Evaluation of Groundwater Characteristics Around Bonoloyo Public Cemetery, Surakarta: Residential Distance and Septic Tank

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Abstract. Groundwater quality near burial sites is an overlooked source of microbial contamination. Decomposition processes can release pathogens, yet little is known about their impact in Indonesia. We examined groundwater around Bonoloyo public cemetery, collecting two samples inside and three outside the cemetery, with an average distance of 81.6 m from residential septic tanks and graves. Physical, chemical, and biological parameters were assessed alongside secondary data on well depth, elevation, and distances from contamination sources. All samples exceeded the permissible coliform limit set by the Indonesian Ministry of Health Regulation (*Permenkes*) No. 32/2017, and two samples tested positive for *E. coli*. These findings indicate that groundwater in the study area is not safe for direct consumption. The results highlight an urgent need for local health authorities to promote preventive measures such as boiling or chlorination before household use.

1 Introduction

Groundwater is a vital resource for human consumption and ecological processes [1]; however, despite covering 70% of the earth's surface, only a fraction (approximately 0.5% of all freshwater) is readily available for use [2,3] . While global freshwater use approaches 2 trillion m³ annually, a large proportion is allocated to agriculture (70%) and industry (20%), leaving a marginal share for domestic needs [4]. But in contrast, unsustainable extraction and contamination from inadequate sanitation and burial practices have precipitated a clean water crisis affecting billions worldwide [1].

Groundwater serves as a critical buffer in many communities, especially in the Global South, supporting sustainable water access aligned with the UN Sustainable Development Goal 6 [5]. In Surakarta, patterns of urbanisation, poor sanitation infrastructure, and reliance on shallow wells elevate risks of fecal contamination, including *E. coli* and total coliforms, common waterborne disease agents [6].

Burial grounds are underappreciated sources of groundwater contamination, as decomposition fluids (leachate) migrate through porous soils into aquifers [7]. Limited research in other regions has reported elevated microbial and chemical contaminants linked to cemeteries. In Indonesia, burial grounds often lie in close proximity to residences, yet no

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specific regulation mandates separation distances for protecting drinking water sources. For instance, Indonesian statutory provisions for public cemeteries focus on land-use and environmental compatibility, not on safeguarding groundwater quality [8]. In contrast, Australia recommends a minimum separation of 20 m, and the Red Cross suggests 250 m from any water source [9].

At Bonoloyo Public Cemetery in Surakarta; a 28 ha public cemetery set at elevations between 112–143 m above sea level where residents live within and around cemetery borders, often relying on groundwater from shallow wells for daily use. The site's topographic variations may facilitate leachate infiltration through natural gradients.

Here, we evaluate physical, chemical, and biological groundwater quality in wells located inside and around TPU Bonoloyo, investigating proximity to septic tanks and burial plots, with the objective of assessing its suitability for household consumption.

2 Methods

2.1 Study design

This study employed a nonexperimental, exploratory design to analyze the physical, chemical, and microbiological characteristics of groundwater in and around Bonoloyo public cemetery, Surakarta, Central Java, Indonesia.

2.2 Study site and sampling

Groundwater samples were collected from five wells: two inside the cemetery and three in surrounding residential areas located within 150 m of the site (Fig. 1). Sampling was purposive, considering proximity to burial plots, septic tanks, and household use. Wells were flushed for 2–3 min, sterilized with 70% ethanol, and 1 L of water was collected in sterile jerricans. Samples were transferred to sterile glass bottles and stored at 4 °C until analysis, which was performed within 24 h.

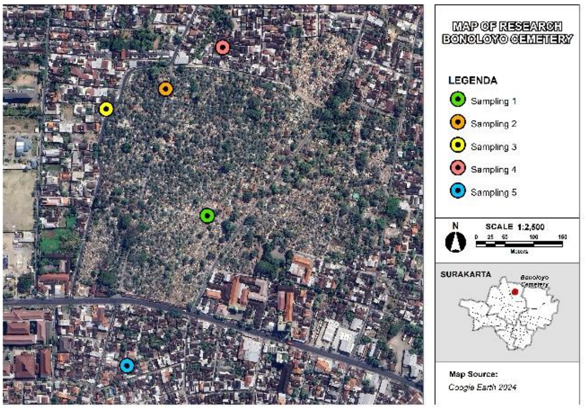

Fig. 1 Map of research

2.3 Laboratory analysis

Lactose Broth (LB; 12 g L^{-1}), Brilliant Green Lactose Bile Broth (BGLBB; 20 g L^{-1}), and Eosin Methylene Blue agar (EMB; 36 g L^{-1}) were prepared according to manufacturer instructions. LB and BGLBB were dispensed into test tubes equipped with Durham tubes, whereas EMB was poured into sterilized Petri dishes. All media were sterilized by autoclaving at 121 °C, 2 atm, for 20 min.

Sampling bottles (1000 mL) were sterilized by boiling for 30 min, and jerry cans were rinsed with water at 100 °C. Glassware and culture media were sterilized in two stages: moist heat (autoclave, 121 °C, 20 min, 2 atm) followed by dry heat (oven, 160 °C, 120 min).

Water samples were characterized for physical, chemical, and biological parameters. Physical properties included total dissolved solids (TDS, measured with a TDS meter), temperature (thermometer), and organoleptic characteristics (odor and taste). Chemical properties were assessed using a pH meter. Biological analyses targeted *E. coli* and total coliforms using the Most Probable Number (MPN) method and streak tests [10].

The assay comprised three stages. In the presumptive test, water samples (1 mL) were inoculated into three tubes containing 9 mL LB with Durham tubes and incubated at 37 °C for 24 h, a temperature optimal for coliform growth [11]. Positive reactions were indicated by a yellow color shift and gas production. Confirmatory tests were performed by inoculating LB-positive cultures into BGLBB and incubating at 44 °C for 24 h to select for fecal coliforms. Positivity was determined by turbidity and gas formation. In the completed test, cultures from confirmatory-positive tubes were streaked onto EMB agar; metallic green colonies indicated coliform presence [11]. MPN values were interpreted using Thomson's probability table.

2.4 Data analysis

Quantitative data (TDS, temperature, pH, coliform counts) and qualitative data (taste, odor, E. coli) were evaluated against the Indonesian Drinking Water Standards [12].
Table. 1

Table. 1 Indonesian National Drinking Water Standards

Parameter	Unit	Standard value
Temperature	°C	Ambient temperature ± 3
Total dissolved solids	mg/L	≤ 1000
Odor	–	None
Taste	–	None
pH	–	6.5–8.5
Total coliform	CFU/100 mL	≤ 50
E. coli	CFU/100 mL	0

3 Result and discussion

3.1 Results

Bonoloyo Public Cemetery (TPU) is located between 7°32′09.5″S–7°32′24.2″S and 110°49′37.9″–110°49′30.3″E, and is bordered by residential areas separated by Jl. Sumpah Pemuda (south), Jl. Bromo Raya (west–north), and Jl. Gn. Slamet (east). Jl. TPU Bonoloyo divides the cemetery into eastern and western blocks. Five sampling sites were selected: two inside the cemetery and three outside (**Fig. 1**). Sites were positioned at elevations of 100–107 m with well depths ranging from 10–15 m (**Table. 2**). Three wells (sites 3–5) were located near septic tanks (3–15 m), one of which (site 3) was also used for drinking water.

Table. 2 Sampling location data

Sampling point	Lattude	Longitude	Altitude (masl)	Depth (m)	Distance from septic tank (m)	Distance from septic tank (m)
1	7°32'12.5"	110°49'28.9"	107	15	3	-
2	7°32'12.4"	110°49'29.0"	109	15	-	-
3	7°32'28.1"	110°49'26.7"	101	12.5	3.5	31
4	7°32'10.2"	110°49'32.1"	100	10.5	10	80
5	7°32'13.6"	110°49'25.5"	100	10	15	134

Total coliform counts ranged from 0 to ≥1,898 CFU 100 mL^{-1}. Sites 1, 2, 3, and 5 exceeded the maximum permissible level for drinking water (50 CFU mL^{-1} [12]). High counts at sites 1 and 3 coincided with relatively lower pH values, consistent with previous observations that groundwater acidity is inversely correlated with bacterial abundance [9]. *E. coli* was detected at sites 3 and 5, indicated by metallic green colonies on EMB agar (**Fig. 2**).

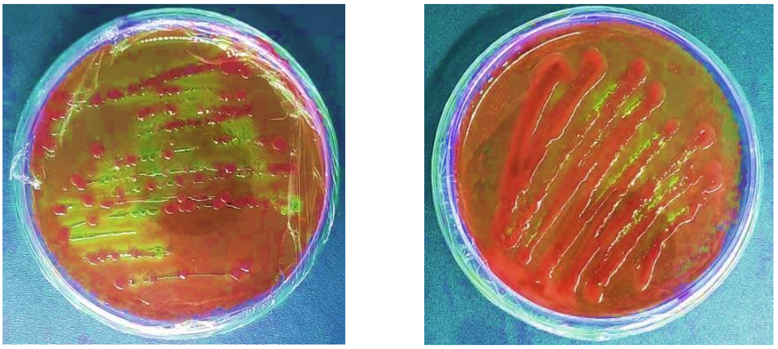

Fig. 2 Positive *E. coli* result

This finding parallels reports from cemeteries in Brazil and Iran where *E. coli* was strongly associated with burial activity and septic contamination. The presence of *E. coli* in sites 3 and 5 exceeded national drinking water standards (0 CFU mL^{-1}). Overall, the data suggest that well proximity to septic tanks, rather than cemetery location per se, exerts the strongest influence on microbial contamination [13].

Water temperatures ranged from 28–33 °C (mean 29.8 °C), within safe limits for potable water [12]. 8 [14].

Groundwater pH varied narrowly (7.1–7.3). Samples from within the cemetery exhibited slightly lower values, plausibly linked to organic matter released during decomposition, as reported in Portuguese cemetery studies [15]. Despite these shifts, all samples remained within the acceptable range for drinking water.

Collectively, these results indicate that septic tank proximity and well depth are stronger determinants of microbiological risk than cemetery boundaries alone. Although Bonoloyo Cemetery lies adjacent to residential areas, groundwater quality was not consistently degraded inside versus outside the burial ground. Instead, localized factors such as septic tank distance (≤15 m) and shallow well depth (≤12.5 m) explained the presence of coliforms and *E. coli*.

3.2 Conclusion

Groundwater surrounding Bonoloyo Cemetery met national standards for dissolved solids, temperature, taste, odor, and pH [12]. However, total coliform levels exceeded permissible limits in multiple sites, rendering the water unsuitable for direct consumption. *E. coli* contamination at sites 3 and 5 further indicated fecal pollution, most likely associated with septic tank proximity. These findings suggest that septic tank distance exerts a stronger influence on groundwater microbiological quality than the presence of the cemetery itself.

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