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Assessing Seasonal Changes in Groundwater Quality in a South Indian Industrial Centre: A Geospatial Approach to Evaluate Drinking Water Safety and Health Risks

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Abstract: One of the largest industrial hubs in south India, Ranipet, has contaminated groundwater due to the discharge of waste from small-scale enterprises such as leather tanneries. This study collected groundwater samples throughout two distinct seasons in 2023 to assess the quality of 55 distinct open and tube wells for consumption and health risks. To determine if the groundwater samples were suitable for human consumption, we compared their physicochemical properties to worldwide drinking water standards (WHO). The majority of them were categorised as Ca-Cl and mixed Ca-Mg-Cl types by Piper's trilinear diagram. The spatial distributions of various groundwater quality characteristics were displayed through the use of inverse distance weighted (IDW) spatial interpolation. Indicating that the majority of the samples obtained during the rainfall seasons (NE monsoon: 82.8%; SW monsoon: 78.6%) were 'rich' for consumption were these criteria, which included the Water Quality Index (WQI). Nonetheless, 80–84.3% of the samples that were taken throughout the NE and SW monsoon rainfall seasons had "good" quality. By calculating the Hazard Quotient (HQ), we assessed the non-carcinogenic health concerns that adults and children might face from consuming the nitrate-rich groundwater. According to our findings, there was no evidence of a health risk for adults or children during either of the rainy seasons. During the rainy seasons, roughly 41–37% of the samples were harmful to children's health, while 19–21% were potentially harmful to adults.

Key words: GIS, health risk, water quality index, nitrate pollution.

Introduction

Groundwater is a crucial natural resource for agriculture, socioeconomic growth, and the supply of drinking water. It is an unquestionably unique resource for arid and semiarid areas. However, contamination of the groundwater is linked to about 80% of diseases in underdeveloped nations. Groundwater quality has been impacted by overexploitation for drinking and agriculture worldwide, and a variety of human activities have contaminated this resource (Aishwarya et al., 2023; Ahada and Suthar 2017; Anand et al., 2017). In many parts of India, particularly in regions with increased urban growth, groundwater contamination from various anthropogenic activities is readily apparent. The dumping of industrial and domestic effluents in unsightly locations due to population growth has increased the potential for hazardous water to seep into the groundwater system (Anand et al., 2019; Anandkumar et al., 2008; Annapoorna

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and Janardhanab, 2015). As a result, monitoring the suitability of groundwater for residential and agricultural uses requires the evaluation of its quality.

Necessity of the Study

The present study is imperative due to the pressing issue of groundwater contamination in Ranipet, a major industrial hub in south India, stemming from waste discharge, particularly from leather tanneries. The urgent need arises from the potential public health risks associated with consuming contaminated groundwater, which serves as a primary drinking water source for the local population. By conducting a thorough analysis of groundwater quality during two distinct seasons and comparing physicochemical properties with global drinking water standards, the study aims to provide insights into the extent of contamination and its implications for human health (Aravena et al., 1993). The incorporation of GIS technology enables a spatially informed assessment, crucial for identifying contamination hotspots and guiding targeted interventions. The utilization of the Water Quality Index and Hazard Quotient adds a comprehensive dimension, aiding in the communication of water quality and assessing health risks for specific demographics (Etier et al., 2020). Overall, the study addresses a critical need for informed decision-making, regulatory measures, and remediation strategies to safeguard both groundwater resources and public health in the region.

Experimental Section

Study Area

The research region is in Tamil Nadu, India's southwest corner of the Ranipet district. Figure 1 illustrates the 2234 km^2 that it covers. The principal towns in this area include Arakkonam, Arcot, Kalavai, Kaveripakkam, Palar, Panapakkam, Ranipet, Sholinghur, and Walajahpet. According to a census conducted on August 15, 2019, there are 288 significant settlements in the study area, with a total population of roughly 12,10,277. Tamil Nadu, a state in South India, contains the study area in its northern section. The research region is the Ranipet district of Tamil Nadu, which is located between latitudes 12° 35′ 00″ and 12° 55′ 00″N and longitudes 78° 30′ 00″ and 78° 50′ 00″E (Figure 1). There are

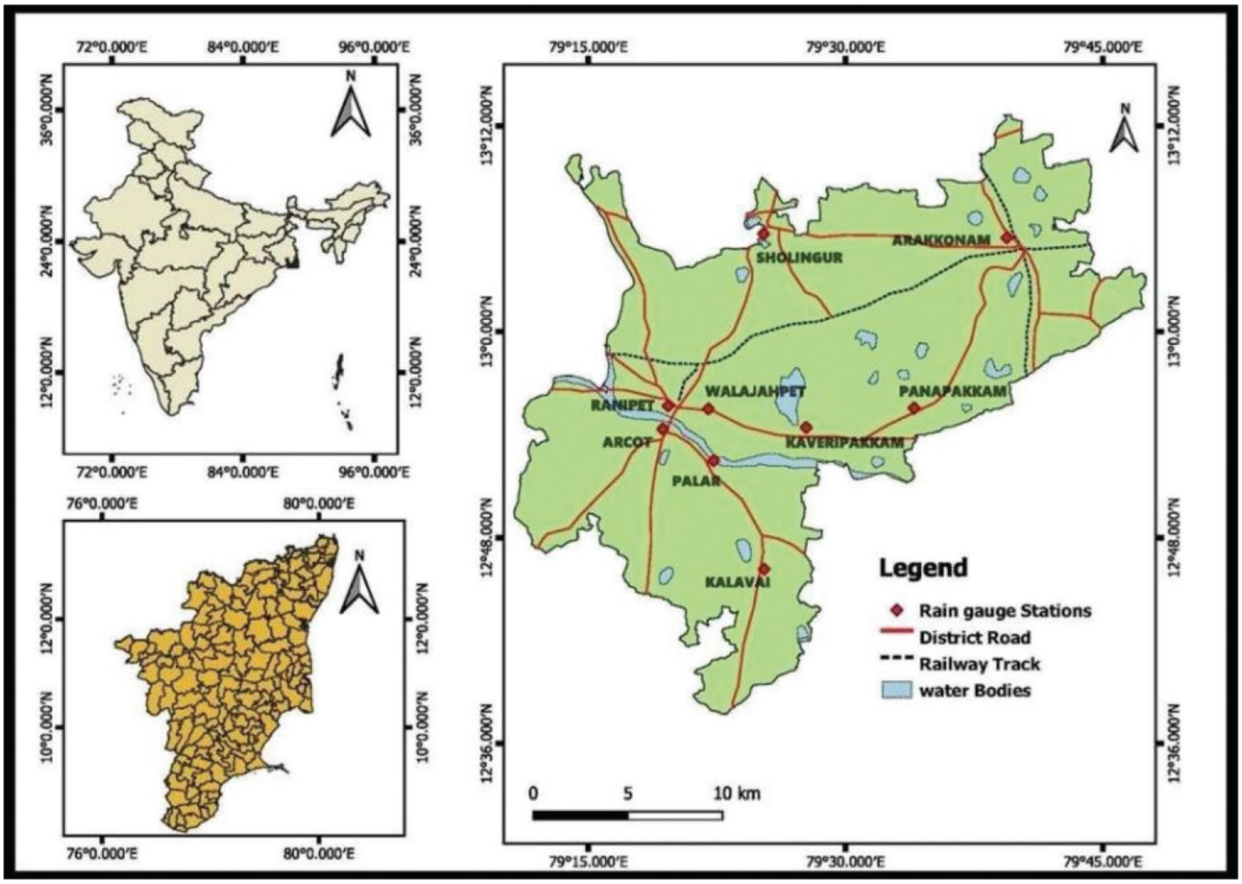

Figure 1: Study area map.

2234 km^2 in total geographical area. According to the 2011 Census, there are 288 significant communities in the study region with a total population of 1,210,277. This region experiences a tropical environment. The region has minimum and maximum temperatures of 26.3 °C and 38.5 °C, respectively, with an average annual temperature of 27.9 °C. December is the coldest month, with an average high temperature of 28.7 °C (82.9 °F) and a low temperature of 28.5 °C (66.6 °F). The Palar River, which flows into Tamil Nadu from Andhra Pradesh near the Kanakanachi Amman shrine, is the region's primary water source.

Groundwater Analysis

Groundwater analysis is the study of water that is kept below the surface of the Earth, mostly in aquifers. In order to analyse physical properties like temperature, colour, and turbidity, the procedure entails strategically placing wells for sample and monitoring (Govindaraj et al., 2022, 2023a). pH levels, dissolved oxygen, electrical conductivity, main ions (calcium, magnesium, sodium, chloride, sulphate, bicarbonate), trace elements (iron, manganese, arsenic, fluoride), and nutrients (nitrogen, phosphorus) are all included in the examination of chemical composition. Potential health risks associated with microbial contamination are closely examined. Isotope analysis offers light on the age and source of groundwater (Govindaraj et al., 2023a, 2023c). Furthermore, it is essential to comprehend recharge zones, groundwater flow, and the use of computer models in modelling.

Groundwater Potential Assessment

It has proven possible to identify groundwater potential zones by integrating thematic maps with GIS. It was possible to infer an aquifer's temporal change using remote sensing satellite imagery. To integrate all of the multidisciplinary data, subsurface lithological data from geo-electrical surveys and GIS have been employed (Kalpana et al., 2024; Karunanidhi et al., 2019).

Groundwater potential zones have been identified using the Digital Elevation Model (DEM). Granite and gneisses make up the hard rock formation that covers the North Pennar River basin in the Pavagadha taluk of Karnataka. This region experiences a shortage of water for drinking and irrigation. Topographic maps were used to create the DEM. In the end, three zones have been defined: extremely poor groundwater potential, decent to moderate groundwater potential, and very good to good groundwater potential.

Materials and Methods

Materials

The materials and methods section of this research study meticulously delineates the instruments, apparatus, and procedures utilized in the investigation. For the purpose of reproducibility and transparency, a comprehensive listing of materials is provided, including specific brands and sources. However, to better address the reviewer's concerns regarding groundwater contamination, particularly from small-scale enterprises such as leather tanneries in the Ranipet industrial hub, additional analysis and insights are warranted (Karunanidhi et al., 2020; Kavitha et al., 2023).

Specifically, an in-depth examination of the sources and mechanisms of groundwater contamination, with a focused lens on the operations of small-scale enterprises like leather tanneries, will be incorporated into this section. Table 1 depicts the nitrate dispersion in groundwater around the world. This analysis will delve into the various processes and activities associated with these enterprises that may contribute to groundwater pollution, such as the discharge of untreated effluents,

Table 1: Nitrate dispersion in groundwater around the world

Location (Country)	*Nitrate concentration (mg/L)*	*References*
Mithi sub-district, Thar Desert, Pakistan	3.4−1610	Soomro et al. (2017)
Roundhill Landfill Vicinity of South Africa	2−28	Nyika and Onyar (2019)
Central Arava Valley, Israel	7−273	Oren et al. (2003)
Lower Kelantan Basin, Kelantan, Malaysia	2−46	Sefie et al., (2015)
Central-Western Guanzhong Basin, China	0−90	Zhang et al., (2019)
Nakdong River Basin, Korea	0−383	Min et al. (2002)
Shanmuganadhi River basin, South India	0.1−160	Karunanidhi et al. (2019a, 2019b)
Nanganur County, South India	25−198	Adimalla et al. (2019)
Tirupur district, Tamil Nadu, India,	2−35	Duraisamy et al. (2018)

improper waste disposal practices, and potential leakage from storage facilities (Latha et al., 2023).

Methodology

Sample gathering and examination – We gathered groundwater samples from fifty-five distinct wells located throughout the research region. Samples were taken in two distinct seasons of a sample year (2023): September 2023 and June 2023. Each of them stood for the NE and SW monsoon seasons. The American Public Health Association's standard recommendations were followed for testing water quality parameters in a lab setting. The analytical methods are displayed in Table 2, and the physicochemical characteristics of groundwater samples collected are shown in Table 3.

Table 2: Methods utilised to determine physicochemical characteristics in groundwater samples from the research area (APHA, 2005)

Physicochemical parameters	*Methods*
EC, pH and TDS	Field water quality instrument
Na^+ and K^+	Flame Photometer
Ca^{2+} and Mg^{2+}	Titration using 0.05 N EDTA
Cl^-	Titration using 0.05 N $AgNO_3$
HCO^{3-} and CO_3^{2-}	Titration using 0.01 N H_2SO_4
NO^{3-}, SO_4^{2-} and F^-	Spectrophotometer

Water Quality Index

The Water Quality Index (WQI) was computed using the physicochemical parameters and the weighted arithmetic technique. Based on the qualitative value of each attribute for consumption, a weight (wi) (minimum of 2 and maximum of 5) was assigned to each. The following equation (1), =∑=Wiwnni1 (1), was used to determine the relative weight (Wi), where the parameter count is n.

In a similar manner, the concentration of a parameter (Ci) (mg/L) was divided with the WHO guideline for the same parameter (Si) (mg/L) to determine the quality rating scale qi for each parameter.= × ( )qCS 100Ultimately, the Water Quality Index was calculated by adding up all of the SIi using the following formulas: SI WQI SI = ∑ i (4) W ii qi = − (3). WQI is divided into five categories: excellent (WQI < 50), good (WQI > 50 and < 100), poor (WQI > 100 and < 200), extremely poor (WQI > 200 and < 300), and unsuitable (WQI > 300) for drinking.

Health Risk Assessment

In general, the health risk evaluation takes into account three primary pathways: oral consumption, skin absorption, and inhalation through the mouth and nose. The usual routes of exposure to water are oral intake and dermal absorption (Li and Qian, 2011; Manivannan et al., 2023). We evaluated the potential health risks

Table 3: Physicochemical characteristics of groundwater samples collected during four seasons in a year. The sample period (2023) was separated into seasons based on the winter and summer rainfalls in the research region

Parameters	*Not permissible limits WHO (2011) Standards*	*NE monsoon (November 2023)*		*SW monsoon (September 2023)*	
		No. of Samples Exceeding permissible Limits	*Percentage of samples Exceeding permissible Limits*	*No. of Samples Exceeding permissible Limits*	*Percentage of samples Exceeding permissible Limits*
TDS	1500 mg/L	9	16.4%	13	23.6%
pH	< 6.5 & > 8.5	6	10.9%	13	23.6%
Calcium (Ca^{2+})	200 mg/L	2	3.6%	10	18.2%
Magnesium (Mg^{2+})	150 mg/L	5	9.1%	7	12.72%
Sodium (Na^+)	200 mg/L	7	12.7%	11	20%
Potassium(K^+)	10 mg/L	6	10.9%	16	29.1%
Nitrate (NO_3^-)	45 mg/L	2	3.6%	19	34.5%
Chloride (Cl^-)	600 mg/L	9	16.34%	15	27.3%
Sulphate (SO_4^{2-})	400 mg/L	0	0%	3	5.5%
Fluoride (F^-)	1.5 mg/L	Ons	0%	0	0%

for both adults and children consuming nitrate-bearing groundwater at four different levels, in accordance with USEPA guidelines: (i) risk identification; (ii) dosage evaluation; (iii) exposure assessment; and (iv) hazard characterisation.

Result and Discussion

Hydrogeochemical Facies

The sequence of rainfall amounts during the various sampling seasons is as follows: NE monsoon > SW monsoon. The research area's rainfall periods are represented by the sampling seasons. The average depth of groundwater is 6.6 meters, with a maximum depth of 36.25 meters during rainy seasons and a low depth of 0.96 meters during non-rainy seasons (Tallapragada et al., 2023a, 2023b). According to the geographical disparity analysis, over all seasons, groundwater steadily rises in depth relative to ground level in the west. However, greater rainfall during the NE and SW monsoon seasons caused the groundwater to reach its maximum level in November. Piper (1944) used trilinear diagrams to categorise groundwater from four distinct seasons into distinct hydrogeochemical facies (Figure 2). Ca-Cl and mixed Ca-Mg-Cl facies were represented by the majority of the samples. A portion of these were the Na-Cl facies.4.2. Assessment of suitability for ingestion.

Consumption Aptness Assessment

Aptness Evaluation Utilising Outdoor Measurements of pH and TDS

The harmful health effects of drinking water with physicochemical properties over allowable limits are shown in Table 3. According to WHO recommendations, a pH of 6.5 to 8.5 is appropriate for drinking. The samples have the most ideal pH during the Northeast monsoon season over 1400 km^2 (83.5%), and over 54 km^2 (3.6%) they are not allowed. 158 km^2 (the

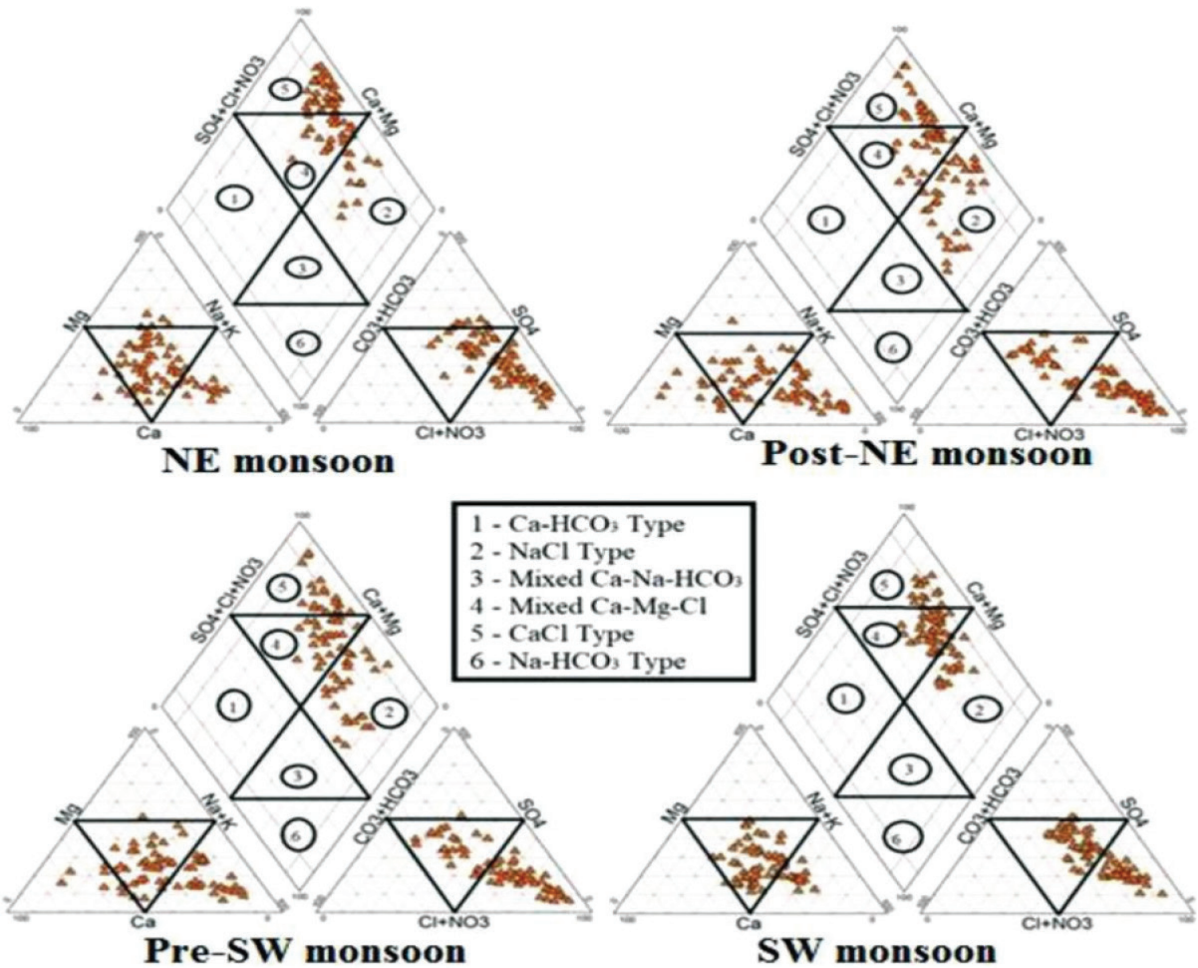

Figure 2: Piper trilinear graphs depict the hydrogeochemical facies of groundwater samples collected over four seasons.

SW monsoon) is off-limits to habitation during the other season (Venkatesan et al., 2022a, 2022b). The pH of these samples may have been decreased by less carbonates and bicarbonates in the groundwater. The SW monsoon season had superior groundwater quality than the NE monsoon season, according to TDS readings. In various seasons, 274 km^2 (17.6%, SW monsoon) and 205 km^2 (10.6%, NE monsoon) are covered (Figure 3). The number of samples within each TDS-based appropriateness class is displayed in Figure 4 and Table 4.

Major Cations based Aptness Evaluation

The samples that were taken from 1631 km^2 (91.6%) had the highest Na concentrations, and those from over 167 km^2 (13.4%) could not be consumed during the Northeast monsoon season. The samples taken from nearly the whole study area were deemed inadmissible during the NE monsoon (74.7%) and SW monsoon (75.7%) seasons based on the concentrations of K. Nonetheless, the majority of the samples from the NE monsoon season (82.6%) and the SW monsoon season (61.4%) were deemed acceptable. In 36.7% of samples

Table 4: The percentage of samples reflecting groundwater suitability classes based on TDS throughout different seasons over a year of sampling (2017-2018) in the research region

TDS (mg/L)	*NE monsoon (% Samples)*	*SW monsoon (% Samples)*
< 500 Most Desirable	0	0
500–1500 Maximum Allowable	82.4	78.4
> 1500 Not Permissible	17.6	21.6

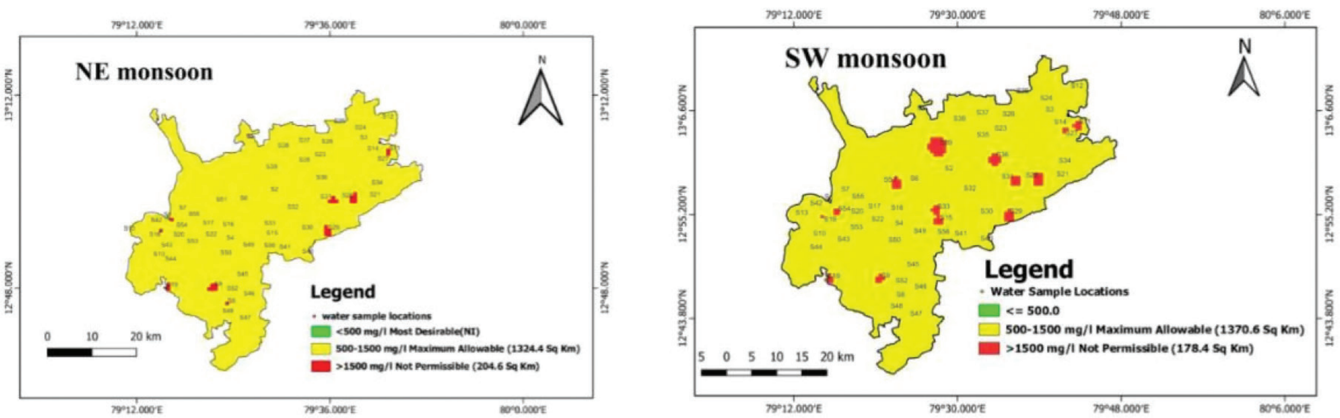

Figure 3: TDS-based groundwater quality classes of four different seasons over a year of monitoring (2023) in a South Indian industrial centre.

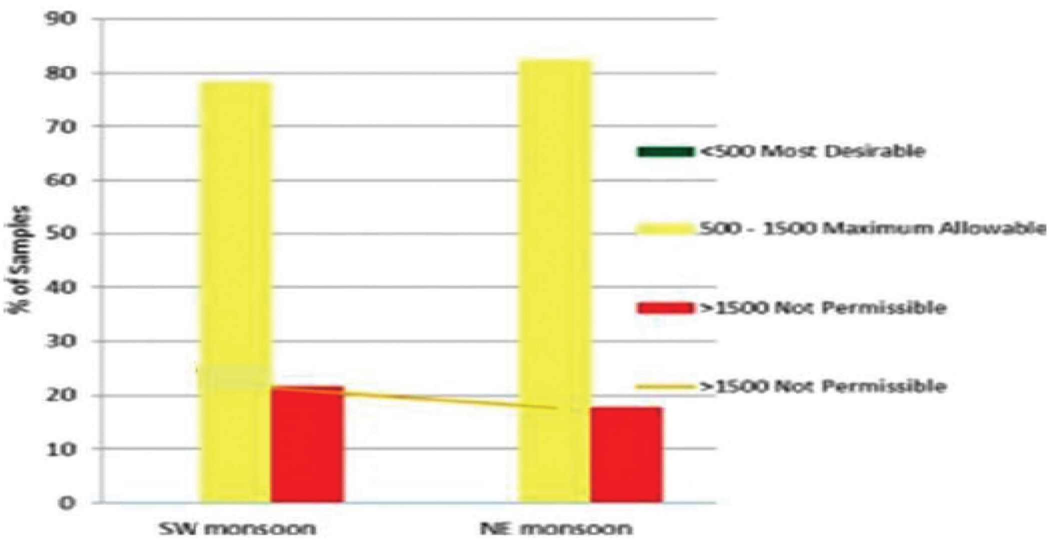

Figure 4: Groundwater samples (in percent) indicating TDS-based acceptability classes for consumption during different seasons over a year of sampling (2023) in an industrial centre of south India.

from the NE monsoon season and 41.3% from the SW monsoon season, the concentration of Ca was high (> 200 mg/L). Ca > 200 mg/L was found in fewer samples from the NE monsoon (16.7%) and SW monsoon (11.3%) seasons.

Major Anions based Aptness Evaluation

There were fewer samples with Ca > 200 mg/L from the NE monsoon (16.7%) and SW monsoon (11.3%) seasons. In comparison to Ca, Mg was lower in these groundwater samples. According to our findings, 212 km^2 (11.9%) of the SW monsoon season, 106 km^2 (5.1%) of the SW monsoon season, 38 km^2 (1.8%) of the NE monsoon season, and 14 km^2 (7.3%) of the NE monsoon season were not fit for human consumption. Figure 5 shows its regional distribution over four distinct seasons. Over a 34 km^2 (4.4%) area, it was within the maximum permissible limit (< 45 mg/L) during the NE monsoon season.

Water Quality Index (WQI)

WQI provided the suitability grades for the groundwater samples collected during four distinct seasons (Table 5). The 'excellent' category was not represented by any of the groundwater samples. According to our research, the quality of the groundwater declined during the rainy seasons. In the NE monsoon season, about 47.2% of samples (26 samples) fell into the "good" category, whereas 64% of samples (29 samples) fell into the "poor" category. Comparably, roughly 40% (22 samples) of the SW monsoon samples fell into the "good" category, and 60% (33 samples) fell into the "poor" category. The five WQI classes of samples are displayed in Figure 6 to help see the aptness distributions throughout the study area.

Health Risk Assessment

The process of evaluating the risk to human health involves identifying the type and severity of harmful consequences that may arise from exposure to hazardous materials in contaminated areas. Table 7 depicts the non-carcinogenic hazards from HQ consumption for children and adults found in groundwater samples from four distinct seasons collected over a year in the research region (2017-2018). Residents of the research region now use samples taken from wells for drinking and other household purposes. Table 6 depicts the hazard quotient (HQ) for children and adults in the research

Table 5: The number of samples in different WQI-based groundwater classes for consumption in four distinct seasons throughout a year of sampling (2023) in the research region

WQI range	*Drinking water quality classes*	*NE monsoon (November 2023)*		*SW monsoon (September 2023)*	
		No. of Samples	*% of samples*	*No. of Samples*	*% of Samples*
<50	Excellent	0	0	0	0
50-100	Good	21	38.1	18	32.7
100-200	Poor	34	61.58	37	67.2
200-300	Very Poor	0	0	0	0
>300	Unsuitable	0	0	0	0

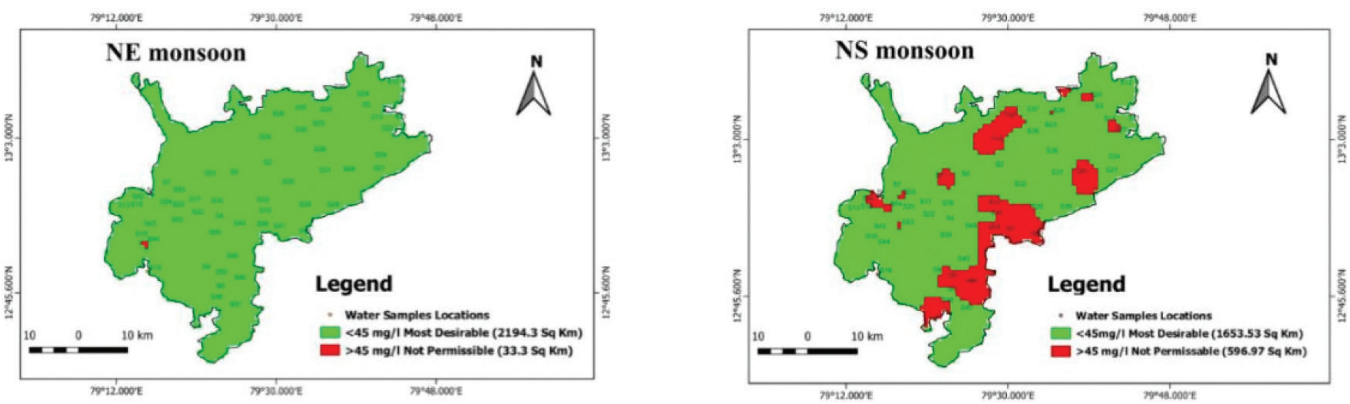

Figure 5: Spatial fluctuation of nitrate content in groundwater samples collected over different seasons during a year (2017-2018) in a south Indian industrial centre.

Table 6: The hazard quotient (HQ) for children and adults in the research region was calculated based on nitrate consumption via direct ingestion pathway throughout different seasons of the sample year (2023).

Sample ID & Age categories	*NE monsoon (November 2023)*		*SW monsoon (September2023)*	
	Children	*Adults*	*Children*	*Adults*
S1	0.00	0.00	0.00	0.00
S2	0.00	0.00	0.00	0.00
S3	0.00	0.00	0.02	0.04
S4	0.00	0.00	0.00	0.00
S5	0.00	0.00	0.00	0.00
S6	0.00	0.00	0.03	0.07
S7	0.00	0.00	0.00	0.00
S8	0.00	0.00	0.14	0.11
S9	0.00	0.00	0.01	0.00
S10	0.00	0.00	0.00	0.00
S11	0.00	0.00	0.14	0.11
S12	0.00	0.00	0.00	0.00
S13	0.00	0.00	0.00	0.00
S14	0.00	0.00	0.01	0.00
S15	0.00	0.00	0.00	0.00
S16	0.00	0.00	0.00	0.00
S17	0.00	0.00	0.00	0.00
S18	0.00	0.00	0.00	0.00
S19	0.00	0.00	0.17	0.13
S20	0.00	0.00	0.00	0.00
S21	0.00	0.00	0.00	0.00
S22	0.00	0.00	0.00	0.00
S23	0.00	0.00	0.16	0.12
S24	0.00	0.00	0.00	0.00
S25	0.00	0.00	0.00	0.00
S26	0.00	0.00	0.00	0.00
S27	0.00	0.00	0.00	0.00
S28	0.00	0.00	0.14	0.15
S29	0.00	0.00	0.00	0.00
S30	0.00	0.00	0.06	0.05
S31	0.00	0.00	0.00	0.00
S32	0.00	0.00	0.00	0.00
S33	0.00	0.00	0.00	0.00
S34	0.00	0.00	0.00	0.00
S35	0.00	0.00	0.16	0.13
S36	0.00	0.00	0.00	0.00
S37	0.00	0.00	0.00	0.00
S38	0.00	0.00	0.00	0.00
S39	0.00	0.00	0.00	0.00
S40	0.00	0.00	0.03	0.05
S41	0.00	0.00	0.00	0.00
S42	0.00	0.00	0.00	0.00
S43	0.00	0.00	0.02	0.03
S44	0.00	0.00	0.00	0.00
S45	0.00	0.00	0.01	0.00

S46	0.00	0.00	0.01	0.00
S47	0.00	0.00	0.00	0.00
S48	0.00	0.00	0.00	0.00
S49	0.00	0.00	0.01	0.03
S50	0.00	0.00	0.01	0.04
S51	0.00	0.00	0.00	0.00
S52	0.00	0.00	0.00	0.00
S53	0.00	0.00	0.00	0.00
S54	0.00	0.00	0.01	0.01
S55	0.00	0.00	0.00	0.00
Min	0.00	0.00	0.00	0.00

Table 7: Non-carcinogenic hazards from HQ consumption for children and adults were found in groundwater samples from four distinct seasons collected over a year in the research region (2017-2018)

HQ category for various age group	*NE monsoon (November 2023)*		*SW monsoon (September 2023)*	
	Children	*Adult*	*Children*	*Adult*
Safe NS<1 (PS)	70(100%)	70(100%)	70(100%)	70(100%)
Risk NS>1(PS)	0	0	0	0

region was calculated based on nitrate consumption via direct ingestion pathway throughout different seasons of the sample year (2023). Because of methemoglobinemia or blue baby syndrome, which can result in newborn death, nitrate in groundwater can be harmful to health (Venkatesan et al., 2023).

Conclusion

In an industrial hub of south India (Ranipet), the suitability of groundwater for human consumption was evaluated using physicochemical parameters of ground samples taken from 55 distinct wells throughout four distinct seasons (NE and SW monsoons) during the sampling year (2023). They proposed that the groundwater quality is impacted by rainfall during the NE and SW monsoon seasons. Ca-Cl and mixed Ca-Mg-Cl types were prevalent, according to the Piper trilinear diagrams, and some samples were associated with the Na-Cl facies. The improper groundwater samples based on TDS (number of SW monsoon season (n = 13) > NE monsoon season (n = 9)). During both of the non-rainfall seasons, concentrations of other main ions, including sodium, potassium, calcium, chloride, sulphate, and nitrate, were also higher above the maximum allowed levels (WHO) for consumption. None of the groundwater samples (all seasons combined) met the Water Quality Index

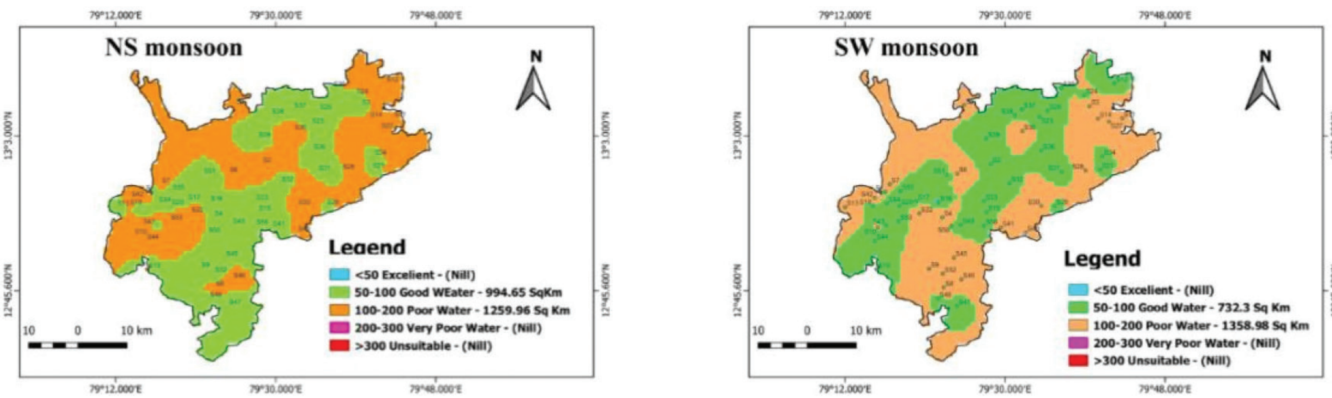

Figure 6: Geographical distribution of WQI based groundwater aptness classes for consumption during two seasons over industrial centre of South India.

(WQI)'s "excellent" criteria. The categories "very poor" and "unsuitable" were only observed in NE monsoon season samples. About 44.3% of samples from the NE monsoon season fell into the "good" category, and 55.7% fell into the "poor" category. Comparably, of all the samples collected during the SW monsoon season, about 40% fell into the "good" group and 60% into the "poor" category.

Recommendation Improve the Present Scenario

Our research revealed that drinking the nitrate-rich groundwater in the study area during the dry seasons poses health concerns to both adults and children. The primary reason for the absence of any health danger during both rainy seasons is the diluting of pollutant ions caused by the rainwater recharge.

It is also advisable to counsel the farmers in this area to apply fewer fertilizers containing nitrates, especially in the non-rainy seasons. The majority of studies on water quality are restricted to comparing results with WHO acceptable limit standards. However, incorporating health risk calculations utilizing approaches akin to our study for various age groups of individuals can aid in comprehending the detrimental impacts on health in various parts of the globe.

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Author Contributions

V G: Writing-original draft, conceptualization, investigation, resources, software and formal analysis, methodology and supervision, Data curation. J G: Writing-original draft, software and formal analysis. J S: Data collection and manuscript writing.

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.

References

Aishwarya Lakshmi, A., Amalraj, S. and G. Venkatesan (2023). Granules as precursors in the working of upflow anaerobic sludge blanket reactor: A review on the impacts of granulation. *Asian Journal of Water, Environment and Pollution*, **20(4):** 41-45.

Ahada, C.P.S. and S. Suthar (2017). Assessment of human health risk associated with high groundwater fluoride intake in southern districts of Punjab, India. *Expo Health*, **10(4):** 1-9. https://doi.org/10.1007/s12403-017-0268-4

Anand, B., Karunanidhi, D., Subramani, T., Srinivasamoorthy, K. and R.Y. Raneesh (2017). Prioritization of sub-watersheds based on quantitative morphometric analysis in lower Bhavani basin, Tamil Nadu, India using DEM and GIS techniques. *Arab. J. Geosci*., **10:** 552.

Anand, B., Karunanidhi, D., Subramani, T., Srinivasamoorthy, K. and M. Suresh (2019). Long-term trend detection and spatiotemporal analysis of groundwater levels using GIS techniques in Lower Bhavani River Basin, Tamil Nadu India. *Environ. Dev. Sustain*., **22:** 2779-2800. https://doi.org/10.1007/s10668-019-00318-3

Anandakumar, S., Subramani, T. and L. Elango (2008). Spatial variation and seasonal behavior of rainfall pattern in Lower Bhavani River basin, Tamil Nadu, India. *Ecoscan*, **2(1):** 17-24.

Annapoorna, H. and M.R. Janardhanab (2015). Assessment of groundwater quality for drinking purpose in rural areas surrounding a defunct copper mine. *Aquat. Procedia*, **4(1):** 1-22. https://doi.org/10.1016/j.aqpro.02.088.

Aravena, R., Evans, M.L. and J.A. Cherry (1993). Stable isotopes of oxygen and nitrogen in source identification of nitrate from septic systems. *Ground Water*, **31(2):** 180-186. https://doi.org/10.1111/j.1745-6584.1993.tb01809.x

Etier, I., Murugan, C.A., Kannan, N. and G. Venkatesan (2020). Measurement of secure power meter with smart IOT applications. *Journal of Green Engineering*, **10(12):** 12961-12972.

Govindaraj, V., Sankar, J.I., Gnanamanickkam, J.N.G. and S. Amala (2022). Demarcation of non-carcinogenic risk zones based on the intake of contaminated groundwater in an industrial area of southern India using geospatial techniques. *Desalination and Water Treatment*, **274:** 140-149.

Govindaraj, V., Murugan, K., Baskar, P. and J. Sathaiya (2023b). Treatment of dairy wastewater and sludge production using algae bio reactor. *Asian Journal of Water, Environment and Pollution*, **20(3):** 77-83.

Govindaraj, V., Manoharan, K., Sakthivel, S., Guruchandran, K. and W. Mathew (2023a). A combined approach for the treatment of textile dye bath effluent using CO_2 gas. *Asian Journal of Water, Environment and Pollution*, **20(2):** 59-65.

Govindaraj, V., Manokaran, K., Sathaiya, J. and P. Baskar (2023c). Environmentally-friendly bio-coagulants: A cost-effective solution for groundwater pollution treatment. *Asian Journal of Water, Environment and Pollution*, **20(3):** 19-28.

Kalpana, M., Venkatesan, G. and S. Padma (2024). Analysing the effectiveness of municipal wastewater sludge, bagasse ash, rice husk ash and plastic waste powder for manufacturing bricks. *Asian Journal of Water, Environment and Pollution*, **21(1):** 71-79.

Karunanidhi, D., Aravinthasamy, P., Subramani, T., Wu, J. and K. Srinivasamoorthy (2019). Potential health risk assessment for fluoride and nitrate contamination in hard rock aquifers of Shanmuganadhi River basin, South India. *Hum. Ecol. Risk Assess. Int. J.*, **25(1-2):** 250-270. https://doi.org/10.1080/10807039.2019.1568859.

Karunanidhi, D., Aravinthasamy, P., Kumar, D., Subramani, T. and P.D. Roy (2020). Sobol sensitivity approach for the appraisal of geomedical health risks associated with oral intake and dermal pathways of groundwater fluoride in a semi-arid region of south India. *Ecotoxicol. Environ. Saf.*, **194:** 110438. https://doi.org/10.1016/j.ecoenv.2020.110438

Kavitha, S., Kanchana, K. and G. Venkatesan (2023). Long range (LoRa) and alert network system for forest fire prediction. *Asian Journal of Water, Environment and Pollution*, **20(6):** 61-66.

Latha, A., Ganesan, R., Venkatesan, G. and P. Baraneedharan (2023). Removal of toxic heavy metal ion from tannery effluent by using *Fusarium subglutinans* and *Hylocereus undatus*. *Desalination and Water Treatment*, **312:** 70-78.

Li, P. and H. Qian (2011). Human health risk assessment for chemical pollutants in drinking water source in Shizuishan City, Northwest China. *Iran. J. Environ. Health Sci. Eng.*, **8(1):** 41-48.

Manivannan, H., Anguraj, B.L. and G. Venkatesan (2023). Hydrolysis of fruit waste to reduce sugars using sulphonated magnetic carbonaceous catalyst. *Asian Journal of Water, Environment and Pollution*, **20(6):** 45-51.

Tallapragada, V.V.S., Venkatesan, G., Manisha, G., Sivakumar, N., Kumar, A. and J. Karthika (2024). Multispectral image processing using ML-based classification approaches in satellite images. *In:* Artificial Intelligence, Blockchain, Computing and Security - Proceedings of the International Conference on Artificial Intelligence, Blockchain, Computing and Security, ICABCS 2023, **1:** 734-738.

Tallapragada, V.V.S., Chaudhary, S., Glory, J.S., Venkatesan, G., ...Maheswari, Kumar, B.U. and E. Rajesh (2024). Deep learning based approach for rice prediction from authenticated block chain mode. *In:* Artificial Intelligence, Blockchain, Computing and Security - Proceedings of the International Conference on Artificial Intelligence, Blockchain, Computing and Security, ICABCS 2023, **1:** 550-556.

Venkatesan, G. and T. Subramani (2022a). Groundwater potential mapping and natural remediation through artificial recharge structures in Vellore District, Tamil Nadu, India using geospatial techniques. *Desalination and Water Treatment*, **254:** 229-237. doi: 10.5004/dwt.2022.28351

Venkatesan, G., Arul Murugan, C., Isac, S.J. and N. Gladson (2022b). Experimental investigation on load carrying capacity of hollow and composite pile materials in layered soil. *Materials Today: Proceedings*, **65(9):** 3951-3958.

Venkatesan, G., Kuberan, M., Jegadeesh, S. and B.V. Praveen (2023). Carbon capture and storage with ionic liquids; Industrial flue gas trapping in calcination process. *Asian Journal of Water, Environment and Pollution*, **20(2):** 85-91. doi: 10:3233/AJW230028