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HYDROGEOCHEMICAL CHARACTERISTICS AND ESTIMATION OF WATER QUALITY INDEX FOR ASSESSMENT OF DRINKING WATER IN THE YAGACHI WATERSHED USING GEOSPATIAL TOOLS

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Abstract: The suitability of groundwater quality of 35 bore wells located in the Yagachi watershed area of Chikkamagaluru and Hassan districts of Karnataka state was assessed for drinking purpose based on the various water quality parameters. Standard methods for physico-chemical analysis of groundwater samples were employed and the results of analysis showed the following concentration ranges: pH (5.18-7.61), EC (112-3085μS/cm), TH (41-1106mg/l), TDS (68-2220 mg/l), F^- (0.3-0.8mg/l), NO_3^- (0.15-48.6 mg/l), HCO_3^- (28.77-283.53 mg/l), SO_4^{2-} (3-218.45mg/l) and Ca^{2+} (8.02-224.45mg/l), Mg^{2+} (3.04-71.95 mg/l), Na^+ (10.41-220 mg/l), K^+ (0.76-195.5 mg/l). The ionic dominance for the major cations and the anions respectively were in the order of Ca^{2+}> Na^+>Mg^{2+}> K^+ and Cl^->HCO_3^->SO_4^{2-}>NO_3^->F^-. Some of the constituents of the groundwater samples analyzed were above the guidelines set by both national (BIS) and international (WHO, 2011) bodies for drinking water. Water Quaity Index (WQI) method was adopted to assess the quality of groundwater for drinking purpose. Geographical Information System (GIS) capabilities are used to classify zones of groundwater quality for drinking purpose. Assessment of groundwater samples from various parameters indicates that groundwater in some parts of the study area is chemically unsuitable for drinking purpose.

Key words: Yagachi watershed, Arc GIS 10.8, Drinking water quality, Groundwater, WQI

I. INTRODUCTION

Water resources are crucial for sustaining life and are also a critical strategic resource for promoting social, cultural, and economic advancement in the country. They also contribute significantly to the preservation of the balance of the environment (Li and Qian 2018). Indeed, a complex interaction of several elements affects the chemical composition of subsurface water bodies such as geology, climate, topography, hydrogeological condition, human activity etc., (Sophocleous, 2002). The substances and elements that dissolve in water depend on the kinds of rocks and minerals that it comes into contact with. The concentration and dilution of chemicals in water bodies are influenced by precipitation type and amount (snow, rain, etc.). Elevated temperatures have the potential to accelerate chemical reactions and evaporation, resulting in the concentration of dissolved materials. Differences in runoff, evaporation, and biological activity brought on by seasonal fluctuations can result in differences in groundwater chemistry. Understanding the hydrogeochemistry of groundwater and water quality are important for sustainable development and effective management of groundwater resources in any given terrain (Tarawneh et al., 2019). The present study pertains to the evaluation of the physico-chemical characteristics of the groundwater in the Yagachi watershed region wherein the people are dependent on the groundwater for their needs. The paper also provides an assessment on the suitability of the groundwater for drinking purpose based on Water Quality Index (WQI).

II. STUDY AREA

The study area, Yagachi watershed is a part of the Hemavathi River basin, an important sub-basin of river Cauvery and encompasses part of Chikkamagaluru and Hassan districts of Karnataka State, India. The Yagachi river rises in the Bababudan hill range of Western ghats in Chikkamagaluru district, Karnataka state, at an altitude of 1867m above the Mean Sea Level (MSL). Geographically, the basin area lies between 75^0 38′ 44″ E and 75^0 54′ 8″ E longitude and 13^0 6′ 28″ N and 13^0 23′ 19″ N latitude (Fig. 1) which falls in Survey of India topographical sheet Nos.48 O/11, 48 O/12, 48 O/15 & 48 O/16. The topography of the Yagachi watershed area ranges from 954 m to 1867 m above the MSL (Fig. 2). The study area is underlain entirely by the Dharwar Super Group of rocks with recent alluvial deposits along the courses of the ephermal streams of Yagachi river. The bedrock is mainly constituted of Archaean granitic gneisses. Yagachi watershed area shows many geomorphological features such as structural hills and valleys, pediments, pediplains, and gently sloping smooth surfaces of eroded bedrocks between hills and plains with the veneer of detritus. The survey carried out in the study area by the present investigator indicates that the soils of the district display a wide diversity and are quite fertile. The soil types noticed are red soil, red sandy soil, mixed soil, and silty clay soil. Among these textural soils, the watershed area is mostly covered by red insitu sandy soil. Alluvial soil covers the banks of the major stream. The research area's climate is categorised as sub-tropical and is dominated by SW monsoon rainfall.

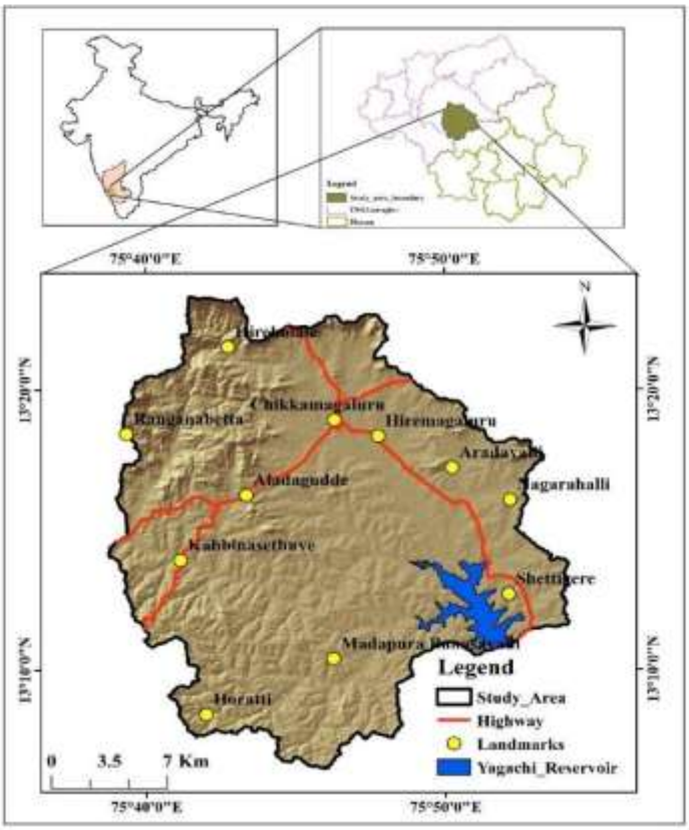


Figure.1 Study area map of the Yagachi watershed.

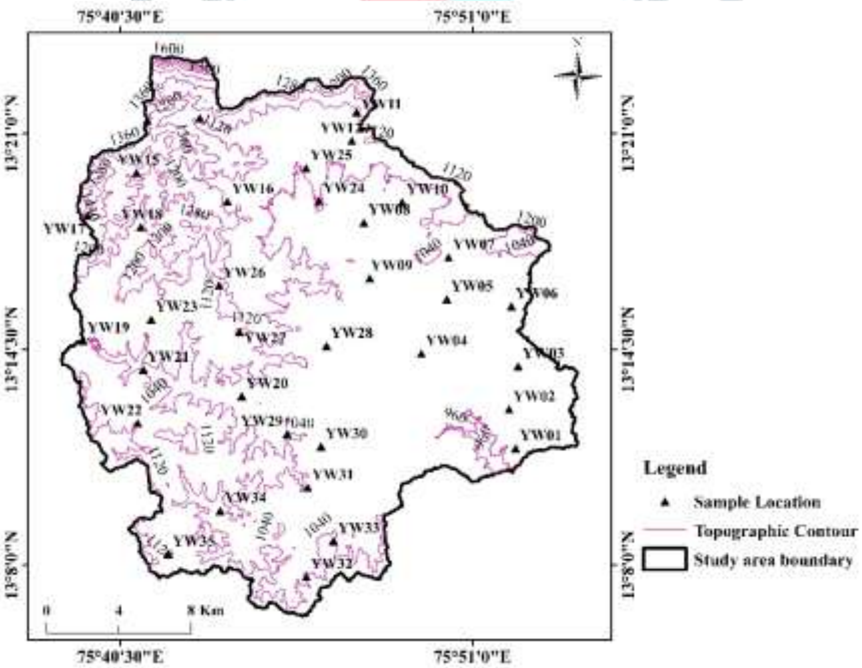


Figure.2 The groundwater sample locations around the Yagachi watershed.

III. MATERIALS AND METHODS

In April, 2022, 35 groundwater samples (1 L capacity) were collectedin duplicate from 35 bore wells in the unconfined aquifer and placed in new, pre-cleaned polypropylene bottles. In order to eliminate stagnant groundwater, water was pumped out of bore wells for approximately ten minutes prior to the collection of water samples. Water was filtered with a 0.45 Millipore membrane before being sampled. All the groundwater samples were stored at 4° C in the research laboratory and their analyses were completed within a week from the date of collection of the water samples. Chemical analysis of the water samples was performed at the Karnataka State Engineering Research Station, Krishnarajasagara, Mandya District, and Karnataka State using the analytical techniques recommended by the American Public Health Association (APHA 1995). Titrimetric analysis was performed to analyze the contents of Ca^{2+} and Mg^{2+} using standard EDTA. The elements Na^{+} and K^{+} were analysed using systronics flame photometer model 129. The titration method was utilized to determine HCO^{-}_{3} and CO^{2-}. The conventional $AgNO_3$ titration method was used to measure Cl^{-}. UV spectrophotometry was used to determine SO_4^{2-}. Using the cadmiumcolumn reduction method, $NO3^-$ was ascertained. There were only negligible amounts of CO_3^{2-} found in water samples. TDS (mg/L) and TH (mg/L) were calculated using the method that Raghunath (1987) described.

After analyzing every ten samples, the known standard was run in order to preserve the analytical precision. For each sample, an overall precision was calculated and expressed as a percentage of the relative standard deviation (RSD). The total data reproducibility for anions is found to be within 5%, while the analytical precision for cations is determined to be within 10%. The Charge Balance Errors (CBC) were determined within the allowable limit of ±10%, utilizing the formula provided by Freeze and Cherry in 1979.

$$CBE = \frac{\Sigma mc - \Sigma ma}{\Sigma mc + \Sigma ma} \times 100$$

Where, mc is the molarity of cation species and ma is the molarity of anion species.

In this study, the spatial analysis of various physicochemical parameters was carried out using Geographic Information System (GIS) mapping techniques, with ArcGIS 10.8 software serving as the primary tool. Incorporating spatial analysis into groundwater resource assessments is essential for achieving accurate and intuitive visual representation (Shaikh and Birajdar; 2024). Interpolation methods are generally categorized into statistical and geostatistical approaches. Deterministic interpolation techniques, such as Inverse Distance Weighted (IDW), generate surfaces based on the assumption that points closer to each other are more alike than those farther apart (El Mountassir et al., 2020). For this study, thematic spatial distribution maps were generated for each parameter—namely pH, electrical conductivity (EC), total dissolved solids (TDS), magnesium (Mg^{2+}), calcium (Ca^{2+}), chloride (Cl^-), potassium (K^+), bicarbonate (HCO_3^-), sodium (Na^+), and sulphate (SO_4^{2-})—using both the IDW and Kriging interpolation techniques. Each groundwater quality parameter has been spatially categorized into zones based on its concentration levels, using thematic distribution maps. These zones indicate whether the parameter values fall within acceptable/desirable or permissible limits, as defined by BIS (2012) and WHO (2011) guidelines for drinking water.

Table.1 Statistical analysis of groundwater quality parameters and its coherence with BIS and WHO standards

Parameters	Drinking-water standards		Min	Max	Mean	SD
	BIS 2012	WHO, 2011				
pH	6.5-8.5	6.5-8.5	5.18	7.61	6.61	0.51
EC (µS/cm)	750-3000	<1500	112	3085	729	625.06
TDS (mg/L)	500-2000	600-1000	68	2220	452.09	439.17
TH (mg/L)	200-600	<500	41	1106	275.51	234.21
Ca^{2+} (mg/L)	75-200	100-300	8.02	224.45	68.39	58.44
Mg^{2+} (mg/L)	30-100	-	3.04	71.95	21.43	16.69
Na^+ (mg/L)	-	50-200	10.41	220	49.45	41.69
K^+ (mg/L)	-	12	0.76	195.5	15.79	36.76
HCO_3^- (mg/L)	300-600	-	28.77	283.53	108.74	61.16
Cl- (mg/L)	250-1000	250	29.3	1075.26	188.75	217.19
SO_4^{2-} (mg/L)	200-400	250	3	218.45	51.82	56.79
F^- (mg/L)	1-1.5	1.5	0.3	0.8	0.51	0.15
NO_3^- (mg/L)	45	50	0.15	48.6	9.03	13.26

IV. The Water Quality Index (WQI)

Horton (1965) created the Water Quality Index (WQI) initially using weighted arithmetic calculations. Later studies (Brown et al., 1972; Pramoda et al., 2022; Rajashekara et al., 2023; Basavaraju et al., 2024) created different WQI models based on the weighted arithmetic method of weighing and rating various water quality parameters. The WQI is a dimensionless quantity having a range of values from 0 to 100. Based on a variety of water quality parameters, the WQI is a unique digital rating expression that conveys the overall status of the water quality, such as excellent, good, fair, etc., at a certain location and time. In the current investigation, 13 pertinent parameters have been selected (Table.2) in order to determine the WQI using the weighted arithmetic index approach (Brown, 1972). The total water quality is represented by the value of WQI, which is the cumulative influence of different water quality measures. The WQI is calculated in three steps. Initially, weights (wi) are assigned to all 13 parameters (EC, pH, TDS, TH, Ca^{2+}, Mg^{2+}, Na^+ , K^+, Cl^-, HCO_3^-, SO_4^{2-}, NO_3^- and Fluorides (F-) according to their relative significance for the overall quality of drinking water.

Step: 1 Calculation of the unit weight (W_n) factors for each parameters by using the formula

$$\boldsymbol{W_n = \frac{K}{S_n}}$$

Where S_n= Standard sesirable value of the n^{th} parameter

$$\boldsymbol{K = \frac{1}{\frac{1}{S_1}+\frac{1}{S_2}+\cdots+\frac{1}{S_n}} = \frac{1}{\Sigma\frac{1}{S_n}} \ldots..(1)}$$

Step-2 Calculation of the sub-index (Qn) values by using formula

$$\boldsymbol{Q_n = \frac{(V_n - V_0)}{(S_n - V_0)} \times 100 \ldots..(2)}$$

Where

Vn=mean concentration of the n^{th} parameter

Sn= standard desirable value of the n[th] parameters
V_0= actual values of the parameters in Pure water (generally V_0=0, for most parameters except for pH)
Step-3 Combining Step-1 and Step-2 WQI is calculated as follows

$$WQI = \frac{\sum W_n\ Q_n}{\sum W_n}$$

Table.2 Calculation of unit weight (Wn) for WQI

Sl.No	Parameters	BIS STANDARD;2012 (Sn)	1/Sn	Σ 1/Sn	K=1/(Σ1/Sn)	Wn=K/Sn	Ideal Value (Vo)
1	pH	8.5	0.118	1.36	0.74	0.087	7
2	EC	300	0.003	1.36	0.74	0.002	0
3	TDS	500	0.002	1.36	0.74	0.001	0
4	TH	300	0.003	1.36	0.74	0.002	0
5	Ca^{2+}	75	0.013	1.36	0.74	0.010	0
6	Mg^{2+}	30	0.033	1.36	0.74	0.025	0
7	Na^{+}	20	0.050	1.36	0.74	0.037	0
8	K^{+}	10	0.100	1.36	0.74	0.074	0
9	HCO_3^-	244	0.004	1.36	0.74	0.003	0
10	SO_4^{2-}	200	0.005	1.36	0.74	0.004	0
11	Cl^-	250	0.004	1.36	0.74	0.003	0
12	NO_3^-	45	0.022	1.36	0.74	0.016	0
13	F^-	1	1.000	1.36	0.74	0.736	0
			1.36			ΣWn= 1	

Table.3 WQI classification for groundwater of the study area (Brown et al, 1972)

Season	Category	Excellent	Good	Fair	Poor	Unfit
	WQI Range	0-25	26-50	51-75	75-100	>100
Pre-monsoon	Total samples	-	07	18	6	4
	%	-	20%	51.43%	17.14%	11.43%

V. RESULT AND DISCUSSION

a) Physico-chemical characteristics

The groundwater's average cation abundance in terms of meq/l, cation order of abundance Ca^{2+}> Na^{+}>Mg^{2+}> K^{+} and anions order of abundance Cl^-> HCO_3^-> SO_4^{2-}> NO_3^->F^-. In the groundwater samples, the average contributions of individual to total cationic content are: 44.11% Ca^{2+}, 31.89% Na^{+}, 13.82%Mg^{2+}, and 10.18% K^{+} (Fig.5.3A). On average anions in groundwater are made up of 52.60% Cl^-, 30.30% HCO_3^-, 14.44% SO_4^{2-}, and 2.52% NO_3^- and 0.14% F^-. Average concentration of Ca^{2+}+Mg^{2+} (5.15 meq/l) exceeds Na^{+}+K^{+} (2.52 meq/l), whereas HCO_3^-+SO_4^{2-} (4.15 meq/l) exceeds Cl^-+NO_3^- (3.24 meq/l). Spatial distribution of the level of concentrations of physico-chemical properties in the study area have been shown in the form of isoline maps (Figs. 3A to 3M).

b) Hydrogen ion concentration (pH)

pH is a key indicator for evaluating the quality and pollution levels of an aquifer system, as it is closely linked to other chemical components of groundwater. It reflects the concentration of hydrogen ions, with pure water having a neutral pH. In the current study, pH values range from 5.18 to 7.61, the average pH is 6.61 which falls within the acceptable range for drinking water (6.5–8.5), however (14 samples) 40% of the groundwater is slightly acidic in nature (Fig. 3A).

c) Electrical conductivity (EC)

Electrical conductivity (EC) is a measure of a substance’s ability to conduct electrical current through water and is directly proportional to the concentration of dissolved materials. The desirable limit of EC for drinking water is 750 µS/cm. In the present study, EC values range from 112 to 3085 µS/cm (Fig. 3B). Elevated EC levels at certain locations suggest possible sewage intrusion into the aquifer, particularly in areas close to dense urban settlements, suggesting exceeding EC concentration in 13 samples (YW01, YW03, YW04, YW05, YW07, YW08, YW09, YW10, YW11, YW12, YW16, YW25 and YW30).

d) Total hardness (TH)

Total Hardness (TH) refers to the concentration of dissolved calcium and magnesium in water. As groundwater moves through soil and rock, it dissolves naturally occurring minerals particularly calcium and magnesium-since water is an effective solvent for these elements. In the present study, hardness values range from 41 to 1106 mg/L. Groundwater samples at YW08, YW09, YW11 and YW12 sampling locations exceeded the permissible limit of 600 mg/L (Fig.3 C). Elevated levels of hardness in groundwater may be associated with health issues such as kidney stones and heart disease.

e) Total dissolved solids (TDS)

Total Dissolved Solids (TDS) represent the weight of residue left after a water sample is evaporated to dryness. It includes dissolved ions such as calcium, magnesium, sodium, potassium, carbonate, bicarbonate, chloride, and sulfate. In the present study, TDS values range from 68 to 2220 mg/L (Fig. 3D). According to BIS standards, the acceptable limit for potable water is less than 500 mg/L. Elevated TDS levels may be attributed to rock water interaction as well agricultural activities, residential runoff, soil leaching, and point-source pollution from industrial discharges or sewage treatment plants (Boyd, 2000). Samples exceeding the permissible limit were recorded at the following sampling locations: YW01, YW04, YW05, YW07, YW08, YW09, YW10, YW11, YW12, YW16, YW25, and YW30.

f) Calcium (Ca^{2+})

Calcium enters the aquifer system primarily through the leaching of calcium-bearing minerals. In the study area, calcium concentrations range from 8.02 to 224.45 mg/L (Fig.3 E). Samples from YW09 and YW11 locations exceeded permissible limit of 200 mg/L. The higher concentrations observed are likely attributed to carbonate mineral dissolution and localized geochemical conditions within the aquifer system.

g) Magnesium (Mg^{2+})

It is a key parameter contributing to water hardness. In the study area, its concentration ranges from 3.04 to 71.95 mg/L (Fig.3 F). All the samples are found well within the permissible limit of 100 mg/L.

h) **Sodium (Na^{+})**

Sodium is a highly reactive alkali metal commonly found in groundwater. It originates from rocks and soils containing sodium compounds, which readily dissolve and release sodium into the water. In the study area, sodium concentrations range from 10.41 to 220 mg/L (Fig.3 G). One sample YW09 found to contain higher concentration of sodium exceeding the permissible limit of 200mg/L (WHO, 2017). Elevated Na^{+} levels suggest the weathering of rock-forming minerals, particularly silicate minerals such as alkali feldspars which are found in abundance in the study area, and/or the dissolution of soil salts due to evaporation (Stallard and Edmond, 1983). Additionally, high sodium concentrations in aquifers may also result from cation exchange processes (Kangjoo Kim and Seong-Taekyun, 2005).

i) **Potassium (K^{+})**

Potassium is found in many minerals and most types of rocks. These rocks are relatively soluble and gradually release potassium, leading to an increase in its concentration in groundwater over time. In the present study, potassium levels range from 0.76 to 195.5 mg/L (Fig.3 H). Seven groundwater samples exceed the 12 mg/L (YW03, YW08, YW09, YW10, YW12, YW19 and YW35).

j) Bicarbonate (HCO_3^{-})

Bicarbonate in groundwater is formed through the reaction of carbon dioxide with water on carbonate rocks such as limestone and dolomite. The carbon dioxide present in the soil interacts with rock-forming minerals, leading to the formation of bicarbonate and creating an alkaline environment in the groundwater. In the study area, bicarbonate levels range from 28.77 to 283.53 mg/L (Fig.3 I), which is within the permissible limit of 600 mg/L.

k) **Chloride (Cl^{-})**

In the present study, chloride (Cl^{-}) concentrations range from 29.3 to 1075.26 mg/L (Fig.3 J). Samples YW01, YW08, YW09, YW10, YW11, YW12, YW16 show chloride concentrations exceeding the permissible limit of 250 mg/L. Elevated chloride levels in groundwater pose a potential risk to human health (Pius et al., 2012; Sadat Noori et al., 2014). The high concentrations may be attributed to natural processes such as mineral dissolution, as well as anthropogenic inputs including agricultural runoff, wastewater infiltration.

l) Sulphate (SO_4^{2-})

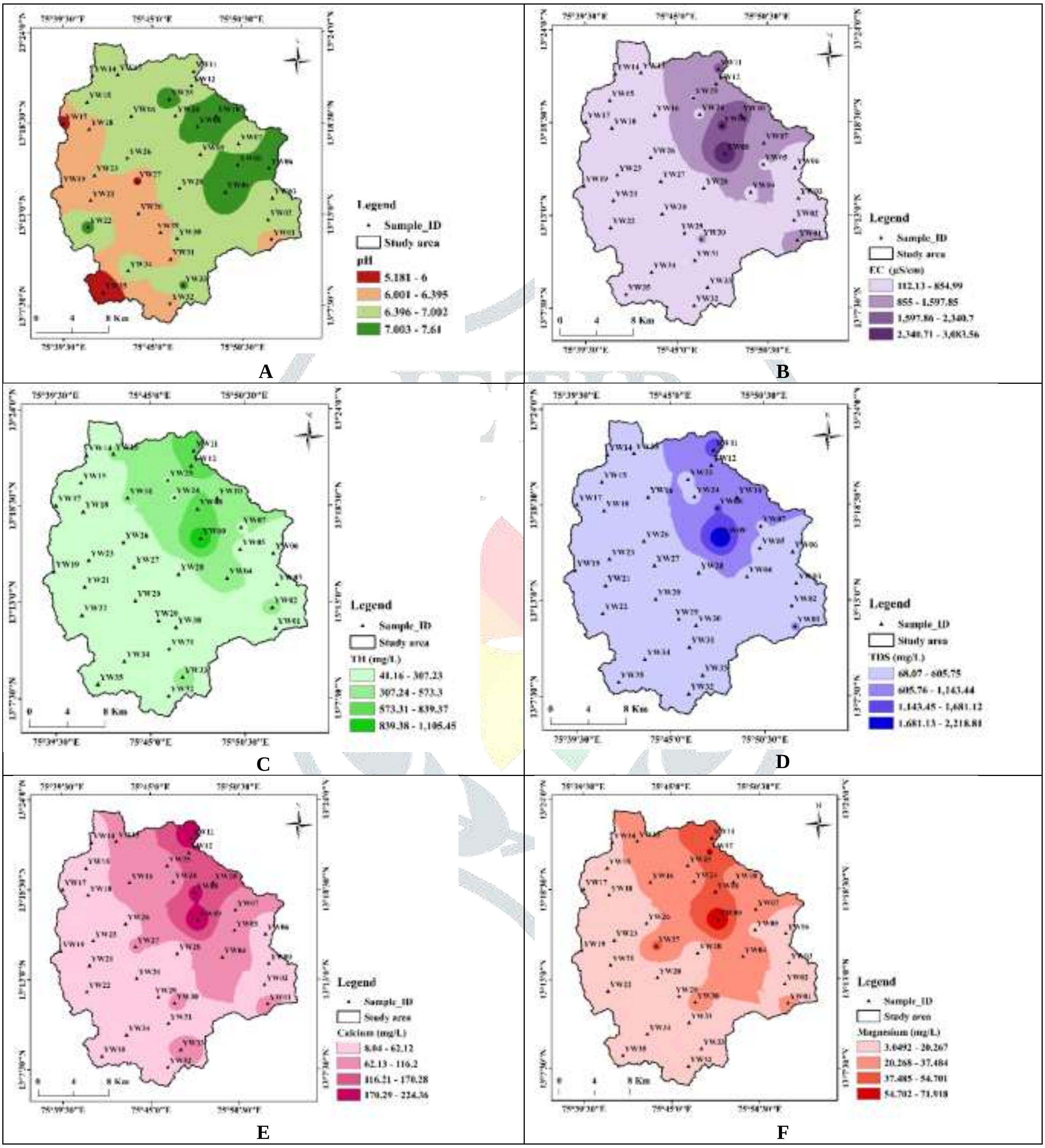
Sulphate in groundwater is dissolved and leached from rocks containing gypsum, iron sulfides, and other sulfur-bearing compounds. In this study, sulphate concentrations are found to range from 3 to 218.45 mg/L and the level of concentration of sulphate in one sample YW09 is not within the acceptable limit of 200 mg/L (Fig.3 K). In addition to natural sources, elevated sulphate levels can also result from agricultural runoff containing sulphate-based fertilizers, industrial effluents, and sewage infiltration. In arid and semi-arid regions, high evaporation rates and long groundwater residence times can further increase sulphate levels.

m) Nitrate (NO_3^{-})

Nitrate is a naturally occurring ion and an essential component of the nitrogen cycle. However, elevated nitrate levels in groundwater are undesirable, as they can cause methemoglobinemia (blue baby syndrome) in infants under six months of age (Egereonu & Nwachukwu, 2005). High nitrate concentrations pose significant health risks when exceeding the permissible limit of 45 mg/L (Kumar et al., 2012, 2014). In the study area, nitrate concentrations range from 0.15 to 48.6 mg/L (Fig.3 L). The groundwater representing the samples YW02, YW08, YW09 slightly exceeding the permissible limits across the region. This may be attributed to the influx of sewage into the aquifer.

n) Fluoride (F^{-})

Fluoride in groundwater is primarily geogenic, originating from natural sources. As the lightest halogen and one of the most reactive elements (Kaminsky et al., 1990), fluoride typically occurs in trace amounts or as a major ion at higher concentrations (Gaciri & Davies, 1993; Apambire et al., 1997; Fantong et al., 2010). It is released into groundwater through interactions between water and fluoride-bearing minerals, particularly in regions with granites and granitic gneisses. These rocks often contain fluorite (CaF_2) as an accessory mineral (Ozsvath, 2006; Saxena & Ahmed, 2003), which plays a key role in regulating groundwater fluoride geochemistry (Deshmukh et al., 1995). Additionally, fluoride is abundant in other rock-forming minerals such as apatite, micas, amphiboles, and clay minerals (Karro & Uppin, 2013; Narsimha & Sudarshan, 2013; Naseem et al., 2010; Jha et al., 2010; Rafique et al., 2009; Carrillo-Rivera et al., 2002). The study area is largely covered by granites and granitic gneisses. However, low level of fluoride concentration is found and they range from 0.3 to 0.8 mg/L (Fig.3 M). None of the groundwater samples shows fluoride concentration exceeding the permissible limit of 1.5 mg/L.



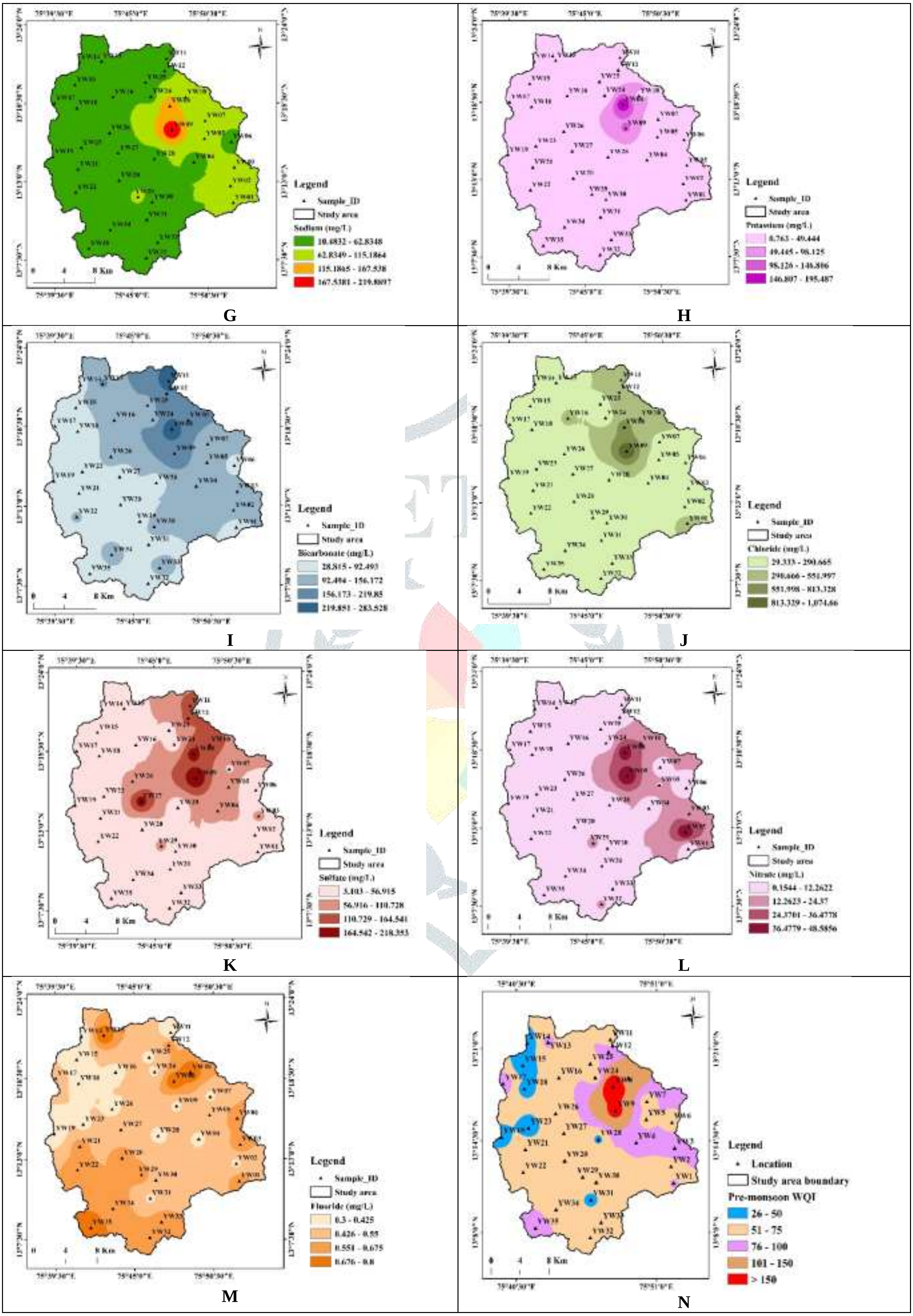


Figure.3 Spatial distribution maps of pH, EC, TH,TDS, EC, Ca, Mg, Na, K, HCO_3, Cl, SO_4, NO_3, F (A to M) and WQI (N).

o) Correlation matrix

The provided correlation matrix for various water quality parameters reveals significant relationships among the parameters (Table 4). In the groundwater samples (n=35), individual cation reveal the following relationships with the other variables: Ca^{2+} shows strong correlation with HCO_3^-, Cl^-, SO_4^{2-}, Mg^{2+}, Na^+, K^+ and Ca^{2+} shows weak correlation with TDS, NO_3^- and F^-. Mg^{2+} shows strong correlation with HCO_3^-, SO_4^{2-}, Cl^- and weak correlation with NO_3^- and F^-. Na^+ and K^+ shows positive correlation with HCO_3^-, SO_4^{2-}, Cl^- and weak correlation with TDS, TH, EC, NO_3^- and F^-. Electrical conductivity (EC) shows strong positive correlations with total hardness (TH) and total dissolved solids (TDS), indicating that these parameters are closely linked to the ionic content in the water. Calcium (Ca^{2+}) and magnesium (Mg^{2+}) exhibit strong positive correlations with each other, as well as with bicarbonate (HCO_3^-), sulphate (SO_4^{2-}), and chloride (Cl^-), suggesting that these cations are primarily derived from the dissolution of carbonate and sulphate minerals, and weathering of silicate minerals. Sodium (Na^+) and potassium (K^+) also show strong correlations with each other and with other ions, implying common sources, such as natural mineral dissolution and anthropogenic like fertilizer application and sewage effluents. Nitrate (NO_3^-) exhibits strong positive correlations with Na^+ and K^+, indicating that it may also be influenced by anthropogenic sources. Fluoride (F^-) shows moderate correlations with several ions, reflecting its presence from both natural and anthropogenic sources. Overall, these correlations highlight the interconnected nature of water quality parameters and suggest that both natural geochemical processes and human activities significantly have influenced the groundwater chemistry.

Table.4 Pearson's correlation co-efficient matrices of the physico-chemical variable of the groundwater samples

	pH	EC	TH	TDS	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	SO_4^{2-}	Cl^-	NO_3^-	F^-
pH	1												
EC	0.45	1											
TH	0.36	0.93	1										
TDS	0.39	0.97	0.94	1									
Ca^{2+}	0.25	0.30	0.27	0.34	1								
Mg^{2+}	0.16	0.41	0.42	0.47	0.88	1							
Na^+	0.13	0.29	0.24	0.28	0.68	0.66	1						
K^+	0.07	0.26	0.30	0.32	0.61	0.61	0.77	1					
HCO_3^-	0.16	0.31	0.34	0.40	0.90	0.86	0.62	0.64	1				
SO_4^{2-}	0.06	0.31	0.27	0.36	0.77	0.82	0.74	0.68	0.67	1			
Cl^-	0.26	0.33	0.29	0.33	0.89	0.83	0.85	0.71	0.74	0.72	1		
NO_3^-	-0.03	0.10	0.16	0.13	0.49	0.48	0.79	0.71	0.49	0.64	0.57	1	
F^-	0.14	0.32	0.29	0.41	0.37	0.48	0.13	0.18	0.39	0.34	0.25	-0.03	1

p) Water quality index

The Water Quality Index (WQI) map for the study area was developed using ArcGIS 10.8, based on selectively chosen quality parameters to classify groundwater into categories such as excellent, good, poor, very poor, and unsuitable for drinking purposes (Tables 3 and 5; Fig. 3(N)). The WQI map reveals that the majority of the study area (52%) has 'Fair' groundwater quality, 20% of the samples fall in 'Good' class, 17% in 'Very Poor' and 11% in 'Unsuitable' classes. Overall, groundwater quality across most of the study area is good to fair, making it suitable for drinking and domestic uses. The present findings demand continuous monitoring of groundwater quality in order to minimise the undesirable effects caused by poor quality of water.

Table.5 WQI classification for groundwater of the study area (Brown et al, 1972)

WQI	Pre-monsoon
0-25 (Excellent)	-
26-50 (Good)	YW14, YW15, YW18, YW19, YW23, YW28, YW31
51-75 (Fair)	YW02, YW05, YW06, YW07, YW11, YW16, YW20, YW21, YW22, YW24, YW25, YW26, YW27, YW29, YW30, YW32, YW33, YW34
75-100 (Very poor)	YW01, YW03, YW04, YW12, YW13, YW17
>100 (Unfit)	YW08, YW09, YW10, YW35

VI. CONCLUSION

For sustainable development and efficient groundwater resource management in each watershed, it is critical to comprehend the hydrogeochemistry of groundwater and water quality. The present author by collecting the groundwater samples made an attempt to evaluate physico-chemical characteristics, spatial variation in the distribution of individual groundwater variables (TDS, TH, Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, SO_4^{2-}, Cl^- and NO_3^-), inter-elemental relationships among the groundwater's major anions and cations, and natural sources of dissolved solids in the groundwater. Further, quality of groundwater for drinking purpose was ascertained by computing WQI. The study brings to light that the natural hydrochemical processes such as mineral dissolution, ion exchange, evapotranspiration, and redox reactions which control the uptake and distribution of solutes, are the main factors influencing the hydrochemical makeup of groundwater in the study region. Anthropogenic activities represent an additional and different source of solutes.

Thirteen important physic-chemical characteristics (EC, pH, TDS, TH, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, HCO_3^-, SO_4^{2-}, NO_3^-, and F^-) based on their relative importance for the overall quality of drinking water, have been chosen for the current study and the weighted arithmetic index method was used to determine the WQI. Groundwater samples were classified into five classes based on WQI values; Excellent (0-25), Good (26-50), Fair (51-75), Very Poor (75-100) and Unfit (>100). Out of 35 groundwater samples, 7 samples belong to Good, 18 to Fair, 6 to Very Poor and 4 to Unfit categories. The degree of concentrations of pollutants or contaminants in water samples may be the cause for variable values. All the locations needs to be monitored and if necessary treated before supplying for human consumption.

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