www.gondwanags.org.in
Research Article

ISSN : 2455-1953
JGSR
Journal of Geosciences Research
Vol. 11, No.2, July, 2026, pp. 174-180

Geostatistical Analyses for Validation of Hydrogeochemical Behaviour of Groundwater from Neoproterozoic Aquifers of Chandrapur District, Central India

Yogesh Murkute[1*], Mamta Jaunjalkar[1], Soumya Ranjan Hota[2], Rabindra Nath Hota[3] and Shreerup Goswami[4]

[1]P. G. Department of Geology, RTM Nagpur University, Nagpur- 440 001, Maharashtra, India
[2]Geo Consultants Pvt. Ltd., Bhubaneswar - 751 006, Odisha, India
[3]P. G. Department of Geology, Fakir Mohan University, Balasore - 756 089, Odisha, India
[4]P. G. Department of Geology, Utkal University, Bhubaneswar - 751 004, Odisha, India
(*Corresponding author E-mail: yogmurkute@rediffmail.com)

Abstract

The study area, signifying the rural part from Central India, has the groundwater as the only source for all water-utilities. Here, the Neoproterozoic Penganga limestone forms the main groundwater-bearing aquifer systems. The three factors are resulted from geostatistical analysis; wherein the 47.334% has been regarded as the geogenic factor, 24.298% represents anthropogenic input and 14.374% is alkalinity factor. The phenon line at r = 0.55 value illustrates three distinct clusters as an outcome of factor analysis responsible for above mentioned factors. The high values of EC and TDS (1016 to 2519 µS/cm and 650.2 – 1612.2 mg/l, respectively) signify the involvement of multiple combinations of cations and anions, undoubtedly from the both geogenic and non-geogenic sources. Silicate weathering is found to be a major geogenic reason responsible for the release of solute; while the non-geogenic inputs are introduced through the household waste, irrigation-return-flow, animal wastes and the use of agricultural and soil nourishments.

Keywords: Geostatistical Analyses, Hydrogeochemical Behaviour, Groundwater, Neoproterozoic Aquifers, Chandrapur District, Central India

Introduction

The hydrogeochemical behaviour of the groundwater is the consequential of the interaction between the chemical-ions of minerals phases, released from the aquifer-rocks at the rock-water interface (Das *et al.*, 2012; Xu *et al.*, 2018; Mahanta and Goswami, 2024). This complex process, which governs the groundwater-chemistry has also the geogenic-control in deciding groundwater quality (Si *et al.,* 2009; Li *et al.*, 2011; Mahanta and Goswami, 2024). The anthropogenic interventions also pose further deterioration of the groundwater quality (Ravikumar *et al.*, 2011; Agoubi *et al.*, 2013; Bauder *et al.*, 2014; Amiri *et al.*, 2015; Adimalla and Qian 2019; Eyankware *et al.,* 2020; Murkute *et al.,* 2025).

In recent investigations, it has been pointed out that groundwater-contaminants are the carriers of hazards to human health and hence the studies are concentrated on apprehension of geostatistical, geochemical as well as health related complications (Hirojeet *et al.,* 2015; Zhang *et al.,* 2019; Eyankware *et al.,* 2020; Gogulothu *et al.,* 2022, Hota *et al.,* 2025; Divya *et al.,* 2026). In fact, such interconnected investigations will contribute in framing the policies and strategies for remedial measures, planning, regulations to alleviate groundwater contamination, done by geogenic as well as anthropogenic-inputs.

The present investigation focuses on PG2 watershed representing the Penganga River catchment from Chandrapur district, Maharashtra, Central India; wherein the source for all water-utilities is the only groundwater. The groundwater quality tests have been carried out from the adjoining catchments; however, there is unsatisfactory information on groundwater-quality-characters. Thus, it is attempted here to examine the groundwater hydrogeochemistry of involving geostatistical approach. Accordingly, the factor as well as cluster evaluations have comprehensively been initiated to recognize the numerous governing factors of hydrogeochemical characteristics (Hota *et al.*, 2023, Chatterjee *et al.,* 2023). In addition, the multiple regression analysis and human health risk assessment have also been considered (Wu and Sun, 2016; Subba Rao, 2020; Gogulothu *et al.,* 2022; Das *et al.,* 2023). Present study paves the initial step in understanding the hydro-geochemistry of the study area and its implications in quality issues pertaining to health risk analysis.

Study Area

The PG2 watershed, named after the River Penganga, lies 90 km on southwest tip of Chandrapur city (latitude - 19º38'32":19º48'23" N and longitude - 78º50'12":79º05'51" E) and

(Received : 07 September 2025 ; Revised Form Accepted : 02 June 2026)
https://doi.org/10.56153/g19088-025-0277-102

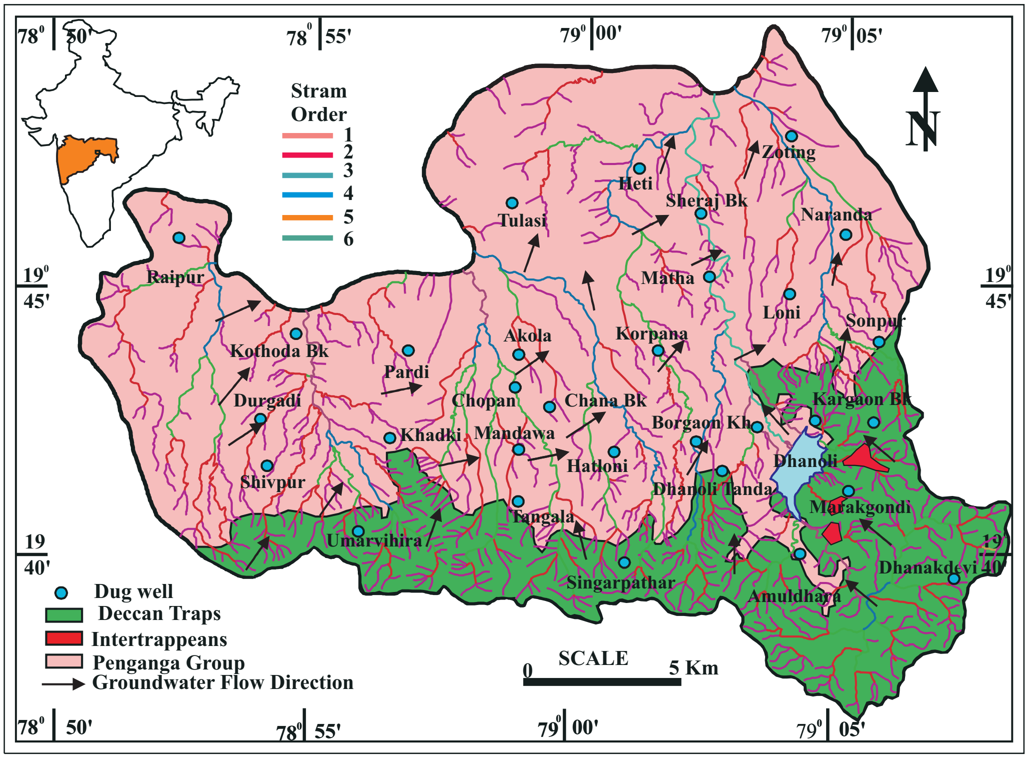

Fig. 1. Location, geological and sample-collection map of study area

sprawls over 339.98 km^2. It comes under semi-arid climatical surroundings. The minimum temperature remains 8ºC in and it goes up to 46ºC. Humidity varies from 7 to 91% with 1200 mm monsoon-rainfall. The watershed drains down through the dendritic drainage system and eventually meets the Penganga River, which flows from northern-tip of watershed.

Geology and Hydrogeology

The aquifer of Neoproterozoic Penganga limestones (Fig.1) covers the whole northern and central part of watershed, wherein the driven dug wells have usual diameter from 3 to 6 m, depth up to 20 meters below ground level (mbgl) and yield of 50 to 250 m^3/day (GSDA, 2015). The overlying Deccan Trap-basalts are well disposed on the southern boundary of the watershed. Seldom, the inter-trappean sedimentary beds, partially covered by Basaltic flows, are also exposed. The dug wells penetrated in basalts have a depth and diameters up to 20 mbgl and from 2 to 6 m respectively, with the groundwater yield of 50 to 200 m^3/ day from these wells (GSDA, 2015).

Material and Methods

The hydrogeochemical survey for groundwater-sample collections was completed during pre-monsoon 2024. Though, all wells have installed electric pumps for water abstraction, the samples were collected by pre-rinsed polyethylene samples-collector. The sample bottles were kept ready before the field visits and forty-five groundwater samples abstracted from dug-wells, filtered and then collected in one-liter pre-rinsed polyethylene bottles and subjected to analytical measures of major cations and anions.

All the physico-chemical parameters have been investigated as per the APHA (2012) and analytical data have been summarized in Table 1.

The Pearson's bivariate r-values have been employed to find

Table 1: Analytical data for 45 groundwater samples from study area

Particulars	pH	EC	TDS	TA	TH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	F^{-}	NO_3^{-}
			mg/l												
Min	7.6	1016.0	650.2	150.0	312.8	70.5	33.3	43.1	0.6	7.8	150.3	70.7	101.4	0.5	49.5
Max	8.7	2519.0	1612.2	420.0	879.8	195.3	97.6	149.5	5.3	24.6	548.3	271.3	318.5	1.9	182.5
Avg	8.1	1713.4	1096.5	280.2	577.5	136.6	57.5	84.1	2.0	12.8	338.6	138.5	186.7	1.1	139.5
STDEV	0.3	335.2	214.5	57.1	130.5	30.1	19.4	27.7	1.0	3.1	105.9	47.0	51.7	0.4	39.5
COV	4.0	19.6	19.6	20.4	22.6	22.0	33.7	33.0	51.6	23.9	31.3	33.9	27.7	35.8	28.3
BIS (2020) Acceptable Limits	6.5 - 8.5	-	-	-	200	75	30	-	-	200	200	250	200	1.0	45
WHO (2017) Acceptable Limits	6.5 - 9.2	-	-	-	100	75	30	-	10	200	150	250	200	1.0	50

STDEV – Standard Deviation, COV – Covariance out the interrelationship of all parameters with their progression towards positiveness or negativeness. The distinct geostatistical scrutinizes encompassing the factor and the cluster analyses have been employed to understand hydrogeochemical processes governing the groundwater chemistry. Besides, the multiple-regression analysis was considered to deal with TDS parameter as a linear regression on some of the constituent cations-anions.

Hydrogeochemical Behavior of Groundwater

The minimum and maximum values of pH, recorded from Penganga limestones are 7.6 and 8.7, respectively. The average value of EC value (1713.4 µS/cm), advocates multifold progression in groundwater characterization (Subba Rao, 2017). The high TDS (max: 1612.2 mg/L) contribute the salinity to the groundwater and as per Subba Rao *et al.,* (2021) such conditions suggest contributions from geogenic sources, in addition to non-geogenic sources fitting to agricultural practices as well as the introduction of domestic-leftover. The 18% of groundwater samples have TH value less than 500 mg/L as per WHO (2017). The concentration of Ca^{2+} varies from 70.5 to 195.3 mg/L; the Mg^{2+} content ranges from 33.3 – 97.6 mg/L. The Na^{+} content ranges from 43.1 to 149.5 mg/L and the K^{+} concentration varies from 0.6 – 5.3 mg/L.

Generally, in the soil zone, CO_2 is released and HCO_3^- is produced by the disintegration in mineral-suites, CO_2 influence at the atmospheric-stage, in addition to partial or complete decomposition of the organic matter; nevertheless, higher concentration of HCO_3^- (ranging from 150.3 to 548.3 mg/L, in study area) in the groundwater system is due to the prevalent mineral-dissolution (Mohapatra and Goswami, 2012; Subba Rao, 2018). The NO_3^- contents (49.5 - 182.5 mg/l) in groundwater commonly corroborates the interaction with dairy waste, sewage waste, septic-pond outflows, decay of agricultural rotten-products as well as partially decomposed animal-body pars (Raju *et al.,* 2009; Murkute, 2014; Subba Rao *et al.,* 2021; He *et al.,* 2019; Murkute *et al.,* 2025). The SO_4^{2-} (101.4 – 318.5 mg/l) in groundwater of present study area possibly have been released through the gypsum mineral, added as the soil conditioner and from redox reaction of sulphide-based mineral-suites added in composts as well as manures (Hota *et al.,* 2025). The anthropogenetic responsible factors like domestic wastes and sewage-outflows are the usual source of Cl^- (70.7 - 271.3 mg/l; Laxman *et al.*, 2019). Fluoride content grades between 0.5 - 1.9 mg/l, wherein the chief sources of F^- anion are the phosphatic fertilizers leaching in substrate with the mineral suites like fluorite, apatite, hornblende, biotite *etc.* (Murkute, 2014). The highest value of CO_3^{2-} content from the study area is 24.6 mg/l; wherein the possible source is the carbonate generating minerals at the rock water interface in the host rock (Das *et al.,* 2023).

Geostatistical Evaluation

The interrelationship of various geostatistical investigations with the hydrogeochemistry of groundwater from the study area is discussed herewith.

Correlation Coefficient (r)

Pearson's bivariate r-values (Table 2) reveals momentous positive relationship between pH and TA (r = 0.594). The TDS exhibits positive correlation with Ca^{2+}, Mg^{2+}, Na^{+}, HCO_3^- and Cl^- (r = 0.772, 0.754, 0.738, 0.829 and 0.737, respectively); similarly, it unravels moderate positive connection with SO_4^{2-} (r =0.447), K^+ (r =0.322) and NO_3^- (r =0.299). The constructive (+ ve) correlations among the Ca^{2+} and Mg^{2+} (r =0.422), Na^+(r =0.483) and HCO_3^- (r =0.697) shows the ion-origin clearly from like-geogenic-source (Cl^-, NO_3^-, SO_4^{2-} are not geogenic) (Subba Rao *et al.*, 2021); while, positive r-values, (TH) with Ca^{2+} (r =0.834), Mg^{2+} (r =0.853), Na^+ (r =0.568), HCO_3^- (r = 0.804) and Cl^- (r =0.602) found to pertain with groundwater hardness. The positive association among Na^+ with Cl^- (r =0.936) and Na^+ with HCO_3^- (r =0.590) suggests their derivation from domestic wastes and from geogenic origin; whereas the correlations exhibited through the high positive values between SO_4^{2-} and K^+ (r = 0.875) as well as NO_3^- and K^+ (r = 0.686) put-on view the agrochemical background (Das *et al.*, 2023).

Factor Analysis

The 3 significant factors derived in present study have correspondingly eigenvalues of 5.662, 3.410 and 1.749, which account for 40.443%, 24.356% and 12.489% of variances, along with the overall variance 77.288 %. The factor 1 reveals very robust positive loadings arranged over the TDS (0.936), TH (0.905), Ca^{2+} (0.746), Mg^{2+} (0.780), Na^+ (0.810), CO_3^{2-} (0.757), HCO_3^- (0.865) and Cl^- (0.834), representing the involvement of TDS, TH with the present three cations and three anions may evidently be correspond to the geogenic influence. The cations-anions in second factor

Table 2: Pearson's bivariate correlation coefficients (r) between pairs of groundwater parameters (above diagonal) and apparent correlation coefficients deduced from dendrogram (below diagonal)

	pH	TDS	TA	TH	Ca^{2+}	Mg^{2+}	Na^+	K^+	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	F^-
pH	**1.00**	- 0.231	0.594*	- 0.228	- 0.231	- 0.156	- 0.233	0.148	- 0.131	- 0.296*	-0.225	0.081	0.061	0.086
TDS	- 0.005	**1.00**	- 0.147	0.904*	0.772*	0.754*	0.738*	0.322*	0.790*	0.829*	0.737*	0.447*	0.299*	0.232
TA	0.594	- 0.005	**1.00**	- 0.137	- 0.150	- 0.083	- 0.276	0.134	- 0.167	- 0.258	-0.223	0.180	0.249	0.251
TH	- 0.005	0.904	- 0.005	**1.00**	0.834*	0.853*	0.568*	0.190	0.667*	0.804*	0.602*	0.341*	0.175	0.073
Ca^{2+}	- 0.005	0.750	- 0.005	0.750	**1.00**	0.422*	0.483*	0.065	0.525*	0.697*	0.495*	0.247	0.149	0.080
Mg^{2+}	- 0.005	0.568	- 0.005	0.568	0.568	**1.00**	0.475*	0.250	0.597*	0.660*	0.520*	0.326*	0.145	0.043
1.00	- 0.005	0.611	- 0.005	0.189	0.611	0.568	**1.00**	- 0.028	0.622*	0.590*	0.936*	0.032	0.000	- 0.020
K^+	- 0.005	0.189	- 0.005	0.189	0.189	0.189	0.189	**1.00**	0.303*	- 0.056	-0.085	0.875*	0.686*	0.641*
CO_3^{2-}	- 0.005	0.599	- 0.005	0.599	0.599	0.568	0.599	0.189	**1.00**	0.635*	0.565*	0.365*	0.312*	0.371*
HCO_3^-	- 0.005	0.817	- 0.005	0.817	0.750	0.568	0.611	0.189	0.599	**1.00**	0.622*	0.027	- 0.191	- 0.080
Cl^-	- 0.005	0.611	- 0.005	0.611	0.611	0.568	0.936	0.189	0.599	0.611	**1.00**	- 0.064	- 0.029	- 0.054
SO_4^{2-}	- 0.005	0.189	- 0.005	0.189	0.189	0.189	0.189	0.875	0.189	0.189	0.189	**1.00**	0.751*	0.623*
NO_3^-	- 0.005	0.189	- 0.005	0.189	0.189	0.189	0.189	0.719	0.189	0.189	0.189	0.719	**1.00**	0.624*
F^-	- 0.005	0.189	- 0.005	0.189	0.189	0.189	0.189	0.628	0.189	0.189	0.189	0.628	0.628.	**1.00**

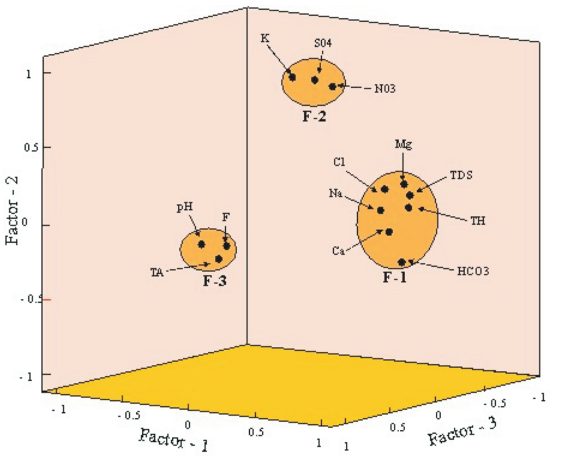

Fig. 2. Factor loadings of hydrogeochemical parameters of study area in block-diagram

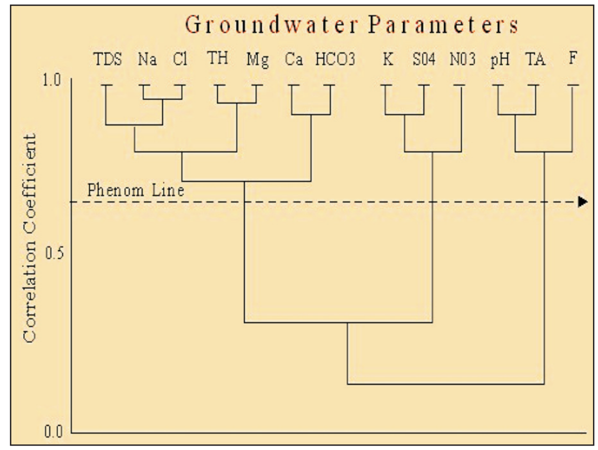

Fig. 3. Dendrogram and phenom line for hydrogeochemical parameters of study area

loaded on K^+ (0.901), SO_4^{2-} (0.917), NO_3^- (0.863) and F^- (0.807) corresponds to fertilizers and soil condition enhancer and hence clearly conveys anthropogenic influence; while the last factor (3), loaded over the pH (0.914) and TA (0.872) is noticeably an alkalinity factor. All the factor loadings in block-diagram (Fig.2) exhibit matching-up with the deductions of the factor loadings (Table 3), once again confirming their interrelationships.

Cluster Analysis and Phenon Line

The cluster analysis brings out (i) the dendrogram (Fig.3) with the phenon line demarcation on r = 0.55 and (ii) three cluster-collections, in which cluster 1 comprises Total dissolved solids, total hardness, some cations (Ca^{2+}, Mg^{2+} and Na^+) and some anions (Cl^- and HCO_3^-); cluster 2 encompasses cation (K^+), some anions (SO_4^{2-}, NO_3^- and F^-); while cluster 3 embraces pH and TA. The cophenetic correlation coefficient in tune of 0.902 value rationally substantiates the greater accuracy of this analysis. The dendrogram also exhibits the conformism on factors and also the perceptible coefficients amongst the groundwater characters, as presented in Table 4. The parameters of cluster 1 show geogenic relevance and hence significantly contribute towards the TDS content in groundwater (Murkute and Pradhan, 2025).

Multiple-Regression Statistics

Although, factor and cluster statistical-analyses classify the groundwater parameters into closely related groups, the multiple regression-statistics depict the TDS parameter as a linear regression on some of the constituent cations-anions. Here, the scientific reckoning is "$TDS = 22.46 + 0.958\ Ca^{2+} + 1.023\ Mg^{2+} + 0.949\ Na^+ + 1.450\ K^+ + 0.6\ CO_3^{2-} + 0.99\ HCO_3^- + 1.005\ Cl^- + 0.963\ SO_4^{2-} + 0.975 NO_3^- + 3.222 F^-$". The calculated 'F' value 5456.581 (Table 4) for the regression comparation exceeding the critical value (2.90) confirms the numerical significance of the equational values. The values derived through the computation of 'F' for cations (Ca^{2+}, Mg^{2+} and Na^+); anions (CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-} and NO_3^-) surpass the limiting (7.45) value at the significance-level of 0.01, which suggest significant involvement of these cations-anions to the TDS.

Discussion

The pH value of Penganga limestones (7.6 to 8.7), the average EC value (1713.4 µS/cm) and the high TDS (max: 1612.2

Table 3: Varimax rotated factor loadings of fourteen groundwater parameters

Parameter	Factor 1	Factor 2	Factor 3
pH	-0.136	0.058	**0.914**
TDS	**0.936**	0.297	-0.121
TA	-0.267	0.139	**0.872**
TH	**0.905**	0.176	-0.114
Ca^{2+}	**0.746**	0.118	-0.191
Mg^{2+}	**0.780**	0.177	-0.006
Na^+	**0.810**	-0.105	-0.124
K^+	0.064	**0.901**	0.062
CO_3^{2-}	**0.757**	0.343	-0.105
HCO_3^-	**0.865**	-0.134	-0.206
Cl^-	**0.834**	-0.174	-0.069
SO_4^{2-}	**0.176**	0.917	0.058
NO_3^-	0.049	**0.863**	0.087
F^-	0.01	**0.806**	0.029
Eigenvalue	5.662	3.410	1.749
Percentage of total variance	40.443	24.356	12.489
Cumulative percentage of total variance	40.443	64.799	77.288

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser normalization
Highest positive values are shown in bold numbers

Table 4: Complete ANOVA for testing the significance of regression equation and individual ions

Source of variation	Sum of squares	Degrees of freedom	Mean squares	F
Regression	2023955.031	10	202395.503	5456.581§
Ca^{2+}	39862.626	1	39862.626	1074.679*
Mg^{2+}	16538.228	1	16538.228	445.870*
Na^+	33877.092	1	33877.092	913.326*
K^+	48.480	1	48.480	1.307
CO_3^{2-}	414.700	1	414.700	11.180*
HCO_3^-	493481.299	1	493481.299	13304.252*
Cl^-	97124.788	1	97124.788	2618.483*
SO_4^{2-}	117797.803	1	117797.803	3175.828*
NO_3^-	68760.139	1	68760.139	1853.773*
F^-	6.964	1	6.964	0.188
Deviation	1261.141	34	37.092	--.--
Total variation	2025216.172	44	--.--	--.--

§$F_{v1=10,v2=34,\alpha=0.01} = 2.90$ *$F_{v1=1,v2=34,\alpha=0.01} = 7.45$

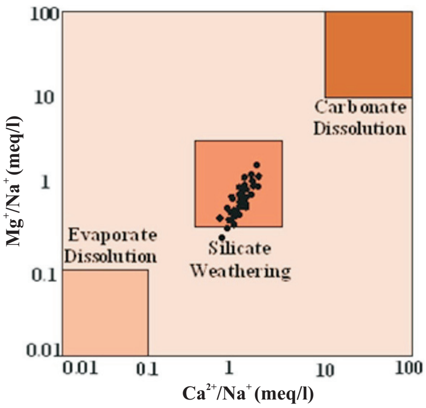

Fig. 4. Interrelationship of Mg^{2+}/Na^{+} and Ca^{2+}/Na^{+}

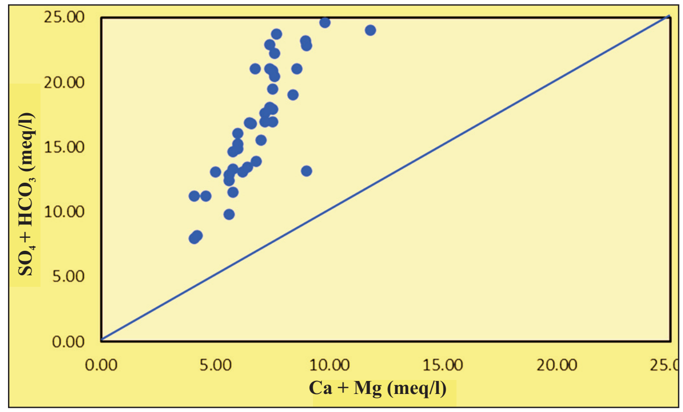

Fig. 5. Scatter diagram of $SO_4^{--} + HCO_3^{-}$ and $Ca^{++} + Mg^{++}$ Interrelationship

mg/l) clearly advocate the multifold progression in groundwater characterization (Subba Rao, 2017) and suggest the contributions from geogenic sources. The 82% of groundwater samples have TH value exceeding the 500 mg/L maximum permissible limit (MPL) of WHO (2017).

Typically, the plagioclase-feldspar (calcic) existing in the mineral composition of rocks is the typical geogenic-cause of calcium-cation liberation; which ultimately gets dissolved in groundwater (Hota *et al.,* 2023). The amphiboles, pyroxenes, mica as well as gypsum and dolomite traces escalate ion exchange of Mg^{2+} concentration in water, beneath the surface (Subba Rao., 2021; Gogulothu *et al.,* 2022), yet again pointing out the geogenic response. The common dominance of both calcium-magnesium cations in some of the samples, may unravel strong and long-period-weathering of Mg^{2+} rich carbonate rock (dolomite) exhibiting the natural-geogenic liberation; the strong-involvement of pesticides, fertilizers, household wastes, sewage tank and their spill-ways anthropogenically place the Mg^{2+} in groundwater beneath the aquifers (Thivya *et al.,* 2018; Roy *et al.,* 2018; Mgbenu and Egbueri., 2019). Both the sodic and potassic feldspars (microcline and orthoclase) represent the geogenic discharge; conversely the potassium-enriched manures, household domestic wastes, return-flows of irrigation correspond to the anthropogenic over-concentration of Na^{+} and K^{+} (Gupta *et al.,* 2008; Subba Rao *et al.,* 2020).

About 98% of the collected samples, NO_3^{-} concentration is above the MPL after WHO (2017) and BIS (2020). The SO_4^{2-} (101.4 – 318.5 mg/L) in groundwater of present study area possibly have been released from gypsum, which is added as the soil conditioner and from redox reaction of sulphide-based mineral-suites added in composts and manures (Hota and Goswami, 2018; Hota *et al.,* 2025). The anthropogenic factors like domestic wastes and sewage-outflows are the usual source of Cl^{-} (70.7 - 271.3 mg/L; Laxman *et al.,* 2019). Fluoride content grades between 0.5 - 1.9 mg/L, wherein the chief sources of F^{-} anion are the phosphatic fertilizers leaching in substrate with the mineral suites like fluorite, apatite, hornblende, biotite etc. (Murkute, 2023). The highest value of CO_3^{2-} content from the study area is 24.6 mg/L; wherein the possible source is the carbonate generating minerals at the rock water interface in the host rock (Das et al., 2023). The scatter graph of [Mg^{2+}/Na^{+}] and [Ca^{2+}/Na^{+}] clearly signifies the foremost influence of silicate-weathering pointing out the geogenic source of solute generation (Fig. 4); (Murkute, 2014; Li *et al.*, 2019). The $SO_4^{--} + HCO_3^{-}$ and $Ca^{++} + Mg^{++}$ interrelationship (Fig. 5) corroborates the silicate weathering process of geogenic origin for source of solute generation (Ramesh and Elango 2011). The covariation-count of NO_3^{-}+Cl^{-}/HCO_3^{-} vs TDS (Table 2) demonstrates the positive correlation (0.419), unveiling the nongeogenic influence (Murkute, 2014; Abu-alnaeem *et al.*, 2018; Subba Rao *et al.,* 2021).

Conclusions

The alkaline phase of groundwater from study area with high values of EC and TDS (1016 to 2519 µS/cm and 650.2 – 1612.2 mg/L, respectively) confirms multiple contributions of cations and anions, certainly from both geogenic and non-geogenic sources. Silicate weathering is found to be evident geogenic reasons in groundwater regime accountable for the release of solute; while the non-geogenic inputs are introduced through the household waste, irrigation-return-flow, animal wastes and the use of agricultural and soil nourishments. The three factors conceivable for variances, resulted through factor analysis, 47.334% has been regarded as the geogenic factor, 24.298% represents anthropogenic input and 14.374% is alkalinity factor. The phenon line at r = 0.55 value also depicts three distinct clusters as shown in the outcome of factor analysi

Funding

YAM received part funding of RTMNU research project funding scheme (No. RTMNU-769, Dt.02/12/2023). MPJ received part funding as scholarship through Mahajyoti / 2022 / Ph.D. Fellow/1002(487).

Author Contributions

YM: Investigation, Writing of Original Draft**,** Editing and Finalization of Manuscript. **MJ**: Field work and Figure Drafting and Writing of Original Draft of the Manuscript. **SRH**: Statistical Analysis and Interpretation, **RNH**: Statistical Analysis, Interpretation and Figure Drafting, **SG**: Writing of Draft, Interpretation and Editing of Revised Draft of the Manuscript.

Conflict of Interests

There are no financial and non-financial competing interests.

References

Abu-alnaeem, M.F., Yusoff, I., Ng, T.F. *et al.* (2018). Assessment of groundwater salinity and quality in Gaza coastal aquifer, Gaza strip, Palestine: an integrated statistical, geostatistical and hydrogeochemical approaches study. Sci. Tot. Environ., v. 615, pp. 972–989. https://doi.Org /10.1016/j.scitotenv.2017.09.320

Adimalla, N. and Qian, H. (2019). Groundwater quality evaluation using water quality index (WQI) for drinking purposes and human health risk (HHR) assessment in an agricultural region of Nanganur, south India. Ecotoxicol. Environment. Safe., v.176, pp.153–161.

Agoubi, B., Kharroubi, A. and Abida, H. (2013). Hydrochemistry of groundwater and its assessment for irrigation purposes in the coastal Jeffara aquifer, southeastern Tunisia. Arab. Jour. Geosci., v. 6, pp.1163–1172.

Amiri, V., Rezaei, M., Sohrabi, N., *et al.* (2014). Groundwater quality assessment using entropy-weighted water quality index (EWQI) in Lenjanat, Iran. Environment. Earth Sci., v.72, pp. 3479–3490.

APHA (2012). Standard methods for the examination of water and wastewater. American Public Health Association/American Water Works Association/Water Environment Federation, Washington DC.

Bauder, T.A., Waskom, R.M., Sutherland, P.L. and Davis, J.G., *et al.* (2014). Irrigation water quality criteria. Colorado State University Extension, No. 0.506p.

Bureau of Indian Standards (BIS) (2020). Indian standard drinking water specifications (IS: 10500). Edition 2.2 (2003–2009). Bureau of Indian Standards, New Delhi, 26p.

Chatterjee, T., Behera, D., Patra, P.K. and Goswami, S (2023). Delineation of the Groundwater Potential Zone in Kantli River Basin, Jhunjhunu District, Rajasthan: A Geospatial Approach. Jour. Geosci. Res., v.8, pp.142-152.

Das, U., Hota, S.R., Das, R. and Hota, R.N. (2023). Statistical and geochemical evaluation of fluoride-rich groundwater from north coastal part of Odisha. Jour. Geol. Soc. India, v. 99, pp. 1705–1715. https://doi.org/10.1007/s12594-023-2526-3

Divya, A.S., Joji, V.S. and Dipankar Saha (2026). Evaluation of Groundwater Contamination for Fluoride in Pullamapatti Watershed, Northern Tamil Nadu, India: An Emphasis on Human Health Risk Assessment. Jour. Geosci. Res., v.11(1), pp.77-84.

Eyankware, M.O., Aleke, C.G., Selemo, A.O.I. and Nnabo, P.N. (2020). Hydrogeochemical studies and suitability assessment of groundwater quality for irrigation at Warri and environs, Niger Delta Basin, Nigeria. Groundwat. Sustain. Develop., v.10, pp.100293.

Gogulothu, S., Subba Rao, N., Das, R. and Dhakate, R. (2022). Geochemical evaluation and suitability of groundwater quality for irrigation purpose in an agricultural region of south India. Appl. Water Sci., v. 12, pp. 142. https://doi.org/10.1007/s13201-022-01583-w

GSDA (2015). Report on dynamic groundwater resources of Maharashtra (as on 2007–08). Groundwater Surveys and Development Agency, Water Supply and Sanitation Department, Government of Maharashtra and Central Ground Water Board, Central Region, Nagpur.324p.

Gupta, S., Mahato, A., Roy, P., Datta, J.K. and Saha, R.N. (2008). Geochemistry of groundwater, Burdwan district, West Bengal, India. Environmen. Geol., v.53, pp.1271–1282.

He, X., Wu, J. and He, S. (2019). Hydrochemical characteristics and quality evaluation of groundwater in terms of health risks in Luohe aquifer in Wuqi County of the Chinese Loess Plateau, Northwest China. Hum. Ecol. Risk Assess., v. 25, pp. 32–51. https://doi.org/10.1080/10807039.2018.1531693

Herojeet, R., Rishi, M.S., Kishore, N. *et al.* (2015). Integrated approach of heavy metal pollution indices and complexity quantification using chemometric models in the Sirsa Basin, Nalagarh Valley, Himachal Pradesh, India. Chinese Jour. Geochem., v.34, pp.620–633.

Hota, R.N., Hota, S.R., Murkute, Y.A., Goswami, S. and Das, R. (2025). Comprehensive Assessment of Drinking Water Quality Indices: A Review. Jour. Geol. Soc. India, v. 101(3), pp. 291-299.

Laxman, D.K., Satyanarayana, E., Dhakate, R. and Saxena, P.R. (2019). Hydrochemical characteristics concerning fluoride contamination in groundwater of Maheshwaram Mandal, RR District, Telangana State, India. Groundwat. Sustain. Develop., v. 8, pp.474–483.

Li, P., Wu, Q., and Wu, J. *et al.* (2011). Groundwater suitability for drinking and agricultural usage in Yinchuan area, China. Int. Jour. Environment. Sci., v. 1(6), pp.1241–1249.

Mahanta, N. and Goswami, S. (2024). Groundwater vulnerability to fluoride pollution and health risk assessment in the western part of Odisha, India. Environ. Sci. Poll. Res., pp. 1-19. https://doi.org/10.1007/s11356-024-33620-3.

Mgbenu, C.N. and Egbueri, J.C. (2019). The hydrogeochemical signatures, quality indices, and health risk assessment of water resources in Umunya district, Southeast Nigeria. Appl. Water Sci., v. 9, pp. 1–19.

Mohapatra, H. and Goswami, S. (2012). Impact of coal mining on soil characteristics around Ib River Coalfield, Orissa, India. Jour. Environment. Biol., v. 33(4), pp.751–756.

Murkute, Y.A. (2014). Hydrogeochemical characterization and quality assessment of groundwater around Umrer Coal Mine area, Nagpur District, Maharashtra, India. Environment. Earth Sci., v.72, pp.4059–4073.

Murkute, Y.A., Hota, S.R., Hota. R.N., Hota, Goswami S. and Das, R. (2025) Nitrate Nightmares: Nitrate Contamination and Health Risks in a Rapidly Expanding City of Central India. Water Air Soil Poll., v. 236, pp. 68. https://doi.org/10.1007/s11270-024-07703-3

Murkute, Y.A. and Pradhan, A.P. (2025). Geostatistical Appraisal to Comprehend Hydrogeochemical Environment of Major Ions and Depiction of Groundwater Suitability from Part of Balaghat District (M.P.), Central India. Nature Environ. Poll. Technol., v. 24(1), pp.1-8.

Raju, N.J., Ram, P. and Dey, S. (2009). Groundwater quality in the lower Varuna River basin, Varanasi district, Uttar Pradesh, India. Jour. Geol. Soc. India, v. 73, pp.178–192.

Ramesh, K. and Elango, L. (2011). Groundwater quality and its suitability for domestic and agricultural use in Tondiar river basin, Tamil Nadu, India. Environ. Monit. Assess., v. 184, pp. 3887–3899. https://doi.org/10. 1007/s10661-011-2231-3

Ravikumar, P., Venkatesharaju, K., Prakash, K.L. and Somashekhar, R.K. (2010). Geochemistry of groundwater and groundwater prospects evaluation, Anekal Taluk, Bangalore urban district, Karnataka, India. Environment. Monit. Assess. https://doi.org/10.1007/s10661-010-1721-z

Roy, A., Keesari, T., Hemant Mohokar, U. K., Bitra, S. *et al.* (2018). Assessment of groundwater quality in hard rock aquifer of central Telangana state for drinking and agriculture purposes. Appl. Water Sci., v. 8, pp.124-130.

Si, J., Feng, Q., Wen, X., Su, Y., Xi, H. and Chang, Z. (2009). Major ion chemistry of groundwater in the extreme arid region northwest China. Environment. Geol., v. 57(5), pp. 1079–1087.

Subba Rao, N., Ravindra, B. and Wu, J. (2020). Geochemical and health risk evaluation of fluoride-rich groundwater in Sattenapalle Region, Guntur district, Andhra Pradesh, India. Hum. Ecol. Risk Assess., v. 26, pp.2316–2348.

Subba Rao, N., Dinakar, A., Sravanthi, M. and Kumari, B.K. (2021). Geochemical characteristics and quality of groundwater evaluation for drinking, irrigation, and industrial purposes from a part of hard rock aquifer of South India. Environment. Sci. Poll. Res., v. 28, pp.31941–31961.

Subba Rao, N. (2017). Hydrogeology: Problems with solutions. PHI Learning Pvt. Ltd., 265p.

Subba Rao, N. (2018). Groundwater quality from a part of Prakasam district, Andhra Pradesh, India. Appl. Water Sci., v. 8, pp. 30. https://doi.org/10.1007/s13201-018-0665-2

Thivya, C., Chidambaram, S., Thilagavathi, R., Venkatraman, G., Ganesh, N., Panda, B. and Prasanna, M.V. (2018). Short-term periodic observation of the relationship of climate variables to groundwater quality along the KT boundary. Jour. Clim. Change, v. 4, pp.77–86.

World Health Organization (WHO) (2017). World health organization guidelines for drinking water quality (Vol. 1, Incorporating the First and Second Addenda, Recommendations). Geneva.

Wu, J. and Sun, Z. (2016). Evaluation of shallow groundwater contamination and associated human health risk in an alluvial plain impacted by agricultural and industrial activities, mid-west China. Expos. Health, v. 8(3), pp. 311–329. https://doi.org/10.1007/s12403-015-0170-x

Xu, Y., Dai, S., Meng, K., Wang, Y., Ren, W., Zhao, L., Christie, P. and Teng, Y. (2018). Occurrence and risk assessment of potentially toxic elements and typical organic pollutants in contaminated rural soils. Sci. Tot. Environ., v. 630, pp.618–629.

Zhang, W., Ma, L., Abuduwaili, J., Ge, Y., Issanova, G. and Saparov, G. (2019). Hydro-chemical characteristics and irrigation suitability of surface water in the Syr Darya River, Kazakhstan. Environment. Monit. Assess., v. 191, pp.572-578.