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Study of Groundwater and Its Quality Parameters on Soil Nutrient Dynamics in Northern Parts of Ranebennur Taluk, Haveri District, Karnataka, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The study of groundwater and its quality parameters in Northern Ranebennur taluk is crucial for understanding their impact on soil nutrient dynamics, which directly affects agricultural productivity. By assessing groundwater quality, the research aims to optimize soil management practices and ensure sustainable agriculture in the region. This study aimed to uncover how groundwater quality impacts soil properties in Northern Ranebennur, Haveri district. Researchers collected 150 groundwater and soil samples from 50 villages. Findings revealed that groundwater-irrigated soils had a pH range of 6.58 to 8.90, averaging at 7.50. The average EC was 2.04 dS m^{-1}, and ESP varied between 3.33 and 18.06 percent. Soil nutrients showed mean values of 318.51 kg/ha for nitrogen, 43.33 kg/ha for phosphorus, and 277.60 kg/ha for potassium. Zinc was notably deficient, copper ranged from low to medium, while manganese and iron were moderately to highly available. The study uncovered intriguing connections between groundwater quality and soil properties. Groundwater pH showed a strong positive correlation with soil pH (r = 0.430**). Groundwater SAR was significantly linked with soil EC (r = 0.218*). Groundwater RSC had a notable positive relationship with soil ESP (r = 0.488**) and pH (r = 0.202**). Groundwater SAR also correlated significantly with soil ESP (r = 0.422**). Interestingly, groundwater EC was positively correlated with soil potassium, iron, and zinc, while it negatively impacted nitrogen, phosphorus, and copper levels. Sodium in groundwater showed a positive relationship with soil nitrogen, potassium, and iron, but a negative one with phosphorus. Boron levels in groundwater strongly correlated with soil boron (r = 0.883**). Finally, groundwater SAR was negatively correlated with soil nitrogen, phosphorus, and potassium.

Keywords: groundwater; correlation; nutrient status; SAR; ESP; irrigated soil.

1. INTRODUCTION

Groundwater is a vital yet finite resource for agriculture, demanding meticulous management. During base-flow periods, higher groundwater velocities can increase chemical ion concentrations. Grasping the quality of irrigation water is key for agricultural success. Overexploitation deepens local groundwater tables, leading to deteriorated water quality. Improper irrigation practices, even with high-quality water, can turn soils saline or alkaline, harming crop yields. Mismanagement threatens agricultural productivity. Sustainable groundwater use is essential for long-term agricultural viability. Implementing balanced practices can prevent soil degradation and preserve water quality, ensuring a thriving agricultural future.

Soil stands out as a critical factor, being a nutrient reservoir vital for plant growth. However, nutrient availability varies widely. In India, per-capita land availability has plummeted from 0.5 to 0.08 hectares due to population growth. Around 80% of farms are small or marginal, with an average size of less than 1 hectare. Research consistently demonstrates the land's potential for three to four times greater productivity using existing technologies. With proper management, land won't pose a significant constraint in feeding the growing population. This has necessitated concentrating on the soils having production constraints, which also include salt affected soils. The poor performance of crops in salt affected soils may be due to excess quantities of soluble salts and higher exchangeable sodium percentage, which consequently result in nutritional disorders in plants [1]. Excess salt content in the soil creates high osmotic pressure of soil solution, which obstructs water and nutrient uptake by plant roots. The nutrients present in ground water can be varied due to various factors, i.e., parent material, soluble minerals, leaching, runoff and top fertile soil. The excess soluble salts present in the groundwater influences soil parameters and encourage soils for degradation.

Improvements are needed in the soil and water measurement techniques used for conjunctive water management, given the declining productivity of agricultural lands due to various stresses [2]. Groundwater remains a necessity in areas lacking alternative irrigation options, such as Karnataka and specifically Ranebennur taluk in Haveri district, despite the known decrease in crop quality and yield. Understanding the extent of damage caused to land by using low-quality underground water for irrigation is crucial. This knowledge will guide efforts to mitigate the negative impacts on agricultural productivity and sustainability. Refining measurement techniques can help optimize water use and preserve soil health in regions reliant on groundwater for irrigation. Agriculture dominates Ranebennur taluk, with 70.88% of the land cultivated and 16.15% sown multiple times. Bore wells irrigate 61.9% of the net cultivated area [3]. In the semi-arid Northern Ranebennur taluk, low rainfall and high temperatures exacerbate groundwater quality issues, leading to increased salinity and contamination. These problems impair soil fertility and nutrient availability, compounding water scarcity and reducing crop yields. Consequently, the region faces heightened risks to agricultural productivity and food security. Given this, soil characterization across various landforms is crucial for effective land management. Soil chemical analysis aids in evaluating fertility, nutrient loss, and fertilizer needs. Studies have linked soil chemistry to groundwater quality, pivotal for crop growth in Northern Ranebennur. Understanding these relationships is vital for optimizing agricultural productivity and sustainable land use.

2. MATERIALS AND METHODS

In Northern parts of Ranebennur, 150 groundwater samples from tube wells across 50 villages were meticulously collected. The precise geographical coordinates of each sample were recorded using GPS technology. To ensure clarity and purity, tube wells were initially allowed to discharge water for 15 minutes, guaranteeing sediment-free samples. These water samples, then, were carefully transferred into 500 ml polyethylene bottles, which were pre-rinsed with the sample water to avoid contamination. Additionally, 2-3 drops of toluene were added to each bottle to inhibit microbial growth during storage. After sealing the bottles airtight and labeling them with unique codes and village names, the samples underwent filtration using ordinary filter paper in the laboratory to eliminate any remaining dirt or dust particles. Each sample was meticulously labeled and subjected to comprehensive chemical analysis to evaluate various parameters essential for understanding groundwater quality in the region.

Soil types were recorded alongside water sampling, with soil samples extracted from the same fields at a depth of 30 cm, including some clods. Both water and soil samples underwent analysis for various parameters, including ionic composition. Information on the soil and groundwater from different locations in Northern Ranebennur taluk was documented in detail.

Groundwater and soil samples were analyzed using a range of techniques. Groundwater pH was measured potentiometrically and electrical conductivity (EC) using a conductivity meter. Sodium and potassium concentrations were determined via flame photometry, while carbonates and bicarbonates were assessed through titrimetric methods with standard reagents. Chloride levels were found by titration with $AgNO_3$ and sulfate levels were measured using a spectrophotometer. Nitrate levels were obtained through Kjeldahl distillation, and boron was analyzed using the azomethine-H method. For soil analysis, bulk density was calculated from water displacement, while total porosity and aggregate stability were measured using standard methods. Soil pH and electrical conductivity were assessed from soil-water suspensions. Organic carbon, nitrogen, phosphorus and potassium were analyzed using Walkley-Black titration, Kjeldahl method, Olsen's method, and flame photometry, respectively. Exchangeable sodium, calcium, and magnesium were determined via EDTA titration, and micronutrients were extracted using DTPA and measured by atomic absorption spectrophotometry.

A shapefile delineating the boundaries of Northern Ranebennur taluk was generated using ArcGIS 10.1, incorporating vector data. The associated database file (dbf) was accessed within the project window, with X-coordinates designated in the X-field and Y-coordinates in the Y-field. Simultaneously, the file representing the Northern parts of Ranebennur taluk was opened, and within ArcGIS's spatial analyst "interpolate grid option" under the surface menu was chosen. In the subsequent "grid specification dialogue," the output grid was set to match the extent of the Northern Ranebennur taluk, and the kriging interpolation method was applied [4] as depicted in Fig. 1 indicating the study area's location. Additionally, a correlation analysis was conducted using IBM SPSS Statistics 23 [5] to establish relationships between groundwater characteristics and soil properties.

3. RESULTS AND DISCUSSION

3.1 Chemical Characteristics of Groundwater

Table 1 outlines the chemical properties of groundwater samples collected from Northern Ranebennur taluk, revealing important insights into water quality and its potential impact on soil properties. The pH values of these samples ranged from 6.60 to 8.20, with an average of 7.21, indicating a neutral to slightly alkaline nature. The electrical conductivity (EC) values, ranging from 0.68 to 5.67 dS m^{-1} and averaging 3.30 dS m^{-1}, suggest varying levels of dissolved salts, which can affect plant growth and soil structure. Sodium (Na^{+}) concentrations in the groundwater varied from 10.12 to 44.70 mmol L^{-1}. High sodium levels are particularly concerning as they can displace essential ions like magnesium (Mg^{2+}) and calcium (Ca^{2+}) in the water. When sodium replaces these ions, it gets absorbed by clay particles in the soil. This displacement reduces soil permeability, leading to poor soil structure and water infiltration issues. Verma *et al*. [6] highlighted this phenomenon, emphasizing the detrimental effects on soil health. Calcium (Ca^{2+}) and magnesium (Mg^{2+}) concentrations in the groundwater samples ranged from 1.40 to 13.45 mmol L^{-1} and 0.78 to 6.90 mmol L^{-1}, respectively. These ions are crucial for maintaining soil structure and fertility. The presence of adequate levels of Ca^{2+} and Mg^{2+} helps to counteract the negative effects of high sodium, promoting better soil aggregation and permeability. Therefore, monitoring and managing the balance of these ions in irrigation water is essential to sustain soil health and agricultural productivity.

The chemical properties of groundwater in Northern Ranebennur taluk reveal crucial insights into soil-water interactions and potential impacts on agricultural productivity. A majority of the groundwater samples were within safe limits, which is encouraging for agricultural use. However, higher magnesium (Mg^{2+}) concentrations in the groundwater can elevate soil pH and trigger reverse cationic exchange processes. This reverse exchange occurs when magnesium ions in the soil are replaced by sodium (Na^{+}) ions from the groundwater. As a result, calcium (Ca^{2+}) and magnesium (Mg^{2+}) concentrations in the soil can increase in certain areas, leading to an imbalance in soil chemistry. Studies by Savalia *et al*. [7] and Yadav *et al*. [8] have observed this phenomenon and its implications for soil health.

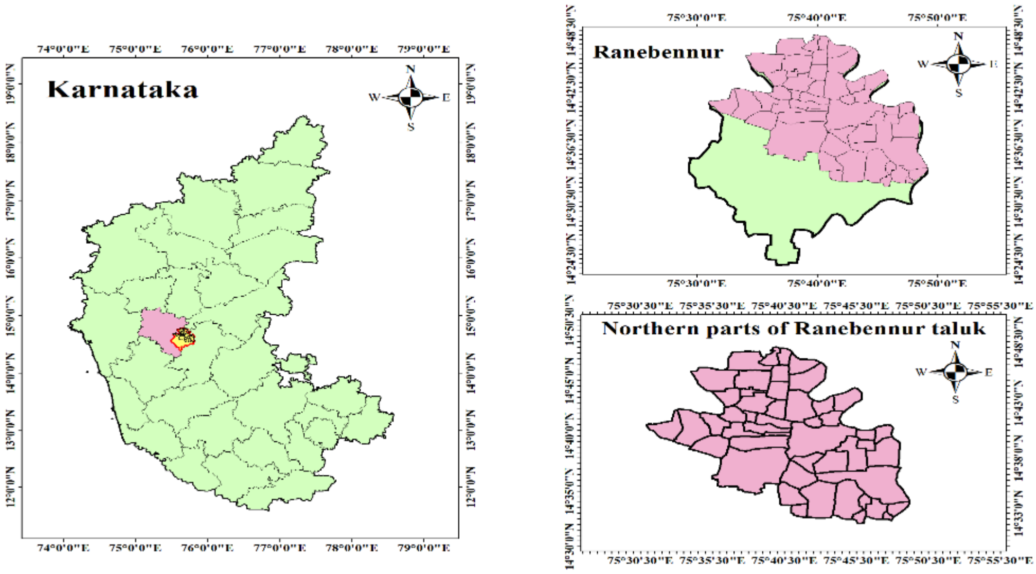

Fig. 1. Location of the study area

Table 1. Analysis of groundwater chemical composition in Northern parts of Ranebennur taluk

Parameters	Range	Mean	SD	CV
pH	6.60-8.20	7.21	0.50	14.19
EC (dS m^{-1})	0.68-5.67	3.30	0.88	26.84
Na^{2+} (mmol L^{-1})	10.12-44.70	26.04	6.73	25.87
Ca^{2+} (mmol L^{-1})	1.40-13.45	5.00	2.02	40.46
Mg^{2+} (mmol L^{-1})	0.78-6.90	2.56	1.00	38.97
SAR	4.74-24.30	14.05	4.26	30.38
B (mg L^{-1})	0.05-2.35	0.57	0.40	70.32
RSC (mmol L^{-1})	-9.20-9.27	1.15	3.22	281.34

The Sodium Adsorption Ratio (SAR) values ranged from 4.74 to 24.30, while the Residual Sodium Carbonate (RSC) values varied from -9.20 to 9.27 mmol L^{-1}. SAR is a critical parameter for evaluating the sodicity of irrigation water, which affects soil structure and permeability. Higher SAR values indicate a greater proportion of sodium relative to calcium and magnesium, which can lead to soil dispersion and reduced infiltration rates. The increase in SAR values with rising pH and electrical conductivity (EC) of groundwater can be attributed to the higher solubility and prevalence of sodium ions over calcium and magnesium ions. Kumar *et al*. [9] highlighted this relationship, emphasizing the adverse effects of high sodium levels on soil physical properties.

RSC values provide additional insight into the potential impact of irrigation water on soil. Positive RSC values indicate an excess of carbonate (CO_3^-) and bicarbonate (HCO_3^-) ions relative to calcium and magnesium, which can precipitate as insoluble carbonates, reducing their availability in the soil. Variations in RSC concentrations could be due to fluctuations in the concentrations of dissolved CO_3^- and HCO_3^- ions. When dissolved sodium is lower than dissolved calcium and magnesium, RSC values tend to be negative, suggesting that the water has the potential to precipitate calcium and magnesium, which can mitigate the adverse effects of high sodium levels.

Boron (B) levels in groundwater samples ranged from 0.05 to 2.35 mg L^{-1}, with an average of 0.57 mg L^{-1}. Boron is an essential micronutrient for plant growth, but its concentration must be carefully managed. At low levels, boron is beneficial, supporting various physiological functions in plants. However, at higher concentrations, boron can become toxic, leading to leaf burn and reduced crop yields. The observed range of boron levels in the groundwater samples indicates variability in boron availability, which could influence crop performance depending on the specific boron tolerance of the crops being cultivated. The chemical properties of groundwater in Northern Ranebennur taluk reveal a complex interplay between ion concentrations, soil pH, and potential impacts on soil structure and fertility. Higher magnesium concentrations can lead to elevated soil pH and reverse cationic exchange, while SAR and RSC values provide insight into the potential for soil dispersion and carbonate precipitation. Boron levels, although variable, highlight the need for careful management to ensure optimal crop growth. Understanding these interactions is essential for developing sustainable irrigation practices that maintain soil health and agricultural productivity.

Table 2 offers a comprehensive snapshot of the chemical properties and nutrient status of soils from groundwater-irrigated areas. The soil pH, averaging at 7.50, falls within the neutral to moderately alkaline range, which suggests that the soils are neither strongly acidic nor overly alkaline. This pH range is generally conducive to plant growth, as most crops thrive in neutral to slightly alkaline soils. The average electrical conductivity (EC) of 2.04 dS m-1 reflects a moderately saline environment. Although higher EC values are noted, indicating a higher concentration of dissolved salts, the majority of the soils fall below the 2 dS m^{-1} threshold that defines saline soils, as per Richards [10]. This suggests that while the use of salt-containing groundwater for irrigation does impact soil salinity, the soils in this study area remain largely non-saline.

The nitrogen content in the soil samples varies between 178.34 and 462.24 kg ha^{-1}, with an average of 318.51 kg ha^{-1}. This range indicates a moderate to high nitrogen status, essential for plant growth as nitrogen is a critical component of amino acids and proteins. However, the variability might reflect differences in soil management practices or organic matter content across the samples. Phosphorus (P_2O_5) and potassium (K_2O) levels also show significant variability, with P_2O_5 ranging from 23.13 to 43.33 kg ha^{-1} and K_2O from 208.32 to 395.68 kg ha^{-1}. These levels generally fall within medium to high ranges, suggesting that the soils are relatively well-supplied with these essential nutrients, which are vital for root development and overall plant health.

The exchangeable cations, including calcium (Ca^{2+}), magnesium (Mg^{2+}), and sodium (Na^+), exhibit notable variability. The levels of Ca^{2+} and Mg^{2+} range from 9.20 to 16.90 cmol(p^+) kg^{-1} and 7.25 to 37.25 cmol(p^+) kg^{-1}, respectively, indicating a variation in soil texture and mineral composition. High levels of exchangeable sodium (1.55 to 7.82 cmol(p^+) kg^{-1}) can be detrimental to soil structure and plant growth due to its potential to cause soil dispersion and reduced permeability. However, calcium plays a crucial role in replacing sodium ions on the soil exchange complex. This ion exchange process helps in mitigating the adverse effects of sodium by forming sodium sulfate, which is then leached away, as discussed by Sharma *et al*. [2]. This process helps in maintaining soil structure and reducing salinity levels. The observed variability in exchangeable Ca^{2+} and Mg^{2+} can be attributed to the differences in soil clay content, as noted by Nayak *et al*. [11]. Soils with higher clay content tend to have greater cation exchange capacities, influencing the availability of these cations. The overall nutrient status, with low to medium nitrogen and medium to high levels of P_2O_5 and K_2O, suggests a generally fertile environment, although the impact of salinity and sodium levels might need to be managed to optimize soil productivity.

Table 3 highlights the intricate relationships between various groundwater and soil properties, underscoring how these parameters interact and influence each other. The electrical conductivity (EC) of groundwater shows a significant positive correlation with the EC of irrigated soil (r = 0.361**). This correlation reflects the impact of groundwater salinity on soil salinity. As groundwater with higher EC is used for irrigation, it introduces more dissolved salts into the soil, raising its EC. This relationship is crucial because elevated soil EC can affect plant growth by altering the soil's osmotic potential, making it harder for plants to take up water and nutrients. The correlation between groundwater EC and soil pH (r = 0.223*) suggests that as the concentration of soluble salts in groundwater increases, so does the pH of the soil. This occurs because salts in groundwater often include basic ions, which can increase soil pH. Chopra *et al.* [12] noted this effect, indicating that the soluble salts present in groundwater contribute to soil alkalinity.

Additionally, the significant positive correlation between the pH of groundwater and the pH of irrigated soils (r = 0.330*) indicates a direct influence of groundwater pH on soil pH. When groundwater with a higher pH is used for irrigation, it elevates the soil pH over time, contributing to soil alkalinity. This is important because changes in soil pH can affect nutrient availability and microbial activity in the soil. The Sodium Adsorption Ratio (SAR) of groundwater shows a positive correlation with the EC of irrigated soil (r = 0.218*). SAR measures the ratio of sodium ions to calcium and magnesium ions in water. Higher SAR values often indicate an excess of sodium relative to calcium and magnesium, which can lead to soil structure problems. The increased sodium content from high SAR groundwater contributes to higher soil EC by increasing the amount of soluble salts in the soil.

The Residual Sodium Carbonate (RSC) of groundwater exhibits a positive correlation with soil pH (r = 0.202**). RSC is calculated based on the concentrations of carbonate and bicarbonate relative to calcium and magnesium. High RSC values indicate an excess of carbonate and bicarbonate ions, which can lead to higher soil pH by increasing the amount of sodium in the soil solution. This aligns with Awanish *et al.* [13] who described how high RSC contributes to elevated soil pH by increasing sodium levels in the soil. The strong positive correlation between groundwater EC and the Exchangeable Sodium Percentage (ESP) of irrigated soils (r = 0.488**) highlights how increasing salinity in groundwater influences the amount of sodium adsorbed onto soil particles. Higher EC in groundwater introduces more salts, which can increase the ESP by displacing calcium and magnesium ions from the soil exchange sites, leading to higher sodium adsorption.

Similarly, the SAR of groundwater correlates significantly with the ESP of irrigated soils (r = 0.422**). High SAR values in groundwater lead to an increase in ESP because the excess sodium relative to calcium and magnesium promotes the exchange of sodium for calcium and magnesium on the soil particles. As a result, more sodium gets adsorbed, increasing the ESP and soil pH, as calcium and magnesium precipitate as carbonates. Singh and Kundu [14] describe this process, noting that higher SAR levels cause an accumulation of sodium in the soil, which adversely affects soil structure and fertility. In summary, the positive correlations observed in Table 3 illustrate how groundwater quality parameters, such as EC, pH, SAR, and RSC, influence soil properties like EC, pH, and ESP. These interactions highlight the complex dynamics between irrigation practices and soil chemistry, emphasizing the importance of managing groundwater quality to maintain soil health and optimize agricultural productivity.

Table 2. Soil chemical composition and nutrient status in groundwater-irrigated area

Village Name	Sample No.	pH	EC dS m^{-1}	Primary nutrients kg ha^{-1}			Ex-Na^+ cmol(p+) kg^{-1}	ESP	Ex-Ca^{2+}	Ex-Mg^{2+}
				N	P_2O_5	K_2O			cmol(p+) kg^{-1}	
Airani	V_1S_1	7.45	0.60	386.41	58.17	309.12	2.03	11.68	22.20	15.40
	V_1S_2	6.58	3.60	404.23	27.94	222.56	7.57	15.90	19.80	9.20
	V_1S_3	7.15	1.29	336.24	57.25	255.36	5.43	6.87	22.00	15.00
Ankasapur	V_2S_1	7.95	0.83	229.65	60.00	395.68	6.28	7.76	31.80	14.20
	V_2S_2	6.85	1.49	333.85	29.77	282.24	5.90	12.48	27.55	16.00
	V_2S_3	7.94	2.00	323.25	51.53	255.36	3.65	4.06	22.20	16.50
Aremallapur	V_3S_1	7.70	1.07	347.41	39.39	241.92	3.07	12.66	20.20	12.20
	V_3S_2	8.05	1.37	189.04	30.92	239.23	3.59	10.56	32.45	13.50
	V_3S_3	7.90	2.28	337.87	35.27	282.24	5.04	14.18	20.50	14.40
Belur	V_4S_1	6.79	0.94	426.00	30.69	236.00	3.79	10.16	35.00	16.40
	V_4S_2	7.20	3.14	233.25	40.08	322.56	7.80	17.60	23.24	13.50
	V_4S_3	7.22	1.04	325.20	35.72	255.36	6.38	16.09	22.56	9.60
Bevinahalli	V_5S_1	7.32	0.40	258.56	65.95	224.44	1.59	9.89	26.60	16.80
	V_5S_2	7.20	1.34	335.52	56.33	254.01	5.80	8.91	37.34	14.60
	V_5S_3	7.00	1.53	254.42	35.95	208.32	4.42	5.29	23.45	13.70
Chalageri	V_6S_1	7.30	0.70	362.64	35.27	366.11	1.89	6.94	20.23	9.40
	V_6S_2	7.13	4.67	254.28	61.14	263.42	1.96	14.42	19.77	16.70
	V_6S_3	7.21	3.03	344.63	29.31	262.08	6.80	14.17	18.33	16.80
Channapur	V_7S_1	8.00	1.16	265.12	35.50	213.69	3.17	6.11	23.20	12.50
	V_7S_2	7.35	2.57	189.34	58.62	337.88	2.92	4.29	22.34	15.60
	V_7S_3	7.40	3.35	248.56	44.88	224.44	4.09	5.09	36.40	13.60
Chikka Aralahalli	V_8S_1	6.80	2.01	357.83	32.52	282.24	2.78	12.81	26.40	14.20
	V_8S_2	7.35	0.98	335.20	28.63	255.36	3.59	8.37	30.60	12.50
	V_8S_3	7.20	3.10	353.45	31.14	241.92	1.75	6.79	22.11	15.60
Chikka Kuravatti	V_9S_1	7.40	2.69	198.04	60.91	339.23	2.59	12.80	23.60	16.60
	V_9S_2	7.38	2.36	325.82	63.20	282.24	4.12	8.40	19.89	14.60
	V_9S_3	7.40	3.46	413.05	30.92	336.00	1.81	17.68	14.50	13.50
Choudayyadanapur	$V_{10}S_1$	8.00	1.57	242.26	37.56	322.56	6.69	10.43	22.80	9.40
	$V_{10}S_2$	7.08	2.43	366.20	42.59	255.36	5.49	13.37	22.40	15.60
	$V_{10}S_3$	6.80	4.89	200.55	28.85	324.44	7.75	16.62	35.34	14.60

Village Name	Sample No.	pH	EC dS m^{-1}	Primary nutrients kg ha^{-1}			Ex-Na^{+} cmol(p+) kg^{-1}	ESP	Ex-Ca^{2+}	Ex-Mg^{2+}
				N	P_2O_5	K_2O			cmol(p+) kg^{-1}	
Devagondana katti	$V_{11}S_1$	7.80	3.46	357.52	38.47	254.01	4.69	7.61	28.00	9.80
	$V1_1S_2$	7.15	2.30	205.40	65.49	308.32	1.87	12.35	20.20	16.60
	$V_{11}S_3$	7.92	1.41	234.49	44.88	309.12	3.89	10.10	30.25	15.60
Gangapur	$V_{12}S_1$	8.01	3.13	424.26	33.43	322.56	6.48	13.46	26.00	14.60
	$V_{12}S_2$	6.74	0.90	357.28	60.91	255.36	3.28	10.78	24.67	16.60
	$V_{12}S_3$	7.09	2.81	306.60	34.12	395.68	2.65	12.66	27.38	16.90
Gudagur	$V_{13}S_1$	8.13	1.48	252.85	63.20	282.24	5.24	7.62	33.40	14.60
	$V_{13}S_2$	7.32	3.07	305.20	40.30	255.36	5.60	12.04	30.23	15.60
	$V_{13}S_3$	7.57	2.92	334.40	38.47	341.92	2.23	9.89	21.34	16.80
Guddadanveri	$V_{14}S_1$	7.30	0.93	193.04	42.14	239.23	4.99	8.75	25.60	12.40
	$V_{14}S_2$	7.81	1.79	331.80	38.47	282.24	4.51	15.57	23.24	11.80
	$V_{14}S_3$	7.90	2.10	257.04	31.37	309.12	4.41	14.92	20.50	12.70
Guddaguddapur	$V_{15}S_1$	7.45	0.47	424.20	36.18	322.56	3.06	10.72	34.60	12.80
	$V_{15}S_2$	8.01	3.63	361.23	63.66	355.36	3.58	13.26	22.45	13.80
	$V_{15}S_3$	7.20	2.13	236.53	33.66	295.68	2.26	8.94	25.34	14.70
Hanumapur	$V_{16}S_1$	7.50	1.45	303.52	60.91	282.24	4.97	11.59	26.68	12.60
	$V_{16}S_2$	7.95	4.02	261.40	40.53	355.36	6.02	15.93	30.55	11.70
	$V_{16}S_3$	7.85	2.04	332.63	33.43	241.92	3.05	12.77	21.45	10.60
Harangiri	$V_{17}S_1$	7.30	1.82	245.28	60.00	239.23	5.50	4.15	30.27	12.20
	$V_{17}S_2$	6.76	1.31	321.63	31.60	282.24	3.87	6.49	23.24	15.80
	$V_{17}S_3$	7.60	2.25	262.12	68.01	336.00	6.34	12.14	22.99	16.70
Heeladahalli	$V_{18}S_1$	7.42	4.56	195.36	53.13	322.56	7.82	18.06	13.20	29.75
	$V_{18}S_2$	7.24	2.31	268.53	38.01	255.36	3.23	12.28	15.60	21.62
	$V_{18}S_3$	7.50	1.49	342.80	56.33	324.44	4.36	7.57	14.60	27.37
Hirebidari	$V_{19}S_1$	8.10	1.47	362.23	36.18	254.01	4.01	6.12	15.80	27.00
	$V_{19}S_2$	7.15	2.54	351.80	64.58	308.32	3.51	3.82	16.20	32.00
	$V_{19}S_3$	7.95	2.36	332.23	42.82	266.11	4.89	8.06	15.70	24.87
Honnatti	$V_{20}S_1$	7.70	3.34	344.40	37.10	263.42	4.03	9.78	12.20	31.25
	$V_{20}S_2$	8.20	3.07	193.04	33.43	262.08	4.87	6.90	14.60	34.87
	$V_{20}S_3$	7.95	2.02	362.84	35.50	313.69	4.33	16.28	11.50	32.50
Hullikatti	$V_{21}S_1$	7.60	0.65	344.00	38.01	237.88	3.42	5.90	16.60	16.87
	$V_{21}S_2$	7.10	1.34	462.24	40.30	224.44	3.05	12.84	14.60	28.12

Village Name	Sample No.	pH	EC dS m^{-1}	Primary nutrients kg ha^{-1}			Ex-Na^{+} cmol(p+) kg^{-1}	ESP	Ex-Ca^{2+}	Ex-Mg^{2+}
				N	P_2O_5	K_2O			cmol(p+) kg^{-1}	
	$V_{21}S_3$	7.97	2.54	336.24	31.14	382.24	2.37	12.85	13.60	25.75
Hullatti	$V_{22}S_1$	6.90	4.00	351.84	35.72	255.36	6.70	16.79	12.60	30.62
	$V_{22}S_2$	7.72	3.49	317.05	59.77	241.92	1.92	14.55	12.70	23.12
	$V_{22}S_3$	7.09	2.70	316.40	28.85	239.23	2.49	10.45	16.60	30.75
Hunashikatti	$V_{23}S_1$	7.72	2.16	193.06	52.67	282.24	2.29	12.08	12.00	16.50
	$V_{23}S_2$	7.88	0.73	344.26	38.24	236.00	3.81	11.08	14.70	35.00
	$V_{23}S_3$	6.87	3.49	327.48	33.43	322.56	2.31	7.92	14.60	25.00
Kajjari	$V_{24}S_1$	7.70	4.34	242.07	44.88	355.36	6.86	15.83	12.60	26.75
	$V_{24}S_2$	6.90	1.17	223.86	58.85	224.44	3.19	6.18	12.70	19.12
	$V_{24}S_3$	7.15	2.48	261.05	23.13	354.01	4.46	3.33	10.10	29.25
Kakol	$V_{25}S_1$	8.00	4.25	417.24	36.18	309.12	7.53	16.44	11.80	26.62
	$V_{25}S_2$	7.27	2.31	373.25	28.85	322.56	1.99	6.80	14.60	21.00
	$V_{25}S_3$	7.14	4.40	243.56	35.50	345.36	1.57	14.18	15.50	33.75
Kamadod	$V_{26}S_1$	7.85	0.87	375.52	61.58	295.68	4.23	8.22	16.80	16.12
	$V_{26}S_2$	7.90	3.99	266.44	51.75	282.24	5.87	14.29	14.60	20.00
	$V_{26}S_3$	8.00	1.27	383.63	38.01	255.36	4.11	9.57	15.60	26.75
Karur	$V_{27}S_1$	7.90	1.39	353.25	33.43	251.92	5.00	10.13	14.60	27.37
	$V_{27}S_2$	7.80	3.52	325.65	43.05	239.23	5.97	12.96	12.80	17.00
	$V_{27}S_3$	6.82	2.42	367.22	36.18	232.24	4.33	9.48	12.80	32.00
Konanatambigi	$V_{28}S_1$	7.90	0.85	344.41	67.33	316.00	2.19	10.10	14.40	34.87
	$V_{28}S_2$	7.90	1.18	178.34	33.21	322.56	5.95	9.27	13.50	21.25
	$V_{28}S_3$	7.96	2.23	333.81	55.19	255.36	2.66	11.96	14.10	34.00
Kudrihal	$V_{29}S_1$	7.35	1.06	421.00	31.60	214.44	6.35	6.73	13.80	32.87
	$V_{29}S_2$	7.70	2.39	412.22	55.42	254.01	2.48	11.05	14.20	16.87
	$V_{29}S_3$	7.50	1.53	316.23	41.45	208.32	2.00	10.97	13.10	27.37
Kunabev	$V_{30}S_1$	7.90	0.47	209.56	33.89	236.11	5.65	12.56	14.80	16.87
	$V_{30}S_2$	7.25	1.80	341.52	67.78	263.42	1.75	5.52	13.60	32.25
	$V_{30}S_3$	7.15	3.15	263.42	32.52	262.08	1.55	12.98	14.20	24.75
Maidur	$V_{31}S_1$	6.79	1.48	334.81	33.89	313.69	6.06	17.98	15.80	26.00
	$V_{31}S_2$	7.22	1.49	365.20	37.79	237.88	3.73	12.54	14.50	29.50
	$V_{31}S_3$	7.15	2.94	372.43	42.37	244.44	4.89	9.27	13.50	16.12
Medleri	$V_{32}S_1$	6.90	1.37	226.44	36.18	362.24	4.85	3.95	15.80	28.00

Village Name	Sample No.	pH	EC dS m^{-1}	Primary nutrients kg ha^{-1}			Ex-Na^{+} cmol(p+) kg^{-1}	ESP	Ex-Ca^{2+}	Ex-Mg^{2+}
				N	P_2O_5	K_2O			cmol(p+) kg^{-1}	
	$V_{32}S_2$	7.85	2.24	345.22	38.24	255.36	3.32	6.79	16.70	29.75
	$V_{32}S_3$	7.95	2.16	305.41	56.33	241.92	6.47	4.78	14.60	36.00
Nadiharalalli	$V_{33}S_1$	7.70	4.55	246.24	58.17	239.23	7.79	14.25	15.40	27.37
	$V_{33}S_2$	7.10	0.72	354.86	37.56	282.24	4.71	12.63	15.40	25.62
	$V_{33}S_3$	7.15	2.20	427.05	32.98	336.00	5.54	11.87	14.40	19.00
Nalawagala	$V_{34}S_1$	8.30	0.95	241.04	58.85	222.56	1.99	9.23	15.70	7.25
	$V_{34}S_2$	7.20	0.54	416.23	40.30	255.36	4.12	10.20	14.60	28.12
	$V_{34}S_3$	7.13	2.02	336.24	65.49	254.44	4.20	4.32	11.60	17.00
Nukapur	$V_{35}S_1$	8.30	1.12	285.55	38.01	264.01	5.43	4.18	13.60	19.62
	$V_{35}S_2$	7.36	2.46	344.52	43.51	238.32	3.37	6.72	12.00	31.62
	$V_{35}S_3$	8.24	2.09	267.46	55.19	309.12	2.23	11.34	14.10	16.62
Padmavathipur	$V_{36}S_1$	7.70	1.56	364.85	40.76	372.56	2.58	9.66	15.80	27.00
	$V_{36}S_2$	7.20	2.34	329.27	37.79	235.36	1.79	9.65	13.50	32.12
	$V_{36}S_3$	7.45	0.67	363.40	44.88	295.68	3.19	12.31	15.60	34.75
Rahutanakatti	$V_{37}S_1$	8.40	1.06	293.04	56.33	282.24	3.51	12.10	14.60	32.00
	$V_{37}S_2$	7.20	2.16	362.24	51.53	265.36	3.40	11.59	15.50	24.37
	$V_{37}S_3$	7.36	4.50	366.46	31.14	221.92	7.60	17.80	13.60	33.37
Ramapur	$V_{38}S_1$	6.97	2.31	328.06	61.60	239.23	3.58	5.26	16.20	26.87
	$V_{38}S_2$	7.01	1.12	453.24	51.30	292.24	1.74	7.83	13.40	17.37
	$V_{38}S_3$	7.50	0.62	432.03	36.87	356.00	4.07	7.87	14.10	37.25
Ranebennur	$V_{39}S_1$	8.60	0.70	212.23	32.52	322.56	3.34	5.64	11.20	22.00
	$V_{39}S_2$	7.45	4.57	316.20	34.58	265.36	7.43	16.72	15.10	34.62
	$V_{39}S_3$	7.43	1.27	334.44	34.81	234.44	3.31	12.63	12.20	33.25
Shidaganahal	$V_{40}S_1$	8.90	1.30	290.43	45.34	257.01	1.91	9.85	14.80	19.59
	$V_{40}S_2$	8.34	2.50	355.85	46.95	228.32	6.66	4.16	13.50	36.12
	$V_{40}S_3$	7.10	1.46	422.06	65.72	236.11	2.40	4.46	14.70	28.00
Shrinivasapur	$V_{41}S_1$	7.47	3.18	411.23	42.14	263.42	3.28	10.83	12.40	18.87
	$V_{41}S_2$	7.93	2.02	315.23	32.75	262.08	2.85	4.30	13.30	33.37
	$V_{41}S_3$	6.95	0.91	285.56	40.76	213.69	6.33	9.32	12.80	17.82
Somlapur	$V_{42}S_1$	7.80	0.80	315.23	52.21	257.88	1.82	6.58	12.80	34.87
	$V_{42}S_2$	7.20	1.35	317.40	49.24	220.44	6.26	8.11	13.50	33.12
	$V_{42}S_3$	7.60	0.51	295.64	35.72	282.24	5.17	9.18	15.60	16.97

Village Name	Sample No.	pH	EC dS m^{-1}	Primary nutrients kg ha^{-1}			Ex-Na^+ cmol(p+) kg^{-1}	ESP	Ex-Ca^{2+}	Ex-Mg^{2+}
				N	P_2O_5	K_2O			cmol(p+) kg^{-1}	
Udagatti	$V_{43}S_1$	8.00	3.36	314.83	53.13	254.36	3.13	14.54	16.20	27.37
	$V_{43}S_2$	7.95	0.48	421.44	60.57	231.92	6.24	10.61	16.40	27.00
	$V_{43}S_3$	7.79	1.54	418.24	37.33	219.23	4.63	13.76	14.30	29.00
Venkatapur	$V_{44}S_1$	8.10	0.48	314.25	30.69	282.24	6.55	8.14	14.40	27.25
	$V_{44}S_2$	7.15	2.45	215.56	37.10	346.00	3.01	5.16	13.20	27.87
	$V_{44}S_3$	7.30	1.48	191.14	32.75	362.56	5.78	11.76	14.30	36.87
Waderayanahalli	$V_{45}S_1$	6.87	2.70	310.23	42.59	215.36	2.73	11.00	9.60	19.99
	$V_{45}S_2$	7.37	0.95	332.43	58.40	274.44	5.58	5.55	15.50	31.75
	$V_{45}S_3$	7.22	1.25	194.74	30.23	254.01	4.20	11.39	9.20	26.75
Yakalasapur	$V_{46}S_1$	7.20	0.39	354.84	49.92	238.32	3.48	5.94	10.80	26.75
	$V_{46}S_2$	8.10	1.47	331.05	31.83	379.12	6.39	13.06	11.90	31.75
	$V_{46}S_3$	7.60	3.22	421.23	39.85	332.56	3.72	4.77	11.40	15.25
Yallapur T medleri	$V_{47}S_1$	6.83	1.07	343.26	30.00	257.36	2.92	5.55	13.10	34.62
	$V_{47}S_2$	7.92	1.96	280.33	51.53	294.68	6.44	9.32	12.50	24.87
	$V_{47}S_3$	7.01	2.13	367.52	35.72	283.24	5.87	13.78	13.60	33.37
Yattinahalli	$V_{48}S_1$	7.36	1.28	263.43	34.35	258.36	5.43	8.95	15.00	17.95
	$V_{48}S_2$	7.98	2.19	362.64	60.69	242.92	3.84	5.78	16.50	18.72
	$V_{48}S_3$	6.92	0.90	323.23	44.43	239.23	1.75	6.94	13.40	25.75
Yellapur T honnatti	$V_{49}S_1$	7.45	1.23	357.66	32.52	282.24	2.99	12.55	15.20	30.62
	$V_{49}S_2$	7.36	4.59	379.25	40.08	326.00	7.73	15.93	14.50	33.12
	$V_{49}S_3$	8.25	1.46	303.40	54.73	352.56	5.63	10.87	13.90	26.12
Yennihosahali	$V_{50}S_1$	7.79	1.34	294.74	49.92	225.36	5.75	13.85	14.80	30.75
	$V_{50}S_2$	7.31	2.64	352.84	31.83	227.44	4.46	6.41	13.90	26.75
	$V_{50}S_3$	7.25	1.07	410.44	28.63	252.01	3.44	11.89	13.50	27.37
Minimum		6.58	0.39	178.34	23.13	208.32	1.55	3.33	9.20	7.25
Maximum		8.90	4.89	462.24	68.01	395.68	7.82	18.06	16.90	37.25
Mean		7.50	2.04	318.51	43.33	277.60	4.25	10.27	14.02	26.61
S.D		0.44	1.11	65.97	11.61	45.26	1.71	3.71	1.82	6.33
C.V		5.91	54.50	20.71	26.79	16.30	40.38	36.17	13.01	23.79

Table 3. Correlation coefficient (r) between properties of groundwater and soil samples

Water / Soil	pH	EC	SAR	RSC
pH	0.430**	0.323*	0.137	0.202**
EC	0.328*	0.561**	0.481**	0.253**
ESP	0.158	0.488**	0.422**	0.289**

***. Correlation is significant at the 0.01 level (2-tailed).*
**. Correlation is significant at the 0.05 level (2-tailed).*

Table 4. Available micronutrients status of soil samples collected from groundwater irrigated areas

Village Name	Sample No.	Zn	Fe	Cu	Mn	B
		mg kg^{-1}				
Airani	V_1S_1	0.34	3.89	1.87	2.99	1.21
	V_1S_2	0.36	5.16	0.98	3.33	0.84
	V_1S_3	0.17	6.14	0.29	8.65	1.98
Ankasapur	V_2S_1	0.16	7.18	1.66	5.66	1.16
	V_2S_2	0.38	4.33	0.79	5.47	0.93
	V_2S_3	0.35	7.16	0.26	9.36	2.00
Aremallapur	V_3S_1	0.34	9.82	0.38	5.86	1.01
	V_3S_2	0.21	2.73	0.27	8.72	0.84
	V_3S_3	0.27	11.84	0.28	6.77	1.21
Belur	V_4S_1	0.14	3.87	0.37	8.35	1.91
	V_4S_2	0.18	7.58	0.27	3.69	0.84
	V_4S_3	0.14	5.32	0.31	6.71	1.17
Bevinahalli	V_5S_1	0.28	4.26	0.55	2.37	1.84
	V_5S_2	0.38	11.62	1.16	7.88	1.98
	V_5S_3	0.68	8.93	0.91	8.93	1.96
Chalageri	V_6S_1	0.26	5.70	1.64	4.50	1.68
	V_6S_2	0.42	10.65	1.33	8.65	1.84
	V_6S_3	0.36	8.30	0.19	8.31	0.21
Channapur	V_7S_1	0.24	2.78	1.76	4.26	1.19
	V_7S_2	0.36	6.62	0.88	6.42	1.16
	V_7S_3	0.19	7.12	0.24	5.92	1.84
Chikka Aralahalli	V_8S_1	0.18	10.86	1.63	4.92	1.86
	V_8S_2	0.38	8.06	0.79	9.36	1.97
	V_8S_3	0.35	5.47	0.38	6.97	1.95
Chikka Kuravatti	V_9S_1	0.14	10.64	0.24	4.65	1.06
	V_9S_2	0.22	5.16	0.36	4.20	1.02
	V_9S_3	0.41	11.48	0.76	8.78	0.90
Choudayyadanapur	$V_{10}S_1$	0.34	11.98	0.19	4.75	0.79
	$V_{10}S_2$	0.26	11.64	0.37	3.07	1.00
	$V_{10}S_3$	0.11	9.90	0.34	9.53	0.86
Devagondana katti	$V_{11}S_1$	0.29	10.75	0.61	7.40	1.79
	$V1_1S_2$	0.47	9.00	0.77	6.82	0.94
	$V_{11}S_3$	0.13	2.87	0.46	8.87	1.04
Gangapur	$V_{12}S_1$	0.16	4.65	0.19	5.26	1.20
	$V_{12}S_2$	0.29	3.76	0.85	6.52	0.67
	$V_{12}S_3$	0.28	5.57	0.11	5.32	1.14
Gudagur	$V_{13}S_1$	0.41	6.20	0.39	8.21	0.99
	$V_{13}S_2$	0.34	6.12	0.28	3.26	1.04
	$V_{13}S_3$	0.26	2.60	0.22	6.27	0.76
Guddadanveri	$V_{14}S_1$	0.58	9.44	0.27	6.27	1.05
	$V_{14}S_2$	0.17	5.43	0.25	5.92	0.84
	$V_{14}S_3$	0.33	10.81	0.21	2.56	1.07

Village Name	Sample No.	Zn	Fe	Cu	Mn	B
		mg kg^{-1}				
Guddaguddapur	$V_{15}S_1$	0.17	8.61	0.19	4.25	1.84
	$V_{15}S_2$	0.25	8.35	0.27	2.85	1.19
	$V_{15}S_3$	0.21	8.46	0.18	6.78	1.13
Hanumapur	$V_{16}S_1$	0.17	7.40	0.16	2.49	0.88
	$V_{16}S_2$	0.33	6.97	0.17	2.07	0.92
	$V_{16}S_3$	0.17	4.18	0.18	5.44	1.15
Harangiri	$V_{17}S_1$	0.32	7.99	1.17	2.32	0.94
	$V_{17}S_2$	0.18	9.99	0.26	5.61	1.06
	$V_{17}S_3$	0.43	5.96	0.22	9.33	1.07
Heeladahalli	$V_{18}S_1$	0.24	7.87	2.99	6.03	0.97
	$V_{18}S_2$	0.36	9.70	0.38	5.25	0.80
	$V_{18}S_3$	0.28	9.07	1.36	5.64	1.27
Hirebidari	$V_{19}S_1$	0.18	9.29	1.77	8.33	1.38
	$V_{19}S_2$	0.41	7.56	0.78	5.38	1.19
	$V_{19}S_3$	0.34	6.91	0.19	8.55	1.05
Honnatti	$V_{20}S_1$	0.26	9.34	0.38	3.55	0.36
	$V_{20}S_2$	0.21	11.23	0.39	7.99	0.93
	$V_{20}S_3$	0.24	4.08	1.77	2.77	1.05
Hullikatti	$V_{21}S_1$	0.36	5.94	0.88	5.55	1.27
	$V_{21}S_2$	0.17	11.87	0.24	4.18	0.26
	$V_{21}S_3$	0.19	8.35	1.62	6.75	1.19
Hullatti	$V_{22}S_1$	0.38	8.90	0.79	5.13	0.28
	$V_{22}S_2$	0.31	10.98	0.29	2.49	1.05
	$V_{22}S_3$	0.34	8.94	0.21	9.37	0.38
Hunashikatti	$V_{23}S_1$	0.23	9.35	0.28	6.57	1.00
	$V_{23}S_2$	0.26	9.92	0.24	2.39	1.08
	$V_{23}S_3$	0.15	4.13	0.17	7.01	1.00
Kajjari	$V_{24}S_1$	0.16	3.93	0.25	4.38	0.91
	$V_{24}S_2$	0.47	6.02	0.98	5.13	0.87
	$V_{24}S_3$	0.29	5.43	0.26	2.57	1.34
Kakol	$V_{25}S_1$	0.23	2.71	0.93	4.38	1.22
	$V_{25}S_2$	0.29	3.79	0.88	7.60	1.09
	$V_{25}S_3$	0.25	7.04	0.91	5.48	0.91
Kamadod	$V_{26}S_1$	0.16	10.48	3.22	8.58	1.22
	$V_{26}S_2$	0.15	5.82	1.12	3.13	0.32
	$V_{26}S_3$	0.14	6.91	1.47	3.06	0.34
Karur	$V_{27}S_1$	0.22	4.92	2.34	2.87	1.30
	$V_{27}S_2$	0.41	10.91	0.26	5.63	1.13
	$V_{27}S_3$	0.34	9.07	0.11	9.30	0.92
Konanatambigi	$V_{28}S_1$	0.29	7.05	1.12	2.91	0.22
	$V_{28}S_2$	0.14	3.76	0.28	3.88	0.34
	$V_{28}S_3$	0.17	4.43	2.18	4.72	1.40
Kudrihal	$V_{29}S_1$	0.27	11.00	0.13	3.35	1.91
	$V_{29}S_2$	0.18	10.01	2.17	9.35	1.96
	$V_{29}S_3$	0.12	7.20	1.16	7.60	0.93
Kunabev	$V_{30}S_1$	0.17	6.87	1.18	5.81	0.95
	$V_{30} S_2$	0.17	10.90	0.16	4.45	0.83
	$V_{30}S_3$	0.21	11.61	2.12	6.79	1.34
Maidur	$V_{31}S_1$	0.18	10.17	2.91	8.14	1.32
	$V_{31}S_2$	0.13	6.57	0.39	8.52	0.91
	$V_{31}S_3$	0.17	7.78	1.35	6.29	1.04
Medleri	$V_{32}S_1$	0.16	9.50	1.76	4.97	2.00
	$V_{32}S_2$	0.19	11.48	0.88	8.01	1.22
	$V_{32}S_3$	0.18	6.73	0.88	5.54	1.21

Village Name	Sample No.	Zn	Fe	Cu	Mn	B
		mg kg^{-1}				
Nadiharalalli	$V_{33}S_1$	0.24	4.53	1.47	3.38	1.40
	$V_{33}S_2$	0.36	3.47	2.35	9.53	0.32
	$V_{33}S_3$	0.16	4.90	4.25	8.27	1.00
Nalawagala	$V_{34}S_1$	0.18	6.78	1.19	4.05	0.22
	$V_{34}S_2$	0.17	4.62	1.48	8.89	1.23
	$V_{34}S_3$	0.35	3.67	1.73	6.89	0.20
Nukapur	$V_{35}S_1$	0.42	6.90	1.62	4.78	1.91
	$V_{35}S_2$	0.18	7.37	2.32	7.54	1.13
	$V_{35}S_3$	0.23	4.32	4.21	7.75	1.07
Padmavathipur	$V_{36}S_1$	0.35	2.74	0.73	4.20	1.30
	$V_{36}S_2$	0.19	11.91	1.33	8.29	1.18
	$V_{36}S_3$	0.39	5.95	0.79	8.88	1.12
Rahutanakatti	$V_{37}S_1$	0.29	5.02	0.29	3.86	0.34
	$V_{37}S_2$	0.15	7.24	0.76	7.35	1.13
	$V_{37}S_3$	0.14	10.09	0.49	8.12	1.02
Ramapur	$V_{38}S_1$	0.16	3.65	0.27	7.42	0.97
	$V_{38}S_2$	0.13	2.54	0.57	6.53	1.21
	$V_{38}S_3$	0.24	7.47	0.98	5.89	0.36
Ranebennur	$V_{39}S_1$	0.47	5.52	1.03	4.62	1.13
	$V_{39}S_2$	0.28	9.16	0.47	6.52	1.08
	$V_{39}S_3$	0.22	9.35	0.21	5.28	1.11
Shidaganahal	$V_{40}S_1$	0.29	11.58	0.17	5.78	1.32
	$V_{40}S_2$	0.15	11.94	0.28	9.09	1.13
	$V_{40}S_3$	0.22	4.58	1.19	5.14	0.25
Shrinivasapur	$V_{41}S_1$	0.15	2.83	1.12	3.41	0.40
	$V_{41}S_2$	0.14	7.11	0.14	8.35	1.12
	$V_{41}S_3$	0.13	11.81	1.35	4.78	1.32
Somlapur	$V_{42}S_1$	0.21	4.70	0.66	8.70	0.40
	$V_{42}S_2$	0.16	3.80	0.19	4.58	1.16
	$V_{42}S_3$	0.11	6.63	2.38	3.18	0.32
Udagatti	$V_{43}S_1$	0.17	3.44	0.39	6.67	1.22
	$V_{43}S_2$	0.14	5.89	0.61	4.80	1.22
	$V_{43}S_3$	0.25	2.88	0.78	7.32	1.13
Venkatapur	$V_{44}S_1$	0.41	6.09	1.38	6.70	1.02
	$V_{44}S_2$	0.34	4.43	1.16	4.06	1.04
	$V_{44}S_3$	0.28	11.61	0.85	2.94	0.32
Waderayanahalli	$V_{45}S_1$	0.13	7.83	3.11	5.17	0.34
	$V_{45}S_2$	0.28	2.63	0.36	7.67	1.32
	$V_{45}S_3$	0.47	9.89	0.28	8.67	1.26
Yakalasapur	$V_{46}S_1$	0.16	6.23	1.12	9.04	0.93
	$V_{46}S_2$	0.18	6.60	0.27	3.30	1.12
	$V_{46}S_3$	0.28	8.24	2.16	6.42	1.32
Yallapur T medleri	$V_{47}S_1$	0.28	6.77	0.29	5.57	1.01
	$V_{47}S_2$	0.41	2.52	0.28	6.36	0.40
	$V_{47}S_3$	0.34	10.03	1.14	3.75	1.27
Yattinahalli	$V_{48}S_1$	0.26	2.90	1.05	7.88	1.02
	$V_{48}S_2$	0.18	4.43	0.55	2.97	0.32
	$V_{48}S_3$	0.16	7.71	0.22	3.79	0.95
Yellapur T honnatti	$V_{49}S_1$	0.12	6.35	2.13	8.59	1.02
	$V_{49}S_2$	0.17	2.53	1.31	9.41	1.04
	$V_{49}S_3$	0.22	6.44	0.75	6.75	1.12
Yennihosahali	$V_{50}S_1$	0.23	8.54	1.27	4.08	1.12
	$V_{50}S_2$	0.16	8.69	1.13	5.68	0.32
	$V_{50}S_3$	0.43	4.30	2.15	7.17	1.27

Village Name	Sample No.	Zn	Fe	Cu	Mn	B
				mg kg^{-1}		
Minimum		0.11	2.52	0.11	2.07	0.20
Maximum		0.68	11.98	4.25	9.53	2.00
Mean		0.25	7.11	0.90	5.96	1.06
S.D		0.10	2.75	0.80	2.10	0.43
C.V		40.96	38.74	89.32	35.22	41.05

Table 5. Correlation coefficient (r) between various parameters of groundwater samples v/s soil nutrient status

Soil / Water	N	P_2O_5	K_2O	Zn	Fe	Cu	Mn	B
pH	-0.349**	-0.234**	-0.432**	-0.248*	-0.481**	-0.114*	-0.149*	0.219*
EC	-0.123*	-0.116*	0.163*	0.172*	0.247*	-0.171*	0.171	-0.159
Na^+	0.222**	-0.197*	0.217**	-0.174	0.465**	-0.115	0.158	-0.278
Ca^{2+}	-0.091	-0.016	0.126	0.187*	0.004	-0.014	-0.010	0.134
Mg^{2+}	-0.06	0.106	-0.027	0.010	0.147*	0.020	0.026	0.315**
B	-0.256*	-0.144	0.144	-0.107*	0.101	0.159	0.119	0.883**
SAR	-0.347*	-0.239*	-0.214*	-0.146	0.163	-0.113	0.102	0.268*
RSC	0.150	0.120	-0.212*	-0.142	-0.106	-0.126	-0.051	0.162*

***. Correlation is significant at the 0.01 level (2-tailed).*
**. Correlation is significant at the 0.05 level (2-tailed).*

Table 4 provides detailed insights into the availability of essential micronutrients-zinc (Zn), iron (Fe), manganese (Mn), copper (Cu), and boron (B)-in the soil samples from the study area, highlighting significant variations and potential factors affecting nutrient availability. Zinc (Zn) levels ranged from 0.11 to 0.68 mg kg^{-1}, with an average of 0.25 mg kg^{-1}. This relatively low availability of zinc is of concern as zinc is a critical micronutrient for plant growth, involved in various physiological processes including enzyme function and protein synthesis. The low levels observed can be attributed to the elevated soil pH in the study area. High pH conditions often lead to the precipitation of zinc as insoluble zinc hydroxides and carbonates, which reduces its availability to plants. Vijayshekhar *et al.* [15] discussed how alkaline soils often bind zinc in forms that plants cannot easily absorb, thus limiting its effectiveness.

Iron (Fe) content in the soil varied from 2.52 mg kg^{-1} to 11.98 mg kg^{-1}. Iron is another essential micronutrient involved in chlorophyll formation and electron transfer in photosynthesis. The variation in Fe content might reflect differences in soil organic matter, texture, and pH. In alkaline soils, iron can become less available due to its conversion to insoluble forms, although the range observed here suggests that, overall, iron availability is relatively adequate in most of the samples.

Manganese (Mn) and Copper (Cu) showed average concentrations of 5.96 mg kg^{-1} and 0.90 mg kg^{-1}, respectively. Manganese, like iron, is important for photosynthesis and other metabolic processes. Its medium to high availability indicates that most soils have sufficient manganese, though availability can fluctuate based on soil pH and organic matter content. Copper's average concentration suggests it is present but in lower amounts. Copper has a tendency to form strong bonds with organic matter, which can render it less available to plants, especially in soils rich in organic content, as noted by Nayak *et al*. [11].

The hot water-soluble boron (B) concentration averaged at 1.06 mg kg^{-1}. Boron is crucial for cell wall formation and reproductive growth. The average levels reported are generally within safe limits for most crops, indicating that boron availability is not a major concern in this study area. Organic carbon levels were generally reported as low to medium, which impacts the availability of micronutrients. Organic matter plays a significant role in nutrient availability by influencing soil structure and microbial activity. Lower organic carbon levels may affect the availability of nutrients, including copper, by reducing the binding capacity of organic matter. Overall, the analysis reveals that zinc is deficient as a micronutrient, copper availability ranges from low to medium, while manganese and iron availability are generally adequate to high. These variations highlight the importance of soil pH and organic matter in determining nutrient availability. Adequate management practices, such as pH adjustment and organic matter enhancement, could help address deficiencies and optimize nutrient availability for better plant health and productivity.

Table 5 highlights the intricate relationships between groundwater electrical conductivity (EC) and various soil properties, as well as the impact of groundwater sodium (Na+), Sodium Adsorption Ratio (SAR), and other parameters on soil nutrient availability. The positive correlations between groundwater EC and soil potassium (K) (0.163*), iron (Fe) (0.247*), manganese (Mn) (0.171), and zinc (Zn) (0.172*) suggest that higher groundwater salinity is associated with increased concentrations of these nutrients in the soil. This could be due to the fact that as groundwater EC rises, it introduces more salts into the soil, which can sometimes include essential nutrients. However, this increase may not always be beneficial, as excessive salinity can also hinder nutrient uptake and affect soil health. Conversely, the negative correlations between groundwater EC and soil nitrogen (N) (-0.123*), phosphorus (P) (-0.116*), copper (Cu) (-0.171*), and boron (B) (-0.159) indicate that higher groundwater salinity is associated with lower levels of these nutrients in the soil. Increased soil pH and $CaCO_3$ content can lead to the formation of insoluble compounds, such as Zn(OH) and $ZnCO_3$, which decrease zinc availability. Similarly, elevated pH reduces nitrogen and phosphorus availability due to changes in nutrient solubility and mobility. Nayak et al. [11] highlighted that higher pH results in reduced availability of zinc, as it becomes less soluble and more likely to form insoluble compounds. The negative correlation with copper could be attributed to its strong binding with organic matter and the adverse effects of increased salinity on its availability.

Groundwater sodium (Na^+) showed positive correlations with soil nitrogen (N) (0.222**), potassium (K) (0.217**), and iron (Fe) (0.465**), reflecting that increased sodium content in groundwater is linked to higher levels of these nutrients in the soil. Sodium can influence the availability of other nutrients by altering soil properties and interactions. However, the negative correlation with soil phosphorus (P) (-0.197*) suggests that higher sodium levels might impede phosphorus availability, likely due to changes in soil structure and nutrient interactions. The significant decrease in iron (Fe) with rising pH is attributed to the conversion of Fe^{2+} to Fe^{3+} ions. As Singh *et al*. (2012) noted, this conversion reduces iron availability because Fe^{3+} ions are less soluble compared to Fe^{2+} ions, particularly in alkaline soils. Boron (B) demonstrated a significant positive correlation with boron in soil (0.883**), indicating that higher levels of boron in groundwater correspond to higher boron levels in the soil. However, the negative correlations with nitrogen (N) (-0.256*) and zinc (Zn) (-0.107*) imply that increased boron might be associated with lower availability of these nutrients. This could be due to competitive interactions or changes in soil chemistry affecting nutrient availability.

Sodium Adsorption Ratio (SAR) in groundwater showed a positive correlation with soil boron (B) (0.268*) and a negative correlation with nitrogen (N) (-0.347*), phosphorus (P) (-0.239*), and potassium (K) (-0.214*). Higher SAR values indicate a higher proportion of sodium relative to calcium and magnesium in groundwater. As SAR increases, it often leads to higher exchangeable sodium percentage (ESP) and increased soil pH, which can diminish the availability of nutrients like nitrogen, phosphorus, and potassium by altering their solubility and reducing their uptake by plants. Naga et al. [16] discussed how increased SAR contributes to higher ESP and soil pH, adversely affecting nutrient availability while enhancing sodium levels [17,18]. In summary, the correlations detailed in Table 5 underscore the complex interactions between groundwater quality parameters and soil nutrient availability. Increased salinity and sodium content can influence nutrient dynamics, often negatively affecting the availability of essential nutrients like nitrogen, phosphorus, and potassium, while also impacting the availability of micronutrients such as zinc and copper. Understanding these relationships is crucial for effective soil and water management in agriculture to ensure optimal nutrient availability and crop growth [19-21].

4. CONCLUSION

This study concludes that irrigation water in Northern Ranebennur taluk is largely neutral to alkaline, yet its prolonged use has negatively affected soil quality, contributing to increased salinity and alkalinity. The soils in irrigated areas show deficiencies in zinc, variable copper availability, and adequate to excessive levels of manganese and iron, while nutrient levels for nitrogen, phosphorus, and potassium vary from low to high. The adverse impact of using groundwater from older bore wells on soil salinity is evident, with 62% of such wells providing poor-quality water. These findings highlight the critical need for careful groundwater management and tailored irrigation practices to maintain soil health and maximize agricultural productivity, underscoring the principle that "a drop of water well managed can yield a field of plenty."

DATA AVAILABILITY STATEMENT

The datasets generated and analyzed during the study are not publicly available due to privacy or ethical restrictions. However, anonymized data may be available from the corresponding author upon reasonable request and with permission from the relevant authorities.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc have been used during writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology.

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1. Yes for small sentence corrections

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. De Candolle A. Origin of cultivated plants D. Appleton. 1885;48.
2. Sharma JP, Landey RJ, Kalbande AR, Mandal C. Morphological, physical and chemical characteristics and land use plans of different landforms in Pratapgarh region of Southern Rajasthan. Agropedol. 1996;9(3):76-83.
3. Anonymous. Government of India, ministry of water resource central ground water board. Ground Water Information Booklet, Haveri district, Karnataka; 2019.
4. NRC-NRSA. Manual on nationwide mapping of land degradation using multi-temporal satellite data. Natural resource census - national remote sensing agency, Dept. of Space, Govt. of India, Hyderabad; 2007.
5. Panse VG, Sukhatme PV. Statistical methods for agricultural workers. Statistical methods for agricultural workers., (Ed. 3); 1954.
6. Verma BL, Sharma Y, Singhania RA. Quality of underground irrigation waters of Churu district in Rajasthan. Journal of the Indian Society of Soil Science. 2003;51 (2):214-216.
7. Savalia SG, Gundalia JD, Mathukia RK. Assessment and management of underground water quality in different land slopes of South Saurashtra (Gujarat). International Journal of Tropical Agriculture. 2006;24:219-228.
8. Yadav KK, Singh D, Singh PK. Assessment of groundwater quality of Rajsamand district of Rajasthan. In Presented inthe 77th Annual Convention of the Indian Society of Soil Science held during December. 2012;3-6.
9. Kumar DR, Badrinath MS, Chikkaramappa T, Jagadeesh BR. An assessment of ground water quality in eastern dry zone (Kolar district) of Karnataka. Environment and Ecology. 2007;25(1): 80-92.
10. Richards LA. ed., Diagnosis and improvement of saline and alkali soils (No. 60). US Government Printing Office; 1954.
11. Nayak RK, Sahu GC, Nanda SSK. Characterization and classification of the soils of Central Research Station, Bhubaneswar; 2002.
12. Chopra, Rahul, Kumawat BL. Singh, Ajeet and Gochar, Rajendra. Evaluation of underground irrigation water quality of Sri madhopur panchayat samiti, district Sikar, Rajasthan. Annals of biology. 2014;30(2): 350-353.
13. Awanish K, Mishra VN, Srivastava LK. Evaluation of soil fertility status of available N, P and K in Inceptisol of Raipur district of Chhattisgarh. International Journal of Interdisciplinary and Multidisciplinary Studies. 2015;2(6):98-104.
14. Singh R, Kundu DK. Physico-chemical and hydraulic characteristics of soils of major sub-groups of Eastern India. Journal of the Indian Society of Soil Science. 2010;58 (3):267-278.
15. Vijaysekhar R, Kuligod VB, Basavaraj PK, Dasog GS, Salimath SB. Studies on micronutrient status in important black soil series of UKP command, Karnataka.

Andhra Agricultural Journal. 2000;47(1&2): 141-143.
16. Naga SR, Yadav BL, Sharma SR. Effect of different levels of RSC in irrigation waters, zinc and iron on soil properties and yield of wheat on loamy sand soil. Green Farming. 2013;4:330-333.
17. Bhat MA, Grewal MS, Rajpaul R, Wani SA, Dar EA. Assessment of groundwater quality for irrigation purposes using chemical indices. Indian Journal of Ecology. 2016;43(2):574-579.
18. Dudal R. Dark clay soils of tropical and subtropical regions. Dark clay soils of tropical and subtropical regions; 1965.
19. Yadav RL, Meena MC. Available micronutrients status and their relationship with soil properties of Degana soil series of Rajasthan. Journal of the Indian Society of Soil Science. 2009;57(1):90-92.
20. Kwon HI, Koh DC, Cho BW, Jung YY. Nutrient dynamics in stream water and groundwater in riparian zones of a mesoscale agricultural catchment with intense seasonal pumping. Agricultural Water Management. 2022;261: 107336.
21. Abliz A, Tiyip T, Ghulam A. et al. Effects of shallow groundwater table and salinity on soil salt dynamics in the Keriya Oasis, Northwestern China. Environ Earth Sci. 2016;75:260. Available:https://doi.org/10.1007/s12665-015-4794-8

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