissolved salts, hardness, cadmium, chromium, nickel, and manganese concentrations. The result indicates that textile industries are vital in polluting the basin's groundwater resources. The chloride and nitrate ions are present above the crop tolerable limits in most samples. The spatial distribution of IWQI unveils that the groundwater is highly polluted in the floodplains of the basin and not suitable for irrigation purposes. The basin needs immediate water quality management actions to restore the aquifers and reclaim the productivity of agricultural lands. The index developed based on the MCDA approach would help planners to prioritise location-specific actions to implement mitigation measures.

Keywords: *Irrigation water quality, groundwater pollution, heavy metals, multi-criteria decision analysis, geographic information system*

Introduction

Water has a significant role in all domestic, drinking, irrigation, and industrial activities. Growing population, industrialisation, urbanisation, and climate change have accelerated regional water utilisation and demand, especially groundwater (Zakhem and Hafez, 2015). Globally, around 65 percent of groundwater is used for drinking, 20 percent for irrigation and livestock activities, and 15 percent for industry and mining (Salehi *et al.*, 2018). Significantly, the arid and semi-arid region's population depends primarily on groundwater resources rather than surface water because of its scarcities (Wu *et al.*, 2017). The increase in the population paved the way for intensive irrigation practices that created enormous stress on groundwater utilisation. The excessive extraction of groundwater degrades its quality and increases salinity levels in groundwater (Balasubramani, 2020). Using saline water for irrigation practices affects crop production and results in the degradation of land (Pulido-Bosch *et al.*, 2018). On the other hand, the excessive use of fertilisers on the agro-lands to increase crop productivity contaminates groundwater quality. Several studies on groundwater quality concerning these issues are reported in different parts of India (Singh *et al.*, 2011; Rao *et al.*, 2012; Rajesh *et al.*, 2012; Ramesh and Elango, 2012; Haritash *et al.*, 2017; Kawo and Karuppannan, 2018; Jasortia *et al.*, 2018).

In groundwater studies, the hydro-geochemical processes control the water quality compositions and suitability for irrigation practices (Suresh *et al.*, 2010; Singh *et al.*, 2011; Islam *et al.*, 2017). Traditionally, the hazardous properties of groundwater quality for irrigation practices are evaluated through the Sodium Adsorption Rate (SAR), Residual Sodium Carbonate (RSC), Sodium Percentage (Na%), Kelly's Ratio (KR), and the Magnesium Hazard Ratio (MHR) (Kumaraswamy, 1986; Islam *et al.*, 2017). Investigating samples using trace elements analysis and isotope geochemical analysis is also becoming popular as it helps examine the trace contaminations in groundwater quality (Zakhem and Hafez, 2015). As groundwater quality is an essential factor of irrigated agricultural practices in arid and semi-arid regions, assessing its suitability for irrigation is pertinent (Malakar *et al.*, 2019).

Several groundwater studies demonstrated the power of GIS due to its inevitability in spatial analysis and visualising capabilities (Manap *et al.*, 2013; Delbari *et al.*, 2016; Jasrotia *et al.*, 2018; Kawo and Karuppannan, 2018; Verma *et al.*, 2020). Many researchers globally use GIS-based Water Quality Index (WQI) methods to comprehend the suitability of groundwater for different uses (Dhanasekarapandian *et al.*, 2016). Initially, Horton developed WQI (1965) based on the arithmetic mean weighted calculations. Later, several indexing methods were developed based on the type of tasks and their requirements and incorporated with GIS-based analysis (Brown, 1970; Mohan *et al.*, 1996; CCME, 2001; Babiker *et al.*, 2007; Kumar and Alappat, 2009; Poonam *et al.*, 2013; Jahin *et al.*, 2020). In recent years, Multi-Criteria Decision Analysis (MCDA) has been introduced in index-based water quality assessments to arrive at appropriate weights for the parameters considered and reduce subjectivity (Bozdag, 2015; Kavurmaci and Karakuş, 2020). Thus, integrating GIS, MCDA and water quality index allows effective visualisation and makes the overall analysis more sound, objective, and simple (Simsek and Gunduz, 2007).

The present study aims at assessing the groundwater suitability for irrigated agriculture in the Noyyal Basin using an irrigation water quality index (IWQI) through the MCDA approach in GIS. The study basin comprises many active industrial regions that create many environmental issues, including pollution of groundwater resources. As agriculture is one of the chief occupations of the basin, the determination of IWQI is essential for devising appropriate planning strategies.

Materials and methods

Study area

The boundary of the Noyyal basin is demarcated with the help of CARTOSAT-1 Digital Elevation Model (DEM) data using the hydrological tool from ArcGIS 10.1 (Fig. 1). The basin is a sub-basin of the Cauvery basin which lies between 10º 54' N to 11º 19' N latitudes and 76º 39' E to 77º 55' E longitudes and covers nearly 3,500 km^2 area. The basin's lithology is composed of hard consolidated and unconsolidated formations. The hard-consolidated rocks are represented

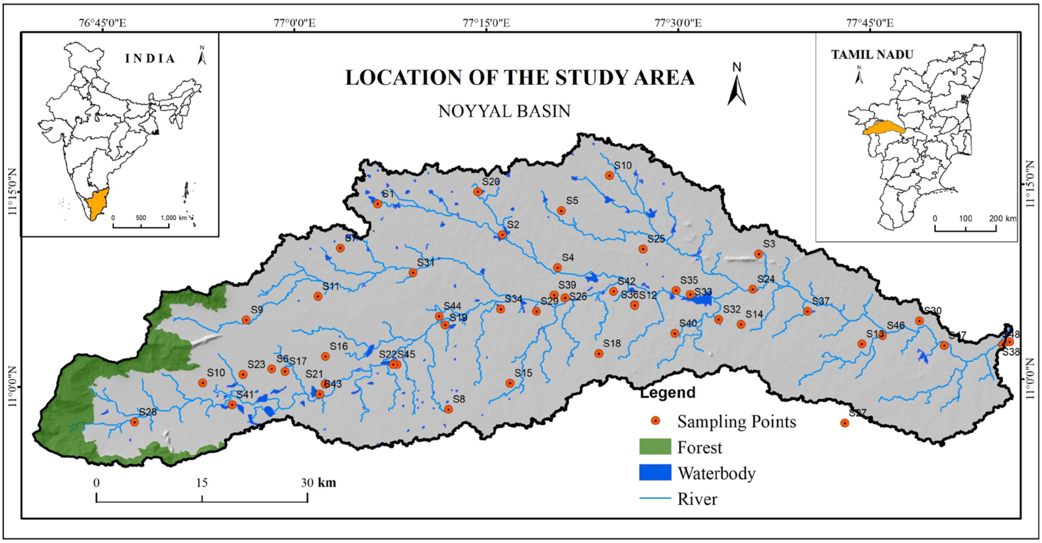


Fig. 1: Location of the study area

by weathered and fractured Granite Gneisses, Granites, and Charnockites. Groundwater mainly occurs under phreatic conditions in the weathered mantle and semi-confined conditions in the fractured zones. The depth of the water table ranges from 7 m to 45 m bgl. The western part of the basin has a deep aquifer (> 30m), while the central and eastern portions have a moderate to shallow aquifer (<30m). The agricultural land use of the basin occupies a significant portion, followed by built-up, forest land, and fallow land. The Noyyal basin is in the cotton belt of Tamil Nadu, with favourable geographic and climatic conditions that shelter the many hosiery and textile industries. The basin is spread over four districts, viz. Coimbatore, Tiruppur, Erode and Karur comprising 11 taluks and 20 blocks. Coimbatore and Tiruppur are the two important cities where the highly polluting bleaching and dyeing industries predominate in the river floodplains. Most industrial clusters are closer to the mainstream to satisfy their water needs and easy wastewater disposal. These industries consume about 90 million litres of water daily for textile processing and discharge over 87 million litres as effluents over the Noyyal River. These effluents contain a high load of Total Dissolved Solids (TDS) and heavy metals concentration. The unregulated textile industries and their continuous discharges of effluents led to groundwater contamination that renders infertile land and low productivity of crops.

Field investigation, sample collection, and analysis

The dug and bore well irrigations are the most common type of irrigation practised in the basin, followed by canal and tank irrigation. Hence, an assessment of groundwater quality is essential for crop planning. A total of 48 groundwater samples were collected from dug and bore wells of the basin, of which 21 were collected nearer to the main river course (where the industrial activities prevail mostly). The samples were collected during

June 2018 (pre-monsoon season), and the location of the samples is shown in Fig. 1.

Each sample is collected in two pre-washed bottles: one is to determine the major cations and anions concentration, and the other is preserved by acidifying with HNO_3 for trace element (heavy metal) analysis. The physical characteristics of groundwater, such as pH, Electrical Conductivity (EC), and Total Dissolved Solvents (TDS), were measured at the sampling sites. All the collected samples were transported immediately to the laboratory to determine the major cations of calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K) and anions of bi-carbonate (HCO_3), chloride (Cl), sulphate (SO_4) and nitrate (NO_3). Ca, Mg, HCO_3 and Cl were estimated by titration method; Na and K were analysed with the help of a Flame Photometer; SO_4 was determined using a UV spectrophotometer. Acid digestion has been done for the acidified samples with HNO_3 and HCL acid based on the guidelines of the ICP-MS (US EPA, 1992) 3005a method for heavy metals analysis. The trace elements of chromium (Cr), manganese (Mn), lead (Pb), cadmium (Cd), nickel (Ni), copper (Cu), iron (Fe), and zinc (Zn) have been analysed with the help of Thermo ICP-MS X Series II model. The instrument's detection limit is parts per trillion (ppt) level. The measurements of all the selected trace elements were done in triplicates, with less than 10 percent standard deviations.

Hazard properties of groundwater to agriculture crops

The seven hazardous properties of groundwater to crops are identified. They are: i) salinity hazard (EC and TDS), ii) carbonate and bicarbonate hazard (Residual Sodium Carbonate and Permeability Index), iii) magnesium hazard (Magnesium Ratio), iv) specific ion toxicity (Chloride, Sodium), v) salinity and alkalinity hazard (USSL class) vi) heavy metal toxicity (Cr, Cd, Mn, Fe, Ni, Zn, Pb, Cu) and vii) miscellaneous effects (pH, Hardness, Nitrate).

Salinity hazards (EC and TDS)

Salinity is one of the most crucial factors determining water quality for irrigation purposes (Jeong *et al.*, 2016). The accumulation of salt content in the root zone of the crops leads to the deterioration of crop yield (Ayers and Westcot, 1985). The salinity hazard for the collected samples was measured in terms of their electrical conductivity (EC in µS/cm units) and total dissolved solvents (TDS in ppm units).

Carbonate, bicarbonate and magnesium hazards

The excess of bicarbonate over the alkaline earth elements (Mg and Ca) is a carbonate hazard. It is calculated by the Residual Sodium Carbonate (RSC) and Permeability Index (PI) (Table 1). The continuous exposure to concentrated RSC results in the burning of leaves and affects the crop yield (Ramesh and Elango, 2012). The value of RSC ranges from negative to positive values. The negative value implies no carbonate hazard, and the positive value indicates the existence of carbonate hazards for irrigation.

Magnesium hazard is one of the crucial factors affecting irrigation water quality (Nagaraju, 2014; Adimalla *et al.*, 2018). The magnesium hazard calculates the ratio of magnesium to calcium (Table 1). The excessive magnesium in water affects the crop yield.

Table 1: The formula used to calculate different Hazard Ratio/Index

Hazard	Index/Ratio	Formula Used
Carbonate and bicarbonate hazard	Residual Sodium Carbonate	$RSC=(CO_3+HCO_3) - (Ca+Mg)$
	Permeability Index	$PI = \frac{Na + \sqrt{HCO3}}{Ca + Mg + Na} X\ 100$
Magnesium hazard	Magnesium Ratio	$MR = \frac{Mg}{Ca + Mg} X\ 100$
Specific ion toxicity (Sodium)	Sodium Adsorption Ratio	$SAR = \frac{Na}{\sqrt{Ca + Mg/2}}$
	Kelly Ratio	$KR = \frac{Na}{Ca + Mg}$
	Sodium Soluble Percent	$SSP = \frac{Na + K}{Na + K + Ca + Mg} X\ 100$

Specific Ion toxicity

The specific ion toxicity slightly varies from other hazards where the plants absorb specific ions in an excess quantity that accumulates in the leaves, resulting in crop damage. The primary toxic ions in irrigation water are sodium, chloride, and boron (Richard, 1954). Here, the toxicity of sodium and chloride are analysed, which are the major pollutants in the dyeing and bleaching industrial environment. Sodium toxicity is estimated with Sodium Adsorption Ratio (SAR), Kelly's Ratio (KR), and Sodium Soluble Percent (SSP) (Table 1).

SAR is one of the significant criteria for assessing the groundwater quality of irrigation (Todd and Mays, 2013). SAR is the ratio of sodium concentration to calcium and magnesium concentration. The Kelly Ratio is also employed to assess the sodium hazard, where the sodium is measured against calcium and magnesium concentration (Wilcox, 1955). Similarly, the Sodium Soluble Percent is also used to calculate sodium concentration. Chloride ion concentrations less than 150 mg/l would be a desirable range for irrigation.

Salinity and alkalinity hazard

The EC and SAR are the two most common water quality factors that influence the standard rate of infiltration and permeability of water. This combined effect of salinity and alkalinity is assessed through the USSL diagram (Richard, 1954). The USSL diagram classifies the water for irrigation based on its SAR and EC values. The sodium hazard is classified as C1 (Low), C2 (Medium), C3 (High), and C4 (Very High); the salinity class as S1 (Low), S2 (Medium), S3 (High), and S4 (Very High).

Trace element toxicity

The trace element, also termed a micro-nutrient, is an essential nutrient of crops. However, crops' surplus intake of trace elements leads to toxicity and affects their growth. It is essential to assess the trace element toxicity in an industrial region where the influence of contaminants is predominant. In general, the excess intake of Cu results in leaf chlorosis, and excess Zn leads to stem chlorosis (Asano *et al.*, 2007). The Pb and Cd in contaminated water are highly harmful

Table 2: Recommended trace element concentration for irrigation waters

Trace Element	Recommended Maximum Concentration (mg/l)	Remarks
Cr	0.1	Conservative limits are recommended due to a lack of knowledge on its toxicity to plants.
Mn	0.2	Toxic to several crops at a few-tenths to a few mg/l, but usually only in acid soils.
Fe	5	Not toxic to plants in aerated soils but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum.
Ni	0.2	Toxic to many plants at 0.5 mg/l to 1.0 mg/l; reduced toxicity at neutral or alkaline pH.
Cu	0.2	Toxic to several plants at 0.1 to 1.0 mg/l in nutrient solutions.
Zn	2	Toxic to many plants at widely varying concentrations; reduced toxicity at pH > 6.0 and in fine textured or organic soils.
Pb	5	Inhibit plant cell growth at very high concentrations.
Cd	0.01	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans.

Source: Ayers and Westcot (1985)

to human health and are not recommended for irrigation purposes (Gupta and Gupta, 1998). Ayers and Westcot (1985) created the guidelines for the trace element concentration limits for irrigation water, which were followed in this study (Table 2). Accordingly, the trace elements concentration such as Cr, Mn, Pb, Cd, Ni, Cu, Fe, and Zn were assessed in this study.

Apart from these hazard parameters, the study also assessed the minor water quality factors such as pH, hardness, and nitrate concentrations.

Irrigation Water Quality Index (IWQI)

A methodology is framed to assess the groundwater quality and suitability for irrigation by considering the hazardous nature of water to crops. It is complex to generalise the overall quality of water with different interactions of several hazard parameters. Hence, the MCDA approach is used in this study by incorporating all the hazard factors to arrive at IWQI. The Analytical Hierarchical Process (AHP) is one of the commonly used approaches of MCDA. The AHP provides objective mathematics to avoid the subjective and personal preferences of an individual or a group in the arrival of a decision. This approach allows the researchers to determine the criteria weights based on the pair-wise comparison matrix. These comparisons are performed using a scale of absolute judgments representing how much more one element dominates another to a given attribute (Saaty, 2008). The pair-wise comparison matrix of evaluation criteria (Aij = 1/Aij) is as follows,

$$A_{ij} = \begin{pmatrix} a11 & a12 & \cdots & a1n \\ a21 & a22 & \cdots & a2n \\ \vdots & \vdots & \ddots & \vdots \\ an1 & an2 & \cdots & ann \end{pmatrix} = \begin{pmatrix} 1 & a12 & a13 & a1n \\ 1/a12 & 1 & a23 & a2n \\ \vdots & \vdots & \ddots & \vdots \\ 1/a1n & 1/a2n & \cdots & 1 \end{pmatrix} \quad (1)$$

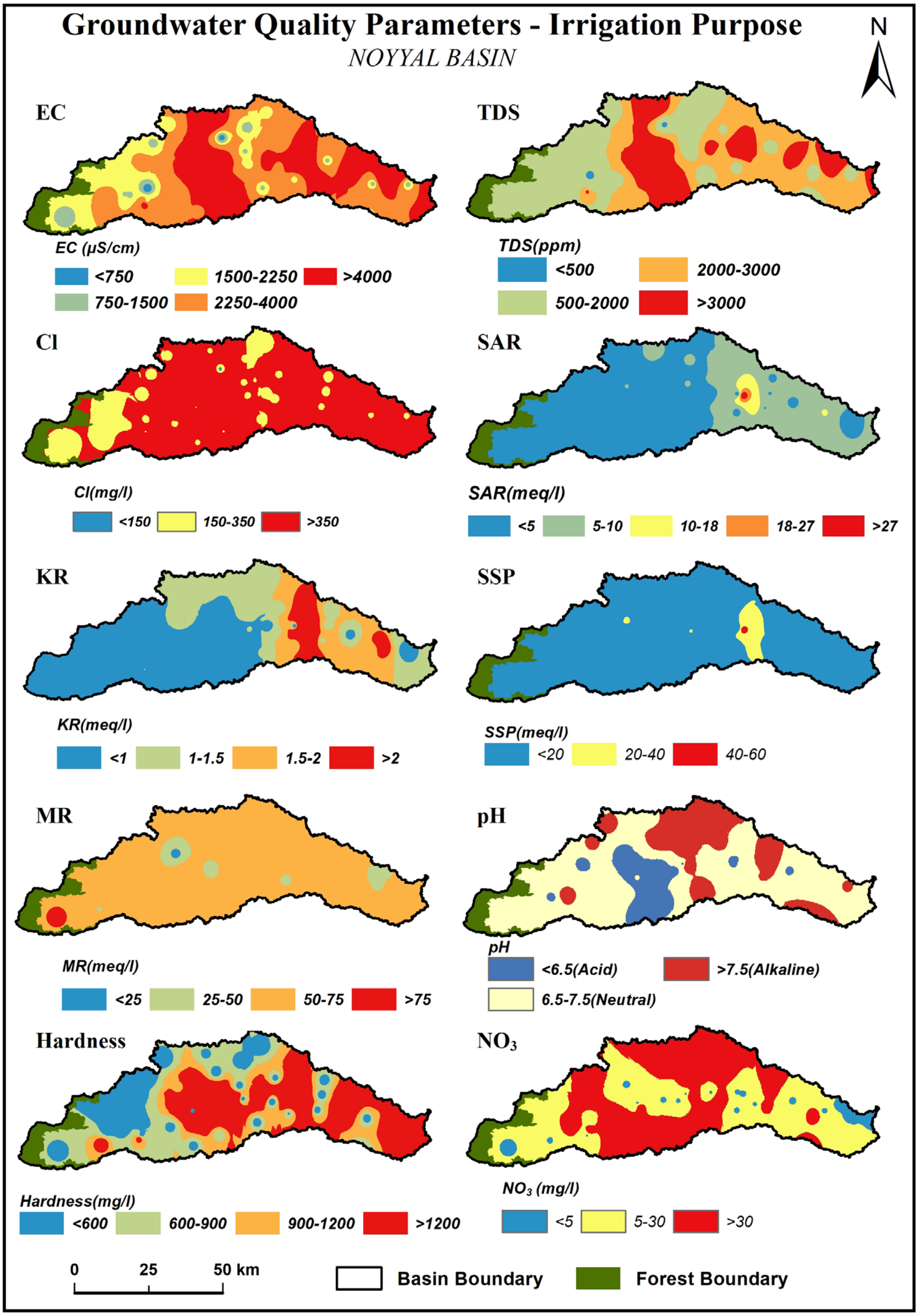


Fig. 2: Spatial representation of physico-chemical characteristics of groundwater in the Noyyal basin

Table 3: Pairwise comparison matrix for the major hazard factors

Hazards	Sal. Haz	Carb. Haz.	Mg. Haz.	Sal. & Alk. Haz.	Sp. Ion. Tox.	Trace. Ele. Tox.	Misc. Effects
Sal. Haz	1.00	2.00	3.00	0.50	2.00	3.00	3.00
Carb. Haz.	0.50	1.00	0.50	0.25	0.33	0.50	2.00
Mg. Haz.	0.33	2.00	1.00	0.25	0.33	2.00	2.00
Sal. & Alk. Haz.	2.00	4.00	4.00	1.00	3.00	4.00	3.00
Sp. Ion. Tox.	0.50	3.00	3.00	0.33	1.00	3.00	2.00
Trace. Ele. Tox.	0.33	2.00	0.50	0.25	0.33	1.00	3.00
Misc. Effects	0.33	0.50	0.50	0.33	0.50	0.33	1.00
Total	5.00	14.50	12.50	2.92	7.50	13.83	16.00

Table 4: Normalised relative weight matrix for the major hazard factors

Number of Variables (N)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Random Index (RI)	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.54	1.56	1.57	1.58

Table 5: Random indices for the matrix of various sizes (Saaty, 1980)

Hazards	Sal. Haz	Carb. Haz.	Mg. Haz.	Sal. & Alk. Haz.	Sp. Ion. Tox.	Trace Ele. Tox.	Misc. Effects	Aggregated Weight
Sal. Haz	0.20	0.14	0.24	0.17	0.27	0.22	0.19	0.20
Carb. Haz.	0.10	0.07	0.04	0.09	0.04	0.04	0.13	0.07
Mg. Haz.	0.07	0.14	0.08	0.09	0.04	0.14	0.13	0.10
Sal. & Alk. Haz.	0.40	0.28	0.32	0.34	0.40	0.29	0.19	0.32
Sp. Ion. Tox.	0.10	0.21	0.24	0.11	0.13	0.22	0.13	0.16
Trace. Ele. Tox.	0.07	0.14	0.04	0.09	0.04	0.07	0.19	0.09
Misc. Effects	0.07	0.03	0.04	0.11	0.07	0.02	0.06	0.06

Satty's rating scale represents the intensity of importance of the criteria. The scale ranges from 1 to 9, signifies equal importance to extremely strong importance; similarly, the reciprocal values from 1/2 to 1/9 indicate less importance to extremely less importance. The sum of the values in each column of the pair-wise matrix is given by,

$$C_{ij} = \sum_{i=1}^{n} A_{ij} \tag{2}$$

Each element in the matrix is divided by its column total to generate a normalised pair-wise matrix as follows:

$$X_{ij} = \frac{C_{ij}}{\sum_{i=1}^{n} C_{ij}} \tag{3}$$

The weighted matrix is obtained by dividing the sum of the normalised column of matrix Xij by the number of criteria' n' as follows:

$$W_{ij} = \frac{\sum_{i=1}^{n} X_{ij}}{n} \tag{4}$$

Here, a pair-wise comparison matrix is computed to obtain a relative weight score for seven major hazardous factors (F), first sub-criteria (S1), and second sub-criteria (S2) based on their hazard nature. The pair-wise comparison matrix and its normalised relative weight scores obtained for the major hazard factors (F) are given in Table 3 and Table 4.

The consistency of the judgment is checked with the consistency ratio (CR), calculated as follows:

$$CR = CI/RI \tag{5}$$

where CI is the Consistency Index, and RI is the Random Index (RI is given in Table 5.)

$$CI = (\lambda_{max} - n)/(n-1) \tag{6}$$

where λ_{max} is the principal eigenvalue and n is the number of comparisons.

When the CR value is less than 0.1, the judgment of prioritisation is significant, and the weightage value would be acceptable. The weightage index for the major hazardous factors (F), first sub-criteria (S1), second sub-criteria (S2), and their Consistency Ratio (CR) is given in Table 6 and Table 7. The global weight is calculated by multiplying the weight of major criteria, first sub-criteria and second sub-criteria. The summation of weighted scoring is used to arrive at IWQI.

The index values were interpolated using the geostatistical-based IDW algorithm in the GIS environment. Finally, the basin is classified into three classes: highly suitable, moderately suitable, and not suitable for groundwater irrigation.

Results

Physico-chemical characteristics of groundwater

The descriptive statistics for the analysed physico-chemical parameters and trace elements were tabulated in Table 8. The derived parameters of RSC, PI, MR, SAR, KR, SSP, and USSL are calculated from the respective formulas and presented in Fig. 2. The spatial representation of results shows that most samples have high electrical conductivity (77%) and high total dissolved salts (46%). The samples with high EC and TDS indicate that those aquifers were highly susceptible to salinity hazards. The result of RSC and PI indicates that most of the samples are under the excellent category and do not exhibit any infiltration issues in the soil. The SAR, KR, and SSP indices are under good to excellent (90%) categories. The result indicates that the basin has a very low intensity for sodium and carbonate hazards. However, long-term use of sodium and bicarbonate irrigation water would affect soil permeability (Donean, 1975). The chloride concentration of the basin is moderate to very high ranges (96%) under unsuitable ranges for irrigation. The basin has a high magnesium hazard (88%) for irrigation that comes under doubtful to unsuitable classes. The precipitation of calcium and magnesium made to increase the sodium per cent in groundwater. Similarly, the excess intake of chloride ions causes toxicity to sensitive crops. The high chloride toxicity leads to leaf burn and turns defoliation (Ayers and Westcot, 1985). The pH of the collected samples ranges

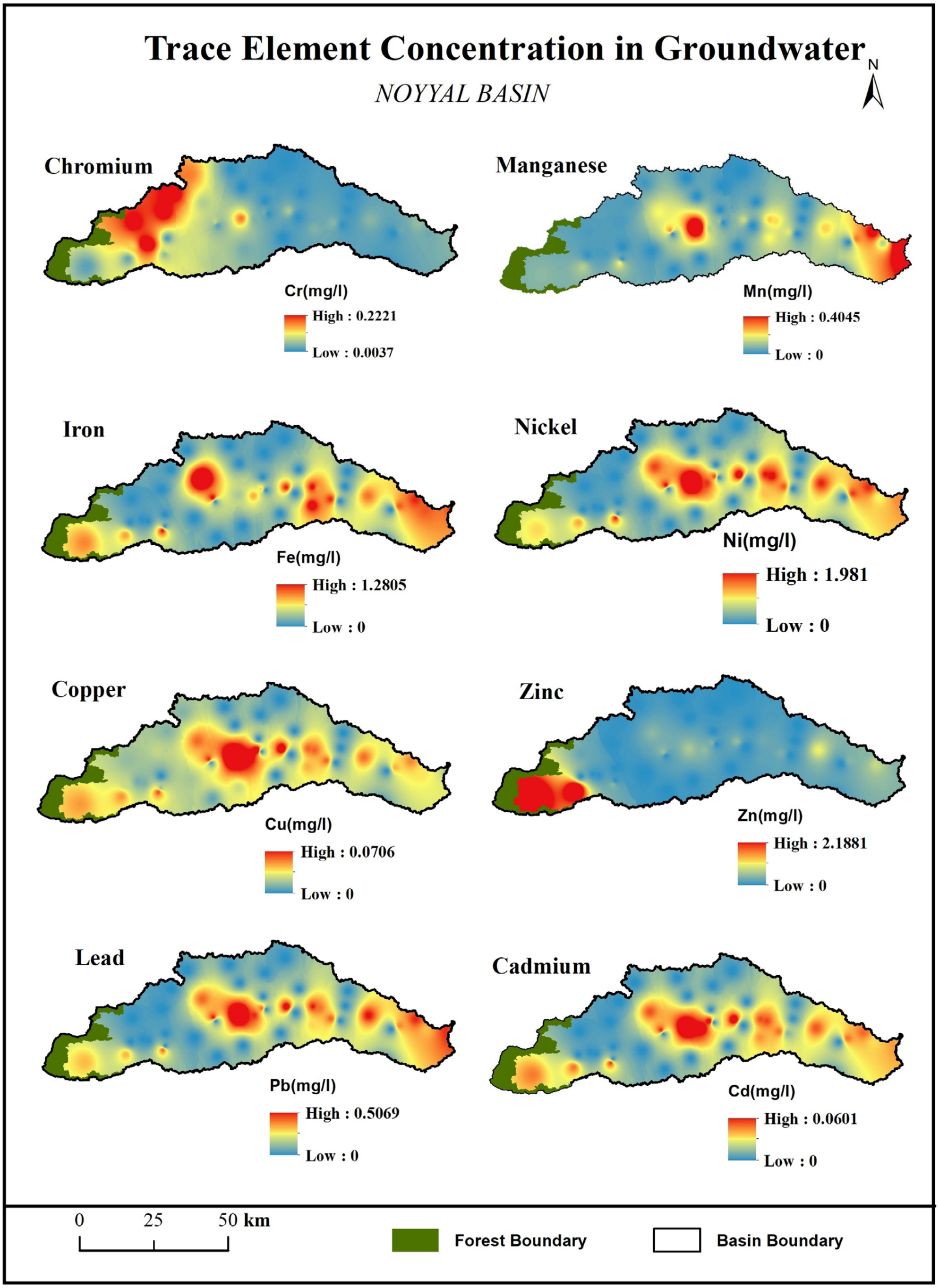
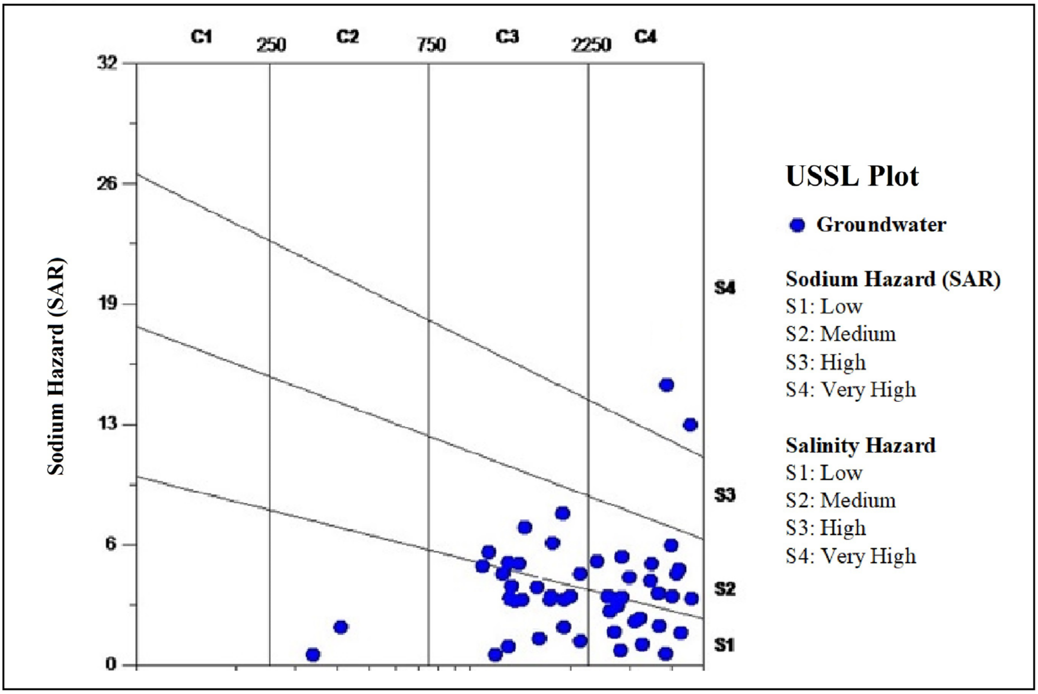


Fig. 3: Spatial representation of trace element concentrations of groundwater in the Noyyal basin



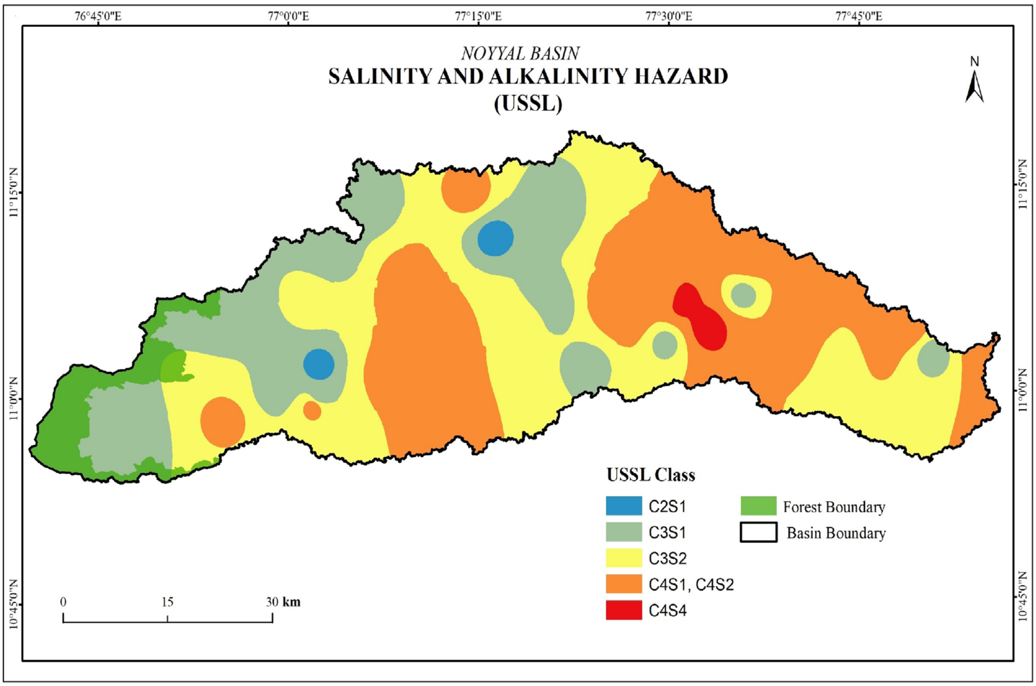


Fig. 4: USSL diagram and spatial representation of salinity and alkalinity hazard in the Noyyal basin

Table 6: Weightage index and CR for hazardous factors of irrigation

Hazard Type	Sub - Criteria 1 (S1)	Sub- Criteria 2 (S2)	Irrigation Suitability Class	No. of Samples (%)	Sub-Criteria Weight	Global Weight
Salinity Hazard	EC (µs/cm)	<750	Excellent	6	0.376	0.0380
		750-1500	Good	23	0.237	0.0239
		1500-2250	Moderate	15	0.172	0.0174
		2250-4000	Poor	19	0.120	0.0121
		>4000	Very Poor	37	0.095	0.0096
	TDS	<500	Good	6	0.480	0.0485
		(ppm)	Moderate	48	0.262	0.0265
		2000-3000	Poor	15	0.155	0.0157
		>3000	Very Poor	31	0.103	0.0104
Carbonate and Bi-Carbonate Hazard	RSC (meq/l)	<1.5	Good	100	0.545	0.0196
		1.5-2.5	Doubtful	-	0.287	0.0103
		>2.5	Unsuitable	-	0.168	0.0060
	PI	<40	Suitable	96	0.545	0.0196
		(meq/l)	Doubtful	2	0.287	0.0103
		>60	Unsuitable	2	0.168	0.0060
Specific Ion Toxicity0	Cl (mg/l)	<150	Good	4	0.545	0.0230
		150 - 350	Moderate	60	0.287	0.0121
		>350	Poor	36	0.168	0.0071
	SAR (meq/l)	<10	Excellent	94	0.480	0.0303
		10-18	Good	4	0.262	0.0166
		18-27	Doubtful	-	0.155	0.0098
		>27	Unsuitable	2	0.103	0.0065
	KR (meq/l)	<1	Excellent	50	0.480	0.0139
		1 – 1.5	Good	38	0.262	0.0076
		1.5-2	Doubtful	4	0.155	0.0045
		>2	Unsuitable	8	0.103	0.003
	SSP (%)	<20	Excellent	92	0.545	0.0118
		20-40	Good	6	0.287	0.0062
		40-60	Doubtful	2	0.168	0.0036
Magnesium Ratio (meq/l)		<25	Good	4	0.480	0.0475
		25-50	Moderate	8	0.262	0.0259
		50-75	Doubtful	86	0.155	0.0153
		>75	Unsuitable	2	0.103	0.0102
Salinity and Alkalinity Hazard (USSL)		C2S1	Good	4	0.480	0.1512
		C3S1, C3S2	Moderate	38	0.262	0.0825
		C4S1, C4S2	Poor	54	0.155	0.0488
		C4S4	Very Poor	4	0.103	0.0324
Misc. Effect	Total Hardness (mg/l)	<600	Good	63	0.480	0.0100
		600-900	Moderate	2	0.262	0.0054
		900-1200	Poor	4	0.155	0.0032
		>1200	Very Poor	31	0.103	0.0021
	pH	6.8-7.2	Good	30	0.545	0.0113
		6.5-6.7, 7.3-8.5	Moderate	54	0.287	0.0060
		<6.5>8.5	Poor	16	0.168	0.0035
	Nitrate (mg/l)	<5	Good	44	0.545	0.0113
		5 - 30	Doubtful	8	0.287	0.0060
		>30	Unsuitable	48	0.168	0.0035

Table 7: Weightage index and CR for trace element toxicity

Criteria (S1)	Sub-Criteria (mg/l) (S2)	No. of Samples (%)	Sub-Criteria Weight	Global Weight
Chromium	<0.1	85	0.545	0.0063
	0.1-1	15	0.287	0.0033
	>1	-	0.168	0.0020
Copper	<0.2	100	0.545	0.0063
	0.2-5	-	0.287	0.0033
	>5	-	0.168	0.0020
Iron	<5	100	0.545	0.0063
	5-20	-	0.287	0.0033
	>20	-	0.168	0.0020
Nickel	<0.2	56	0.545	0.0063
	0.2-2	44	0.287	0.0033
	>2	-	0.168	0.0020
Zinc	<2	98	0.545	0.0063
	2-10	2	0.287	0.0033
	>10	-	0.168	0.0020
Cadmium	<0.01	56	0.545	0.0063
	0.01-0.05	42	0.287	0.0033
	>0.05	2	0.168	0.0020
Lead	<5	100	0.545	0.0063
	5-10	-	0.287	0.0033
	>10	-	0.168	0.0020
Manganese	<0.2	96	0.545	0.0063
	0.2-10	4	0.287	0.0033
	>10	-	0.168	0.0020

between 6 and 8.2. Around 58% of samples are neutral, and the remaining (42%) are acidic to alkaline. Nearly 35% of samples are hard in nature, and the nitrate concentration is found to be moderate to high (56%) with low irrigation suitability.

The trace element analysis reveals that lead, iron, and copper concentration is under desirable ranges with high suitability for irrigation (Fig. 3). However, the chromium, nickel, zinc, and manganese concentrations are in low to moderate classes and possess suitability issues for irrigation. The high toxic element Cd is under the moderate to unsuitable ranges (44%) for irrigation.

The combined effect of salinity and alkaline hazard is assessed with the USSL diagram (Fig. 4). The groundwater samples that possess the USSL class of C3-S1 (30%), C4-S2 (40%), C4-S1(14%), C3-S2 (8%),

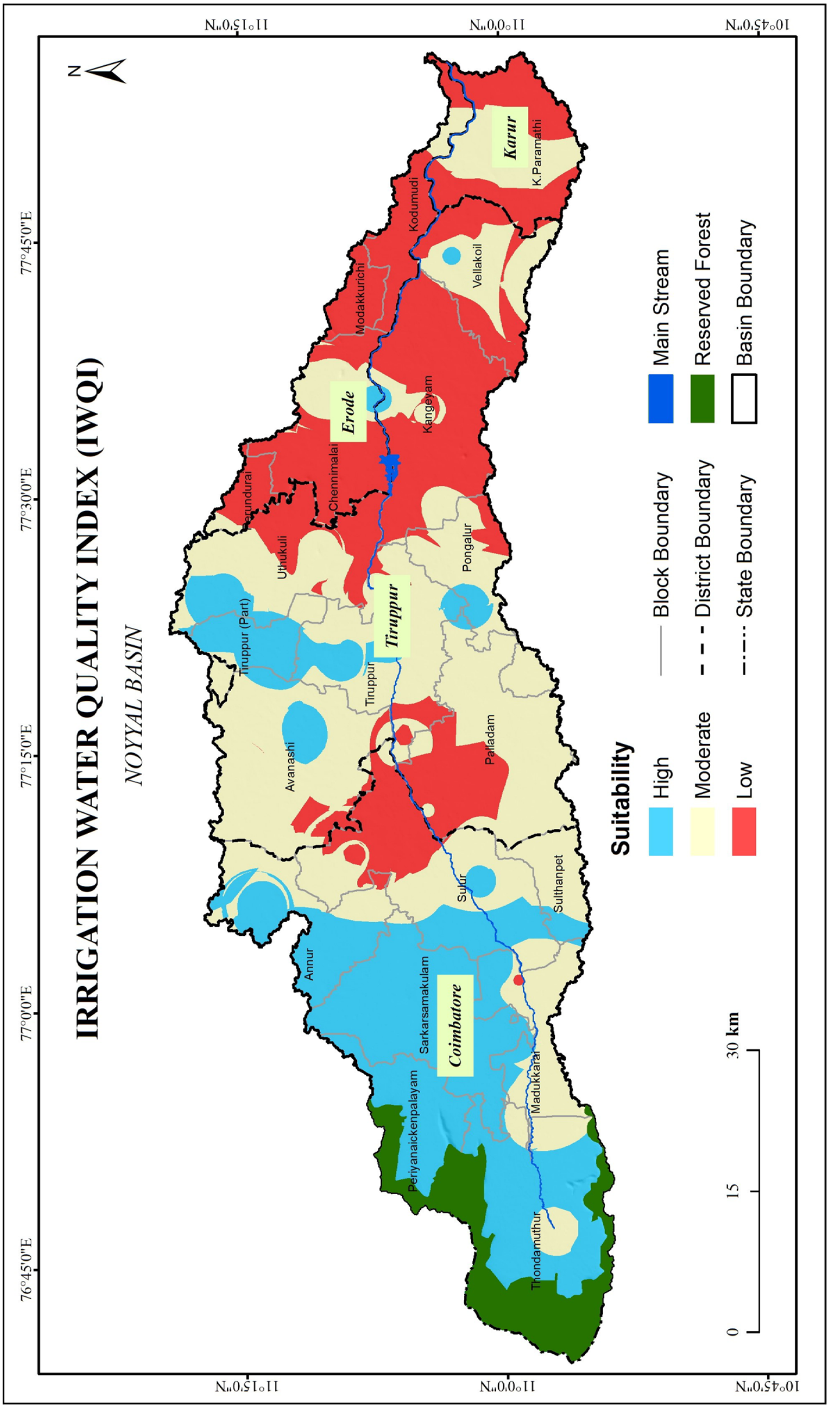


Fig. 5: Irrigation Water Quality Index (IWQI) of the Noyyal basin

Table 8: The descriptive statistics of the physico-chemical and trace elements concentrations

Parameters	Min	Max	Mean	Standard Deviation
pH	6	8.2	7	0.58
EC (μs/cm)	78	14,569	3726	2980
TDS (ppm)	56	9470	2505	1955
Hardness (mg/l)	302	6200	1500	312
Na (mg/l))	9	1650	235	237
K (mg/l)	1	315	48	46
Ca (mg/l)	11	450	77	67
Mg (mg/l)	2	250	70	44
HCO_3	40	960	359	183
Cl (mg/l)	101	9088	1018	1660
SO_4 (mg/l)	2	97	35	30
NO_3 (mg/l)	2	66	26	23
Cr (mg/l)	0.00335	0.222	0.052	0.065
Mn (mg/l)	0	0.405	0.038	0.070
Fe (mg/l)	0	1.281	0.278	0.346
Ni (mg/l)	0.00001	1.982	0.405	0.505
Cu (mg/l)	0	0.071	0.015	0.016
Zn (mg/l)	0	2.191	0.189	0.419
Pb (mg/l)	0	0.507	0.102	0.129
Cd (mg/l)	0	0.060	0.014	0.017

C2-S1 (4%), and C4-S4 (4%). Two samples are under very high salinity, and a very high alkaline class (C4-S4) is unsuitable for agriculture. The continuous utilisation of C4-S4 class water for long-term irrigation purposes would increase the soil's salinity and alkalinity hazard (Lauchli and Epstein, 1990).

Spatial analysis of irrigation water quality

The spatial analysis of results show that the study area's TDS and EC constantly increase from the west to the east. Similarly, sodium hazards were also found to be high in the eastern part of the basin. In contrast, the carbonate hazard is low throughout the basin and shows a high hazard in the western part due to carbonate rock interactions (CGWB, 2008). The basin exhibits high magnesium, nitrate, and chloride ion toxicity, which needs suitable measures before irrigation. The trace element concentration of groundwater except Cr and Zn is high in the floodplains. Cr and Zn are found to be high in the western part of the basin.

Irrigation Water Quality Index (IWQI)

The prepared hazardous layers were rated based on the weights obtained from AHP and overlaid to arrive at an indexing score. The resultant map shows the IWQI for the Noyyal basin (Fig. 5). The result shows that 30% of the study area has high suitable groundwater, and 30% is under unsuitable groundwater for irrigation purposes. Geographically, the western part of the basin shows high suitability, the central part has moderate, and the eastern part has low suitability of groundwater for irrigation.

Discussion

The basin has a high hazard for salinity (EC and TDS), magnesium and chloride ions toxicity. The spatial visualisation of results found that the eastern part of the basin is hard in nature and exhibits very high EC, TDS, hardness, and heavy metals of Cd, Cr, Ni, and Mn. The IWQI results show that about 70% of the study area is under moderate to unsuitable ranges. Although the western part of the basin has good to moderate groundwater quality, it deteriorates towards the east, where the industrial activities are highly concentrated. Administratively, the blocks of the Coimbatore district have a good quality of groundwater, and the blocks of Tiruppur, Erode and Karur districts have low suitability of water for irrigation. The study reveals that the porous medium and shallow aquifers have a high tendency for contaminant interactions that lead to low irrigation suitability in the downstream regions. In contrast, the region with hard rock formations, other than the floodplains of river Noyyal, has deep aquifers with poor contact with contaminants and falls under the moderate to high irrigation suitability category.

The contaminated groundwater of the downstream region is widely used for domestic and irrigation purposes. The continuous usage of polluted water with heavy inputs of fertilisers for irrigation severely deteriorates the shallow aquifers of the basin. The remediation of the trace element deteriorated aquifers is a complex and time-consuming process; however, it can be improved gradually by introducing effective rainwater harvesting and constructing artificial recharge sites. Basic treatment of groundwater before utilising it for irrigation would lessen crop damage. Blending contaminated water with fresh water in the optimum proportion will protect the crop from salinity hazards (Zaman *et al.*, 2018). A reasonable amount of gypsum in addition to irrigation water will reduce the sodicity hazard. The continuous usage of degraded groundwater will lead to several direct and indirect effects on agriculture, including low productivity of crops, soil salinity, depletion of the water table, and change in freshwater biology (Prabha *et al.*, 2013). Therefore, the basin needs strict regulation on groundwater usage to arrest further degradation of land and restore the contaminated aquifers.

Conclusion

The Noyyal river basin comprises several industrial hubs; still, agricultural activities are highly dependent on the water resources of the basin. The result of the study indicates that the textile industries in the middle parts of the basin play a vital role in polluting the basin's groundwater resources. As agricultural and industrial activities are equally contributed to the economic development of the basin, proper groundwater conservation plans and land use regulations are to be immediately to restore the aquifers and reclaim the land productivity. This study has applied MCDA techniques to the geochemical indices generated from the major and trace elemental analysis of the groundwater samples and provided a synthesized spatial picture of the irrigation water quality of the basin. It helps planners to devise action-oriented plans and regulations to implement in the highly affected regions.

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References

Adimalla, N., & Venkatayogi, S. (2018). Geochemical Characterization and Evaluation of Groundwater Suitability for Domestic and Agricultural Utility in Semi-Arid Region of Basara, Telangana State, South India. *Applied Water Science, 8*(1), 1-14.

Asano, T., Burton, F., & Leverenz, H. (2007). *Water Reuse: Issues, Technologies, and Applications*. McGraw-Hill Education.

Ayers, R. S. & Westcot, D. W. (1985). Water Quality for Agriculture, FAO Irrigation and Drainage, Paper No. 29, Rev. 1, *UN Food and Agriculture Organization*, Rome.

Babiker, S., Mohamed, M. A. A. & Hiyama, T. (2007). Assessing Groundwater Quality Using GIS. *Water Resources Management*, 21, 699–715.

Balasubramani, K., Rutharvel Murthy, K., Gomathi, M., & Kumaraswamy, K. (2020). Integrated assessment of groundwater resources in a semi-arid watershed of South India: Implications for irrigated agriculture. *GeoJournal*, 85, 1701–1723.

Bozdag, A. (2015). Combining AHP with GIS for Assessment of Irrigation Water Quality in Çumra Irrigation District (Konya), Central Anatolia, Turkey. *Environmental Earth Sciences*, 73(12), 8217-8236.

Brown, R. M., McClelland, N. I., Deininger, R. A. & Ronald, G. T. (1970). A Water Quality Index - Do We Dare? *Water Sewage Works*, 11, 339–343.

CCME, (2001). Canadian Environmental Quality Guidelines for the Protection of Aquatic Life, *CCME Water Quality Index: Technical Report*, 1.0.

CGWB, (2008). District Groundwater Brochure, Tamil Nadu, Technical report series, *Central Ground Water Board*, Chennai.

Delbari, M., Amiri, M., & Motlagh, M. B. (2016). Assessing Groundwater Quality for Irrigation using Indicator Kriging Method. *Applied Water Science, 6*(4), 371-381.

Dhanasekarapandian, M., Chandran, S., Devi, D. S., & Kumar, V. (2016). Spatial and Temporal Variation of Groundwater Quality and its Suitability for Irrigation and Drinking Purpose using GIS and WQI in an Urban Fringe. *Journal of African Earth Sciences, 124*, 270-288.

Donean, L. D. (1975). Water Quality for Irrigated Agriculture. In: Poljakoff-Mayber A., Gale J. (eds) Plants in Saline Environments. *Ecological Studies (Analysis and Synthesis)*, 15, Springer, Berlin, Heidelberg.

Gupta, U. C., & Gupta, S. C. (1998). Trace Element Toxicity Relationships to Crop Production and Livestock and Human Health: Implications for Management. *Communications in Soil Science and Plant Analysis, 29*(11-14), 1491-1522.

Haritash, A. K., Mathur, K., Singh, P., & Singh, S. K. (2017). Hydrochemical Characterisation and Suitability Assessment of Groundwater in Baga–Calangute Stretch of Goa, India. *Environmental Earth Sciences, 76*(9), 341.

Horton, R. K. (1965). An Index Number System for Rating Water Quality, *Journal of Water Pollution Control Federation*, 37(3), 300–306.

Islam, A. T., Shen, S., Bodrud-Doza, M. D., & Rahman, M. S. (2017). Assessing Irrigation Water Quality in Faridpur District of Bangladesh using Several Indices and Statistical Approaches. *Arabian Journal of Geosciences, 10*(19), 1-25.

Jahin, H. S., Abuzaid A. S., & Abdellatif A. D. (2020). Using Multivariate Analysis to Develop Irrigation Water Quality Index for Surface Water in Kafr El-Sheikh Governorate, Egypt. *Environmental Technology & Innovation, 17*, 100532.

Jasrotia, A. S., & Bhagat, B. D. (2018). Geographical Information System (GIS) Based Groundwater Quality Mapping in the Western Doon Valley, Dehradun, Uttaranchal State. *Groundwater for Sustainable Development*, 6, 200-212.

Jeong, H., Kim, H., & Jang, T. (2016). Irrigation Water Quality Standards for Indirect Wastewater Reuse in Agriculture: A Contribution Toward Sustainable Wastewater Reuse in South Korea. *Water, 8*(4), 169.

Kavurmaci, M. & Karakuş, C. B. (2020). Evaluation of Irrigation Water Quality by Data Envelopment Analysis and Analytic Hierarchy Process-Based Water Quality Indices: The case of Aksaray City, Turkey. *Water, Air, & Soil Pollution*, 231(2), 1-17.

Kawo, N. S., & Karuppannan, S. (2018). Groundwater Quality Assessment using Water Quality Index and GIS Technique in Modjo River Basin, Central Ethiopia. *Journal of African Earth Sciences, 147*, 300-311.

Kumar, D. & Alappat, B. (2009). NSF-Water Quality Index: Does It Represent the Experts' Opinion? *Practice Periodical* of Hazardous, Toxic, and *Radioactive Waste Management*, 13(1), 75-79.

Kumaraswamy, K. (1986). *Spatial Aspect of Water Resources and Management in the Vaippar Basin*, Unpublished Ph.D. Thesis in Geography, University of Madras, Chennai.

Lauchli, A. & Epstein, E. (1990). Plant Responses to Saline and Sodic Conditions. *Agricultural Salinity Assessment and Management*, 71, 113-137.

Malakar, A., Snow, D. D., & Ray, C. (2019). Irrigation Water Quality—A Contemporary Perspective. *Water, 11*(7), 1482.

Manap, M., Sulaiman, W. N. A., Ramli, M. F., Pradhan, B., & Surip, N. (2013). A Knowledge-Driven GIS Modeling Technique for Groundwater Potential Mapping at the Upper Langat Basin, Malaysia. *Arabian Journal of Geosciences, 6*(5), 1621-1637.

Mohan, S. V., Nithilla, P. & Reddy, S. J. (1996). Estimation of Heavy Metals in Drinking Water and Development of Heavy Metal Pollution Index, *Journal of Environmental Science and Health*, Part A, Environmental Science and Engineering & Toxic and Hazardous Substance Control, 31(2), 283-289.

Nagaraju, A., Sunil Kumar, K., & Thejaswi, A. (2014). Assessment of Groundwater Quality for Irrigation: A Case Study from Bandalamottu Lead Mining Area, Gundur District, Andhrapradesh, South India. *Applied Water Science*, 4(4), 385-396.

Poonam, T., Tanushree, B., & Sukalyan, C. (2013). Water Quality Indices-Important

Tools for Water Quality Assessment: A Review. *International Journal of Advances in Chemistry, 1*(1), 15-28.

Prabha, S., Kumar, M., Kumar, A., Das, P., & Ramanathan, A. L. (2013). Impact Assessment of Textile Effluent on Groundwater Quality in the Vicinity of Tirupur Industrial Area, Southern India. *Enviromental Earth Sciences*, 70 (7), 3015–3022.

Pulido-Bosch, A., Rigol-Sanchez, J. P., Vallejos, A., Andreu, J. M., Ceron, J. C., Molina-Sanchez, L., & Sola, F. (2018). Impacts of Agricultural Irrigation on Groundwater Salinity. *Environmental Earth Sciences, 77*(5), 1-14.

Rajesh, R., Brindha, K., Murugan, R., & Elango, L. (2012). Influence of Hydrogeochemical Processes on Temporal Changes in Groundwater Quality in a Part of Nalgonda District, Andhra Pradesh, India. *Environmental Earth Sciences, 65*(4), 1203-1213.

Ramesh, K., & Elango, L. (2012). Groundwater Quality and its Suitability for Domestic and Agricultural Use in Tondiar River Basin, Tamil Nadu, India. *Environmental Monitoring and Assessment, 184*, 3887–3899.

Rao, N. S., Rao, P. S., Reddy, G. V., Nagamani, M., Vidyasagar, G., & Satyanarayana, N. L. V. V. (2012). Chemical characteristics of groundwater and assessment of groundwater quality in Varaha River Basin, Visakhapatnam District, Andhra Pradesh, India. Environmental Monitoring and Assessment, 184(8), 5189-5214.

Richard, L. A. (1954). Diagnosis and Improvement of Saline and Alkali Soils. Agriculture Handbook 60, *United States Department of Agriculture*, Washington DC, USA.

Saaty, T. L. (2008). Decision Making with the Analytic Hierarchy Process, *International Journal of Services Sciences*, 1(1), 83–98.

Salehi, S., Chizari, M., Sadighi, H., & Bijani, M. (2018). Assessment of Agricultural Groundwater Users in Iran: A Cultural Environmental Bias. *Hydrogeology Journal, 26*(1), 285-295.

Simsek, C. & Gunduz, O. (2007). IWQ Index: A GIS-Integrated Technique to Assess Irrigation Water Quality. *Environmental Monitoring and Assessment*, 128, 277-300.

Singh, A. K. Tewary, B. K., & Sinha, A. (2011). Hydrochemistry and Quality Assessment of Groundwater in Part of NOIDA Metropolitan City, Uttar Pradesh. *Journal of the Geological Society of India* 78(6), 523-540.

Suresh, M., Gurugnanam, B., Vasudevan, S., Dharanirajan, K., & Raj, N. J. (2010). Drinking and Irrigational Feasibility of Groundwater, GIS Spatial Mapping in Upper Thirumanimuthar Sub-Basin, Cauvery River, Tamil Nadu. *Journal of the Geological Society of India, 75*(3), 518-526.

Todd, D. K. & Mays, L. W. (2013). Groundwater Hydrology, *John Wiley & Sons*, New York.

US EPA, (1992). Acid Digestion of Waters for Total Recoverable or Dissolved Metals for Analysis by FLAA or ICP Spectroscopy. *Washington, DC, USA*.

Verma, P., Singh, P. K., Sinha, R. R., & Tiwari, A. K. (2020). Assessment of groundwater quality status by using water quality index (WQI) and geographic information system (GIS) approaches: a case study of the Bokaro district, India. *Applied Water Science, 10*(1), 1-16.

Wilcox, L. V. (1955). Classification and Use of Irrigation Waters, United States Department of Agriculture Circle. *American Journal of Science*, 8(3), 123-128.

Wu, Z., Zhang, D., Cai, Y., Wang, X., Zhang, L., & Chen, Y. (2017). Water Quality Assessment Based on the Water Quality Index Method in Lake Poyang: The Largest Freshwater Lake in China. *Scientific Reports, 7*(1), 1-10.

Zakhem, B. A. and Hafez, R. (2015). Heavy Metal Pollution Index for Groundwater Quality Assessment in Damascus Oasis, Syria, *Environmental Earth Sciences*, 73(10), 6591-6600.

Zaman, M., Shahid, S. A., & Heng, L. (2018). Irrigation Water Quality. In *Guideline for Salinity Assessment, Mitigation, and Adaptation using Nuclear and Related Techniques*, 113-131. Springer, Nature.

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