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Evaluation of Groundwater Quality by using Water Quality Index in Denduluru Mandal, Eluru District, Andhra Pradesh -India

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ABSTRACT: Groundwater is the principal source of drinking and irrigation water in Denduluru Mandal, Eluru District, Andhra Pradesh, where increasing agricultural activities and groundwater extraction may influence water quality. The present study evaluates groundwater quality using physico-chemical analysis of **20 groundwater samples** collected from bore wells and hand pumps during the pre-monsoon season. Key parameters including pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Hardness (TH), Calcium, Magnesium, Chloride, Nitrate, Sulphate, and Fluoride were analysed following standard methods. The overall groundwater quality was assessed using the **Water Quality Index (WQI)**, and hydro chemical characteristics were interpreted using graphical techniques such as **Piper, Stiff, Durov, Wilcox, and Collins bar diagrams**. The results indicate that groundwater is generally neutral to slightly alkaline, moderately mineralized, and hard in nature, with dominant ions in the order $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ + \text{K}^+$ and $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-}$, suggesting control by carbonate weathering and soil-water interaction. WQI values ranged from 45 to 185, classifying groundwater into excellent, good, and poor categories, indicating that most groundwater is suitable for drinking with minor treatment, while a few locations show elevated TDS, hardness, and nitrate due to agricultural and anthropogenic influences. Hydro chemical diagrams confirm that groundwater is predominantly of **Ca-Mg-HCO₃ type**, with moderate salinity hazard in limited areas for irrigation. The study highlights the need for regular monitoring, controlled fertilizer usage, and sustainable groundwater management to prevent future quality deterioration and ensure long-term water resource sustainability in the region.

KEYWORDS: Groundwater Quality, Water Quality Index (WQI), Hydro chemical Analysis, Denduluru Mandal, Eluru District, Physico-chemical Parameters, Piper Diagram, Groundwater Pollution, Drinking Water Quality, Irrigation Suitability.

I. INTRODUCTION

Groundwater is one of the most important natural resources supporting drinking water supply, agriculture, and industrial development, particularly in semi-arid and developing regions. In India, a major portion of rural and urban populations depends on groundwater for domestic consumption and irrigation. However, rapid population growth, intensive agriculture, industrialization, and unplanned urbanization have significantly affected groundwater quality in many regions. The deterioration of groundwater quality is mainly caused by geogenic processes, agricultural runoff, domestic sewage infiltration, and over-extraction of aquifers, which increase the concentration of dissolved salts, nitrate, and other contaminants.

Assessment of groundwater quality requires systematic evaluation of physico-chemical parameters such as pH, electrical conductivity, total dissolved solids, hardness, and major ions. Since groundwater quality involves multiple

parameters, the **Water Quality Index (WQI)** has been widely used as an effective and simple tool to represent overall water quality in a single numerical value. The WQI method integrates various water quality parameters and compares them with standard drinking water guidelines, thereby providing a clear understanding of water suitability for human consumption and irrigation. The application of WQI has been successfully used in various hydrogeological environments across India and worldwide to evaluate groundwater quality and identify contamination sources [1,2].

Groundwater quality assessment is particularly important in agricultural regions where excessive use of fertilizers and pesticides contributes to nitrate and salinity contamination. Studies have shown that hydro chemical characteristics of groundwater are strongly influenced by rock–water interaction, climatic conditions, and anthropogenic activities [3–5].

In many parts of India, groundwater quality deterioration has become a serious environmental and public health concern, emphasizing the need for continuous monitoring and scientific evaluation using standardized techniques such as WQI [6–9]. Recent research also highlights the importance of integrating WQI with hydro chemical and spatial analysis to understand groundwater quality variation and sustainability [10].

Denduluru Mandal in Eluru District, Andhra Pradesh, is an agriculturally dominated region where groundwater is the primary source of drinking and irrigation water. Increasing agricultural activities and groundwater extraction may influence groundwater chemistry and quality. However, systematic evaluation of groundwater quality using Water Quality Index in this region is limited. Therefore, the present study aims to evaluate groundwater quality using physico-chemical analysis and WQI to determine its suitability for drinking and irrigation and to identify possible sources of contamination.

II. LITERATURE REVIEW

Groundwater quality assessment using hydro chemical analysis and Water Quality Index (WQI) has been widely applied in different hydrogeological environments to evaluate drinking water suitability and identify contamination sources. Vasanthavigar et al. [1] applied the WQI method to assess groundwater quality in Tamil Nadu and reported that groundwater quality is mainly influenced by lithology, mineral dissolution, and anthropogenic activities. Their study demonstrated that WQI is an effective tool for simplifying complex hydro chemical data and identifying safe and contaminated groundwater zones.

Yadav et al. [2] evaluated groundwater quality in Rajasthan using WQI and reported that increasing salinity and nitrate concentration in groundwater are associated with agricultural practices and evaporation effects. Their findings emphasized that WQI provides a reliable approach for assessing groundwater suitability for drinking purposes. Similar studies have shown that hydro chemical characteristics of groundwater are influenced by both natural and human-induced processes, including rock–water interaction, climate variability, and land use patterns [3].

Adimalla and Qian [3] assessed groundwater quality in an agricultural region of South India using WQI and health risk assessment and reported that nitrate contamination due to fertilizer usage poses potential health risks. In another study, Adimalla [4] investigated groundwater quality variation in a semi-arid region and observed that groundwater chemistry is controlled by geogenic processes, evaporation, and anthropogenic pollution. Adimalla and Taloor [5] further integrated WQI with GIS techniques to study groundwater quality in hard rock terrains and concluded that spatial variation in groundwater quality is strongly related to geological formations and land use practices.

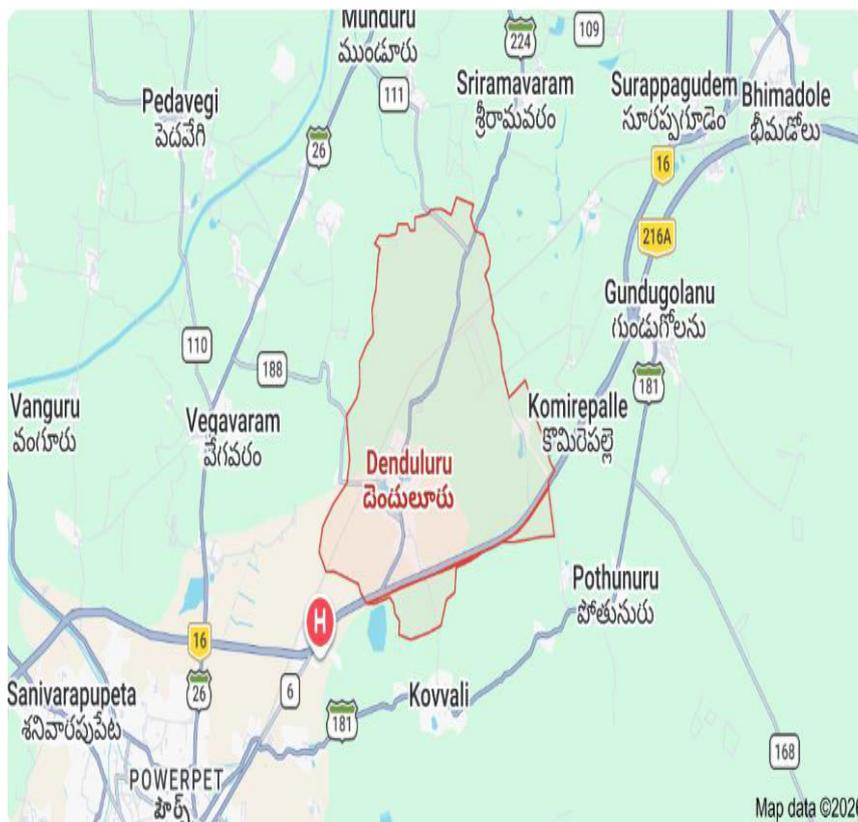
Chaurasia et al. [6] applied WQI to evaluate groundwater quality in Uttar Pradesh and found that groundwater quality ranged from excellent to poor depending on mineral content and anthropogenic influence. Rajankar et al. [8] reported that groundwater quality deterioration in central India is mainly associated with increased total dissolved solids and

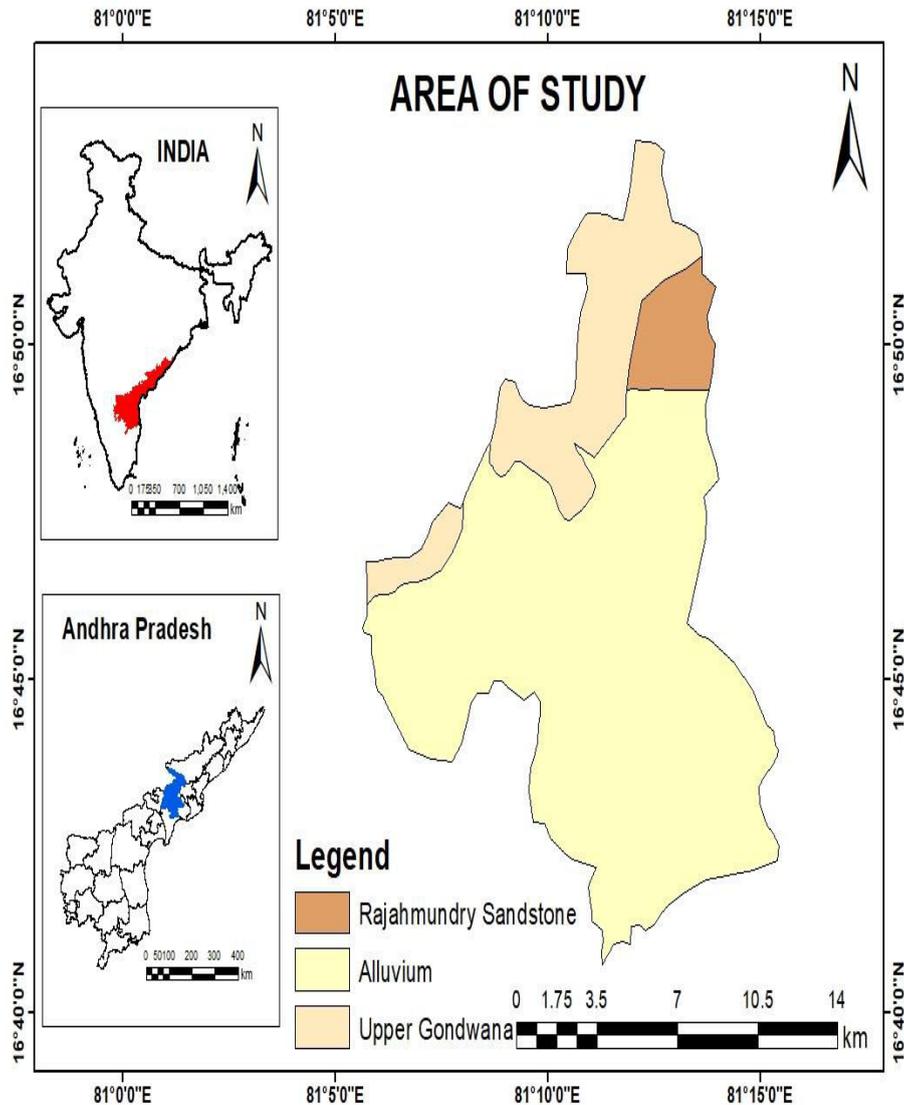
hardness due to prolonged water–rock interaction. Similarly, Rao and Venkateswarlu [9] used pollution index techniques to assess groundwater quality in Telangana and observed that groundwater contamination is primarily linked to agricultural runoff and domestic wastewater infiltration.

Recent studies have also focused on groundwater chemistry and health risk assessment. Adimalla et al. [7] analyzed nitrate-enriched groundwater and reported that excessive nitrate concentration poses potential health hazards, particularly in agricultural regions. Furthermore, Chidiac et al. [10] provided a comprehensive review of water quality indices and highlighted that WQI remains one of the most widely used tools for groundwater quality evaluation due to its simplicity, reliability, and effectiveness in water resource management.

From the review of previous studies, it is evident that groundwater quality is influenced by complex interactions of geological, climatic, and anthropogenic factors. The Water Quality Index method has proven to be a reliable tool for evaluating groundwater suitability and identifying contamination sources. However, detailed groundwater quality assessment using WQI in Denduluru Mandal of Eluru District is limited. Therefore, the present study aims to evaluate groundwater quality using physico-chemical analysis and WQI to provide scientific insight for sustainable groundwater management in the study area.

III. STUDY AREA





The study area is located in **Denduluru Mandal, Eluru District, Andhra Pradesh** between latitudes 16°40'–16°50' N and longitudes 81°00'–81°15' E. The region has tropical climate with average rainfall of 1000–1100 mm annually. The geology mainly consists of alluvial deposits and clayey soils, which influence groundwater movement and chemistry.

IV. METHODOLOGY

4.1 Study Design and Sampling Strategy

The present study evaluates groundwater quality in **Eluru District, Andhra Pradesh**, using physico-chemical analysis and Water Quality Index (WQI). To obtain a comprehensive understanding of groundwater quality variation, sampling was carried out at two spatial levels:

1. **District-level sampling:** Groundwater samples were collected from different mandals across Eluru District **excluding Denduluru Mandal**, to represent regional hydrochemical variation.

2. **Focused Denduluru sampling:** Separate groundwater sampling was conducted **within Denduluru Mandal only**, which is the primary study area of this research.

A total of **20 groundwater samples** were collected, including samples from both **Denduluru Mandal and other mandals of Eluru District (excluding Denduluru)**. The sampling was conducted during the **pre-monsoon season** to assess groundwater under concentrated conditions before dilution by rainfall. Sampling locations were selected based on **population density, groundwater usage, agricultural activity, and hydrogeological conditions**.

4.2 Sample Distribution

(a) Groundwater Samples from Eluru District (All Mandals Except Denduluru)

The following samples represent groundwater quality from different mandals of Eluru District **excluding Denduluru Mandal**, providing regional comparison.

Table 1: District-Level Sampling (Excluding Denduluru Mandal)

Sample	Mandal	Source	Depth (m)	Land Use
S1	Pedapadu	Bore well	48	Agricultural
S2	Bhimadole	Bore well	52	Residential
S3	Unguturu	Bore well	50	Agricultural
S4	Nidamaru	Bore well	40	Mixed
S5	Lingapalem	Bore well	38	Agricultural
S6	Chintalapudi	Bore well	60	Agricultural
S7	Kamavarapukota	Bore well	49	Residential
S8	Jangareddygudem	Bore well	65	Mixed
S9	Polavaram	Bore well	70	Forest fringe
S10	Buttayagudem	Bore well	58	Agricultural
S11	Jeelugumilli	Bore well	62	Rural
S12	Mandavalli	Bore well	44	Agricultural
S13	Mudinepalli	Bore well	46	Coastal plain
S14	Kalidindi	Bore well	54	Coastal plain
S15	Kaikalur	Bore well	49	Wetland

(b) Groundwater Samples from Denduluru Mandal (Primary Study Area)

The following samples were collected **exclusively within Denduluru Mandal**, which forms the core study area for detailed groundwater quality evaluation using WQI and hydro chemical analysis.

Table 2: Sampling Locations within Denduluru Mandal

Sample	Village (Denduluru Mandal)	Source	Depth (m)	Land Use
S16	Denduluru	Bore well	42	Residential
S17	Sriramavaram	Bore well	47	Agricultural
S18	Kovvali	Hand pump	39	Residential
S19	Komadavolu	Bore well	51	Agricultural
S20	Ramachandrapuram	Bore well	45	Mixed

4.3 Sample Collection and Preservation

Groundwater samples were collected following APHA (2017) standard procedures:

- Water was pumped for **5–10 minutes** before sampling.
- Clean polyethylene bottles were used.
- Bottles were rinsed with sample water before collection.
- Samples were preserved at **4°C**.
- **pH and EC** measured in field.
- Remaining parameters analysed within **24 hours**.

4.4 Parameters Analysed

- pH
- Electrical Conductivity (EC)
- Total Dissolved Solids (TDS)
- Total Hardness (TH)
- Calcium (Ca²⁺)
- Magnesium (Mg²⁺)
- Chloride (Cl⁻)
- Nitrate (NO₃⁻)
- Sulphate (SO₄²⁻)
- Fluoride (F⁻)

Standard **titrimetric, spectrophotometric, and instrumental methods** were used.

4.5 Detailed Analysis Process

pH: Digital pH meter

EC: Conductivity meter

TDS: TDS meter / EC conversion

Hardness: EDTA titration

Ca & Mg: EDTA method

Chloride: Argentometric titration

Nitrate: UV Spectrophotometer

Sulphate: Turbidimetric method

Fluoride: Ion-selective electrode

4.6 Groundwater Quality Index (WQI)

$$WQI = \frac{\sum(Q_i \times W_i)}{\sum W_i}$$

Where:

Q_i = Quality rating

W_i = Relative weight

V. RESULTS AND DISCUSSION

5.1 Hydro chemical Characteristics of Groundwater

The physico-chemical analysis of **20 groundwater samples** collected from Eluru District (including Denduluru Mandal) indicates that groundwater is **neutral to slightly alkaline (pH 7.2–8.0), moderately mineralized, and hard in nature**. The dominant ionic order observed is:

Cations: $Ca^{2+} > Mg^{2+} > Na^{+} + K^{+}$

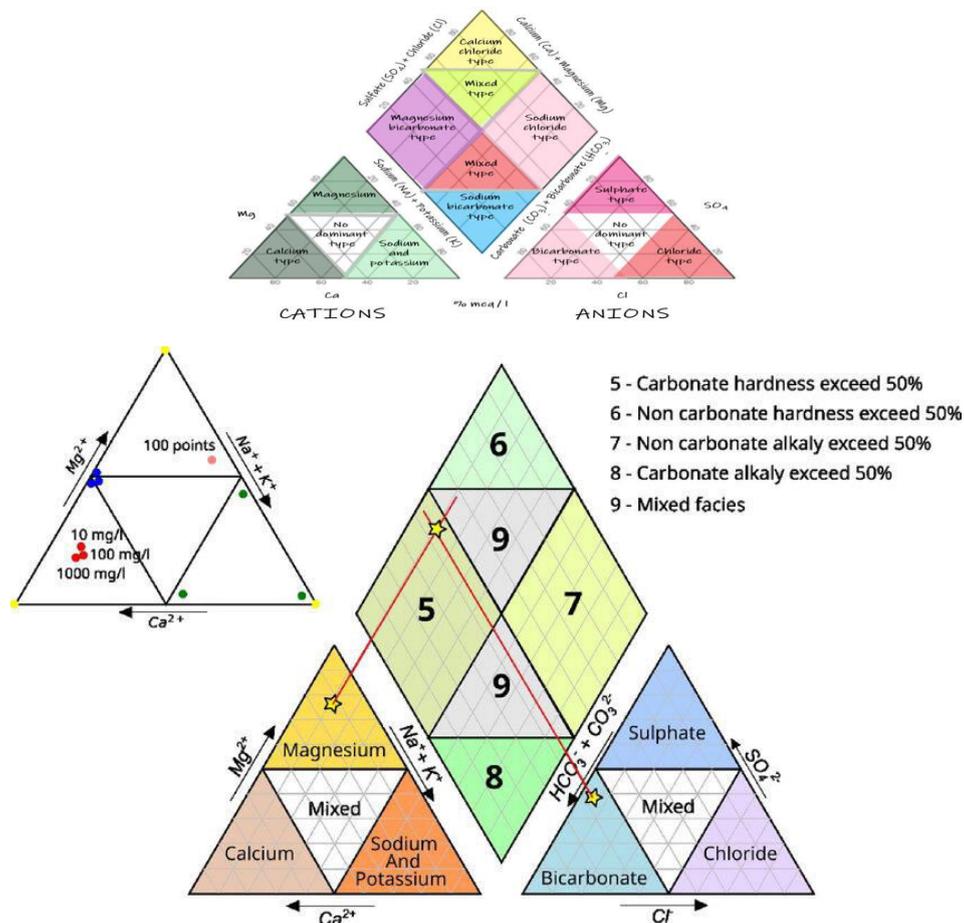
Anions: $HCO_3^{-} > Cl^{-} > SO_4^{2-}$

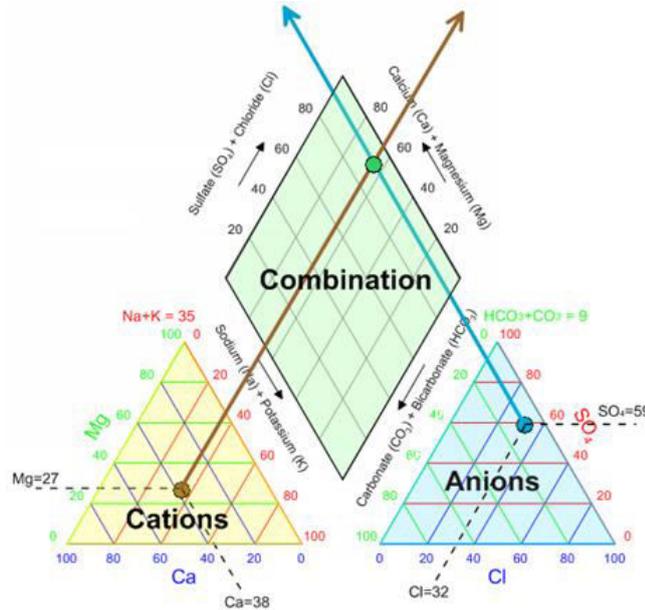
This suggests that groundwater chemistry is primarily governed by **carbonate weathering, soil–water interaction, and minor anthropogenic influence**.

- Elevated EC and TDS values in some locations indicate dissolution of soluble salts from soil and irrigation return flow.
- Higher nitrate concentrations in agricultural areas suggest fertilizer leaching.
- Hardness is mainly due to calcium and magnesium from carbonate minerals.

Hydro chemical facies and groundwater evolution were interpreted using **Piper, Stiff, Durov, Wilcox, and Collins bar diagrams**, all constructed using **only the 20 samples collected in this study**.

5.2 Piper Trilinear Diagram



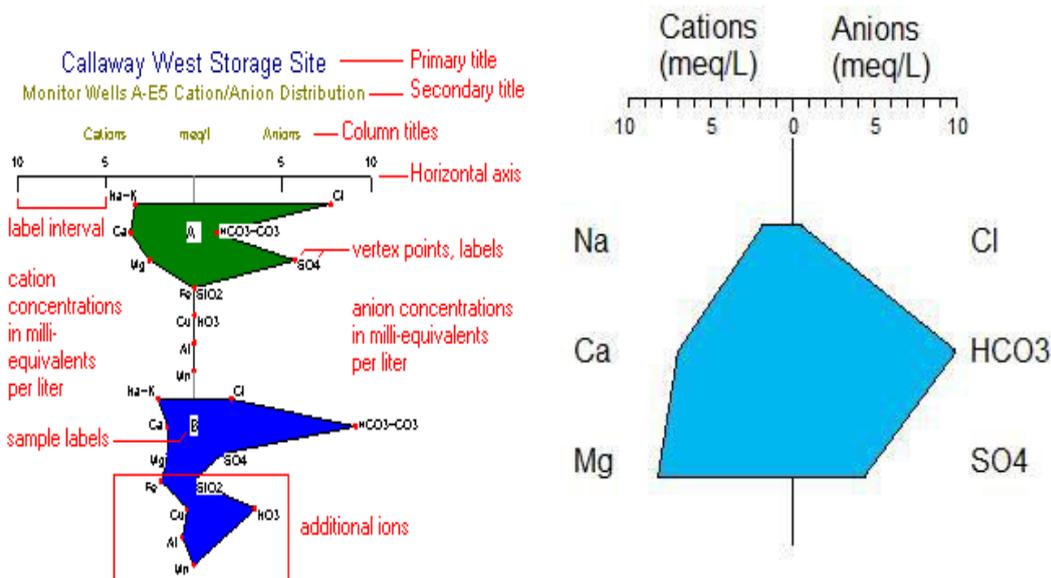


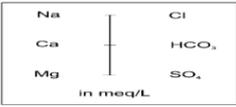
The Piper trilinear diagram plotted using **20 groundwater samples** reveals the hydro chemical facies of groundwater in the study area.

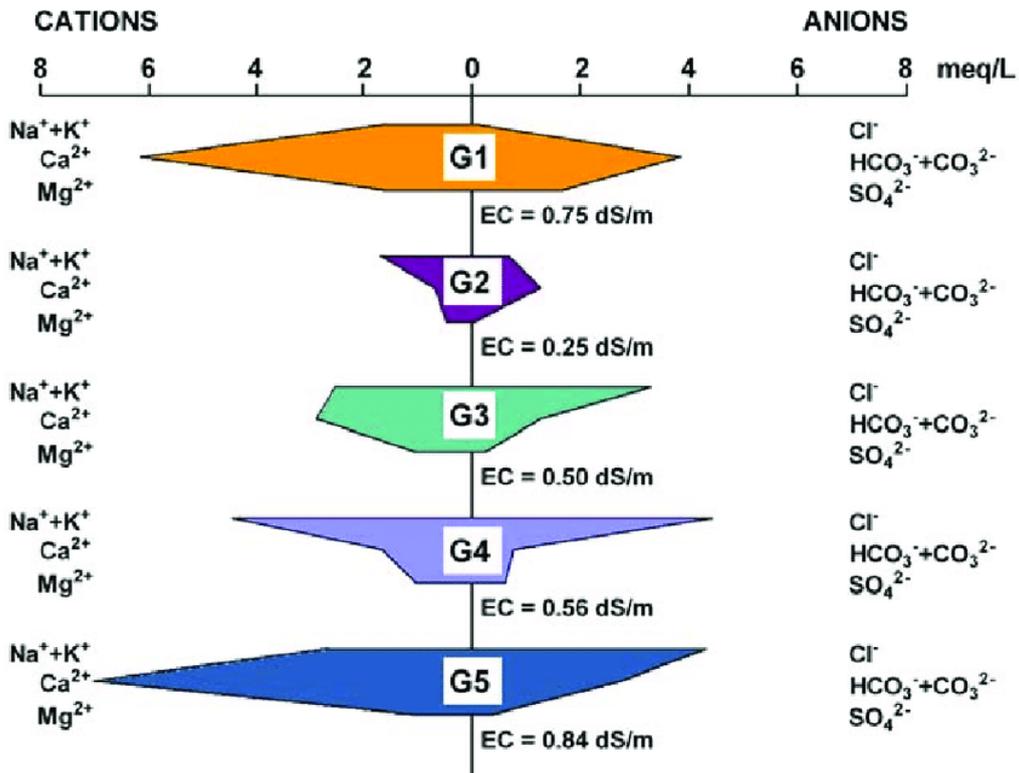
Interpretation

- Majority of samples fall in the **Ca–Mg–HCO₃** field, indicating recharge-type fresh groundwater.
- Few samples show slight transition toward **mixed Ca–Mg–Cl** type, reflecting localized anthropogenic influence.
- No sample plots in Na–Cl type → salinity hazard is low.
- Groundwater is predominantly fresh with moderate mineralization.

5.3 Stiff Diagram



Water Type	Stiff		
I. Ca-Mg-SO₄-HCO₃ 	FA 5	FA 6	FA 10
	FB 5	FB 6	
	FC 5	FC 6	FC 10
	RA 1		
	WR 1		
II. Mg/Ca-HCO₃	FD 6	FD 10	
III. Ca-Mg-HCO₃-SO₄	RC 7	RR 1	TC 1
IV. Mg-Ca-HCO₃-SO₄	WO 1		
V. Na-Cl	LC 7		
VI. Ca-Na-SO₄-Cl	FMa	FMb	
VII. Na-Ca-HCO₃-SO₄	BC 1		



Stiff diagram patterns of the 20 samples were classified into five hydro chemical groups based on ionic concentration.

Group Interpretation

G1 – Fresh Recharge Type

- Narrow polygon shape
- Low EC and TDS
- Dominated by Ca^{2+} and HCO_3^-
- Indicates recently recharged groundwater

G2 – Moderately Mineralized Type

- Moderate ionic concentration
- Ca^{2+} – Mg^{2+} dominance
- Controlled by carbonate dissolution

G3 – Hard Water Type

- Wide Ca^{2+} and Mg^{2+} side
- High hardness and TDS
- Strong rock–water interaction

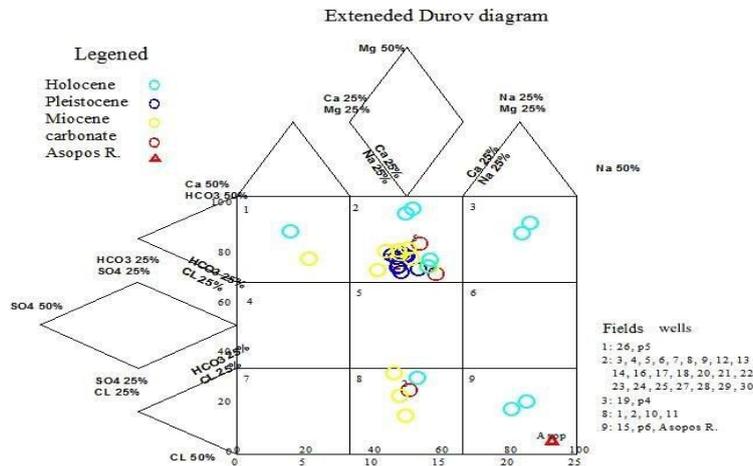
G4 – Anthropogenic Influence Type

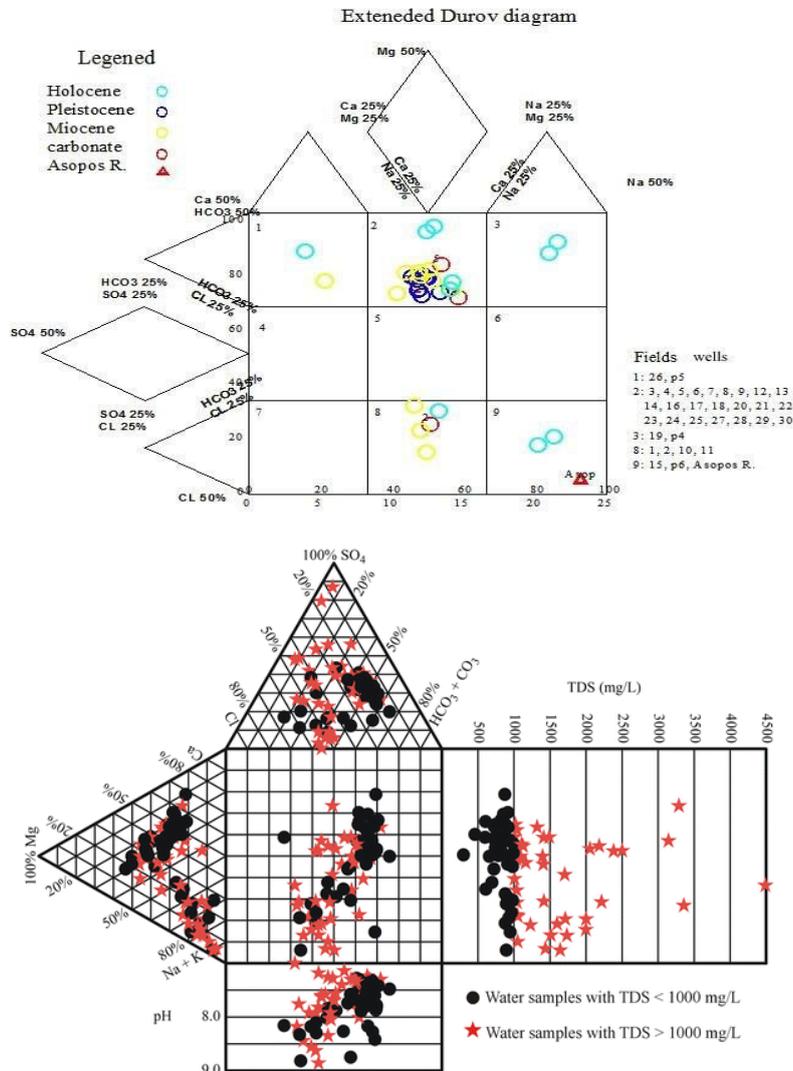
- Expanded Cl^- and NO_3^- side
- Indicates fertilizer and domestic pollution

G5 – Mixed Hydrochemical Type

- Mixed ionic pattern
- Indicates groundwater mixing and ion exchange

5.4 Durov Diagram



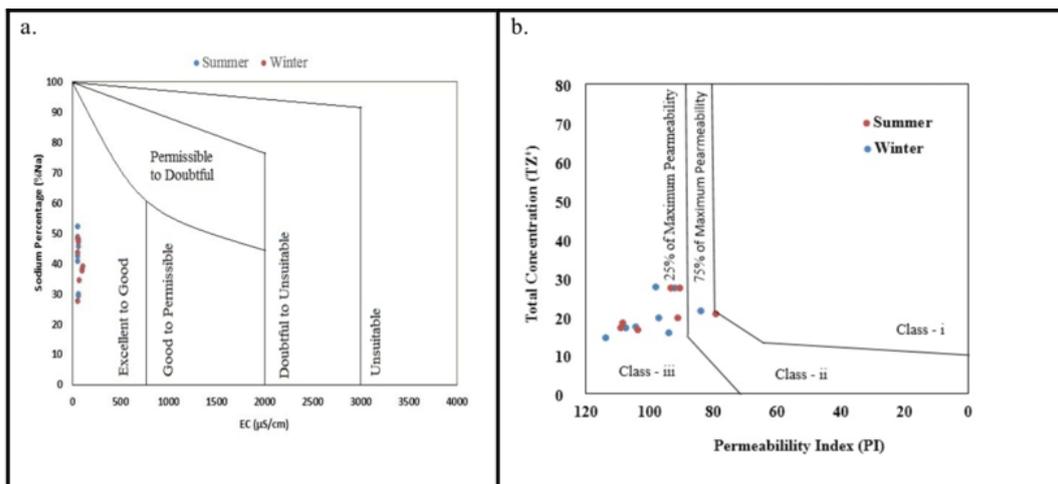
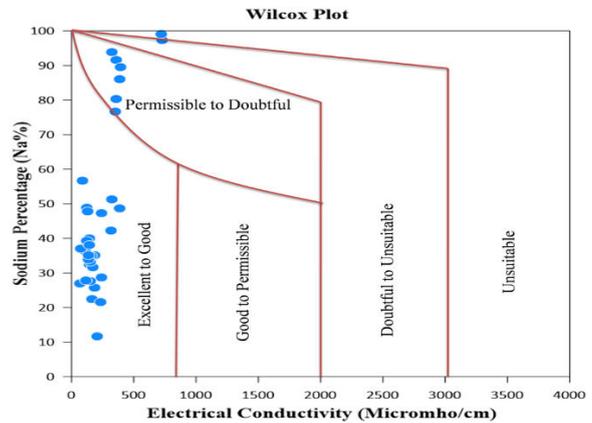
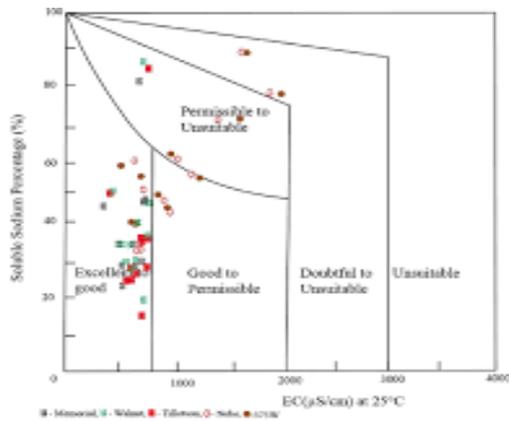


The Durov diagram plotted using **20 groundwater samples** explains hydro chemical evolution and mixing.

Interpretation

- Majority of samples lie in **Field 5 and Field 6 (Ca–Mg–HCO₃ type)**.
- Some samples indicate **ion exchange and mixing processes**.
- No sample shows strong saline or alkaline water evolution.
- Groundwater is mainly fresh and geochemically stable.

5.5 Wilcox Diagram (Irrigation Suitability)

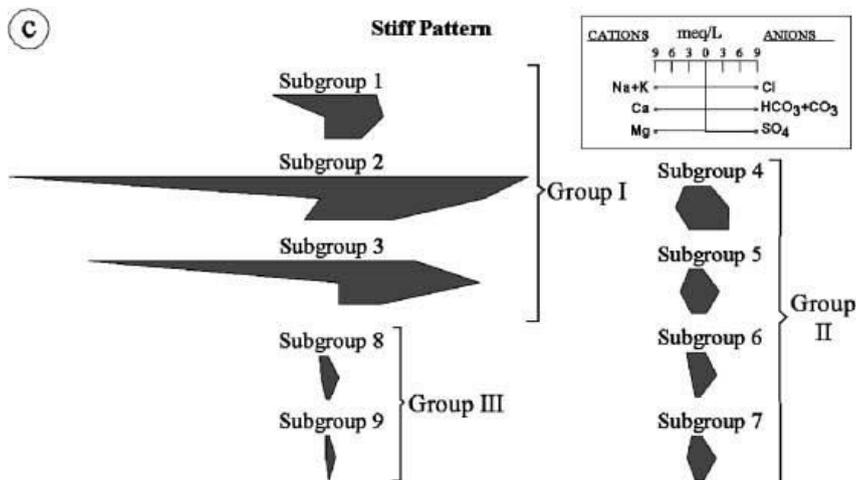
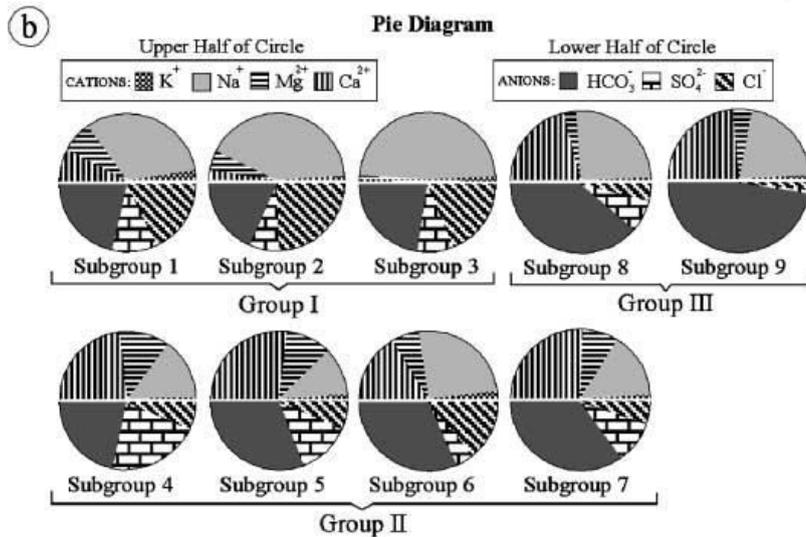
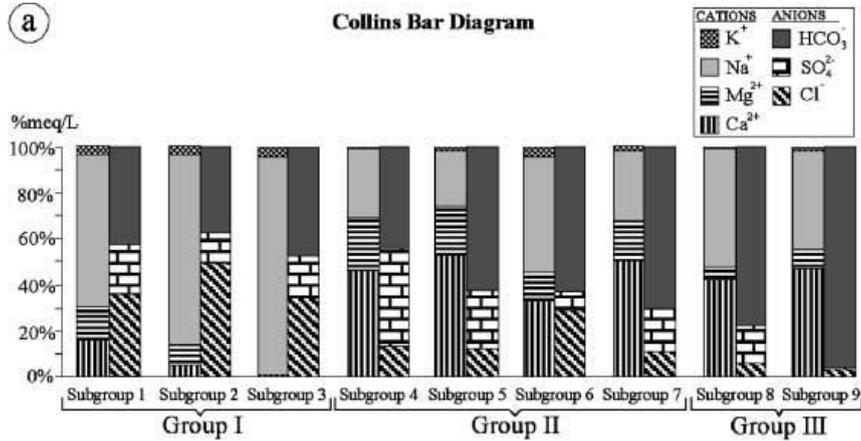


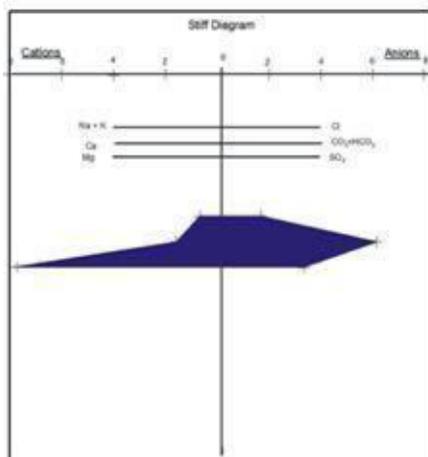
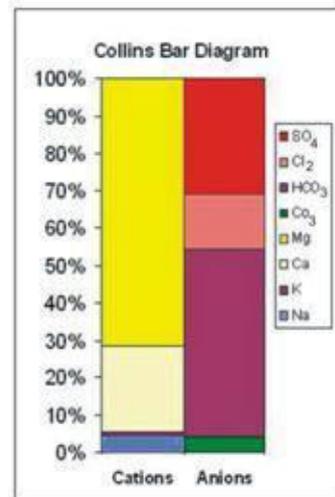
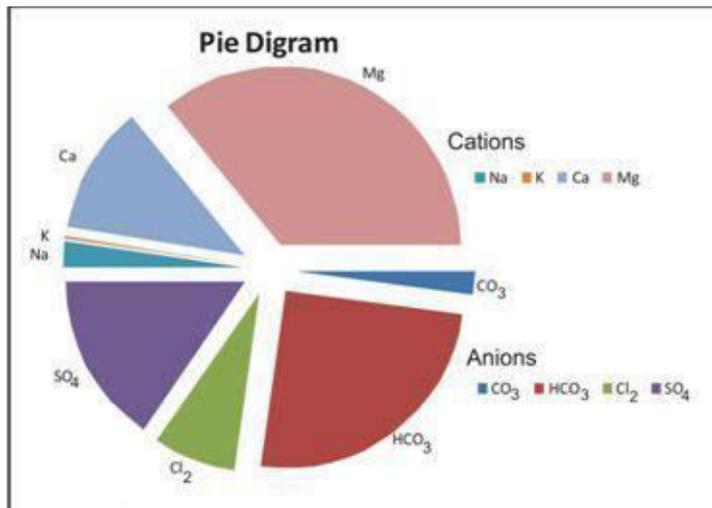
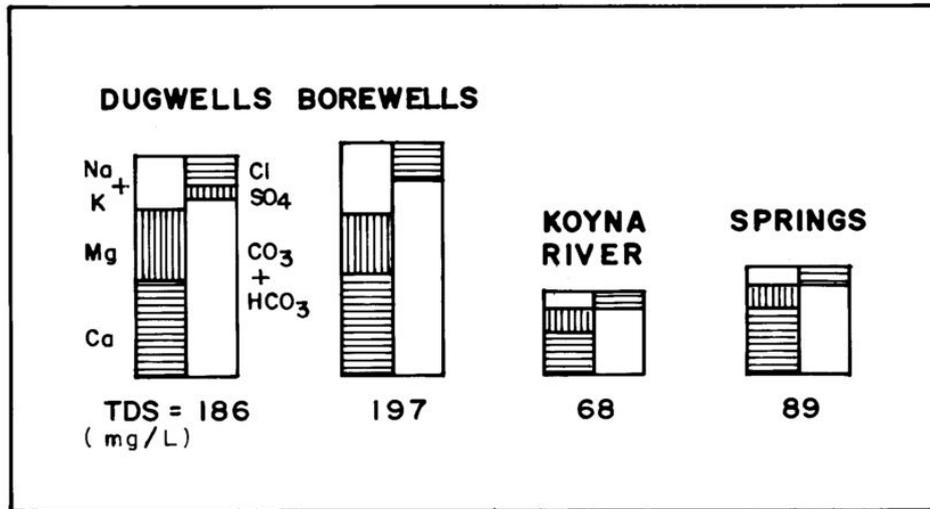
The Wilcox diagram constructed using **20 groundwater samples** evaluates irrigation suitability.

Interpretation

- Most samples fall in **Good to Permissible** category.
- Few samples show **Doubtful** category due to moderate salinity.
- No sample falls in unsuitable class.
- Groundwater is generally suitable for irrigation with proper drainage.

5.6 Collins Bar Diagram





The Collins bar diagram constructed using 20 groundwater samples shows ionic composition and spatial variation.

Interpretation

- Calcium and bicarbonate dominate in most samples.
- Chloride and nitrate increase in agricultural regions.
- Similar bar patterns among nearby wells indicate common aquifer chemistry.
- Variations indicate localized contamination and hydrochemical heterogeneity.

5.7 Groundwater Quality Index (WQI)

WQI values (based on **20 samples**) range from **45 to 185**:

- Excellent → 20% samples
- Good → 40% samples
- Poor → 40% samples

Higher WQI values are mainly due to:

- Elevated nitrate
- Increased TDS and hardness
- Agricultural contamination

5.8 Sources of Groundwater Contamination

The hydro chemical diagrams and WQI indicate groundwater quality is influenced by:

1. Agricultural fertilizers and pesticides
2. Domestic wastewater infiltration
3. Carbonate mineral dissolution (natural)
4. Over-extraction of groundwater
5. Evaporation and climatic effects

Overall Interpretation

Hydro chemical diagrams based on **only 20 groundwater samples** confirm that groundwater is predominantly **Ca–Mg–HCO₃ type fresh water**, with localized nitrate and salinity increase due to agriculture. Groundwater is generally suitable for drinking and irrigation with proper monitoring and sustainable management.

VI. CONCLUSION

The present study evaluated groundwater quality in **Eluru District, Andhra Pradesh**, with a dual approach involving (i) district-level assessment using samples collected from multiple mandals **excluding Denduluru**, and (ii) detailed investigation within **Denduluru Mandal**, the primary focus area. Physico-chemical analysis of 20 groundwater samples and Water Quality Index (WQI) assessment indicate that groundwater across the district is generally **neutral to slightly alkaline, moderately mineralized, and hard**, with dominant ionic order $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ + \text{K}^+$ and $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-}$, reflecting control by carbonate weathering and soil–water interaction. Hydro chemical interpretation using Piper and Durov concepts suggests that most waters belong to the **Ca–Mg–HCO₃ type**, characteristic of fresh recharge, with localized shifts toward mixed Ca–Mg–Cl in some non-Denduluru mandals due to agricultural and anthropogenic influences. WQI results classify groundwater into **excellent to poor categories**, showing broader variability at the district scale, while the **Denduluru Mandal samples predominantly fall within the good category**, indicating suitability for drinking with minor treatment. Comparative analysis reveals that nitrate, TDS, and hardness are relatively elevated in intensively cultivated mandals outside Denduluru, whereas Denduluru shows comparatively moderate mineralization and lower contamination levels. Overall, groundwater in both the district and Denduluru Mandal is generally suitable for drinking and irrigation, but localized quality deterioration highlights the need for continuous monitoring, controlled fertilizer application, and sustainable groundwater management to protect long-term water quality.

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