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Ph And Total Dissolved Solids In Drinking Water: Associations With Gastrointestinal Health In Rural South India

Daniel Finney Sankuru[1], Venkata Phanikumar Gopisetty[2], Sumedha Sahanasree Dasari[3], Medepalli Alexander[4], Phanindra Dulipala[5], Ravi Kiran K[6]
[1]Postgraduate, Dept. of Community Medicine, Katuri Medical College and Hospital, Guntur (drdanielysc@gmail.com)
[2]Assistant Professor, Dept. of Community Medicine, Katuri Medical College and Hospital, Guntur (phanikumar131192@gmail.com)
[3]Consultant Dentist, Andhra Prime Hospitals, Guntur (sahanasmily7@gmail.com)
[4]Medical officer, Apollo ur life health care, Hyderabad (alexandermedepalli@gmail.com)
[5]Professor and Head, Dept. of Community Medicine, Katuri Medical College and Hospital, Guntur (drpdulipala@gmail.com)
[6]Statistician, Dept. of Community Medicine, Katuri Medical College and Hospital, Guntur (ravikiranstatistician@gmail.com)

Abstract
Introduction: *Poor water quality, particularly abnormal pH and high Total Dissolved Solids (TDS), contributes significantly to gastrointestinal (GI) disorders in rural India, where 90% of households rely on untreated groundwater, and 21% of communicable diseases are water-related. This study examines these associations in Palnadu District, Andhra Pradesh, a region with documented groundwater contamination.*
Methods: *A cross-sectional study was conducted from November 1-30, 2024, among 504 adults from 150 rural households across three villages in Edlapadu Mandal, Palnadu District, selected via multi-stage random sampling. Water samples were tested for pH and TDS using calibrated digital meters. GI symptoms were assessed through structured interviews. Chi-square tests and ANOVA were used for statistical analysis ($p < 0.05$).*
Results: *Of 504 water samples, 89.7% had normal pH (6.5-8.5, mean 7.64 ± 0.49), and 10.3% had abnormal pH (8.5, mean 7.89 ± 1.36, range 5.8-9.3). GI symptoms were significantly higher with abnormal pH (84.6% vs. 69.9%, $p = 0.026$) and unsafe TDS levels (>900 ppm, 94.1% vs. 66.1%, $p < 0.0001$). Well water had the highest TDS (mean 729.65 ± 296.5 ppm). Reverse Osmosis (RO) water use for drinking significantly reduced GI symptoms (33.3% vs. 86.2%, $p < 0.00001$).*
Conclusions: *Abnormal pH and high TDS significantly increase GI symptom risk in rural Palnadu District, with well water posing the greatest risk. RO systems offer substantial protection, but comprehensive water quality interventions, including affordable treatment solutions, are essential for public health.*
Keywords: *water quality, pH, Total Dissolved Solids, gastrointestinal health, rural India, Palnadu District, groundwater, nitrate contamination*

INTRODUCTION

Access to safe and clean drinking water is a cornerstone of public health, particularly in rural areas where water quality poses significant challenges. Water quality is shaped by physical, chemical, and biological parameters, with pH and Total Dissolved Solids (TDS) being critical indicators of potability and potential health risks. Research suggests that abnormal pH levels and high TDS concentrations in drinking water are associated with gastrointestinal disorders, such as diarrhea, dyspepsia, and other waterborne illnesses, especially in vulnerable populations [1,2]. The lack of centralized water treatment facilities in rural areas amplifies the need to assess water quality and its health impacts to inform effective public health interventions.

Water Quality and Its Health Implications

pH measures the hydrogen ion concentration in water, determining its acidity or alkalinity. The United States Geological Survey (USGS) recommends a pH range of 6.5 to 8.5 for drinking water, as extreme values can corrode pipes, leading to heavy metal contamination and adverse health effects [3]. Alkaline water with high pH may reduce stomach acidity, impairing digestion and increasing susceptibility to gastrointestinal infections, while acidic water may irritate the digestive tract [4]. The Environmental

Protection Agency (EPA) classifies TDS as a secondary drinking water contaminant, recommending a limit of 500 mg/L, though higher levels are common in rural and underdeveloped regions [5]. High TDS, indicative of dissolved minerals, salts, and organic matter, can pose health risks, including gastrointestinal distress, kidney damage, and metabolic imbalances [6].

Water Quality in Rural India

Studies across India consistently highlight poor water quality in rural regions. A 2013 study in Jhunjhunu District, Rajasthan, found that high TDS levels were associated with a higher prevalence of gastrointestinal diseases, underscoring the need for regular water quality monitoring [7]. Similarly, a 2022 study identified significant correlations between poor water quality and gastrointestinal health issues in rural India, particularly among vulnerable age groups [8]. Recent research by Malan et al. further supports this, showing that inadequate water, sanitation, and hygiene practices in rural North Indian villages are associated with adverse health outcomes, including gastrointestinal diseases [9]. These findings align with global studies indicating that households reliant on untreated groundwater face elevated risks of gastrointestinal illnesses due to high mineral content and microbial contamination [10,11]. Given these nationwide concerns, region specific investigations are essential.

Relevance to the Study Area

Palnadu District, Andhra Pradesh, characterized by semi-arid conditions, depends heavily on groundwater sources, which often exhibit high TDS levels due to mineral leaching from geological formations. According to the Central Ground Water Board's Annual Ground Water Quality Report 2024, Palnadu District is among the districts with significant nitrate contamination in groundwater, with 51.43% of analyzed samples exceeding the permissible limit of 45 mg/L set by the Bureau of Indian Standards (BIS) [12]. This evidence highlights the urgent need to assess water quality and its impact on gastrointestinal health in this region, addressing a critical gap in local data.

Objectives

1. To estimate the pH and TDS levels of the water used for drinking and cooking by rural households
2. To assess the association of pH and TDS levels of water with the gastrointestinal health of rural households

MATERIALS & METHODS

Operational Definitions:

pH Levels:

pH was operationally defined according to United States Geological Survey (USGS) and World Health Organization (WHO) guidelines [3,4]:

Normal pH: 6.5-8.5 (USGS recommended range for drinking water)
Abnormal pH: <6.5 or >8.5 (outside USGS recommended range)

The USGS defines pH as a measure of hydrogen ion concentration determining water's acidity or alkalinity, with extreme values capable of corroding pipes and leading to heavy metal contamination [3]. WHO guidelines specify that pH values above 8.0 can hinder chlorination effectiveness, increasing microbial risks, while acidic water (pH <6.5) may leach toxic metals like lead or copper [4].

Total Dissolved Solids (TDS) Levels:

TDS was operationally categorized based on established water quality standards according to WHO [4],

Excellent: 50-300 ppm
Good: 300-600 ppm
Fair: 600-900 ppm
Poor: 900-1200 ppm
Very Poor: 1200-2000 ppm
Unacceptable: >2000 ppm

For analytical purposes, TDS levels were dichotomized as:

Safe TDS: 50-900 ppm (combining Excellent, Good, and Fair categories)
Unsafe TDS: >900 ppm (combining Poor, Very Poor, and Unacceptable categories)

The 900 ppm threshold was selected based on WHO guidelines indicating that TDS above 500-600 mg/L may pose health risks due to contaminants like heavy metals, nitrates, or salts, and Virginia Cooperative Extension research showing increased health risks above 900 ppm in rural groundwater-dependent communities. EPA classifies TDS as a secondary drinking water contaminant with a recommended limit of 500 mg/L, though higher levels are common in rural and underdeveloped regions [5].

Gastrointestinal (GI) Symptoms:
GI symptoms were operationally defined as the presence of any of the following symptoms experienced within the past 30 days: diarrhea (loose or watery stools), nausea, abdominal pain or cramping, indigestion, and heartburn. GI symptom burden was defined as reporting at least two of these symptoms within the past 30 days to capture significant health impacts. This 30-day recall period was chosen to standardize recall and reduce bias while capturing recent water-related health effects.

Study design:
This study employed a cross-sectional design to investigate the association between water quality parameters (pH and Total Dissolved Solids, TDS) and gastrointestinal (GI) health among adults in rural households of Edlapadu Mandal, Palnadu District, Andhra Pradesh, India.

Study setting and population:
The study was conducted in Edlapadu Mandal, selected due to its documented high TDS and nitrate levels in groundwater, as reported by the Central Ground Water Board (2024) [12]. The target population included adults aged over 30 years from households that had resided in the area for at least one year and used local water sources (e.g., panchayat water, bore pumps, wells) for drinking and/or cooking. A total of 504 adults from 150 households were studied.

Study period:
The study was conducted over a four-week period from November 1-30, 2024.

Sample size calculation:
The sample size was calculated using the standard formula for cross-sectional studies. The estimated prevalence of gastrointestinal diseases was set at twenty-five percent, based on findings by Magana-Arachchi and Wanigatunge, who reported high GI disease prevalence in rural areas with elevated TDS levels [11]. Consequently, the complement of this prevalence was seventy-five percent. A standard normal deviate of 1.96 was used, corresponding to a ninety-five percent confidence interval. The margin of error was set at seven percent to ensure precision in detecting associations between water quality parameters and gastrointestinal health outcomes.

Using these parameters, the calculation proceeded as follows: the square of the standard normal deviate (3.8416) was multiplied by the prevalence (0.25) and its complement (0.75), yielding 0.7203. This value was then divided by the square of the margin of error (0.0049), resulting in approximately 147 households. The calculated sample size of 147 households was rounded up to 150 rural households to ensure adequate statistical power for detecting meaningful associations between water quality and gastrointestinal health outcomes in the study population.

Sampling technique:
A multi-stage random sampling method was used to select 150 rural households in Edlapadu Mandal:

Stage 1: Mandal Selection
Edlapadu was selected from Palnadu District's 28 mandals due to its high TDS and nitrate levels, as reported by the Central Ground Water Board (2024) [12], making it suitable for studying water quality impacts on GI health.

Stage 2: Village Selection
Edlapadu has 13 villages. Three villages-Solasa, Thimmapuram, and Unnava-were randomly selected using a lottery method from a list obtained from local administrative records, ensuring unbiased selection.

Stage 3: Household Selection
The 150 households were equally allocated across the three villages, with 50 households per village. Eligible households, identified from local records, had resided in the area for at least one year and used local water sources for drinking and/or cooking. Systematic random sampling was used, with the sampling interval (k) calculated by dividing the number of eligible households in each village by 50. Assuming approximately 267 eligible households per village (based on ~4,000 households in Edlapadu across 13 villages, adjusted for ~80% eligibility), ($k = 267 \div 50 = 5.34$), rounded to 5. Every 5th household was selected after a random starting point chosen using a random number generator, until 50 households were reached per village. Exact household counts for Solasa, Thimmapuram, and Unnava were used when available during data collection; otherwise, this estimate was verified in the field.

Stage 4: Individual Selection
From the 150 selected households, all adults aged over 30 years were included, totaling 504 individuals.

Inclusion criteria:

Households: Resided in Edlapadu Mandal, Palnadu District, Andhra Pradesh, for at least one year and used local water sources (e.g., panchayat water, bore pumps, wells) for drinking and/or cooking to ensure long-term exposure to local water quality.

Individuals: Adults aged >30 years from selected households, as this group may have increased susceptibility to chronic gastrointestinal issues due to prolonged environmental exposure, consistent with studies on water-related health risks in older adults [8].

Exclusion criteria:

Households where individuals were undergoing treatment for gastrointestinal diseases, to avoid confounding from pre-existing medical conditions.

Households using bottled or Reverse Osmosis (RO) water for cooking, to focus on the impact of untreated local water sources. (Note: Households using RO water for drinking were included in specific analyses to assess its protective effect, as shown in Table 6.)

Individuals who consumed spicy or high-fat/protein meals within 48 hours of the interview, to minimize dietary confounding of gastrointestinal symptoms.

Data collection:

Data were collected using a semi-structured, pre-tested questionnaire administered through face-to-face interviews with the 504 selected adults. The questionnaire captured sociodemographic details, household water source usage, and individual GI symptoms (e.g., diarrhea, vomiting, abdominal pain, nausea) over the past 30 days to standardize recall and reduce bias. Water samples from household drinking and cooking sources were collected in sterile containers, stored at 4°C, and transported to the laboratory within 24 hours. pH and TDS levels were measured using calibrated Ocean Star Digital pH and TDS meters, with daily calibration to ensure accuracy.

Ethical considerations:

Ethical clearance was obtained from the Institutional Ethics Committee, Katuri Medical College & Hospital, Guntur (Approval No. IEC/KMCH/2024/G-7, dated 28-10-2024) prior to conducting the study. Informed consent was obtained from all participants before data collection, and all ethical guidelines were strictly followed throughout the study.

Data analysis:

Data were entered into Microsoft Excel and analyzed using IBM SPSS v.20. Descriptive statistics (percentages, frequencies, means, standard deviations) summarized water quality parameters and GI symptom prevalence. Inferential statistics included chi-square tests for categorical associations (e.g., pH/TDS levels and GI symptoms, water source and GI symptoms) and ANOVA for comparing mean TDS levels across water sources. A p-value < 0.05 was considered statistically significant.

RESULTS

The study included 504 adults aged over 30 years from 150 randomly selected rural households across three villages (Solasa, Thimmapuram, Unnava) in Edlapadu Mandal, Palnadu District, Andhra Pradesh, India. Demographic, socioeconomic, and water usage characteristics are presented in Table 1. Of the 504 participants, 280 (55.6%) were male, and 224 (44.4%) were female. The age distribution included 110 (21.8%) aged 30-39 years, 130 (25.8%) aged 40-49 years, 140 (27.8%) aged 50-59 years, and 124 (24.6%) aged 60 years and above, with a mean age of 52.6 ± 11.3 years. Socioeconomic status, assessed using the Modified BG Prasad Scale (2024), showed 30 (6.0%) in Class I (upper), 70 (13.9%) in Class II (upper middle), 120 (23.8%) in Class III (middle), 180 (35.7%) in Class IV (lower middle), and 104 (20.6%) in Class V (lower). The primary water source was panchayat water for 232 (46.0%) participants, followed by bore pump for 176 (34.9%) and well for 96 (19.0%). RO water was used for drinking by 156 (31.0%) participants, while 348 (69.0%) used non-RO water.

Table 1: Demographic and Water Usage Characteristics of Study Participants,

Characteristic	Category	N (%)
Age (years)	30–39	110 (21.8%)
	40–49	130 (25.8%)
	50–59	140 (27.8%)
	60 and above	124 (24.6%)
Gender	Male	280 (55.6%)
	Female	224 (44.4%)
Socioeconomic Status	Class I (Upper)	30 (6.0%)
	Class II (Upper Middle)	70 (13.9%)
	Class III (Middle)	120 (23.8%)
	Class IV (Lower Middle)	180 (35.7%)
	Class V (Lower)	104 (20.6%)
Primary Water Source	Panchayat water	232 (46.0%)
	Bore pump	176 (34.9%)
	Well	96 (19.0%)
Use of RO Water for Drinking	Yes	156 (31.0%)
	No	348 (69.0%)

Distribution of Water pH

Water pH was measured in 504 household water samples (Table 2). Of these, 452 (89.7%) samples had normal pH (6.5-8.5), with a mean pH of 7.64 ± 0.49, while 52 (10.3%) had abnormal pH (<6.5 or >8.5), with a mean pH of 7.89 ± 1.36.

Table 2: Distribution of Normal and Abnormal pH of Water

pH of Water	Mean ± SD	N(%)
Normal (6.5–8.5)	7.64 ± 0.49	452(89.7%)
Abnormal (<6.5 or >8.5)	7.89 ± 1.36	52(10.3%)

Distribution of Water TDS Levels

TDS levels were categorized based on standard thresholds (Table 3). Of the 504 samples, 156 (30.9%) were good (300-600 ppm, mean 495.4 ± 81.1 ppm), 140 (27.8%) were excellent (50-300 ppm, mean 106.4 ± 63.9 ppm), 140 (27.8%) were fair (600-900 ppm, mean 784.5 ± 85.4 ppm), 40 (7.9%) were poor (900-1200 ppm, mean 1091.4 ± 116.8 ppm), and 28 (5.6%) were very poor (1200-2000 ppm, mean 1279.1 ± 29.8 ppm). No samples exceeded 2000 ppm (unacceptable).

Table 3: Distribution of Water Based on TDS Levels

TDS of Water (ppm)	Mean ± SD	N(%)
Excellent (50–300)	106.4 ± 63.9	140(27.8%)
Good (300–600)	495.4 ± 81.1	156(30.9%)
Fair (600–900)	784.5 ± 85.4	140(27.8%)
Poor (900–1200)	1091.4 ± 116.8	40(7.9%)
Very Poor (1200–2000)	1279.1 ± 29.8	28(5.6%)
Unacceptable (>2000)	-	0

Overall Gastrointestinal Symptom Prevalence

Among the 504 study participants, 352 (70.0%) reported experiencing at least two gastrointestinal symptoms within the past 30 days, while 152 (30.0%) reported fewer than two symptoms or remained asymptomatic (Figure 1). The most prevalent individual GI symptoms were indigestion (296, 58.7%), followed by heartburn (248, 49.2%), nausea (120, 23.8%), and diarrhea (108, 21.4%). Abdominal pain or cramping was the least frequently reported symptom (48, 9.5%) (Figure 2). This high prevalence of multiple GI symptoms underscores the significant burden of water-related gastrointestinal health issues in the rural population of Edlapadu Mandal.

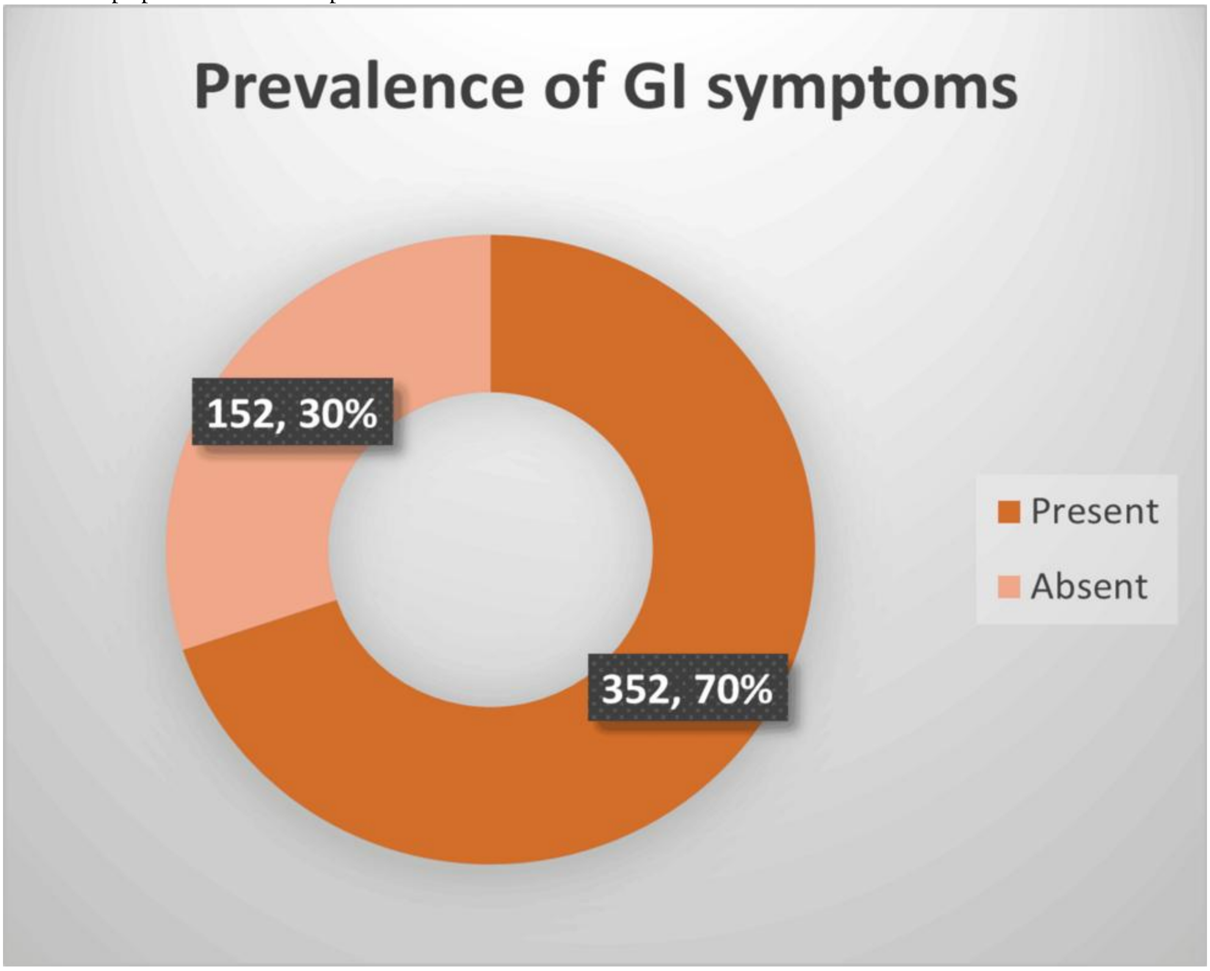

Figure 1: Presence of Gastrointestinal Symptoms (At Least Two Symptoms)

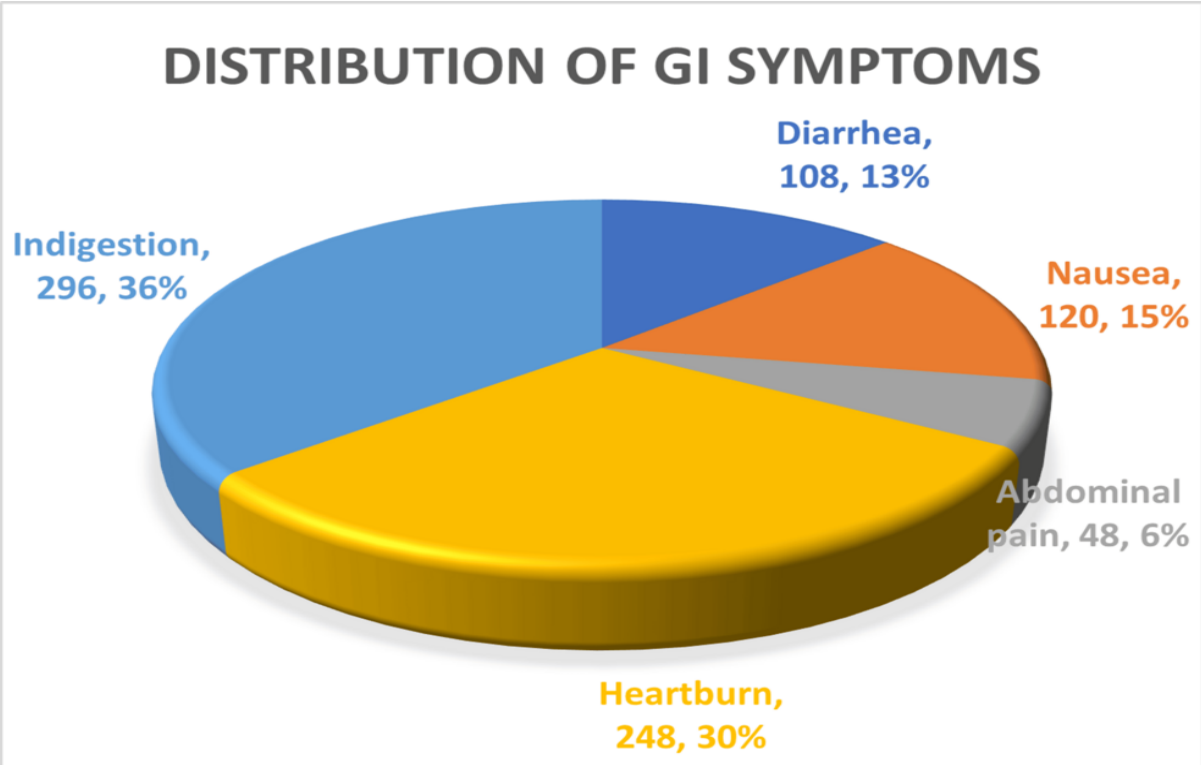

Figure 2: Distribution of Specific Gastrointestinal Symptoms

Association Between pH Levels and GI Symptoms

The association between water pH and gastrointestinal (GI) symptoms was assessed (Table 4). Of the 452 participants using water with normal pH (6.5-8.5), 316 (69.9%) reported GI symptoms, compared to 44 (84.6%) of the 52 using water with abnormal pH (<6.5 or >8.5). The association was significant ($\chi^2 = 4.94$, $p = 0.026$, $p < 0.05$ considered significant).

Table 4: pH Levels of Drinking Water and Gastrointestinal Health

pH of Water	**Mean ± SD**	**N(%)**	**GI Symptoms (Present)**	**GI Symptoms (Absent)**	**Chi-square Value**	**p-value**
Normal (6.5–8.5)	7.64 ± 0.49	452 (89.7%)	316 (69.9%)	136 (30.1%)	4.94	0.026
Abnormal (<6.5 or >8.5)	7.89 ± 1.36	52 (10.3%)	44 (84.6%)	8 (15.4%)		

Association Between TDS Levels and GI Symptoms

TDS levels were dichotomized as safe (50-900 ppm, n=436, 86.5%) and unsafe (>900 ppm, n=68, 13.5%) for drinking (Table 5). Of the 436 participants using safe TDS water, 288 (66.1%) reported GI symptoms, compared to 64 (94.1%) of the 68 using unsafe TDS water. The association was highly significant ($\chi^2 = 21.99$, $p < 0.0001$, $p < 0.001$ considered significant).

Table 5: Safe and Unsafe TDS Levels of Drinking Water and Gastrointestinal Health

TDS vs GI Symptoms	**Present N(%)**	**Absent N(%)**	**Total**	**Chi-square Value**	**p-value**
Safe (50–900 ppm)	288 (66.1%)	148 (33.9%)	436	21.99	<0.0001
Unsafe (>900 ppm)	64 (94.1%)	4 (5.9%)	68		
Total	352	152	504		

Sources of Cooking Water

Cooking water sources were analyzed (Table 6). Panchayat water was used by 232 (46.0%) participants, bore pump by 176 (34.9%), and well by 96 (19.0%). Mean TDS levels varied significantly across sources (panchayat water: 364.87 ± 347.23 ppm; bore pump: 545.7 ± 332.7 ppm; well: 729.65 ± 296.5 ppm; ANOVA $F = 43.55$, $p < 0.0001$, $p < 0.001$ considered significant).

Table 6: Sources of Cooking Water

Cooking Water	**Mean ± SD**	**N(%)**	**ANOVA Value**	**p-value**
Panchayat Water	364.87 ± 347.23	232(46.0%)	43.55	<0.0001
Bore Pump (Motor & Manual)	545.7 ± 332.7	176(34.9%)		
Wells	729.65 ± 296.5	96(19.0%)		

GI Symptoms and Water Usage

The impact of water usage patterns on GI symptoms was assessed (Table 7). Of the 156 (31.0%) participants using RO water for drinking but other sources for cooking, 52 (33.3%) reported GI symptoms, compared to 300 (86.2%) of the 348 (69.0%) using non-RO water for both drinking and cooking. The association was highly significant ($\chi^2 = 143$, $p < 0.00001$, $p < 0.001$ considered significant).

Table 7: Occurrence of GI Symptoms Due to Varied Water Usage

RO Water Usage	GI Symptoms-Present N(%)	GI Symptoms - Absent N(%)	Total	Chi-square Value	p-value
Drinking (RO) + Cooking (Other)	52 (33.3%)	104 (66.7%)	156(31.0%)	143	<0.00001
Drinking (Other) + Cooking (Other)	300 (86.2%)	48 (13.8%)	348(69.0%)		
Total	352(69.8%)	152(30.2%)	504(100%)		

DISCUSSION

This cross-sectional study in Edlapadu Mandal, Palnadu District, conducted in November 2024, highlights significant associations between drinking water quality (pH and TDS) and gastrointestinal (GI) symptoms among 504 adults from 150 rural households. The findings underscore the public health implications of water quality in resource-constrained settings.

Water pH and GI Health

Water samples with abnormal pH (<6.5 or >8.5, range 5.8-9.3) were associated with a higher GI symptom prevalence (84.6% vs. 69.9%, p = 0.026). This may reflect metal leaching from pipes at extreme pH levels or reduced chlorination efficacy, increasing microbial risks [3,4]. Unlike Juneja and Chaudhary's findings in Jhunjhunu, Rajasthan, where no pH-health link was observed (p > 0.05) due to a narrower pH range (7.0-8.5) [7], Edlapadu's broader range suggests local factors like pipe corrosion may contribute. Further research should explore specific mechanisms, such as heavy metal or microbial contamination.

TDS Levels and GI Health

High TDS (>900 ppm) was strongly associated with GI symptoms (94.1% vs. 66.1%, p < 0.0001), consistent with WHO guidelines noting health risks above 500-600 mg/L due to contaminants like nitrates or salts [4]. The 900 ppm threshold was chosen based on prior studies in rural India showing health risks above this level, reflecting local groundwater conditions [6, 11]. Compared to Magana-Arachchi and Wanigatunge's 90% prevalence with TDS >1000 ppm [11] and Malan et al.'s 85% with mean TDS 600-800 ppm [9], Edlapadu's higher prevalence suggests greater contamination, possibly nitrates, as 51.43% of local groundwater exceeds BIS limits (45 mg/L) [12]. Specific TDS components should be analyzed in future studies.

Overall Gastrointestinal Symptom Burden and Comparative Analysis

This study found a high gastrointestinal (GI) symptom burden, with 70% of participants (n=352/504) reporting at least two symptoms (e.g., diarrhea, nausea, abdominal pain, heartburn, indigestion) and 30% reporting none (Figure 1). Specific symptom prevalence was indigestion (58.7%), heartburn (49.2%), nausea (23.8%), diarrhea (21.4%), and abdominal pain (9.5%) (Figure 2). This exceeds Vasudevan and Raj's 11.8% GI prevalence over three months in rural South India [8] and Malan et al.'s 57.2% waterborne disease prevalence over a year in North India [9], likely due to our 30-day focus. Chronic symptoms (indigestion, heartburn) suggest prolonged exposure to poor water quality, while lower diarrhea (21.4%) compared to Stauber et al.'s 33% in rural Alabama [10] may reflect seasonal or adaptive factors. Our 94.1% GI prevalence at TDS >900 ppm aligns with Magana-Arachchi and Wanigatunge's 90% in high-contamination areas [11], driven by nitrates, as 51.43% of Palnadu groundwater exceeds limits (45 mg/L) [12], urging water quality interventions.

Sources of Cooking Water

Well water had the highest mean TDS (729.65 ± 296.5 ppm), contributing to elevated GI risks, likely due to geological or agricultural contamination [12]. Malan et al. reported similar well water risks in North India (mean TDS 600-800 ppm, 85% GI prevalence) [9]. Interventions targeting well water quality are critical.

Water Usage Patterns

RO water use for drinking significantly reduced GI symptoms (33.3% vs. 86.2%, p < 0.00001), aligning with Vasudevan and Raj's 78% GI prevalence with untreated water [8] and Malan et al.'s 30-40% reduction with treated water [9]. However, high costs and maintenance limit RO adoption in rural areas, necessitating subsidized solutions or improved water infrastructure to ensure safe drinking and cooking water.

Comparison with Previous Studies

Edlapadu's findings highlight a stronger pH-GI association than Juneja and Chaudhary [7] and higher TDS-related GI prevalence than Magana-Arachchi and Wanigatunge [11] and Malan et al. [9], likely due to local contaminant profiles. RO water's protective effect aligns with prior studies [8,9], emphasizing treatment's role in rural health.

Limitations

The study's cross-sectional design limits causality inference for water quality (pH, TDS) and GI symptoms (Tables 3, 4, 6). Self-reported GI symptoms (Figures 1-2) may have recall bias. The sample, limited to three villages in Edlapadu Mandal, may not generalize to other regions.

CONCLUSIONS

Water quality plays a critical role in preventing gastrointestinal health issues in rural communities. Significant associations between abnormal pH levels, high Total Dissolved Solids (TDS), and gastrointestinal symptoms-as well as the influence of cooking water sources and usage patterns-highlight the urgent need for regular water quality monitoring and comprehensive treatment strategies. Public health policies should prioritize improving water infrastructure and promoting affordable water purification technologies, such as Reverse Osmosis systems, to ensure safe drinking and cooking water in areas like Edlapadu Mandal, ultimately enhancing community health outcomes.

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