

 Open AccessArticle Information**Received:** May 5, 2024**Accepted:** June 27, 2024**Published:** July 31, 2024Keywords

*Escherichia coli*,  
Coliform,  
Total Bacterial Count,  
Presumptive Test,  
Taiz,  
Ibb,  
Yemen.

Authors' Contribution

Al-Hadheq and Al-Aboud conceived and designed the experiments. Al-Hadheq performed the experiments; Al-Hadheq, Al-Aboud, and Al-Arabi analyzed the data and wrote the first draft of the manuscript. Al-Maktari contributed to the writing of the manuscript. Al-Hadheq, Al-Asbahi, Al-Shehari, Edress, and Al-Ofairi agree with the manuscript results and conclusions. All authors have read, revised, and approved the final manuscript.

**How to cite**

Al-Hadheq A.A., Edrees W.H., Al-Aboud, M., Al-Arabi A., Al-Maktari M., Al-Shehari, W.A., Al-Badani I., Al-Asbahi, B., Al-Ofairi, B.A., 2024. Assessment of Bacteriological Quality of Drinking Water in Taiz and Ibb Governorates, Yemen. PSM Microbiol., 9(2): 19-27.

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## INTRODUCTION

Water is a natural resource that is critical to human survival (Adimalla and Qian, 2023; Ugwu *et al.*, 2017). It sustains all forms of life and generates jobs and wealth in the water, tourism, and recreation industries. The global slogan "Water is Life" implies that water is one of the most basic human needs. Life as we know it on our planet would be impossible without water (Adimalla *et al.*, 2022; Bekele *et al.*, 2018).

Water distribution networks are critical in modern communities because their proper operation is directly related to the well-being of the population (Desta and Befkadu, 2020; Desta *et al.*, 2022). The high clay content of the soil, which results in a slow rate of water percolation and a significant distance to the groundwater, will lead to a greater likelihood of bacterial survival compared to the well-aerated sand. Nevertheless, the extended duration of the flow permits ample time for the water to undergo filtration prior to its entry into the groundwater (Adetunde and Glover, 2010). A multitude of significant challenges that jeopardize the existence of humanity on Earth arise from the scarcity of potable water in numerous areas, along with the degradation of environmental aesthetics (Adimalla 2020; Bote and Desta, 2022).

Microorganisms have a significant impact on the quality of water, particularly concerning waterborne diseases. The specific bacteria that are associated with these diseases include *Salmonella* spp., *Shigella* spp., *Escherichia coli*, and *Vibrio cholera*. These factors contribute to the occurrence of typhoid fever, diarrhea, dysentery, gastroenteritis, and cholera (Adetunde and Glover, 2010). Consequently, water is analyzed microbiologically in order to assess its hygienic condition and its appropriateness for common purposes (Ohanu *et al.*, 2012; Ashraf and Iqbal, 2020; Saleem *et al.*, 2020; Urooj *et al.*, 2022). Yemen is classified as a developing country that does not have effective policies or programs in place to manage or prevent the spread of disease-

causing microbes among its people (Al-Hadheq *et al.*, 2023; Mengstie *et al.*, 2023; Al-Ofairi *et al.*, 2024). The World Health Organization (WHO) reports that over 30% of the global population lacks access to potable water. Every year, 829,000 individuals suffer from diarrhea caused by drinking contaminated water, inadequate sanitation, and poor hand hygiene (WHO, 2019).

In order to provide a safe source of drinking water, it is essential to perform observation for the existence of pathogens (Iqbal and Ashraf, 2022). Nevertheless, doing a comprehensive examination of the water supply for each bacterium would be costly and time-consuming. Instead, an indicator organism is employed to signal the potential existence of harmful bacteria, which are capable of causing diseases (Charles *et al.*, 2015). In this research, we have performed the microbiological analysis of drinking water samples from Taiz and Ibb governorates to assess the quality of drinking water from the bacterial side.

## MATERIALS AND METHODS

### Study area and period

This cross-sectional study was carried out in different areas of water supply in the Taiz and Ibb governorates, Yemen, during the period from January to February 2023. In total, 99 water samples from different sources, distribution networks, and house tanks in Taiz and Ibb governorates were collected for bacteriological analysis.

### Sample collection

Drinking water samples were aseptically collected in a sterilized 300-mL capacity and placed in an insulated cold box for transport to a water testing laboratory. Water samples were examined as soon as possible on arrival and always within 6 hours of collection (Prescott *et al.*, 2005).

## Microbiological analysis

For the total bacterial count, about one mL of each water sample was separately inoculated onto a plate containing 25 mL of nutrient agar with 1 mL of water sample and incubated at 37°C for 72 hours. The total bacterial visible colonies were counted after the incubation period according to the following formula: CFU/mL = (Number of colonies × dilution factor) / volume of culture plate.

Furthermore, the detection of *Enterococcus faecalis* was performed by inculcating one mL of water sample into 10 mL of Azide dextrose broth and incubating at 37°C for 24 h. Investigation of *Escherichia coli* was done by inculcating one mL of water sample into 10 mL of MacConkey broth and incubated at 37°C as a presumptive test for 48 h. In addition, the Eosin Methylene blue was inoculated by loop and incubated at 37°C for 24 h to check the positive presumptive test. The isolation of coliform was done by using MacConkey agar which differentiates between lactose and non-lactose fermenter organisms, where coliforms are lactose fermenters and produce pink colonies on this medium after the incubation period. The quality control of each process was done by incubating two control plates to check the sterility of the samples (American Public Health Association 2005; Dhawale and LaMaster, 2003).

## Statistical analysis

The data collected from the results of microbiology tests were analyzed by using SPSS Version 16. P-values of less than 0.05 ( $P<0.05$ ) were considered statistically significant.

## RESULTS

### Results of studied samples from Taiz government

The fecal bacteria were not present in all studied water sources, but the high total bacterial counts were in Al-Hoban ( $18\times10^2$  CFU/100mL), followed by Kalaba ( $16\times10^2$  CFU/100mL), and the low number was in Al-Dabab ( $13\times10^2$  CFU/100mL), as shown in Table 1. Our findings showed that the relationship between the free chlorine ratio and the total bacterial count was variable in some regions, where the high ratio of free chlorine was in the distribution reservoir and the low ratio was in Bab Mosa, whereas in Al-Shamasi, Al-Markazi, and Kalaba, the ratio was variable. However, the total bacterial count was high in Bab Mosa, while in Kalaba, Al-Shamasi, and the distribution reserve, it was the same. It also shows no growth of the fecal bacteria in all studied regions.

**Table 1.** The bacterial count of samples taken from some water sources in Taiz government.

Water Sources	Total Bacterial Count (TBC) $\times 10^2$ CFU per 100 mL			Fecal Bacteria/100 mL		
	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>	Mean	Coliform/ <i>E. coli</i>	<i>E. faecalis</i>
Kalaba	16	10	11	12	0	0
Al Dapab	5	13	6	8	0	0
Al- Hoban	15	18	20	18	0	0

The total bacterial count before and after sterilization and the effectiveness of sterilization showed that the effectiveness of sterilization was

high in Al-Markazi, low in Bab Mosa, and variable in other regions, as shown in Table 2.

**Table 2.** The total bacterial count before and after sterilization and the effectiveness of sterilization.

Regions	Total Bacterial Count (TBC) $\times 10^2$ CFU per 100 mL		Effectiveness of Sterilization
	Before sterilization	After sterilization	
Distribution Reservoir	12	2	83.3%
Bab Mosa	12	4	66.7%
Al-Shamasi	12	2	83.3%
Al-markazi	12	1	91.7%
Kalaba	12	2	83.3%

### Results of studied samples from Ibb government

The number of bacteria in samples collected from different sources of water in the Ibb government was

higher in Al-Sign Al-Markazi well and lower in Al-Salaba; however, there was no growth of fecal bacteria in all studied water samples, as shown in Table 3.

**Table 3.** The number of bacteria in samples taken from some water sources in Ibb governorate.

Wells	Total Bacterial Count (TBC) $\times 10^2$ CFU per 100 mL			Fecal Bacteria/100 mL	
	Number of Samples			Mean	Coliform/ <i>E. coli</i>
	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>		
Al-Salaba	0	2	1	1	0
Al-Mala'ab	4	11	16	10	0
Al-Segn Al-Markazi	11	15	9	11	0
Seven	10	6	6	7	0
Eight	7	5	10	7	0

Our finding showed that the number of bacteria in samples taken from the distribution network of five regions supplied by Al-Salaba and Al-Mala'ab wells was higher in the Mophleh line, followed by Al-

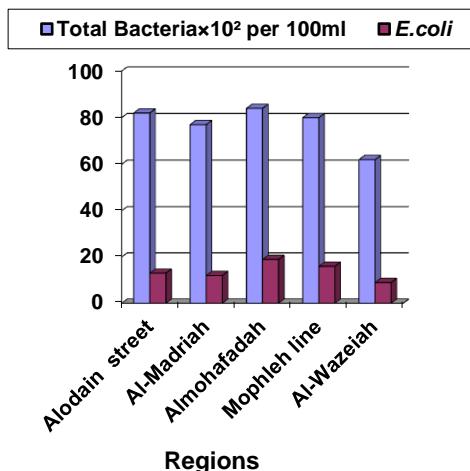
Madariah, Alodain Street, and Al-Wazeiah regions, but the lower number was in the Al-Mohafadah region. However, the fecal bacteria were not present in all regions, as shown in Table 4.

**Table 4.** The bacterial count in samples taken from distribution network of different regions that is supplied by Al-Salaba and Al-Mala'ab.

Region	Total Bacterial Count (TBC) $\times 10^2$ CFU per 100 mL			Fecal Bacteria/100 mL	
	Number of samples			Mean	Coliform/ <i>E. coli</i>
	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>		
Alodain street	31	19	25	25	0
Al-Madriah	45	42	37	41	0
Almohafadah	16	13	21	16	0
Mophleh line	56	61	63	60	0
Al-Wazeiah	12	17	38	22	0

Our results showed that a higher number of total bacteria and *E. coli* were present in Al-Mohafadah region and a lower number were in Al-Wazeiah

region, however, *E. faecalis* was not present, as shown in Figure (1).



**Fig. 1.** The total bacterial count and *E. coli* of samples taken from Al-Salaba and Al-Mala'ab wells.

The number of bacteria in samples taken from the distribution network of the two regions was supplied by Al-Signs Al-Markazi well, where a higher number was present in the Wadi Al-Dahab region and a lower number in the Al-Signs Al-Markazi region, and *E. faecalis* was not present, as shown in Table (5). Our

findings showed that the number of bacteria in samples taken from the distribution network of two regions supplied by Al-Signs Al-Markazi well, where a higher number was present in the Wadi Al-Dahab region and a lower number in the Al-Signs Al-Markazi region and *E. faecalis* was not present.

**Table 5.** The bacterial count of samples taken from distribution network of different regions supplied by Al-Signs Al-Markazi wells.

Region	Total Bacterial Count (TBC) $\times 10^2$ CFU/100 mL			Fecal Bacteria/100 mL		
	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>	Mean	Coliform/ <i>E. coli</i>	<i>E. faecalis</i>
Al-Signs Al-Markazi	51	56	72	59	0	0
Wadi Al-Dahab	82	75	87	81	0	0

These results showed that the higher number was present in the Akamat Easa region, followed by the Haratha region, while the lower number was in the

Dar Al-Sharaf region. However, the fecal bacteria were not present in all studied regions, as shown in Table (6).

**Table 6.** The bacterial count of samples taken from distribution network of different regions that are supplied by seven and eight wells.

Region	Total Bacterial Count (TBC) $\times 10^2$ CFU/100 mL			Fecal Bacteria/100 mL		
	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>	Mean	Coliform/ <i>E. coli</i>	<i>E. faecalis</i>
Haratha	55	58	64	59	0	0
Dar Al-Sharaf	42	38	54	44	0	0
Akamat Easa	63	54	71	62	0	0

Finally, the number of bacteria in samples taken from houses in tanks of three regions was supplied by seven and eight wells, where the higher number of total bacteria was present in the Haratha region

followed by Akamat Easa region; however, the number of *E. coli* was high in Haratha, Akamat Easa, and Dar Al-Sharaf, as shown in Table (7).

**Table 7.** The bacterial count in samples of houses tanks from different regions that are supplied by Seven and Eight wells.

Region	Bacterial load in samples (CFU/100 mL)						Mean bacterial load (CFU/100 mL)		
	1 <sup>st</sup> TBC x10 <sup>2</sup>	E.coli	2 <sup>nd</sup> TBC x10 <sup>2</sup>	E.coli	3 <sup>rd</sup> TBC x10 <sup>2</sup>	E.coli	TBC x10 <sup>2</sup>	Coliform/ E. coli	E. fecalis
Haratha	85	16	82	18	73	11	80	15	0
Dar Al-Sharaf	65	23	81	29	69	10	71	21	0
Akamt Easah	59	12	67	14	70	20	65	15	0

## DISCUSSION

The occurrence of waterborne diseases in developed countries is generally low due to a generally good system of water treatment, distribution, and monitoring. Waterborne diseases are among the leading causes of morbidity and mortality in low- and middle-income countries, frequently called developing countries.

In wealthy countries, the incidence of waterborne infections is often low due to an effective system of water treatment, distribution, and monitoring. Waterborne infections are a significant source of illness and death in poor and middle-income nations, sometimes referred to as developing countries (Adimalla, and Qian, 2023).

Yemen, such a developing country, suffers from a lot of water-related health problems. Contaminated or polluted water is water that contains poisonous chemicals, pathogenic organisms, industrial waste, or sewage. The majority of diseases in underdeveloped nations such as typhoid, cholera, and hepatitis can be attributed to the absence of potable water (Ohanu *et al.*, 2012; Penna *et al.*, 2002).

In Taiz governorate, the results of the study showed no growth of indicator bacteria in all studied water samples. This means that these waters are free from pathogenic bacteria. Thus, these waters are drinkable and fit for human consumption from a bacteriological perspective. In addition, the total bacterial count was high in Bab Mosa, while in Kalaba, Al-Shmasi, and the distribution reserve, it was the same. It also shows no growth of the fecal bacteria in all

studied regions. Similar findings were reported in Ethiopia (Mengstie *et al.*, 2023) and Iran (Shahryari *et al.*, 2020). Other studies have also reported the high bacteria count in water (Moazeni *et al.*, 2013; Kouchesfahani *et al.*, 2015; Ashraf *et al.*, 2019; Fatima *et al.*, 2021).

In addition, the present study found that there was no growth of indicator bacteria in all samples taken from the Ibb Governorate wells and distribution network, but the samples taken from house tanks (10%) showed growth of *E. coli*, which indicates that the water is unacceptable for human consumption according to WHO (World Health Organization and UNICEF, 2015; World Health Organization, 2019). This could be attributed to the presence of gelatinous layers accumulating on the walls of the tank, resulting in turbidity (Lewandowski and Beyenal, 2007). Similar findings were reported in Iraq (Aldhamin, 2023), Sudan (El Emam, and El Jalii, 2010), Indonesia (Alfian *et al.*, 2023), Eucadur (Molina *et al.*, 2024), Nepal (Shrestha *et al.*, 2022), and Pakistan (Shafique *et al.*, 2020). In addition, other reports revealed that most bacteria contaminating drinking water in Aden and Hadhramout governorates were *E. coli* (Hassan *et al.*, 2008; Bin Hamed and Bubakr, 2019). A high rate of *E. coli* was reported in drinking water in Thailand (Yongyod *et al.*, 2023) and Indonesia (Alfian *et al.*, 2023).

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

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