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Role of Groundwater Quality in Promoting Sustainable Aquaculture and Environmental Sustainability in Pedavadlapudi, Guntur, India

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Abstract
Groundwater serves as a primary source of drinking water, irrigation, and aquaculture in rural regions of India. Assessing its quality is essential to determine its suitability for various uses and its contribution to environmental sustainability. The present study aims to evaluate the groundwater quality of Pedavadlapudi village, Guntur District, Andhra Pradesh, and to assess its suitability for sustainable aquaculture while comparing its compliance with drinking water standards. Groundwater samples were collected from selected locations in Pedavadlapudi village. Physicochemical parameters including pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), total hardness, alkalinity, chlorides, sulphates, nitrate, dissolved oxygen (DO), and selected heavy metals were analyzed using standard laboratory procedures. The results were compared with drinking water standards prescribed by the Bureau of Indian Standards (IS 10500:2012) and World Health Organization guidelines. Analysis revealed that certain parameters exceeded the permissible limits for drinking water as per Bureau of Indian Standards (IS 10500:2012) and World Health Organization guidelines. However, the groundwater exhibited favorable characteristics such as balanced pH and adequate mineral content, which are suitable for aquaculture practices. Although the groundwater of Pedavadlapudi village is unsuitable for direct drinking without treatment, it is appropriate for sustainable aquaculture applications. Proper utilization of this resource can promote eco-friendly fish culture practices, enhance rural livelihoods, and contribute to environmental sustainability aligned with the vision of Green India.

Keywords: Groundwater quality, Aquaculture suitability, Physico-chemical parameters, Heavy metals, Sustainable aquaculture, Environmental sustainability

Introduction

Groundwater plays a crucial role in India's water security, particularly in rural and semi-urban regions (Central Ground Water Board, 2020). In Andhra Pradesh, groundwater is extensively used for domestic supply, irrigation, and fish farming (Nagaraju et al., 2022). However, rapid urbanization, agricultural runoff, and geogenic processes often alter groundwater chemistry (Putheti et al., 2008; Rajendran et al., 2020). Pedavadlapudi village, located in Guntur District of Andhra Pradesh, depends largely on borewell water. The hydro chemical characteristics of groundwater determine its suitability for various applications. While high salinity, hardness, and dissolved solids may make water unsuitable for drinking, moderate mineralization can support aquaculture productivity (Gentelini et al., 2021). Sustainable aquaculture is recognized as an environmentally responsible practice that enhances food security while maintaining ecological balance (Yakushev et al., 2020). Proper assessment of groundwater quality helps in resource management, preventing health risks and promoting environmental sustainability in line with India's green development initiatives (Mohanadas et al., 2023).

Objectives

To analyse the physico-chemical characteristics of groundwater in Pedavadlapudi. To compare groundwater quality with drinking water standards (BIS and WHO).
To evaluate the suitability of groundwater for aquaculture practices. To assess the environmental implications of groundwater utilization.
To suggest sustainable management strategies for groundwater resources.

Scope of the Study
The study is confined to selected borewell locations in Pedavadlapudi village. It evaluates seasonal variations in groundwater quality. The analysis focuses on drinking and aquaculture suitability. The findings support environmental sustainability and green development policies. The study contributes baseline data for future hydrogeochemical research.

Methods
Area Pedavadlapudi village is situated near Mangalagiri in Guntur District, Andhra Pradesh. The area experiences a tropical climate with moderate rainfall and intensive agricultural activities (Central Ground Water Board, 2020).

Sample Collection
Groundwater samples were collected from three representative handpump locations during summer, rainy, and winter seasons (May 2025, September 2025, and January 2026). Samples were collected in pre-cleaned polyethylene bottles following standard procedures (American Public Health Association, 2017).

Parameters Analysed
pH Electrical Conductivity (EC) Total Dissolved Solids (TDS) Total Hardness Alkalinity Chlorides Sulphates Nitrates Dissolved Oxygen (DO) Iron

Analytical Methods
Laboratory analysis was conducted following standard procedures recommended by Bureau of Indian Standards guidelines and World Health Organisation (Bureau of Indian Standards, 2012; World Health Organization, 2017). Statistical tools such as mean, standard deviation, and correlation analysis were used. Hydrochemical facies were interpreted using Piper and Gibbs diagrams.

Results
The groundwater quality of Pedavadlapudi village was evaluated at three sampling stations during May 2025, September 2025, and January 2026. The results were compared with drinking water standards prescribed by the World Health Organization (WHO) and Bureau of Indian Standards (BIS 10500) (World Health Organization, 2017; Bureau of Indian Standards, 2012). The findings are presented in Tables 1-3.

Table 1. Groundwater Quality Parameters at Sampling Station 1: Pedavadlapudi Tenali Mangalagiri Road

S. No	Parameters	May 2025	Sep 2025	Jan. 2026	Water Quality Standard (WHO)	Water Quality Standard (BIS)
1	pH	7.12	7	7.88	6.5-8.5	6.5-8.5
2	Electrical conductivity (EC)	37.8	38.8	32.5	-	-
3	Total Dissolved Solids (TDS)	2303	2417	3011	500	500
4	Hardness	936	1223.6	1145	50-200	200
5	Dissolved Oxygen (DO)	6.74	6.39	1.65	5	-
6	Alkalinity	360	310	406	-	200
7	Nitrate	2.21	8.78	46.6	50	45
8	Chlorides	278.3	363.7	682.9	250	250
9	Sulphates	224.5	284.8	355.3	250	200
10	Iron	0.01	0.014	0.25	0.3	0.3

Table 2. Groundwater Quality Parameters at Sampling Station 2: Pedavadlapudi Primary Health Centre

S. No.	Parameters	May 2025	Sep. 2025	Jan. 2026	Water Quality Standard (WHO)	Water Quality Standard (BIS)
1	pH	7.1	7.1	7.43	6.5-8.5	6.5-8.5
2	Electrical conductivity (EC)	20.5	14.5	13.2	-	-
3	Total Dissolved Solids (TDS)	1376	1295	1320	500	500
4	Hardness	620	1034	709.8	50-200	200
5	Dissolved Oxygen (DO)	7.54	8.42	0.81	5	-
6	Alkalinity	388.1	305	504	-	200
7	Nitrate	1.37	8.56	44.35	50	45
8	Chlorides	212.7	201.1	217.2	250	250
9	Sulphates	141.7	173.3	48.2	250	200
10	Iron	0.01	0.011	0.11	0.3	0.3

Table 3. Groundwater Quality Parameters at Sampling Station 3: Pedavadlapudi Railway Station Point

S. No.	Parameters	May 2025	Sep 2025	Jan. 2026	Water Quality Standard (WHO)	Water Quality Standard (BIS)
1	pH	7.3	7.3	7.31	6.5-8.5	6.5-8.5
2	Electrical conductivity (EC)	14.7	10.8	17.6	-	-
3	Total Dissolved Solids (TDS)	68.3	809	864	500	500
4	Hardness	215.2	440	439.2	50-200	200
5	Dissolved Oxygen (DO)	2.50	2	2.21	5	-
6	Alkalinity	240.5	345	364	-	200
7	Nitrate	0.68	7.89	42	50	45
8	Chlorides	48.1	40.5	109.5	250	250
9	Sulphates	66.1	106.2	22.2	250	200
10	Iron	0.01	0.01	0.01	0.3	0.3

The groundwater quality analysis of Station 1 in Pedavadlapudi reveals a mixed hydrochemical character, showing limitations for drinking purposes but certain advantages for aquaculture applications (Putheti et al., 2008). The pH values ranged from 7.0 to 7.88, indicating neutral to slightly alkaline conditions. These values fall within the permissible limits of 6.5–8.5 recommended by the World Health Organization and the Bureau of Indian Standards (World Health Organization, 2017; Bureau of Indian Standards, 2012). From a pH perspective alone, the water does not pose acidity or alkalinity-related health risks and is chemically suitable for both drinking and aquaculture. A stable, slightly alkaline pH is also favorable for fish growth, metabolic activity, and nutrient cycling in aquaculture ponds (Yakushev et al., 2020). However, Electrical Conductivity (EC) values ranging from 32.5 to 38.8 indicate a high ionic concentration in the groundwater. Elevated EC reflects the presence of dissolved salts resulting from mineral weathering, rock-water interaction, and possible salinity influence (Rajendran et al., 2020). This is further confirmed by the Total Dissolved Solids (TDS) values, which ranged between 2303 and 3011 mg/L—far exceeding the desirable drinking water limit of 500 mg/L (Bureau of Indian Standards, 2012).

Such high TDS levels classify the water as highly saline and unsuitable for regular human consumption, as excessive dissolved salts can cause gastrointestinal irritation, scaling in pipes, and long-term health concerns. Nevertheless, in aquaculture systems, moderate salinity can be advantageous for certain species, especially brackish water organisms, as it improves osmotic balance and disease resistance when properly managed (Gentelini et al., 2021). Total Hardness values ranging from 936 to 1223.6 mg/L indicate that the water is "very hard," greatly exceeding the permissible drinking limit of 200 mg/L (Bureau of Indian Standards, 2012). This hardness is primarily due to elevated concentrations of calcium and magnesium ions. While very hard water is undesirable for drinking because it affects taste, causes scaling, and may contribute to kidney stone formation in susceptible individuals, it can be beneficial in aquaculture. Calcium and magnesium are essential for fish skeletal development, scale formation, enzymatic activity, and metabolic functions. Hard water also enhances pond productivity by stabilizing biological processes and improving nutrient availability (Nagaraju et al., 2022). Thus, although unsuitable for domestic use, high hardness can positively influence fish culture. Dissolved Oxygen (DO) levels, however, present a concern. The DO concentration decreased sharply to 1.65 mg/L in January, which is far below the minimum 5 mg/L required to sustain healthy aquatic life (World Health Organization, 2017).

Low DO levels may result from organic contamination, increased microbial decomposition, seasonal stagnation, or reduced photosynthetic activity during colder months. In aquaculture, insufficient DO can cause fish stress, reduced feeding, slow growth, and even mortality. Therefore, aeration systems are essential if this groundwater is used for fish farming, particularly during winter or periods of high organic load (Yakushev et al., 2020). Alkalinity values between 310 and 406 mg/L exceed the permissible drinking limit of 200 mg/L, indicating high buffering capacity (Bureau of Indian Standards, 2012). Although high alkalinity may cause a bitter taste in drinking water, it is advantageous in aquaculture because it stabilizes pond pH and prevents sudden fluctuations caused by photosynthesis and respiration cycles. Stable pH conditions promote better feed conversion, enhance microbial activity beneficial for nutrient cycling, and support overall pond productivity (Gentelini et al., 2021). Nitrate concentrations reached 46.6 mg/L in January, slightly exceeding the permissible drinking limit of 45 mg/L (Bureau of Indian Standards, 2012). Elevated nitrate levels often indicate agricultural runoff, fertilizer leaching, or anthropogenic contamination from nearby activities. High nitrate in drinking water poses health risks such as methemoglobinemia (blue baby syndrome) in infants. However, in controlled aquaculture systems, moderate nitrate levels can stimulate phytoplankton growth and enhance natural productivity. Excessive accumulation, though, may lead to eutrophication and oxygen depletion, requiring careful monitoring (Mohanadas et al., 2023). Chloride concentrations up to 682.9 mg/L and sulphate levels reaching 355.3 mg/L also exceed recommended drinking water standards (Bureau of Indian Standards, 2012). Elevated chloride levels may indicate salinity intrusion, evaporation effects, or sewage contamination, while high sulphate can cause a laxative effect in drinking water and contribute to corrosion. In aquaculture, moderate chloride concentrations can help fish maintain osmotic balance and reduce stress, but excessive levels must be controlled to prevent adverse effects on freshwater species (Rajendran et al., 2020).

Iron concentrations remain within permissible limits (below 0.3 mg/L), indicating no significant iron contamination (Bureau of Indian Standards, 2012). This suggests that iron-related staining, taste issues, or toxicity are not major concerns in this groundwater source. Overall, the groundwater at Station 1 is chemically unsuitable for drinking due to excessively high TDS, hardness, alkalinity, chlorides, sulphates, and borderline nitrate levels. However, its mineral-rich composition, stable pH, and high buffering capacity make it moderately suitable for aquaculture, particularly for species tolerant to elevated salinity and hardness. With proper aeration to maintain dissolved oxygen and regular water quality monitoring to control nutrient levels, this groundwater resource can be effectively utilized for sustainable aquaculture development while remaining inappropriate for direct domestic consumption without treatment (Nagaraju et al., 2022).

The groundwater quality assessment of Station 2 in Pedavadlapudi indicates that while the water is not suitable for drinking purposes, it possesses characteristics that can support aquaculture activities with proper management. The pH values range from 7.1 to 7.43, showing a neutral to slightly alkaline nature. These values fall well within the acceptable limits (6.5–8.5) recommended by the World Health Organization and the Bureau of Indian Standards (World Health Organization, 2017; Bureau of Indian Standards, 2012). A stable and slightly alkaline pH is generally favorable for aquatic organisms, as it supports metabolic functions, nutrient availability, and overall pond stability. Therefore, from the perspective of pH alone, the groundwater does not pose chemical stress either for drinking or aquaculture. However, Total Dissolved Solids (TDS) values ranging from 1295 to 1376 mg/L significantly exceed the recommended drinking water limit of 500 mg/L (Bureau of Indian Standards, 2012). Elevated TDS indicates the presence of high concentrations of dissolved salts and minerals, which may affect taste, cause scaling in household plumbing systems, and pose long-term health concerns if consumed regularly. Hence, the water is unsuitable for potable use without treatment. In aquaculture, however, moderate levels of dissolved salts can be beneficial, as they improve osmotic regulation in fish and may enhance resistance to certain diseases when maintained within manageable levels (Gentelini et al., 2021).

Total hardness values between 620 and 1034 mg/L classify the water as very hard, far exceeding the desirable limit for drinking water (200 mg/L as per BIS guidelines) (Bureau of Indian Standards, 2012). High hardness results primarily from elevated concentrations of calcium and magnesium ions. While very hard water is undesirable for domestic consumption due to scaling problems and potential health concerns, it is often advantageous in aquaculture. Calcium and magnesium are essential for skeletal development, scale formation, enzyme activation, and physiological stability in fish. Hard water can also improve reproductive performance and reduce stress in cultured species, thereby supporting healthy growth and productivity (Nagaraju et al., 2022). A significant concern in Station 2 is the sharp decline in Dissolved Oxygen (DO) levels to 0.81 mg/L in January, which is critically low compared to the minimum requirement of approximately 5 mg/L for sustaining healthy aquatic life (World Health Organization, 2017). Such low DO concentrations may result from seasonal stagnation, reduced photosynthetic activity, organic matter decomposition, or increased microbial respiration. Without adequate oxygen, fish may experience stress, reduced feeding, slow growth, and even mortality. Therefore, if this groundwater is to be used for aquaculture, aeration systems such as mechanical aerators or diffused air systems are essential to maintain sufficient oxygen levels and ensure fish survival (Yakushev et al., 2020).

Alkalinity values ranging from 305 to 504 mg/L exceed the permissible drinking water limit of 200 mg/L (Bureau of Indian Standards, 2012). High alkalinity indicates strong buffering capacity, meaning the water can resist sudden changes in pH. Although this may make the water less desirable for drinking due to taste issues, it is beneficial in aquaculture systems. Stable pH conditions prevent stress in fish, enhance nutrient cycling, and improve feed utilization efficiency. Thus, high alkalinity contributes positively to pond ecosystem stability (Gentelini et al., 2021). Nitrate concentrations reached 44.35 mg/L in January, approaching the permissible limit of 45 mg/L for drinking water (Bureau of Indian Standards, 2012). Elevated nitrate levels may indicate agricultural runoff, fertilizer leaching, or anthropogenic contamination. While high nitrate poses health risks for human consumption, particularly for infants, moderate nitrate levels in aquaculture can stimulate phytoplankton growth and enhance natural productivity. However, excessive nitrate accumulation may lead to eutrophication and oxygen depletion, necessitating regular monitoring (Mohanadas et al., 2023). Chloride and sulphate concentrations remain within permissible limits in most months, suggesting moderate salinity and absence of severe contamination from saline intrusion or industrial discharge (Bureau of Indian Standards, 2012). Moderate chloride levels can assist fish in maintaining osmotic balance, while acceptable sulphate levels minimize risks of laxative effects or corrosion in drinking systems. Iron concentrations also remain within safe limits, indicating no significant iron-related issues such as staining, unpleasant taste, or toxicity (Bureau of Indian Standards, 2012). Overall, the groundwater at Station 2 is unsuitable for potable use due to high TDS, hardness, alkalinity, and borderline nitrate levels. Nevertheless, its neutral pH, moderate salinity, high buffering capacity, and mineral richness make it chemically stable and potentially suitable for aquaculture. With proper oxygen management through aeration and regular monitoring of nutrient levels, this groundwater source can effectively support fish growth and sustainable aquaculture development in the region (Nagaraju et al., 2022).

The groundwater quality assessment of Station 3 in Pedavadlapudi reveals a moderately mineralized water type that presents certain limitations for drinking purposes but remains potentially suitable for freshwater aquaculture with appropriate management. The pH values range narrowly between 7.3 and 7.31, indicating a stable, neutral to slightly alkaline nature. These values fall comfortably within the permissible limits (6.5–8.5) prescribed by the World Health Organization and the Bureau of Indian Standards (World Health Organization, 2017; Bureau of Indian Standards, 2012). Such stability in pH suggests chemical equilibrium and minimal risk of acidity or alkalinity-related health impacts. For aquaculture, a stable pH within this range is highly desirable, as it supports metabolic efficiency, enzyme activity, nutrient availability, and overall physiological balance in fish (Yakushev et al., 2020). Total Dissolved Solids (TDS) show seasonal variation at this station. In May, the value of 68.3 mg/L falls well within permissible drinking limits, indicating low salinity and good palatability. However, during September and January, TDS levels increase significantly to between 809 and 864 mg/L, exceeding the desirable limit of 500 mg/L (Bureau of Indian Standards, 2012). This seasonal rise may be attributed to evaporation, concentration of dissolved salts, or increased mineral dissolution (Rajendran et al., 2020).

Elevated TDS affects taste and may cause scaling in domestic systems, thereby reducing suitability for potable use during those months. Nevertheless, in aquaculture, moderate TDS levels can be tolerated by many freshwater species and may even support osmotic regulation when not excessively high (Gentelini et al., 2021). Total hardness values range from 215 to 440 mg/L, exceeding the permissible drinking water limit of 200 mg/L in all seasons (Bureau of Indian Standards, 2012). This indicates that the groundwater is consistently classified as hard water due to the presence of calcium and magnesium ions. Hard water is generally undesirable for domestic consumption because it causes scaling in pipes, reduces soap efficiency, and may contribute to long-term health concerns in susceptible individuals. However, in aquaculture systems, moderate hardness is beneficial. Calcium and magnesium are essential for skeletal development, scale formation, reproductive health, and enzymatic activity in fish. Hard water also helps stabilize biological processes within the pond ecosystem and can reduce stress in cultured species (Nagaraju et al., 2022). A notable limitation at Station 3 is the consistently low Dissolved Oxygen (DO) concentration, ranging from 2 to 2.5 mg/L. These values are below the recommended minimum level of approximately 5 mg/L required to sustain healthy aquatic life (World Health Organization, 2017). Low DO levels may result from organic matter decomposition, limited water movement, or reduced photosynthetic activity. Without adequate oxygen, fish may experience stress, suppressed immunity, reduced feeding behavior, and slow growth. Therefore, if this groundwater is utilized for aquaculture, oxygen supplementation through mechanical or diffused aeration systems becomes essential to maintain optimal pond conditions and prevent mortality (Yakushev et al., 2020). Alkalinity values exceed the BIS recommended limit of 200 mg/L, indicating high buffering capacity (Bureau of Indian Standards, 2012).

While elevated alkalinity may make the water less suitable for drinking due to taste and scaling concerns, it is advantageous for aquaculture. High alkalinity stabilizes pond pH and prevents rapid fluctuations caused by daily photosynthesis and respiration cycles. This buffering effect contributes to a more stable aquatic environment, improving feed efficiency, survival rates, and overall pond productivity (Gentelini et al., 2021). Nitrate concentrations remain within the limits prescribed by the World Health Organization but approach the BIS threshold (42 mg/L in January) (World Health Organization, 2017; Bureau of Indian Standards, 2012). This suggests potential influence from agricultural runoff or anthropogenic activities. Although the nitrate levels do not currently exceed safe limits, the upward trend indicates a possible risk of contamination if not properly monitored. In aquaculture, moderate nitrate concentrations may enhance phytoplankton productivity; however, excessive accumulation could lead to eutrophication and oxygen depletion (Mohanadas et al., 2023). Chloride and sulphate concentrations remain within permissible limits, indicating comparatively lower salinity than observed in Station 1 (Bureau of Indian Standards, 2012). This suggests that Station 3 groundwater is less influenced by salinity intrusion and may be more suitable for freshwater aquaculture species. Iron concentrations also remain within safe limits, eliminating concerns related to staining, unpleasant taste, or toxicity (Bureau of Indian Standards, 2012). Overall, the groundwater at Station 3 can be considered moderately unsuitable for drinking due to persistent hardness and seasonal increases in TDS and alkalinity. However, its stable pH, acceptable salinity levels, and beneficial mineral composition make it suitable for freshwater aquaculture, provided that adequate oxygen management is implemented. With proper aeration and periodic water quality monitoring, this groundwater source can effectively support sustainable fish culture while remaining unsuitable for direct domestic consumption without treatment (Nagaraju et al., 2022).

Table 4. Comparative Analysis of All Stations

Parameter	Drinking Suitability	Aquaculture Suitability
pH	Suitable	Suitable
TDS	Unsuitable (S1 & S2 severe)	Moderate (species dependent)
Hardness	Unsuitable	Beneficial
DO	Poor in Jan (all stations)	Requires aeration
Alkalinity	Unsuitable	Beneficial
Nitrate	Borderline	Productive in controlled level
Iron	Safe	Safe

Discussion

The mineral-rich groundwater of Pedavadlapudi village in Guntur District, Andhra Pradesh, significantly enhances aquaculture productivity due to its favorable physicochemical properties (Putheti et al., 2008; Nagaraju et al., 2022). A key factor is the elevated alkalinity, indicative of the water's capacity to neutralize acids, primarily resulting from bicarbonates, carbonates, and hydroxides. In aquaculture systems, alkalinity supports phytoplankton growth by providing a stable carbon source essential for photosynthesis. Enhanced phytoplankton production increases primary productivity, which subsequently supports zooplankton populations that serve as a natural food source for fish larvae and juveniles. This natural food web reduces reliance on artificial feed and lowers operational costs.

Furthermore, higher alkalinity improves nutrient utilization, particularly of nitrogen and phosphorus, by maintaining favorable chemical conditions in pond water. It also mitigates sudden pH fluctuations caused by daytime photosynthesis and nighttime respiration, thereby preserving ecological balance (Yakushev et al., 2020). In addition to alkalinity, the presence of calcium (Ca^{2+}) and magnesium (Mg^{2+}), which contribute to water hardness, significantly enhances fish health and development. Calcium is essential for bone and scale formation, eggshell strength during breeding, muscle contraction, nerve transmission, and osmotic balance. Fish, particularly in freshwater systems, absorb calcium directly from water via their gills and skin, suggesting that mineral-rich groundwater is highly beneficial for accelerated growth and reduced mortality.

Although required in smaller quantities, magnesium plays a crucial role in enzyme activation, metabolic processes, and skeletal development. Moderate hardness improves disease resistance, reduces physiological stress, and promotes overall fish health, thereby supporting sustainable aquaculture growth in Pedavadlapudi (Gentelini et al., 2021). The buffering capacity of groundwater is significant in maintaining stable pond pH levels, which is essential for aquaculture species that thrive within a pH range of 6.5–8.5. This buffering capacity, closely associated with alkalinity, allows the water to resist abrupt pH changes. Pond ecosystems typically experience a rise in pH during the day due to photosynthesis and a decline at night due to respiration. Groundwater with high alkalinity stabilizes these fluctuations, thereby enhancing feed conversion efficiency, improving survival rates, and reducing the formation of toxic ammonia, particularly at elevated pH levels.

Consequently, the chemically stable environment fostered by mineral-rich groundwater supports optimal fish growth and productivity (Rajendran et al., 2020). Station 1 demonstrates relatively high levels of electrical conductivity (EC) and total dissolved solids (TDS), indicative of mild salinity and mineral enrichment. These attributes suggest the potential for brackish water aquaculture, facilitating the cultivation of species such as Penaeus shrimp, tilapia, and milkfish. Brackish water aquaculture can enhance economic returns, diversify aquaculture practices, and reduce dependence on freshwater resources. However, careful salinity management and controlled integration with freshwater are essential to prevent stress on freshwater species and maintain optimal culture conditions (Mohanadas et al., 2023). Despite these benefits, the sustainability of aquaculture systems necessitates the implementation of effective management practices.

Maintaining adequate dissolved oxygen (DO) levels is crucial, as oxygen is vital for fish respiration. Elevated biological productivity and organic matter decomposition can lead to oxygen depletion, particularly during nocturnal hours. Consequently, aeration systems, including paddle wheel aerators, diffused air systems, and mechanical surface aerators, are essential to sustain DO levels above 5 mg/L, thereby ensuring optimal fish health. Furthermore, periodic water quality monitoring is vital to prevent sudden deterioration. Regular evaluation of parameters, including pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), nitrate, ammonia, hardness, and alkalinity, facilitates early contamination detection, disease outbreak prevention, and efficient feed management (Yakushev et al., 2020). Preventing nitrate contamination is a crucial component of sustainable aquaculture. Nitrate can infiltrate groundwater via agricultural runoff, fertilizer leaching, or sewage infiltration. Elevated nitrate levels may result in algal blooms, oxygen depletion, ecological imbalance, and indirect fish toxicity through ammonia transformation. Preventive strategies, including controlled fertilizer application, maintenance of vegetative buffer zones, proper waste management, and avoidance of excessive pond fertilization, are essential to maintain nitrate concentrations within safe limits (Putheti et al., 2008). Although the groundwater is suitable for aquaculture, it may not fully comply with drinking water standards established by the World Health Organization and the Bureau of Indian Standards due to high total dissolved solids (TDS), hardness, or nitrate concentrations (World Health Organization, 2017; Bureau of Indian Standards, 2012).

Therefore, if intended for domestic use, treatment methods such as reverse osmosis, ion exchange softening, blending with low-TDS water, or activated carbon filtration should be employed to ensure potable quality. Overall, the mineral-rich groundwater of Pedavadlapudi plays a dual role, promoting sustainable aquaculture through high alkalinity, adequate hardness, stable pH buffering, and moderate salinity, while simultaneously necessitating responsible management practices including aeration, monitoring, pollution prevention, and appropriate treatment for domestic use. When scientifically managed, this groundwater resource can significantly contribute to sustainable aquaculture development and environmental sustainability in rural Andhra Pradesh (Nagaraju et al., 2022). The comparative assessment of groundwater quality at three sampling locations—Pedavadlapudi-Tenali-Mangalagiri Road (Station 1), Primary Health Center (Station 2), and Railway Station Point (Station 3)— reveals spatial and seasonal variations in hydrochemical properties. While pH values at all stations remained within the permissible range of 6.5–8.5, as stipulated by the World Health Organization and the Bureau of Indian Standards (World Health Organization, 2017; Bureau of Indian Standards, 2012), most other parameters exceeded drinking water standards.

This indicates that the groundwater is chemically mineralized and influenced by both geogenic and anthropogenic factors (Central Ground Water Board, 2020). A consistent characteristic across all stations is the elevated levels of Total Dissolved Solids (TDS) and Total Hardness. Station 1 exhibits extremely high TDS and hardness, suggesting intense mineral dissolution, potential salinity intrusion, and prolonged water–rock interaction. Station 2 also demonstrates high mineralization, whereas Station 3 experiences seasonal increases in TDS, particularly during post-monsoon and winter periods, likely due to evaporation concentration and leaching processes.

The consistently high hardness values at all stations reflect a dominance of calcium and magnesium ions, consistent with the geological composition of the aquifer system. From a potable water perspective, these elevated levels reduce suitability due to taste alteration, scaling issues, and potential long-term health concerns (Rajendran et al., 2020).

Dissolved oxygen (DO) levels exhibit seasonal constraints across the study area, most notably in January. The observed reductions in DO at all stations suggest potential stagnation, increased organic decomposition, diminished recharge, or temperature-induced changes in solubility. Although groundwater generally contains lower DO concentrations than surface water, the recorded values are insufficient for direct aquaculture application without aeration. This underscores the need for oxygen supplementation if groundwater is to be utilized in fish culture systems (Yakushev et al., 2020).

Alkalinity levels exceeding recommended thresholds at all stations indicate a strong buffering capacity. While this limits its suitability for potable water, it provides ecological stability in aquaculture ponds by mitigating pH fluctuations associated with daily photosynthetic cycles. Moderate to high concentrations of chlorides and sulfates, particularly at Station 1, suggest localized salinity influences, potentially resulting from agricultural return flows or anthropogenic inputs.

Nitrate concentrations nearing or slightly exceeding permissible limits further suggest agricultural runoff or fertilizer leaching, which may pose health risks if the water is consumed untreated. Nevertheless, moderate nutrient levels can enhance primary productivity in aquaculture systems when effectively managed (Mohanadas et al., 2023).

In summary, the analysis indicates that groundwater in Pedavadlapudi is characterized by high mineral content, primarily hardness, and moderate to high salinity in localized regions. Although these attributes limit its direct use for domestic purposes, they offer specific advantages for aquaculture. This is largely due to the stable pH, buffering capacity, and mineral availability, which collectively enhance fish growth and pond productivity (Gentelini et al., 2021). The present study concludes that groundwater quality in Pedavadlapudi exhibits variability across sampling stations, generally surpassing permissible drinking water limits for key parameters such as total dissolved solids, hardness, alkalinity, and occasionally nitrate. Although pH and iron levels remain within acceptable ranges, the consistently elevated mineral content renders the groundwater unsuitable for direct potable use without treatment methods, including desalination, softening, or blending.

However, from an aquaculture perspective, the mineral-rich nature of the groundwater offers significant potential (Nagaraju et al., 2022). High concentrations of calcium and magnesium support skeletal development and metabolic functions in fish, while elevated alkalinity provides buffering capacity that stabilizes pond pH. A primary constraint across all stations is the low dissolved oxygen levels during certain seasons, necessitating mechanical aeration for sustainable fish culture (Yakushev et al., 2020).

Conclusion

In conclusion, the groundwater in Pedavadlapudi is unsuitable for potable use; however, it is appropriate for aquaculture purposes, provided effective oxygen management and consistent water quality monitoring are implemented. Utilizing this resource scientifically can significantly contribute to the sustainable development of aquaculture and environmental management within the region, while addressing domestic water needs through appropriate treatment processes. Future Study Recommendations: Long-term seasonal monitoring of groundwater quality; Heavy metal and microbial contamination assessment; GIS-based groundwater quality mapping; Impact of climate change on groundwater recharge; Development of low-cost water treatment systems for rural drinking use; Integrated water resource management strategies for sustainable development.

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Author Contributions

Conception and Design, MGS; Data Collection, MGS; Methodology, MGS; Writing and Original draft preparation, MGS; Writing – review and editing, CJ; Supervision, CJ

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Competing interest

The authors declare no competing interests.

Ethics approval

In this study, we prioritized ethical considerations. Prior to each interview, the participants were informed about the study's objectives, procedures, and their right to withdraw at any time. The interview data were securely stored and utilized solely for the purposes of this research.

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