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Comparative Analysis of Groundwater Quality Index for Bhavani River Basin Using Remote Sensing and Statistical Analysis

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ABSTRACT

This research was conducted to examine the drinking (WQI_1) and irrigation (WQI_2) water quality for the Bhavani river basin using statistical methodologies. The study area geographically covers up to 4207 km^2. For evaluating the Water Quality Index (WQI), fourteen groundwater parameters were employed and the data was gathered for two decades (1972–1990 & 2010–2019). The groundwater parameters include TDS, pH, EC, TH, Ca^{2+}, Mg^{2+}, Na^+, K^+, CO_3^{2-}, HCO_3^-, NO_3^-, Cl^-, F^- and SO_4^{2-}. The weightage arithmetic approach was utilized to compute the WQI_1 and all the parameters were spatially represented using Arc GIS 10.3 software. To compute the WQI_2, the Sodium Absorption Ratio (SAR), Sodium Percentage (%Na), Residual Sodium Carbonate (RSC), Magnesium Hazard Ratio (MHR), Kelly's Ratio (KR), Permeability Index (PI) and Potential Salinity (PI) are employed. The hydro-geochemical features are statistically examined using the Piper trilinear diagram, Gibbs plot, correlation matrix and PCA biplot. The study results suggest that irrigation-and drinking-water quality is worsening from 2% to 44% of the studied region. Statistical analysis also yields satisfactory findings for both decades. According to the geochemical study, the anion and cation ranking for the 1972 decade is $Mg^{2+} > Ca^+ > Na^+ > K^+ = Cl^- > HCO_3^- > CO_3^{2-} > SO_4^{2-}$, while the ranking for the 2019 decade is $Na^+ > Mg^{2+} > Ca^+ > K^+ = HCO_3^- > Cl^- > SO_4^{2-} > CO_3^{2-} > F^-$. The research indicates viable locations for drinking and irrigation reasons, while the low groundwater quality areas need effective treatment procedures before groundwater utilization.

KEYWORDS: Groundwater, Hydro-geochemistry, Remote sensing, Statistical analysis, Water quality index.

INTRODUCTION

One of the great advantages of groundwater is its capacity to replenish, yet it has a limited quantity of resources. Due to the expanding human population, agriculture sector, the rapid rise of industrialization and urbanization, the demand for groundwater is also increasing (Ram et al., 2021). Based on the above-mentioned parameters, groundwater drought conditions grow at the same time and groundwater contamination is also severely increasing (Lakshmi et al., 2021). The quality of groundwater was poisoned for a given period and it's quite difficult to reestablish the original quality (Gougazeh & Sharadqah, 2009; Malik & Bhagwat, 2021). So, the conservation of groundwater from incorrect discharge and other activities is particularly crucial for feature creation. For contemporary agriculture, tonnes of fertilizers, insecticides and herbicides are utilized by large-growing farmers (Gnanachandrasamy et al., 2020). The consumption of dirty water for drinking and agricultural purposes creates serious health hazards and production has been lowered owing to crop damage (Osta et al., 2022). Researchers and organizations employed the remote

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sensing and Geographical Information System (RS & GIS) technology for identifying prospective zones, water-quality mapping, recharge structures, mining sites, water disposal, … etc. (A et al., 2017; Sajil Kumar, 2020).

Previously, no spatial or analytical approaches were used in the irrigation- and drinking-water quality investigation of the Bhavani river basin. Furthermore, some researchers have used statistical and analytical methodologies to assess groundwater quality in various study regions across the world (Mondal, 2020; Saravanan et al., 2020; Verma et al., 2020). The goal of this study was to determine groundwater quality in the study region utilizing remote - sensing techniques and statistical approaches. This study's outcome includes irrigation- and drinking-water quality maps for effective irrigation and groundwater management.

Study Area Details

The Bhavani basin is geographically located from 11° 15′ to 11° 81′ N latitude and 77° 0′ to 78° 87′ E longitude, as given in Fig. 1. There are 26 rain-gauge stations located inside the basin and the annual average rainfall was 811 mm. The basin climate changes are mostly sub-tropical and the temperature ranges from 22ºC to 40º C (moderate zone). The Bhavani river basin covers both undulating and plain topography, starting from the western part of the basin to the eastern part. The western part of the basin has higher to lower elevations ranging from 2132 to 161 m (AMSL).

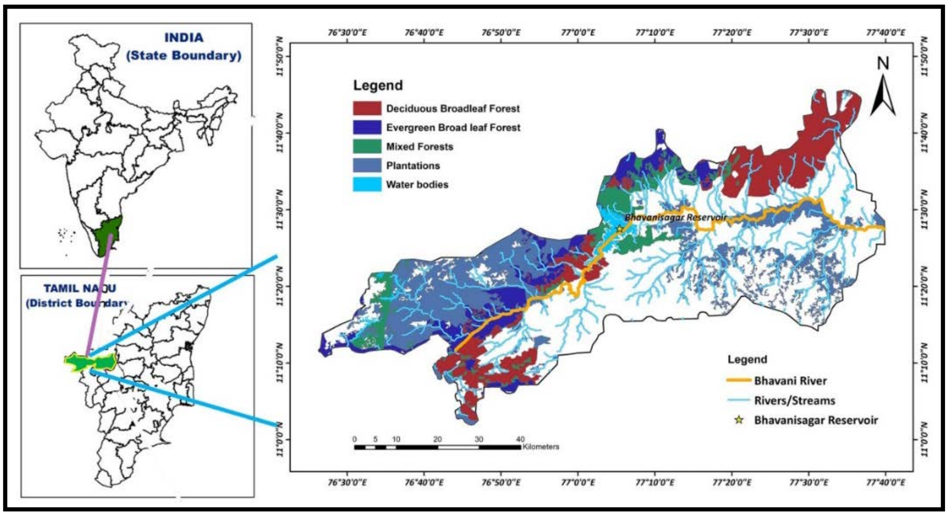

Figure (1): Spatial representation of the study area

Data Collection

The Survey of India (SOI) topo-maps (13 No's & 1:50,000) were identified inside the study area (58A/ (6, 7, 10, 11 to 15), 58 E/ (2, 3, 6 to 10)) & the boundaries of the study area were derived from the collected topo-sheets. From the observations, well-groundwater samples were collected for the years 1972-1990 (37 observation wells) and 2010-2019 (70 observation wells). The rainfall- (35 years), groundwater level- (42 years) and water-quality data - (14 parameters) for 36 years was collected from the State Ground and Surface Water Resources Data Centre, Chennai.

Methodology for WQI Mapping

For the identification of drinking- and irrigation-water quality in suitable places in the study area, the following methods are used. Direct field observation data, such as pH and EC, are observed in the field itself. The remaining parameters were calculated using the standard analytical procedure given by the American Public Health Association (APHA) (Eaton et al., 2017). For locating observation wells in the study area, handheld GPS (accuracy 5m) is used. The observed water-quality parameter was compared with the standard water quality guidelines given by the World Health Organization (WHO, 2017) and the Bureau of Indian Standards (BIS, 2012) (BIS, 2020), as given in Table 1. The groundwater geochemical and hydro-geochemical features were plotted using a piper trilinear diagram and Gibbs plot. Then, statistical analysis was carried out using PCA and correlation analysis. The piper trilinear diagram was developed using AquaChem

4.0 software and statistical analysis was conducted using SPSS software.

Table 1. The Bhavani river basin water-quality parameters compared with standards

Parameters	WHO (2017) *	BIS (2015) *	1972-1990				2011-2019			
			Min	Max	Mean	SD	Min	Max	Mean	SD
TDS (mg/l)	<1000	500-2000	211	1875.	708.39	401.7	206.00	2810.50	708.26	418.24
TH (mg/l)	<600	<200	118	895.01	365.33	174.2	116.55	899.60	299.72	133.10
pH (on scale)	6.5-8.5	6.5-8.5	7.42	8.52	8.17	0.28	7.45	8.60	8.23	0.21
EC (µS/cm)	<1400	750-3000	399	3580	1311.62	765.6	380.00	5197.50	1158.64	663.20
Ca^{2+} (mg/l)	100-300	75-200	27.96	177.91	55.69	27.54	6.00	106.00	35.70	18.25
Mg^{2+} (mg/l)	<50	30-100	9.63	148.42	54.89	28.70	13.92	154.18	51.14	23.88
Na^{+} (mg/l)	50-200	<200	15.17	498.52	115.03	93.62	12.50	616.00	116.28	83.81
K^{+} (mg/l)	<55	<10	0.00	97.48	9.94	15.97	0.10	97.33	21.08	19.75
CO_3^{-2} (mg/l)	<120	<250	0.96	49.60	20.64	9.73	0.00	36.00	10.27	9.82
HCO_3^{-} (mg/l)	<1000	<300	87.33	686.00	285.43	117.1	48.81	526.18	221.62	89.40
NO_3^{-} (mg/l)	<50	<45	4.00	48.07	20.27	12.44	0.10	58.71	17.29	11.39
Cl^{-} (mg/l)	<250	250-1000	18.88	460.81	152.81	122.8	40.40	1302.75	171.15	158.54
F^{-} (mg/l)	1-1.5	<1.5	nil	nil	nil	nil	0.05	2.56	0.70	0.42
SO_4^{2-} (mg/l)	<250	200-400	7.54	271.10	65.46	59.95	12.83	389.25	90.99	66.21

* The lower values indicate an acceptable limit and the higher values indicate the permissible limit.

Drinking-water Quality Index (WQI_1)

The World Health Organization (2017) gives standard guidelines for the identification of proper drinking-water quality. Horton and Brown (1972) developed a weighted arithmetic method for calculating the water-quality index. This method gives standard and accurate results for the given water-quality parameters. The following weighted arithmetic method, Eqn. 1, was used to calculate the WQI (Roy et al., 2020; Chakraborty et al., 2022).

$$(WQI)_1=\frac{\sum_{a=1}^{n} \mathrm{Q_a W_a}}{\sum_{a=1}^{n} \mathrm{W_a}} \quad (1)$$

where, n = no. of water-quality parameters, W_a = unit weight of the i^{th} parameter (the quality parameter is inversely proportional to the standard parameter suggested from the common guidelines), Q_a = water-quality rating for i^{th} water-quality parameter.

Irrigation-water Quality (WQI_2)

For irrigating crops, adequate quality groundwater is needed, which will be found using the following Equations 2-8. The following quality parameters are used to identify suitable locations. Sodium Absorption Ratio (SAR) (Chakraborty et al., 2022), Sodium Percentage (%Na) (Aragaw & Gnanachandrasamy, 2021), Residual Sodium Carbonate (RSC) (Osta et al., 2022), Magnesium Hazard Ratio (MHR), Kelly's Ratio (KR) (Ram et al., 2021), Permeability Index (PI) and Potential Salinity (PI) equations are given as follows:

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

$$\mathrm{\%Na}=\frac{\mathrm{Na}}{(\mathrm{Ca^{2+}}+\mathrm{Mg^{2+}}+\mathrm{Na^{+}})} \quad (3)$$

$$\mathrm{RSE}=\left(\mathrm{HCO_3^{-}}+\mathrm{CO_3^{2-}}\right)-(\mathrm{Ca^{2+}}+\mathrm{Mg^{2+}}) \quad (4)$$

$$\mathrm{MHR}=\frac{\mathrm{Mg^{2+}}}{(\mathrm{Ca^{2+}}+\mathrm{Mg^{2+}})}\times 100 \quad (5)$$

$$\mathrm{KI}=\frac{\mathrm{Na^{+}}}{(\mathrm{Ca^{2+}}+\mathrm{Mg^{2+}})} \quad (6)$$

$$\mathrm{PI}=\frac{\left(\mathrm{Na^{+}K^{+}}\right)+\sqrt{\mathrm{HCO_3^{-}}}}{\mathrm{Ca^{2+}Mg^{2+}Na^{+}+K}}\times 100 \quad (7)$$

$$\mathrm{PS}=\mathrm{Cl^{-}}+(1/2)\mathrm{SO_4^{2-}} \quad (8)$$

Correlation Analysis

Correlation analysis was used to identify the direct relationship between the water-quality parameters. The correlation between the parameters near +1 or -1 will indicate the perfect relationship between the parameters. Then, the values from +1 to +0.5 and -1 to -0.5 show strong (+8 to +1/-8 to -1), moderate (+0.5 to +0.8/-0.5 to -0.8) and weak (<+0.5/<-0.5) relations between the parameters.

PCA Biplot Analysis

The principal component analysis (PCA) is defined as the representation of a large number of groundwater samples by summarizing them into a smaller set of data for easy visulization in the study area (Gnanachandrasamy et al., 2018). The observation of groundwater samples and prediction of different water-quality parameters are compared in terms of eigen-values and eigen-vectors.

Hydro-geochemical Analysis

The graphical representation of the dissolved salts present in the collected groundwater samples is shown in the piper trilinear diagram. The study-area water quality was plotted with major cations (Na^+, K^+, Ca^+ and Mg^{2+}) and anions (Cl^-, SO_4^{2-}, CO_3^{-2} and HCO_3^-) present in the water samples (Lakshmi et al., 2021; Sangeetha et al., 2020).

RESULTS AND DISCUSSION

The different groundwater-quality parameters were spatially analyzed and discussed in the following sections. Each water-quality chemical property is compared with the standard permissible limit given by the World Health Organization (WHO, 2017) and the Bureau of Indian Standards (BIS, 2015).

Total Dissolved Solids (TDS)

Industrial effluents, domestic waste and agricultural leaching cause a major problem for increasing TDS in surface-and groundwater (Devi & Singh, 2022; Sutradhar & Mondal, 2021). From the WQI analysis, the TDS value ranged between 211 and 1875 mg/l (1972 decade) and between 227 and 2508 mg/l (2010 decade). The standard permissible limit (WHO, 2017) of TDS for drinking and irrigation water is <500-2000 mg/l. For increasing industrial effluents, the TDS value also increased from 1972 to 2019 for the western part of the study area.

Total Hardness (TH)

This representation of calcium and magnesium is present in the groundwater samples. Increasing the concentration of such minerals may cause major health issues (Bindal & Singh, 2019). In the study area, the TH value was found to be in the range for the 1972 decade 119-895 mg/l and for the 2010 decade 14-120 mg/l. The permissible limit (WHO, 2017) of TH is 600 mg/l, but in the 1972 decade, TH was higher and exceeded the permissible limit for the northern part of the basin-like Karamadai and Mettupalayam.

Hydrogen Ion Concentration (pH)

The pH was one of the most important parameters directly influenced by the other chemical parameters and it's easily identified with portable meters (pH meters) in the sampling field itself (S.n. et al., 2020). From the analysis, the study-area pH value was higher in the 2010 decade (7.5-8.6) compared to that in the 1972 decade (7.4-8.5). The pH permissible limit for drinking and irrigation water was 6.5-8.5 (WHO, 2017). The southern part of the basin has a more alkaline nature of groundwater available because of industrial effluents and deep well injection of dyeing wastewater.

Electrical Conductivity (EC)

EC is defined as a measure of soluble substances to conduct the electrical current from the observed groundwater samples (Shahnawaz et al., 2019; Susaiappan et al., 2021). The analyzed EC value for the study area ranges between 401 and 3580 µS/cm (1972 decade) and between 386 and 2497 µS/cm (2010 decade). The permissible limit for irrigation and drinking water ranges from 3000 µS/cm (WHO, 2017) to 750 µS/cm (BIS, 2015). The irrigation-water EC value was higher on the northern side of the basin in the 1972 decade and the drinking water was within the permissible limit for both decades.

Calcium (Ca^{2+})

The Ca^{2+} enters the aquifer system through the leaching of calcium minerals present in the soil layers (Kouser et al., 2022; Ram et al., 2021). From the analysis, Ca^{2+} observed for the 1972 decade was 28-178 mg/l and for the 2010 decade, the value was 6-100 mg/l. The permissible limit of calcium was 200mg/l (BIS, 2017). In both decades, the Ca^{2+} value was within the permissible limit.

Magnesium (Mg^{2+})

A higher hardness value considers Mg^{2+} to exceed the quality level (Kamaraj et al., 2021). The Bhavani basin Mg^{2+} level for the 1972 decade was 10-148 mg/l and for the 2010 decade 14-120 mg/l (permissible limit 100 mg/l). In both decades, water quality exceeds the permissible limits given by BIS and WHO.

Sodium (Na^+)

The study-area Na^+ ranges from 13-313 mg/l for the 2018 decade and in the 1972 decade, it was 15-498 mg/l. The standard limit of Na^+ was 200 mg/l (WHO,2017). The Na^+ concentration exceeded the permissible limit in the northern part of the Bhavani basin (Nambiyur & Karamadai). Higher Na^+ indicates the deformation of sodium minerals from the rocks and soil particles.

Potassium (K^+)

Most of the rocks and soils have released potassium. Compared to the year 1972, the level of K^+ minerals was regularly increasing, infiltrated into the groundwater aquifer and stored (Lakshmi et al., 2021; Naidu et al., 2021). From the analysis, the basin K^+ level increased from 1972 to 2019 (15-97 mg/l). It was increasing year by year due to the weathering of rock minerals continuously developing K^+ minerals in the groundwater. The standard permissible limit of K^+ is 50 mg/l (WHO, 2017).

Carbonate and Bicarbonate (CO_3^{2-} and HCO_3^-)

Increasing the carbonate level in the water above 200 mg/l will worsen the taste of the water. Initially, the HCO_3^- level was high in the 1972 decade (87-686 mg/l), then the level was reduced 49-424 mg/l). The standard permissible limit for $CO_3^{2-}$and HCO_3^- is <600 mg/l.

Fluoride and Nitrate (F^- & No_3^-)

The F^- concentration for the study area was increased to exceed the standard limit (<1.5 mg/l) from (0.11-2.6) mg/l (Kamaraj et al., 2021; Vijai & Khan, 2019). In groundwater, higher F^- concentration causes major health issues for humans. The higher amount of nitrate also causes predominant health issues, like cancer, ulcer, … etc. (Adimalla et al., 2019). The Bhavani-basin nitrate level was within the permissible limit (<50 mg/l) for the entire study area (4-48 mg/l) (1972 decade) and the value exceeded the limit for the 2010 decade, ranging from 1 to 69 mg/l.

Chloride (Cl^-) and Sulphate (So_4^{2-})

Chloride and SO_4^{2-} are commonly present in wastewater worldwide, particularly in saline water (Nageswara Rao et al., 2022; Swain et al., 2022). The concentration of chloride varies from 19 to 461 mg/l (1972 decade) and from 40 to 300 mg/l (2010 decade). The spatial distribution of chloride exceeds the standard limit (250 mg/l) for the Karamadai and Mettupalayam regions. The SO_4^{2-} also exceeds the limit of 13-324 mg/l (2010 decade). For the 1972 decade, it has slightly increased to exceed the standard limit (250 mg/l) of SO_4^{2-} (8-269 mg/l).

Water Quality Index

Drinking-water Quality Index

The drinking-water quality index for the Bhavani basin was compared with 1972-1990 and 2010-2019 water-quality data shown in Figs. 2 and 3. The rainfall was one of the major parameters for increasing or decreasing the groundwater quality (Adimalla et al., 2019; Bhatu, 2020; Isaac & Siddiqui, 2022). The WQI was divided into five major classes based on the water quality present in the study area. In the northern and southern parts of the basin, 60% (2524 km^2), falling under the poor category of groundwater, was observed. Compared to the 1972 decade, groundwater quality increased from 2% (84 km^2) to 44% (1851 km^2) in the 2010 decade. The WQI ranges from 17 to 107 and the maximum value is observed in the Karamadai area for the 2010 decade. Then, the remaining areas fall under the good (1851 km^2) to moderate (1599 km^2) category zones. Poor and very poor groundwater quality was observed in the Coonoor and Kothagiri regions and the maximum value was observed in the Karamadai, Mettupalayam and Sathyamangalam areas. Overall, the increased rainfall in the region directly relates to the groundwater quality of the study area.

Irrigation-water Quality

The quality parameters are SAR, SP, RSC, MR, KR, PI and PI, as given in Table 2. All the water-quality parameters were derived for the standard unit mill equivalent per litter ($meql^{-1}$) (Kadam et al., 2019). To measure the Na^+ effect on the soil and water in the presence of Ca^{2+} and Mg^{2+}, SAR was used. For both decades, the SAR value was only slightly less than the standard limit (10 $meql^{-1}$) and ranged from 0.41 to 4.83 $meql^{-1}$ for all 107 groundwater sample locations. SP was <20 $meql^{-1}$, denoting that the groundwater has an excellent quality compared to >80 $meql^{-1}$. For the study, 65% (19.7 $meql^{-1}$) of the samples have excellent quality and 35% (up to 38.8 meql^{-1}) of the samples had good quality of water from 1972-1990. In the 1972 decade, 68% (1.25-1.91 meql^{-1}) of the area had a marginal level of RSC, 27% (0.43-1.12 meql^{-1}) of the area had a safe amount of RSC and 5% (>2.25 meql^{-1}) of the area only was not suitable for irrigation. Compared to the 1972 decade, 77% of the samples were unsuitable for irrigation in the 2010 decade. Only 9% were under the safe-irrigation areas. The total of 107 sample locations have exceeded the permissible limit for MR, where the level ranged from 43 to 78 meql^{-1}. In the 1972 decade, 37 samples were below the standard limit of 0.66 meql^{-1}, while 76% (1 meql^{-1}) of the samples in the 2010 decade were below the safe limit. The study showed that most of the sample locations are suitable for irrigation and the value ranges from 0.3 to 4 meql^{-1}. In the 1972 decade, (95%) of the sample locations were suitable for irrigation compared to the 2010 decade (57%). The remaining 40% of the locations are good-salinity areas.

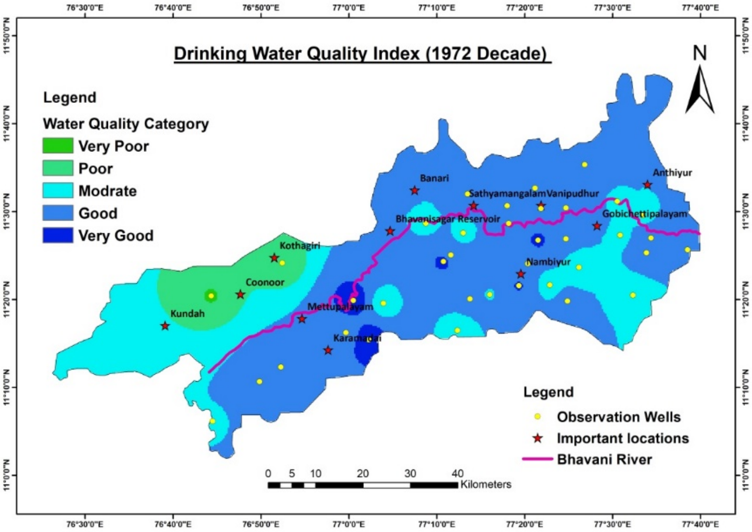

Figure (2): Drinking-water quality index for the 1972 decade

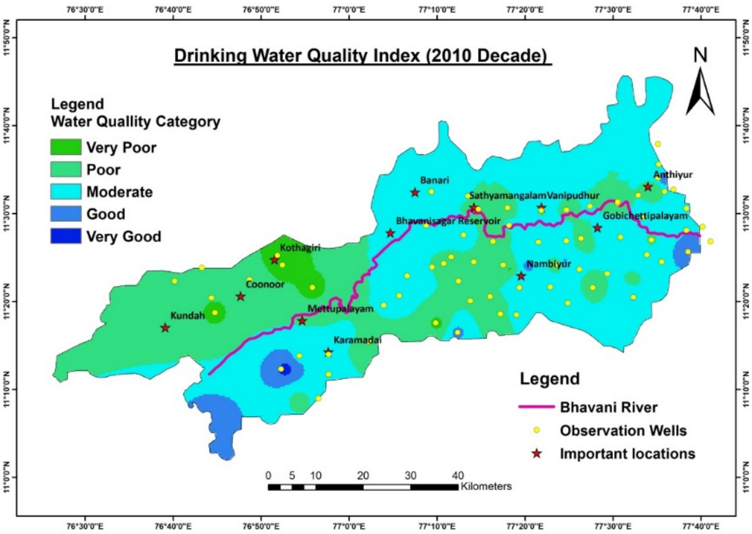

Figure (3): Drinking-water quality index for the 2010 decade

Table 2. Irrigation-water quality parameters

Water Quality Parameters	Permissible Limit	Water Quality	No. of Samples		% of Samples	
			1972-1990	2010-2019	1972-1990	2010-2019
Sodium Absorption Ratio (SAR) ($meql^{-1}$)	<10	Excellent	37	70	100	100
	10-26	Good	nil	nil	nil	nil
	>26	Unsuitable	nil	nil	nil	nil
Sodium Percentage (SP) ($meql^{-1}$)	<20	Excellent	24	nil	65	nil
	20-40	Good	13	25	35	36
	40-80	Permissible	nil	45	nil	64
	>80	Unsuitable	nil	nil	nil	nil
Residual Sodium Carbonate (RSC) ($meql^{-1}$)	<1.25	Safe	10	9	27	13
	1.25-2.25	Marginal	25	7	68	10
	>2.25	Unsuitable	2	54	5	77
Magnesium Ratio (MR) ($meql^{-1}$)	<25	Safe	Nil	nil	Nil	Nil
	>25	Unsafe	37	70	100	100
Kelly's Ratio (KR) ($meql^{-1}$)	<1	Safe	37	53	100	76
	1-2	Permissible	Nil	15	nil	21
	>2	Unsafe	nil	2	Nil	3
Permeability Index (PI) ($meql^{-1}$)	>75	Excellent	nil	41	Nil	59
	25-75	Good	18	29	49	41
	<25	Unsuitable	19	nil	51	nil
Potential Salinity (PI) ($meql^{-1}$)	<5	Excellent	35	40	95	57
	5-10	Good	2	28	5	40
	>10	Unsuitable	nil	2	nil	3

Correlation Analysis

Correlation analysis relates the groundwater parameters for the identification of interactions within the parameters. Compared to the 1972 decade, the 2010 decade has a higher correlation between the parameters, as shown in Table 3. The correlations between the parameters are: TDS *vs.* EC (0.99), Na^+ (0.92), Cl^- (0.95), SO_4^{2-} (0.91), TH *vs.* Mg^{2+} (0.96), EC *vs.* Na^+ (0.92), Cl^- (0.95), SO_4^{2-} (0.92) and Na^+ *vs.* SO_4^{2-} (0.90), with higher r^2 values (>0.9) in the parameters for the 1972 decade. For the 2010 decade, the correlations between the parameters are: TDS *vs.* TH (0.94), Mg^{2+} (0.97), TH *vs.* EC (0.88), Ca^{2+} (0.83), Cl^- (0.81), EC *vs.* Mg^{2+}(0.97), Mg^{2+} *vs.* SO_4^{2-} (0.82) and Na^+ *vs.* Cl^- (0.87).

PCA Biplot Analysis

The 2010-decade groundwater parameters are evenly distributed in the biplot diagram and presented in Fig. 4. It is shown that the % of variance was more than 50 for both decades and the sum eigen-values are also evenly distributed in each collected groundwater sample (Saleem et al., 2016; Zhang et al., 2019).

Hydro-geochemical Analysis

The piper trilinear diagram is divided into nine hydro-geochemical facies based on the water type present in each of the geochemical facies, as shown in Figs. 5 & 6. The parameters are arranged as: $Ca^+CO_3^{-2}$, $Ca^+HCO_3^-$, Na^+Cl^-, Ca^+, $Mg^{2+}Cl^-$, Ca^+Cl^-, $Ca^+Na^+HCO_3^-$ and $Na^+HCO_3^-$ (Roy et al., 2020). According to the geochemical facies diagram, 34.4% of the area in both decades is covered by a mixture of Ca^+ and $Mg^{2+}Cl^-$ types. For the 1972 decade, the domination of cations was present in the water samples and it will form a mixture of $Ca^+Mg^{2+}Cl^-$ and $Ca^+Na^+HCO_3^-$ in 28% of the study area, then, the remaining parameters, like Na^+ CO_3^{-2}, $Na^+HCO_3^-$, Ca^+Cl^- and Na^+ Cl^- form the western and eastern parts of the study area (Kamaraj et al., 2021; Lakshmi et al., 2021). For the 2010 decade, the major cations were present in the order of $Na^+ > Mg^{2+} > Ca^+ > K^+$, while the anions were present in the order of $HCO_3^- > Cl^- > SO_4^{2-} > CO_3^{-2} > F^-$. $Mg^{2+} > Ca^+ > Na^+ > K^+ > Cl^- > HCO_3^- > CO_3^{-2} > SO_4^{2-}$, as in the 1972 decade. From the observed piper trilinear diagram, dissolved salts changed water-quality parameters from the previous decade to the present decade.

Table 3. Pearson's correlation matrix for water-quality parameters

1972-1990	TDS*	TH*	pH	EC*	Ca^{2+}	Mg^{2+}	Na^{+}*	K^{+}	CO_3^{-2}	HCO_3^{-}	NO_3^{-}	Cl^{-}	SO_4^{2-}
TDS	1.00												
TH	**0.81**	1.00											
pH	0.06	0.15	1.00										
EC	**0.99**	0.83	0.03	1.00									
Ca^{2+}	0.65	**0.89**	0.02	0.67	1.00								
Mg^{2+}	**0.82**	**0.96**	0.22	0.83	0.73	1.00							
Na^{+}	**0.92**	0.57	-0.04	**0.92**	0.39	0.62	1.00						
K^{+}	0.54	0.29	0.07	0.53	0.34	0.23	0.46	1.00					
CO_3^{-2}	0.28	0.09	0.69	0.23	-0.15	0.23	0.31	0.14	1.00				
HCO_3^{-}	0.67	0.42	0.28	0.62	0.20	0.50	0.66	0.38	0.68	1.00			
NO_3^{-}	0.73	0.75	-0.03	0.72	0.74	0.68	0.53	0.44	-0.02	0.28	1.00		
Cl^{-}	**0.95**	**0.86**	0.03	**0.95**	0.75	**0.84**	**0.84**	0.41	0.14	0.48	0.76	1.00	
SO_4^{2-}	**0.91**	0.62	-0.06	**0.92**	0.45	0.66	**0.90**	0.63	0.19	0.57	0.62	0.79	1.00

2010-2019	TDS*	TH*	pH	EC*	Ca^{2+}	Mg^{2+}*	Na^{+}	K^{+}	CO_3^{-2}	HCO_3^{-}	NO_3^{-}	Cl^{-}	F^{-}	SO_4^{2-}
TDS	1.00													
TH	**0.86**													
pH	0.08	-0.01	1.00											
EC	**0.94**	**0.88**	0.11	1.00										
Ca^{2+}	0.74	**0.83**	0.11	0.72	1.00									
Mg^{2+}	**0.81**	**0.97**	0.04	**0.85**	0.67	1.00								
Na^{+}	**0.89**	0.70	0.15	**0.92**	0.58	0.68	1.00							
K^{+}	0.30	0.07	0.21	0.28	0.04	0.12	0.22	1.00						
CO_3^{-2}	0.26	0.19	0.72	0.28	0.12	0.20	0.29	0.39	1.00					
HCO_3^{-}	0.55	0.50	0.13	0.55	0.36	0.51	0.54	0.41	0.36	1.00				
NO_3^{-}	0.52	0.39	0.17	0.39	0.28	0.39	0.33	0.42	0.31	0.28	1.00			
Cl^{-}	**0.86**	**0.81**	0.00	**0.94**	0.70	0.78	0.87	0.11	0.12	0.33	0.21	1.00		
F^{-}	0.51	0.52	0.21	0.52	0.40	0.51	0.48	0.29	0.43	0.69	0.23	0.38	1.00	
SO_4^{2-}	**0.87**	**0.81**	0.10	**0.85**	0.60	**0.82**	0.77	0.21	0.20	0.38	0.35	0.75	0.39	1.00

* indicates higher correlation values between the water-quality parameters, Unit of each parameter was mg/l, except for pH (on the scale) and EC (µS/cm).

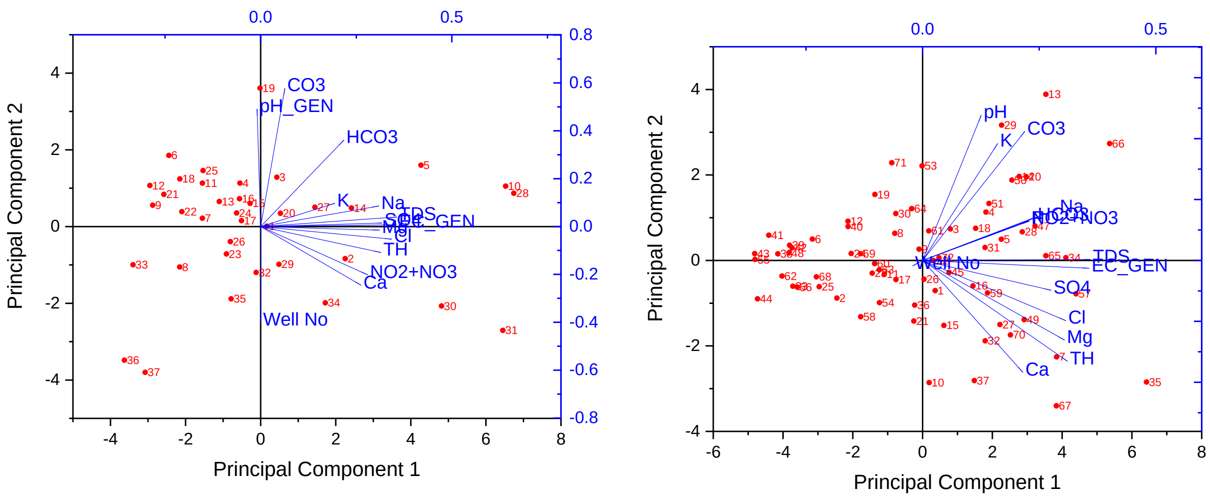

Figure (4): PCA biplot analysis for the 1972 decade (left) and the 2010 decade (right)

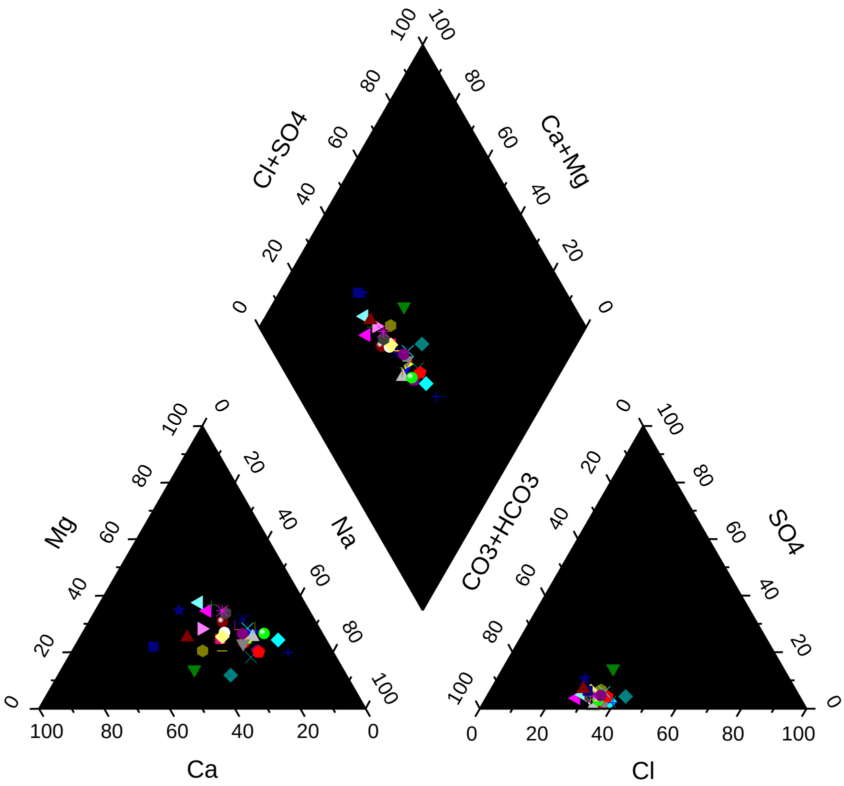

Figure (5): Piper trilinear diagram for the 1972 decade

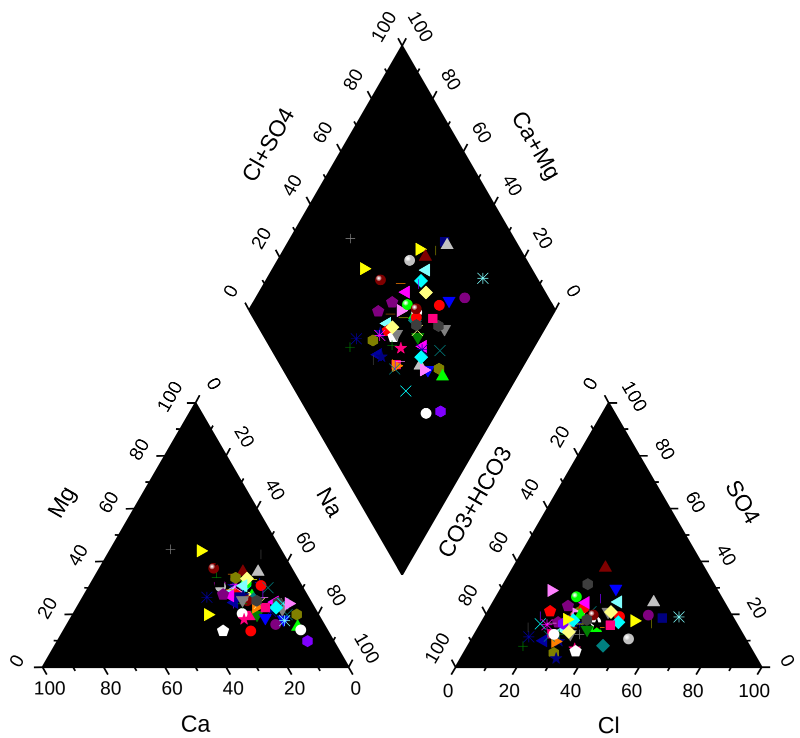

Figure (6): Piper trilinear diagram for the 2010 decade

CONCLUSIONS

The current study aims to estimate the quality of drinking and irrigation water in the Bhavani river basin using various statistical and geographical methods. GIS-based groundwater-quality analysis yields accurate and acceptable findings. The statistical analysis gives an acceptable relationship between the groundwater parameters. The calculated water-quality index decreased from the 1972 decade to the 2010 decade. The drinking-water quality has decreased in Mettupalayam, Nambiyur, Sathyamangalam and Gopichettipalayam. The study area's water quality decreased from good (2524 km^2) to moderate (1599 km^2) and from moderate (968 km^2) to poor (1851 km^2). The correlation analysis gives good results and higher r^2 values (>0.9) were found in the 2010 decade. From the PCA biplot, for the 1972 decade, all the parameters are closely related to the nearby parameters, while for the 2010 decade, the distance between the parameters is comparatively high. The hydro-geochemical analysis gives the major cations and anions present in the samples in the order of Mg^{2+}> Ca^{+}> Na^{+}> K^{+} = Cl^{-}>HCO_3^{-}>CO_3^{-2}>SO_4^{2-} (1972 decade) and Na^{+}> Mg^{2+}> Ca^{+}> K^{+} = HCO_3^{-}>Cl^{-}>SO_4^{2-}>CO_3^{-2}>F^{-} (2010 decade). The WQI gradually decreased from the 1970 decade to the 2020 decade. Finally, the analyzed WQI maps were utilized to determine optimal drinking- and irrigation- water areas. Decision makers can use the indicated site outcomes to establish groundwater quality-based water-management methods.

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REFERENCES

A, R., Kuruppath, N., and Kannan, B. (2017). “Identification of potential groundwater recharge zones using remote sensing and geographical information system in amaravathy basin". Journal of Remote Sensing & GIS, 06(04). https://doi.org/10.4172/2469-4134.1000213

Adimalla, N., Venkatayogi, S., and Das, S.V.G. (2019). “Assessment of fluoride contamination and distribution: A case study from a rural part of Andhra Pradesh, India". Applied Water Science, 9 (4), 1-15. https://doi.org/10.1007/s13201-019-0968-y

Aragaw, T.T., and Gnanachandrasamy, G. (2021). “Evaluation of groundwater quality for drinking and irrigation purposes using GIS-based water-quality index in the urban area of Abaya-Chemo sub-basin of Great Rift Valley, Ethiopia". Applied Water Science, 11 (9), 1-20. https://doi.org/10.1007/s13201-021-01482-6

Bhatu, H. (2020). “Study on groundwater potential using MODFLOW for Kalipat village". Indian Journal of Pure & Applied Biosciences, 8 (3), 539-544. https://doi.org/10.18782/2582-2845.8110

Bindal, S., and Singh, C.K. (2019). “Predicting groundwater arsenic contamination: Regions at risk in highest populated state of India". Water Research, 159, 65-76. https://doi.org/10.1016/j.watres.2019.04.054

Bureau of Indian Standards. (2020). “Product manual for drinking water according to is 10500: 2012". 158 (4), 626.e1-626.e2.

Chakraborty, B., Roy, S., Bera, B., Adhikary, P.P., Bhattacharjee, S., Sengupta, D., and Shit, P.K. (2022). “Evaluation of groundwater quality and its impact on human health: A case study from Chotanagpur plateau fringe region in India". Applied Water Science, 12 (3), 1-14. https://doi.org/10.1007/s13201-021-01539-6

Dash, S., and Kalamdhad, A.S. (2021). “Hydrochemical dynamics of water quality for irrigation use and introducing a new water-quality index incorporating multivariate statistics". Environmental Earth Sciences, 80 (3), 1-21. https://doi.org/10.1007/s12665-020-09360-1

Devi, K.S., and Singh, K.K. (2022). “Assessment of irrigational indices in surface water and shallow groundwater in the alluvial plain of Barak Valley, Assam, Northeast India". Geological Journal, 57 (2), 818-831. https://doi.org/10.1002/gj.4198

Eaton, A.D., Franson, M.A.H., Association, A.P.H., and American Water Works Association- Water Environment Federation. (2005). “Standard methods for the examination of water and wastewater". In: American Public Works Association.

Gnanachandrasamy, G., Dushiyanthan, C., Jeyavel Rajakumar, T., and Zhou, Y. (2020). “Assessment of hydro-geochemical characteristics of groundwater in the lower Vellar river basin: Using geographical information system (GIS) and water-quality index (WQI)". In: Environment, Development and Sustainability, 22 (2). Springer, Netherlands. https://doi.org/10.1007/s10668-018-0219-7

Gnanachandrasamy, G., Zhou, Y., Bagyaraj, M., Venkatramanan, S., Ramkumar, T., and Wang, S. (2018). “Remote sensing- and GIS-based groundwater potential zone mapping in Ariyalur district, Tamil Nadu". Journal of the Geological Society of India, 92 (4), 484-490. https://doi.org/10.1007/s12594-018-1046-z

Gougazeh, M., and Sharadqah, S. (2009). “Groundwater vulnerability to contamination in Jordan evaluated at two levels of analysis". Jordan Journal of Civil Engineering, 3(4), 314-321.

Isaac, R., and Siddiqui, S. (2022). “Application of water-quality index and multivariate statistical techniques for assessment of water quality around Yamuna river in Agra region, Uttar Pradesh, India". Water Supply, 22 (3), 3399-3418. https://doi.org/10.2166/ws.2021.395

Kadam, A.K., Wagh, V.M., Muley, A.A., Umrikar, B.N., and Sankhua, R.N. (2019). “Prediction of water-quality index using artificial neural network and multiple linear regression modeling approach in Shivganga river basin, India". Modeling Earth Systems and Environment, 5 (3), 951-962. https://doi.org/10.1007/s40808-019-00581-3

Kamaraj, J., Sekar, S., Roy, P. D., Senapathi, V., Chung, S. Y., Perumal, M., and Nath, A. V. (2021). “Groundwater pollution index (GPI) and GIS-based appraisal of groundwater quality for drinking and irrigation in coastal aquifers of Tiruchendur, South India". Environmental Science and Pollution Research, 28 (23), 29056-29074. https://doi.org/10.1007/s11356-021-12702-6

Kharake, A.C., and Raut, V.S. (2021). “An assessment of water-quality index of Godavari river water in Nashik city, Maharashtra". Applied Water Science, 11 (6), 1-11. https://doi.org/10.1007/s13201-021-01432-2

Kouser, B., Bala, A., Verma, O., Prashanth, M., Khosla, A., and Ahmad, R. (2022). “Hydrochemistry for the assessment of groundwater quality in the Kathua region, Jammu and Kashmir, India". Applied Water Science. https://doi.org/10.1007/s13201-022-01673-9

Lakshmi, R.V., Raja, V., Sekar, C.P., and Neelakantan, M.A. (2021). “Evaluation of groundwater quality in Virudhunagar Taluk, Tamil Nadu, India by using statistical methods and GIS technique". Journal of the Geological Society of India, 97 (5), 527-538. https://doi.org/10.1007/s12594-021-1719-x

Malik, A., and Bhagwat, A. (2021). “Modeling groundwater-level fluctuations in urban areas using artificial neural network". Groundwater for Sustainable Development, 12 (July), 100484. https://doi.org/10.1016/j.gsd.2020.100484

Mondal, V.A.K.N.C. (2020). “Identification of groundwater potential zones using RS, GIS and AHP techniques: A case study in a part of Deccan Volcanic Province (DVP), Maharashtra, India". Journal of the Indian Society of Remote Sensing, 3. https://doi.org/10.1007/s12524-019-01086-3

Nageswara Rao, K., Swarna Latha, P., and Ramesh Kumar, P.V. (2022). “Groundwater quality assessment for irrigation use in the Godavari Delta region of east-coast India using IRWQI and GIS". Water Supply, 22 (3), 2612-2629. https://doi.org/10.2166/ws.2021.454

Naidu, S., Gupta, G., Singh, R., Tahama, K., and Erram, V. C. (2021). “Hydrogeochemical processes regulating the groundwater quality and its suitability for drinking and irrigation purposes in parts of coastal Sindhudurg district, Maharashtra". Journal of the Geological Society of India, 97 (2), 173-185. https://doi.org/10.1007/s12594-021-1649-7

Oseke, F.I., Anornu, G.K., Adjei, K.A., and Eduvie, M.O. (2021). "Assessment of water quality using GIS techniques and water-quality index in reservoirs affected by water diversion". Water-Energy Nexus, 4, 25-34. https://doi.org/10.1016/j.wen.2020.12.002

Osta, M. El, Masoud, M., Alqarawy, A., Elsayed, S., and Gad, M. (2022). "Groundwater suitability for drinking and irrigation using water-quality indices and multivariate modeling in Makkah Al-Mukarramah province, Saudi Arabia". Water (Switzerland), 14 (3). https://doi.org/10.3390/w14030483

Pal, S., Kundu, S., and Mahato, S. (2020). "Groundwater potential zones for sustainable-management plans in a river basin of India and Bangladesh". Journal of Cleaner Production, 257, 120311. https://doi.org/10.1016/j.jclepro.2020.120311

Pradhan, S., Banerjee, G., Majumder, A., and Mazumdar, A. (2020). "Water-quality assessment of lower Ganga river near Haldia applying water quality index method".

Ram, A., Tiwari, S.K., Pandey, H.K., Chaurasia, A.K., Singh, S., and Singh, Y.V. (2021). "Groundwater quality assessment using water-quality index (WQI) under GIS framework". Applied Water Science, 11 (2), 1-20. https://doi.org/10.1007/s13201-021-01376-7

Roy, S., Hazra, S., Chanda, A., and Das, S. (2020). "Assessment of groundwater potential zones using multi-criteria decision-making technique: A micro-level case study from red and lateritic zone (RLZ) of West Bengal, India". Sustainable Water Resources Management, 6 (1), 1-14. https://doi.org/10.1007/s40899-020-00373-z

S.n., J., Muramthookil Thomas, G., Rohith Raj, R.V., Masetti, A., Tammana, A., Motheram, M., and Gutlapalli, N.C. (2020). "Assessment of water-quality index and study of the impact of pollution on the rivers of Kerala". Materials Today: Proceedings, 43 (xxxx), 3447-3451. https://doi.org/10.1016/j.matpr.2020.09.084

Sajil Kumar, P.J. (2020). "Hydro-geochemical and multivariate statistical appraisal of pollution sources in the groundwater of the lower Bhavani river basin in Tamil Nadu". Geology, Ecology and Landscapes, 4 (1), 40-51. https://doi.org/10.1080/24749508.2019.1574156

Saleem, M., Hussain, A., and Mahmood, G. (2016). "Analysis of groundwater quality using water-quality index". Cogent Engineering, 3 (1). https://doi.org/10.1080/23311916.2016.1237927

Sangeetha, S., Krishnaveni, M., and Mahalingam, S. (2020). "GIS-based seasonal variation of groundwater quality and its suitability for drinking in Paravanar river basin, Cuddalore district, Tamil Nadu, India". Indian Journal of Geo-marine Sciences, 49 (4), 686-694.

Saravanan, S., Saranya, T., Jennifer, J. J., Singh, L., Selvaraj, A., and Abijith, D. (2020). "Delineation of groundwater potential zone using analytical hierarchy process and GIS for Gundihalla watershed, Karnataka, India". Arabian Journal of Geosciences, 13 (15), 0-17. https://doi.org/10.1007/s12517-020-05712-0

Shahnawaz, H., Kirpalni, C., and Asif Iqbal, M. (2019). "Investigation and assessment on groundwater quality index from Sanganer Tehsil Jaipur (Rajasthan)". Materials Today: Proceedings, 42, 1732-1736. https://doi.org/10.1016/j.matpr.2020.11.098

Susaiappan, S., Somanathan, A., and Sulthan, M.T. (2021). "Suitability of water sources for domestic and irrigation purposes around corporate dumpsite". Polish Journal of Environmental Studies, 30 (4), 3803-3812. https://doi.org/10.15244/pjoes/131201

Sutradhar, S., and Mondal, P. (2021). "Groundwater suitability assessment based on water-quality index and hydrochemical characterization of Suri Sadar sub-division, West Bengal". Ecological Informatics, 64 (May), 101335. https://doi.org/10.1016/j.ecoinf.2021.101335

Swain, S., Sahoo, S., and Taloor, A. K. (2022). "Groundwater-quality assessment using geospatial and statistical approaches over Faridabad and Gurgaon districts of national capital region, India". Applied Water Science, 12 (4), 1-14. https://doi.org/10.1007/s13201-022-01604-8

Verma, P., Singh, P.K., Sinha, R.R., and 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. https://doi.org/10.1007/s13201-019-1088-4

Vijai, K., and Khan, S.M.M.N. (2019). “Analysis of groundwater-quality for irrigation purpose in Pennagaram block of Dharmapuri district, Tamilnadu, India". Materials Today: Proceedings, 48 (xxxx), 527-534. https://doi.org/10.1016/j.matpr.2021.07.330

Zhang, Q., Xu, P., and Qian, H. (2019). “Assessment of groundwater-quality and human-health risk (HHR): Evaluation of nitrate". International Journal of Environmental Research and Public Health.