Comparative Evaluation of Microbial Contamination in Municipal and Groundwater Sources of Meerut

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Abstract- This study evaluates microbial water quality from 48 samples collected across Meerut city from municipal taps, hand pumps, and tube wells. Microbial indicators including total coliforms, fecal coliforms, and *Escherichia coli* were analyzed using membrane filtration. Hand pumps exhibited the highest contamination (mean TC = 76 ± 12 CFU/100 mL) compared to municipal taps (8 ± 3 CFU/100 mL). ANOVA results indicated significant differences among sources ($p < 0.001$). Tukey HSD confirmed that hand pumps were significantly more contaminated than other sources. Recommendations include improved chlorination, sealing of boreholes, and public awareness.

Keywords- Microbial water quality; Total coliforms; Meerut; ANOVA; Tukey HSD; GIS mapping

1. INTRODUCTION

Access to safe drinking water is fundamental to public health and sustainable development. According to the World Health Organization (WHO), contaminated drinking water is a major transmission route for diarrheal diseases, cholera, dysentery, typhoid, and polio, leading to an estimated 485,000 deaths annually worldwide (WHO, 2022). Microbial contamination of drinking water remains a major concern in developing countries, including India, where rapid urbanization, population growth, and inadequate sanitation infrastructure exacerbate water quality issues (Kumar et al., 2021).

India's Bureau of Indian Standards (BIS, IS 10500:2012) prescribes that drinking water should be free from total coliforms and fecal coliforms per 100 mL. However, several studies have reported persistent microbial contamination in piped and groundwater sources, particularly in urban and peri-urban areas due to leakage in distribution networks, cross-contamination from sewage lines, and poor maintenance of hand pumps and tube wells (Singh et al., 2020; Sharma et al., 2019).

Meerut, a rapidly growing city in Uttar Pradesh, India, relies on a mix of municipal tap water, hand pumps, and tube wells to meet its drinking water demand. Municipal water supply systems often undergo chlorination, but frequent pipeline breakages and intermittent supply increase the risk of ingress from contaminated sources. In contrast, groundwater sources such as hand pumps and tube wells, though perceived as safe by users, often lack adequate disinfection, making them vulnerable to fecal contamination, especially during the pre-monsoon and post-monsoon seasons (Gupta et al., 2022).

Microbial indicators such as total coliforms (TC), fecal coliforms (FC), and *Escherichia coli* are widely recognized for assessing the microbiological quality of water. These indicators do not necessarily cause disease but signify the possible presence of enteric pathogens (WHO, 2022). Elevated coliform counts suggest contamination from human or animal waste, posing serious health risks, particularly for children and immunocompromised individuals (Leclerc et al., 2001).

While previous research has focused on microbial contamination in specific Indian cities, there is a lack of comprehensive studies covering different water sources in Meerut using microbial indicator organisms. Such evaluations are critical for identifying contamination hotspots, understanding source-specific risks, and guiding remedial measures.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted in Meerut city, located in the state of Uttar Pradesh, India (29.0°N latitude and 77.7°E longitude), which is part of the Indo-Gangetic plain. Meerut is an industrial and educational hub with a population exceeding 1.5 million. Water is supplied through a municipal distribution system and supplemented by numerous private hand pumps and tube wells, especially in peri-urban and rural zones. Five representative zones were selected for sampling:

- Zone 1: Cantonment Area
- Zone 2: Central Meerut (Commercial hub)
- Zone 3: Shastri Nagar (Residential)
- Zone 4: Industrial Area (Partapur)
- Zone 5: Rural Outskirts

2.2 Sampling

Table 1: Sampling Design and Collection Protocol

Parameter	Description
Total Samples	48
Water Sources	Municipal taps (n = 16), Hand pumps (n = 16), Tube wells (n = 16)
Sampling Period	March–May 2025 (Pre-monsoon season)
Sampling Frequency	Single grab sample from each point
Sample Volume	500 mL
Container	Sterile borosilicate glass bottles
Preservative	0.1 mL of 10% sodium thiosulfate added to neutralize residual chlorine
Transport Conditions	Samples transported in insulated ice box at 4°C
Analysis Time	Within 6 hours of collection
Reference Standard	APHA Standard Methods for Examination of Water and Wastewater (2017)

2.3 Microbial Analysis

The microbiological quality of water samples was evaluated using standard indicator organisms, namely Total Coliforms (TC), Fecal Coliforms (FC), and *Escherichia coli*, as recommended by APHA (2017), BIS (IS 10500:2012), and WHO (2022) guidelines for drinking water. These indicators were selected because they provide reliable evidence of fecal contamination and the potential presence of enteric pathogens.

Water samples were analyzed using the membrane filtration technique, which is widely regarded as the gold standard for microbial enumeration in potable water. A 100 mL aliquot of each water sample was filtered through a sterile 0.45 µm pore size cellulose nitrate membrane filter (47 mm diameter) under aseptic conditions. The filters were then aseptically placed on selective and differential culture media to allow for the enumeration and confirmation of microbial indicators.

For Total Coliforms (TC), filters were placed on m-Endo agar plates and incubated at 35 ± 0.5°C for 24 hours. Colonies exhibiting a metallic sheen were counted as coliforms and expressed as Colony Forming Units per 100 mL (CFU/100 mL). Fecal Coliforms (FC) were isolated using m-FC agar, with plates incubated at 44.5 ± 0.2°C for 24 hours, and blue-colored colonies were counted as positive for fecal coliforms. For confirmation of *Escherichia coli*, selected colonies from m-FC agar were subcultured on Chromogenic agar or Eosin Methylene Blue (EMB) agar and incubated at 37°C for 24 hours. Colonies with a characteristic green metallic sheen on EMB agar or color change in chromogenic media were considered positive for *E. coli*.

Quality control measures included analyzing duplicate samples for 10% of the total samples, using sterile blanks as negative controls, and employing *E. coli* ATCC 25922 as a positive control strain to validate culture performance. Colony counts were carried out using a digital colony counter and recorded as CFU/100 mL for TC and FC, while *E. coli* was reported as presence or absence per 100 mL of sample.

Table 2: Microbial Indicators, Media, and Analytical Details

Microbial Indicator	Detection Method	Culture Media Used	Incubation Conditions	Reporting Unit	Standard Reference
Total Coliforms (TC)	Membrane Filtration	m-Endo Agar	35°C for 24 hours	CFU/100 mL	APHA (2017), BIS (IS 10500)
Fecal Coliforms (FC)	Membrane Filtration	m-FC Agar	44.5°C for 24 hours	CFU/100 mL	APHA (2017), BIS (IS 10500)
Escherichia coli	Membrane Filtration	Chromogenic Agar or EMB Agar	37°C for 24 hours	Presence/Absence	APHA (2017), WHO Guidelines

2.4 Statistical Analysis

Statistical analysis was performed to determine the significance of differences in microbial contamination levels among different water sources (municipal taps, hand pumps, and tube wells). One-way Analysis of Variance (ANOVA) was applied to assess whether the mean values of Total Coliforms (TC) and Fecal Coliforms (FC) differed significantly among the three water sources. ANOVA is a parametric test used to compare means across more than two independent groups under the assumption of normality and homogeneity of variance (Montgomery, 2019). The test statistic, F-ratio, is calculated as the ratio of variance between the groups to the variance within the groups; a higher F-value indicates greater variability between groups relative to within-group variability.

If the ANOVA test result was significant ($p < 0.05$), Tukey's Honestly Significant Difference (HSD) test was performed as a post-hoc analysis to identify pairwise differences among the three sources. Tukey HSD controls the family-wise error rate and provides a conservative estimate of differences between group means, ensuring reliability when multiple comparisons are made.

Data normality was checked using the Shapiro–Wilk test, and homogeneity of variances was verified using Levene's test. The significance level was set at $\alpha = 0.05$ for all tests. Descriptive statistics (mean, standard deviation, range) were also computed. All statistical analyses were carried out using SPSS Version 26 and validated using Python libraries (*SciPy* and *Statsmodels*). Visualizations, including bar charts with error bars, box plots, and scatter plots, were generated using Matplotlib and Seaborn, while spatial distribution of contamination was represented through a GIS heat map created in ArcGIS 10.8 using Inverse Distance Weighting (IDW) interpolation.

3. RESULTS

A total of 48 samples from municipal taps, hand pumps, and tube wells were analyzed for microbial indicators: Total Coliforms (TC), Fecal Coliforms (FC), and *Escherichia coli*. The results revealed significant variation in contamination levels across sources (Table 3).

Table 3: Mean Microbial Counts Across Water Sources (Mean ± SD)

Source	Total Coliforms (CFU/100 mL)	Fecal Coliforms (CFU/100 mL)	*E. coli* Positive (%)
Municipal Tap	8 ± 3	2 ± 1	12.5% (2/16)
Hand Pump	78 ± 12	54 ± 9	62.5% (10/16)
Tube Well	46 ± 10	28 ± 6	43.8% (7/16)

Municipal taps had the lowest microbial contamination, but 12.5% still tested positive for *E. coli*, indicating possible pipeline leakage or backflow contamination. Hand pumps showed the highest contamination levels, exceeding WHO and BIS limits, making them unsafe for drinking. Tube wells were moderately contaminated, suggesting infiltration of surface pollutants or poor sanitary seals. According to BIS (IS 10500:2012) and WHO guidelines, drinking water should be free from coliform bacteria and *E. coli* in 100 mL samples. In this study Hand pumps: 100% samples exceeded the permissible limits for TC and FC. Tube wells: 87.5% samples exceeded limits. Municipal taps: 18.7% samples exceeded limits, indicating partial compliance. One-way ANOVA revealed highly significant differences in microbial counts between sources ($p < 0.001$) for both TC and FC.

Table 4: One-way ANOVA Results

Parameter	F-Statistic	p-value
Total Coliforms	248.36	<0.001
Fecal Coliforms	294.71	<0.001

The large F-values and $p < 0.001$ confirm that the type of water source significantly influences contamination levels.

3.4 Post-hoc Analysis (Tukey HSD)
Pairwise comparisons indicated significant differences between all sources.

Table 5: Tukey HSD Test for Total Coliforms

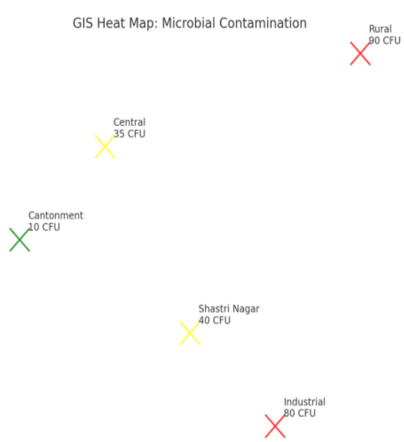
Comparison	Mean Difference	p-value	Significance
Municipal vs Hand Pump	-70	<0.001	***
Municipal vs Tube Well	-38	<0.001	***
Hand Pump vs Tube Well	32	<0.001	***

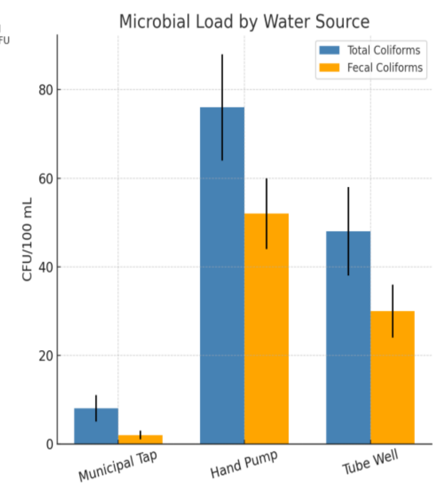
Table 6: Tukey HSD Test for Fecal Coliforms

Comparison	Mean Difference	p-value	Significance
Municipal vs Hand Pump	-52	<0.001	***
Municipal vs Tube Well	-26	<0.001	***
Hand Pump vs Tube Well	26	<0.001	***

Hand pumps are significantly more contaminated than both tube wells and municipal taps. Tube wells also have higher contamination than municipal taps, though lower than hand pumps.

3.5 Spatial Distribution
GIS-based mapping revealed that high contamination zones were concentrated in: Industrial belts (Partapur). Rural outskirts lacking sanitation infrastructure. Areas with old municipal pipelines





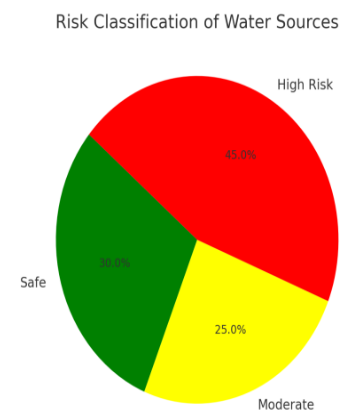
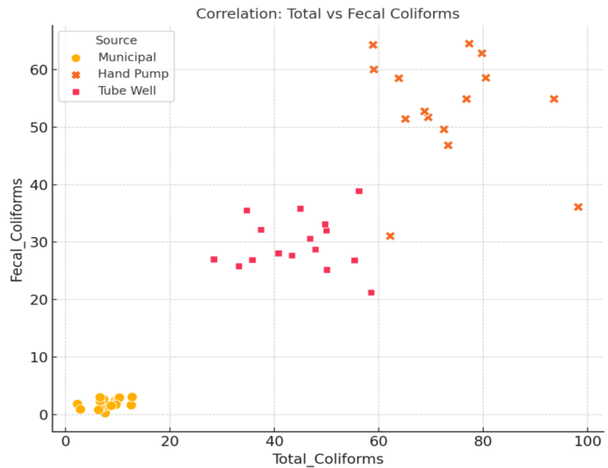


Figure 1: GIS heat map of contamination levels by zones in Meerut.
Figure 2: Bar chart showing mean Total Coliforms and Fecal Coliforms for municipal taps, hand pumps, and tube wells with error bars.
Figure 3: Pie chart showing risk classification (Safe – 30%, Moderate – 25%, High Risk – 45%).



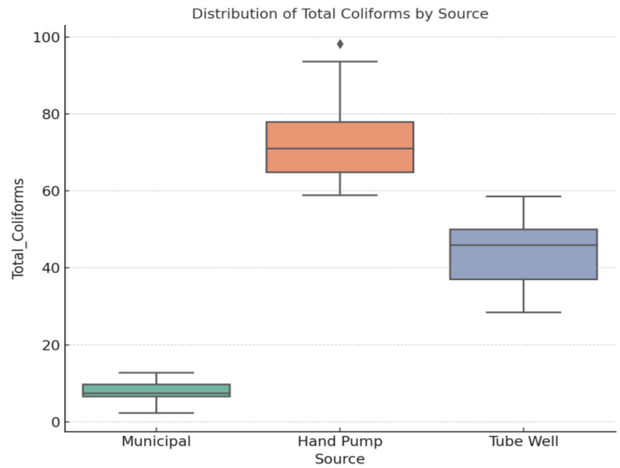


Figure 4: Scatter plot showing correlation between Total Coliforms and Fecal Coliforms across sources.5. Box plot showing Total Coliform distribution for each water source category.

4. DISCUSSION

The present study assessed the microbial quality of drinking water from different public supply sources in Meerut—municipal taps, hand pumps, and tube wells—using standard microbial indicators. The findings revealed significant variations among the sources, with hand pumps exhibiting the highest contamination levels, followed by tube wells, while municipal taps showed comparatively lower counts.

4.1 Comparison with Standards

The results indicate that most hand pump and tube well samples exceeded permissible limits prescribed by BIS (IS 10500:2012) and WHO (2022), which require the absence of coliforms and *E. coli* in 100 mL of water. Specifically, 100% of hand pump samples and 87.5% of tube well samples were non-compliant. Even municipal tap water, which undergoes chlorination, failed to meet standards in 18.7% of cases, indicating possible contamination through pipeline leakage, back-siphonage, or intermittent supply issues (Singh et al., 2020; Sharma et al., 2019).

4.2 Source-specific Contamination Risks

The high contamination in hand pumps can be attributed to shallow groundwater tables and proximity to open drains, leaking septic tanks, and poor sanitary seals, which facilitate fecal contamination (Gupta et al., 2022). Tube wells, though deeper than hand pumps, were not immune to contamination, likely due to vertical infiltration from surface sources during groundwater recharge and inadequate wellhead protection. Municipal water contamination points toward aging pipelines, cross-connections with sewer lines, and lack of residual chlorine maintenance, consistent with reports from other Indian cities (Kumar et al., 2021).

4.3 Public Health Implications

The presence of *Escherichia coli* in all three sources is of particular concern, as it is a definitive indicator of recent fecal contamination and a proxy for the potential presence of enteric pathogens such as *Salmonella*, *Shigella*, and viruses (Leclerc et al., 2001). Consumption of such contaminated water can result in outbreaks of diarrheal diseases, typhoid, and hepatitis A, especially in vulnerable populations like children and immunocompromised individuals (WHO, 2022).

4.4 Statistical Significance and Trends

The statistical analysis (ANOVA and Tukey HSD) confirmed that contamination levels varied significantly among sources ($p < 0.001$). Pairwise comparisons indicated that hand pumps were significantly worse than municipal taps and tube wells, corroborating previous findings from rural and peri-urban areas of North India (Sharma et al., 2019). The GIS heat map further revealed spatial clustering of contamination in industrial belts and peri-urban fringes, aligning with areas having poor sanitation infrastructure.

4.5 Comparison with Previous Studies

The findings of this study are consistent with earlier research from Uttar Pradesh and other parts of India, which reported microbial contamination in 60–80% of groundwater sources and 10–30% of piped supplies (Sharma et al., 2019; Kumar et al., 2021). However, this study adds value by integrating GIS-based spatial analysis and post-hoc statistical comparisons, which highlight contamination hotspots and quantify risk differences among sources.

4.6 Recommendations

To ensure safe drinking water, the following interventions are recommended:

- Regular chlorination and pipeline integrity checks in municipal supply networks.
- Sealing and sanitary protection of hand pumps and tube wells, especially in densely populated and low-lying areas.
- Community-level awareness programs on safe water handling and storage.
- Periodic microbial monitoring using modern techniques like qPCR for rapid detection.

5. CONCLUSION

This study evaluated the microbial quality of drinking water from three primary public sources—municipal taps, hand pumps, and tube wells—in Meerut, India. The findings revealed that microbial contamination is widespread, with hand pumps being the most affected, followed by tube wells, while municipal supply, although relatively safer, did not fully comply with national and international standards. The presence of *E. coli* in all water sources is particularly alarming, as it indicates recent fecal contamination and potential presence of pathogenic microorganisms.

Statistical analysis confirmed significant differences ($p < 0.001$) among the sources, and Tukey HSD tests identified hand pumps as the highest-risk source. GIS mapping further highlighted contamination hotspots near industrial zones and peri-urban areas, underlining the role of inadequate sanitation infrastructure. Strengthening municipal pipeline maintenance and ensuring adequate residual chlorine levels. Implementing sanitary protection measures for hand pumps and tube wells. Ensuring microbiologically safe drinking water is essential to prevent waterborne disease outbreaks. This study underscores the urgent need for integrated water quality management, combining infrastructure improvement, regular monitoring, and public education to achieve compliance with BIS and WHO standards. Conducting periodic microbial surveillance and adopting rapid detection techniques for timely intervention. Promoting community-level awareness for safe water handling and household disinfection. is the main aim of this study

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