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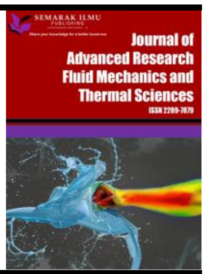

Assessment and Hydro Chemical Classification of Groundwater Quality in the Western Delta Region of the Godavari River, Andhra Pradesh: Suitability for Drinking Purpose

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ABSTRACT

The Godavari River is the largest river in southern India, flowing through five states before entering the Bay of Bengal in Andhra Pradesh. Historically, the Godavari Basin has shared water flows among its six states. However, due to declining rainfall and surface water flow, farmers and villagers have increasingly relied on groundwater for their daily activities, including drinking and agriculture. To evaluate the suitability of groundwater for drinking and other uses, the current study analyzed physical and chemical parameters, such as pH, TDS, Alkalinity, Total hardness, Sodium, Potassium, and chlorides, in parts of the Godavari Western Delta using APHA methods. Comparisons were made with the standard limits recommended by the Bureau of Indian Standards (BIS). Results showed that most chemical parameters had higher values during the summer season compared to other seasons. Furthermore, based on the TDS classification, 90% of the samples were classified as brackish water; based on the EC classification, 40.90% of the samples were categorized as saline; and based on the chlorides/Stuyfzand classification, 40.90% of the samples were classified as brackish water during the summer season. Additionally, most water samples in the study area were categorized as hard or very hard based on the total hardness.

1. Introduction

Water is an indispensable natural resource that is vital for the survival of life on Earth [1]. It is one of the most plentiful natural substances [2]. Access to clean drinking water is a fundamental human health requirement. Everyone on Earth needs at least 20-50 liters of clean freshwater per day. India is one of the most populous and agriculturally dependent nations in the world. As a result, a significant amount of water is required for various purposes. Groundwater is readily available, even during the summer months, leading to an exponential increase in demand and necessity [1,3]. There

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are several states in India where more than 90% of the population relies on groundwater for drinking and other purposes [4].

Groundwater is a heterogeneous mixture that is formed by the combination of various substances as it flows beneath the earth's surface and encounters different formations and deposits. Subterranean water is a critical resource that is widely used for various purposes, including irrigation, industrial processes, and domestic purposes [5]. It is estimated that groundwater meets almost 40% of the global water demand and is a vital source of water for food production, accounting for 30% of the total water used for this purpose [6].

However, groundwater resources are under immense pressure due to over-extraction, contamination, and climatic changes, leading to an alarming stage of water crisis in many parts of the world [7]. Nearly one-third of the global population depends on groundwater for their water needs [8]. The quality of groundwater is influenced by several major chemicals that play a significant role in its classification and assessment [5].

Groundwater pollution poses significant health risks to humans and animals, and the severity of these health effects depends on the specific pollutants present in the water [8]. It is essential to monitor and manage groundwater resources to ensure their sustainability for future generations.

The assessment of groundwater composition is of paramount significance, as it determines its suitability for diverse applications such as drinking, irrigation, and industrial uses. The general process of evaluating the physical, chemical, and biological properties of water concerning its natural quality, human impact, and intended uses, particularly those that may affect human health and the health of aquatic ecosystems, is referred to as water quality assessment. For any region, a groundwater quality map is crucial for evaluating the safety of water for drinking and irrigation purposes, as well as for identifying potential health issues [9].

To assess the impact of pollution, industrialization, and urbanization on groundwater, it is necessary to examine certain physicochemical properties. These properties are typically used to describe the financial status of groundwater [10]. Hydrochemical research has revealed the quality of water suitable for agricultural, irrigation, drinking, and industrial purposes [11]. Consequently, this study aimed to analyze the chemical makeup of groundwater samples and to characterize the quality of groundwater in specific regions of the Godavari Western Delta in Andhra Pradesh, India.

2. Methodology

2.1 Study Area

West Godavari District is one of the 26 districts in the state of Andhra Pradesh and is in the coastal region of the state. It is situated between the Northern latitudes of $16^0$58' and $16^0$19' and between the Eastern longitudes of $81^0$19' and 81051', covering parts of Survey of India toposheet numbers 65H6, 65H7, 65H9, 65H10 and 65H11 on a scale of 1:50,000. The location of the study area is shown in Figure 1. The district is bordered by the Eluru district in the west, the Godavari River in the east, Krishna District in the south, and Bay of Bengal in the north. According to the 2011 census of India, the district has a total area of 2178.4 square kilometres and a population of 17,79,935. The administrative headquarters of the district is in Bhimavaram.

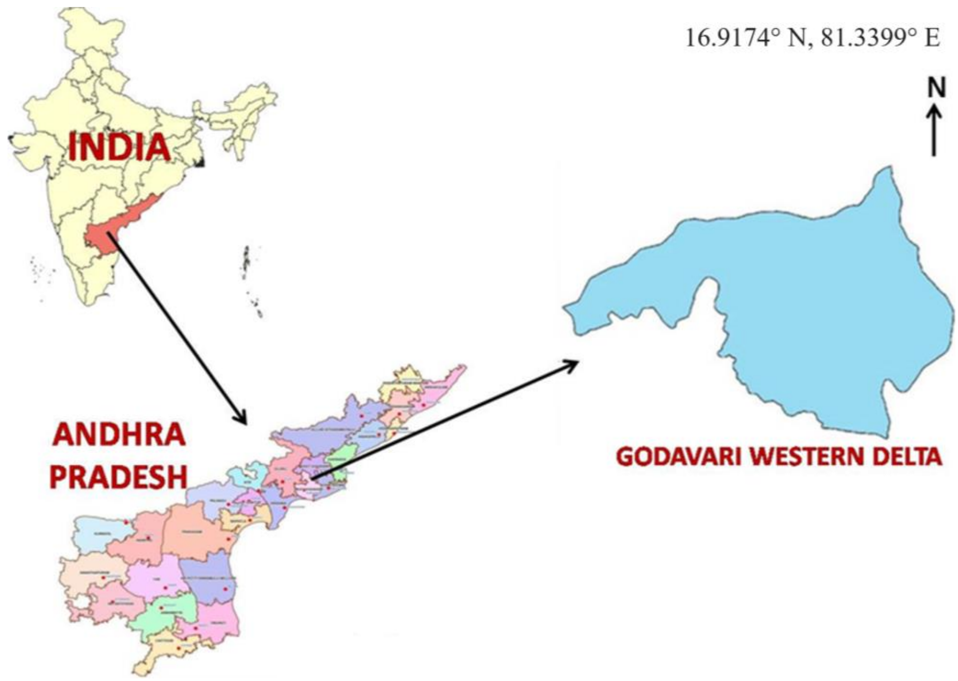

Fig. 1. Study area map

2.2 Assessment of Groundwater Samples

Groundwater samples were collected from 22 locations in selected villages of the Godavari Western Delta region. The collected water samples were transferred into a pre-cleaned polythene container for the analysis of their chemical characteristics. Chemical analyses were performed to determine the major ion concentrations of the water samples collected from different locations using the standard procedures recommended by APHA. Analytical data can be used for the classification of water for utilitarian purposes and for ascertaining the various factors that depend on the chemical characteristics of water.

Samples were collected during three seasons (rainy, winter, and summer) following the standard methods prescribed for sampling. Standard methods and procedures were used for quantitative estimation of water quality parameters. All chemicals were of AR grade and used for this purpose. The standards prescribed by the APHA were used to calculate the water quality indices.

The in-situ parameters such as temperature, pH, electrical conductivity (EC), and total dissolved solids (TDS) were measured in the field using portable digital meters such as pH, EC, and TDS meters. Additionally, the samples were analyzed in the laboratory for water quality metrics and chemical parameters using standard methods. The total hardness (TH), calcium (Ca^{2+}), and magnesium (Mg^{2+}) were determined by the titrimetric method following the standard ethylenediaminetetraacetic acid (EDTA) method, sodium (Na^+), and potassium (K^+) using a flame photometer, and bicarbonate (HCO_3^-) and chloride (Cl^-) by titration. The sulfate and nitrate ion concentrations were estimated by the gravimetric method using a flame photometer. All values are presented in milligrams per liter (mg/L).

3. Results

3.1 Turbidity

Turbidity into water is due to the colloidal and extremely small dispersion. It is the cloudiness of water caused by a variety of particles and is another key parameter in drinking water analysis. The values vary from 1.0NTU to 5.6NTU with an average of 3.4NTU during rainy season, 0.1NTU to 3.5NTU with an average of 1.6NTU during winter season and 0.0NTU to 3.6NTU with an average of 1.1NTU during summer season. The water samples showed more turbidity during the rainy season as excess seepage of water due to heavy rainfall leads to increased particulate matter. Conversely, the decrease in turbidity during the summer season is mainly contributed by very less seepage of water and reduced groundwater levels.

3.2 pH

pH is a term used universally to express the intensity of the acid or alkaline condition of a solution [12]. A pH meter measures the acidity or alkalinity of water or other liquids [13]. Most of the water is slightly alkaline due to the presence of carbonates and bicarbonates. Generally, P^H of water is influenced by buffering capacity of water. During the present study the values vary from 7.1 to 8.3 during rainy season, 6.5 to 8.2 in winter season and 7.5 to 8.5 in summer season.

3.3 Total Alkalinity

Alkalinity of water is its capacity to neutralize a strong acid and it is normally due to the presence of bicarbonate, carbonate and hydroxide compound of calcium, sodium, and potassium. If the alkalinity is high in water, the taste becomes unpleasant. In the present study, alkalinity values vary from 80ppm to 500ppm with an average value of 256ppm in rainy season, 105ppm to 450ppm with an average of 423ppm during winter season and 200ppm to 620ppm with an average of 384ppm during summer season. Higher seepage during the rainy season leads to the dissolution of more alkaline compounds, which could contribute to higher alkalinity levels. However, the average alkalinity is lower during this season, suggesting that other factors such as dilution or changes in groundwater levels might be influencing the results. Lower seepage and reduced groundwater levels during the winter season might concentrate the alkaline compounds, leading to higher average alkalinity. The higher average alkalinity during the summer season could be due to the increased concentration of alkaline compounds as a result of lower groundwater levels.

3.4 Nitrates

This is the highest oxidized form of Nitrogen. Biological oxidation of nitrogenous substances from sewage is the main source of nitrate. Groundwater contains nitrate due to leaching nitrate with the percolating water. Groundwater can also be contaminated by sewage and other wastes rich in nitrates. In the present study area, the nitrates from fertilizers leach through soil into the subsurface aquifer system leading to groundwater pollution. The values range from 0.1ppm to 67.3ppm with an average of 11ppm during rainy season, 0.00ppm to 42ppm with an average of 26ppm during winter season and 1.8ppm to 70ppm with an average of 32ppm during summer. The winter season has an average nitrate concentration of 26 ppm, which is higher than the rainy season but lower than the summer season. These variations can be attributed to factors such as agricultural activities, sewage, and other waste sources that contribute to nitrate pollution in groundwater.

3.5 Sodium

In the present study the sodium values vary from 44ppm to 150ppm with an average of 93ppm during rainy season, 37ppm to 148ppm with an average of 143ppm during winter season and 60ppm to 426ppm with an average of 157ppm during summer season. The sodium concentrations in the groundwater samples vary across different seasons, with the highest average sodium levels observed during the summer season (157 ppm) and the lowest during the rainy season (93 ppm). These variations are likely influenced by factors such as agricultural activities, sewage, and other waste sources that contribute to sodium pollution in groundwater.

3.6 Chlorides

Chloride usually occurs as NaCl, $CaCl_2$ and MgCl in widely varying concentration, in all natural waters. They enter water by solvent action of water on salts present in the soil, from polluting material like sewage and trade wastes (Shaikh and Mandre, 2009). In the present study the sodium values vary from 16ppm to 291ppm with an average of 126ppm during rainy season, 15ppm to 324ppm with an average of 200ppm during winter season and 19ppm to 497ppm with an average of 248ppm during summer season. The sodium concentrations in the groundwater samples vary across different seasons, with the highest average sodium levels observed during the summer season (248 ppm) and the lowest during the rainy season (126 ppm). These variations are likely influenced by factors such as agricultural activities, sewage, and other waste sources that contribute to sodium pollution in groundwater. The high sodium levels can be attributed to the solvent action of water on salts present in the soil and the presence of polluting materials like sewage and trade wastes.

3.7 Correlation Coefficient

Correlation coefficient is commonly used to measure and establish the relationship between two variables. It is a simplified statistical tool to show the degree of dependency of one variable to the other [14]. Water quality depends on several parameters. If strong correlation exists among different parameters and the combined effect of inter relationship among these parameters reflect on the quality of water. The task of monitoring the quality of water can be facilitated if correlations among the water quality parameters are known [15].

Several types of correlation coefficient exist, each with their own definition and own range of usability and characteristics. All the assume values in the range from −1 to +1, where +1 indicates the strongest possible agreement and −1 the strongest possible disagreement. As tools of analysis, correlation coefficients present certain problems, including the propensity of some types to be distorted by outliers and the possibility of incorrectly being used to infer a causal relationship between the variables.

The results of correlation coefficient for various physico chemical parameters in three seasons for groundwater extracted from closed systems, treated groundwater extracted from closed systems and groundwater extracted from open systems are summarized in Table 1 to Table 7.

In rainy season, highly positive correlation observed between magnesium and total hardness (0.80); calcium and total hardness; calcium and nitrates (0.71) Table 1. A highly negative correlation is observed between alkalinity and pH (-0.38). A very poor positive correlation is observed between alkalinity and turbidity; sodium and magnesium (0.10). There is no correlation between magnesium and alkalinity; magnesium and nitrates (0.00).

Table 1
Correlation matrix of water quality parameters of treated groundwater during rainy season

Parameter	pH	TDS	Turb.	Alk.	T.H	NO_3	Ca	Mg	Na^+	K^+	Cl^-
pH	1.00										
TDS	-0.18	1.00									
Turb.	-0.02	-0.15	1.00								
Alk.	-0.38	0.54	0.10	1.00							
T.H	-0.18	0.61	0.14	0.12	1.00						
NO_3	-0.13	0.56	0.07	0.17	0.43	1.00					
Ca	-0.13	0.48	0.09	0.19	0.71	0.71	1.00				
Mg	-0.14	0.45	0.11	0.00	0.80	0.00	0.14	1.00			
Na^+	0.25	0.54	-0.13	0.23	0.17	0.30	0.17	0.10	1.00		
K^+	-0.08	0.23	-0.13	-0.23	0.05	0.21	-0.12	0.16	0.07	1.00	
Cl^-	0.13	0.64	-0.25	0.01	0.63	0.13	0.26	0.68	0.47	0.25	1.00

Correlation coefficient of treated groundwater extracted from closed systems, shows highly positive correlation observed between calcium and total hardness (0.87) in winter (Table 2). A highly negative correlation is observed between turbidity and pH (-0.62). A very poor positive correlation is observed between sodium and calcium (0.15); nitrates and turbidity (0.15). There is no correlation between TDS and pH; turbidity and TDS; potassium and calcium (0.00).

Table 2
Correlation matrix of water quality parameters of treated groundwater during winter season

Parameter	pH	TDS	Turb.	Alk	T.H	NO_3	Ca	Mg	Na^+	K^+	Cl^-
pH	1.00										
TDS	0.00	1.00									
Turb.	-0.62	0.00	1.00								
Alk	0.03	0.53	0.40	1.00							
T.H	-0.17	0.57	0.33	0.67	1.00						
NO_3	-0.05	0.40	0.15	0.38	0.24	1.00					
Ca	-0.16	0.39	0.47	0.59	0.87	0.14	1.00				
Mg	-0.09	0.52	-0.09	0.39	0.62	0.24	0.15	1.00			
Na^+	0.12	0.50	0.02	0.52	0.37	0.41	0.15	0.50	1.00		
K^+	-0.12	0.42	-0.05	0.32	0.09	0.43	0.00	0.18	0.30	1.00	
Cl^-	0.03	0.49	0.21	0.57	0.69	0.22	0.57	0.47	0.53	0.06	1.00

In summer, a highly positive correlation is observed between calcium and total hardness; magnesium and total hardness (0.84); total hardness and TDS (0.75) (Table 3). A highly negative correlation is observed between turbidity and pH (-0.15). A very poor positive correlation is observed between chlorides and pH (0.11); turbidity and TDS (0.12); potassium and magnesium (0.14). There is no correlation between TDS and pH; potassium and pH (0.00).

Table 3
Correlation matrix of water quality parameters of treated groundwater during summer season

Parameter	pH	TDS	Turb.	Alk	T.H	NO_3	Ca	Mg	Na^+	K^+	Cl^-
pH	1.00										
TDS	0.00	1.00									
Turb.	-0.15	0.12	1.00								
Alk	0.01	0.63	0.44	1.00							
T.H	-0.11	0.75	0.27	0.66	1.00						
NO_3	-0.08	0.33	0.15	0.37	0.43	1.00					
Ca	-0.09	0.59	0.14	0.50	0.84	0.58	1.00				
Mg	-0.09	0.69	0.31	0.60	0.84	0.15	0.42	1.00			
Na^+	0.22	0.37	0.35	0.37	0.31	-0.04	0.14	0.37	1.00		
K^+	0.00	0.42	0.06	0.52	0.05	0.29	-0.06	0.14	0.13	1.00	
Cl^-	0.11	0.42	0.11	0.10	0.35	0.04	0.41	0.19	0.33	0.01	1.00

3.8 Hydro Chemical Classification

Chemical classification also throws light on the concentration of various predominant cations, anion and their interrelationships. Several techniques and methods have been developed to interpret chemical data. Zaporozee (1972) has summarized various modes of data representation and discussed their possible uses.

3.8.1 Classification based on total dissolved solids (TDS)

Groundwater is characterized by significant chemical variability, which is influenced by factors such as geological substrate, subsurface residence time, and groundwater interactions [16]. As water flows through the surface geological environment, dissolved solids and major ions increase [17]. The chemical composition of groundwater is a critical factor in determining its suitability for various applications.

The classification of groundwater based on total dissolved solids (TDS) is an important factor to consider. According to Freeze and Cherry [18], groundwater can be classified into different types based on TDS, as shown in Table 4.

The data generated during the study period indicates that in the rainy season, 40.9% of the water was classified as freshwater and 50% as brackish water. In the winter season, 27.27% was classified as freshwater and 72.72% as brackish water. During the summer season, 9.09% was classified as freshwater and 90% as brackish water. The groundwater classification based on TDS is presented in Table 4.

Table 4
Classification of water quality based on TDS in three seasons

TDS Range (ppm)	Classification	Rainy	Winter	Summer
<500	Fresh water	40.90%	27.27%	09.09%
500-30000	Brackish water	50.09%	72.72%	90.90%
30000-50000	Saline water	0.0%	0.0%	0.0%
>50000	Brine water	0.0%	0.0%	0.0%

3.8.2 Classification based on Electrical Conductivity (EC)

Groundwater can also be classified into five categories based on electrical conductivity Table 5. According to the data obtained in the present study, 9.09% of the samples fell under the category of good water quality. In comparison, 54.54% of the samples were found to be within the permissible limit of 36.3%. In the rainy season, 4.54% of the samples were categorized as good, 31.8% were within the permissible limit, 50% were brackish, and 13.63% were categorized as saline. In the winter season, 27.27% of the samples were found to be within the permissible limit, 31.8% were brackish, and 40.90% were categorized as saline. It is important to note that no samples were found to have excellent water quality during any of the four seasons.

Table 5
Classification of water quality based on EC during three seasons

EC Range (µS/cm)	Classification	Rainy	Winter	Summer
0-333	Excellent	0.0%	0.0%	0.0%
333-500	Good	09.09%	04.54%	0.0%
500-1000	Permissible	54.54.0%	31.88%	27.27%
1000-1500	Brackish	36.36%	50.00%	31.80%
1500-10000	Saline	0.0%	13.63%	40.90%

3.8.3 Classification based on total hardness

Hardness in water is principally attributable to divalent cations. The hardness of water is typically categorized as either temporary or permanent. Temporary hardness is mainly attributed to carbonate and bicarbonate ions of calcium and magnesium. On the other hand, permanent hardness arises from sulfates and chlorides of calcium and magnesium. Hardness is often calculated as the equivalent concentration of calcium carbonate, and it is also used as a measure of scale formation in water heaters and low-pressure boilers. It is worth noting that the hardness of water tends to increase during the summer season compared to other times of the year. Most water samples from the study area fall within the hard and very hard categories, as indicated in Table 6.

Table 6
Water hardness is classified based on the Total Hardness during the three seasons

Total Hardness Range (ppm)	Classification	Rainy	Winter	Summer
0-75	Soft	4.54%	0.0%	0.0%
75-150	Moderately Hard	40.90%	27.27%	0.0%
150-300	Hard	40.90%	50.0%	36.36%
>300	Very Hard	13.63%	22.72%	63.63%

3.8.4 Classification based on chlorides/Stuyfzand's classification

The hydrochemistry of groundwater in diverse settings can be evaluated using the scheme recommended by Stuyfzand [19]. This scheme incorporates unique features from other existing classifications, as well as a new type of assessment criteria for sub-divisions. It has been effectively used to decipher the hydrogeological characteristics of an aquifer. Stuyfzand's primary classification is based on chloride concentration, as shown in Table 7.

According to Stuyfzand's classification, the data collected during this study indicate that 54.54% of water samples fall under the freshwater category and 45.45% belong to the fresh brackish water category during the rainy season. During the winter season, 63.63% of water samples are classified as freshwater, while 27.27% fall under the fresh brackish water category and 9.09% belong to the brackish water category. In the summer season, 31.81% of water samples belong to the freshwater category, 27.27% belong to the fresh brackish water category, and 40.90% of samples are categorized as brackish water.

Table 7
Classification of water quality based on Chlorides during three seasons

Chloride Range (ppm)	Classification	Rainy	Winter	Summer
<5	Oligohaline	0.0%	0.0%	0.0%
30-150	Fresh	54.54%	63.63%	31.81%
150-300	Fresh-brackish	45.45%	27.27%	27.27%
>300	Brackish	0.0%	9.09%	40.90%

4. Conclusions

The study conducted in the Godavari Western Delta region of Andhra Pradesh, India, aimed to assess the chemical composition of groundwater samples and characterize their quality. The analysis of 22 water samples collected during three seasons (rainy, winter, and summer) revealed significant variations in physicochemical parameters such as turbidity, pH, total alkalinity, nitrates, sodium, chlorides, and total hardness. The correlation coefficient analysis showed strong relationships between various parameters, indicating the interdependence of these factors in determining water quality.

The classification of groundwater based on total dissolved solids (TDS), electrical conductivity (EC), total hardness, and chlorides revealed that most samples fell into the brackish water category, with some samples classified as freshwater or saline water. The study highlights the importance of monitoring groundwater quality to ensure its sustainability for future generations, particularly in regions where it is a critical source of water for various purposes. Values ranged from 1.0 to 5.6 NTU during the rainy season, indicating moderate turbidity. Most water samples were slightly alkaline, with pH values between 7.1 and 8.5. Total hardness values varied from 80 to 620 ppm, indicating a significant presence of bicarbonate, carbonate, and hydroxide compounds. Nitrates concentrations ranged from 0.1 to 70 ppm, suggesting potential contamination from fertilizers and sewage. Sodium and Chlorides concentrations were significant, indicating the presence of salts and potential pollution from human activities. Most samples were classified as hard or very hard, indicating the presence of divalent cations like calcium and magnesium. The study emphasizes the need for continued monitoring and management of groundwater resources to mitigate the impacts of pollution, industrialization, and urbanization on water quality.

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