Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2022.28901

274 (2022) 140–149
October

Demarcation of non-carcinogenic risk zones based on the intake of contaminated groundwater in an industrial area of southern India using geospatial technique

Govindaraj Venkatesan[a*], Joyal Isac Sankar[b], Jerome Nithin Gladson Gnanamanickkam[c], Amala S[d]

[a]*Department of Civil Engineering, Saveetha Engineering College, Chennai-602 105, Tamil Nadu, India, Tel. +91-9789290995; email: peccivilvenkat@gmail.com; ORCID: https://orcid.org/0000-0001-8506-6479*
[b]*Department of Electrical and Electronics Engineering, Saveetha Engineering College, Chennai-602 105, Tamil Nadu, India, Tel. +91-9965882354; email: joyalisac@saveetha.ac.in; ORCID: https://orcid.org/0000-0002-8611-1865*
cDepartment of Mechanical Engineering, Saveetha Engineering College, Chennai-602 105, Tamil Nadu, India, Tel. +91-7708940279; email: jeromenithingladson@saveetha.ac.in
dDepartment of Geology, College of Engineering, Guindy, Anna University, Chennai-600 025, Tamil Nadu, India, Tel. +91-6379118716; email: gvenkatesan@saveetha.ac.in

Received 27 February 2022; Accepted 30 August 2022

ABSTRACT

Using geospatial approaches, this study aims to delineate the non-carcinogenic risk zones based on the consumption of contaminated groundwater in the Vaniyambadi region of northern Tamil Nadu. The availability of water is key to the sustainability of societies and to the quality of life. When it comes to groundwater, quantity and quality are both crucial. More health concerns are associated with drinking polluted water. The use of pesticides, fertilizers, wastewater discharge, and industrial effluents can all contaminate water sources. Twenty groundwater samples were taken in order to comprehend and examine the physicochemical parameters as well as to determine the amount of nitrate in the groundwater and how it affects people's health. The piper trilinear diagram makes it clear that SO_4 or Cl predominates in the samples, indicating that all of the samples come into the "strong acids exceed weak acids" category. It is mostly explained by the existence of industries and agricultural activities. To determine several thematic maps and determine the groundwater quality, the Inverse Distance Weighted (IDW) method, an interpolation method in ArcGIS, is employed. According to research on the general quality of groundwater, the water in the study region indicates that it should not be used directly for consumption and that no effective irrigation can be done with it unless salt-tolerant crops are grown. Hazard quotients (HQ) were used as a criterion for evaluating non-carcinogenic risks in both adults and children. The findings suggest that everyone is at danger from nitrate ingestion regardless of age oral consumption of groundwater high in nitrates About 82% of children, 73% of women, and 55% of men are at risk for health problems. For all groups, the health risks associated with nitrate absorption through skin are essentially nonexistent.

Keywords: Groundwater; Industrial area; Non-carcinogenic risk; Geospatial techniques; Northern Tamil Nadu, India

*Corresponding author

This article was originally published with errors in the name of the corresponding author and affiliations. This version has been updated. Please see Corrigendum in vol. 277 (2002) 317 (doi: 10.5004/dwt.2022.29013

1. Introduction

Groundwater supply must be safeguarded because humankind's sustainability and survival are largely dependent on water. Power generation, agricultural productivity, environmental purity, and industrial expansion are some of the natural and human-made processes that rely on water availability. Scientists prioritise access to fresh water and the prevention of contamination in this time of water scarcity and pollution. The earth's widely accessible natural resource, groundwater, has been used as a result of the massive population growth, industry diversification, and industry diversification. More than 3 d without water are not enough for humans to survive [1]. Therefore, groundwater is the liquid that fills the crevices and voids in soil, sand, and rock that are in the saturated zones under the land surface. One of the things required for human survival is it [2]. Percolating water enters the aquifer, where it is held and travels slowly through geological strata [3]. One of the most serious environmental problems of our century is the gradual decline in fresh water supply during the past few decades [4]. Due to increased industrialization, urbanisation, population growth, and overuse of groundwater resources, water management and conservation have become increasingly difficult [5]. The discharge of agricultural, domestic, and industrial waste to the resource, land use patterns, geological formation, rainfall patterns, and infiltration rate are all factors that affect groundwater quality. Groundwater contains a higher proportion of dissolved constituents than surface water because it interacts with different minerals in the geologic strata on a more frequent basis [6]. Water-borne diseases continue to be a major concern in India, with a large population affected by either infectious or chemical water-borne diseases [42].

By assessing both the daily water consumption rate and the hazard factor of the specific pollutants, human health risk can be evaluated [43,44]. All around India, studies on the evaluation of fluoride and nitrate risks and the effects on human health have been done [6–10] The tanning business is one of India's oldest sectors [11,12]. Large commercial tanneries were established when tanneries proliferated in response to the rising demand for leather and leather items. In addition to using a lot of water during production, the tanning industry is a major producer of both tanned and untanned solid waste as well as liquid effluents [13,14]. The main goals were to create a database of the Vaniyambadi area by preparing various thematic maps, to assess lulc changes over a ten-year period (2008–2018), to demarcate favorable groundwater quality domains for drinking and agricultural practices using geospatial techniques, and to evaluate the human health risks associated with nitrate contamination in groundwater.

2. Experimental section

2.1. Study area

The research area (Fig. 1) is in South India, in the Tamil Nadu state's northern region, northeast of the Tirupattur district. The research area also includes the town of Vaniyambadi. The population of the Vaniyambadi Municipality is 95,061. To define the study area, Survey of India toposheet 57L/10 (SOI 2011) was used. It has an area of 24 km^2 and is bordered by latitudes 12°40′14.7″–12°42′50.1″ N and longitudes 78°34′57.9″–78°39′12.9″ E. This area is traversed by the Palar River, which runs from Kanakanachi in Andhra Pradesh to Tamil Nadu [15]. The elevation of the ground varies from 330 MSL to 414 MSL. Vaniyambadi's climate is classified as tropical by the

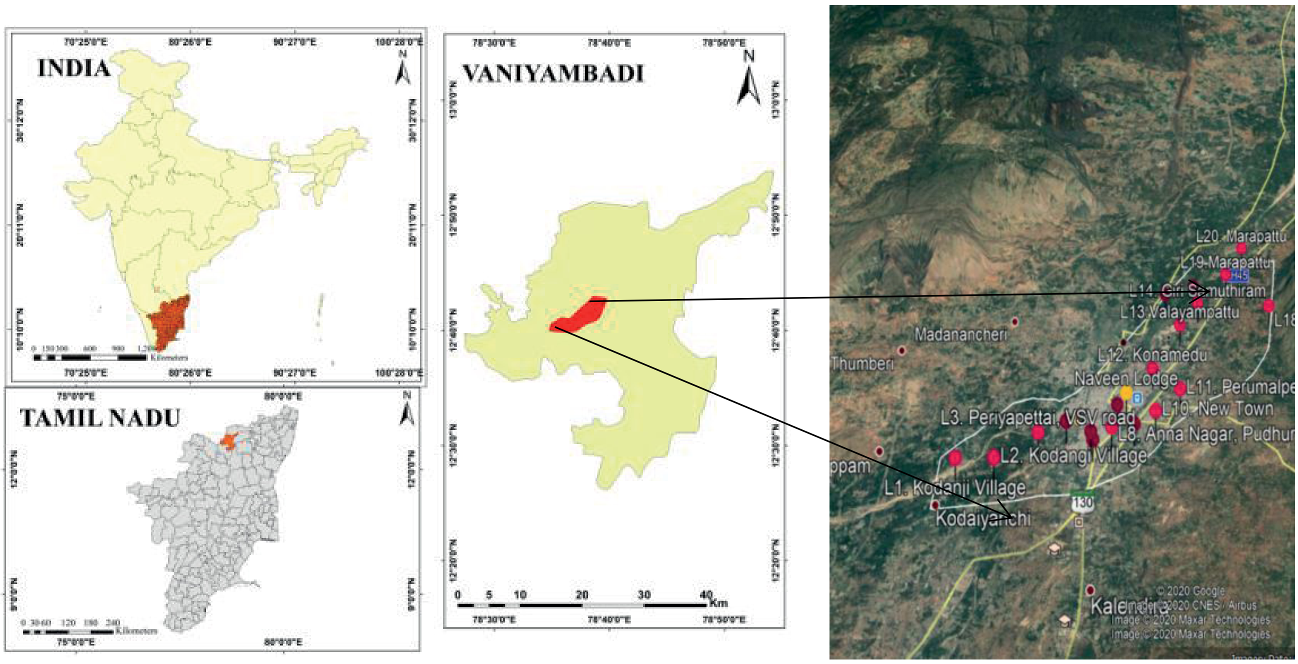

Fig. 1. Sample locations from study area.

Koppen–Geiger climate classification since summer precipitation is higher than winter precipitation. The summer season, with temperatures averaging over 35.5°C, runs from March 14 to May 28, and the winter season, with temperatures averaging below 30°C, runs from October 28 to January 19. 27.2°C is the average annual temperature [16]. The southwest (SW) and northeast (NE) monsoon seasons are when the study area experiences the majority of its rainfall [17,18]. Clay soil (ustifluvents), which predominates in this region along with red soil, makes up a significant component of the research area and is found over the flood plain of the Palar River (CGWB). The acid to intermediate charnockite of Archean age, pyroxene granulite and garnet gneiss, granite, and epidote hornblende gneiss are the main rock types discovered. There is virtually little Archean charnockite outcrop in the research region.

2.2. Need for the study

Vaniyambadi is one of the major industrial area and the people living in this region mainly depend on groundwater for their needs. Surface water, groundwater, and soil are highly polluted due to industrial effluents. As per WHO standards 45 g/L is the permissible limit of nitrate for human intake. The excess of nitrate in drinking water causes many health problems in adults as well as in children. In children, it may cause the blue baby disorder which is caused by the reduction of oxygen in the blood of babies.

3. Materials and methods

3.1. Sample collection and analysis

A total of 20 samples were taken at random during the month of January 2020 from wells that were mostly used for drinking, farming, and domestic purposes. From Kodaiyanchi (12°40′14.7″ N – 78°34′57.9″ E) to Marapattu (12°42′50.1″ N – 78°39′12.9″ E), water samples were taken. Using the portable GPS device, the Longitude and Latitude (GPS) coordinates of each sampling well were recorded. Clean 1 L polythene bottles with an acid wash before being rinsed twice with an environmental sample were used to collect and store the samples. The indicators of water quality were examined in accordance with the American Public Health Association's guidelines (APHA, 2005). The results of the physicochemical parameters of groundwater samples are displayed in Table 1. HANNA EC/TDS metre used to measure EC, TDS, and salinity; portable water quality kit used to detect pH. The presence of Ca^{2+}, Mg^{2+}, Cl^{-}, CO_3^{2-}, and HCO_3^{-} was examined using the titration method, whilst the presence of Na^{+} and K^{+} was determined using a flame photometer. A UV spectrophotometer was used to analyse SO_4^{2-}, NO_3^{-}, and F^{-}. Piper's trilinear diagram is plotted using AquaChem software using main cations and anions.

3.2. Ionic balance error

The total quantity of the major cations must be comparable to or below 10% of the total amount of the major anions in order for the chemical analysis of each groundwater sample to be accurate. Eq. (1) can be used to determine the ion balance error (IBE).

Table 2
Quality of irrigation water based on electrical conductivity

Electrical conductivity (μS/cm)	Water class	Percentage of samples (%)
<250	Excellent	Nil
250–750	Good	Nil
750–2,000	Permissible	30%
2,000–3,000	Doubtful	25%
>3,000	Unsuitable	45%

$$\text{IBE} = \frac{\left(\sum \gamma^C - \sum \gamma^A\right)}{\left(\sum \gamma^C + \sum \gamma^A\right)} \quad (1)$$

where γ^C γ^A are indicating the total cations and anions concentration expressed in meq/L. The computed ion-balance error (IBE) indicates that all the samples are within the limit of ±10%.

3.3. Groundwater quality evaluation

The groundwater resources are continuously exploited and contaminated due to overpopulation and industrialization. Less availability of good quality water tends people to take polluted water. The assessment of groundwater quality is crucial for home, industrial, and agricultural uses since groundwater is essential for the entire population. Drinking-water quality guidelines are chiefly for the protection of public health. Both qualitative and quantitative evaluations are essential to control the water quality from different sources of supply [19–21]. Drinking water quality was analyzed from physicochemical parameters like TDS pH and using a piper tri-linear diagram also. The four primary parameters for assessing the quality of water for irrigation are residual sodium carbonates (RSC), sodium hazard (sodium adsorption ratio-SAR), water salinity (EC), and permeability index (PI). Based on these numbers, diagrams like the USSL diagram and Wilcox Diagram can be produced and studied. Eqs. (2)–(5) are used to determine the SAR, Na%, RSC, and PI.

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

$$\text{Na\%} = \frac{\left(\text{Na}^+ + K^+\right)\times 100}{\text{Ca}^{2+}+\text{Mg}^{2+}+\text{Na}^+ + K^+} \quad (3)$$

$$\text{RSC} = \left(\text{HCO}_3^- = +\text{CO}_3^{2-}\right) - \left(\text{Ca}^{2+}+\text{Mg}^{2+}\right) \quad (4)$$

$$\text{PI} = \frac{\text{Na}^+ + \sqrt{\text{HCO}_3^-}}{\text{Ca}^{2+}+\text{Mg}^{2+}\text{Na}^+}\times 100 \quad (5)$$

Table 1
Analytical results of physicochemical parameters of groundwater samples

Sample number	Longitude (°)	Latitude (°)	Elevation (m)	Source of water	TDS	pH	Calcium (Ca^{2+})	Magnesium (Mg^{2+})	Sodium (Na^{+})	Potassium (K^{+})	Nitrate (NO_3^-)	Chloride (Cl^-)	Sulphate (SO_4^{2-})	Fluoride (F^-)	TH	SAR	PS	RSC	PI
Location 1	78.58275	12.67075	351	Bore well	941	5.86	120	58	367	26	45	390	125	0.1	542	9.7	60.5	6.7	118.6
Location 2	78.59044	12.66942	354	Dug well	1,650	5.8	161	57	462	12	68	491	192	0	640	11.2	61.4	10.3	98.3
Location 3	78.59964	12.67314	344	Bore well	1,820	6.91	326	146	441	19	82	1,941	396	0.2	1,423	7.2	40.9	21.1	84.8
Location 4	78.60558	12.67442	340	Bore well	909	7.2	66	46	192	37	71	241	512	0.2	357	6.3	56.6	–0.2	191.0
Location 5	78.61042	12.67144	340	Bore well	896	5.9	382	61	273	7	17	1,262	286	0.1	1,209	4.8	33.3	20.1	76.8
Location 6	78.61669	12.67644	342	Bore well	2,210	6.29	132	94	272	12	92	396	154	0.1	722	6.2	45.7	11.2	98.9
Location 7	78.61064	12.66958	361	Bore well	564	2.64	186	124	320	6	18	1,126	276	0.1	981	6.3	41.7	15.5	88.6
Location 8	78.61483	12.67158	352	Bore well	820	5.45	140	29	149	44	95	425	220	0.1	471	4.2	44.7	7.0	117.8
Location 9	78.61961	12.67133	356	Dug well	1,730	5.2	190	59	452	18	63	496	237	0.2	721	10.4	58.3	12.0	93.6
Location 10	78.6245	12.67331	347	Bore well	3,620	6.11	272	152	226	21	57	1,862	374	0.2	1,313	3.8	28.3	19.7	82.6
Location 11	78.64061	12.67736	353	Bore well	1,550	7.1	74	94	282	57	70	275	496	0.1	577	7.2	54.3	8.3	111.0
Location 12	78.65964	12.68314	355	Bore well	1,560	4.8	151	56	464	11	69	492	182	0	650	12.2	60.4	11.3	99.3
Location 13	78.66558	12.68442	347	Bore well	1,730	7.91	337	155	432	18	72	1,831	386	0.1	1,533	6.2	41.9	19.1	73.8
Location 14	78.67042	12.69144	346	Bore well	907	8.2	76	66	182	47	81	251	521	0.1	367	5.3	46.6	0.1	181.0
Location 15	78.68669	12.69644	343	Bore well	886	4.9	372	51	282	8	19	1,382	276	0.2	1,129	3.8	34.3	19.1	68.8
Location 16	78.69064	12.70958	345	Dug well	2,190	6.39	142	84	281	14	89	402	134	0.2	718	6.4	47.7	12.2	97.9
Location 17	78.70483	12.71158	362	Bore well	554	2.57	172	132	318	7	19	1,086	268	0.2	971	6.1	44.7	14.5	82.6
Location 18	78.71961	12.71133	353	Dug well	920	5.55	120	19	139	34	55	435	210	0.2	461	4.3	43.7	7.0	127.8
Location 19	78.7245	12.71331	358	Dug well	1,810	6.2	180	69	122	19	53	486	247	0.3	731	11.4	59.3	13.0	91.6
Location 20	78.7345	12.72331	349	Dug well	3,710	6.21	282	162	236	11	67	1,762	364	0.1	1,213	2.8	27.3	18.7	83.6

3.4. Health risk assessment

The three most prevalent ways that humans are exposed to trace metals are through the mouth and nose, skin absorption, and direct ingestion. These are ingested by drinking water that contains them, and they are absorbed through the skin [22,23]. According to the USEPA, risk assessments for both children's and adults' health were conducted in four stages: (i) risk recognition, (ii) dose evaluation, (iii) estimation of exposure, and (iv) hazard depiction [24]. Since nitrate is declared as non-carcinogenic pollutants by USEPA (2014) importance is given.

In the present study, health risk evaluation was done among children and adults for nitrate in groundwater based on consumption of drinking water. The hazard quotient for both dermal contact and oral intake was calculated. The average regular dosage (ADD) through oral intake in children and adults from groundwater sources were calculated using Eq. (6) [25].

$$ADD_{oral} = \frac{(CPW \times IR \times ED \times EF)}{(ABW \times AET)} \quad (6)$$

In the equation above, the average regular dosage (ADD) represents the consumption rate of nitrate (mg/kg/d), the concentration of pollutants in the groundwater (mg/L), the exposure duration (ED) in years, the exposure frequency (d/y), the intake rate (IR) in L/d, the mean average weight of the human body (ABW) in kg, and the mean exposure time (AET) in years, which is equivalent to the expected lifespan of a person 365 d/y are used as the conversion factor in computations. For calculations, as per USEPA water usage by adults (both men and women) is taken as 2.5 L/d, and by children is 0.9 L/d (WHO 2017; USEPA 2014). The period of exposure for men, women, and children is taken as 64, 67 and 12 y respectively (Narsimha and Rajitha 2018). AET values were taken as 23,360, 24,455, and 4,380 for men, women, and children correspondingly. Average weight (ABW) is taken as 64, 67, and 15 kg for men, women, children appropriately.

The average dosage for dermal (DAD) absorption of nitrate containing water by children and adults from groundwater sources was calculated using Eq. (7).

$$DAD = \frac{(TC \times Ki \times EV \times EF \times ED \times SSA \times CF)}{(ABW \times AET)} \quad (7)$$

Here DAD is the average dermally absorbed dose (mg/kg d); TC is the contact duration which is 0.4 h/d for all categories. Ki is the dermal adsorption parameters taken as 0.001 cm/h, EV is the bathing frequency (times/d) considered as once in a day [26,27]. Skin surface area (SSA) is taken as 16,600 cm^2 for adults and 12,000 cm^2 for children, correspondingly. CF is the unit conversion factor [28]; EF is the exposure frequency (d/y) which is 365 d/y. The exposure duration ED is considered as 64 and 67 y for men and women, and 12 y for children [29]. ABW is taken as 65 kg for men, 55 kg for women, and 15 kg for children, respectively. AET values were taken as 23,360, 24,455, and 4,380 for men, women and children correspondingly.

The reference value indicates the dosage of non-carcinogenic dangers in humans. The exposure of contaminants surpassing this value results in toxic effects. It is indicated as hazard quotient (HQ), which is calculated using Eq. (8):

$$HQ = \frac{ADD_{oral}}{RfD} \text{ and } HQ = \frac{DAD_{derm}}{RfD} \quad (8)$$

where the oral exposure reference dosage is signified by RfD which is 1.6 mg/kg/d for NO_3^- while for F^- it is 0.04 mg/kg/d [30]. The hazard quotient (HQ) was computed for all groundwater samples for the age groups 'children' and 'adults' (both men and women). Eventually, the safe ($HQ < 1$) and risk ($HQ > 1$) samples were identified based on the HQ values.

The numbers for the aforementioned computations must be depending on the study region because these parameters won't be the same for all areas [31,32].

3.5. Spatial analysis

One of the key tools for determining various parameters using spatial distribution maps is the geographic information system, or GIS [33,34]. ArcGIS version 10.2.1 software was used to generate different thematic maps, such as spatial variations of physicochemical parameters, using an interpolation method namely Inverse Distance Weighted (IDW).

4. Results and discussion

4.1. Hydrogeochemical facies

In this study, the term "hydrochemical facies" is used to describe the chemical characteristics of ground-water solutions that occur in hydrologic systems. The response of chemical activities taking place inside the lithologic framework, as well as the water flow pattern, are reflected in the facies. Trilinear diagrams, isometric fence diagrams, and maps that display the chemical isopleths inside particular formations all display the distribution of these facies. The presence of different facies within a single formation or a collection of formations with similar mineral composition suggests that the distribution of the facies is altered by ground-water flow through the aquifer system. The hydro-geochemical facies is inferred from the piper trilinear diagram. chemical relationships of groundwater can be accurately understood from the diagram [35]. The piper diagram consists of two triangles each for cations and anions in meq/L. The diamond-shaped field indicates the combined single point of cations and anion fields and inference is made on the hydro-geochemical facies concept (Fig. 2). The whole field has 100 parts, with the vertical representing 100. In the lower-left, cations (Ca^{2+}, Mg^{2+}, Na^+, K^+) are plotted as a single point. Similarly, the anion group (CO_3^{2-} + HCO_3^- and Cl^-), are plotted in the lower right trilinear field. These plots denote relative dissolved concentrations of constituents in groundwater. A point is formed by the intersection of lines projected from the cation and anion facies. This implies the central diamond-shaped fields which indicate the overall chemical character of groundwater. The plotting of the cation and anions indicates the relative concentrations of the constituents in the groundwater but not the absolute concentration. Hydrochemical facies can be classified based on dominant ions in the facies through this trilinear diagram [36]. Samples are categorized based on their position in the trilinear piper diagram. Based on the ion concentrations the sample plots in various facies on the piper trilinear diagram is furnished [35,36]. Based on the dominance of a particular ion the sample finds a spot in the anion and cation triangle (Fig. 2). The samples can be categorized into various types based on their position in the anion/cation triangle. Among the 11 representative samples collected, 45.45% of the samples are sodium–potassium type, 45.45% samples plots on the no dominant region, and the rest 9.1% found in the calcium type region of the cation triangle. In the anion triangle, 81.8% of samples find a spot in the chloride type region and the rest occupies in the non-dominant type. From the piper diagram it is visible that all the samples are under the 'strong acids exceed weak acids' division; this indicates that the samples are dominated with SO_4^{2-} or Cl^-. The presence of the tanning industry in the study area accounts for the above statement as strong acids are possible effluents from the tanning industry.

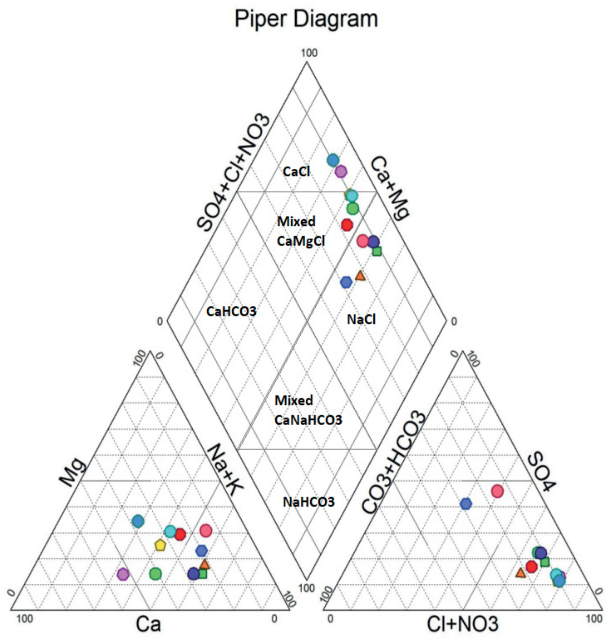

Fig. 2. Chemical facies of groundwater on Piper trilinear diagram.

4.2. Evaluation of water quality

4.2.1. Drinking water quality

pH is the measure of Hydrogen ion concentration which indicates the extent of acidity or alkalinity of a solvent. The normal range of pH in the surface water is between 6.5 and 8.5 while 6 to 8.5 for groundwater. In our collected samples, we can see that the pH values show a maximum of 8.02 and a minimum of 6.9 and 7.4 is the average pH value [45]. The pH values indicate that the water in the area is slightly alkaline in nature. The maximum permissible pH level for groundwater is 8.5 and here all the water samples are within the permissible limit. TDS is defined as the total solid materials dissolved in a solution which can be in the ionized state or non-ionized. TDS doesn't include the suspended colloids or dissolved gases. The type of water quality and salinity is indicated by the TDS. Thus, the standard of drinking water is determined from the quantity of TDS present. High TDS indicates that the water is highly mineralized, and this water is improper either for consumption or for industrial use. The concentration of TDS above 2,000 ppm produces laxative effects. TDS is classified into four categories. Freshwater which is having a value of less than 1,000 mg/L. Brackish water which is having a value between 1,000–10,000 mg/L, Saline water having TDS between 10,000–100,000 mg/L, and brine water with TDS greater than > 100,000 mg/L respectively. Groundwater in the study area represents freshwater and brackish water classification, sixteen out of twenty water sample TDS value exceeds 1,000 mg/L and less than 10,000 mg/L. Only four samples fall under the freshwater category. The increased amount of TDS indicates the increased amount of pollutants in it. The dominance of SO_4 or Cl may be due to the use of agricultural fertilizers, pesticides, and also the effluents from the tanning industry.

4.2.2. Suitability for irrigation

One of the main reasons for the presence of salts in irrigation water is the mineral weathering of rocks and minerals. Other secondary sources include atmospheric deposition of oceanic salts, salts in rainwater, and seawater intrusion into groundwater aquifers. Fertilizer chemicals, which reach water sources, may also affect the irrigation water quality.

4.2.3. Electrical conductivity

Salinity hazards in crops can be determined using electrical conductivity. The increased amount of salinity results in lowering of the osmotic activity of plants by interfering with the intake of water and nutrients from the soil [37]. Sixteen out of twenty samples go beyond the allowable limit for irrigation purposes [38]. Out of twenty water samples, none of them falls under the excellent or good categories which indicates that all the EC values are above 750 µS/cm (Table 2). This indicates that out of twenty samples, nine cannot be used for any kind of cultivation.

4.2.4. USSL diagram

The salt adsorption ratio (SAR), one of the irrigation water quality metrics, is primarily utilised in the management of sodium-affected soils. The suitability of water for agricultural activities can be inferred from the quantity of the primary alkaline and earth alkaline cations present. By analysing the pore water extracted from the soil, it was possible

Table 3
Hazard quotients (HQ) computed for children and adults (women and men) based on oral intake and dermal contact of nitrate in groundwater

Sample no.	NO_3 (mg/L)	HQ oral			HQ dermal		
		Children	Adult-Women	Adult-Men	Children	Adult-Women	Adult-Men
S1	45	1.69	0.94	0.70	9.00×10^{-3}	3.40×10^{-3}	2.87×10^{-3}
S2	68	2.55	1.42	1.06	1.36×10^{-2}	5.13×10^{-3}	4.34×10^{-3}
S3	82	3.08	1.71	1.28	1.64×10^{-2}	6.19×10^{-3}	5.24×10^{-3}
S4	71	2.66	1.48	1.11	1.42×10^{-2}	5.36×10^{-3}	4.53×10^{-3}
S5	17	0.64	0.35	0.27	3.40×10^{-3}	1.28×10^{-3}	1.09×10^{-3}
S6	92	3.45	1.92	1.44	1.84×10^{-2}	6.94×10^{-3}	5.87×10^{-3}
S7	18	0.68	0.38	0.28	3.60×10^{-3}	1.36×10^{-3}	1.15×10^{-3}
S8	95	3.56	1.98	1.48	1.90×10^{-2}	7.17×10^{-3}	6.07×10^{-3}
S9	63	2.36	1.31	0.98	1.26×10^{-2}	4.75×10^{-3}	4.02×10^{-3}
S10	57	2.14	1.19	0.89	$1.14{\times}10^{-2}$	4.30×10^{-3}	3.64×10^{-3}
S11	70	2.63	1.46	1.09	1.40×10^{-2}	5.28×10^{-3}	4.47×10^{-3}
Minimum	17	0.64	0.35	0.27	3.40×10^{-3}	1.28×10^{-3}	1.09×10^{-3}
Maximum	95	3.56	1.98	1.48	1.90×10^{-2}	7.17×10^{-3}	6.07×10^{-3}
THI		2.31	1.28	0.96	1.23×10^{-2}	4.65×10^{-3}	3.94×10^{-3}
%Affected		82%	73%	55%	0%	0%	0%

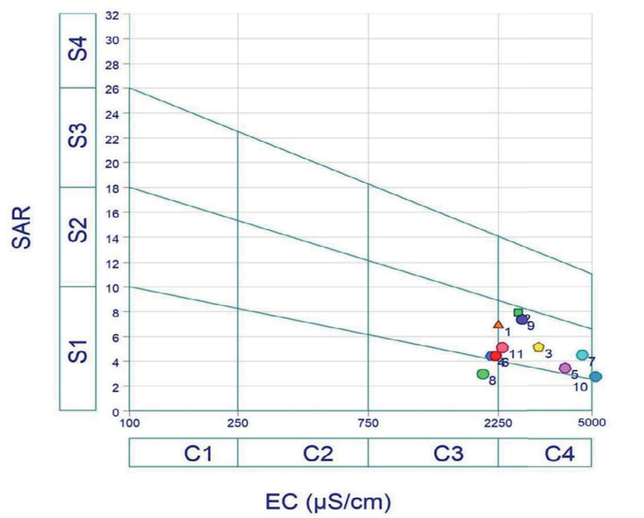

Fig. 3. Salinity and alkalinity hazard of irrigation water USSL diagram.

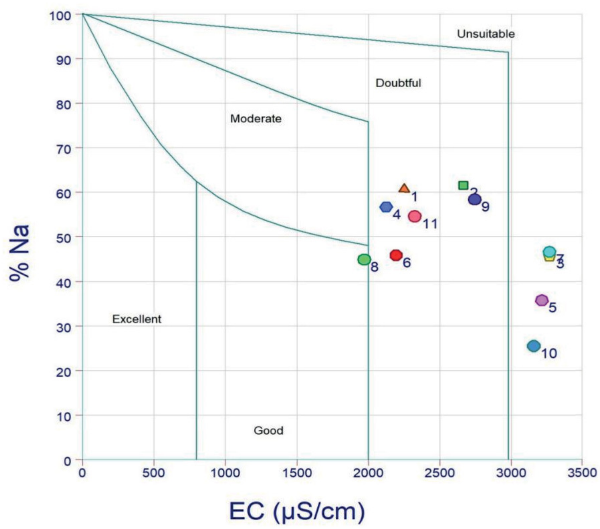

Fig. 4. Suitability of groundwater for irrigation in Wilcox diagram.

to determine the sodicity risk of the soil, another common diagnostic parameter. The USSL map (Fig. 3), Eq. (2) makes it clear that 72.72% of the samples fall in the C4-S2 zone, 18.18% of the samples fall in the C3-S2 region, and the remaining 9.1% of the samples plot in the C3-S1 region. The samples primarily fall into the C3 and C4 classes based on electrical conductivity. As a result, these samples are unsuitable for irrigation. Of the samples, remarkably high salinity water was identified in 72.72% of them. The groundwater can, however, be periodically used for irrigation if the following requirements are met: extremely porous soil; an area with appropriate drainage; a supply of irrigation water sufficient to induce leaching; and the presence of salt-tolerant crops. The remaining waters are discovered to be rather salty (C3). In places with inadequate drainage, the use of C3 type water is restricted. Even if the water is used in an area where there is good drainage and crops that can withstand salt, care should be taken to limit the salinity. The samples are determined to be of the S1 and S2 types based on the SAR results. S2 type water, or medium sodium water, makes up 90.9% of the sample. Under low leaching conditions, medium sodium water can result in a significant degree of sodium hazard if fine-textured soil has greater levels of cation exchangeability.

S2 type water can be used in locations with permeability and coarse-textured soil. For agricultural tasks, water with low sodium or S1 type water is recommended. It is best to stay away from utilising this water in areas with crops that are sensitive to sodium, though. It is wise to assume that more than 90% of the samples are unsuitable for irrigation based on the USSL diagram. If the water is treated to lessen the amount of salts and sodium present, they can be used for irrigation.

4.2.5. Sodium percentage (%Na)

The proportion of salt is a factor that determines whether groundwater is suitable for farming. In meq/L, the sodium percentage concentrations are given. Eq. (3) is utilised to determine it. Six of the samples that were taken fall into the category of being good to permitted for irrigation. Five samples that fall into the questionable category have sodium contents that are higher than 60% and cannot be used to grow all kinds of crops. When a higher sodium concentration is seen in irrigation, the clay particles have an opportunity to absorb the sodium ions and transfer the Mg and Ca ions. The process of Na in water being exchanged for Ca and Mg in soil reduces permeability, which leads to soil that drains poorly [38–41].

4.2.6. Wilcox diagram

Wilcox classified groundwater according to electrical conductivity and sodium content. According to the established criteria, the Wilcox diagram divides electrical conductance, which is shown in eqm as the abscissa, and sodium content, which is shown as ordinance, into zones that indicate good and unhealthy waters. Groundwater is broken down into several categories in the figure, including excellent to good, good to permissible, permissible to doubtful, doubtful to unsuitable, and inappropriate. The diagram indicates the pre-monsoon sodium % vs electrical conductivity values. Between 20% and 65% of sodium is present in samples, and electrical conductivity ranges from 2,000 to 3,500 s/cm. The samples placement in the Wilcox diagram can be used to determine whether or not they are suitable for irrigation (Fig. 4). We can see from the figure that 36.36% of the sample is unsuitable for irrigation. Wilcox figure indicates that 54.54% of the samples fall into the zone of uncertainty to inappropriateness. Only one sample is found to be suitable for irrigation, and even that sample is located extremely near the graph's dubious region. The graphic demonstrates that the water samples are not suitable for irrigation. This can be because of any contamination that might have happened as a result of the local enterprises.

4.2.7. Residual sodium carbonate

Residual sodium carbonate (RSC) is also used as a criterion to gauge irrigation water quality. Alkalinity risks in soil are indicated by residual sodium carbonate. The amount of carbonate and bicarbonate in groundwater that is greater than the total of calcium and magnesium is known as the residual sodium carbonate level. Eq. (4) is used to compute RSC. We may comprehend that the water in the study region is unsuitable for irrigation based on the RSC value. Only one of the eleven samples has a value below 1.25 meq/L, which allows it to be used directly for irrigation of all types of crops; the other ten samples all have values higher than 2.5 meq/L, which prevents them from being used for irrigation of any sort.

4.2.8. Permeability index (PI)

The appropriateness of irrigation water is also assessed using the permeability index as a criterion. Chemical traces in the soil that influence irrigation, such as salt, calcium, magnesium, and bicarbonate, might negatively impact soil permeability. Eq. (5) is used to calculate it, and the data are recorded in meq/L. To establish if the water is appropriate for irrigation, pl values are utilized. It is discovered to be over 60 meq/L, which indicates unsuitability. Its measurements fall between 76.8 and 119. Here, every sample is greater than 60 meq/L, demonstrating the unsuitability of the water in the research location.

4.3. Health risk assessment

Oral ingestion and skin exposure are the parameters used to assess the non-carcinogenic risk in both children and adults exposed to nitrate-rich groundwater (Table 3). Calculating the danger quotient was done. The total hazard index should be less than one, per USEPA recommendations. It signifies non-carcinogenic risk for human life once it surpasses. From the derived HQ values, safe and risk samples for children and adults were identified. Except for two samples, all of the oral consumption of nitrate-rich groundwater data indicate that more than one sample is in the risk zone for all other samples. For children, the minimal value is 0.64; for women and men, it is 0.35; and for both, it is 0.27. The outcome also demonstrates that all three categories are equally impacted by the consumption of nitrate-rich water. When children consume groundwater that is high in nitrates, 82% of children are impacted. Affected are 73% of women and 55% of men.

5. Conclusions

The results of the physicochemical investigation show that the water in the study area is fresh to brackish and very slightly alkaline. If the strong acids (Cl^- and SO_4^{2-}) in ground water samples outnumber the weak acids (HCO_3^- and CO_3^{2-}), this suggests that Cl^- or SO_4^{2-} is in charge. The majority of locations had nitrate concentrations higher than the legal limit for drinking, making it clear that the water cannot be directly consumed. No effective irrigation can be done with this water until and until they are salt-tolerant crops since the salinity hazard of the area is high to very high and also because the residual sodium carbonate, sodium%, and permeability index values are beyond the maximum permitted level.

Since the study area is well known for agricultural activities and industries, the involvement of pesticides, fertilizers, and industrial wastes can also cause changes in the concentration of ions. These variations in concentration of ions include magnesium, calcium, sodium, potassium, chlorine, and fluoride. They may be caused by geogenic and anthropogenic activities. The examination of land use and land cover shows that this area is becoming more urbanized. Over the past 10 years, there have been noticeable changes to the land. Settlements have grown while the amount of vegetation has significantly diminished.

Based on HQ measurements for both adults and children, the risk of non-carcinogenic effects was evaluated. That leads us to the conclusion that hazards are the same for everyone, regardless of age. Because oral ingestion of groundwater with a high nitrite level puts 82% of children, 73% of women, and 55% of men at danger. THI ranges from 0.64 to 3.56 for toddlers, 0.27 to 1.48 for adults (men), and 0.35 to 1.98 for adults (women). Constant consumption of nitrate-rich water may seriously harm children's health. For all groups, the health risks associated with nitrate absorption through skin are essentially nonexistent. With the exception of two samples, all other samples (>45 mg/L) exceed the permissible limit of nitrate intake. This could occur as a result of the use of herbicides and fertilizers in the area.

5.1. Recommendations

According to the health risk analysis study, skin contact poses no health risk, but drinking groundwater with a greater nitrate content poses a substantial risk to both children and adults' health. By establishing an artificial recharge structure, impurities like too much nitrate in groundwater can be reduced. Therefore, it is possible to advise the construction of artificial recharge. In order to prevent water and land contamination, all enterprises should use the zero-liquid discharge (ZLD) concept.

Author contributions

V.G. conceived, designed, conducted, analysis interpretation of data and drafted the manuscript.

J.S. conducted the literature search and drafted the manuscript. J.G. was involved in the analysis interpretation of data. A.S. data collections. All authors read and approved the final manuscript.

Conflict of interest

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

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envres.2021.111238.

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