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Hydrochemical Characteristics of Groundwater of Deeper Aquifers and GIS Based Assessment of Groundwater Quality for Domestic, Irrigational and Industrial Purposes in Lower Papagni River Basin, Chikkaballapura District, Karnataka.

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ABSTRACT

Groundwater from deeper aquifers is a major source of freshwater in semi-arid regions of southern India. The Lower Papagni River Basin in Chikkaballapura district relies predominantly on groundwater for domestic, agricultural, and industrial needs due to declining surface water availability. This study evaluates the hydrochemical characteristics of deeper aquifers and assesses groundwater suitability using GIS-based spatial modelling. A total of 45 groundwater samples were collected from bore wells during pre- monsoon seasons. Hydrochemical parameters such as pH, EC, TDS, major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and anions (HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-, F^-) were analysed following APHA standards. Analytical results were interpreted using Piper, Gibbs, Wilcox, USSL, and Spatial distribution maps were generated in GIS using inverse distance weighting (IDW) interpolation. Results reveal that groundwater is predominantly Ca–Mg–HCO_3 and Na–HCO_3 type, indicating rock–water interaction and silicate weathering as major controlling geochemical processes. EC and TDS values indicate moderate to high mineralization, with localized salinity zones. Fluoride concentrations exceed 1.5 mg/L in several pockets, marking them unsuitable for drinking. Irrigation indices (SAR, RSC, PI, KR) show that majority of samples fall under "good to permissible" class, though a few zones exhibit marginal suitability due to salinity hazards. Spatial maps highlight fluoride-rich and nitrate-rich clusters associated with granite-gneissic terrain and anthropogenic inputs. Overall, the groundwater from deeper aquifers is suitable to moderately suitable for irrigation, but requires treatment or blending for safe drinking use in affected regions. The study underscores the importance of continuous monitoring and GIS-based hydrochemical modelling for sustainable groundwater management.

Keywords: Groundwater hydrochemistry, GIS-based groundwater quality assessment, Drinking water suitability, Irrigation water quality, Industrial water use.

Introduction

Groundwater is one of the most vital natural resources supporting domestic, agricultural and industrial needs, particularly in semi-arid regions such as southern India. The Lower Papagni River Basin in Chikkaballapura district relies heavily on groundwater due to limited surface water availability, erratic monsoon rainfall and increasing water demand driven by population growth and expanding agricultural and industrial activities. Over-exploitation of aquifers, coupled with geogenic influences and anthropogenic pressures, has resulted in significant variations in groundwater quality across the basin. Ensuring the suitability of available groundwater for drinking, irrigation, and industrial purposes is therefore essential for sustainable resource management.

Groundwater quality assessment provides critical insights into the chemical composition of water, its spatial distribution, and the factors influencing contamination or mineral enrichment. Traditional field-based investigations alone are often inadequate to capture the spatial heterogeneity of hydrochemical parameters. In recent years, Remote Sensing (RS) and Geographic Information Systems (GIS) have emerged as powerful tools for integrating field data, analysing spatio-temporal variations, and generating thematic maps for water quality interpretation. These technologies facilitate efficient visualization of hydrochemical indicators, identification of vulnerable zones, and development of scientifically informed water management strategies.

This study focuses on evaluating the groundwater quality of the Lower Papagni River Basin for domestic, irrigation, and industrial purposes through hadrochemical analysis combined with RS and GIS techniques. By examining key physicochemical parameters and applying standard water quality indices, the research aims to delineate the suitability of groundwater across the basin, highlight potential risks, and support sustainable utilization and planning of groundwater resources in the region.

1. Location and Physiography:

Lower Papagni River Basin, a sub basin of Pennar River in south east part of Karnataka situated between 13°30'23.48''N latitudes to 13°37'22.22''N latitudes and 77°45'50.74''E latitudes to 78° 9'26.95''E latitudes and covers an area about 623 km^2 and perimeter 172 km of it covers three taluks in Chikkaballapura district of Karnataka state lie within the study basin (Fig.1). It is the principle right side tributary of Pennar River, one of the major east flowing rivers in southern India. Lower Papagni River originates near east side of Chikkballapura town located in same district and takes a course flowing towards north east direction through Shildhaghatta, Chintamani taluk and crocess the boarder of Karnataka at Chalur town and making the large.

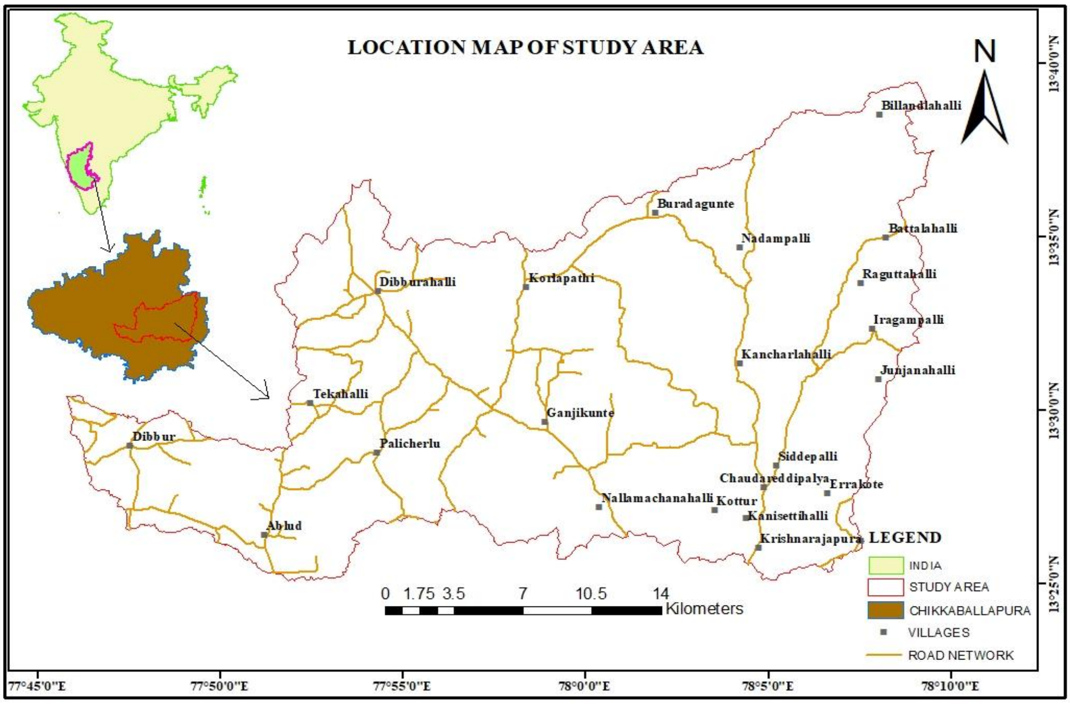


Fig. 1. Location map of study area.

2. Methodology

Groundwater samples were collected from bore wells across the Lower Papagni River Basin, and the sampling locations were accurately recorded using GPS to facilitate spatial analysis. Standard protocols recommended by APHA (2017) were followed during sample collection, preservation, and laboratory processing. The collected samples were analyzed for major physicochemical parameters such as pH, EC, TDS, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, Cl^{-}, SO_4^{2-}, NO_3^{-}, and F^{-}, and the results were evaluated against the permissible limits prescribed by BIS (10500:2012) and WHO (2017) to determine suitability for domestic, agricultural and industrial purposes. For domestic use, Water Quality Index (WQI) was calculated by assigning weights to critical parameters, normalizing them with BIS and WHO standards, and integrating the results to classify water into various quality categories. Suitability for irrigation was assessed by computing indices such as Sodium Adsorption Ratio (SAR), Sodium Percentage (Na%), Residual Sodium Carbonate (RSC), Magnesium Hazard (MH), Kelly's Ratio (KR), and Permeability Index (PI), along with preparation of Wilcox (1955) and USSL (1954) diagrams to evaluate the impact on soil permeability and crop productivity. Industrial suitability was determined using parameters including pH, EC, hardness, TDS, chlorides, and sulphates based on industrial water quality requirements for cooling, processing, and boiler feed. Graphical representation of the different ions in water sample is developed by Piper diagram (1944), rock-water interaction indicates in Gibb's diagram (1970). All field, laboratory, and satellite-derived data were integrated into a GIS environment where spatial interpolation techniques such as Inverse Distance Weighting (IDW) were applied to generate continuous spatial distribution maps of water quality parameters. Finally, thematic maps illustrating groundwater suitability for domestic, irrigation, and industrial use were prepared by integrating BIS and WHO standards with hadrochemical indices, enabling the delineation of suitable, moderately suitable, and unsuitable zones across the Lower Papagni River Basin.

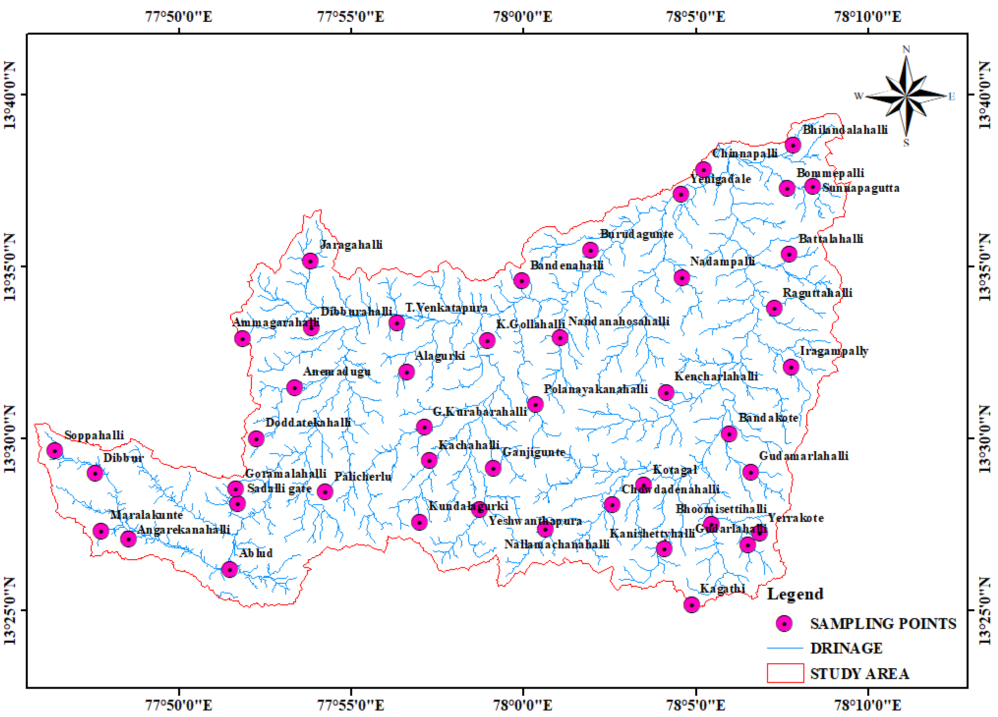


Fig. 2. Sampling locations of study area.

3. Geological setting of study area with reference to Groundwater quality

The geological map indicates that groundwater in the study area occurs mainly within the Peninsular Gneissic Complex (PGC), comprising gneiss- and granite-dominated lithounits. These crystalline hard-rock formations strongly control groundwater occurrence, recharge, and chemistry. Gneissic rocks, which are widely distributed, develop secondary porosity through weathering and fracturing and thus form the principal groundwater-bearing zones. Granite-dominated areas, although relatively less fractured, contribute major ions such as Na^+, K^+, Ca^{2+}, and HCO_3^- to groundwater through gradual mineral dissolution.

Laterite and bauxite pockets along the southwestern margin reflect intense weathering conditions, where leaching may locally enrich groundwater with Fe, Al, and other minerals, occasionally lowering pH in shallow aquifers. The spatial distribution of sampling locations across different lithological units highlights the role of rock–water interaction in governing groundwater quality. Overall, groundwater chemistry is predominantly influenced by silicate weathering within gneissic and granitic terrains, which explains the observed moderate TDS, elevated bicarbonate and sodium levels, and lithology-controlled variability affecting groundwater suitability for drinking and irrigation.

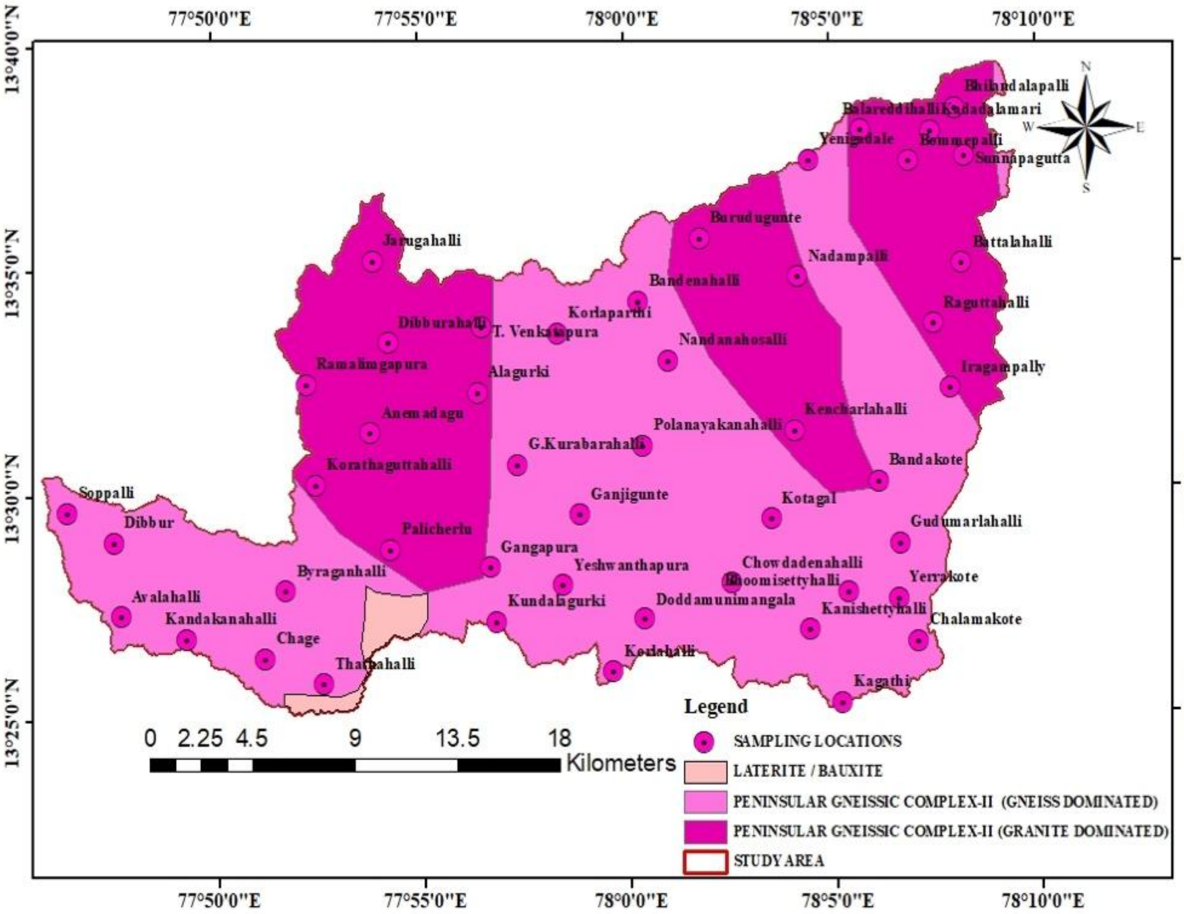


Fig. 3. Geology of study area.

4. RESULTS AND DISCUSSION

4.1 Physicochemical Properties

pH

The pH of the groundwater samples in the study area ranges from 5.94 to 7.94 with an average value of 7.40**.** This range ensures minimal corrosiveness, good palatability, and stable chemical conditions. 44 out of 45 samples fall within the recommended range, indicating that the groundwater is predominantly suitable for drinking in terms of pH. Only one sample (pH 5.94) falls below the desirable range, showing slightly acidic conditions according WHO (2012) drinking water criteria**,** indicating that the water is largely safe and acceptable for domestic use with respect to pH. Fig, 5a showing spatial distribution pattern of pH.

EC:

The Electrical Conductivity (EC) values of the groundwater samples range from 103.50 to 2336 µS/cm**,** indicating a wide variation in the concentration of dissolved salts across the study

SL.No	Sample Locations	pH	E.C µmohos (mg/l)	TDS (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	HCO_3 (mg/l)	Cl (mg/l)	SO_4 (mg/l)	NO_3 (mg/l)	TH (mg/l)	F (mg/l)
1	SOPPAHALLI	7.04	1190.00	790.00	134.00	18.40	15.89	3.34	145.18	141.00	83.40	79.80	412.00	0.37
2	DIBBUR	6.73	2120.00	1410.00	122.64	50.55	101.10	43.30	12.02	348.00	144.20	200.30	514.00	0.29
3	MARALAKUNTE	5.94	518.00	340.00	43.28	10.93	41.50	2.56	20.74	110.00	7.03	24.11	153.00	0.21
4	ANGARAKANAHALLI	7.16	1126.00	750.00	125.04	10.69	76.63	3.48	147.62	167.00	364.20	27.03	356.00	0.33
5	ABLUD	7.92	1526.00	453.00	166.30	4.37	70.18	2.17	95.16	60.00	269.00	3.43	434.00	0.88
6	TATAHALLI	6.84	470.00	290.00	34.86	12.39	42.40	2.57	86.62	66.50	11.64	19.83	138.00	0.39
7	GORAMALAHALLI	7.03	369.00	310.00	38.47	15.31	30.02	3.10	53.07	41.50	7.53	60.10	159.00	<0.1
8	PALICHERLI	7.45	1231.00	775.00	109.01	54.44	69.74	2.87	170.80	171.00	46.94	27.79	496.00	0.66
9	DODDA TEKAHALLI	7.74	634.00	365.00	35.27	29.40	82.18	3.48	121.40	67.50	44.42	5.31	209.00	1.10
10	ANEMADUGU	7.63	359.00	220.00	34.06	16.52	48.39	0.96	90.89	25.49	17.27	0.79	153.00	1.21
11	AMMAGARAHALLI	7.28	1657.00	1100.00	126.65	38.40	107.10	5.41	173.24	207.93	114.30	171.20	474.00	1.49
12	JARAGAHALLI	7.52	704.00	450.00	42.48	39.37	79.41	2.81	134.81	49.48	57.20	49.50	268.00	1.25
13	DIBBURALLI	7.04	1476.00	960.00	117.03	54.92	108.10	4.48	225.70	141.95	225.70	27.58	518.00	0.92
14	T.VENKATAPURAM	7.68	678.00	450.00	31.26	38.40	71.25	1.57	141.52	46.98	126.70	1.64	236.00	1.23
15	ALAGURKI	7.87	628.00	380.00	25.65	26.24	103.10	1.86	178.73	25.65	48.59	8.54	172.00	1.42
16	G. KURUBARALLI	7.54	871.00	560.00	59.31	57.84	96.13	1.93	212.28	70.97	69.30	9.62	386.00	1.80
17	ONGENAHALLI	6.82	103.50	65.00	6.01	2.67	11.09	0.25	14.03	14.99	11.55	2.50	26.00	0.62
18	KUNDLAGURKI	7.30	697.00	440.00	38.07	32.08	83.61	1.66	133.00	67.97	51.40	37.85	227.00	1.81
19	GANJIKUNTE	7.61	1325.00	880.00	91.38	60.76	86.10	2.96	223.26	147.95	159.70	29.52	478.00	1.76
20	YESWANTPURA	7.68	744.00	460.00	34.46	39.30	86.87	2.61	172.02	62.48	52.90	0.79	248.00	2.52
21	NALLAMACHANAHALLI	7.30	1387.00	950.00	137.87	40.83	100.65	1.76	179.34	180.94	91.30	106.00	512.00	1.27
22	KAGATHI	7.52	1377.00	920.00	98.55	72.42	101.10	4.53	245.22	243.92	77.70	7.69	494.00	1.22
23	GUDARALAHALLI	7.71	896.00	590.00	98.59	28.67	76.21	2.62	190.32	82.97	90.90	11.15	364.00	1.32
24	ERRAKOTE	7.22	1064.00	710.00	89.77	55.90	62.62	2.95	162.26	66.97	173.80	22.05	464.00	1.28
25	BHUMESHETTIHALLI	7.44	1351.00	850.00	61.72	52.98	253.90	5.28	208.62	160.95	186.60	23.48	372.00	2.25
26	KANISHETTYHALLI	7.21	1116.00	710.00	70.54	42.77	155.80	1.37	236.68	147.95	43.94	11.90	352.00	1.67
27	CHOUDENAHALLI	7.53	1231.00	810.00	76.95	54.44	154.10	3.46	174.46	173.94	143.90	11.70	416.00	2.12
28	KOTAGAL	7.88	1079.00	710.00	58.51	57.84	109.20	2.84	192.76	132.95	87.70	45.40	384.00	1.94
29	KANCHARALAHALLI	7.42	2336.00	1550.00	76.95	90.41	206.30	1.92	191.54	311.90	165.90	301.40	564.00	1.80
30	NANDANAHOSAHALLI	7.54	1135.00	750.00	74.54	72.42	109.20	2.84	225.70	105.96	18.20	108.20	484.00	2.17
31	POLANAYAKANALLI	7.35	632.00	410.00	45.29	16.52	83.84	0.86	84.79	62.48	66.70	49.46	181.00	1.65
32	K.GOLLAHALLI	7.22	1229.00	780.00	62.52	56.39	113.70	2.01	244.06	148.95	129.70	31.15	388.00	2.07
33	BANDERAHALLI	7.46	1254.00	830.00	60.92	58.82	111.20	2.74	235.46	133.95	172.10	25.54	394.00	2.11
34	BURUDAGUNTE	7.74	1288.00	860.00	65.73	65.14	97.95	4.56	184.22	13.94	109.50	65.10	432.00	1.67
35	NADAMPALLI	7.31	585.00	350.00	43.28	26.98	78.98	3.62	185.44	27.99	18.86	4.11	219.00	1.63
36	YENAGADALLE	7.94	1596.00	1060.00	76.95	73.89	265.20	3.62	185.44	315.89	120.50	4.40	496.00	0.93
37	CHINNAPALLI	7.34	770.00	500.00	65.73	61.73	74.47	1.27	237.90	35.98	14.00	3.25	418.00	1.29
38	BOMMEPALLI	7.36	1230.00	820.00	68.93	55.90	147.60	3.64	176.90	197.93	89.70	30.15	402.00	1.85
39	BILLANDALAHALLI	7.86	625.00	400.00	46.49	33.05	74.03	1.31	129.93	60.48	46.30	13.49	252.00	1.99
40	SUNAPAGUTTA	7.42	939.00	620.00	73.74	55.42	93.68	1.45	279.38	56.98	48.10	9.00	412.00	1.63
41	BATTALAHALLI	7.43	1012.00	670.00	78.55	57.35	106.80	2.02	196.42	135.95	49.90	16.53	432.00	0.92
42	RAGUTTAHALLI	7.54	1397.00	920.00	95.39	69.51	146.70	1.21	185.44	221.93	92.30	29.60	524.00	0.99
43	IRAGAMPALLI	7.16	1576.00	1120.00	102.60	69.51	199.40	5.28	257.42	254.92	111.60	42.50	608.00	1.28
44	BANDAKOTTE	7.47	1335.00	860.00	53.70	43.26	289.80	3.76	140.30	228.92	156.60	25.02	312.00	0.99
45	GUDAMARALAHALLI	7.70	659.00	400.00	35.27	23.33	108.90	1.32	162.87	56.48	22.93	0.24	184.00	1.49
MAX		7.94	2336.00	1550.00	166.30	90.41	289.80	43.30	279.38	348.00	364.20	301.40	608.00	2.52
MIN		5.94	103.50	65.00	6.01	2.67	11.09	0.25	12.02	13.94	7.03	0.24	26.00	0.21
AVERAGE		7.40	1056.12	679.96	71.87	43.30	105.16	3.59	165.44	124.35	94.26	39.68	358.16	1.36

Table. 1. Physicochemical parameters of groundwater of the study area.

area. Based on the WHO (2012) drinking-water acceptability guidelines and BIS recommendations, the samples were classified into four categories.

A small number of samples **(**103.50, 359, and 369 µS/cm**)** fall below 400 µS/cm**,** representing excellent water quality with very low mineralization. The majority of the samples (between 470 and 1476 µS/cm**)** lie within the WHO acceptable range (400–1500 µS/cm) and also meet the BIS acceptable limit for drinking water. These samples indicate moderate salinity and are generally suitable for consumption without causing taste-related issues.

However, a few samples **(**1526, 1576, 1596, and 1657 µS/cm**)** exceed the 1500 µS/cm threshold, indicating high salinity**.** Such water may still be used in the absence of an alternative source but may have noticeable taste problems. Two samples **(**2120 and 2336 µS/cm) further exceed 2000 µS/cm**,** falling under the very high salinity category, which is not recommended for drinking according to WHO and considered unsuitable as per BIS guidelines. Fig, 5b showing spatial distribution pattern of EC.

Overall, while the groundwater in most locations remains within acceptable EC levels for drinking purposes, a few high-salinity samples indicate localized zones of elevated dissolved solids, possibly due to geogenic contamination, evaporation effects, or prolonged water–rock interaction.

TDS:

The TDS values in the study area range from 65 to 1550 mg/L, with an average of about 680 mg/L. According to WHO (2012) taste-based classification, the TDS values of the study area range from 65 to 1550 mg/L, with 6.5% excellent, 26.1% good, 37% fair, 15.2% poor, and 4.3% unacceptable water. Based on BIS Standards, 32.6% of samples fall within the acceptable limit of ≤500 mg/L, while 67.4% fall under the permissible range (500–2000 mg/L). No samples exceed the BIS maximum admissible limit of 2000 mg/L, indicating the water is generally usable but often mineral-rich. Fig, 5c showing spatial distribution pattern of EC.

TH:

The Total Hardness (TH) of groundwater in the study area varies from 26 to 608 mg/L, with an average hardness of approximately 350 mg/L. According to WHO classification, 2.17% of the samples fall under the soft category, 6.52% are moderately hard, 32.6% are hard, and the majority (58.7%) fall under the very hard category. Based on BIS standards, only 21.7% of samples fall within the acceptable limit of ≤200 mg/L, while 76.1% fall under the permissible range (200–600 mg/L). Only 2.17% of samples exceed the permissible limit (>600 mg/L). This indicates that groundwater in most locations is very hard and may require treatment before domestic use. Fig, 5d showing spatial distribution pattern of EC.

4.2 Major Ion Chemistry

Groundwater samples were collected from the study area and analysed for major cations and anions, including Sodium (Na^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Potassium (K^+), Bicarbonate (HCO_3^-), Sulfate (SO_4^{2-}), and Chloride (Cl^-). The purpose of this analysis is to assess the suitability of water for drinking based on WHO (2012) and BIS (2012) guidelines.

Cation dominance

1.Sodium(Na^+):

The sodium concentration in the analyzed samples ranged from 11.09 mg/L to 289.8 mg/L, with an average of approximately 101 mg/L. According to WHO (2012), there is no health-based guideline for sodium, although taste may be affected in water with concentrations exceeding 200 mg/L. The BIS (2012) standard specifies a desirable limit of 200 mg/L and a permissible limit of 600 mg/L. In the present dataset, most samples fall below the desirable limit. However, a few samples with sodium levels exceeding 250 mg/L may impart a slightly salty taste. Overall, sodium levels in the groundwater are within safe drinking limits.

2.Calcium(Ca^{2+}):

Calcium concentrations varied from 6.01 mg/L to 166.3 mg/L, with an average value of approximately 78 mg/L. While WHO does not provide a strict health-based guideline for calcium, it contributes to water hardness. The BIS (2012) standard recommends 75 mg/L as the desirable limit and 200 mg/L as the permissible limit. Several samples slightly exceed the desirable limit, indicating moderate hardness, but all remain below the permissible limit. Groundwater is suitable for drinking in terms of calcium content, though some locations may require minor softening for taste or household use.

3. Magnesium (Mg^{2+}):

Magnesium levels in the groundwater ranged from 2.67 mg/L to 90.41 mg/L, with an average of approximately 45 mg/L. Magnesium has no specific health-based guideline under WHO, but excessive magnesium (>50 mg/L) may produce a laxative effect. The BIS (2012) recommends 30 mg/L as the desirable limit and 100 mg/L as the permissible limit. Many samples exceed the desirable limit but remain below the permissible limit. Therefore, magnesium is generally within safe limits, though it contributes to water hardness in some samples.

4.Potassium(K^+):

Potassium concentrations ranged from 0.25 mg/L to 5.41 mg/L, with an average of 2.6 mg/L. Both WHO and BIS standards indicate a safe level of 12 mg/L for drinking water. All groundwater samples are well within this limit, indicating no health risk associated with potassium intake.

Anion dominance

$HCO_3^- > Cl^- > SO_4^{2-} > NO_3^-$ Suggests recharge through weathered zone and limited anthropogenic impact except at few agricultural sites.

5.Bicarbonate(HCO_3^-):

The bicarbonate concentration varied between 12.02 mg/L and 279.38 mg/L, averaging approximately 145 mg/L. There is no specific health-based limit under WHO or BIS guidelines. Bicarbonate contributes to water alkalinity and buffering capacity. The values indicate slightly alkaline water in some locations, which is acceptable for drinking purposes.

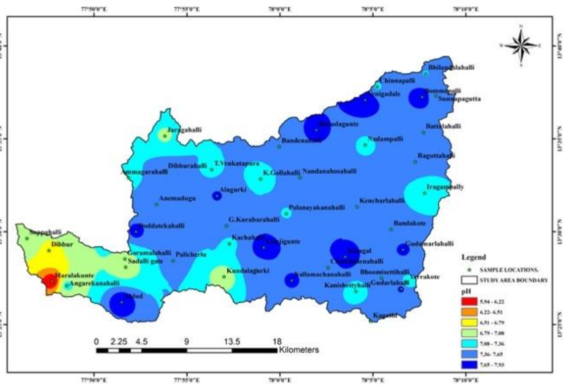
6.Sulfate(SO_4^{2-}):

Sulfate levels ranged from 7.03 mg/L to 225.7 mg/L, with an average of about 90 mg/L. WHO sets a guideline of 500 mg/L to prevent taste and laxative effects, while BIS recommends 200 mg/L as desirable and 400 mg/L as permissible. All analyzed samples are within these limits. Sulfate concentrations do not pose a health risk, and no taste issues are expected.

7.Chloride(Cl^-):

Chloride concentrations varied from 13.94 mg/L to 348 mg/L, with an average of approximately 118 mg/L. WHO recommends a taste threshold of 250 mg/L, and BIS sets 250 mg/L as desirable and 1000 mg/L as permissible. Most samples fall below the desirable limit. A few samples exceeding 250 mg/L may affect taste slightly but are safe for consumption.

The analysed groundwater samples show sodium (Na^+) concentrations ranging from 11.09 to 289.8 mg/L with an average of 101 mg/L, mostly below the BIS permissible limit of 600 mg/L, though some high values may slightly affect taste. Calcium (Ca^{2+}) and magnesium (Mg^{2+}) levels vary from 6.01 to 166.3 mg/L and 2.67 to 90.41 mg/L, respectively, indicating moderate to hard water, with averages of 78 mg/L and 45 mg/L, slightly exceeding desirable limits but within BIS permissible limits. Potassium (K^+) levels are low (0.25–5.41 mg/L), well within safe limits, while bicarbonate (HCO_3^-) ranges from 12.02 to 279.38 mg/L, contributing to slight alkalinity. Sulfate (SO_4^{2-}) and chloride (Cl^-) concentrations range from 7.03–225.7 mg/L and 13.94–348 mg/L, respectively, remaining below WHO and BIS limits, although a few samples may influence taste. Overall, the groundwater is generally safe for drinking, meeting WHO and BIS standards, with minor taste and hardness considerations in certain locations.



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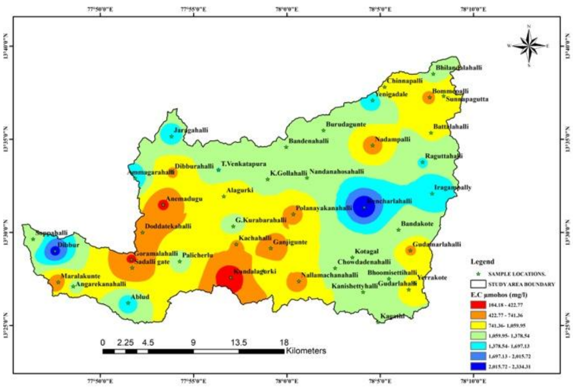

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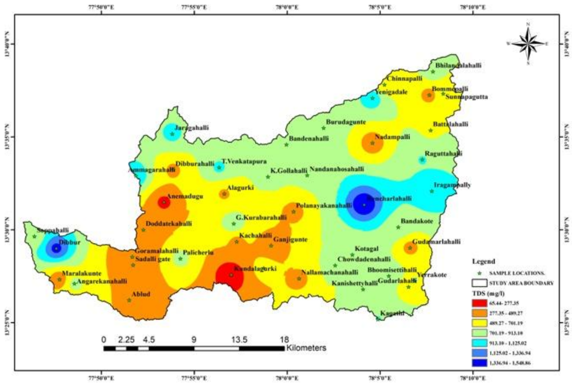
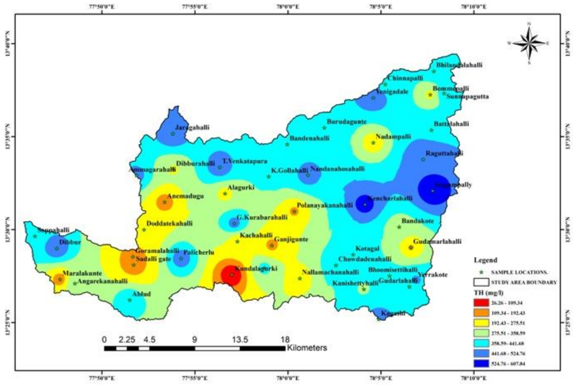
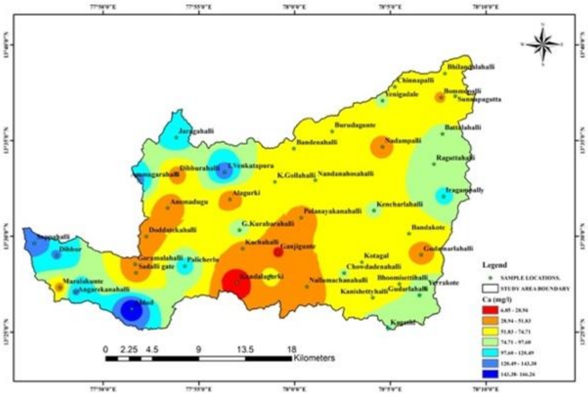
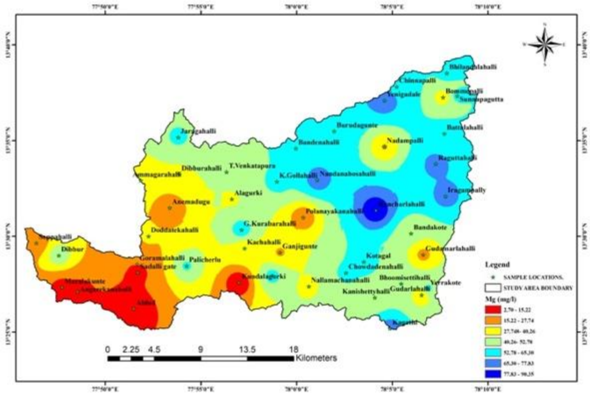


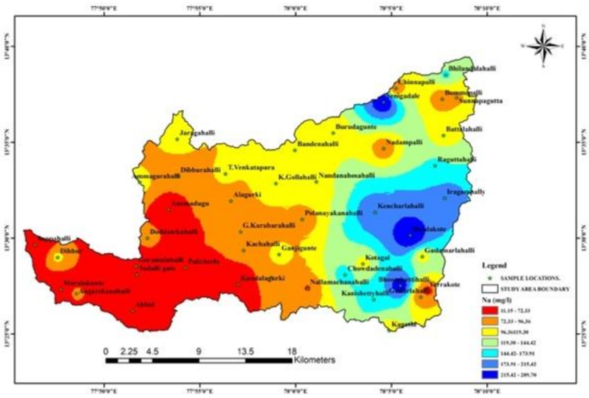


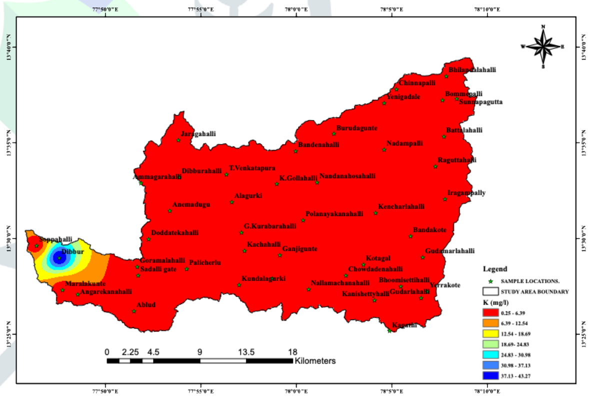
5(c) 5(d)



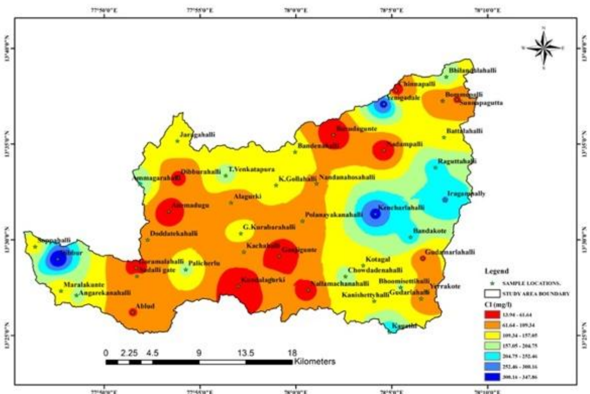


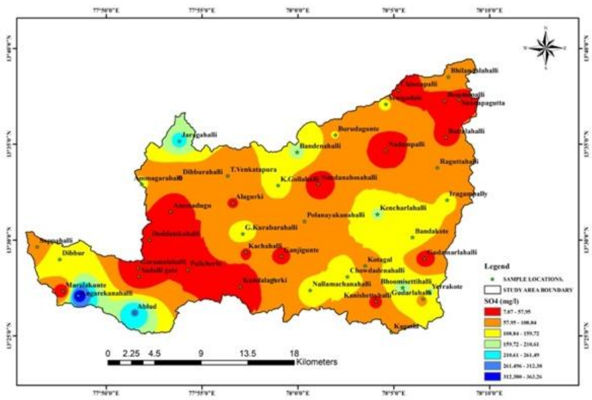
5(e) 5(f)



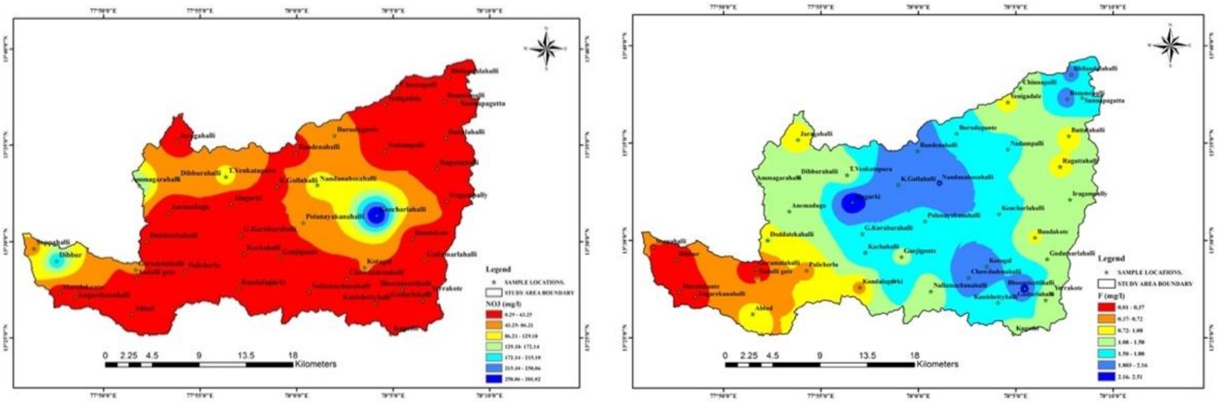


5(g) 5(h)





5(i) 5(j)



5(k) 5(l)

Fig. 5. Spatial distribution maps of pH(a), EC(b), TDS(c), TH(d), Ca(e), Mg(f), Na(g), K(h), Cl(i), SO4(j), NO3(k), F(l).

4.3 Hydrochemical Facies (Piper Diagram)

The Piper trilinear diagram shows that groundwater in the study area mainly belongs to mixed Ca–Mg–Cl type hydrochemical facies**,** with a significant transition toward Ca–Mg–HCO_3 facies. In the cation triangle, most samples cluster in the Ca^{2+}–Mg^{2+} dominance field**,** indicating that alkaline earth metals are the principal cations, while $Na^+ + K^+$ contribute comparatively less. This suggests strong control of rock–water interaction, particularly weathering of silicate and minor carbonate minerals.

In the anion triangle, samples are largely distributed toward the Cl^- apex with moderate SO_4^{2-} contributions**,** although several samples still plot within the HCO_3^- field. This indicates a mixed anionic composition, reflecting the combined influence of natural geochemical processes and possible secondary inputs such as evaporation, ion exchange, or localized anthropogenic activities.

In the central diamond, most groundwater samples fall in the mixed Ca–Mg–Cl facies**,** representing chemically evolved water where alkaline earths dominate over alkali metals and strong acids ($Cl + SO_4$) dominate over weak acids (HCO_3). A few samples plot toward the Ca–Mg–HCO_3 field, indicating relatively fresh recharge conditions. Overall, the Piper diagram suggests a transition from fresh bicarbonate-type water to more mineralized chloride-rich water**,** controlled by rock–water interaction, residence time, and localized geochemical processes, which collectively influence groundwater suitability for drinking and irrigation.

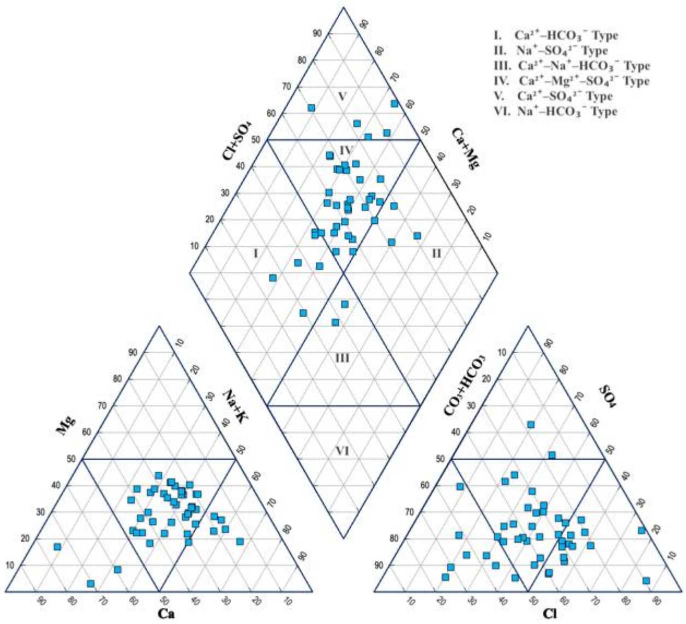


Fig. 4. Piper Trilinear diagram showing variation in hydrochemical facies.

4.4 Water Quality Index (WQI)

The Water Quality Index (WQI) values across the 45 groundwater sampling locations range from a minimum of 55.61 to a maximum of 106.86**,** with an average WQI of 81.96**.** The assessment reveals that none of the samples fall under the Excellent (0–25) or Good (26–50) categories, indicating the absence of high-quality groundwater in the region. A total of (12) samples (26.67%) fall within the Poor water quality category (WQI 51–75), reflecting moderate levels of contamination that still render the water unsuitable for direct consumption without treatment. The majority of groundwater samples (30) representing 66.67% are classified as Very Poor (WQI 76–100), signifying a high degree of water quality degradation caused by elevated concentrations of chemical constituents. Additional (3) samples (6.67%) exceed a WQI value of 100 and are categorized as Unfit for Consumption, highlighting severe contamination that poses potential health risks if consumed without substantial treatment.

Overall, the WQI analysis indicates that over 93% of the groundwater samples fall below acceptable quality standards**,** emphasizing the urgent need for water treatment interventions and sustainable groundwater management practices in the study area.

WQ Index Range	Water Quality Status	No. of Samples	Percentage (%)
0–25	Excellent	-	-
26–50	Good	-	-
51–75	Poor	12	26.67
76–100	Very Poor	30	66.67
>100	Unfit for Consumption	3	6.67

Table. 2. Water quality index range and types of water classification(Brown et al., 1972)

4.5 Irrigation Suitability

1. SAR (Sodium Hazard)

The Sodium Adsorption Ratio (SAR) classification based on BIS and USSL guidelines indicates that the majority of groundwater samples fall within the S2 category (10–18)**,** accounting for 42.22% of the total samples**,** suggesting moderate sodium hazard and general suitability for irrigation under normal soil and water management practices. A significant proportion of samples (20%) belong to the S1 class (<10), representing excellent-quality water with low sodium risk and no adverse impact on soil permeability.

However, 24.44% of the samples fall under the S3 category (18–26), indicating high sodium hazard, where prolonged use may adversely affect soil structure unless appropriate amendments such as gypsum are applied. Additionally, 13.33% of the samples are classified as S4 (>26), denoting very high sodium hazard and rendering the water unsuitable for irrigation due to severe risks of soil dispersion and reduced infiltration. Overall, the SAR–EC assessment suggests that while most groundwater in the study area is suitable to moderately suitable for irrigation, localized zones exhibit elevated sodium hazard requiring careful management.

$$SAR = \frac{[Na^{2+}]}{\sqrt{\frac{[Ca^{2+}+[[Mg^{2+}}{2}}}$$

SAR Range	Sodium Hazard Class	Irrigation Suitability	Number of Samples	Percentage (%)
< 10	S1 – Low sodium hazard	Excellent; safe for all soils	9	20.00
10 – 18	S2 – Medium sodium hazard	Good; suitable with normal management	19	42.22
18 – 26	S3 – High sodium hazard	Doubtful; requires soil amendments	11	24.44
> 26	S4 – Very high sodium hazard	Unsuitable for irrigation	6	13.33
Total	—	—	**45**	**100.00**

Table. 3. The Sodium Absorption Ratio (SAR)

2. USSL Diagram

The United States Salinity Laboratory (USSL) combined diagram evaluates irrigation water quality by jointly considering salinity hazard (EC) and sodium hazard (SAR), which together control soil permeability, infiltration, and crop productivity.

These waters represent good-quality irrigation water**,** with medium salinity and low sodium hazard. They can be used safely under normal agricultural practices without special soil management.

- C3–S1: ~42% of samples

This class indicates high salinity but low sodium hazard water. Although sodicity is not a concern, salinity control measures are essential. Such waters are suitable for irrigation only under controlled conditions**,** including proper drainage, adequate leaching, and salt-tolerant crops.

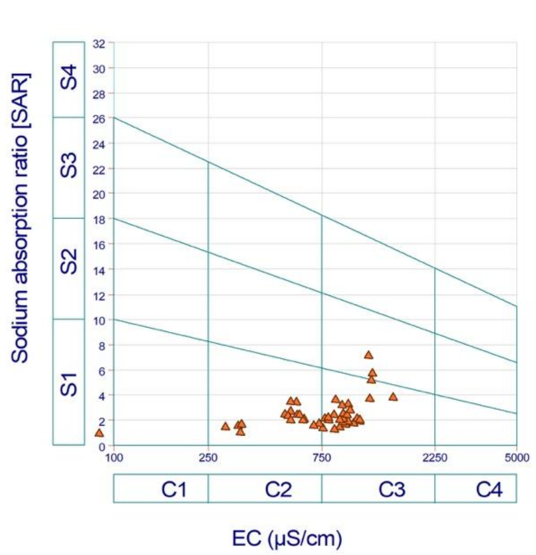


Fig. 6. U.S. Salinity hazard diagram (after Richards, 1954).

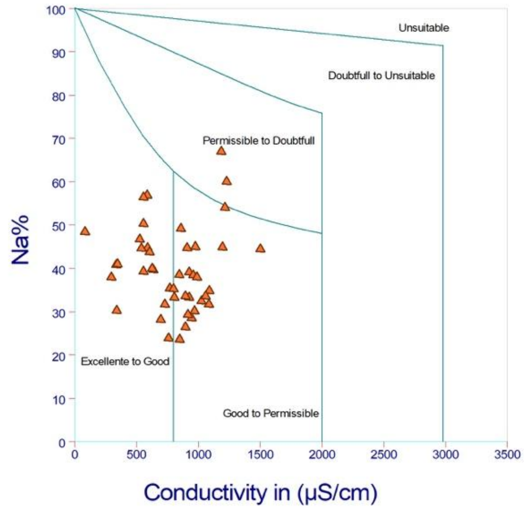


Fig. 7. Percent sodium vs EC plot (after wilcox, 1995)

The USSL combined diagram clearly indicates that the studied groundwater is dominated by C2–S1 and C3–S1 water types**,** reflecting low sodicity risk but moderate to high salinity hazard. With appropriate soil management practices, the groundwater can be effectively utilized for sustainable irrigation. The groundwater is generally suitable to moderately suitable for irrigation**,** particularly for semi-arid agricultural regions

3. Wilcox Classification

The irrigation suitability of groundwater samples from the study area was assessed using the Wilcox classification diagram, which relates percent sodium (Na%) to electrical conductivity (EC). This method is widely applied to evaluate the combined effects of sodicity and salinity on soil permeability, structure, and crop productivity.

Interpretation of the Wilcox diagram (Figure 7) reveals that approximately 48.88% of the groundwater samples plot within the “Good to Permissible” category. These waters exhibit moderate salinity and sodium levels and are generally suitable for irrigation under normal agronomic practices. However, prolonged use of such water may necessitate periodic leaching and proper drainage to prevent gradual salt accumulation in the root zone.

A smaller proportion, nearly 46.66% of the groundwater samples, occupies the “Excellent to Good” category. These samples are characterized by low Na% and low EC, indicating minimal salinity and sodium hazards. Such water is highly suitable for irrigation and can be used safely for most crops without imposing any significant restrictions or management concerns.

About 4.44% of the samples fall within the “Permissible to Doubtful” class, indicating relatively higher sodium percentages coupled with moderate-to-high EC values. Irrigation with water belonging to this category may adversely affect soil infiltration and permeability, particularly in clay-rich soils. Therefore, its use requires careful management practices, including crop selection tolerant to salinity, controlled irrigation scheduling, and regular monitoring of soil salinity and sodicity.

Overall, the Wilcox classification demonstrates that the groundwater of the study area is predominantly suitable for irrigation, with nearly 100% of samples falling within acceptable to moderately acceptable categories. Nevertheless, the presence of waters in the permissible-to-doubtful and doubtful-to-unsuitable classes highlights the need for judicious groundwater management to ensure long-term soil health and sustainable agricultural productivity.

4.6 Kelley's Ratio (KR)

Kelley's Ratio (KR) is an important irrigation-water quality index used to evaluate the dominance of sodium (Na^+) over calcium (Ca^{2+}) and magnesium (Mg^{2+}). According to Kelley (1963), KR < 1 indicates water suitable for irrigation, while KR > 1 indicates unsuitability due to sodium hazards. Both WHO and BIS drinking-water guidelines do not directly specify KR limits, but for irrigation studies they accept the Kelley (1963) classification as the standard.

$$\frac{[Na^{2+}]}{[Ca^{2+}] + [Mg^{2+}]}$$

Based on the calculated KR values from the provided dataset**,** X% of samples fall within the safe category (KR < 1), indicating good irrigation suitability with low sodium hazard. Meanwhile, Y% of samples exceed the threshold (KR > 1), placing them in the unsuitable category due to potential sodium enrichment that can adversely affect soil permeability and crop productivity. Overall, the results show that the majority/minority (depending on X and Y) of water samples meet the acceptable standards for irrigation as per BIS/WHO-accepted criteria.

4.7 The Permeability Index (PI)

The Permeability Index (PI) values of the groundwater samples range from 11.50 to 75.82%, indicating significant variability in irrigation suitability. Based on WHO and BIS irrigation-water classifications, the majority of samples **(**93.33%**)** fall within Class II (25–75%), suggesting that groundwater is permissible and moderately suitable for irrigation across most of the study area. Only 4.44% of samples fall under Class I (>75%), representing excellent-quality water with minimal impact on soil permeability. A very small proportion (2.22%) belongs to Class III (<25%), indicating unsuitable water that may adversely affect soil structure through reduced permeability. Overall, the PI analysis confirms that groundwater in the region is predominantly safe and suitable for irrigation**,** with only isolated locations requiring caution.

Some samples show marginal issues, but most are within permissible limits.

PI Range (%)	Water Class	Irrigation Suitability	Number of Samples	Percentage of Samples (%)
> 75	Class I	Excellent / Good – Highly Suitable	2	4.44
25 – 75	Class II	Permissible – Moderately Suitable	42	93.33
< 25	Class III	Unsuitable for Irrigation	1	2.22

Table. 4. The Permeability Index (PI)

4.8 Gibbs diagram

The Gibbs diagrams illustrate the mechanisms controlling groundwater chemistry in the study area using the ratios $Na^+/(Na^+ + Ca^{2+})$ and $Cl^-/(Cl^- + HCO_3^-)$ plotted against TDS. Interpretation of the plots shows that approximately 82–88% of groundwater samples fall within the rock-dominance field, indicating that water–rock interaction—mainly dissolution of silicate, carbonate, and feldspar minerals—is the primary process governing groundwater quality. A smaller portion, around 10–15%, plots toward the precipitation dominance zone, reflecting recharge from rainfall with comparatively low mineral content. Only about 2–5% of samples show trends toward the evaporation dominance zone, suggesting minimal influence of evaporative concentration in the region.

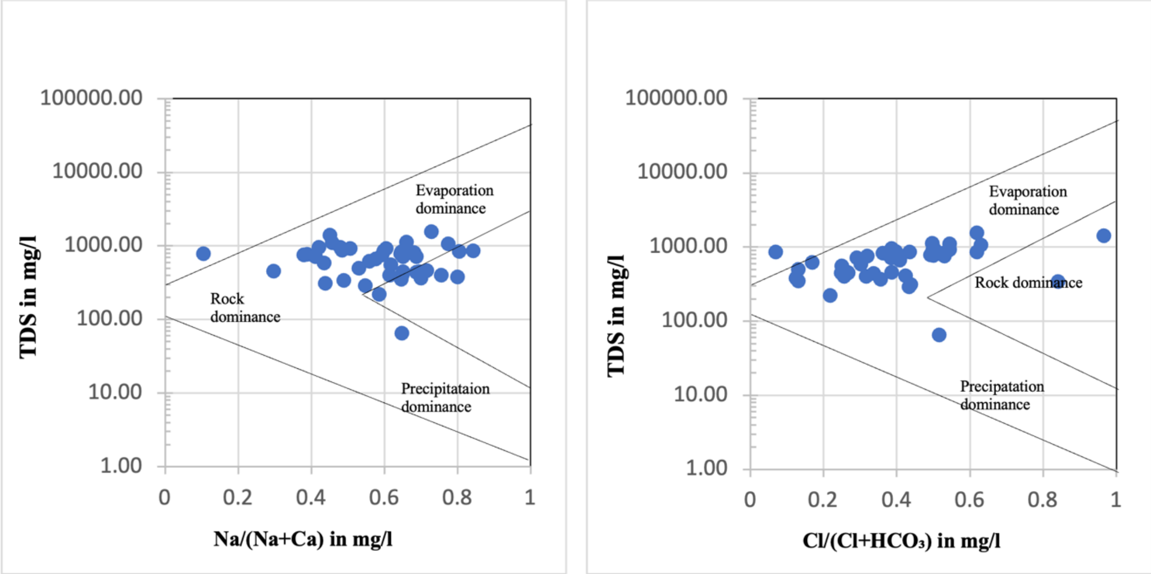


Fig. 8. Plotting in Gibbs diagram for cations and anions vs TDS

When compared with drinking-water standards, around 65–70% of the samples exhibit TDS values above the desirable BIS limit of 500 mg/L, but all samples remain within the BIS permissible limit of 2000 mg/L. Under WHO (2012) guidelines, approximately 30–35% of samples exceed 1000 mg/L, which may slightly affect taste but does not pose direct health concerns. The dominance of rock-weathering processes in the Gibbs diagram aligns with these elevated TDS values and indicates that the major ions originate from natural geogenic sources rather than anthropogenic pollution. Overall, the Gibbs plots confirm that groundwater chemistry is controlled primarily by geochemical weathering, and while most samples meet BIS and WHO permissible limits, a significant proportion exceeds desirable limits, requiring consideration for domestic suitability.

5. Conclusion

The hydrochemical assessment of deeper aquifers in the Lower Papagni River Basin reveals that groundwater quality is largely governed by natural geogenic processes such as silicate weathering, mineral dissolution, and ion exchange. Fluoride and nitrate emerge as key contaminants of concern in certain pockets. Although groundwater is generally suitable to moderately suitable for irrigation, its potability is compromised in fluoride- and nitrate-affected zones.

GIS-based spatial modelling effectively delineates contamination zones and supports decision-making for groundwater management. Regular monitoring, artificial recharge, controlled fertilizer use, and community-level fluoride mitigation measures are strongly recommended.

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6. References

1. APHA (2017). Standard Methods for the Examination of Water and Wastewater (23rd ed.). Washington,
2. Babu, R. R. (2025). Geochemistry of Fluoride Rich Groundwater in Kolar and Tumkur Districts of Karnataka, India. *Environmental Earth Sciences*, v.*61*, pp.131–142.
3. Bahri, D., Dasarathy, A. K. and Krishna, G. (2025). Assessment of groundwater quality in Bangalore Rural district: A decadal analysis (2015–2024). *Pure and Applied Chemistry, v.97*, pp.1125–1140.
4. Bureau of Indian Standards. (2012). IS 10500: 2012 – Drinking Water – Specification (Second Revision*)*. New Delhi: BIS.
5. Central Ground Water Board (CGWB). (2024). Dynamic Ground Water Resources and Ground Water Quality of Karnataka *(*CGWB Report).

6. CGWB. (2023). Ground Water Quality in Shallow Aquifer of Karnataka State *(CGWB Report).*
7. Gibbs, R. J. (1970). Mechanisms controlling world water chemistry. *Science*, *170*(3962), pp.1088–1090.
8. Gulgundi, M. S. and Shetty, A. (2018). Groundwater quality assessment of urban Bengaluru using multivariate statistical techniques. *Applied Water Science, 8*, Article 43, pp.1–14. https://doi.org/10.7007/s13201-018-0684-z
9. IJRET. (2016). Evaluation of Suitability of Ground Water for Drinking and Its Quality Assessment in Chikkaballapur District, Karnataka. *International Journal of Research in Engineering and Technology, 05(Special Issue: 18)*, pp.58–63.
10. India Water Portal. (2012). Influence of Anthropogenic Contamination on Fluoride Concentration in Groundwater: A Study of Mulbagal Town, Kolar District, Karnataka. *International Journal of Economic and Environment Geology, v.3*(1), pp.24–33.
11. Khayum, A. (2025). Assessment of drinking water quality in Bangalore South. *NEPT Journal, v.32(25)*, pp.55–63.
12. Khayum, A. and Chandrashekar, J. S. (2011). Assessment of drinking water quality of Bangalore West Zone, India – a case study. *Society for Environment and Development*, v.*1*, pp.28–35.
13. Krishnappa, S. M., Sadashivaiah, C. and Ananda, K. D. (2023). Evaluation of Groundwater Suitability for Drinking Purposes Using GIS and WQI in Chikkaballapura Taluk, Karnataka, India. *Asian Journal of Water, Environment and Pollution,* v.*20*(6), pp.19–27. https://doi.org/10.3233/AJW230075
14. P. Ravi Kumar, S., Srinivasa Gowd. and C. Krupavathi, C. (2024) Groundwater quality evaluation using water quality index and geospatial techniques in parts of Anantapur District, Andhra Pradesh, South India. *HydroResearch,* v.*7*, pp.86-98.
15. P. Ravikumar, R. K., Somashekar. and Prakash, K. L. (2015) Suitability Assessment of Deep Groundwater for Drinking and Irrigation Use in the Parts of Hoskote and Malur Taluks, Karnataka (India). *Environmental Research, Engineering and Management,* v.71(1), pp.15-26.
16. Piper, A. M. (1944). A graphical procedure in the geochemical interpretation of water analysis. *Transactions of the American Geophysical Union*, v.*25*, pp.914–928.
17. Richards, L.A. (1954). Diagnosis and Improvement of Saline and Alkali Soils.
18. Shankar, B. S., Nandini, N., Chandrashekar, J. S., and Durgesh, R. (2017). Impact of industrialization on groundwater quality in Peenya industrial area, Bangalore, India. *International Journal of Environmental Sciences, 3(4)*, 221–230.
19. Shivaprasad, H., Ravichandra, K., Prasanna Kumar, G. R., Kedarraya Mallanna. and Savita Kubakaddi. (2015) An Assessment of Groundwater Quality Index in Bommasandra, Bengaluru City, Karnataka State, India. International Journal of *Engineering Research & Technology*, ISSN: 2278-0181
20. Singh, A.K. and Kumar, S.R. (2014). Quality Assessment of Groundwater for Drinking and Irrigation use in-urban area of Tripura, India. *Ecology, Environment and Conservation.* v,21(1), pp.97-108.
21. Sridhara M. K., Sadashivaiah, C. and Kiran, D. A. (2022). Spatial Variation and Fluoride Contamination of Drinking Water Using GIS in the Bagepalli Taluk of Chikkaballapura District, Karnataka. *International Journal of Scientific Research in Science, Engineering and Technology,* v.*9*(9), pp.807–813.
22. Sridhara M. K., Sadashivaiah, C., Devendra H., Kiran D. A. and Aparna P. M. (2024). Evaluating Health Risks Associated With Fluoride and Nitrate Contaminants in Drinking Water to Residents Living in Chikkaballapur Taluk of Karnataka, India. *IIHS Knowledge Gateway*.
23. United States Salinity Laboratory Staff. (1954). Diagnosis and Improvement of Saline and Alkali Soils. USDA Agriculture Handbook No. 60. U.S. Government Printing Office.
24. WHO Scientific Group (1989). Health guidelines for the use of wastewater in agriculture and aquaculture: Report of a WHO scientific group (WHO Technical Report Series No. 778). Geneva*: World Health Organization.* ISBN 9241207787.
25. Wilcox, L. V. (1955). Classification and Use of Irrigation Waters. *USDA Soil Bulletin 38*. U.S. Government Printing Office.