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Article

Hydrogeochemical Assessment of Groundwater Quality for the Irrigation Purpose in the Northern Parts of Y.S.R. Kadapa District, Andhra Pradesh

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ABSTRACT

The objective of this study is to conduct hydrogeochemical studies of groundwater in the surrounding Kalasapadu and Porumamilla mandals of Y.S.R. Kadapa District, Andhra Pradesh. Due to the presence of extensive irrigational practices, household requirements and groundwater requirements have significantly increased in this region. The water samples were gathered throughout November and December 2024 and were analyzed for pH. To prevent contamination, standard procedures and recommended measures were followed for electrical conductivity (EC), total dissolved solids (TDS), major cations (calcium, magnesium, sodium, and potassium), and anions (carbonate, bicarbonate, chloride, sulfate, fluoride, and nitrate). Groundwater quality for irrigation purposes was evaluated using a variety of irrigational quality indices, including percent sodium (%Na), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), magnesium hazard (MH), and permeability index (PI). This water is fit for human consumption as pH is primarily alkaline and shows low EC values. Moderate salinity is induced by the sodium (Na), and 14.28% of samples fall into the "good" category, 39.28 % of the samples are a part of the doubtful class, and 46.42 % of samples fall under the permissible class. According to SAR values, all groundwater samples that fall into the "good" category have an average MH of about 49%, which indicates a moderate risk related to magnesium, and an average RSC of 0.30 meq/L, which indicates minimal sodium risk. 17.85% of the samples belong to the irrigation-suitable class, 96.43% of the groundwater samples have a negative ratio, which indicates reverse exchange, whereas 3.57% of the groundwater samples have a positive ratio, which indicates direct exchange.

Key words: Drinking and irrigation, Groundwater quality, Porumamilla and Kalasapadu, YSR district

1. INTRODUCTION

Water is necessary for human survival, as well as all forms of development [1]. Huge population expansion, increased urbanization, expanding industries, and massive agricultural operations around the world have all contributed to a massive increase in the mandate for freshwater for home, agricultural, and industrial uses in recent years [2-8]. Groundwater is a life elixir, but it has been plagued by challenges in recent years, particularly in terms of quality, particularly in dry and semiarid areas [7,9,10,13]. Agricultural pollutants, such as chemicals, insecticides, and other metal contamination, make water unsafe for human consumption [4,6,12,19]. As a result, understanding the hydrogeochemistry of water is critical for evaluating water for drinking, agriculture, and other uses [5,17]. Aquifer quality is affected by recharged water, meteorological rainfall, inland groundwater, and underground geochemical processes [28]. As a result, knowing hydrochemistry is crucial for evaluating groundwater quality in any location where groundwater is utilized for drinking and farming [26,32]. Chlorides are crucial for identifying when wastewater is contaminating groundwater [29]. In over-irrigated fields, high evapotranspiration generally tends to raise the saline and chloride concentration at the plant roots. The presence of nitrates suggests that inadequate sanitation practices are probably contaminating the groundwater, which gradually seeps into the percolation process [18]. Higher concentrations of nitrates pose a major health risk because they break down in the body into nitrite, which binds to hemoglobin and prevents oxygen transmission, resulting in methemoglobinemia, which is especially dangerous for newborns [3]. It also depends on the host rock, weathering intensity, residence time, and external factors such as precipitation and temperature. Hydrogeochemical processes such as weathering, dissolution, ion exchange, etc., control the concentration of primary and secondary ions in groundwater [10]. Groundwater quality has been steadily worsening in recent decades as a result of the presence of pesticides and fertilizers [29].

2. MATERIALS AND METHODS

2.1. Study Area

The study area has a hot, semiarid climate with the monthly mean, lowest, and maximum temperatures being 27°C, 14°C, and 44°C, respectively, and the average yearly rainfall is 759 mm. As the Pennar River and its tributaries drain nearly the whole YSR Kadapa District, the district is appropriately known as the Pennar district. Kunderu, Sagileru, and Tummalavanka are some of the significant tributaries

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that join the river from the north, whereas Chitravati, Papaghni, Buggavanka, Cheyyeru, and Kalletivagu are some of the tributaries that join the river from the south. The tributaries of the Cheyyeru are the Bahuda, Mandavi, Pullangi, and Gunjaneru. Due to cyclonic storms in the Bay of Bengal causing high rainfall, the district's rivers and streams are primarily ephemeral. The study area falls in the Survey of India Toposheet No: 57 J/13 & 16. A sample location of the study area is shown in Figure 1.

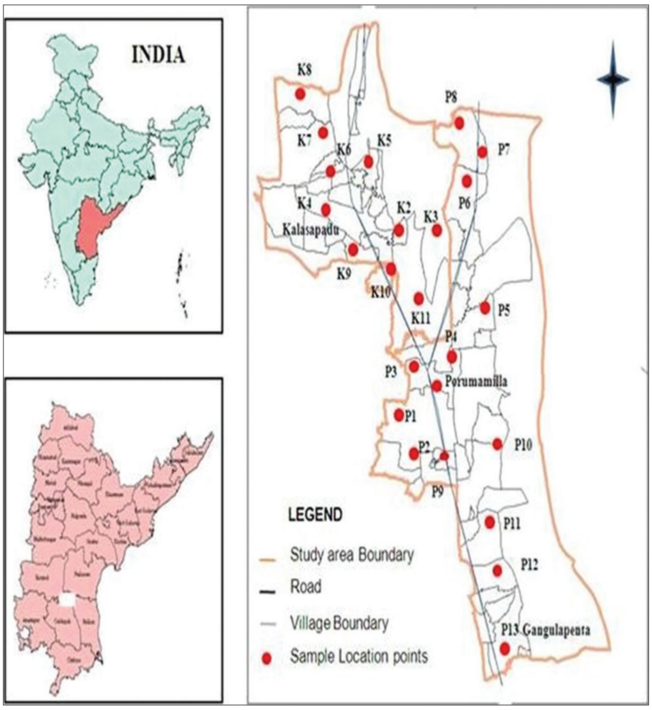

Figure 1: Location map of the study area

2.2. Methodology

A total of 28 groundwater samples were taken from bore wells from the villages of Kalasapadu and Porumamilla mandals in the Y.S.R. District of Andhra Pradesh. Polyethylene vials that had been well cleaned and dried were used to collect the samples. Following conventional procedures, the water samples were examined for pH, electrical conductivity (EC), total dissolved solids (TDS), and key cations, including calcium and magnesium, and anions such as carbonate, bicarbonate, chloride, sulfate, fluoride, and nitrate [28]. Recommended measures were implemented to avoid contamination. A conductivity meter was used to measure EC and pH, respectively; TH, Ca^{2+}, Mg^{2+}, CO_3^{2-}, HCO_3^{-}, and Cl^{-} were all measured titrimetrically using a TDS meter. The ion-selective electrode (Orion 4-star ion meter, Model: pH/ISE) was utilized to assess fluoride, and the spectrophotometer method was employed to determine nitrates.

2.3. Irrigation Parameters

2.3.1. Sodium percentage (Na%)

The Na percentage values in the study area range from 25.22 to 74.91, with a mean of 53.34, and the samples, 14.28% fall into the good category, 39.28% into the questionable class, and 46.42% into the permitted class [Table 1 and 2].

2.3.2. Sodium adsorption ratio (SAR)

The degree to which irrigation water tends to engage cation exchange processes in soil can be determined by calculating SAR. It is dangerous when sodium replaces adsorbed calcium and magnesium because it damages the soil structure and makes it compacted and impermeable [27].

2.3.3. Magnesium hazard (MH)

Crop output is reduced when the MH value <50 is recommended for irrigation, and MH value >50 is not recommended for irrigation [26].

Table 1: Formulation of the irrigation parameters

S. No.	Index	Formula	References	Classification
1	Sodium percentage (Na%)	$\text{Na\%} = \frac{(Na^{+}+K^{+})}{Ca^{+2}+Mg^{+2}+Na^{+}+K^{+}} \times 100$	Ushurhe, 2024	%Na<20: Excellent class %Na=20–40:Good %Na=40–60: Permissible %Na=60–80:Doubtful %Na>80:Unsuitable
2	Sodium adsorption ratio (SAR)	$\text{SAR} = \frac{Na^{+}}{\sqrt{\frac{Ca^{+2}+Mg^{+2}}{2}}}$	Wu, 2024	SAR<10:Excellent water class SAR=10–18:Good SAR=18–26:Doubtful SAR>26:Unsuitable
3	Kelly's ratio (KR)	$\text{KR} = \frac{Na^{+}}{Ca^{+2}+Mg^{+2}}$	Kelly, 1963	KR<1:Suitable KR>1:Unsuitable
4	Residual sodium carbonate (RSC)	$\text{RSC} = \left(HCO_3^{-}+CO_3^{-2}\right)-\left(Ca^{+2}+Mg^{+2}\right)$	Eaton, 1950	RSC<1.25:Good RSC=1.25–2.5:Doubtful RSC>2.5:Unsuitable
5	Magnesium hazard ratio (MHR)	$\text{MHR} = \frac{Mg^{+2}}{Ca^{+2}+Mg^{+2}} \times 200$	Yazdi, 2024	MHR<50:Suitable MHR>50:Unsuitable
6	Permeability index (PI)	$\text{PI} = \frac{Na^{+}+\sqrt{HCO_3^{-}}}{Ca^{+2}+Mg^{+2}+Na^{+2}+K^{+}}$	Doneen, 1964	PI>75%:Suitable PI=25–75%:Good PI<25%:Unsuitable

Table 2: Statistical evaluation of the physicochemical characteristics.

Parameter	Units	Minimum	Maximum	WHO (2018) Standard value
pH	-	7.76	8.53	6.5 to 8.5
EC	µS/cm	620	2720	200 to 800
TDS	mg/L	520	1720	<500
TH	mg/L	80	310	500
Na^+	mg/L	12	140	< 2gm
K^+	mg/L	35	120	100
Ca^{2+}	mg/L	15	90	500
Mg^{2+}	mg/L	10	89	50
F^-	mg/L	0.68	3.52	1.5
Cl^-	mg/L	24	152	200–300
HCO_3^-	mg/L	110	420	22–26
NO_3^-	mg/L	32	74	50
SO_4^-	mg/L	140	580	-

EC: Electrical conductivity, TDS: Total dissolved solids, TH: Total hardness

As a result, water with MH values < 50 can be used for irrigation; however, water with MH values > 50 cannot.

2.3.4. Kelly's ratio (KR)

KR >1 shows the excessive sodium in water unsuitable for irrigation; on the other hand, <1 is considered suitable for irrigation.

3. RESULTS AND DISCUSSION

Following recommended precautions to prevent contamination, the water samples were collected in November 2024 and analyzed for pH, EC, TDSs, major cations such as calcium and magnesium, and anions such as bicarbonate, carbonate, chloride, sulfate, fluoride, and nitrate [Table 3]. Groundwater quality for irrigation purposes was evaluated using a variety of irrigational quality indices, including percent sodium (%Na), SAR, residual sodium carbonate (RSC), MH, PI, and KR.

3.1. Drinking Purpose

3.1.1. Major ion chemistry

Table 2 displays the physicochemical parameters' statistical data. The alkaline character of groundwater is indicated by its pH, which ranges from 7.76 to 8.53. EC is between 620 and 2720 µS/cm. Class I groundwater has a low salt content (EC <1500 µS/cm), class II

Table 3: Concentrations of physicochemical parameters in the study area

S. No.	Name of the village	pH	EC	TDS	TH	Ca^{2+}	Mg^{2+}	Cl^-	Na^+	K^+	HCO_3^-	So_4^-	No_3^-	F^-
			µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	Ranga Samudram	8	850	560	120	40	22	36	120	90	150	140	56	0.89
2	Harijanawada	8.2	870	580	96	35	16	25	140	120	128	250	46	0.68
3	Porumamilla	8.4	1520	980	130	25	26	55	86	65	154	260	48	1.56
4	Porumamilla central	8.3	1600	970	120	22	24	69	120	60	156	180	53	1.58
5	Porumamilla south	8.2	1620	1200	160	23	35	56	65	50	220	280	56	1.12
6	Kattakindapalli	8.2	1320	850	110	18	19	39	70	40	128	230	47	0.96
7	Kavalakuntla	8.4	1100	670	100	27	18	31	80	46	110	360	32	1.38
8	Akkalareddypalle	8.2	980	560	110	90	10	24	86	50	128	340	35	1.3
9	Sancharala	8.1	2720	1700	310	70	60	110	85	35	142	165	48	1.68
10	Buraganampalle	7.8	2300	1500	180	34	35	68	110	60	180	250	52	3.52
11	Yellayapalli	7.8	2450	1520	240	32	52	148	90	70	420	280	65	1.6
12	Ganugapenta	7.9	2300	1420	200	28	41	92	125	80	320	430	74	1.26
13	Muddireddypalli	8.2	1460	950	140	22	28	61	50	90	310	580	63	1.23
14	Lingareddepalle	7.76	2300	1300	230	56	89	120	55	40	360	260	64	0.68
15	Kalasapadu	7.8	620	560	180	22	38	45	60	38	420	230	68	0.86
16	Rajupalem	8.12	1200	750	120	18	26	42	65	45	190	410	62	1.34
17	Singarayapalle	8.53	1300	1200	150	45	28	81	12	46	140	320	55	1.32
18	Singarayapalle 2	8.23	1200	700	130	32	25	56	45	38	146	300	54	1.23
19	Ramapuram 1	8.5	1700	1120	200	15	46	68	48	50	240	190	43	1.4
20	Rama puram 2	8.4	2300	1720	230	23	48	130	43	55	130	220	42	2.56
21	Agraharam	8.3	790	520	130	26	23	24	40	58	130	250	45	1.23
22	Agraharam	8.3	1200	760	120	28	19	36	56	54	136	160	62	1.53
23	Gangayapalli 1	8.21	1100	720	80	28	12	35	54	65	250	190	68	1.25
24	Gangayapalli 2	8.2	970	780	120	25	21	32	70	60	150	220	73	1.35
25	Obulapuram 1	8.1	1600	980	120	18	24	52	110	65	130	240	72	2.56
26	Obulapuram 2	8.12	2400	1600	180	29	36	152	58	56	250	240	43	1.65
27	Sankaravaram 1	8.2	1560	980	150	22	35	78	60	54	150	168	40	1.34
28	Sankaravaram 2	8.5	920	670	90	32	14	42	70	50	250	150	56	1.14

EC: Electrical conductivity, TDS: Total dissolved solids, TH: Total hardness groundwater has a medium salt concentration (EC 1500–3000 µS/cm), and class III groundwater has a high salt concentration (EC >3000 µS/cm) [26]. 53.57% of the samples are classified as class I (low salt concentration) and 46.42% as class II (average salt concentration) based on this EC categorization. With a mean of 1232 mg/L, TDSs range from 520 to 1720 mg/L. The majority of the samples fall inside the TDS permissible range. The range of total hardness (TH) is 80–310 mg/L. The maximum amount of TH that can be consumed is 500 mg/L. However, according to Xie *et al.* [27], TH <75 falls into the soft category; 75–150 into the moderately hard category; 150–300 into the hard category; and >300 into the extremely hard category. According to this classification, 35.71% of the samples fall into the hard group, whereas 64.28% of the samples fall into the moderately hard category. The main cause of water hardness is due to the interaction between water and geological formations. Nitrate concentration ranges from 32–74 mg/L, and 62.5% of samples are above the permissible limit [28]. Magnesium is a crucial component of sedimentary rocks such as dolomite, metamorphic rocks such as talc and tremolite-schists, volcanic rocks such as basalts, and basic igneous rocks such as dunite, pyroxenite, and amphibolites. Talc, hornblende, augite, biotite, olivine, and serpentine are some of the main minerals that contain magnesium. EC, pH, and TH parameters are within the permissible limit; hence, the samples are suitable for drinking purposes.

3.2. Cations

Ca^{2+} ranges from 15–90 mg/L, Mg^{2+} concentrations vary from 10–89 mg/L, and the entire groundwater sample has calcium and magnesium levels within the allowable range. Magnesium ions can fit in the middle of six octahedral coordinated water molecules because they are smaller than sodium or calcium ions. Despite the relative solubilities of their salts, the calcium concentration in groundwater is typically higher than the magnesium amount, which is consistent with their relative abundance in rocks. Basic igneous rocks such as dunite, pyroxenite, and amphibolites, volcanic rocks such as basalts, metamorphic rocks such as talc and tremolite-schist, and sedimentary rocks such as dolomite all contain magnesium. Among the main minerals that contain magnesium are olivine, augite, biotite, hornblende, serpentine, and talc. K+ concentrations range from 35 to 120 mg/L, and only three samples have K+ concentrations over the allowable limit. Only two samples are above the allowable limit of Na+, which spans from 12 to 140 mg/L.

Table 4: Irrigation parameters

Parameter	Class	Category value	Obtained sample	
			No of sample	% of sample
Na%	Excellent	<20	Nil	Nil
	Good	20–40	4	14.28
	Permissible	40–60	13	46.42
	Doubtful	60–80	11	39.28
	Unsuitable	>80	Nil	Nil
SAR	Excellent	<10	28	100
	Good	10–18	Nil	Nil
	Doubtful	18–26	Nil	Nil
	Unsuitable	>26	Nil	Nil
RSC	Good	<1.25	21	75%
	Doubtful	1.25–2.5	6	21.42
	Unsuitable	>2.5	1	3.57
MH	Suitable	<50	5	17.85
	Unsuitable	>50	23	82.14
KR	Suitable	<1	17	60.71
	Unsuitable	>1	11	39.28

%Na: Percent sodium, SAR: Sodium adsorption ratio, RSC: Residual sodium carbonate, MH: Magnesium hazard, KR: Kelly's ratio

3.3. Anions

The range of Cl^- concentrations is 24–152 mg/L. Liquid inclusions, which comprise a very small percentage of the rock's volume, and rock minerals that contain chloride, including sodalite and chlorapatite, which are extremely small components of igneous and metamorphic rocks, are examples of microscopic sources of chloride in groundwater. Although the majority of the chloride in groundwater is sodium chloride, the chloride content can also be caused by base-exchange reactions, phosphate mineral weathering, and household sewage [20,21]. The range of sulfate concentrations is 140–580 mg/L, and the entire groundwater sample falls within the acceptable range. Sulfur minerals, heavy metal sulfides, which are frequently found in igneous and metamorphic rocks, gypsum and anhydrite, which are found in some sedimentary rocks, are the sources of sulfate in rocks. HCO_3 varies from 110 to 420 mg/L, and every groundwater sample has bicarbonate and chloride levels below the allowable limit. The range of sulfate concentration is 140–580 mg/L, and the entire groundwater sample falls within the acceptable range.

3.4. Irrigation Parameters

14.28% of the samples are in the excellent category, with a mean sodium value of 53.10 and a range of 20.53 to 74.91%. 39.28% belong to the dubious class and 46.42% to the permitted class [Table 4-6]. The concentration of sodium is a significant criterion in the irrigation classification of water. The permeability index (PI) has a mean of 66.44 and ranges from 0.0 to 92.33. The mean RSC value is −0.30, with a range of −5.28 to 3.49 [22,24]. According to the RSC values, the classification of irrigation water >2.5 with RSC is unsuitable for irrigation; RSC values ranging between 1.25 and 2.5 belong to the doubtful class, and RSC <1.25 are good for irrigation [Table 5]. 70% and 67.5% of samples are deemed appropriate for irrigation, according to KR values, which vary from 0.11 to 1.98 with a mean of 0.88. MH values range from 15.46 to 83.47 with a mean of 60.68. With a mean of 2.34, the samples' SAR values vary from

Table 5: The descriptive statistical analysis of the groundwater samples' irrigation parameters

Parameter	Units	Minimum	Maximum	Mean
% Na	meq/L	20.53	74.91	53.10
PI	meq/L	0.00	92.33	66.44
RSC	meq/L	−5.28	3.49	−0.30
KR	meq/L	0.11	1.98	0.88
MH	meq/L	15.46	83.47	60.68
CA1	meq/L	−12.00	0.48	−2.53
CA2	meq/L	−0.95	0.10	−0.31
SAR	meq/L	0.00	4.92	2.34

%Na: Percent sodium, SAR: Sodium adsorption ratio, RSC: Residual sodium carbonate, MH: Magnesium hazard, PI: Permeability index, KR: Kelly's ratio

Table 6: Drinking purpose of the study area [14].

Parameter	Range	Class	No. of samples	%
pH	<6.5	Not potable	-	-
	6.5–8.5	Potable	27	96
	>8.5	Not potable	1	3
EC	<250	Excellent	-	-
	250–750	Good	1	3
	750–2250	Moderate	21	75
	2250–4000	Bad	7	25
	>4000	Very bad	-	-
TDS	0–1000	Fresh water	19	67
	1000–10000	Brackish water	9	32
	10000–100000	Saline water	-	-
	>100000	Brine water	-	-
TH	<75	Safe	-	-
	75–150	Moderate safe	18	64
	150–300	Hard	10	35
	>300	Very hard	-	-

EC: Electrical conductivity, TDS: Total dissolved solids, TH: Total hardness

0.00 to 4.92. Groundwater samples were classified into the excellent category based on SAR values [23,25]. 75% of samples are classified as good for irrigation, 21.42% as doubtful, and 3.57% as unsuitable for irrigation [8] [Table 5]. Therefore, it can be inferred from the irrigational quality parameters mentioned above that groundwater is not a suitable class for irrigation, and that using this untreated water could harm crops and further reduce yield. Our research has focused on identifying the health risks of fluoride and nitrate in the hard rock terrain of Andhra Pradesh, South India, because groundwater in this area has been impacted by both natural and man-made sources.

4. CONCLUSION

Groundwater in the villages of Kalasapadu and Porumamilla Mandals of Y.S.R. Kadapa District, Andhra Pradesh, is severely stressed by domestic, agricultural, and industrial operations. Moderate EC and pH are primarily alkaline, with high concentrations of dissolved ions such as carbonates and chlorides. The area's TDSs range from 510 to 1698 mg/L, which is higher than the recommended limit of 500 mg/L. This can alter the taste of the water and possibly result in gastrointestinal problems. Potassium levels range from 35 to 120 mg/L, but TH, calcium (Ca^{2+}), and magnesium (Mg^{2+}) concentrations are all within permissible bounds. Even though only two samples were over the allowable limit, high potassium can be harmful to health, especially for people who have kidney problems. The concentrations of sodium (Na^{+}) vary from 12 to 140 mg/L, most likely due to both human activity and natural geological variations. Fluoride levels in a number of samples, ranging from 0.399 to 2.88 mg/L, are higher than the 1.5 mg/L WHO-recommended limit, which can result in health issues such as skeletal and dental fluorosis. The leaching of fluoride-containing minerals in the alkaline environment of the area is the main natural cause of fluoride contamination. In addition, problematic are nitrate concentrations, which are higher than the allowable limit of 45 mg/L in 94% of groundwater samples. The widespread application of nitrogen-based fertilizers in agriculture is the main cause of this contamination.

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AQ3: Kindly cite References 15 and 16 in the text part and also cite in chronological order

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