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Hydro geochemical Insights and Groundwater Quality Assessment of Pulivendula Mandal, Kadapa, Andhra Pradesh

C. Krupavathi, S. Srinivasa Gowd*, P. Ravi Kumar, G.Nagalakshmi, U. Ravali

Department of Geology, Yogi Vemana University, Kadapa, Andhra Pradesh, India

ABSTRACT

Several hydro geochemical processes controlling the geochemistry of aquifers, the suitability of groundwater for agriculture, and routine use were assessed in the Pulivendula area during the current survey. To characterize the main physicochemical components of the aquifer water, a total of 24 drilling locations were selected. The findings showed that the groundwater had an alkaline pH. Due to the ideal limits of total dissolved solids, magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), sulphate (SO_4^{2-}), and chloride (Cl^-), the majority of samples fall within the appropriate range. Residential use of groundwater should be avoided in areas when EC, total hardness, calcium (Ca^{2+}), and nitrate (NO_3^-) slightly exceed recommended standards. With very few exceptions, the groundwater in the research region is appropriate for human consumption, according to the analytical findings. The Piper diagram was utilized to analyze all samples to identify the primary hydro geochemical components found in groundwater. In this area, cations predominate in groundwater with $Ca^{2+} > Na^+ > Mg^{2+} > K^+$, followed by anions $HCO_3^- > Cl^- > SO_4^{2-} > F^-$. According to the Gibbs plot study, the primary hydro geochemical mechanism controlling the geochemistry of the groundwater in this area is the rock-aquifer interaction. It was discovered that the greatest number of water samples was ideal for cultivation.

Key words: Hydrogeochemistry, Groundwater Quality Assessment, Pulivendula, YSR District

1. INTRODUCTION

The main supply of water for agriculture, industry, home usage, and drinking is groundwater [1-4]. The increasing demand for groundwater may be attributed to several factors, including the rapid rise of the population, the development of irrigation, and the increasing trend of industrialization [5-8]. The main causes of anthropogenic contamination, which comes from sources like industrial effluents, agricultural fertilizers, municipal waste water, septic tank effluent, landfills, and animal wastes, are also responsible for the degradation of groundwater quality. A high level of human health and agricultural productivity are directly correlated with water quality [9-11]. In many regions of India, the lack of clean, drinkable water has become one of the most important developmental challenges in recent years [12-14]. Both natural processes and human activity have an impact on groundwater quality, which is a global environmental concern [15,16].

Human health is greatly impacted by the quality of groundwater. A little shift in the quality of the water indicates that the water ecosystem is not working properly [17,18]. Because of weathering from source rocks, human activity, and regional environmental and ecological factors, physical and chemical soluble characteristics have a significant impact on groundwater quality [19-21]. Excessive accumulations of pollutants on the land and contamination of available surface and subsurface water resources were caused by the careless disposal of anthropogenic, agricultural, and mining wastes, the unplanned application of agrochemicals and fertilizers, and public ignorance of environmental concerns [22]. Numerous factors influence the chemical makeup of groundwater, such as precipitation composition, the geology and mineralogy of aquifers and watersheds, and the geological processes that occur inside aquifers [23,24]. Different kinds of water result from the interplay of all these variables. A sustainable development of water resources requires an understanding of the geochemical evolution of groundwater [25]. Geological formations and human activity have a significant impact on the physical and chemical characteristics that determine how the quality of groundwater varies in a given location [26,27]. Water of poor quality has a negative impact on human health and plant development. Soil, lithology, and geology are some of the key elements that affect water quality. Depending on variations in geological formations, water quality can change [28]. Due to water contamination brought on by the disposal of overburden in and near mining zones [29,30]. The depth of the water table, location, and season all affect how pure the groundwater is [31]. The amount and make-up of dissolved solids in water determine the quality in the main [32]. The weathering of rocks and subsequent contributions from soils can both contribute to the area's groundwater quality degradation [33,34]. To determine if the groundwater in and around Pulivendula, Kadapa district, Andhra Pradesh, is suitable for human consumption, this article examines a number of chemical parameters.

***Corresponding author:**
S. Srinivasa Gowd
E-mail: ssgowd@gmail.com

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2. METHODOLOGY

To evaluate the groundwater quality, 24 groundwater samples were taken in the Pulivendula region from chosen bore wells (deep aquifer) and dug wells (shallow aquifer) during the pre-monsoon and post-monsoon seasons of 2024 (May and October). These 1-liter plastic containers that had been previously cleaned were used to gather the water samples. Groundwater sample physicochemical analyses were conducted using American Public Health Association (APHA) standard operating procedures. Following the collection of groundwater samples in the field, the physical characteristics, such as pH, electrical conductivity (EC), and total dissolved solids (TDS), were determined right away. The spectrophotometer was used to analyze the sulfate (SO_4^{2-}), fluoride (F^-), and nitrate (NO_3^-), while the titrimetric method was used to analyze the bicarbonates (HCO_3^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), and chloride (Cl^-). The flame photometer was used to estimate the chemical parameters such as sodium (Na^+) and potassium (K^+). Tables 1 and 2 show the physical characteristics and results of the chemical analysis of groundwater samples.

2.1. Location Accessibility

The area lies between Pulivendula situated between parallels of 78°08'0" to 78°19'0" E L and 14°13'30" to 14°30'0" N L with intended boundary falling in Survey of India topographic sheet 57J 03 on 1:50,000 scale covering an of over 720 km^2. The study area is shown in Figure 1.

2.2. Physiographic and Climate

The research area's southern and central regions are made up of lowlands, ridges, and tall hills. In the research region, contour values vary from 200 to 600 m. There is a 1–35° range in the slope category. The Mogamureru River is the sole seasonal river in the research region, receiving its water during the monsoon season (June to October) and flowing northwest through the southern portion of the study area. The same region is also covered by a few large tanks. The average annual temperature is 32°C, with 100–150 cm of precipitation and a dry environment. December is thought to be the coldest month (25°C), and May is thought to be the warmest (45°C). Every crop is longer than 120 days.

2.3. Study Area

In the drought-stricken and economically challenged Kadapa district of Andhra Pradesh, Pulivendula Mandal is an overfished Mandal. Anantapur district borders the Mandal on the south, Vemula Mandal on the east, Thondur Mandal on the north, and Anantapur district on the west. It is situated in the Kadapa district's western region [Figure 1]. The research region, which covered 182.6 km^2 geographically, had a dendritic structure as a result of geological formations.

2.4. Geology

The research region is a part of Southern India's most important Purana basins. The Lower Cuddapah Super group's Papaghni and

Table 1: Physicochemical parameters concentrations of the study area during pre-monsoon

Sample No.	Well depth (M)	pH	TDS	EC	TH	Ca^{2+}	Mg^{2+}	K^+	Na^+	Cl^-	NO^{3-}	SO_4^{2-}	HCO_3^-	F^-
1	20	7.9	1208.2	724.9	732.5	137.7	94.4	2.84	24.6	163.5	32.9	265.4	453.6	1.7
2	25	8.4	1219.6	731.7	624.6	95.3	93.9	1.96	37.6	175.4	51.4	265.4	460.8	1.9
3	35	8.2	1286.5	771.9	680.2	113.1	96.6	0.94	27.6	175.0	50.4	233.4	548.3	2.5
4	20	8	1090.0	654.0	633.2	122.7	79.4	1.62	9.6	148.5	17.9	250.4	438.6	3.5
5	31	7.9	1330.8	798.5	831.7	152.7	109.4	2.8	39.6	178.5	47.9	280.4	468.6	4.3
6	35	7.65	1341.8	805.1	723.8	110.3	108.9	1.52	52.6	190.4	66.4	280.4	475.8	4.1
7	39	8.15	1408.3	845.0	779.4	128.1	111.6	1.62	42.6	190.0	65.4	248.4	563.3	4.4
8	20	7.68	1105.5	663.3	611.4	105.7	84.4	1.18	14.6	153.5	22.9	255.4	443.6	1.0
9	27	8.39	1116.7	670.0	503.5	63.3	83.9	2.78	27.6	165.4	41.4	255.4	450.8	1.0
10	55	7.87	1184.9	711.0	559.1	81.1	86.6	2.54	17.6	165.0	40.4	223.4	538.3	3.0
11	34	7.95	1065.3	639.2	512.2	90.7	69.4	1.62	46.9	138.5	37.9	240.4	428.6	3.5
12	60	7.47	1293.6	776.2	799.3	172.7	89.4	1.21	69.6	149.5	56.4	214.0	528.6	4.0
13	45	7.39	1210.5	726.3	725.1	160.3	78.9	2.98	72.6	100.4	55.4	140.4	585.8	3.9
14	38	7.99	1205.6	723.4	755.8	168.1	81.6	1.78	72.6	90.0	22.9	128.4	623.3	4.1
15	30	7.75	1158.6	695.2	627.3	146.7	63.4	2.12	43.6	123.5	52.9	188.0	502.6	3.5
16	26	8.31	1095.7	657.4	553.1	134.3	52.9	2.24	46.6	74.4	71.4	114.4	559.8	4.0
17	42	8.43	1112.6	667.5	583.8	142.1	55.6	1.36	36.9	64.0	70.4	102.4	597.3	4.3
18	30	8.2	1088.1	652.8	595.8	140.7	59.4	1.54	59.6	128.5	27.9	230.4	418.6	3.6
19	34	7.05	1322.0	793.2	647.1	128.3	79.4	2.38	62.6	183.5	46.4	271.4	528.3	2.8
20	28	8.04	1192.0	715.2	623.6	136.1	68.9	2.2	62.6	195.4	45.4	239.4	418.6	2.7
21	40	8.1	1260.4	756.2	581.2	114.7	71.6	0.92	33.6	195.0	42.9	256.4	518.6	2.9
22	45	8.5	1321.1	792.6	475.1	102.3	53.4	1.02	36.6	158.5	61.4	286.4	575.8	2.3
23	38	8.07	1361.0	816.6	451.6	110.1	42.9	2.18	26.9	170.4	60.4	286.4	613.3	2.8
24	37	8.4	1201.6	720.9	459.2	108.7	45.6	1.94	49.6	170.0	27.9	254.4	492.6	3.1

EC: Electrical conductivity, TH: Total hardness, TDS: Total dissolved solids, SO_4^{2-}: Sulphate, F^-: Fluoride, NO_3^-: Nitrate, HCO^{3-}: Bicarbonates, Ca^{2+}: Calcium, Mg^{2+}: Magnesium, Cl^-: Chloride, Na^+: Sodium, K^+: Potassium

Table 2: Physicochemical parameters concentrations of the study area during post-monsoon

Sample No.	Well depth (M)	pH	TDS	EC	TH	Ca^{2+}	Mg^{2+}	K^+	Na^+	Cl^-	NO_3^-	SO_4^{2-}	HCO_3^-	F^-
1	25	7.4	1060.3	636.2	600.2	117.7	74.4	3.24	24.6	143.5	12.9	245.4	433.6	1.7
2	30	7.9	1070.8	642.5	492.3	75.3	73.9	2.36	17.6	155.4	31.4	245.4	440.8	1.1
3	40	7.7	1139.0	683.4	547.9	93.1	76.6	1.34	7.6	155.0	30.4	213.4	528.3	3.0
4	25	7.5	942.1	565.3	500.9	102.7	59.4	2.02	35.0	128.5	32.5	230.4	418.6	3.5
5	36	7.4	1182.5	709.5	699.4	132.7	89.4	3.2	19.6	158.5	27.9	260.4	448.6	3.9
6	40	7.15	1191.2	714.7	591.5	90.3	88.9	1.92	32.6	170.4	46.4	260.4	455.8	4.9
7	44	7.65	1256.5	753.9	647.1	108.1	91.6	2.02	22.6	170.0	45.4	228.4	543.3	2.2
8	25	7.18	990.6	594.4	479.1	85.7	64.4	1.58	35.8	133.5	2.9	235.4	423.6	3.7
9	32	7.89	968.1	580.9	371.2	43.3	63.9	3.18	7.6	145.4	21.4	235.4	430.8	3.8
10	60	7.37	1033.5	620.1	426.8	61.1	66.6	2.94	45.8	145.0	20.4	203.4	518.3	1.2
11	39	7.45	936.9	562.1	379.9	70.7	49.4	2.02	26.9	118.5	17.9	220.4	408.6	2.6
12	55	8.4	1161.9	697.2	667.0	152.7	69.4	1.61	49.6	129.5	36.4	194.0	508.6	2.7
13	50	8.3	1080.3	648.2	592.8	140.3	58.9	3.38	52.6	80.4	35.4	120.4	565.8	4.1
14	43	7.49	1072.7	643.6	623.5	148.1	61.6	2.18	52.6	70.0	2.9	108.4	603.3	1.6
15	35	7.25	1039.4	623.6	495.0	126.7	43.4	2.52	23.6	103.5	32.9	168.0	482.6	1.7
16	31	7.81	940.7	564.4	420.8	114.3	32.9	2.64	26.6	54.4	51.4	94.4	539.8	2.5
17	47	7.93	960.5	576.3	451.5	122.1	35.6	1.76	16.9	44.0	50.4	82.4	577.3	4.0
18	35	7.7	958.9	575.3	463.5	120.7	39.4	1.94	39.6	108.5	7.9	210.4	398.6	4.1
19	39	7.69	1173.6	704.1	514.8	108.3	59.4	2.78	42.6	163.5	26.4	251.4	508.3	4.4
20	33	7.54	1068.7	641.2	491.3	116.1	48.9	2.6	42.6	175.4	25.4	219.4	398.6	2.9
21	45	7.6	1138.7	683.2	448.9	94.7	51.6	1.32	13.6	175.0	22.9	236.4	498.6	3.0
22	50	8	1182.9	709.8	342.8	82.3	33.4	1.42	16.6	138.5	41.4	266.4	555.8	3.9
23	43	7.57	1190.1	714.1	319.3	90.1	22.9	2.58	6.9	150.4	40.4	266.4	593.3	5.4
24	42	7.9	1032.1	619.3	538	88.7	25.6	2.34	29.6	150.0	7.9	234.4	472.6	5.5

EC: Electrical conductivity, TH: Total hardness, TDS: Total dissolved solids, SO_4^{2-}: Sulphate, F−: Fluoride, NO_3^-: Nitrate, HCO_3^-: Bicarbonates, Ca^{2+}: Calcium, Mg^{2+}: Magnesium, Cl^-: Chloride, Na^+: Sodium, K^+: Potassium

Chitravati groups make up the stratigraphically studied region [35]. Lithologically, this area is made up of enormous limestone, dolomite, basalt, shale, conglomerate, and some of the most common intrusions (sills) [Figures 2 and 3]. The pediment, pediplain, denudational hills, and structural hills are the main geomorphic characteristics in this area. Groundwater is present in the worn areas of the Chitravathi and Papaghni rock formations. The existence of multiple joints, fractures, and fissure zones in this kind of rock is primarily responsible for the water found in drilled wells in this area. There are good aquifers made of massive limestone, shale, and quartzite, and permanent groundwater levels are often shallow. The depth of the water varies from 10 m to 50 m [36]. Important crops include sweet lime and paddy; banana plantations also yield seasonal fruits like lemon and sweet lime. There is an average of 600–650 mm of rainfall per year, and the north-east monsoon and south-west wind both have an impact.

2.5. Geographical Information System (GIS) Analysis

Understanding water quality study and map development requires the use of GIS. The current investigation was conducted using Arc GIS 10.3 and topographical sheets. Examine the area map created using 1:50,000 scales then create base maps using the World Geodetic System (WGS) 1984 coordinate system. Throughout the study region, the sample collection mapping was delineated using GPS measurements. Using bar graphs and charts, the extended module of Arc GIS 10.2 was utilized to create a range of distribution maps on hardness, pH, and other important cations and anions.

3. MECHANISM CONTROL FACTORS

3.1. Gibbs Diagram and Scatter Plots

Evaporation is a crucial factor that can change groundwater chemistry in addition to precipitation and the water-rock interaction (rock dominance) [37]. Because the majority of the samples occur within the carbonate weathering zone, the scatter plot between the Ca^{2+}/Na^+ and Mg^{2+}/Na^+ values indicates that rock–water interaction is often related with silicate weathering [38].

3.2. Hydro-facial

The chemical makeup of groundwater solutions observed in hydrogeochemical systems is referred to as hydrogeochemical facies [39]. Determining the facies is helpful in comprehending the connections and similarities between various ions found in the groundwater of an aquifer as well as the impact of chemical interactions between minerals and groundwater that take place within a lithological framework. Although there are several methods for

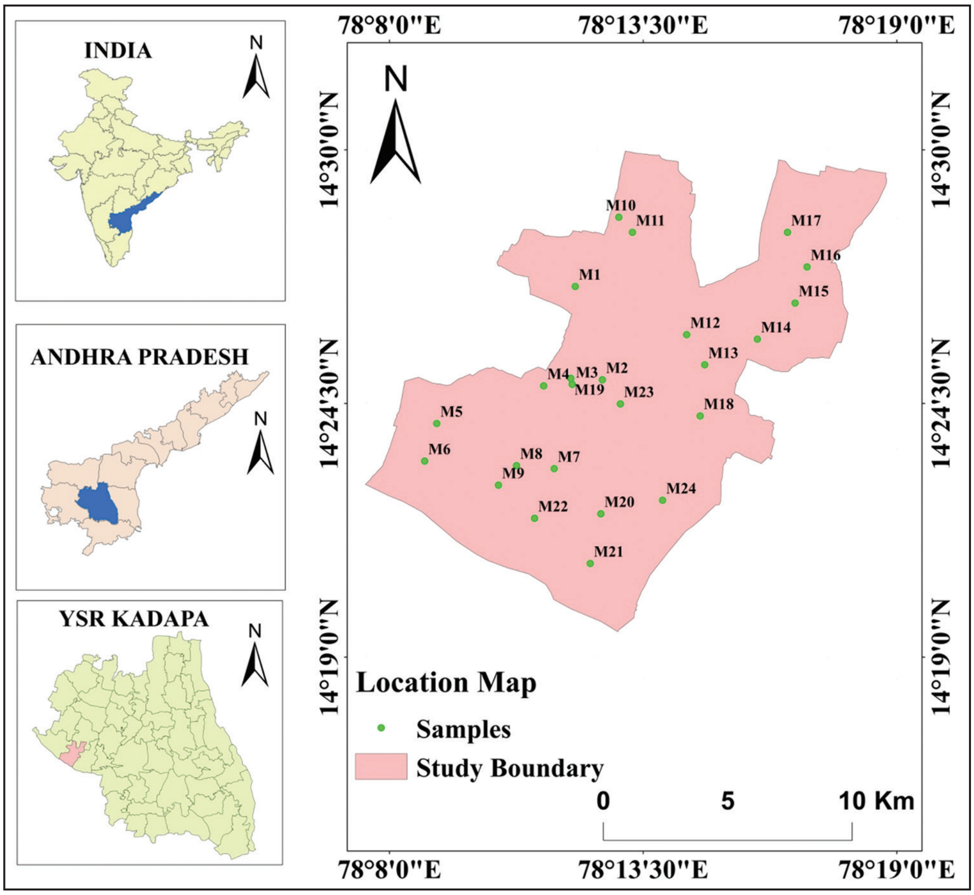

Figure 1: Study area.

Figure 2: Stramatolites in Vempalle formation.

Figure 3: Quartzite hill and Vempalle formations just below quartzite hills and shale beds.

interpreting groundwater hydrogeochemistry, including graphical and statistical analysis, Piper and Gibbs diagrams are frequently utilized to determine hydrogeochemical facies [40]. Six fields [41] are used to depict this diagram: Ca^{2+}- HCO_3^- type, Na^+- Cl^- type, Ca^{2+}- Mg^{2+}- Cl–$^-$ type, Ca^{2+}- Na^++ HCO_3^- – type, Ca^{2+}- Cl^-type, and Na+- HCO_3^- – type.

3.3. Saturation Index (SI)

The SI studies the chemical equilibrium of processes involving minerals and aqueous species [42]. The groundwater sample saturation indices were computed using Phreeqc Interactive version 3.4. The formula that defines the SI system is SI = log10 IAP K mineral, where IAP stands for the ion activity product and K mineral for the solubility constant of the mineral. The soluble mineral in the water sample is fully saturated when SI is equal to 0 [43-45]. Positive specific gravity (SI) values suggest that the sample is super-saturated, which will lead to the mineral tending to precipitate; negative SI values indicate that the sample is under-saturated, and the mineral will dissolve.

4. RESULTS AND DISCUSSION

Chemistry of groundwater Evocative data are calculated and compared with the World Health Organization [46] drinking water quality guidelines [Tables 1 and 2] to assess whether groundwater is suitable for human use. The pH scale runs from 7.0 to 8.5, 7.15 to 8.4, and the mean value of 8 indicates that the groundwater is alkaline. The groundwater samples have EC values ranging from 639.2 to 845 µS/cm and 562.1 to 753.9 µS/cm, respectively, with a mean of 729.5 µS/cm for both seasons. A higher EC value denotes a greater salinity and mineral content in groundwater that has low runoff, high infiltration, and a specific type of discharge [47]. On the other hand, high elevated terrain, heavy runoff, low infiltration and recharge water type, and low salt enrichment are typically linked to low EC values. All inorganic salts that indicate the salinity of the water and its acceptability for human consumption are included in the total dissolved solids (TDS) in water [37]. The TDS in groundwater samples has a mean value of 1215.9 mg/L for both seasons and varies from 1065.3 to 1408.3 mg/L and 936.9 to 1256.5 mg/L [Table 3]. Because nearly all of the samples are beyond the groundwater's EC and fall below the permissible limit of 500 mg/L, they cannot be used for irrigation or drinking. Groundwater water's total hardness (TH) is a result of the presence of metal ions such as Ca^{2+} and magnesium. Higher quantities of water containing TH (>300 mg/L) have been linked to health concerns, including renal difficulties. Hard water is therefore inappropriate for use in homes. Consequently, it is discovered that groundwater is unsuitable for agriculture, irrigation, and drinking in the majority of the research region [48].

4.1. Cation Chemistry

Because it promotes the formation of teeth and bones, the concentration of Ca^{2+} cation in groundwater is a crucial aspect of groundwater chemistry. Table 2 indicates that the Ca^{2+} content in the analyzed samples fluctuates between 63.3 and 172.7 mg/L and between 63.3 and 172.7 mg/L [Figure 4]. The average values for both seasons are 123.6 and 123.6 mg/L, respectively. When compared to the World Health Organization (WHO) guidelines, it shows a slightly higher Ca^{2+} concentration. Ca^{2+}-enriched groundwater is typically found in rocks and minerals such as shale, dolomite, and limestone, as well as in minerals like pyroxene, amphibole, and plagioclase. Moreover, ion exchange and the existence of carbon dioxide in the soil zone are additional sources of Ca^{2+} entering the groundwater [49]. In the same way, the majority of these rocks and minerals in the research region provide Ca^{2+} to the groundwater. Magnesium is typically found in natural waterways alongside Ca^{2+}. It can also come from human (such as mining operations and industrial waste) or geogenic (seawater, ferro-magnesium rocks, and ion exchange) sources. According to Table 3, its content in the study region ranges from 42.9 to 111.6 mg/L and from 22.9 to 91.6 mg/L, with averages of 77.6 and 57.6 mg/L for each season. The majority of samples have K^+ concentrations that are found to be below the allowable limits, and only a small number of samples have K^+ concentrations that are found to be beyond the allowable limits as per the WHO guidelines [Table 2]. In the research region, cations were found to be more abundant in the following order: $Ca^{2+} > Na^+ > Mg^{2+} > K^+$.

4.2. Anion Chemistry

The most significant chemical present in natural water is HCO_3^-. HCO_3^-, which contributes to the alkaline quality of groundwater, is often produced by the weathering of silicate rocks, although it may also arise from primary carbonate and calcareous rocks [50]. Its content in the region is well under the allowable limit, ranging from 418.6 to 623.3 mg/L and 398.6 to 603.3 mg/L [Table 3], with averages of 509.7 and 489.7 mg/L for each season.

A major anion present in groundwater is Cl^-, which can come from a variety of sources, including human sources, leaching, and the weathering of various minerals [11]. Due to its high concentration in groundwater, it has a salty taste and can cause kidney stones, which is bad for human health [51]. The Cl^- content in the study region ranges from 64.0 to 195.4 mg/L and 44.0 to 175.4 mg/L [Table 3], with an average of 152.0 and 132 mg/L for each season. These results show that the groundwater in the area is safe to drink and is within allowable limits [46].

Geogenic and anthropogenic sources can produce SO_4^{2-}, which, at high concentrations, renders groundwater unfit for human consumption. Rich in gypsum material, carbonate sedimentary rocks are the geogenic source of SO_4^{2-}. With an average of 229.6 mg/L and 209.6 mg/L for both seasons, respectively, its concentration

Table 3: Descriptive statistics of the physicochemical parameters of groundwater in the Mogamureru River basin

AQ3

Parameters	WHO international standard (WHO 2017)		Study area ranges (PRM)		Study area ranges (POM)	
	Desirable limits	Permissible limits	Min	Max	Min	Max
pH	6.5	8.5	7.05	8.5	7.15	8.4
EC	-	-	639.2	845	562.1	753.9
TDS	500	1500	1065.3	1408.3	936.9	1256.5
TH	100	500	451.6	831.7	319.3	699.4
HCO_3^-	-	-	418.6	623.3	398.6	603.3
SO_4^{2-}	200	400	102.4	286.4	82.4	266.4
Cl^-	200	600	64	195.4	44	175.4
NO^{3-}	50	-	17.9	71.4	2.9	51.4
F^-	0.5	1.5	1	4.4	1.1	5.5
Ca^{2+}	75	100	63.3	172.7	63.3	172.7
Mg^{2+}	50	150	42.9	111.6	22.9	91.6
Na^+	-	200	9.6	72.6	6.9	52.6
K^+	-	12	0.92	2.98	1.32	3.38

WHO: World Health Organization, EC: Electrical conductivity, TH: Total hardness, TDS: Total dissolved solids, SO_4^{2-}: Sulphate, F^-: Fluoride, NO_3^-: Nitrate, HCO_3^-: Bicarbonates, Ca^{2+}: Calcium, Mg^{2+}: Magnesium, Cl^-: Chloride, Na+: Sodium, K^+: Potassium, PRM: Pre monsoon, POM:Post monsoon varies from 102 to 286.4 mg/L and 82.4 to 266.4 mg/L [Table 3]; this indicates that they are within the allowable limit in accordance with established guidelines [46; Table 2]. The dissolution of F^- in groundwater derived from F^--bearing minerals is primarily responsible for the higher concentration of F^-. The dissolution of F^- in groundwater derived from F^--bearing minerals is primarily responsible for the higher concentration of F^-. This process is influenced by a number of factors, including the source rocks, well depth, residential period, and favorable environments for the upward rise of deep-seated groundwater [52]. The groundwater samples exhibit a range of F^- concentrations, from 1 to 4.4 mg/L and 1.1 to 5.5 mg/L [Table 3], with averages of 3.1 mg/L and 3.2 mg/L for both seasons, respectively. This suggests that a majority of the study area's samples surpass the permission limit [46]. The geogenic processes of weathering, ion exchange, and leaching are most likely the cause of the samples with moderate-to-high F^- concentrations. Dental fluorosis is often brought on by ingesting groundwater that is high in F^- (>1.50 mg/L) [53].

These days, concentrations of NO_3^-, particularly in places where industrialization, intensive agriculture, and population increase have been observed, are thought to be significant groundwater pollutants [54]. NO_3^- can originate from either geological or human sources. The primary man-made sources of NO_3^- in groundwater include septic tanks, pipe leaks, and agricultural runoff resulting from the use of various fertilizers in human populated areas. Groundwater's high NO_3^- content results in health issues that can progress to cancer, stomach issues, and Methaemoglobinemia (also known as "Blue baby" sickness) [55]. The study area's NO_3^- concentrations range from 17.9 to 71.4 mg/L and 2.9 to 51.4 mg/L, respectively [Table 3]; the average for both seasons is 46.5 mg/L, although groundwater samples slightly above the desired limit [46]. The statistical analysis with help of arc GIS of the research field is displayed in Figure 4.

The results show the dominance of anions as $HCO_3^- > SO_4^{2-} > Cl^- > NO_3^- > F^-$ in the study area.

4.3. Gibbs Diagram and Scatter Plot

The bulk of the groundwater samples in our investigation, according to gibbs diagram (GD), was found in the rock-weathering dominance field [Figure 5] [37]. This implies that the primary natural factor influencing the chemistry of groundwater is the interaction between water and rock. The replenishment of fresh surface water into fresh groundwater is referred to as "rock-weathering dominance." Moreover, it implies that groundwater contains the bulk of dissolved carbonate minerals. Furthermore, it is evident that evaporation processes had an impact on groundwater, suggesting that there was a significant ion exchange between groundwater and solid components in surrounding sediment. Based on the analysis of the scatter plot research area, it was determined that the best governing mechanism for determining the hydrochemistry of the silicate-rock materials in the study region is silicate weathering [Figure 6].

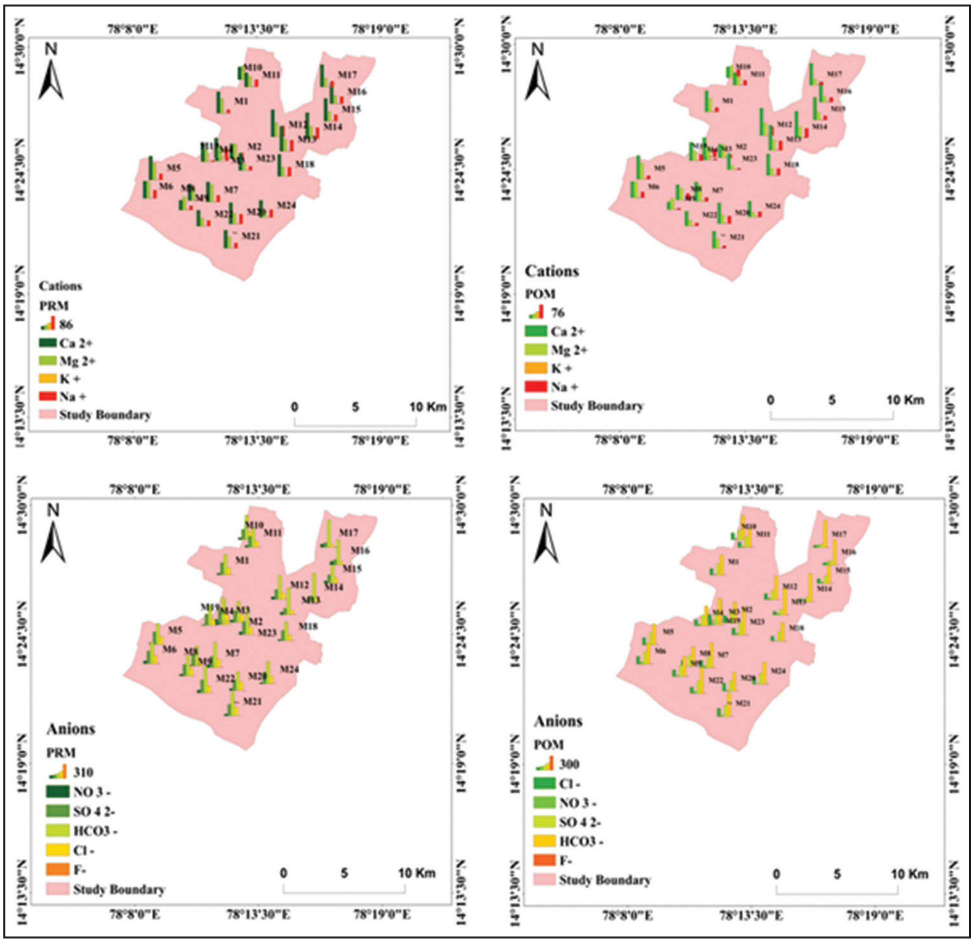

Figure 4: Statistical analysis for pre and post-monsoon.

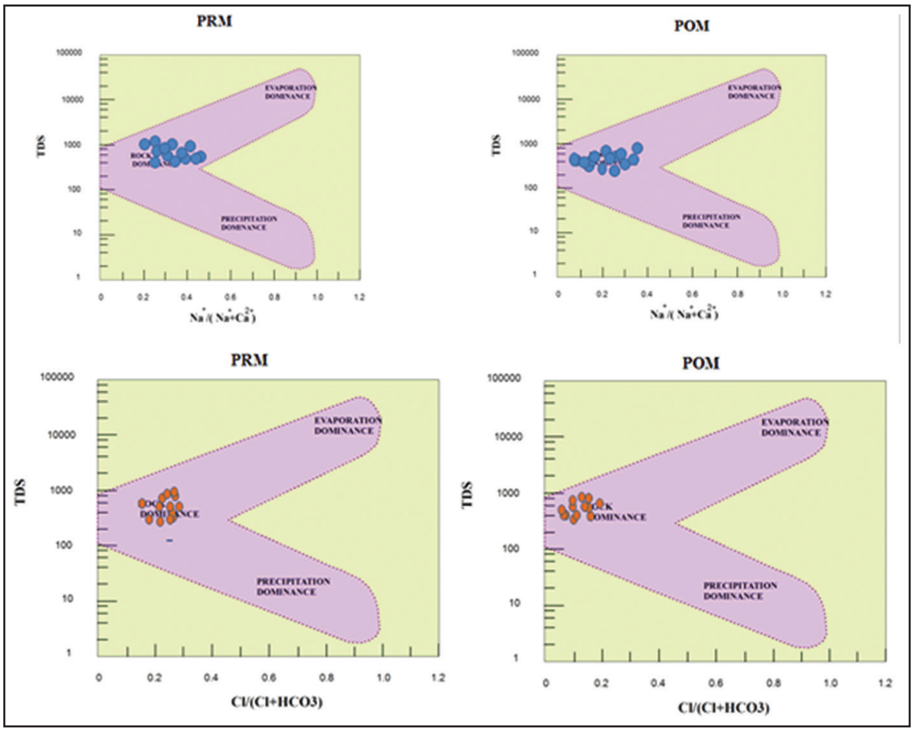

Figure 5: Gibb's diagrams for pre and post-monsoon.

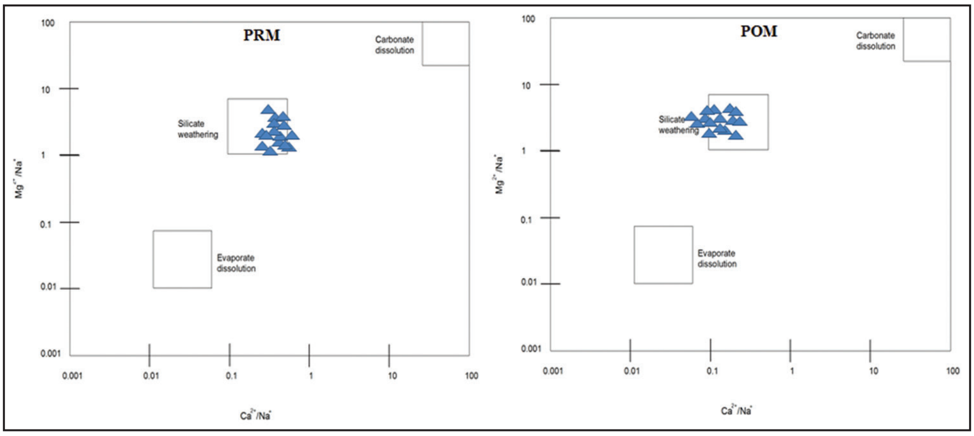

Figure 6: Scatter plots for pre and post-monsoon.

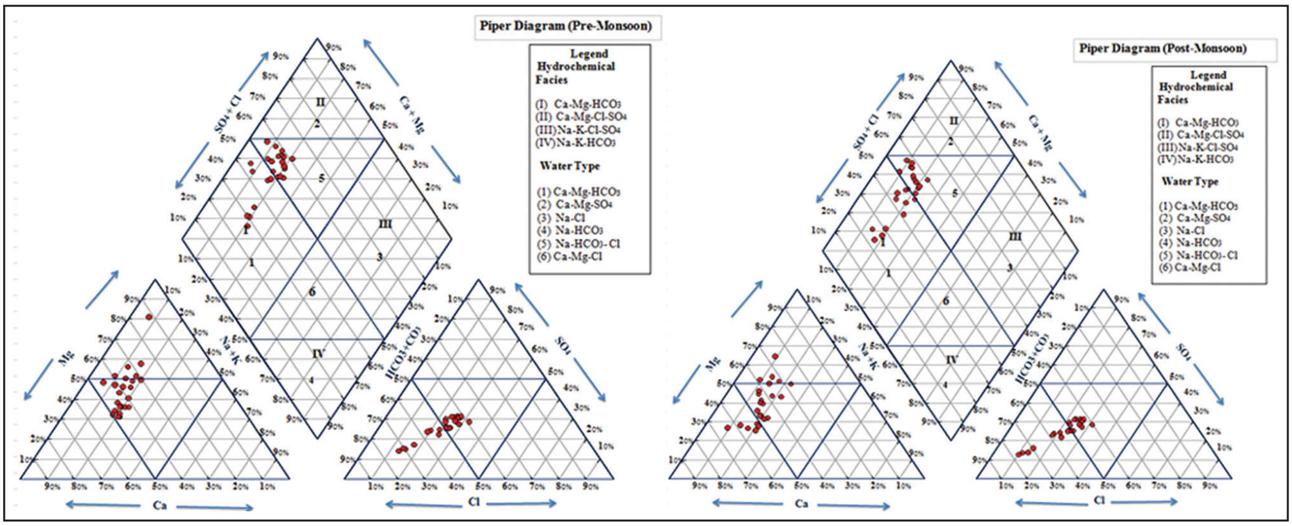

Figure 7: Piper diagrams for pre and post-monsoon.

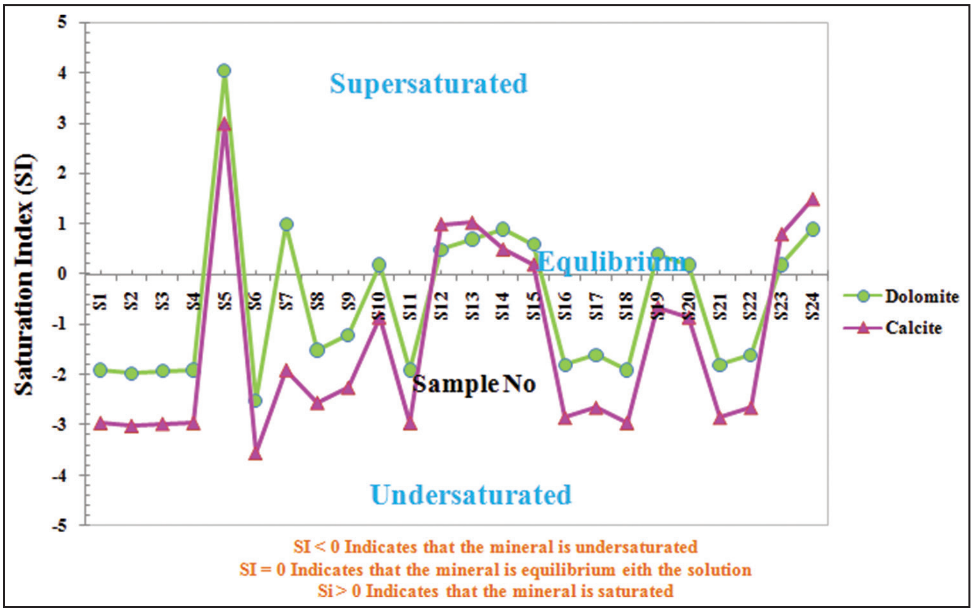

Figure 8: Saturation index.

4.4. Hydro Geochemical Facies

An aquifer system's anions and cations' hydrogeochemical properties are shown in a piper diagram [41]. To determine the overall geochemical character and water quality, the concentrations of the anions (Cl^-, HCO_3^-, and SO_4^{2-}) and cations (Ca^{2+}, Mg^{2+}, Na^+, and $K^{+)}$ were shown in this diagram. Plotted sample data in this study indicate that water samples fall into four different feldspars, with 90% of samples falling into the Ca^{2+}- Mg^{2+}- HCO_3^-facies and the remaining samples falling into other facies [Figure 7]. The Ca^{2+}- Mg^{2+}- HCO_3^-water type demonstrates that the predominant cations are Ca^{2+} and Mg^{2+}, whereas the major anion is HCO_3–. The findings therefore show that weak acids (HCO_3^-) and alkaline earth metals (Ca^{2+}, Mg^{2+}) control the hydrochemistry of the groundwater.

4.5. SI

Index of Saturation SI helps the groundwater system realize its reactive minerals since it is impacted by a variety of solutes that come from the contact with the adjacent sediments. According to SI standards, the majority of groundwater samples (5, 7, 10, 12, 13, 14, 15, 19, 20, 23, and 24) were supersaturated by dolomite mineral, whereas the rest of the samples are under saturated. Sample No. exhibits super saturation with calcite, whereas samples Nos. 5, 12, 13, 14, 15, 23, and 24 exhibit super saturation by dolomite mineral, and the other samples are under saturated [Figure 8].

5. CONCLUSIONS

The chemistry of groundwater is significantly influenced by a variety of processes, including evaporation throughout flow pathways, dissolution, and contact with rocks. Saturation indices for carbonate (calcite, dolomite, and aragonite) and evaporite (anhydrite, gypsum, halite, and sylvite) minerals showed that most groundwater samples significantly under saturated. The earth's alkaline ions rise as a result, and the predominant carbonate mineral dissolves in the groundwater. In groundwater, evaporite mineral dissolution predominates. The Gibbs diagram illustrates how new groundwater recharges from fresh surface water, with the bulk of the samples being plotted in the rock dominance field. Since some of the samples included saline groundwater, it is likely that the groundwater has been contaminated by dissolved evaporites, older deep water, and/or saline surface water along the flow route. The predominant mineral dissolution found in the groundwater samples was carbonate and evaporite. The results demonstrated that surface water sources with Ca-Mg-HCO_3 and Na-HCO_3-Cl water types, as well as the presence of bicarbonate ions in the groundwater, are the primary sources of groundwater recharge. The main controlling factors influencing groundwater salinity are SO_4^{2-} ions, earth alkaline elements, and alkali. Due to the ideal limits of TDS, Mg^+, Na^+, K^+, SO_4^{2-}, and Cl^-, the majority of samples fall within the appropriate range. Residential use of groundwater should be avoided in areas when EC, total hardness, Ca^+, and NO_3^- slightly exceed recommended standards. It was discovered that the greatest number of water samples was ideal for cultivation.

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***Bibliographical Sketch**

Dr. C. Krupavathi completed Ph.D. as DST-Inspire fellow from Department of science and technology, New Delhi. She completed M.Sc., from Yogi Vemana University, Kadapa. She has received DST-Inspire fellow award in the year of 2018. Her research interests are in the areas of Hydrogeochemistry, Water quality, Contamination of Water, Remediation methods. Her contribution has been recognized in many peer-reviewed journals and book chapters.

Dr. S. Srinivasa Gowd obtained Ph.D. Degree from Sri Venkateswara, Tirupati.He has many publications in the peer reviewed national and international Journals. He is currently working as Associate Professor in the Department of Geology, Yogi Vemana University, Kadapa. He completed more than 16 years of teaching experience in Geology. He has been awarded with CSIR-Research Associate, CSIR-Sr. Research Associate (Scientists' Pool Scheme), and DST-Young Scientist fellowships at National Geophysical Research Institute (NGRI), Hyderabad and Sri Venkateswara University, and Tirupati. His research interests are in the areas of Environmental Geochemistry, Hydrogeochemistry, Remote Sensing and GIS and he has supervised many M.Sc. students' projects.

Dr. P. Ravi Kumar (DST-Inspire Fellow) obtained from Ph.D. Degreefrom Yogi Vemana University, Kadapa. He completed M.Sc., from Yogi Vemana University, Kadapa. He has many publications in peer-reviewed national and international Journals. He has received the DST-Inspire Fellow Award in the year 2019. His research interests are in the areas of Hydrogeology, Hydrogeochemistry, Remote sensing and GIS, Groundwater Pollution, and Remediationmethods.

G. Nagalakshmi Devi completed M.Sc., in 2021 from Yogi Vemana University, Kadapa. She is working as Project Fellow in the RUSA project. Her research interests are in the areas of Hydrogeochemistry, Water quality, Contamination of Water, and Remediation methods.

U. Lahari completed M.Sc., in 2022 from Acharya Nagarjuna University, Guntur. She is working as Research Scholar in the Department of Geology, Yogi Vemana University, Kadapa. Her research interests are in the areas of Hydrogeochemistry, Water quality, Contamination of Water, and Remediation methods.