Biological Forum – An International Journal **15(8): 591-601(2023)**

ISSN No. (Print): 0975-1130
ISSN No. (Online): 2249-3239

Hydrochemical Analysis of Groundwater in Southern Ranebennur Taluk, Haveri District, Karnataka

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(Received: 08 June 2023; Revised: 04 July 2023; Accepted: 29 July 2023; Published: 15 August 2023)
(Published by Research Trend)

ABSTRACT: Hydrochemical analysis of groundwater is crucial for assessing its quality and ensuring it meets agricultural safety standards, as poor water quality—characterized by high levels of salts, minerals, or contaminants—can harm soil health, diminish crop yields, and jeopardize long-term agricultural sustainability. This study investigates the groundwater quality in southern Ranebennur taluk, focusing on its suitability for irrigation by examining key parameters such as pH, electrical conductivity (EC), sodium adsorption ratio (SAR), and concentrations of major cations (Na^+, Ca^{2+}, Mg^{2+}, K^+) and anions (Cl^-, HCO_3^-, SO_4^{2-}, CO_3^{2-}, NO_3^-). The results reveal a pH range of 6.44 to 8.00, indicating neutral to slightly alkaline conditions, alongside moderate salinity levels. Notably, sodium and chloride ions were predominant, with SAR values spanning from 6.71 to 24.74 and total dissolved solids (TDS) ranging from 537.6 to 2758.4 mg L^{-1}. Results highlight the risk that elevated sodium and chloride concentrations pose to soil and crop health, underscoring the urgent need for vigilant monitoring and sustainable water resource management to safeguard agriculture in the region.

Keywords: Groundwater, Hydrochemical, Southern Ranebennur, SAR, RSC.

INTRODUCTION

Approximately 97.2% of the world's water is contained in oceans and seas, with the remaining 2.8% existing as groundwater and surface water; notably, groundwater comprises 0.59% and is 30 times more abundant than surface water at just 0.02%. Groundwater quality, a critical focus in water resource studies, is primarily influenced by recharge and discharge patterns, the nature of the host and associated rocks, and anthropogenic contamination. In recent years, the degradation of groundwater quality and quantity due to human activities has gained significant attention (Anon., 2021). The quality of irrigation water is determined by its source, with regional variations largely influenced by geology and climate. Furthermore, significant differences in water quality can arise based on whether the water is sourced from rivers, ponds, or groundwater aquifers, each with distinct geological characteristics. The chemical composition of irrigation water can directly impact plant growth through toxicity or nutrient deficiency, or indirectly by affecting nutrient availability (Ayers and Westcott 1985; Bouaissa *et al.,* 2021). The interactions among various chemical constituents of water can lead to detrimental effects on soil properties and crop growth. Key parameters such as electrical conductivity (EC), sodium adsorption ratio (SAR), and residual sodium carbonate (RSC) are essential for classifying water quality (Baba *et al.,* 2020). The dominant characteristics of the water dictate management strategies for soil reclamation.

Despite an average annual precipitation of 400 m³ per hectare, the country faces significant water shortages, primarily due to erratic and unpredictable rainfall patterns and ineffective water management practices (Duraisamy *et al*., 2019). Many arid and semi-arid regions, as well as some humid coastal areas, struggle with poor groundwater quality, which exacerbates the issue. Competing demands for fresh water from sectors like industry, power generation, and households further diminish the availability of water for agriculture (Gauns *et al.,* 2020). While water scarcity is a pressing concern, the detrimental impacts of groundwater misuse, particularly excessive withdrawal from freshwater aquifers, have not been adequately addressed. To achieve effective irrigation management, it is crucial to judiciously integrate all water resources at the farm, system, and basin levels while employing safe methods for utilizing poor-quality water, including treated sewage (Hanaa and Megahed 2020). The presence of soluble salts in irrigation water—regardless of its source—is critical, as both the total concentration and the specific types of salts determine the water's suitability for agricultural use.

Ranebennur, located at the centre of Karnataka, spans an area of 901 square kilometers and is situated between 14.62 ºN latitude and 75.62 ºE longitude. Agriculture serves as the primary livelihood for the residents of this taluk. The total geographical area measures 90,745 hectares, with the net sown area constituting 70.88% and the area cultivated more than once accounting for 16.15% of the total. Of the net sown area, 61.9% is irrigated via borewells, 0.74% through lift irrigation, while the remaining 37.26% relies on other irrigation sources (Anon, 2019). The research on groundwater quality in southern Ranebennur taluk has focused primarily on hydrochemical parameters, but lacks comprehensive assessment of long-term seasonal variations and the impact of anthropogenic activities on water quality. Further studies are needed to explore groundwater contamination risks and sustainable management practices.

MATERIAL AND METHODS

The study, titled "Hydrochemical Analysis of Groundwater in Southern Ranebennur Taluk, Haveri District, Karnataka," was conducted to assess the quality of irrigation water. Water samples were collected from the study area and analyzed at the Department of Soil Science and Agricultural Chemistry at the University of Agricultural Sciences (UAS) in Dharwad. Ranebennur is located in the geographical center of Karnataka, covering an area of 901 square kilometers and positioned between 14.62ºN and 75.62ºE. Agriculture is the primary occupation in this region, which has a total geographical area of 90,745 hectares. The study focused on the southern part of Ranebennur taluk in Haveri district, Karnataka. Groundwater samples were collected through a systematic survey of the area. Villages in the southern region of Ranebennur taluk were selected for sample collection, resulting in the collection of 153 water samples (Fig. 1).

A total of 153 groundwater samples were gathered from tube wells across 51 villages in the southern part of Ranebennur taluk. The geographical coordinates of each sample were recorded using a GPS (Global Positioning System). Prior to sample collection, the tube wells were allowed to discharge water for approximately 15 minutes to ensure sediment-free, clear water. The collected water samples were stored in 500 ml polyethylene bottles, each rinsed with the water to be sampled. To prevent microbial growth, 2-3 drops of toluene were added, and the bottles were sealed airtight and labeled with the sample code and village name, while also noting the soil type from the respective field. In the laboratory, water samples were filtered through ordinary filter paper to remove any dirt and dust particles, and they were properly labeled. All water samples underwent chemical analysis for various parameters. Simultaneously, soil samples were taken from the same fields at a depth of 30 cm, along with some clods. Both soil and water samples were analyzed for various parameters, including their ionic composition.

The pH of groundwater samples was measured using the potentiometric method (Jackson, 1973), with classifications ranging from acidic (<6.5) to alkaline (>8.0). Electrical conductivity was assessed with the conductometric method, categorizing irrigation water based on salinity hazards (Richards, 1954). Sodium and potassium concentrations were determined using a flame photometer, while calcium and magnesium were estimated via the Versenate titration method. Carbonates and bicarbonates were analyzed through titration with 0.01N H_2SO_4. Chloride content was measured with 0.02N $AgNO_3$, and sulphate concentrations were estimated using a spectrophotometer (Jackson, 1973). Nitrate and boron levels were analyzed using Kjeldahl distillation and the azomethene-H method, respectively, while water quality indices like SAR and RSC were calculated to assess irrigation suitability.

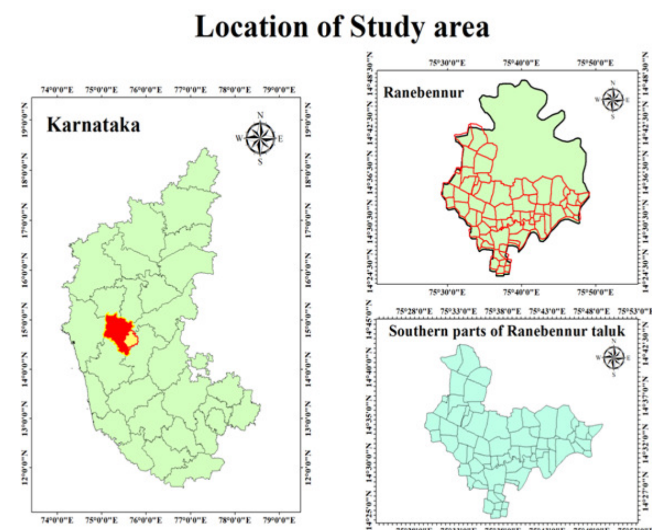

Fig. 1. Map representing study area of southern parts of Ranebennur taluk.

RESULTS AND DISCUSSION

The pH of groundwater samples collected from the southern regions of Ranebennur taluk ranged from 6.44 to 8.00, with an average value of 7.26. The lowest pH level of 6.44 was recorded in samples from Godihal village (Sample code V10S3), indicating slightly acidic conditions. Conversely, Itagi village (Sample code V20S2) exhibited the highest pH of 8.00, classifying the water as alkaline. This variation in pH levels reflects the diverse geochemical processes influencing water chemistry across different locations, which can affect the suitability of water for irrigation. Generally, the pH values in the region's irrigation water ranged from neutral to slightly alkaline. The presence of elevated concentrations of Ca^2, Mg^2, Na, and HCO_3^- ions in groundwater is likely contributing to the higher pH levels. Supporting this, Mahadevaswamy (2011) noted that increased bicarbonate concentrations can elevate water alkalinity, a finding that aligns with observations made by Mishra (2007) ; Riaz *et al.* (2018).

Electrical conductivity (EC) values varied between 0.84 and 4.31 dS/m, with an average measurement of 2.15 dS/m. The lowest EC of 0.84 dS/m was found in the sample from Harogoppa village (Sample code V15S3), indicating low salinity, whereas the highest EC of 4.31 dS/m recorded in Yerikoppi village (Sample code V51S3) raises concerns about potential salinity issues for irrigation. Elevated EC levels can negatively impact plant growth and soil health, underscoring the need for ongoing monitoring of salinity in irrigation waters. Since electrical conductivity indicates the water's capacity to conduct electric current due to dissolved salts, it plays a critical role in influencing crop productivity.

Specifically, the high EC recorded in Yerikoppi village suggests potential risks to agricultural yield, as plants require pure water for optimal absorption. Of the 153 water samples analyzed, 91 were classified as having permissible salinity (C3), while 54 fell into the doubtful category (C4), and 8 were deemed unsuitable (C5) for irrigation. Overall, 59.50% of the samples were found to be fairly suitable for irrigation, while 35.29% were unsuitable under typical conditions, and 5.22% were not recommended for irrigation purposes (Hussain *et al.,* 2022).

Sodium (Na^+) concentrations in the water samples ranged from 9.06 to 38.70 mmol/L, with an average of 19.00 mmol/L. The lowest sodium levels were found in samples from Harogoppa village (Sample code V15S3), while the highest concentrations were recorded in Yerikoppi village (Sample code V51S2). Elevated sodium levels can lead to soil sodicity, which negatively impacts soil structure and permeability. Monitoring sodium levels in irrigation water is essential for evaluating soil health. In this study, Harogoppa village (Sample code V15S3) exhibited the lowest Na^+ concentration of 9.06 mmol/L, compared to the highest concentration of 38.70 mmol/L found in Yerikoppi village (Sample code V51S2). Sodium primarily results from the weathering of minerals and is identified as the dominant cation in irrigation water, followed by calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^+). The high prevalence of Na^+ may indicate potential sodicity issues in the region, as noted by Kumar *et al*. (2017).

Table 1: Ionic Composition of groundwater samples of southern parts of Ranebennur Taluk.

Village code	Village	Sample no.	Sample code	pH	EC (dS m^{-1})	Cations (mmol L^{-1})				Anions (mmol L^{-1})				Anions (mg L^{-1})	
						Na^+	K^+	Ca^{2+}	Mg^{2+}	CO_3^{2-}	HCO_3^-	Cl^{-1}	SO_4^{2-}	NO_3^-	B
V_1	Aladakatti	S_1	V_1S_1	7.42	1.61	12.20	0.051	3.2	1.3	0.8	4.8	8.20	2.5	14.23	0.46
		S_2	V_1S_2	7.41	1.01	10.12	0.023	1.3	0.8	0.7	4.4	4.60	3.3	18.34	0.48
		S_3	V_1S_3	7.47	2.52	18.60	0.025	4.4	3.0	0.9	6.4	17.00	2.5	14.34	0.48
V_2	Antaravalli	S_1	V_2S_1	6.90	1.83	14.00	0.061	3.4	1.6	0.4	4.4	10.80	3.7	31.30	0.48
		S_2	V_2S_2	6.85	2.49	17.40	0.033	6.1	2.2	0.3	6.2	16.00	4.2	26.71	0.42
		S_3	V_2S_3	6.94	2.20	16.90	0.045	3.5	4.8	0.5	4.2	19.00	3.5	18.25	0.46
V_3	Asundi	S_1	V_3S_1	7.18	2.90	20.40	0.035	3.4	4.8	0.8	8.4	16.00	4.6	37.34	0.42
		S_2	V_3S_2	6.96	2.40	20.50	0.054	4.1	2.2	0.4	7.8	18.00	6.3	27.34	0.55
		S_3	V_3S_3	7.16	2.40	22.50	0.056	3.2	1.6	0.6	4.6	16.60	6.3	15.33	0.48
V_4	Badabasapur	S_1	V_4S_1	7.33	2.30	20.00	0.085	4.2	2.4	0.8	4.8	14.46	7.5	56.25	0.40
		S_2	V_4S_2	7.50	2.12	18.00	0.065	3.2	2.0	0.9	4.8	15.64	3.2	14.30	0.46
		S_3	V_4S_3	7.12	1.59	12.80	0.048	4.0	2.2	0.6	3.4	12.60	5.5	15.30	0.50
V_5	Benakanakond	S_1	V_5S_1	7.33	1.72	14.76	0.024	2.2	1.5	0.8	4.2	12.65	4.2	33.21	0.42
		S_2	V_5S_2	7.20	2.11	19.86	0.067	2.2	1.2	0.7	7.6	13.08	4.2	28.31	0.46
		S_3	V_5S_3	7.15	1.73	15.40	0.098	2.2	0.8	0.6	5.6	12.40	2.3	28.34	0.44
V_6	Billahalli	S_1	V_6S_1	7.50	2.58	20.48	0.074	3.4	4.2	0.8	6.2	14.80	3.5	27.25	0.44
		S_2	V_6S_2	7.31	2.17	20.40	0.032	2.9	0.9	0.7	5.8	14.20	6.5	17.36	0.50
		S_3	V_6S_3	7.20	1.06	10.50	0.064	1.2	0.8	0.8	3.4	8.06	3.2	23.85	0.60
V_7	Chikkamaganur	S_1	V_7S_1	7.61	2.75	22.40	0.050	4.7	1.1	0.9	8.4	13.20	3.2	34.23	0.52
		S_2	V_7S_2	7.24	2.33	20.43	0.054	3.1	1.4	0.8	5.4	14.60	5.4	28.23	0.40
		S_3	V_7S3	7.35	2.24	21.00	0.034	1.1	0.9	0.6	6.4	13.00	5.2	23.23	0.70
V_8	Danoagihalli	S_1	V_8S_1	7.02	2.21	19.00	0.032	2.2	1.7	0.5	4.6	12.30	6.2	42.12	0.60

		S_2	V_8S_2	6.92	2.55	22.40	0.043	2.8	1.2	0.0	5.4	13.00	4.5	39.12	0.40
		S_3	V_8S_3	7.10	2.50	23.59	0.064	2.8	1.1	0.3	6.8	13.00	6.2	41.03	0.60
V_9	Fattiepur	S_1	V_9S_1	7.44	2.12	20.78	0.054	1.1	0.7	0.5	4.4	14.46	2.4	17.45	0.53
		S_2	V_9S_2	7.39	2.10	20.63	0.045	2.3	0.9	0.4	4.6	14.46	3.6	19.22	0.53
		S_3	V_9S_3	7.65	1.46	13.51	0.033	2.0	0.8	0.6	3.2	11.80	3.5	18.58	0.57
V_{10}	Godihal	S_1	$V_{10}S_1$	7.14	3.56	28.80	0.045	3.5	2.6	0.3	6.4	18.00	5.5	48.32	0.60
		S_2	$V_{10}S_2$	7.72	2.36	17.00	0.035	5.0	2.2	1.0	7.4	11.00	6.6	14.32	0.40
		S_3	$V_{10}S_3$	6.44	1.53	13.64	0.057	2.4	2.0	0.0	6.2	11.20	3.2	19.32	0.60
V_{11}	Guddadabevinahalli	S_1	$V_{11}S_1$	6.76	2.31	16.34	0.024	5.8	3.4	0.0	6.8	14.00	2.3	42.33	0.52
		S_2	$V1_1S_2$	7.12	2.12	19.00	0.053	1.9	3.0	0.4	6.9	10.40	2.3	28.36	0.40
		S_3	$V_{11}S_3$	7.01	2.53	20.14	0.021	1.3	3.9	0.2	4.0	14.00	4.3	48.36	0.80
V_{12}	Guddadahosahalli	S_1	$V_{12}S_1$	7.05	2.70	21.40	0.046	3.2	2.0	0.3	7.4	15.00	5.3	34.36	0.50
		S_2	$V_{12}S_2$	7.56	2.19	17.00	0.054	4.0	2.4	0.6	6	12.0	2.3	36.32	0.30
		S_3	$V_{12}S_3$	7.31	2.27	20.00	0.064	3.1	0.8	0.4	7.0	12.6	3.2	21.54	0.70
V_{13}	Haligeri	S_1	$V_{13}S_1$	7.80	2.28	20.91	0.048	2.3	2.8	1.0	7.6	12.6	7.0	12.42	0.53
		S_2	$V_{13}S_2$	7.32	1.27	12.57	0.056	1.1	0.7	0.4	5.2	11.4	5.6	18.26	0.52
		S_3	$V_{13}S_3$	7.57	1.22	12.78	0.054	1.1	0.7	0.6	4.4	10.4	3.4	17.15	0.54
V_{14}	Hanumanahall	S_1	$V_{14}S_1$	7.40	1.82	14.70	0.065	4.4	1.2	0.5	7.0	10.0	3.2	21.33	0.52
		S_2	$V_{14}S_2$	7.11	2.05	20.81	0.041	2.4	1.1	0.3	8.2	13.0	3.2	38.21	0.58
		S_3	$V_{14}S_3$	7.25	2.16	20.67	0.046	2.6	0.8	0.4	7.8	13.0	3.2	42.58	0.50
V_{15}	Harogoppa	S_1	$V_{15}S_1$	7.46	0.92	10.38	0.064	0.9	0.6	0.5	5.4	8.0	3.4	15.36	0.40
		S_2	$V_{15}S_2$	7.43	1.02	9.41	0.033	2.3	0.9	0.5	4.8	8.6	3.3	45.38	0.40
		S_3	$V_{15}S_3$	7.76	0.84	9.06	0.033	1.4	0.4	0.8	3.5	9.1	3.2	23.38	0.51
V_{16}	Hediyal	S_1	$V_{16}S_1$	6.90	2.705	21.82	0.044	4.2	1.8	0.0	5.2	13.2	4.3	34.36	0.30
		S_2	$V_{16}S_2$	7.20	2.58	21.96	0.031	3.0	1.6	0.4	6.4	16.0	2.3	35.36	0.45
		S_3	$V_{16}S_3$	6.93	2.87	24.00	0.054	4.0	2.6	0.0	5.8	16.6	6.2	37.84	0.35
V_{17}	Hiremaganur	S_1	$V_{17}S_1$	7.31	4.02	38.04	0.034	4.4	1.6	0.3	3.0	35.2	5.2	25.11	0.55
		S_2	$V_{17}S_2$	7.26	3.06	24.76	0.046	4.1	2.4	0.3	4.3	24.0	4.3	22.31	1.33
		S_3	$V_{17}S_3$	7.52	3.06	27.78	0.065	3.6	2.9	0.7	6.4	22.8	6.0	24.18	0.61
V_{18}	Holeanveri	S_1	$V_{18}S_1$	7.54	2.98	25.61	0.065	3.2	2.0	0.8	3.8	24.2	3.5	12.23	0.50
		S_2	$V_{18}S_2$	7.11	2.19	20.08	0.046	3.1	1.4	0.3	4.8	14.0	3.5	12.33	0.52
		S_3	$V_{18}S_3$	7.35	1.50	13.59	0.051	3.4	1.2	0.4	4.8	13.0	4.2	12.22	0.55
V_{19}	Hulihalli	S_1	$V_{19}S_1$	6.80	1.91	17.78	0.069	2.4	1.2	0.0	6.8	12.7	3.2	47.33	0.20
		S_2	$V_{19}S_2$	7.15	2.14	19.18	0.032	3.1	1.7	0.3	8.0	12.0	4.6	12.33	0.22
		S_3	$V_{19}S_3$	6.95	1.76	15.02	0.054	2.8	1.3	0.0	4.0	14.7	5.6	28.22	0.33
V_{20}	Itagi	S_1	$V_{20}S_1$	7.59	2.09	20.60	0.068	2.1	0.6	0.6	7.2	12.5	5.1	38.33	0.14
		S_2	$V_{20}S_2$	8.00	2.47	20.72	0.065	3.4	1.4	1.4	5.6	14.6	3.2	44.22	0.22
		S_3	$V_{20}S_3$	7.95	2.42	22.12	0.065	2.3	1.8	1.1	5.2	12.6	5.6	32.33	0.38
V_{21}	Kodiyal	S_1	$V_{21}S_1$	6.90	2.66	23.43	0.057	2.5	2.2	0.0	6.8	14.6	6.0	25.33	0.24
		S_2	$V_{21}S_2$	7.10	2.44	21.14	0.095	2.8	1.4	0.3	5.2	16.4	3.5	18.25	0.30
		S_3	$V_{21}S_3$	6.97	1.94	16.52	0.055	2.6	1.5	0.0	3.6	14.6	4.2	28.99	0.66
V_{22}	Kamadod	S_1	$V_{22}S_1$	6.88	2.80	22.59	0.078	4.2	2.2	0.0	6.4	13.0	4.6	26.60	0.33
		S_2	$V_{22}S_2$	7.72	1.52	11.39	0.065	3.4	1.2	0.9	3.4	11.0	3.9	36.22	1.40
		S_3	$V_{22}S_3$	7.09	1.56	13.20	0.054	3.2	1.2	0.2	3.8	14.2	3.5	12.63	0.55
V_{23}	Konanatali	S_1	$V_{23}S_1$	7.40	1.91	16.90	0.069	2.6	1.5	0.5	5.2	14.0	4.0	12.33	1.20
		S_2	$V_{23}S_2$	7.36	2.01	18.59	0.076	3.4	1.2	0.4	6.8	13.2	6.2	12.22	0.50
		S_3	$V_{23}S_3$	7.59	2.34	21.16	0.042	3.9	0.7	0.6	8.4	13.2	4.3	23.22	1.30
V_{24}	Kooli	S_1	$V_{24}S_1$	7.30	2.16	20.79	0.065	1.6	0.1	0.4	9.0	12.6	3.5	26.30	0.50
		S_2	$V_{24}S_2$	7.32	2.22	18.10	0.048	3.8	0.9	0.4	5.4	12.0	4.2	24.32	0.60
		S_3	$V_{24}S_3$	7.72	1.79	14.69	0.025	3.6	1.7	0.9	5.8	14.0	3.6	26.85	0.30
V_{25}	Kotihal	S_1	$V_{25}S_1$	7.42	2.09	20.70	0.052	1.3	0.1	0.4	7.0	12.4	5.0	16.24	0.80
		S_2	$V_{25}S_2$	7.30	2.01	17.87	0.064	2.1	1.0	0.4	5.8	12.7	3.8	28.86	1.05
		S_3	$V_{25}S_3$	7.03	1.83	17.20	0.043	2.6	0.8	0.2	5.8	13.0	3.5	36.22	0.50
V_{26}	Krishnapur	S_1	$V_{26}S_1$	7.16	1.54	13.34	0.065	2.4	1.9	0.3	4.2	9.0	2.6	51.33	0.22
		S_2	$V_{26}S_2$	7.20	1.70	15.78	0.054	1.7	1.2	0.4	3.6	14.0	2.3	44.33	0.30
		S_3	$V_{26}S_3$	7.34	1.62	14.81	0.065	2.2	1.8	0.4	4.2	9.0	5.5	48.33	0.32
V_{27}	Kuppelur	S_1	$V_{27}S_1$	6.90	3.27	29.34	0.057	4.2	1.2	0.0	7.4	16.8	8.6	46.33	0.40
		S_2	$V_{27}S_2$	7.80	1.92	18.81	0.065	2.2	1.8	0.9	5.2	12.0	6.5	52.33	0.32
		S_3	$V_{27}S_3$	7.82	1.82	17.48	0.075	2.4	1.8	1.0	7.2	13.2	4.6	44.33	0.32
V_{28}	Kusagur	S_1	$V_{28}S_1$	7.30	2.32	22.00	0.097	2.2	1.7	0.4	9.8	12.2	4.2	15.33	0.55
		S_2	$V_{28}S_2$	6.90	2.84	23.85	0.056	2.5	2.9	0.0	4.6	12.6	6.3	14.33	0.46

		S_3	$V_{28}S_3$	6.96	2.63	24.95	0.045	2.4	2.8	0.0	4.0	16.8	4.3	16.44	0.40
V_{29}	Kawalettu	S_1	$V_{29}S_1$	6.80	2.02	18.00	0.051	2.8	1.2	0.0	5.2	15.0	3.6	32.22	0.33
		S_2	$V_{29}S_2$	7.23	1.43	13.60	0.045	2.4	0.6	0.4	5.0	9.2	3.6	35.33	0.51
		S_3	$V_{29}S_3$	7.43	1.95	15.60	0.065	2.4	1.4	0.6	5.6	12.6	5.2	44.22	0.42
V_{30}	Laxmapur	S_1	$V_{30}S_1$	6.80	1.25	10.40	0.053	3.0	1.8	0.0	4.8	8.2	4.2	31.32	0.32
		S_2	$V_{30}S_2$	7.50	1.96	17.16	0.054	2.4	1.4	0.7	5.8	10.0	4.3	25.34	0.60
		S_3	$V_{30}S_3$	6.80	2.63	22.88	0.045	2.5	1.5	0.0	6.2	13.8	6.3	26.31	0.30
V_{31}	Lingadalli	S_1	$V_{31}S_1$	7.49	1.88	16.72	0.033	2.2	1.4	0.6	6.6	15.0	4.2	45.36	0.50
		S_2	$V_{31}S_2$	7.22	1.89	18.05	0.064	2.4	0.7	0.4	5.8	11.4	3.3	12.32	0.40
		S_3	$V_{31}S_3$	7.15	1.24	12.00	0.054	1.8	1.7	0.3	5.2	10.6	5.3	34.36	0.50
V_{32}	Magod	S_1	$V_{32}S_1$	7.08	2.02	20.88	0.064	2.2	0.4	0.2	6.0	14.0	4.4	24.66	1.60
		S_2	$V_{32}S_2$	7.10	2.42	22.07	0.024	2.3	1.7	0.4	5.2	14.0	6.2	32.25	0.52
		S_3	$V_{32}S_3$	7.55	1.73	13.85	0.055	5.4	0.2	0.6	4.4	11.3	5.5	40.22	0.50
V_{33}	Makanur	S_1	$V_{33}S_1$	7.34	1.67	14.42	0.033	3.0	1.2	0.4	4.8	11.0	3.2	43.33	0.30
		S_2	$V_{33}S_2$	7.20	1.42	12.07	0.064	2.5	1.6	0.2	5.8	12.7	0.3	49.33	0.22
		S_3	$V_{33}S_3$	7.40	1.54	14.18	0.032	1.1	0.6	0.2	4.2	10.6	4.6	12.33	0.22
V_{34}	Malakanahalli	S_1	$V_{34}S_1$	7.41	1.29	12.16	0.042	1.9	0.7	0.4	4.4	10.0	4.3	23.22	0.52
		S_2	$V_{34}S_2$	7.61	1.62	14.80	0.065	2.4	0.5	0.7	4.6	12.6	5.2	52.00	0.14
		S_3	$V_{34}S_3$	7.30	1.50	12.20	0.054	2.2	1.6	0.4	3.9	12.0	3.3	32.86	1.02
V_{35}	Manakur	S_1	$V_{35}S_1$	7.40	1.86	18.40	0.044	1.4	0.8	0.5	4.2	12.1	3.5	32.24	0.60
		S_2	$V_{35}S_2$	7.36	1.86	17.39	0.046	3.4	1.8	0.4	7.2	10.3	4.2	32.23	0.47
		S_3	$V_{35}S_3$	7.24	2.19	20.13	0.062	3.2	1.4	0.2	5.4	14.0	5.5	21.31	0.47
V_{36}	Mmolnashinahal	S_1	$V_{36}S_1$	7.14	2.54	22.03	0.043	3.2	0.9	0.3	7.4	14.4	4.6	25.62	0.61
		S_2	$V_{36}S_2$	7.27	2.18	20.91	0.058	3.2	1.8	0.3	7.6	12.6	5.0	12.32	0.42
		S_3	$V_{36}S_3$	7.72	1.77	16.40	0.046	4.2	2.8	0.4	4.4	14.0	4.6	18.26	0.48
V_{37}	Mudenur	S_1	$V_{37}S_1$	7.51	1.67	13.52	0.055	2.6	2.5	0.8	6.6	12.6	5.2	28.99	0.66
		S_2	$V_{37}S_2$	7.54	1.86	18.40	0.054	1.2	0.8	0.7	4.8	11.4	4.6	24.60	0.33
		S_3	$V_{37}S_3$	7.40	2.45	21.39	0.055	3.4	1.2	0.4	5.0	13.5	2.9	26.24	0.74
V_{38}	Mustur	S_1	$V_{38}S_1$	7.45	2.53	22.60	0.058	2.7	0.7	0.4	6.6	18.0	5.2	15.99	0.55
		S_2	$V_{38}S_2$	6.94	2.25	20.50	0.025	2.7	1.8	0.2	5.2	12.5	4.3	33.22	0.30
		S_3	$V_{38}S_3$	7.24	2.30	20.89	0.055	2.2	1.8	0.3	7.2	14.6	6.2	32.33	0.48
V_{39}	Nagenahalli	S_1	$V_{39}S_1$	7.31	1.17	16.40	0.035	2.5	1.8	0.4	5.8	11.4	3.6	32.33	0.33
		S_2	$V_{39}S_2$	7.50	1.80	15.40	0.065	1.5	1.7	0.6	4.4	13.6	3.2	25.33	0.22
		S_3	$V_{39}S_3$	7.11	2.59	23.14	0.066	3.2	1.4	0.3	5.2	14.5	3.5	12.25	0.43
V_{40}	Nalawagal	S_1	$V_{40}S_1$	7.10	2.42	22.80	0.053	2.8	1.5	0.2	4.2	15.4	4.3	15.99	0.55
		S_2	$V_{40}S_2$	7.30	2.29	20.18	0.042	3.1	1.7	0.3	5.8	16.6	4.6	12.33	0.22
		S_3	$V_{40}S_3$	7.10	2.86	24.16	0.042	3.9	0.7	0.2	8.4	13.1	4.3	23.22	1.30
V_{41}	Nandihalli	S_1	$V_{41}S_1$	6.82	2.14	20.52	0.066	2.7	1.7	0.0	6.4	14.2	1.6	32.33	0.43
		S_2	$V_{41}S_2$	7.00	2.22	20.81	0.065	2.2	1.8	0.2	5.7	13.5	6.5	25.33	0.52
		S_3	$V_{41}S_3$	6.90	2.09	17.48	0.075	2.4	1.8	0.0	6.2	12.4	4.6	12.25	0.47
V_{42}	Nitapalli	S_1	$V_{42}S_1$	7.35	2.18	20.31	0.054	1.6	1.9	0.4	4.2	13.4	4.6	14.65	0.45
		S_2	$V_{42}S_2$	7.47	1.64	14.76	0.056	3.2	0.8	0.4	4.6	12.0	5.3	18.25	0.60
		S_3	$V_{42}S_3$	7.05	1.89	15.25	0.043	3.4	1.2	0.2	7.2	12.0	1.6	40.00	0.60
V_{43}	Nittur	S_1	$V_{43}S_1$	7.20	1.92	17.82	0.054	2.1	0.9	0.2	5.4	11.2	3.5	26.66	0.60
		S_2	$V_{43}S_2$	7.40	1.80	14.60	0.054	3.5	1.6	0.4	6.0	12.0	6.5	11.23	0.40
		S_3	$V_{43}S_3$	7.50	3.24	29.60	0.042	3.4	2.0	0.4	8.2	15.5	4.6	24.36	0.60
V_{44}	Sanna sangapur	S_1	$V_{44}S_1$	6.90	2.12	20.43	0.048	2.4	1.5	0.0	8.1	14.8	4.0	28.64	0.45
		S_2	$V_{44}S_2$	7.15	1.85	15.81	0.065	2.2	1.8	0.2	5.8	11.5	4.5	25.33	0.22
		S_3	$V_{44}S_3$	7.30	2.88	27.78	0.058	3.4	0.5	0.4	8.4	18.4	2.3	25.35	0.51
V_{45}	Sarvanda	S_1	$V_{45}S_1$	6.97	2.46	22.40	0.064	2.8	0.4	0.0	4.0	12.4	4.3	16.44	0.40
		S_2	$V_{45}S_2$	7.30	2.28	20.47	0.053	2.0	1.8	0.3	5.8	12.5	2.3	23.22	0.50
		S_3	$V_{45}S_3$	7.18	2.84	24.80	0.064	3.9	0.7	0.2	5.4	15.2	6.3	24.33	0.51
V_{46}	Sunakalbidari	S_1	$V_{46}S_1$	7.15	2.70	21.56	0.042	4.5	2.8	0.2	2.0	18.0	4.2	31.32	0.70
		S_2	$V_{46}S_2$	7.36	2.76	23.13	0.054	1.8	2.8	0.4	4.4	16.0	3.3	35.36	0.60
		S_3	$V_{46}S_3$	7.13	2.79	23.39	0.041	3.2	1.8	0.2	9.0	12.4	5.3	34.35	0.40
V_{47}	Tirumaladevira koppa	S_1	$V_{47}S_1$	7.52	2.02	20.05	0.069	2.2	1.3	0.6	3.8	12.4	5.3	35.65	0.60
		S_2	$V_{47}S_2$	7.08	1.80	17.00	0.033	1.6	0.4	0.2	5.2	12.4	3.2	42.36	0.50
		S_3	$V_{47}S_3$	7.69	1.55	12.85	0.058	2.3	1.5	0.8	2.8	11.4	4.3	42.31	0.52
V_{48}	Tumminakatti	S_1	$V_{48}S_1$	7.24	2.48	21.25	0.054	2.2	1.7	0.3	6.2	13.4	5.2	25.26	0.50
		S_2	$V_{48}S_2$	7.45	2.19	20.80	0.035	2.1	1.7	0.4	5.8	12.4	4.3	24.23	0.43
		S_3	$V_{48}S_3$	7.04	2.59	19.70	0.048	3.2	2.8	0.2	5.4	13.5	4.5	24.42	0.30

V_{49}	Ukkund	S_1	$V_{49}S_1$	6.70	2.84	24.26	0.054	3.6	2.8	0.0	9.4	14.6	4.3	32.23	0.50
		S_2	$V_{49}S_2$	7.61	2.33	21.78	0.064	2.4	0.5	0.8	5.4	18.4	3.3	25.35	0.50
		S_3	$V_{49}S_3$	7.40	2.28	20.48	0.042	3.1	1.6	0.5	5.8	13.4	4.2	53.31	0.20
V_{50}	Yalabadigi	S_1	$V_{50}S_1$	7.54	2.26	21.06	0.046	3.1	1.9	0.7	7.2	14.2	5.4	15.36	0.68
		S_2	$V_{50}S_2$	7.39	2.80	24.34	0.048	3.4	1.4	0.4	9.0	16.0	3.5	16.32	0.50
		S_3	$V_{50}S_3$	7.52	3.48	29.6	0.048	2.5	3.8	0.6	5.8	14.0	4.3	15.26	0.51
V_{51}	Yerikoppi	S_1	$V_{51}S_1$	7.43	1.90	14.04	0.055	3.6	1.8	0.5	4.8	12.0	3.3	24.31	0.50
		S_2	$V_{51}S_2$	7.41	4.31	38.7	0.055	3.1	1.8	0.4	9.8	21.0	8.3	23.31	0.40
		S_3	$V_{51}S_3$	7.00	1.89	14.81	0.065	2.1	1.9	0.1	5.8	10.4	6.3	24.31	0.36
Mean				7.26	2.15	19.00	0.052	2.8	1.58	0.4	5.72	13.5	4.34	27.70	0.50
MIN				6.44	0.84	9.06	0.021	0.98	0.1	0.0	2.00	4.6	0.35	11.09	0.22
MAX				8.00	4.31	38.70	0.098	6.10	4.8	1.4	9.80	35.2	8.61	53.31	1.60
S.D				0.26	0.56	4.84	0.014	0.95	0.84	0.27	1.51	3.29	1.33	56.25	0.22
C.V				13.71	26.20	25.49	27.31	33.79	53.21	65.63	26.53	24.38	30.64	11.23	44.91

Potassium (K^+) concentrations in the irrigation water samples ranged from 0.021 to 0.098 mmol/L, with an average of 0.052 mmol/L. The highest K^+ level was found in Benakanakond (Sample code V5S3), while the lowest concentration was reported in Guddadabevinahalli village (Sample code V11S3). Adequate potassium levels are vital for plant health as they play a significant role in enzymatic functions and overall growth. In this study, Guddadabevinahalli village exhibited the lowest K^+ concentration at 0.021 mmol/L, whereas Benakanakond recorded the highest level at 0.098 mmol/L (Hussain *et al.,* 2022). The elevated potassium levels may be attributed to the weathering of potassium-bearing minerals such as K-feldspars and clays. Additionally, excessive potassium in groundwater is frequently associated with the over application of potassium fertilizers, as noted by Divya and Belagali (2012).

Calcium (Ca^{2+}) concentrations in the irrigation water samples ranged from 0.98 to 6.1 mmol/L, averaging 2.81 mmol/L. The lowest calcium levels were found in Harogoppa village (Sample code V15S1), while the highest concentrations were recorded in Antaravalli village (Sample code V2S2). Calcium is vital for plant physiology and soil structure, as its availability directly impacts crop productivity. In particular, calcium is essential for proper plant development and maintaining cell structure. Harogoppa village exhibited the lowest Ca^{2+} concentration at 0.98 mmol/L, whereas Antaravalli village had the highest at 6.1 mmol/L. The presence of calcium in groundwater is mainly due to the dissolution of calcium-rich minerals, a finding that corroborates earlier research by Lai *et al*. (1976) and others, underscoring the importance of calcium levels in determining the quality of irrigation water.

Magnesium (Mg^{2+}) concentrations in the irrigation water samples ranged from 0.11 to 4.80 mmol/L, with an average of 1.58 mmol/L. The lowest levels were observed in Kooli (Sample code V24S1), while the highest concentrations were found in both Antaravalli and Asundi villages (Sample codes V2S3 and V3S1). As an essential nutrient, magnesium plays a crucial role in chlorophyll production and enzyme activation, which are vital for healthy plant growth. Additionally, magnesium contributes to water hardness and is fundamental for chlorophyll synthesis. The lowest recorded Mg^{2+} concentration was 0.11 mmol/L in Kooli, while the highest, at 4.80 mmol/L, was detected in both Antaravalli and Asundi villages. The presence of magnesium in groundwater is primarily influenced by mineral weathering and ion exchange processes. The measured Mg^{2+} concentrations were within acceptable limits, though elevated magnesium levels can adversely affect soil pH and physical properties, as noted by Hussain and Sherif (2015).

The concentration of carbonates (CO_3^{2-}) in the water samples varied from 0 to 1.4 mmol/L, with an average of 0.42 mmol/L. Notably, water samples from Kodiyal (Sample code V21S3) exhibited no detectable carbonates, while Itagi village (Sample code V20S2) recorded the highest concentration. The presence of carbonates can significantly influence soil pH and nutrient availability, which in turn affects the efficiency of irrigation practices. In these water samples, carbonates and bicarbonates exist in equilibrium with atmospheric CO_2. Specifically, Kodiyal village (Sample code V21S3) had the lowest CO_3^{2-} concentration of 0 mmol/L, whereas Itagi village (Sample code V20S2) had the maximum level at 1.4 mmol/L. The levels of carbonates are primarily influenced by the weathering of minerals and the dissolution of carbonic acid in groundwater, as noted by Ramkumar *et al*. (2010); Singh (2020).

Bicarbonate (HCO_3^-) concentrations in the groundwater samples ranged from 2.00 to 9.80 mmol/L, with an average value of 5.72 mmol/L. The lowest bicarbonate levels were observed in Sunakalbidari (Sample code V46S1), while Kusagur village (Sample code V28S1) exhibited the highest levels. Increased bicarbonate concentrations can suggest potential alkalinity issues in irrigation water. Specifically, the groundwater samples from Sunakalbidari (Sample code V46S1) recorded the lowest bicarbonate concentration at 2.00 mmol/L, whereas Kusagur village (Sample code V28S1) had the maximum concentration of 9.80 mmol/L. Elevated levels of bicarbonate in groundwater are often the result of various natural processes, such as the oxidation of organic matter and the dissolution of minerals. According to the guidelines established by UCCC (1974), the observed bicarbonate levels suggest slight to moderate restrictions on irrigation use, a finding that is supported by Ravikumar *et al*. (2007); Hussain *et al.* (2022).

Chloride (Cl^-) concentrations in the water samples varied from 4.60 to 35.20 mmol/L, with an average of 13.52 mmol/L. The lowest chloride levels were detected in Aladakatti (Sample code V1S2), while Hiremaganur (Sample code V17S1) reported the highest levels. Elevated chloride concentrations can adversely affect crops, potentially leading to toxic conditions. Chloride is naturally present in water, primarily resulting from agricultural runoff and the leaching of chloride-rich minerals (Divya and Belagali 2012). Specifically, Aladakatti village (Sample code V1S2) recorded a minimum Cl^- concentration of 4.60 mmol/L, whereas the maximum concentration of 35.20 mmol/L was found in Hiremaganur (Sample code V17S1). Notably, the elevated chloride levels exceed permissible limits (4 mmol/L), suggesting potential anthropogenic impacts. Furthermore, increased chloride concentrations may hinder phosphorus availability for plants (Saleem *et al.*, 2016).

Sulfate (SO_4^{2-}) concentrations in the water samples ranged from 0.35 to 8.61 mmol/L, averaging 4.34 mmol/L. The lowest sulfate level was observed in Makanur (Sample code V33S2), while the highest concentration was recorded in Kuppelur (Sample code V27S1). Elevated sulfate levels can negatively impact both water quality and crop health. The presence of sulfate in groundwater often stems from anthropogenic activities, such as the use of fertilizers. Specifically, Makanur (Sample code V33S2) exhibited a minimal SO_4^{2-} concentration of 0.35 mmol/L, whereas Kuppelur (Sample code V27S1) had the highest concentration at 8.61 mmol/L. Sulfate levels are influenced by mineral dissolution, which may also affect phosphorus availability for plant uptake (Khalil and Arther 2010).

Table 2: Derived parameters of groundwater samples of southern parts of Ranebennur taluk.

Village code	Village Name	Sample No.	Sample code	RSC (mmol L^{-1})	SAR	TH (mg L^{-1})	TDS (mg L^{-1})
V_1	Aladakatti	S_1	V_1S_1	1.1	8.13	13.34	1030.4
		S_2	V_1S_2	3.0	9.87	6.54	646.4
		S_3	V_1S_3	-0.1	9.65	23.42	1612.8
V_2	Antaravalli	S_1	V_2S_1	-0.4	8.85	15.07	1171.2
		S_2	V_2S_2	-1.8	8.52	24.45	1593.6
		S_3	V_2S_3	-3.6	8.29	28.50	1408.0
V_3	Asundi	S_1	V_3S_1	1.0	10.07	28.25	1856.0
		S_2	V_3S_2	1.9	11.55	19.29	1536.0
		S_3	V_3S_3	0.4	14.52	14.57	1536.0
V_4	Badabasapur	S_1	V_4S_1	-1.0	11.00	20.37	1472.0
		S_2	V_4S_2	0.5	11.16	16.22	1356.8
		S_3	V_4S_3	-2.2	07.26	19.04	1017.6
V_5	Benakanakond	S_1	V_5S_1	1.3	10.85	11.67	1100.8
		S_2	V_5S_2	4.9	15.23	10.43	1350.4
		S_3	V_5S_3	3.2	12.57	8.78	1107.2
V_6	Billahalli	S_1	V_6S_1	-0.6	10.50	25.78	1651.2
		S_2	V_6S_2	2.7	14.79	10.94	1388.8
		S_3	V_6S_3	2.2	10.50	6.29	678.4
V_7	Chikkamaganur	S_1	V_7S_1	3.5	13.15	16.26	1760.0
		S_2	V_7S_2	1.7	13.62	13.50	1491.2
		S_3	V_7S3	5.0	21.00	6.45	1433.6
V_8	Danoagihalli	S_1	V_8S_1	1.2	13.60	12.49	1414.4
		S_2	V_8S_2	1.4	15.83	11.93	1632.0
		S_3	V_8S_3	3.2	16.89	11.52	1600.0
V_9	Fattiepur	S_1	V_9S_1	3.1	21.90	5.62	1356.8
		S_2	V_9S_2	1.8	16.30	9.44	1344.0
		S_3	V_9S_3	1.0	11.41	8.28	934.4
V_{10}	Godihal	S_1	$V_{10}S_1$	0.6	16.49	19.44	2278.4
		S_2	$V_{10}S_2$	1.2	8.95	21.54	1510.4
		S_3	$V_{10}S_3$	1.8	9.19	14.22	979.2
V_{11}	Guddadabevinahalli	S_1	$V_{11}S_1$	-2.4	7.61	28.48	1478.4
		S_2	$V1_1S_2$	2.4	12.13	17.09	1356.8
		S_3	$V_{11}S_3$	-1.0	12.49	19.30	1619.2
V_{12}	Guddadahosahalli	S_1	$V_{12}S_1$	2.5	13.27	16.22	1728.0
		S_2	$V_{12}S_2$	0.2	9.50	19.87	1401.6
		S_3	$V_{12}S_3$	3.5	14.32	11.03	1452.8
V_{13}	Haligeri	S_1	$V_{13}S_1$	3.5	13.09	17.27	1459.2
		S_2	$V_{13}S_2$	3.8	13.24	5.62	812.8
		S_3	$V_{13}S_3$	3.1	13.39	5.67	780.8
V_{14}	Hanumanahalli	S_1	$V_{14}S_1$	1.9	8.78	15.92	1164.8
		S_2	$V_{14}S_2$	5.0	15.73	10.52	1312.0
		S_3	$V_{14}S_3$	4.8	15.85	9.78	1382.4
V_{15}	Harogoppa	S_1	$V_{15}S_1$	4.3	11.67	4.91	588.8
		S_2	$V_{15}S_2$	2.0	7.35	9.73	652.8
		S_3	$V_{15}S_3$	2.5	9.55	5.14	537.6
V_{16}	Hediyal	S_1	$V_{16}S_1$	-0.8	12.59	17.89	1731.2
		S_2	$V_{16}S_2$	2.2	14.48	14.07	1651.2

		S_3	$V_{16}S_3$	-0.8	13.21	20.69	1836.8
V_{17}	Hiremaganur	S_1	$V_{17}S_1$	-2.7	21.96	17.57	2572.8
		S_2	$V_{17}S_2$	-1.9	13.73	20.12	1958.4
		S_3	$V_{17}S_3$	0.6	15.40	20.93	1958.4
V_{18}	Holeanveri	S_1	$V_{18}S_1$	-0.6	15.88	16.22	1907.2
		S_2	$V_{18}S_2$	0.6	13.38	13.50	1401.6
		S_3	$V_{18}S_3$	0.6	8.96	13.43	960.0
V_{19}	Hulihalli	S_1	$V_{19}S_1$	3.2	13.25	10.93	1222.4
		S_2	$V_{19}S_2$	3.5	12.38	14.74	1369.6
		S_3	$V_{19}S_3$	-0.1	10.49	12.34	1126.4
V_{20}	Itagi	S_1	$V_{20}S_1$	5.1	17.72	7.71	1337.6
		S_2	$V_{20}S_2$	2.2	13.37	14.25	1580.8
		S_3	$V_{20}S_3$	2.2	15.44	13.15	1548.8
V_{21}	Kodiyal	S_1	$V_{21}S_1$	2.1	15.28	15.30	1702.4
		S_2	$V_{21}S_2$	1.3	14.58	12.75	1561.6
		S_3	$V_{21}S_3$	-0.5	11.53	12.66	1241.6
V_{22}	Kamadod	S_1	$V_{22}S_1$	0.0	12.62	19.54	1792.0
		S_2	$V_{22}S_2$	-0.3	7.51	13.43	972.8
		S_3	$V_{22}S_3$	-0.4	8.89	12.93	998.4
V_{23}	Konanatali	S_1	$V_{23}S_1$	1.6	11.80	12.66	1222.4
		S_2	$V_{23}S_2$	2.6	12.25	13.43	1286.4
		S_3	$V_{23}S_3$	4.4	13.95	12.62	1497.6
V_{24}	Kooli	S_1	$V_{24}S_1$	7.7	22.54	4.40	1382.4
		S_2	$V_{24}S_2$	1.1	11.80	13.19	1420.8
		S_3	$V_{24}S_3$	1.3	8.94	16.21	1145.6
V_{25}	Kotihal	S_1	$V_{25}S_1$	6.0	24.74	3.65	1337.6
		S_2	$V_{25}S_2$	3.1	14.35	9.36	1286.4
		S_3	$V_{25}S_3$	2.6	13.19	9.78	1171.2
V_{26}	Krishnapur	S_1	$V_{26}S_1$	0.2	9.09	13.81	985.6
		S_2	$V_{26}S_2$	1.1	13.10	9.18	1088.0
		S_3	$V_{26}S_3$	0.6	10.47	12.90	1036.8
V_{27}	Kuppelur	S_1	$V_{27}S_1$	2.0	17.85	15.42	2092.8
		S_2	$V_{27}S_2$	2.1	13.30	12.90	1228.8
		S_3	$V_{27}S_3$	4.0	12.06	13.40	1164.8
V_{28}	Kusagur	S_1	$V_{28}S_1$	6.3	15.75	12.49	1484.8
		S_2	$V_{28}S_2$	-0.8	14.51	18.18	1817.6
		S_3	$V_{28}S_3$	-1.2	15.47	17.52	1683.2
V_{29}	Kawalettu	S_1	$V_{29}S_1$	1.2	12.72	11.93	1292.8
		S_2	$V_{29}S_2$	2.4	11.10	8.46	915.2
		S_3	$V_{29}S_3$	2.4	11.31	11.75	1248.0
V_{30}	Laxmapur	S_1	$V_{30}S_1$	0.0	6.71	14.90	800.0
		S_2	$V_{30}S_2$	2.7	12.44	11.75	1254.4
		S_3	$V_{30}S_3$	2.2	16.17	12.41	1683.2
V_{31}	Lingadalli	S_1	$V_{31}S_1$	3.5	12.41	11.38	1203.2
		S_2	$V_{31}S_2$	3.1	14.49	8.87	1209.6
		S_3	$V_{31}S_3$	2.0	9.07	11.49	793.6
V_{32}	Magod	S_1	$V_{32}S_1$	3.6	18.31	7.14	1292.8
		S_2	$V_{32}S_2$	1.6	15.60	12.74	1548.8
		S_3	$V_{32}S_3$	-0.6	8.27	14.30	1107.2
V_{33}	Makanur	S_1	$V_{33}S_1$	1.0	9.95	12.43	1068.8
		S_2	$V_{33}S_2$	1.9	8.43	12.83	908.8
		S_3	$V_{33}S_3$	2.7	15.38	5.21	985.6
V_{34}	Malakanahalli	S_1	$V_{34}S_1$	2.2	10.66	7.62	825.6
		S_2	$V_{34}S_2$	2.4	12.29	8.05	1036.8
		S_3	$V_{34}S_3$	0.5	8.85	12.08	960.0
V_{35}	Manakur	S_1	$V_{35}S_1$	2.5	17.54	6.79	1190.4
		S_2	$V_{35}S_2$	2.4	10.78	15.90	1190.4
		S_3	$V_{35}S_3$	1.0	13.27	13.75	1401.6
V_{36}	Menashinahal	S_1	$V_{36}S_1$	3.6	15.38	11.69	1625.6
		S_2	$V_{36}S_2$	2.9	13.22	15.40	1397.7
		S_3	$V_{36}S_3$	-2.2	8.76	22.01	1132.8
V_{37}	Mudenur	S_1	$V_{37}S_1$	2.3	8.46	16.78	1068.8
		S_2	$V_{37}S_2$	3.5	18.40	6.29	1190.4
		S_3	$V_{37}S_3$	0.8	14.10	13.43	1568.0
V_{38}	Mustur	S_1	$V_{38}S_1$	3.6	17.33	9.62	1619.2
		S_2	$V_{38}S_2$	0.9	13.66	14.15	1440.0
		S_3	$V_{38}S_3$	3.5	14.77	12.90	1472.0
V_{39}	Nagenahalli	S_1	$V_{39}S_1$	1.9	11.18	13.65	748.8
		S_2	$V_{39}S_2$	1.8	12.17	10.74	1152.0
		S_3	$V_{39}S_3$	0.9	15.25	13.75	1657.6
V_{40}	Nalawagal	S_1	$V_{40}S_1$	0.0	15.40	13.49	1548.8
		S_2	$V_{40}S_2$	1.3	13.02	14.74	1465.6
		S_3	$V_{40}S_3$	4.0	15.93	12.62	1830.4
V_{41}	Nandihalli	S_1	$V_{41}S_1$	2.0	13.83	13.74	1369.6

		S_2	$V_{41}S_2$	1.9	14.71	12.90	1420.8
		S_3	$V_{41}S_3$	2.0	12.06	13.40	1337.6
V_{42}	Nitapalli	S_1	$V_{42}S_1$	1.1	15.35	11.81	1395.2
		S_2	$V_{42}S_2$	0.9	10.41	11.36	1049.6
		S_3	$V_{42}S_3$	2.8	10.05	13.43	1209.6
V_{43}	Nittur	S_1	$V_{43}S_1$	2.6	14.54	8.94	1228.8
		S_2	$V_{43}S_2$	1.3	9.14	15.32	1152.0
		S_3	$V_{43}S_3$	3.1	17.94	16.89	2073.6
V_{44}	Sanna sangapur	S_1	$V_{44}S_1$	4.2	14.63	12.16	1356.8
		S_2	$V_{44}S_2$	2.0	11.17	12.90	1184.0
		S_3	$V_{44}S_3$	4.9	19.89	10.54	1843.2
V_{45}	Sarvanda	S_1	$V_{45}S_1$	0.8	17.70	8.63	1574.4
		S_2	$V_{45}S_2$	2.3	14.85	12.40	1459.2
		S_3	$V_{45}S_3$	1.0	16.35	12.62	1817.6
V_{46}	Sunakalbidari	S_1	$V_{46}S_1$	-5.1	11.28	22.76	1728.0
		S_2	$V_{46}S_2$	0.2	15.25	16.02	1766.4
		S_3	$V_{46}S_3$	4.2	14.79	15.40	1785.6
V_{47}	Tirumaladevira koppa	S_1	$V_{47}S_1$	0.8	15.13	10.87	1292.8
		S_2	$V_{47}S_2$	3.4	17.00	5.64	1152.0
		S_3	$V_{47}S_3$	-0.2	9.32	11.92	992.0
V_{48}	Tumminakatti	S_1	$V_{48}S_1$	2.6	15.21	12.49	1587.2
		S_2	$V_{48}S_2$	2.4	15.08	12.24	1401.6
		S_3	$V_{48}S_3$	-0.4	11.37	19.52	1657.6
V_{49}	Ukkund	S_1	$V_{49}S_1$	3.0	13.56	20.51	1817.6
		S_2	$V_{49}S_2$	3.3	18.08	8.05	1491.2
		S_3	$V_{49}S_3$	1.6	13.35	14.32	1459.2
V_{50}	Yalabadigi	S_1	$V_{50}S_1$	2.9	13.31	15.56	1446.4
		S_2	$V_{50}S_2$	4.6	15.71	14.25	1792.0
		S_3	$V_{50}S_3$	0.1	16.67	21.89	2227.2
V_{51}	Yerikoppi	S_1	$V_{51}S_1$	-0.1	8.54	16.40	1216.0
		S_2	$V_{51}S_2$	5.3	24.72	15.15	2758.4
		S_3	$V_{51}S_3$	1.8	10.34	13.43	1209.6
MEAN				1.7	13.21	13.54	1377.9
MIN				-5.1	6.71	3.65	537.6
MAX				7.7	24.74	28.50	2758.4
S.D				1.9	344.63	4.78	361.0
C.V				111.2	26.07	35.28	26.20

Nitrate (NO_3^-) concentrations in the groundwater samples ranged from 11.23 to 56.25 mg/L, with an average concentration of 27.40 mg/L. The lowest nitrate levels were detected in Nittur (Sample code V43S2), whereas the highest concentrations were found in Badabasapur (Sample code V4S1). While nitrate serves as an essential nutrient for plant development, excessive concentrations can contribute to environmental challenges, such as eutrophication. Specifically, Nittur (Sample code V43S2) showed the minimum NO_3^- concentration of 11.23 mg/L, in contrast to Badabasapur (Sample code V4S1), which recorded the maximum level at 56.25 mg/L. Nitrates typically enter aquatic systems through various pathways, including natural soil erosion, the application of agricultural fertilizers, and rainfall (Kapoor and Bamniya, 2011). The process of urea converting to ammonium and then to nitrate enhances nitrate mobility in the soil, posing a risk for groundwater contamination if not utilized by plants.

Boron concentrations in the irrigation water samples ranged from 0.14 to 1.60 mg/L, averaging 0.50 mg/L. The lowest concentration was recorded in Itagi (Sample code V20S1), while Nittur (Sample code V43S2) showed the highest level. Although boron is a crucial micronutrient necessary for plant development, excessive amounts can induce toxicity, especially in sensitive crops. Specifically, Itagi village (Sample code V20S1) reported a boron concentration of 0.14 mg/L, whereas Nittur village (Sample code V43S2) reached 1.60 mg/L. With the permissible limit for irrigation set at 0.5 mg/L, these findings indicate that boron levels could pose a risk to sensitive crops in the region.

The residual sodium carbonate (RSC) values in irrigation water samples from the southern parts of Ranebennur taluk varied from -5.1 to 7.7 mmol/L, with an average of 1.75 mmol/L. The lowest RSC value of -5.1 mmol/L was recorded in samples from Sunakalbidari (Sample code V46S1), suggesting a low risk of sodium-related issues in irrigation. In contrast, Kooli village (Sample code V24S1) reported the highest RSC at 7.7 mmol/L, indicating a potential for sodium accumulation in the soil, which can lead to increased sodicity and negatively affect soil structure and crop health. A positive RSC indicates that sodium may build up in the soil, while a negative RSC reflects a sufficient presence of calcium and magnesium, reducing the risk of sodium accumulation. Moreover, RSC values represent the balance between carbonate and bicarbonate ions derived from calcium and magnesium in the irrigation water. When such water is subjected to evapotranspiration, the precipitation of carbonates and bicarbonates helps lower soil salinity by removing excess sodium from the soil solution (Eaton, 1950). Consequently, elevated RSC levels can improve soil quality by facilitating the precipitation of calcium and magnesium ions. These findings align with previous research by Raja *et al*. (2015); Nisar (2020); Bouaissa *et al.* (2021), underscoring the necessity of monitoring RSC in irrigation management (Hussain *et al.,* 2022).

The sodium adsorption ratio (SAR) of the water samples analyzed ranged from 6.71 to 24.74, with an average value of 13.21. The lowest SAR, noted at 6.71 in samples from Laxmapur (Sample code V30S1), indicates a favorable irrigation water quality with minimal risk of sodium-related soil problems. Conversely, Kotihal (Sample code V25S1) exhibited a high SAR value of 24.74, which presents a significant risk of sodium accumulation in the soil. Elevated SAR levels can lead to soil sodicity, adversely affecting soil permeability and structure, which ultimately impacts plant growth and yield. SAR is a critical measure for assessing the potential for irrigation water to engage in cation exchange reactions within the soil. As sodium displaces adsorbed calcium and magnesium, it can cause soil compaction and decreased permeability, compromising soil integrity. This study revealed that the SAR values generally fell within permissible limits, classifying the irrigation water as a low to medium sodium hazard (S1 class) according to Richards (1954). However, the study also observed the accumulation of salts in deeper soil layers due to percolation from upper horizons, primarily linked to excessive borewell water usage for irrigation, leading to waterlogging and salinization. High SAR values signal risks related to sodium-induced soil degradation, as Na^+ can replace essential Ca^{2+} and Mg^{2+} ions through cation exchange, ultimately affecting soil fertility and crop yields (Gupta, 2005). The observed correlation of increased SAR with higher pH and electrical conductivity (EC) indicates a predominance of soluble Na^+ over Ca^{2+} and Mg^{2+} ions, consistent with the findings of Singh (2020); Bouaissa *et al.* (2021).

Total hardness (TH) in the analyzed irrigation water samples varied from 3.65 to 28.50 mg/L, averaging 13.54 mg/L. The lowest hardness was recorded in samples from Kotihal (Sample code V25S1) at 3.65 mg/L, suggesting that this water is softer and less likely to cause scaling or related complications. Conversely, the highest TH was observed in samples from Antaravalli (Sample code V2S3) at 28.50 mg/L. Elevated total hardness can impact irrigation practices by potentially leading to clogging in irrigation systems and affecting the nutrient availability for crops. TH is primarily influenced by the concentrations of calcium and magnesium in the water. This study confirmed that Kotihal (Sample code V25S1) had the lowest TH value (3.65 mg L^{-1}), while Antaravalli (Sample code V2S3) exhibited the highest (28.50 mg L^{-1}). According to the Bureau of Indian Standards (BIS 2012-IS10500:2012), the permissible range for total hardness in groundwater is 200–600 mg L^{-1}. Most of the water samples analyzed fell within the hard to very hard category, with an average hardness of 491 mg L^{-1} (Palmajumder *et al*. 2021), suggesting potential implications for agricultural practices and the management of irrigation systems.

Total dissolved solids (TDS) in the irrigation water samples varied between 537.6 and 2758.4 mg/L, with an average concentration of 1377.96 mg/L. The lowest TDS value of 537.6 mg/L was recorded in Harogoppa (Sample code V15S3), indicating favorable low salinity levels for irrigation. In contrast, the highest TDS level of 2758.4 mg/L was observed in Yerikoppi village (Sample code V51S2), suggesting serious salinity issues that could hinder crop growth and soil quality. Elevated TDS levels can induce osmotic stress in plants, negatively affecting their ability to uptake water and overall health. Furthermore, high TDS concentrations can alter the taste of water and reduce its potability. This study noted the lowest TDS in Harogoppa (Sample code V15S3) and the highest in Yerikoppi village (Sample code V51S2). Increased TDS levels in irrigation water can lead to the buildup of harmful salts, adversely impacting plant health. The classification of TDS indicates that several water samples fall into the "moderate" to "severe" categories regarding irrigation suitability. A significant correlation was observed between TDS and electrical conductivity (EC), with an average TDS of 632.3 mg/L (Palmajumder *et al*. 2021). These findings are consistent with prior studies by Nisar (2020), underscoring the critical need for TDS monitoring in the management of agricultural water resources.

CONCLUSIONS

The analysis of groundwater samples from the southern regions of Ranebennur taluk reveals significant variability in water quality parameters crucial for irrigation. The pH ranged from slightly acidic to alkaline, with an average value of 7.26, influenced by geochemical processes and the presence of cations like Ca^{2+}, Mg^{2+}, Na^+, and HCO_3^-. Electrical conductivity (EC) values indicated varying salinity levels, with 59.50% of samples deemed suitable for irrigation. However, elevated sodium concentrations (Na^+) could lead to soil sodicity, impacting soil structure and permeability. Key nutrients like potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), and micronutrients like boron (B) also showed diverse levels, influencing plant health and productivity. The presence of carbonates, bicarbonates, sulfates, and nitrates underscored the need for careful management of nutrient dynamics to avoid potential environmental impacts such as eutrophication. Total dissolved solids (TDS) levels varied widely, indicating potential osmotic stress for crops, particularly in areas with high salinity. Overall, this study emphasizes the importance of continuous monitoring and management of irrigation water quality to sustain agricultural productivity and soil health in the region, in alignment with previous research findings.

Future studies should focus on the long-term monitoring of groundwater quality to assess seasonal variations and their impact on agricultural sustainability. Advanced geospatial techniques, such as GIS and remote sensing, could be employed to map water quality trends across larger areas. Additionally, exploring the effects of different irrigation practices on soil salinity and nutrient retention would provide valuable insights. Further research on sustainable water management practices and alternative irrigation sources is also essential to mitigate water quality challenges.

Acknowledgment. We would like to express our deepest gratitude to the Department of Soil Science and Agricultural Chemistry, University of Agricultural Sciences, Dharwad, for providing the necessary resources and support for this research. Special thanks to our supervisor, Dr. Rajakumar G. R., for his invaluable guidance and encouragement throughout the study. We are also grateful to Ramesh and Jakir Hussain K. N. for their constructive insights and assistance in data collection and analysis.
Conflict of Interest. None.

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How to cite this article: Pawan Kumar N., Rajakumar G.R., Ramesh and Jakir Hussain K.N. (2023). Hydrochemical Analysis of Groundwater in Southern Ranebennur Taluk, Haveri District, Karnataka. *Biological Forum – An International Journal, 15*(8): 591-601.