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Study of holy water consumed to treat gastrointestinal ailments in gold deposit areas of May-Hibey, Northwestern Tigray, Ethiopia

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ABSTRACT

In Ethiopia, holy water is used to treat various ailments. This study examined the safety of holy water in May-Hibey, NW Tigray, Ethiopia consumed to treat gastrointestinal ailments. Sensory observation, compositional and elemental analyses of rock samples, and analyses of physicochemical properties and inorganic constituents of holy water samples were conducted. Sensory observation revealed that the water had a musty taste and rotten egg-like odor. Its consumption in drinking rituals caused instant vomiting and loose bowels. Geological studies of rock samples via X-ray diffraction revealed Si (62.456%), Fe (15.441%), and S (7.912%) as major elements. Physicochemical analyses of the holy water samples showed that temperature, electrical conductivity, total dissolved solids, pH, total alkalinity, total hardness, and concentrations of calcium, magnesium, iron, and sulfate were above the permissible limits of the World Health Organization and the Ethiopian Standards Agency. These imply that holy water is unsafe and may cause health complications. Patients believe instant vomiting and diarrhea after drinking rituals are parts of the treatment process. But such effects might be due to the high sulfate content and other chemical properties of the holy water. Studies for establishing the physiological effects of holy water on patients with gastrointestinal ailments are required.

Key words: gastrointestinal ailments, gold deposits, holy water, May-Hibey, sulfate

HIGHLIGHT

- Physical observation of the holy water consumed for treatment rituals was suspected of harmful characteristics.
- Study of its physicochemical characteristics and rock samples of the area showed high sulfur content with many drinking water parameters outside the permissible limits of the WHO and ESA.
- This preliminary scientific study recommends that drinking rituals for extended duration are avoided.

1. INTRODUCTION

Nearly 80% of the people in the developing world depend on traditional medicine for their healthcare needs due to its low cost, high efficacy, and accessibility (Bodeker *et al.* 1997; WHO [World Health Organization] 2002). According to the World Health Organization (WHO), about 40–60% of the populace attending traditional medicine and healing have mental health illnesses (WHO 2002; Baheretibeb *et al.* 2021). As is true for the developing world, four-fifths of the Ethiopian population is still dependent on traditional medicine (Abebe & Hagos 1991). The Ethiopian traditional healthcare system mainly depends on the use of medicinal plants (Abebe & Ayehu 1993; Osman *et al.* 2020). Holy water treatment is also a major part of the Ethiopian traditional healthcare system, especially among the Ethiopian Orthodox Christian community (Teshome-Bahire 2000; Hannig 2013; Baheretibeb *et al.* 2021). Many mental health problems and medical mysteries that challenge modern knowledge of biomedicine and the medical community are often referred to as holy water (holy spring) treatment by traditional healers and Orthodox Christian priests regardless of the patients' religious affiliations.

Holy waters (holy springs) are naturally available in many forms, such as waterfalls, small streams, small reservoirs, and narrow pits. Treatment rituals are carried out in the holy water sites by getting hit by the holy waterfall on the head and shoulder, bathing or wetting oneself with the holy water, getting splashed on the face by the holy water by a priest, immersing oneself in a reservoir or pit of holy water, drinking the holy water, and a combination

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of these rituals. Holy water is believed to embody the spirit of Christ in its healing power and is often used to aid in exorcising demons and evil spirits (Teshome-Bahire 2000; Hannig 2013). Thus, drinking is a rare treatment ritual. It is also believed that holy water loses its healing power if it is taken out of the holy spring site. The treatment rituals are carried out one to three times a day; often in the morning, early afternoon, and in the evening. The rituals can go for consecutive 3, 7, 14, or 21 days. Sometimes, patients may resist carrying out any of the treatment rituals by themselves. Relatives and attendants are involved in assisting or forcing them to carry out the rituals (Baheretibeb *et al.* 2021). We, the authors of this article, have carried out the treatment rituals many times in our lifetimes and witnessed many patients cured by holy water treatment.

The spring water in May-Hibey is one of the holy waters (springs) in Tigray, Ethiopia. It is collected in three rocky, shallow reservoirs (ponds) along its 1.5 km stream. The holy water site is visited by hundreds and sometimes thousands patients with various ailments each year. Treatment rituals in this site are immersing in, and drinking of the holy water. The May-Hibey area is known for its gold deposits (Giday & Konka 2017). Causal sensory observation also indicated that the area may have a high level of sulfur. The beds (floors) and the rims of the stream and the holy water reservoirs as well as the rock surfaces of the area are covered by yellowish coats. The air of the holy water site has also an unpleasant odor, characteristic of rotten eggs. Moreover, patients with gastrointestinal ailments drinking holy water lose their gastrointestinal contents instantly by vomiting and loose bowels (diarrhea). The yellowish rock surfaces of the area, the rotten egg-like odor of the air, and the instant vomiting and diarrhea effects of the holy water on the patients obliged us to suspect the presence of high sulfur levels in the holy water that can cause other health complications. Hence, the present study aimed to describe the characteristics of holy water samples collected from holy water reservoirs and to establish their safety for the drinking rituals. The findings of this preliminary exercise will serve as a stepping-stone for future large-scale research and development and for devising practical measures in regard to this public health concern.

2. MATERIALS AND METHODS

2.1. The study area

The study area is located in the Northwestern Zone of Tigray Regional State, Ethiopia, which is around 294 km northwest of Mekelle city, capital of Tigray. It is nearly 9 km^2, lies between 1,545,650 and 1,548,750 m N and between 387,130 and 390,000 m E. It is accessible by asphalt road from Mekelle via Enda-Selasse to Enda'abaguna and by all-weather gravel road from Enda'abaguna via Meli to the study area at May-Hibey (Giday & Konka 2017).

2.1.1. Geography

The study area is characterized by moderately rugged topography with elevations ranging from 1,002 to 1,302 m and a dendritic drainage pattern. The mainstream of the study area, called May-Tsekente, flows from northwest to southeast.

2.1.2. Geology

The May-Hibey area forms the Neoproterozoic stratigraphy of northern Ethiopia. It comprises metavolcanic, metavolcaniclastic, metasediment, and intrusive syn-tectonic granites. The rocks are intruded by younger aplitic, mafic dykes, and quartz veins. Gold mineralization is interpreted as syn-orogenic lode gold type. As a gold deposit region, the area is characterized by deposits of metal sulfides (Giday & Konka 2017).

2.1.3. Human activities

May-Hibey is home to a sparsely populated farming community that depends on crop cultivation and animal rearing (Giday & Konka 2017). The study area is also a traditional gold mining site that attracts several dozen miners from near and distant places. Moreover, May-Hibey is a site of a holy spring (holy water) that attracts several hundred patients seeking holy water treatment and healing.

2.1.4. Ecology

May-Hibey is a semi-arid to arid area and sparsely vegetated with thorny bushes. Its daily temperature ranges from 28 to 32 °C. Much of the land is punctured by gold mining pits. The soil is highly eroded. Nowadays, the stream dries up quickly after the end of the rainy season. The vegetation is exploited for fuel by the natives, miners, and patients.

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2.1.5. Holy water

Spring water trickles from the foot of the mountain and flows downstream for about 1.5 km. The water is regarded as 'holy' by the community and Ethiopian Orthodox Christian priests of the area. Hence, three simple, rocky reservoirs are constructed along the stream, which are around 500 m apart from each other. The reservoirs hold the holy water to be used for treatment and healing via drinking and immersing (wetting). The floors and walls of the reservoirs are covered by yellowish, rocky coats. Each reservoir is enclosed by curtains tied to simple, makeshift stands or trees. Patients take some water from the reservoirs and carry it to the banks of the stream to perform the wetting (rinsing) and drinking rituals.

2.2. Collection of samples

The study assessed the physicochemical characteristics of the holy water and rock samples collected from the floors of the holy water reservoirs, which are regarded as sampling sites.

2.2.1. Holy water

Three holy water samples were collected in triplicate from each of the three reservoirs. Sample collection, preparation, handling, and analyses were carried out as per established methods on the topic (Gebresilasie *et al.* 2021). The samples were labeled, preserved in an icebox at 4–10 °C, and shipped to the geochemical laboratory in the College of Natural and Computational Sciences (Mekelle University) and the analytical laboratory of Ezana Mining Share Company, Mekelle, Ethiopia, for analyses.

2.2.2. Rock samples

Rock samples were also collected from the floors of the three holy water reservoirs in triplicate and were packed in a dry paper box. The samples were shipped to the analytical chemistry laboratory of the College of Natural and Computational Sciences (Mekelle University) and spread on the laboratory bench for 1 week to dry up completely. Then 300 g of rock sample was crushed and ground in a disc mill to <74 μm diameter size in the analytical laboratory of Ezana Mining Share Company. The ground sample was packed in 100 g sample holder boxes for further study.

2.3. Qualitative observation

2.3.1. Ethical clearance

The proposal for this study was reviewed and approved by the Ethical Review Committee of the Department of Chemistry, College of Natural and Computational Sciences, Mekelle University. Therefore, an on-site qualitative study was carried out by the first author using non-participant observation and organoleptic methods (Liu & Maitlis 2010; Boskou 2015).

2.3.2. Non-participant observation

The author stayed in the holy water site for 1 day (from 6:00 AM to 6:00 PM) to observe the population of patients, their treatment rituals and reactions, and collect some qualitative data (Liu & Maitlis 2010). He also carried out causal discussions with some patients who performed each of the treatment rituals and recorded their stories.

2.3.3. Organoleptic studies

This study was carried out by a panel of 20 volunteering patients who were carrying out the holy water drinking rituals (Boskou 2015). All of them were adult males belonging to the Ethiopian Orthodox Christian community. After signing the informed consent document, each of them responded to a questionnaire on the taste and odor of the holy water. The responses of the panel of volunteers were used in establishing the organoleptic properties of the holy water.

2.4. Laboratory studies of samples

2.4.1. Compositional and elemental analyses of rock samples

Compositional analyses of the processed rock samples were conducted via energy-dispersive X-ray fluorescence (EDXRF 2800) and flame atomic absorption spectroscopy (FAAS) in the laboratories of the Ethiopian Ministry of Mines (Addis Ababa, Ethiopia) and Ezana Mining Share Company (Mekelle, Ethiopia), respectively. Crystallinity of each rock sample was determined using X-ray diffraction (XRD) at Adama Science and Technology University

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(Oromia, Ethiopia). The XRD output was subjected to pattern processing and identification using Jade 6 software (MD, USA) and plotted using Origin 8.0 software (OriginLab Corp., USA).

2.4.2. Analyses of physicochemical properties and inorganic constituents of holy water samples

Holy water samples were analyzed for physicochemical properties and contents of inorganic elements and ions, namely, temperature, pH, turbidity, dissolved oxygen (DO), electrical conductivity (EC), total dissolved solids (TDS), total alkalinity (TA), total Ca, and Mg hardness, Ca, Mg, Na, K, chloride, sulfate, phosphate, and nitrate ions as well as heavy metals using standard analytical methods (ESA [Ethiopian Standards Agency] 2013; Gebresilasie *et al.* 2021). pH was measured using a pH meter (HI-99130, Italy). EC was measured using a conductivity meter (JENWAY, Multi-3410, UK). Turbidity was measured by turbidimeter (AL 250T-IR, Germany). Temperature was measured on-site using a mercury thermometer. DO was determined using a multi-parameter (Multi-3410, Germany). TA was determined by the titrimetric method. The total, Ca, and Mg hardness were determined using the ethylenediaminetetraacetic acid (EDTA) titrimetric method. Chloride concentration was analyzed using argentometric titration. The concentrations of K and Na ions were determined using flame photometry (JENWAY, PFP7, UK). Likewise, the concentrations of sulfate, phosphate, and nitrate ions were measured through UV–visible spectrophotometer (Lambda, CE1021, Australia). Finally, concentrations of heavy metals were determined by FAAS (AA240FC, Australia).

2.5. Analyses and presentation of data

Collected data were analyzed using descriptive and inferential statistical methods with the help of SPSS (Version 20) software. Descriptive data obtained from EDXRF and FAAS were presented in percentages and mg/L. Inferential data on the physicochemical properties and concentrations of inorganic constituents of the holy water samples were analyzed using a *t*-test and presented in mean (±standard deviation) values. Finally, the mean (±SD) values were compared against the permissible limit set for drinking water by the ESA (2013) and the WHO (2010).

3. RESULTS AND DISCUSSION

3.1. Physical observation

3.1.1. Non-participant observation

According to the Ethiopian Christian Orthodox faith, many springs in the country, especially in Tigray, are regarded as holy. Members of the Ethiopian Christian Orthodox faith believe that bathing in and drinking holy waters (holy springs) cures patients of various physical and mental ailments (Baheretibeb *et al.* 2021). Patients suffering from gastrointestinal ailments are advised by traditional healers and Orthodox Christian priests to drink the holy water for three or more days to get cured. Drinking holy water may make patients lose their gastrointestinal contents through instant vomiting and loose bowels (diarrhea). In the present study, patients who were carrying out the holy water drinking rituals affirmed that they were doing it to be cured of gastrointestinal ailments as per advice they received from priests and traditional healers. The first author observed many patients vomiting instantly after drinking the holy water. Many of them attested that their gastrointestinal discomforts were gone and they felt that they were cured. Instant diarrhea may be attributed to the laxative properties of the holy water (Skipton *et al.* 2010). Studies with humans and experimental animals reported that the consumption of water containing higher amounts of sulfate for a few days to a few weeks did not cause any adverse effects except diarrhea or cathartic effects (e.g., Paterson *et al.* 1979; Gomez *et al.* 1995).

3.1.2. Organoleptic properties

All (100%) members of the panel of participants attested to the musty or swampy taste and rotten egg-like odor of the holy water samples. Sulfates occur naturally as part of many minerals, including iron pyrite (FeS), barite ($BaSO_4$), epsomite ($MgSO_4{\cdot}7H_2O$), and gypsum ($CaSO_4{\cdot}2H_2O$) (Greenwood & Earnshaw 1984). These sulfate-containing minerals release some of their contents to water bodies including drinking water (WHO 2004). Likewise, gold sulfide ores, which contain metal sulfides, can release hydrogen sulfide (H_2S) into water bodies. In addition to the swampy taste and rotten egg-like odor of the holy water samples, the rocks on the beds and walls of the holy water reservoirs were yellowish. These indicate the presence of H_2S in the holy

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water. H_2S is easily detectable in water at concentrations as low as 0.5 mg/L. The U.S. EPA (United States Environmental Protection Agency) regarded sulfur at 250 mg/L concentration as a secondary water contaminant with no direct threat to human health at concentrations below 600 mg/L (U.S. EPA [U.S. Environmental Protection Agency] 2003). Similarly, the WHO has established that less than 1.0 mg/L H_2S gives water a musty (swampy) odor and 1.0–2.0 mg/L concentration gives it a rotten egg-like smell (WHO 2010). Sulfates can have laxative effects that may lead to dehydration; and the rotten egg-like tastes and the odor of H_2S can cause nausea (Skipton *et al.* 2010; ESA 2013), leading to vomiting.

3.2. Geochemical observation

The compositional and elemental analyses of the rock samples showed Si (62.456%), Fe (15.441%), and S (7.912%) as major elements. The rock samples yielded analytical-grade gold at 4.356 mg/L concentration (Table 1). Moreover, XRD spectra showed quartz as the dominant phase infraction (Figure 1). The XRD quantitative analysis of the rock samples also showed that the major constituents were quartz, syn (major, SiO_2), silicon sulfide (SiS_2), and polymetallic complexes. The polymetallic complexes were comprised of pyrite (FeS_2), boron nitride (BN), gismandine ($CaAl_2Si_2O_8{\cdot}4H_2O$), siderenikite ($Na_3Mn(PO_4)(CO_3)$), and hematite syn ($Fe_2O_3$). These findings show that the rock samples have high compositions and patterns of sulfur, iron, and gold. In fact, May-Hibey was known to have high gold deposits (Giday & Konka 2017). This study affirmed that the gold deposit exists as gold sulfide ore. These observations imply that weathering of sulfide rocks and gold sulfide ore supply high levels of sulfate to the holy water.

Table 1 | Compositional analyses of concentrated rock samples using EDXRF (%wt) and FAAS (mg/L)

Elemental quantities	Elements													
	Ag	Au	Ti	Sb	Si	Cr	S	Fe	Al	Cu	Ni	Pb	Mn	As
%Wt	–	–	2.012	0.012	62.456	4.128	17.912	15.441	6.342	0.052	1.342	0.372	0.322	2.443
mg/L	11.232	4.356	–	–	–	–	–	–	–	–	–	–	–	–

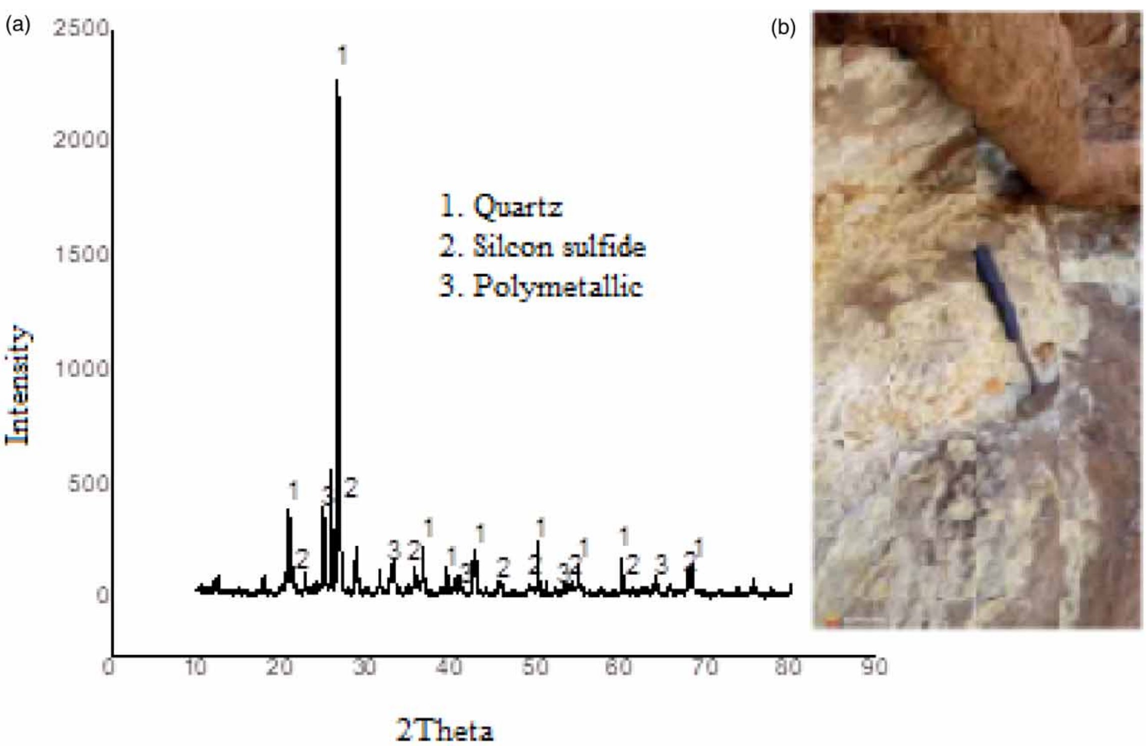

Figure 1 | XRD patterns of gold sulfide ore of the deposit.

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3.3. Physicochemical analyses

3.3.1. Temperature

Temperature is an important physicochemical parameter used in evaluating water quality. It affects the rates of chemical reactions and solubility of gases in the water (Benit & Roslin 2015). Moreover, it may enable the water to enhance or inhibit the growth of microorganisms that affects its taste, odor, and color (Agudelo-Vera *et al.* 2020). In the present study, the mean temperature of the holy water samples ranged from 31.11 (±0.13) to 32.20 (±0.11) (Table 2) – that was above the 25 °C limit established by the WHO (2010) for drinking water. Such higher water temperature could be attributed to the hotter environmental temperature of May-Hibey (Giday & Konka 2017; Gebresilasie *et al.* 2021). Weathering releases reactive constituents such as iron, copper, lead, and gold sulfides. Fe–S bacteria also produce iron sulfide. Chemical reactions in the aquifer that involve these metallic sulfides can raise the temperature of the holy water (U.S. EPA 2003; Saana *et al.* 2016). The high aquifer temperature raises the concentration of H_2S in the holy spring and releases it into the air to give a characteristic rotten egg-like odor.

3.3.2. Turbidity

Turbidity is the measure of water resistance to the passage of light. Suspended soil and sediment particles, carbon-based substances released from gold sulfide deposits, and aquatic microbes enhance turbidity. High water turbidity, in turn, increases the light absorption capacity of the water to raise its temperature (Hawkins & Mann 2007; Gebresilasie *et al.* 2021). In the present study, the mean turbidity values of the holy water samples ranged from 2.19 (± 0.02) to 2.51 (± 0.03) NTUs (Table 2). The values were less than the 5.00 NTUs limit set for drinking water by the WHO (2010) and ESA (2013). This implies that turbidity was less likely to be the principal cause of the high temperature of the holy water samples.

3.3.3. Electrical conductivity

EC is the function of dissolved inorganic matter in ionized form. The mean EC of the holy water samples in the present study ranged from 1,121.00 (±0.11) to 1,292.00 (±0.22) μS/cm (Table 2). The values fall between the

Table 2 | Physicochemical characteristics and concentrations of metallic and non-metallic ions and heavy metals of holy water samples of May-Hibey

		Measurements of physicochemical parameters (mean ± SD) ($n = 3$)				
Physicochemical parameters	**UoM**	**Reservoir 1**	**Reservoir 2**	**Reservoir 3**	**WHO (2010)**	**ESA (2013)**
Temperature	°C	32.20 ± 0.11	31.11 ± 0.12	30.11 ± 0.13	25.00	–
Turbidity	NTU	2.19 ± 0.02	2.61 ± 0.03	2.51 ± 0.01	5.00	5.00
EC	μS/cm	1,251.00 ± 0.52	1,121.00 ± 0.11	1,292.00 ± 0.22	750.00	1,500.00
TDS	mg/L	1,123.21 ± 0.70	1,238.11 ± 0.12	1,281.21 ± 0.12	500.00	1,000.00
pH	–	5.10 ± 0.21	4.92 ± 0.11	5.00 ± 0.01	6.50 – 8.50	6.50 – 8.50
DO	mg/L	5.60 ± 0.11	5.87 ± 0.01	5.78 ± 0.12	5.00 – 7.00	–
TA	mg/L	215.00 ± 5.00	208.00 ± 5.00	221.00 ± 5.00	120.00	200.00
Total hardness	mg/L	375.30 ± 3.00	385.20 ± 3.00	376.20 ± 3.00	300.00	300.00
Calcium	mg/L	85.11 ± 0.13	89.12 ± 0.12	92.12 ± 0.12	100.00	75.00
Magnesium	mg/L	55.12 ± 0.27	53.11 ± 0.34	62.12 ± 0.11	50.00	50.00
Sodium	mg/L	92.15 ± 0.11	102.12 ± 0.14	112.11 ± 0.32	200.00	200.00
Potassium	mg/L	8.23 ± 0.14	9.30 ± 0.13	9.62 ± 0.82	10.00	15
Chloride	mg/L	72.42 ± 0.20	67.11 ± 0.02	81.02 ± 0.22	250.00	250.0
Sulfate	mg/L	412.00 ± 0.23	452.11 ± 0.29	422.11 ± 0.14	250.00	250.00
Phosphate	mg/L	0.18 ± 0.12	0.23 ± 0.12	0.22 ± 0.12	2.00	2.00
Nitrate	mg/L	15.43 ± 0.63	11.86 ± 0.26	12.02 ± 0.82	45.00	50.00
Iron	mg/L	24.16 ± 0.11	26.00 ± 0.17	28.11 ± 0.23	0.30	0.30
Heavy metals	mg/L	BDL	BDL	BDL	0.01 – 5.0	0.01 – 5.0

Heavy metals such as Cu, Zn, Mn, Ca, Pb, Cr, and Au are used in standard analytical methods.
NTUs, Nephelometric Turbidity Units; UoM, unit of measurement; WHO, the World Health Organization; ESA, the Ethiopian Standard Agency; SD, standard deviation; BDL, below the detection limit.

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permissible limit set for drinking water by the WHO (2010) (i.e., 750.00 μS/cm) and the ESA (2013) (i.e., 1,500.00 μS/cm). High EC is attributed to the presence of high amounts of dissolved ions (Gebresilasie *et al.* 2021). The high amount of dissolved ions is characteristic of gold deposit areas. EC has direct relationships with sulfate ion concentration, TDS, total hardness (TH), total alkalinity, and concentrations of polymetallic ions.

3.3.4. Total dissolved solids

TDS is the measure of all solutes in water. The mean TDS of the holy water samples ranged from 1,123.21 (±0.70) to 1,281.21 (±0.12) mg/L. The mean values were much higher than the tolerable limits set for drinking water by the WHO (2010) (i.e., 500.00 mg/L) and the ESA (2013) (i.e., 1,000.00 mg/L) (Table 2). Such high levels of TDS in the holy water reservoirs might be attributed to the accumulation of dissolved metallic ions as a result of the dissolution of weathered constituents from metallic sulfides (Sonkar & Jama 2019) such as silicon sulfide (SiS_2), pyrite (FeS_2), and hematite syn (Fe_2O_3). The unpleasant tastes and odors of the holy water samples, affirmed by the respondents of the organoleptic study, might also be due to the presence of various inorganic ions that increased the level of TDS (John *et al.* 2014; Gebresilasie *et al.* 2021). Water with high TDS content can have laxative effects (Kataria *et al.* 2011; Benit & Roslin 2015; Yasin *et al.* 2015; Aniyikaiye *et al.* 2019).

3.3.5. pH

The mean pH values of the holy water samples ranged from 4.92 (±0.11) to 5.10 (±021). The mean values were much lower than the range (i.e., 6.50 – 8.50) set for drinking water by the WHO (2010)) and the ESA (2013) (Table 2). Such low pH values, which make the holy water acidic, are expected in water samples with high EC and TDS. The low pH and other attributes (high EC and TDS) render the water unsuitable for drinking. Long-term holy water drinking rituals from this source can also be harmful.

3.3.6. Dissolved oxygen

DO is a vital water quality parameter. It is an indicator of water contamination due to microbes and corrosive chemical constituents. A reduced amount of DO is an indication of microbial contamination or corrosion because of chemical substances in the aquifer (U.S. EPA 2003; Gebresilasie *et al.* 2021). The mean DO values of the holy water samples in the present study ranged between 5.60 ± 0.01 and 5.87 ± 0.01 mg/L. The values were within the WHO's (2010) range for drinking water (i.e., 5.00–7.00 mg/L) (Table 2). The level of DO in natural waters is highly reduced because of high temperatures and high concentrations of inorganic ions as a result of a high rate of decomposition of metallic sulfides (Ebenezer 2014). At low DO levels and pH values of less than 7, sulfur occurs as H_2S (Skipton *et al.* 2010; Gebresilasie *et al.* 2021). Thus, the low DO and pH mean values can be regarded as the contributing factors for the musty taste and rotten egg-like smell of the holy water.

3.3.7. Total hardness

TH of water is the measure of dissolved polyvalent metallic ions of calcium and magnesium (Spanos *et al.* 2015). Water below 150 mg/L TH is considered soft, whereas water above 200 mg/L TH is considered hard. The mean TH of the holy water samples in the present study ranged from 375.30 (±3.00) to 385.20 (±3.00) mg/L (Table 2). The values were above the maximum allowable limit of 300.00 mg/L for drinking water set by the WHO (2010) and the ESA (2013). The higher hardness of the holy water might be due to the dissolution of gypsum- and dolomite-containing rocks (Kassa 2015; Gebresilasie *et al.* 2021). The hardness may be permanent as chloride, sulfate, and nitrate salts were present.

3.3.8. Total alkalinity

TA is a measure of the ability of water to neutralize acids mainly because of its carbonate and bicarbonate contents (Gebresilasie *et al.* 2021). The mean TA of the holy water samples ranged between 208.00 (±5.00) and 221.00 (±5.00) mg/L (Table 2). The mean values were above the allowable limit of the WHO (2010) (i.e., 120.00 mg/L) but within the allowable limit of the ESA (2013) (i.e., 200.00 mg/L) for drinking water. This is directly related to the TH of the holy water. The alkalinity of natural waters is the result of the dissolution of carbonate, bicarbonate, borate, silicate, and phosphate salts, and free hydroxyl ions (Woldeamanuale 2017). Hence, TA is the function of calcium, magnesium, sodium, potassium, chloride, and sulfate ions (Gebresilasie *et al.* 2021). However, the yellowish color of the rocky beds (floors) of the holy water reservoirs and the characteristic taste and odor of the holy water samples imply the presence of high amounts of metallic sulfides and low amounts of carbonates.

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3.4. Analyses of inorganic ions and heavy metals

3.4.1. Calcium

Calcium ion (Ca^{2+}) is one of the major components of various rock types. It is, thus, the most common constituent of natural waters ranging from zero to several hundred mg/L (Ndamitso *et al.* 2013). The mean Ca ion contents of the holy water samples ranged from 85.11 ($\pm$0.13) to 92.11 ($\pm$0.12) mg/L. These values were within the acceptable limit set by the WHO (2010) (100.00 mg/L), but above the value set by the ESA (2013) (75.00 mg/L) for drinking water (Table 2). Ca ion reaches groundwater by the natural dissolution of carbonate and decomposition of sulfate, phosphate, and silicate minerals and forms solid scaling on the floors or beds of water bodies (Mensah 2011). Groundwater from gold deposit areas is often hard due to high Ca ion concentration (Kassa 2015; Gebresilasie *et al.* 2021).

3.4.2. Magnesium

Magnesium ion (Mg^{2+}) is another major component of many rock types. It is the most common constituent in natural waters (Ndamitso *et al.* 2013). The mean Mg ion contents of the holy water samples were 53.11 ($\pm$0.34) to 62.12 ($\pm$0.11) mg/L. They were above the permissible limits of the WHO (2010) and ESA (2013) (50.00 mg/L) set for drinking water (Table 2). The main sources of Mg ions for underground waters in gold deposit areas are geological constituents such as dolomite and Mg-containing compounds (Rahmanian *et al.* 2015).

3.4.3. Sodium

The mean Na ion (Na^+) concentrations of the holy water samples were between 92.15 ($\pm$0.11) and 112.11 ($\pm$0.32) mg/L (Table 2). These values are about halfway below the permissible limits established for drinking water by both the WHO (2010) and the ESA (2013) at 200.00 mg/L. When Mg and Na are combined with sulfate, they can have pronounced laxative effects (Benit & Roslin 2015).

3.4.4. Potassium

The mean K ion (K^+) concentrations of the holy water samples were between 8.23 ($\pm$0.14) and 9.62 ($\pm$0.82) mg/L (Table 2). These mean values are slightly less than the upper allowable limit set for drinking water by the WHO (2010) (i.e., 10.00 mg/L) and nearly halfway less than the limit set by the ESA (2013) (i.e., 15.00 mg/L).

3.4.5. Chlorine

The mean Cl ion (Cl^-) contents of the holy water samples ranged from 67.11 ($\pm$0.02) to 81.02 ($\pm$0.22) mg/L. They fall within the permissible limit set by the WHO (2010) and the ESA (2013) for drinking water at 250.00 mg/L (Table 2). The variations in Cl ion contents among the holy water samples might be because of variations in chloride salts in the gold deposits and sediments (Gebresilasie *et al.* 2021).

3.4.6. Sulfate

Sulfur is found in most groundwater bodies in different forms such as sulfate, bisulfide, and hydrogen sulfide depending on the amount of DO in the water and the degree of acidity (i.e., pH) of the water. If the DO level of the water is 1.00 – 2.00 mg/L, sulfur occurs as sulfate (S^{6+}) and sulfate molecules predominate. On the other hand, if the DO level is lower, it occurs as S^{2-} or HS^{-1} at pH > 7 and as H_2S at pH < 7 (John *et al.* 2014). In the present study, the mean sulfate ion $(SO_4)^{-2}$ contents of the holy water samples ranged from 412.00 ($\pm$0.23) to 452.11 ($\pm$0.29) mg/L. The values were much higher than the permissible limit set for drinking water by the WHO (2010) and the ESA (2013) at 250.00 mg/L (Table 2). The levels of sulfate in groundwater in many places are often less than 250 mg/L (UNEP [United Nations Environmental Programme] 1990; U.S. EPA 1999). The high sulfate levels might come from sulfate-containing minerals such as iron and gold sulfides (U.S. EPA 1999; Kataria *et al.* 2011; Obasi & Talabi 2015). They are collectively known as pyrite ores. Sulfate contents of spring waters are correlated to Ca, Mg, Na, and K ion contents. These constituents can lead to diarrhea, dehydration, and weight loss (U.S. EPA 2003; WHO 2004; Kataria *et al.* 2011; Benit & Roslin 2015).

3.4.7. Phosphate

The concentrations of phosphate ion (PO_4^{-2}) in all the holy water samples ranged from 0.18 ($\pm$0.12) to 0.23 ($\pm$0.12) mg/L. The values were far lower than the permissible limit set for drinking water by the WHO (2010)

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and the ESA (2013) at 2.00 mg/L (Table 2). The low concentration of the phosphate ion in the holy water samples is characteristic of gold deposit areas (Obasi & Talabi 2015; Gebresilasie *et al.* 2021).

3.4.8. Nitrate

The mean nitrate ion (NO_3^{-1}) concentrations in the holy water samples were between 11.86 (±26) and 15.43 (±0.63) mg/L (Table 2). These values were three to five times lower than the permissible limit set by the WHO (2010) at 45.00 mg/L and the ESA (2013) at 50.00 mg/L for drinking water.

3.4.9. Iron and other heavy metals

As naturally occurring constituents and synthetic pollutants, heavy metals are critical environmental and public health concerns (Pazalja *et al.* 2021; Rasheed *et al.* 2022). In the present study, iron was the only heavy metal detected in the holy water samples with concentrations ranging from 24.16 (±0.11) to 28.11 (±0.23) mg/L (Table 2). The values were about 80–95 times more than the permissible limit (i.e., 0.30 mg/L) set by the WHO (2010) and the ESA (2013) for drinking water. The higher amount of iron in the holy water could have come from the iron pyrite ore of the deposits. People consuming water containing high iron concentrations suffer from liver diseases (Eruola *et al.* 2011; Ocheri *et al.* 2014). The concentrations of the other heavy metals, namely, copper, zinc, manganese, cadmium, lead, chromium, and gold, were below the permissible limit set by both organizations.

4. CONCLUDING REMARKS

The yellowish rock surfaces and the beds (floors) of the holy water reservoirs and streams, the repulsive rotten egg-like odor of the air of the area, the musty (swampy) to rotten egg-like taste of the holy water, and the vomiting and loose bowel effects of the holy water on the patients need a plausible scientific explanation. The qualitative and quantitative examination of the geochemistry of the rock samples showed high levels of Si, Fe, S, and Au. Quantitative analyses of the physicochemical characteristics of the holy water samples showed high temperature, EC, TDS, TA, and TH and low pH as compared to the allowable limit set for drinking water by the WHO (2010) and the ESA (2013). Moreover, qualitative and quantitative studies of the inorganic ions of the holy water samples showed high levels of sulfate, calcium, magnesium, and iron ions.

At present, the plausible scientific explanation for the vomiting and loose bowel effects of the holy water is the presence of a high level of sulfur compounded by other physicochemical conditions such as high temperature, high EC, high TDS, low pH, high total alkalinity, and high total hardness as well as high concentrations of calcium, magnesium, and iron ions. Studies on the effects of sulfates on human health conducted between the 1970s and early 2000s (WHO 2004) showed that sulfate concentration as high as 1,500 mg/L has no serious effects except catharsis, diarrhea, and some dehydration (UNEP 1990; Esteban *et al.* 1997; U.S. EPA 1999). This implies that the vomiting and loose bowel reactions among the patients may not be linked to the healing effects of the holy water *per se*. Hence, patients carrying out drinking rituals have to concurrently seek medical attention. Moreover, the patients should be advised to avoid holy water drinking rituals for an extended time. Exploring the effects of the holy water on the physiology of the patients as well as against known gastrointestinal parasites and the normal human gut microbial flora may yield better empirical evidence on the effects of the holy water on gastrointestinal ailments.

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AUTHORS' CONTRIBUTIONS

G.G.B., D.B.S., and A.G. conceived the problem of the study. Both authors prepared research proposals and developed the design of the experiments. G.G.B. prepared the first draft of the manuscript and D.B.S. and A.G. reviewed it. D.B.S. edited and produced the submitted manuscript.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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