Assessing Contaminants in Drinking Water: A Case Study of Southern Bengaluru, India.

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Abstract: Background: Human-induced degradation of freshwater resources continues to limit access to safe drinking water, particularly in developing countries, where waterborne diseases remain a major public health concern. This study assessed the physicochemical and microbiological quality of drinking water in southern Bengaluru, India. **Methods**: A total of 150 water samples were collected from households, educational institutions, healthcare facilities, hotels and restaurants, and roadside food vendors. Physicochemical parameters, including pH, total dissolved solids (TDS), and water hardness, were analyzed using standard methods, while bacteriological quality was determined using the most probable number (MPN) technique. **Results**: Approximately 90% of samples met the recommended pH range (6.5–8.5), and 96% complied with acceptable TDS limits. The water hardness analysis revealed that 80.7% of the samples were soft, 13.3% were moderately hard, and 6% were hard. However, 49% of samples recorded MPN values exceeding 100 MPN/100 mL, indicating significant microbial contamination. Pathogenic bacteria, including Escherichia coli, Pseudomonas aeruginosa, Klebsiella spp., Salmonella spp., Shigella spp., Vibrio spp., and Enterobacter spp., were identified. **Conclusion**: Despite acceptable physicochemical quality in most samples, widespread microbial contamination poses serious health risks. **Recommendation**: Regular monitoring, improved sanitation facilities, and enhanced hygiene practices are recommended to ensure the availability of safe drinking water and protect public health.
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Introduction

Water is a fundamental natural resource that covers approximately 71% of the Earth's surface and is indispensable for the survival of all living organisms. It plays a central role in physiological processes, as nearly two-thirds of the human body consists of water, which is essential for metabolism and cellular homeostasis (Samuel and Dominic, 2021). In daily life, water is utilized for domestic, agricultural, recreational, and industrial purposes. However, water intended for human consumption must meet established physical, chemical, and microbiological standards set by regulatory authorities. Potable water is defined as water that poses no significant health risk over a lifetime of use and is free from pathogenic microorganisms and harmful chemical substances (Megersa, 2018).

Access to safe and reliable water supplies is critical for public health and socioeconomic development. Adequate water management, improved sanitation, and sustainable resource utilization contribute significantly to economic growth and poverty reduction (United Nations, 2021). Nevertheless, not all water sources are suitable for drinking. Compliance with established quality guidelines is necessary to ensure that water is both palatable and safe for consumption (Omezuruike et al., 2008).

In many developing regions, inadequate access to clean drinking water remains a major public health concern. Poor water quality is closely associated with the transmission of infectious diseases, particularly in densely populated urban settings. In India, waterborne illnesses continue to impose a substantial disease burden, especially among children under five years of age (Sai Krishna, 2022). Anthropogenic activities such as open defecation, inadequate sanitation systems, poor waste management, damaged distribution pipelines, and flooding further compromise water quality (Hassan-Rashid et al., 2018). Consumption of contaminated water may result in diseases including cholera, dysentery, diarrhea, typhoid fever, and other serious infections.

Previous studies have documented microbial contamination of water sources in Bengaluru. Jessen et al. (2016) reported the predominance of *Escherichia coli*, followed by *Salmonella*, *Shigella*, and *Yersinia* species in the Cauvery River, a major raw water source for the city. Similarly, Abdul Khayum et al. (2011) identified *Pseudomonas aeruginosa*, *Thiobacillus*, *Desulfovibrio*, and *Leptothrix-Sphaerotilus* species in municipal drinking water. Hospital-based investigations have also revealed contamination of water supplies with pathogenic bacteria, including *Pseudomonas*, *Bacillus*, *Klebsiella*, and *Vibrio* species (Murshid et al., 2021; Kirankumar et al., 2019).

In view of these concerns, the present study aimed to assess the physicochemical and bacteriological quality of drinking water from selected locations in southern Bengaluru, India.

Materials and Methods

Collection of Water Samples

A total of 150 drinking water samples were collected from southern Bengaluru, Karnataka, India. Thirty samples each were obtained from hospitals, roadside food vendors, educational institutions (schools, colleges, and universities), residential premises (households, hostels, and paying guest accommodations), and hotels (lodges and restaurants). Samples were collected aseptically in sterile plastic containers and transported to the laboratory for physicochemical and microbiological analysis.

Determination of Physicochemical Parameters

Measurement of pH

The pH of the water samples was measured using a digital pen-type pH meter [PH-009(1)A, ROHS Pvt Ltd]. Prior to analysis, the instrument was calibrated using standard phosphate and borax buffer solutions at pH 6.86 and 4.01, respectively, at 25°C. The electrode was immersed in the sample, and readings were recorded after stabilization (Piyush and Narvdeshwar, 2022).

Determination of Total Dissolved Solids (TDS)

Total dissolved solids were measured using an E-1 portable TDS and EC meter (IONIXX Technologies Ltd). The electrode was immersed in the water sample until a stable reading was obtained, which was subsequently recorded (Rob Samborn, 2008).

Determination of Water Hardness

Total hardness was analyzed using the AQUASOL Total Hardness Test Kit (500) (RAKIRO Biotech Systems Pvt Ltd). Ten milliliters of each water sample were placed in a test jar, followed by the addition of TH 1S reagent and thorough mixing. Subsequently, 10–12 drops of TH 2 reagent were added until a color change was observed. Samples showing a red coloration were titrated with TH 6 reagent dropwise until a blue endpoint was reached.

Total hardness was calculated as:

$CaCO_3$ = 50mg/l x (Number of TH 6 drops)

(Wes Corbyn and Hunter Rising, 2023).

Bacteriological Analysis Using the Most Probable Number (MPN) Method

The presence of total coliforms was determined using the MPN technique in accordance with IS 1622:1981. The procedure involved three sequential stages: presumptive, confirmatory, and completed tests (Abhishek et al., 2017; Bekele, 2019).

Presumptive Test

Water samples (10 mL, 1 mL, and 0.1 mL) were inoculated into five sets of test tubes containing lactose broth with inverted Durham tubes. The 10 mL samples were introduced into double-strength broth, while the smaller volumes were added to single-strength broth. All tubes were incubated at 37°C for 24–48 h. Tubes showing turbidity and/or gas formation were considered presumptively positive and subjected to further analysis.

Confirmatory Test

Positive cultures were streaked onto Eosin Methylene Blue (EMB) agar plates and incubated at 37°C for 24 h. The appearance of colonies with a characteristic green metallic sheen was considered indicative of coliform organisms.

Completed Test

Representative colonies were inoculated into single-strength lactose broth containing Durham tubes and incubated for 24–48 h. Tubes showing acid and gas production were subjected to Gram staining and examined microscopically for Gram-negative, rod-shaped bacteria.

Statistical Analysis

MPN values obtained for each sample group (n = 30) were expressed as mean ± standard deviation and presented graphically.

Results

pH of Drinking Water Samples

The pH values of water samples collected from the five sampling sites are presented in Figure 1. Most samples fell within the acceptable range of 6.5–8.5. However, 13.3% of samples obtained from residential premises and hotels/restaurants exhibited pH values outside the recommended limits.

Total Dissolved Solids

As shown in Figure 1, all samples from educational institutions and hospitals had TDS values within the acceptable range of 50–300 ppm. In contrast, samples from roadside food vendors recorded comparatively higher TDS levels, with 10% exceeding the recommended standard.

Water Hardness

Analysis of total hardness revealed that all samples from educational institutions and hospitals were within the acceptable range of 75–150 mg/L. Conversely, 13.3% of samples from residential premises and roadside food vendors exhibited hardness values above the permissible limit (≥150 mg/L).

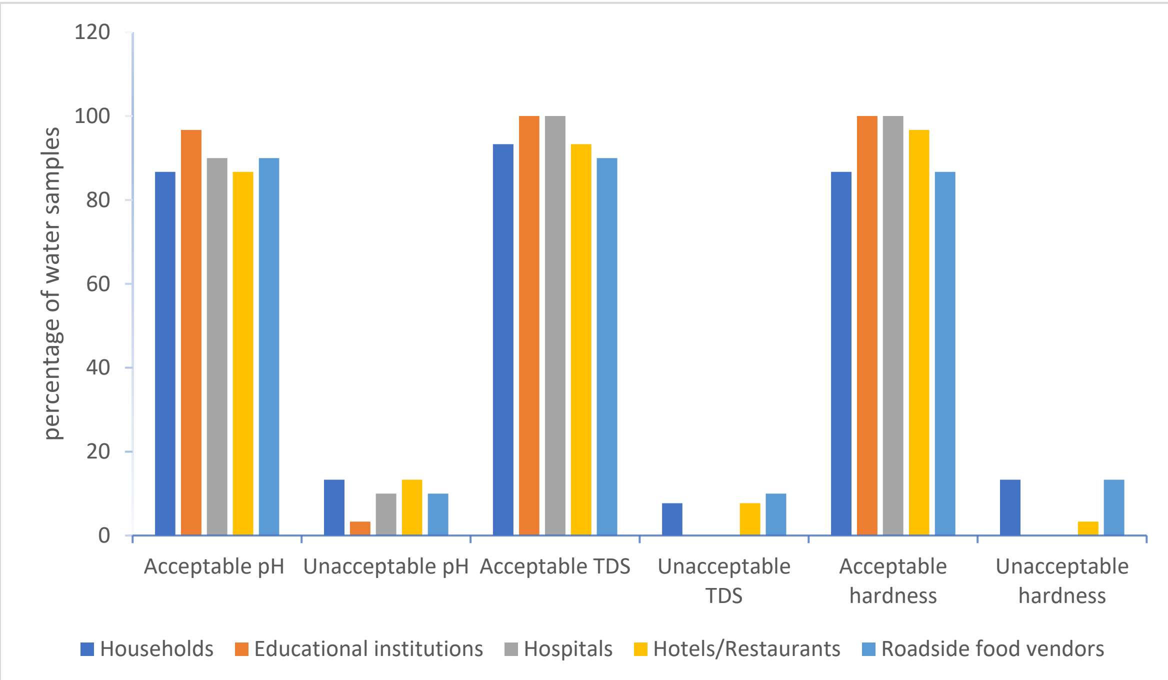

Figure 1: Groupwise distribution of the physicochemical parameters of the drinking water samples. Data represent percentages of water samples with values within and outside the limit of acceptance as recommended by BIS and FSSAI.

Bacteriological analysis of drinking water samples

The bacteriological analysis conducted using the most probable number (MPN) for the enumeration of coliform bacteria as illustrated in Figure 2, revealed that drinking water samples from roadside food vendors analyzed, showed that 86.7% of the tested water samples are above the MPN index of 100cfu/100ml which is above the recommended limit and the highest among from the sampled sources, with the production of green metallic sheen colonies and, stained smear showed gram-negative rods scattered colonies.

The mean deviation of the MPN indices of the water samples analyzed as illustrated in Figure 2, revealed that the household water sample had a lower mean (367.87 ± 108.2), while the roadside food vendors had the highest mean deviation of (1249.13 ±113.6) of MPN index.

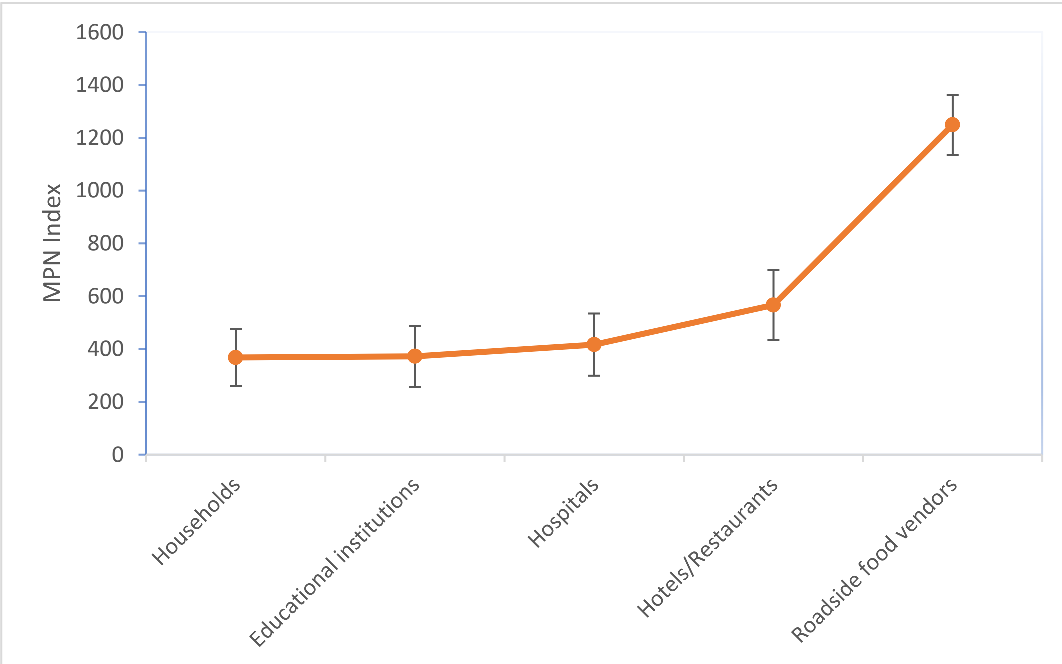

Figure 2: Mean MPN indices of water samples collected from different sites in Bengaluru south. Values represent mean ± SEM (n=30).

Discussion

The physicochemical evaluation of household drinking water indicated that the majority of samples complied with the recommended pH range of 6.5–8.5 established by the Bureau of Indian Standards and the Food Safety and Standards Authority of India. Comparable observations have been reported in previous studies conducted in urban residential settings (Jessen et al., 2021; Muhammad et al., 2018). Nevertheless, a small proportion (13.3%) of samples exhibited pH values outside the acceptable limits. Such deviations may be associated with inadequate storage practices, elevated carbon dioxide levels resulting from poor ventilation, and the placement of water treatment units in close proximity to sanitation facilities, which can influence hydroxyl ion concentration.

Total dissolved solids were generally within the permissible range of 50–300 ppm, consistent with earlier reports from Bengaluru (Abdul Khayum et al., 2011; Narayanaswamy et al., 2022). However, a minority of samples exceeded this threshold, possibly due to the intrusion of untreated wastewater and surface runoff into drinking water sources. Similarly, most samples met acceptable standards for hardness (75–150 ppm), although elevated values were recorded in 13.3% of cases. This trend may be linked to the extensive reliance on borewell water, which is typically enriched with dissolved minerals.

Microbiological analysis revealed substantial contamination in household water supplies, with 40% of samples recording MPN values above 100 CFU/100 mL and demonstrating typical *Escherichia coli* growth on EMB agar. These findings corroborate earlier studies reporting widespread fecal contamination in domestic water sources (Abdul Khayum et al., 2011; Jessen et al., 2021; Srivastava et al., 2020). The observed microbial load may be attributed to the use of multiple water sources, including municipal supplies, borewells, and commercial water vendors, combined with irregular maintenance of household reverse osmosis (RO) systems. Inadequate filter replacement and infrequent servicing likely promote bacterial proliferation.

Water samples obtained from educational institutions demonstrated comparatively superior quality. Nearly all samples exhibited acceptable pH values, with only a minimal proportion showing deviations. Similar trends have been documented in institutional settings where structured sanitation practices are implemented (Boonhok et al., 2021). All samples met recommended standards for TDS and hardness, suggesting effective water management and treatment procedures. Furthermore, microbiological analysis revealed the lowest frequency of elevated MPN values among all sampling sites. Although previous studies have reported sporadic contamination in institutional water supplies (Precha et al., 2020; Mohammad et al., 2023), the relatively low prevalence observed in the present study may reflect routine monitoring, on-site treatment facilities, and consistent maintenance protocols.

Hospital water samples also largely satisfied physicochemical quality requirements, particularly with respect to pH, TDS, and hardness. These findings are consistent with reports from healthcare facilities in other regions (Nisha Gaur et al., 2021; Jai Pal Majra et al., 2022). The stable pH values may be attributed to controlled environmental conditions and limited exposure to external contaminants. Similarly, appropriate treatment processes likely contributed to acceptable TDS and hardness levels.

Despite satisfactory physicochemical characteristics, hospital water supplies exhibited notable microbial contamination, with 36% of samples exceeding the recommended MPN threshold. The frequent detection of *E. coli* indicates persistent fecal contamination. Comparable observations have been documented in previous investigations of hospital and ICU water systems (Latha et al., 2014; Kirankumar et al., 2019; Murshid et al., 2021). The dependence on commercially supplied water and dispenser systems, coupled with insufficient monitoring of storage units and dispensing equipment, may contribute to this problem. Inadequate disinfection and irregular inspection of treatment systems further exacerbate microbial risks.

Drinking water from hotels and restaurants generally exhibited acceptable pH and TDS values, in agreement with earlier studies (Abdul Khayum et al., 2011; Abu Tareq et al., 2024). However, a subset of samples showed deviations, likely resulting from improper storage and exposure to atmospheric contaminants. Wastewater discharge and frequent human contact may also influence water quality in such environments. Although hardness values were mostly within recommended limits, isolated cases of elevated levels were observed.

Bacteriological quality in hotel and restaurant samples was of particular concern, as nearly half of the samples recorded MPN values above permissible limits. Similar levels of contamination have been reported in food service establishments (Narayanaswamy et al., 2022; Thomas et al., 2023). Inadequate sanitation practices, inconsistent maintenance of RO systems, and reliance on external water suppliers appear to be major contributing factors. The absence of systematic quality control mechanisms further increases the risk of contamination.

Water samples collected from roadside food vendors exhibited the poorest microbiological quality among all study sites. Although most samples fell within acceptable pH and TDS ranges, a considerable proportion exceeded recommended limits for TDS and hardness. These deviations may be linked to urban runoff, industrial effluents, and mineral-rich groundwater sources (Peterson and Schindler, 2017).

More than 86% of vendor samples recorded MPN values above 100 CFU/100 mL, with widespread detection of *E. coli* and other coliform bacteria. These findings are consistent with previous reports highlighting severe contamination in informal food vending environments (Abdul Karim and Sultana, 2018; Thomas et al., 2023). The unsanitary surroundings, exposure to dust and waste, absence of treatment facilities, and dependence on uncertified water suppliers collectively contribute to the observed microbial burden.

According to BIS and FSSAI guidelines, potable water must be free from fecal and total coliform bacteria. The detection of coliform organisms in samples from all study locations indicates widespread non-compliance with national standards. Similar patterns have been documented in earlier investigations (Jai Pal Majra et al., 2022; Abu Tareq et al., 2024). The persistent presence of microbial contaminants suggests systemic deficiencies in water handling, treatment, and distribution practices. Key contributing factors include improper storage, inadequate sanitation, irregular maintenance of filtration systems, and insufficient cleaning of reusable water containers.

Overall, the findings underscore the need for strengthened monitoring frameworks, routine inspection of water treatment systems, and improved hygiene practices across domestic, institutional, and commercial settings. Implementation of regular quality-assessment programs, coupled with public awareness initiatives, is essential to minimise health risks associated with contaminated drinking water in southern Bengaluru.

Conclusion

The present study demonstrates that the majority of drinking water samples from southern Bengaluru comply with national physicochemical quality standards, with more than 90% falling within the permissible limits established by the Bureau of Indian Standards and the Food Safety and Standards Authority of India. Although most measured parameters remained within acceptable ranges, prolonged exposure to suboptimal physicochemical conditions may still pose potential health risks over time.

In contrast, bacteriological assessment revealed widespread contamination, with nearly half of the analyzed samples containing total and fecal coliform bacteria. This level of microbial presence represents a significant public health concern and indicates persistent deficiencies in water treatment, handling, and distribution systems. Contamination may arise from a combination of anthropogenic activities, including inadequate sanitation infrastructure, open defecation, improper waste disposal, damaged pipelines, and ineffective sewage management, as well as environmental factors such as flooding.

Water sources that fail to meet established microbiological standards should be considered unsuitable for human consumption. The findings further suggest that although household and institutional treatment systems, including reverse osmosis units, contribute to improving water quality, they do not consistently eliminate microbial contaminants. This highlights the need for improved operational efficiency and maintenance of treatment facilities.

To reduce the risk of waterborne diseases, routine surveillance of drinking water quality should be strengthened, alongside the promotion of hygienic practices and improved sanitation. Regular inspection of distribution networks, timely repair of defective pipelines, and periodic replacement of filtration components are essential. In addition, public awareness programs and regulatory enforcement are necessary to ensure sustained access to safe and potable water and to protect community health in the study area.

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Conflict of interest statement.
There is no conflict of interest

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