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# Physicochemical and microbiological properties of geothermal and non-geothermal water from wells in Dhamar, Yemen

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**Abstract.** The objective of this study was to estimate some physicochemical and microbiological properties of natural geothermal water from four wells located in Dhamar city, including total dissolved salts (TDS), pH, electrical conductivity (EC), temperature (°C), turbidity, total hardness, iron, total bacterial and coliform bacteria counts to determine suitability for drinking and electrical generation purposes. The results showed that the TDS content was 316.6, 316.6, 320 and 936.6 (ppm), pH was 8.87, 7.94, 7.99 and 7.32, EC was 633.3, 633.3, 640 and 1860 (µs/cm), turbidity was 1, 0, 0.5 and 7 (NTU), total hardness was 10, 108, 114 and 70 (mg/L), iron was 0.03, 0.03, 0.04 and 0.06 (mg/L) while the water temperature degrees at source was 46.7, 51.5, 41.5 and 63.5 (°C) in the geothermal water from Aishan, Meshwaf, Thi-Majed, and Mosala wells respectively. Total bacterial count was 4.47, 4.24, 4.35, and 4.60 (log CFU/mL), and total coliform was (≤ 3), (<3), (9.66), and (6.06) (MPN/100 mL) in the geothermal water from Aishan, Meshwaf, Thi-Majed, and Mosala wells respectively. These results indicated that the water from the geothermal wells included in this study did not match some quality parameters for drinking water, and their temperatures were low and insufficient for electrical generation purposes.

***Keywords**: Geothermal water, water quality, physicochemical properties, and Yemen*

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## 1. Introduction

Geothermal activity is recognized in different regions of Yemen as hot springs exposed at the surface, but deep thermal wells are newly recognized, especially in Dhamar city. Thermal springs are springs where the water temperature is higher than the local mean air temperature or springs with water temperature above 36.7 °C. There is no consensus about the exact temperature that characterizes a spring from a thermal spring (Pentecost et al., 2003). Geothermal resources are classified into hydrothermal and petro-geothermal resources (Sowiżdżał, 2018). Hydrothermal resources include hot water and steam reservoirs categorized as liquid- or vapor-dominated (Brown et al., 2012). Geothermal resources are classified based on temperature into seven categories: non-electrical grade (<100 °C), very low temperature (100-150 °C), low temperature (150-190 °C), and moderate temperature (190-230 °C), and high temperature (230-300 °C), and ultrahigh temperature (>300 °C), and steam fields (approximately 240 °C with steam as the only mobile phase) (Sanyal, 2005). Thermal springs can be classified based on the origin of springs, physical properties such as flow rate, temperature, geology, and chemical composition or combination of these properties (La Moreaux & Tanner, 2001). Thermal spring waters are being used in industrial processing, agriculture, aquaculture, bottled water, and the extraction of rare elements. Geothermal waters contain many salts at different concentrations, and some of these salts or organic compounds (if present) can be subject to microbial conversion and (bio) precipitation which microorganisms can oxidize and produce undesirable compounds in water (Sand, 2003). In Mszczonów, the geothermal waters extracted from the boreholes are used in heat plants, whereas after cooling this water, it's directed to the municipal water supply system as drinking water (Tyszer et al., 2020). Olivier et al. (2008) found that water parameters in seven from eight thermal springs located in the southern Waterberg region of the Limpopo Province does not conform to domestic water quality guidelines and makes the water unfit for human consumption because it contains a high fluoride concentration and high value of mercury at one thermal spring.

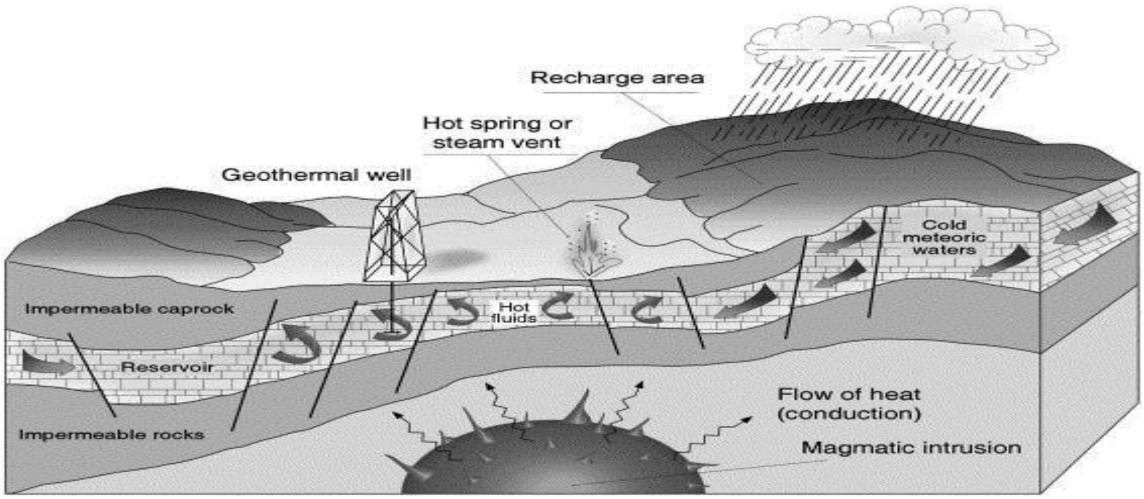


**Figure 1.** Effect of magmatic on the hydrothermal activity in the earth (Barbier, 2002)

Geothermal energy is the energy contained as heat in the earth's interior and internal structure and the heat transfer mechanisms inside the mantle and crust (Barbier, 2002). Figure (1) illustrates the location of geothermal fields on specific areas of the earth and the role of the magmatic on the hydrothermal activity and geothermal fields' formation. The physiological conditions of most natural pools are perfect for bacterial proliferation, and excessive inoculation of pathogens into the pools from humans could cause health problems (Thorolfsdottir & Marteinsson, 2013). Petursdottir et al. (2009) showed relatively low diversity, with only a few dominant players exhibiting seasonal fluctuations. The low biodiversity is probably the salinity of 2.5%, the unusual source and chemical composition of the dilute geothermal seawater, and the high silica content underlining the extreme characteristics of this unique environment. Tobler and Benning (2011) found that the bacterial diversity in silica precipitates from six different Icelandic geothermal sites varied with temperature, but other factors like sinter growth rate also influenced the bacterial community structure. It was impossible to single out one parameter that affected the microbial community, and in geothermal areas, the physicochemical characteristics invariably affect the diversity and structure of microbial communities. The bacterial diversity of the groundwater well increased after air surging (Kim et al., 2017). A vast diversity of microorganisms can be found in pools and other waters used for recreation, originating from different sources, such as humans, animals, or the environment, and fecal contamination can come from the pool guests' feces, the water supply itself, or from animal feces (Martins et al., 1995).

Maintenance of the microbiological quality of water has been used as an essential means of preventing waterborne disease throughout the last century. Total coliform and fecal coliform are the most standard microbiological tests done for water. Microbiological examinations of water are usually applied to ensure that the water is safe for drinking or bathing. Many potential pathogens could be associated with water; it is thus impractical to screen samples for all possible pathogens (Barrell et al., 2000). Aburto-Medina et al. (2020) reported that the total coliform and fecal coliform were not observed in any samples except for the post-bathing water; even there, their presence was at a low concentration (2.3cfu/mL). Amran et al. (2018) study water's physicochemical and microbiological properties from the wells that feed the Dhamar city drinking water distribution system and conclude that the wells located in high population density regions had higher pollution than the water from the water wells located in low population density regions. As a lack in the detailed assessment of the microbial and physicochemical properties of geothermal groundwater from wells, we designed this study to the estimation of some physicochemical properties and microbiological quality for geothermal water from four wells, namely; Aishan, Meshwaf, Thi-Majed, and Mosala, and compare their properties with the properties of water samples from two underground water wells (non-geothermal wells) from Dhamar city, Yemen.

## 2. Materials and Methods

### 2.1. Water sampling

Water samples were taken from the wellhead of Aishan (west of Dhamar city), Meshwaf, Thi-Majed, and Mosala geothermal wells (located in the north of Dhamar city) and water samples from two underground wells (non-geothermal), Mnqd'h valley well is near to the location of geothermal wells (north of Dhamar city), and Azzan well is in the south of Dhamar city. Then the water samples were transported to the laboratory for chemical, physical and microbiological analysis.

### 2.2. Physical and chemical analysis of water

Water temperature was measured immediately after water was pumped from the wells by thermometer. Electrical conductivity (EC), total dissolved salts (TDS), and water pH were measured using a portable pH meter from Hanna Company. Turbidity, total hardness, and iron were measured using the HACH DR/ 890 colorimeter instruments described in the HACH procedure manual (2013).

### 2.3. Microbiological analysis

#### 2.3.1. Total bacterial counts.

Total bacteria count was performed by Plate Count Agar (PCA) method, and decimal dilution series for samples with sterile saline (0.9 % sodium chloride) and 100 µL of each dilution was plating in plate count agar in duplicate plates and incubated at 37 ºC for 24-48 hrs (APHA, 1989).

#### 2.3.2. Total coliform counts.

Estimation of total coliform bacteria in water samples was done by the Most Probable Number (MPN) method in three steps: **(1) Presumptive test.** MPN bacteria in water samples have been estimated using tubes containing Lactose Broth (3 tubes) and incubated at 37 °C for 48 hrs. **(2) Confirmatory test.** A confirmatory test was performed using Eiosine methylene blue (EMB) and incubated at 37 °C for 48 hrs. **(3) Complementary test.** Tubes containing Lactose Broth were used to perform this test and incubated at 37 °C for 48 hrs. The numbers of the positive tubes per dilutions were determined and calculated the MPN index from the MPN Tables (Pepper & Gerba, 2004).

## 3. Result and Discussions

### 3.1. Physicochemical properties of water.

The mineral composition of thermal waters reflects the geological formations found at a depth of origin (Olivier et al., 2008).

#### 3.1.1. Temperature of water.

The optimal use of thermal springs depends on the water's physical and chemical properties. Geothermal water is used for heating industrial buildings, greenhouses, and administrative buildings (Sebesan et al., 2019). The results in table 1 showed that water temperature from the wells was ranged between (41.5-63.5 ºC). The highest temperature was (63.5 ºC) in water from Mosala well, and the lowest was (41.5 ºC) in water from Thi-Majed well, whereas it was (46.7 ºC) and (51.5 ºC) in water from Aishan and Meshwaf wells, respectively. This variation in the water temperature from different wells may be related to the difference in the depth of the wells and its region site. The amounts of cold water from the upper layers that dilute the hot geothermal water and lead to cooling of the water is also causing a variation in temperature of geothermal water, which reaches the surface with different temperature degrees (Sebesan et al., 2019). These results are similar to Murithi (2012), who found that the surface temperatures of geothermal waters in the Tearoha domain range between (50-90 ºC). It is fell in the range of the results of Boguniewicz-Zabłocka et al. (2019) for water existing from boreholes in the Opole region, Poland (20-90 ºC) and with the range of the results reported by Tshibalo et al. (2015) for of thermal spring water from south Africa ( 25-71 ºC) and with the results found by Ghilamicael et al. (2017) in water from five hot springs in Eritrea at source (49.5-100 ºC). But these results are higher than the results of Iswahyudi et al. (2020) for immature geothermal water from hot spring around the Slamet volcano, Indonesia, which was ranged between (40.5-50.4 ºC), while it was lower than the results found in the water at the wellhead of geothermal wells from Sacuieni, Bihor County, Romania (81-82 ºC) (Sebesan et al., 2019).

**Table 1.** Temperature value in water at the wellhead of geothermal and non-geothermal wells

| **Well name** | **Temperature (ºC)** |
|---|---|
| Geothermal wells | |
| **Aishan** | 46.7 |
| **Meshwaf** | 51.5 |
| **Thi-Majed** | 41.5 |
| **Mosala** | 63.5 |
| Non-geothermal wells | |
| **Mnqd'h valley** | 28.9 |
| **Azzan** | 20.9 |

The measured temperature of water at the wellhead of Mnqd'h valley and Azzan wells (non-geothermal wells) was 28.9 and 20.9 ºC, respectively (Table 1). The results indicate that the water temperature value from the Mnqd'h valley well, which is located near the geothermal wells, was higher than the water temperature of the Azzan well, but both non-geothermal wells' water is lower than the water temperature from geothermal wells included in this study. The well's location might be affected by the water temperature, and the variation in the depth of the wells may also affect water temperature from the exact location.

**3.1.2. TDS, EC, and Turbidity of water.**

The results in table 2 showed that the total dissolved salts (TDS) were 316.6, 316.6, 320, and 936.6 (ppm) and the (EC) was 633.3, 633.3, 640, and 1860 (µs/cm), and the turbidity was 1, 0, 0.5 and 7 (NTU) in water from Aishan, Meshwaf, Thi-Majed, and Mosala wells respectively. These results are higher than the results found in water from wells in Dhamar city (Amran et al., 2018). The variations in TDS and EC in water may revert to the variation in the site and the depth of wells and the type of earth layers, but the high value of turbidity is related to contamination of water by clay, plant, and animal residues as reported by (Al-Ghamdi et al., 2014). These results are comparable with the results of Operacz et al. (2020), who found that the EC and TDS value in water from the geothermal borehole in Podhale Basin, Poland, was 1380 µS/cm and 1116.8 (mg/$dm^3$), respectively. The turbidity and EC values in water from the Mosala well are above the Yemeni standards for drinking water (YSMO, 2005), while the water samples from other wells included in this study are within the Yemeni standards.

**3.1.3. pH, total hardness, and iron content of water.**

The results in Table 2 also showed the pH value in the water from the geothermal wells included in this study. The highest value was in the water from Aishan well (8.87), above the drinking water standards limit (YSMO, 2005), whereas it was 7.94, 7.99, and 7.32 in the water from Meshwaf, Thi-Majed, and Mosala wells, respectively. These results fell in the range of Operacz et al. (2020), who found that the pH value in water samples from geothermal boreholes in Podhale Basin in Poland ranged between 6.42- 9.32. It is also similar to the results found in water from geothermal wells (4076) and (4057) in Sacuieni, Bihor County, Romania was 7.2 and 8.2, respectively (Sebesan et al., 2019), but are higher than the pH values of water samples from five hot springs in Eritrea (7.02-7.54) (Ghilamicael et al., 2017). The total hardness and iron contents found in this study were (10, 108, 114, and 70 mg/L) and (0.03, 0.03, 0.04, and 0.06 mg/L) in water from Aishan, Meshwaf, Thi-Majed, and Mosala wells, respectively (Table 2). All these values were within the limits of drinking water standards (YSMO, 2005). These results agree with the results found by Amran et al. (2018) in water samples from the wells that feed the Dhamar city drinking water distribution system.

Table 2 shows a comparison in physicochemical properties of water from geothermal and non-geothermal wells in Dhamar city. The water from Mnqd'h valley and Azzan wells (non-geothermal wells) was lower TDS, EC, and turbidity value, but it was higher in total hardness than the water from geothermal wells included in this study. This TDS and EC value variation might be related to the variation in water temperature between geothermal and non-geothermal wells, but water's other physicochemical properties were not affected by its temperature. These results agree with the results found by Oyem et al. (2014), who noticed a positive correlation between the temperature value and TDS and EC value in groundwater from Boji/Owa area and immediate Suburbs. As temperatures change, the chemical state and the composition of groundwater will be changed (Al-Ghamdi et al., 2014); temperature changes could trigger variations in physical, chemical, and microbial processes in the subsurface environment and cause changes in groundwater quality (Saito et al., 2016).

**Table 2.** Physicochemical properties of water from geothermal and non-geothermal wells in Dhamar city

| Well name | TDS (ppm) | EC (µs/cm) | Turbidity (NTU) | pH | Hardness (mg/L) | Iron (mg/L) |
|---|---|---|---|---|---|---|
| Geothermal wells | | | | | | |
| **Aishan** | 316.6 | 633.3 | 1 | 8.87 | 10 | 0.03 |
| **Meshwaf** | 316.6 | 633.3 | 0 | 7.94 | 108 | 0.03 |
| **Thi-Majed** | 320 | 640 | 0.5 | 7.99 | 114 | 0.04 |
| **Mosala** | 936.6 | 1860 | 7 | 7.32 | 70 | 0.06 |
| Non-geothermal wells | | | | | | |
| **Mnqd'h valley** | 210 | 420 | 0.71 | 8.03 | 60 | 0.05 |
| **Azzan** | 215 | 430 | 1 | 8.05 | 140 | 0.03 |

### 3.2. Microbiological properties of water.

Total bacterial count and total coliform count were conducted in geothermal and non-geothermal wells in Dhamar city to confirm the microbial contamination of water.

#### 3.2.1. Microbiological quality of water.

Total bacterial count of all geothermal water samples from the wells included did not have a significant variation which was 4.47, 4.24, 4.35, and 4.60 (log CFU/mL) in water from Aishan, Meshwaf, Thi-Majed, and Mosala wells, respectively (Table 3). This total bacterial count was above WHO standards for drinking water (WHO, 2008). These results are similar to Petursdottir & Kristjansson (1996), who found the viable bacterial count in the Blue Lagoon was 1.3 × $10^5$ CFU/mL. However, it is higher than the total bacteria count found in the borehole of Peninsula hot springs, Australia (1800 cfu/mL) (Aburto-Medina et al., 2020), and it is higher than the total bacterial count obtained in water from the wells that feeding the drinking water distribution system of Dhamar city (Amran et al., 2018).

**Table 3.** Microbiological quality of water from geothermal and non-geothermal wells in Dhamar city

| Parameters / Well name | Total Bacterial count (Log CFU/mL) | Total Coliform. (MPN/100 mL) |
|---|---|---|
| Geothermal wells | | |
| **Aishan** | 4.47 | $\leq 3$ |
| **Meshwaf** | 4.24 | $< 3$ |
| **Thi-Majed** | 4.35 | 6.06 |
| **Mosala** | 4.60 | 9.66 |
| Non-geothermal wells | | |
| **Mnqd'h valley** | 3.67 | $< 3$ |
| **Azzan** | 2.5 | $< 3$ |
| **Maximum limits*** | < $10^4$ cfu/mL | 0/100 mL |

* WHO, (2008).

The coliform standard is the primary indicator for health risk associated with water for drinking and bathing (Barrell et al., 2000). The MPN value of total coliform was between $\leq 3$, $< 3$, 6.06 and 9.66 MPN/100 mL in the geothermal water from Aishan, Meshwaf, Thi-Majed, and Mosala wells, respectively (Table 3). These results were similar to Aburto-Medina et al. (2020), who found that the total coliform count in geothermal waters from Peninsula hot springs, Australia was <1 cfu/mL. Similar to Thorolfsdottir & Marteinsson (2013) results, they found higher fecal contamination in the geothermal pools in Iceland, where the geothermal water flow was low and bathing guest count was high during the day. High microbiological loads in water from these sources might be related to the contamination from wastewater drainage from Dhamar city and the animal wastes used as fertilizers in agriculture practices in farms near these wells. The variation in water temperature did not affect its microbiological loads. Table 3 showed that the total bacterial and coliform counts in water samples from non-geothermal wells were lower than those from geothermal wells included in this study. This difference in microbial pollution in water may relate to the variation in water temperature that encourages bacteria to grow and multiply in geothermal water. The healthy location might be one of the reasons for variation in microbial loads of water. Surface pollutants can pass through the soil layers into water (Bantin et al., 2020).

## 5. Conclusion

All physical and chemical properties of water from these sources are within the Yemeni standards for drinking water except pH value in water from Aishan well and turbidity and EC value in water from Mosala well, which was above these standards. In contrast, the microbiological properties are above these standards. Temperature values in water from geothermal wells included in this study are low and insufficient for electrical generation purposes. More studies for other geothermal properties in water from these sources are needed. Water temperature values caused some variation in water physicochemical properties such as TDS and EC parameters.

**Conflict of interest.** The author declares that there are no conflicts of interest regarding the publication of this paper.

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