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Research article

Evaluation of groundwater quality for drinking water using a quality index in Abyi Adi, Tigrai, Northern Ethiopia

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A B S T R A C T

High quality, safe and sufficient drinking water is essential for public health and well-being. However, the war on Tigrai damaged the water sources of communities and pose people to health problems. Therefore, the aim of the present study was to assess the quality of water of the town of Abyi Adi, Tigrai, Northern Ethiopia using physicochemical and biological parameters and water quality indices. A total of 36 water samples were collected from four major water sources. The physicochemical and biological parameters were determined using standard analytical procedures for water analysis. The mean values of electrical conductivity and pH ranged from 273.63 to 881.27 μS/cm and 6.68 to 7.42, respectively. Moreover, the experimental results of major cations (Na^{+} = 3.70–14.77 mg/L and Ca^{2+} = 8.50–15.77 mg/L), and anions (HCO_3^- = 21.52–40.77 mg/L, Cl^- = 13.56–40.29 mg/L, NO_3^- = 0.14–0.25 mg/L, NO_2^- = 0.24–0.76 mg/L and PO_4^{3-} = 0.34–1.32 mg/L) were recorded below the World Health Organization (WHO) permissible limits set for drinking water. The water quality index (WQI) that is determined using a weighted arithmetic water quality index method (WAWQIM) was also found in the range of 5.3–37.2. Subsequently, all groundwater sources except Adibakla are classified as excellent or "A" rating. However, the total *coliform* of Maylomin and Chiny water sources were found to be 6.33 MPN/100 mL and 3.67 MPN/100 mL, respectively. Both are higher than the WHO permissible limit set for drinking water. Considering the susceptibility of groundwater to pollution and its impact to human health, regular monitoring and supervision should be performed to keep the water safe for drinking. Accordingly, chlorination water treatment process is recommended to provide safe drinking water.

Abbreviations

a.s.l.	Above Sea levels
CCMEWQI	Canadian Council of Ministers of the Environment Water Quality Index
FAAS	Fast sequential Atomic Absorption Spectrophotometer
NSFWQI	National Sanitation Foundation Water Quality Index
OWQI	Oregon Water Quality Index

(*continued on next page*)

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(*continued*)

%RSD	Percent Relative Standard Deviation
WAWQI	Weighted Arithmetic Water Quality Index
WHO	World Health Organization
WQI	Water Quality Indices

1. Introduction

The quality of water available to a community significantly impacts living standards and well-being of human beings. Nearly 97 % of water faces salination or any sort of contamination [1]. Global and local efforts are essential to ensure the public has access to clean and safe water [2]. The Human Right to Safe Drinking Water and Sanitation, stipulated in a United Nation's resolution, calls for safe, affordable, acceptable, available, and accessible water for drinking and sanitation [3]. Although water plays an essential role in supporting human life and biodiversity, it also poses a great risk in transmitting diseases if it is contaminated [4]. Population growth, rapid urbanization, industrialization, and other anthropogenic activities have contributed in the accumulation of waste and pollutants that end up in water bodies, thereby deteriorating water quality [5].

Groundwater is a vital source of potable water for human consumption and is also crucial for ensuring human health and protecting the environment [6]. However, its quality is vulnerable to both human activities and natural processes. Moreover, groundwater systems are dynamic and prone to contamination; if contaminated, remediation becomes challenging [7]. In many regions, drinking water quality has declined due to anthropogenic activities [8,9]. Thus, assessing water quality, treatment efficiency, and suitability requires consideration of physicochemical and biological parameters [10].

Water quality is one of the crucial parameters for determining water's suitability for human consumption. It is assessed by examining the physicochemical and biological characteristics of water, considering natural conditions, human impacts, and usage [11,12]. In determining water quality, various water quality indices (WQI) are used; among these the weighted arithmetic water quality index (WAWQI), the national sanitation foundation water quality index (NSFWQI), the Canadian council of ministers of the environment water quality index (CCMEWQI), and the Oregon water quality index (OWQI) are commonly accustomed [13,14].

The WQI is an effective tool for determining water suitability for drinking. It consolidates data from various parameters, reflecting their overall influence on water quality [15]. Parameters are weighted based on their significance, making the assessment easier

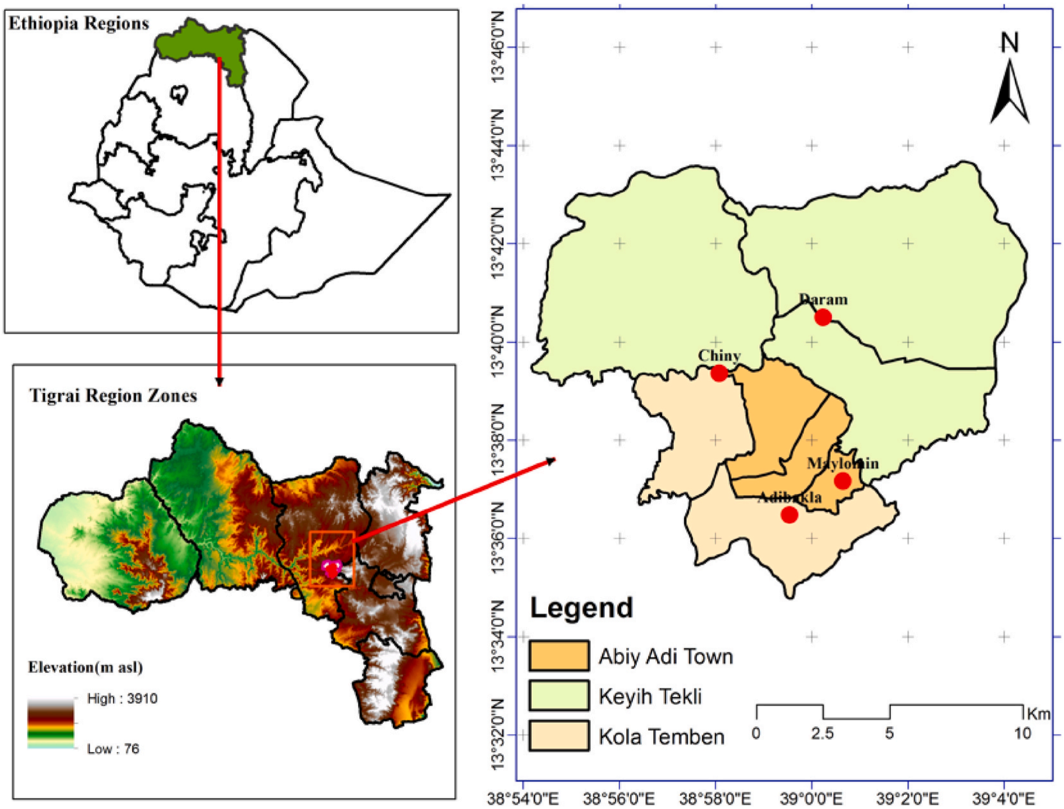

Fig. 1. Map of the study area.

despite its complexity [13]. Therefore, the WQI provides a single numerical value, indicating how the anthropogenic activities have impacted natural water quality [16]. Water quality indices is calculated as a weighted average of all observations of interest using WAWQI method. Thus, the WQI offers an understandable ranking from 0 to 100, where lower values denote better quality [17].

In Ethiopia, most communal water comes from rivers and underground aquifers. Due to the recent war on Tigrai, residents have raised concerns about water quality, poor management, and regulatory oversight in the town of Abyi Adi. Thus, evaluating drinking water quality is essential to ensure safety. To the best of our knowledge, there are no such exclusive works from Tigrai. Therefore, this study aimed to assess the physicochemical and biological parameters of water supply, determine water quality using the WQI method, and ultimately compare its quality with different standards.

2. Materials and methods

2.1. Description of the study area

Abyi Adi, located between 13°37′25″ to 13°49′14″ N latitude and 38°58′01″ to 39°20′19″ E longitude in Central zone of Tigrai, Northern Ethiopia, is bordered by Keyih Tekli to the north and east and Kola Temben to the west and south. It possesses plain topography at an elevation of 1907 m (a.s.l.). It experiences a subtropical steppe climate with an average annual rainfall and a mean annual temperature of 102.19 mm and 22.76 °C, respectively. Four water sources were purposely selected; Maylomin (spring water), Adibakla, Daram, and Chiny (boreholes) (Fig. 1). The study area covers the oldest Mesozoic formation of sandstone largely covered by basement rocks, namely Chiny, Daram and Adibakla are mostly covered by basement rocks and the top part of Maylomin is covered by sandstone, which is a sedimentary rock consisting of quartz sand and its lower area is basement. Moreover, characteristic data of the boreholes are summarized in the following way: Maylomin (flow rate: 2 L/s), Adibakla (depth: 140 m, flow rate: 3 L/s), Daram (depth: 198 m, flow rate: 4 L/s), and Chiny (depth: 105 m, flow rate: 4 L/s).

2.2. Chemicals, reagents and instruments

All chemicals and reagents used were of analytical grade. A pH meter (H199130 HANNA, Italy), a Nephlometric turbidity meter (Aquafluor 8000-001 Turner designs and thermometers for in-situ measurements), UV–Visible spectrophotometer (Lambda EZ201, PerkinElmer, Australia), and fast sequential atomic absorption spectrophotometer (FAAS) (Varian AA 240 FS, Australia) were used in the study.

2.3. Sample collection

A total of 36 drinking water samples were collected in triplicate from four sites over three consecutive dry months (January, February, and March). Samples were taken in prewashed double-capped polyethylene bottles, allowing water to run for 5 min before collection. Before sampling, bottles were rinsed off with the sample water three times. Samples for physicochemical and biological analysis were kept in a light-proof insulated box with ice packs. Samples for heavy metal analysis were preserved with 5 mL HNO_3 and transported to the Analytical and the Environmental Laboratory at Mekelle University for further analysis.

2.4. Physicochemical analysis

Analytical standard protocols were utilized to determine various physicochemical and biological parameters, such as temperature (T), pH, electrical conductivity (EC), turbidity (TUR), total solids (TS), total dissolved solids (TDS), total suspended solids (TSS), dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), total alkalinity (TA), calcium hardness, total hardness (TH), sodium (Na), calcium (Ca), bicarbonate (HCO_3^-), chloride (Cl^-), fluoride (F^-), nitrate (NO_3^-), nitrite (NO_2^-), sulfate (SO_4^{2-}) and phosphate (PO_4^{3-}). All measurements were performed in triplicate. Parameters such as temperature, EC, turbidity, and DO were measured *in-situ* during sampling [18,19].

2.5. Microbiological analyses

The total number of cultural heterotrophic bacteria was determined by serial dilution and plating on general purpose media. Serial dilutions of water samples (1 mL fresh volume) were made with one-fourth strength of Ringers solution. Plate counts of culturally viable bacteria were made on Try tone Soya Agar (TSA; Oxide, Basingstoke, Hampshire, England) amended with 0.1 g/L cyclohexamide. The plates were inoculated with 1 mL of water inoculum and cultured at 37 °C for 24 h [20].

2.6. Heavy metal analysis

About 500 mL of water sample was taken from each site and pre-concentrated to 100 mL in an oven at a temperature of 105 °C for 48 h. Next, 100 mL water sample was transferred into three separate digestive tubes and 20 mL conc. HNO_3 was added to each tube and allowed to evaporate at a temperature of 100 °C in a fume hood till half of its original volume on the digestive stove. The mixture was cooled and then filtered into a 100 mL volumetric flask using Whatman No. 41 filter paper. Finally, the supernatant solution was used to determine the total concentration of heavy metals, such as iron (Fe), copper (Cu), manganese (Mn), chromium (Cr), cadmium (Cd), and lead (Pb) using FAAS [21].

2.7. Determination of water quality index (WQI)

The Weighted Arithmetic Water Quality Index Method (WAWQIM) was used to evaluate water quality using the measured data of physicochemical parameters as described by Tvagi et al. [14] and Patel et al. [17,22], employing the following five steps: selection of parameter for the measurement of water quality; development of rating scale to obtain the rating value (Qi); estimating the unit weight of each indicator parameter (Wi); determining the sub-indices value (Wi x Qi); and aggregating the sub-indices to obtain the overall WQI [18]. Accordingly, the WQI was calculated using the following equation (Eq. (1)):

$$WQI = \frac{\sum Qiwi}{\sum wi} \tag{1}$$

The quality rating scale Qi for each parameter was calculated using the following expression (Eq. (2)):

$$Qi = 100\left[\left(vi - \frac{vo}{si} - vo\right)\right] \tag{2}$$

where v_i is estimated concentration of ith parameter in the analyzed water; v_0 is the ideal value of this parameter in pure water; v_0 = 0 (except pH = 7.0 and DO = 14.6 mg/L); and s_i is the recommended standard value of ith parameter.

The unit weight (wi) for each water quality parameter was also computed using the next formula (Eq. (3)):

$$wi = k/si \tag{3}$$

where k = proportionality constant, computed using the following equation (Eq. (4)):

$$k = \frac{1}{\sum\left(\frac{1}{si}\right)} \tag{4}$$

2.8. Statistical analysis

ANOVA tests were conducted for the parameters analyzed using SPSS (Version, 20). Moreover, quality of standards and other related legislations were also used for interpreting the results.

3. Results and discussion

3.1. Instrument calibrations

Fast atomic absorption spectroscopy (FAAS) was calibrated using three series of working standards for each metal in triplicate measurements. The correlation coefficients of the calibration curves of Fe, Cu, Mn, Cr, Cd and Pb were 0.9998, 0.9989, 0.9892, 0.9879, 0.9988 and 0.9987, respectively. These results confirmed the presence of very high correlation. Precision of the applied method was also evaluated by using replicate measurement of the standard deviation (Mean ± SD) and percent relative standard deviation (%RSD). The percent relative standard deviation (%RSD) of all elements were below 10 % of the mean values which further proved the good

Table 1
The results of physicochemical parameters of Abyi Adi drinking water sources, Mean ± SD (%RSD; N = 9).

Parameter	Sampling sites and average values of physicochemical properties, Mean ± SD (%RSD)				WHO [12]	Ethiopian Standard [25]
	Maylomin	Adibakla	Daram	Chiny		
T (°C)	24.56 ± 0.05 (0.20)	24.58 ± 0.18 (0.73)	25.11 ± 0.13 (0.52)	24.47 ± 0.25 (1.02)	<40	<40
pH	6.92 ± 0.03 (0.43)	7.42 ± 0.11 (1.48)	6.68 ± 0.19 (2.84)	7.13 ± 0.05 (0.70)	6.5–8.5	6.5–8,5
EC (μS/cm)	273.63 ± 2.56 (0.94)	881.27 ± 1.74 (0.20)	281.63 ± 2.41 (0.86)	425.93 ± 1.21 (0.28)	1000	1500
TUB (NTU)	2.38 ± 0.04 (1.68)	2.80 ± 0.07 (2.50)	2.60 ± 0.02 (0.77)	2.57 ± 0.02 (0.78)	5	5
TS (mg/L)	287.67 ± 10.49 (3.65)	445.10 ± 31.94 (7.18)	335.70 ± 10.40 (3.98)	408.97 ± 32.67 (7.99)	1000	1000
TDS (mg/L)	286.30 ± 8.65 (3.02)	440.43 ± 31.03 (7.05)	332.60 ± 10.20 (3.07)	405.70 ± 28.23 (6.96)	500	500
TSS (mg/L)	0.54 ± 0.04 (7.41)	1.16 ± 0.05 (4.31)	1.31 ± 0.05 (3.82)	1.21 ± 0.05 (4.13)	50	50
DO (mg/L)	5.70 ± 0.12 (1.11)	5.56 ± 0.22 (3.96)	5.93 ± 0.37 (6.24)	3.16 ± 0.23 (7.28)	6	2–6
BOD (mg/L)	4.09 ± 0.15 (3.67)	4.62 ± 0.14 (3.03)	4.48 ± 0.18 (4.02)	2.97 ± 0.20 (6.73)	8	–
COD (mg/L)	8.88 ± 0.53 (5.97)	9.26 ± 0.16 (1.73)	9.57 ± 0.17 (1.78)	9.80 ± 0.20 (2.04)	10	–
TA (mg/L)	20.53 ± 1.99 (9.69)	33.78 ± 2.33 (6.70)	18.87 ± 1.81 (9.59)	20.50 ± 2.04 (9.95)	200	200
Ca Hardness (mg/L)	22.20 ± 2.00 (9.00)	36.48 ± 2.88 (7.89)	22.23 ± 1.95 (8.77)	31.35 ± 1.30 (4.15)	200	200
TH (mg/L)	61.97 ± 2.49 (4.02)	222.99 ± 8.43 (3.78)	62.55 ± 4.95 (7.91)	101.43 ± 4.60 (4.53)	300	300

precision and reliability of the method.

3.2. Method validation

Efficiency of the optimized procedure was checked by spiking a known concentration of analyte to the standard solution [23,24]. The spiked and unspiked water samples were digested and analyzed in a similar manner. The calculated recoveries were in the ranges of 81.0–102.5 %, indicating that the concentrations of metals in the water samples were within the acceptable ranges of 80–120 %.

3.3. Physicochemical analysis

The levels of physicochemical parameters that were determined from the drinking water sources of Abyi Adi are summarized in Table 1.

3.3.1. Temperature, pH, electrical conductivity, turbidity

Temperature is a crucial factor in regulating biological and metabolic activities in aquatic organisms. It is influenced by the water source, climate, season, altitude, and industrial and municipal sewage inflow [26]. Higher temperature encourages microbial growth, potentially altering taste of water, odor as well as turbidity and causes corrosion [27]. The temperature recorded for this study ranged from 24.47 to 25.11 °C. The figures were within the permissible limits set by Ethiopian standards and the World Health Organization (WHO) of less than 40 °C.

As the human body is composed of 50–60 % water, pH plays an important role in regulating the body functions. A pH below 5.3 hinders vitamin and mineral absorption. The pH values of the sampling sites ranged from 6.68 to 7.42, which fall within the WHO permissible limit of 6.5–8.5.

Conductivity is an important factor that directly affects water quality. It is used to extract data regarding the rate of mineralization and estimate the amount of chemical reagent usage for treatment. High conductivity can lower the aesthetic value of water by giving a mineral taste. In this study, the electrical conductivity ranged from 273.63 to 881.27 μS/cm with the highest at Adibakla, the site where more agricultural practices were observed. These values are below the WHO limit of 1000 μS/cm and Ethiopian national standard 1500 μS/cm.

Turbidity is commonly used to assess the aesthetic quality of drinking water. The value of turbidity for Abyi Adi water sources ranged from 2.38 to 2.80 NTU, all below the WHO and Ethiopian national standard limit of 5 NTU. In comparison to other findings, the values of temperature, pH and electrical conductivity are consistent with the reported values of Werii catchment, which is close to Abyi Adi. Turbidity in this study is similar with the previously reported values from Abyi Adi (3.41–4.81 NTU) [28] but significantly lower than the values of Werii catchment [29].

3.3.2. Total dissolved solids, total suspended solids and total solids

Water with high solid content can be laxative and have an unpleasant mineral taste. Water containing high TDS levels may consist of oxygen-demanding fractions, mineral salts, organic materials and pathogens that can harm the public. Such type of water may not be advisable for those needing to limit salt intake. The values of solid content (TS: 287.67–445.10 mg/L; TDS: 286.3–440.43 mg/L; TSS: 0.54–1.31 mg/L) of this study are far below the WHO permissible limits for drinking water.

3.3.3. Dissolved oxygen, biological oxygen demand, chemical oxygen demand

Dissolved oxygen (DO), which is influenced by temperature and elevation, is one of the limiting factors for water quality. Higher DO improves water taste but can corrode pipes, while low DO may indicate contamination. In this study, DO ranged from 3.16 to 5.93 mg/L, which fall in the range of the Ethiopian standard and WHO recommended value for drinking water, 2–6 mg/L. Similar results are reported in central Ethiopia [30]. Biochemical oxygen demand (BOD) measures the oxygen required to decompose organic matter. BOD values ranged from 2.97 to 6.42 mg/L, which falls within the permissible limit of WHO, 8 mg/L. Moreover, the results of chemical oxygen demand (COD) of the present study ranged from 8.88 to 9.80 mg/L, which are also far below the WHO limit of 10 mg/L.

3.3.4. Calcium hardness, total hardness and total alkalinity

Water hardness is primarily caused due to the presence of calcium carbonate. Calcium hardness in this study ranged from 22.20 to 36.48 mg/L, which are below the Ethiopian standard and WHO limit for drinking water, 200 mg/L. The total hardness of water is also caused by the existence of cationic (calcium and magnesium) and anionic species (carbonate and bicarbonate). The total hardness of this study was found between 61.97 and 222.99 mg/L, which fall within the WHO limit set for drinking, less than 300 mg/L. These findings are consistent with reported value from the same region, 154.17–360 mg/L [31].

Alkalinity, which is mainly due to the existence of bicarbonate ions, measures the ability to neutralize acids. The average total alkalinity in this study ranged from 18.87 to 33.78 mg/L, significantly below the WHO limit of 200 mg/L for drinking water. These values are much lower than reported figures of 151–501 mg/L [31] in previous studies. The discrepancy could be attributed to factors, such as weathering, the presence of soluble minerals, and geological variations.

3.4. Analysis of cations and anions in the water samples

The concentrations of cations and anions (Na^+, Ca^{2+}, HCO_3^-, F^-, Cl^-, NO_3^-, NO_2^-, PO_4^{3-} and SO_4^{2-}) from the drinking water sources of

Abyi Adi are presented in Table 2.

3.4.1. Sodium ion, calcium ion, and bicarbonate ion

Sodium and calcium are equally abundant in this study area. Sodium levels ranged from 3.70 to 14.77 mg/L, which is below the WHO limit of 20 mg/L for drinking water. Previous studies in the Tigrai region reported sodium levels between 1 and 29 mg/L, aligning with this findings [31]. The level of calcium also ranged from 8.50 to 15.77 mg/L, significantly lower than the WHO limit of 200 mg/L. Moreover, bicarbonate levels ranged from 21.52 to 40.77 mg/L, which are also below the WHO limit of 500 mg/L. Other studies reported higher bicarbonate levels, 54.81–420.3 mg/L, from Adigrat, Tigrai [31].

3.4.2. Anionic species (fluoride, chloride, nitrate, nitrite, phosphate and sulfate ions)

Fluoride contamination poses a global public health threat, with excessive levels in drinking water leading to dental and skeletal fluorosis. Consequently, the WHO has set a maximum limit of 1.5 mg/L for fluoride in drinking water. Although recent reports highlight fluoride presence Tigrai, the fluoride levels in all water sources from Abyi Adi are below detectable limits. Chloride, which can impact the taste of water and cause hyperchloremia at high concentrations, ranged from 13.56 to 40.29 mg/L in this study, which are far below the WHO limit of 250 mg/L. Moreover, other scholars have reported similar chloride levels (2.13 mg/L to 26.12 mg/L) from Adigrat, a town about 100 km north of Abyi Adi [31].

Excessive nitrate and nitrite levels can negatively affect water quality and pose health risks. High nitrate levels (above 10 mg/L) cause infant methemoglobinemia (blue baby syndrome), while nitrite levels rarely exceed 0.1 mg/L. In this study, nitrate levels ranged from 0.14 to 0.25 mg/L, and nitrite levels from 0.24 to 0.76 mg/L, which are all within the WHO permissible limit of 50 mg/L for nitrate and 3 mg/L for nitrite. An anomaly observed vis-à-vis the exceeding amount of nitrite compared to nitrate ions. The findings of the present study are consistent with the previously reported values from the same region [31].

Although phosphate is not harmful to humans, anthropogenic activities and natural minerals significantly impact ecosystems and water quality. Phosphate levels in the present study ranged from 0.34 to 1.32 mg/L, which are below the WHO limit of 2 mg/L. Sulfate, from both natural and industrial sources, can cause bitter taste, laxative effects, and gastrointestinal issues at high levels [32]. The sulfate concentration ranged from 12.57 to 30.58 mg/L, well below the WHO limit of 250 mg/L. In contrast, the findings of the present study is far below the previously reported values from Adigrat, Tigrai [31]. The variation in the amount of sulfate could be due to the differences in topography and industrialization.

3.4.3. Heavy metal analysis (iron, chromium, manganese, copper, lead and cadmium)

The levels of heavy metals measured for the drinking water sources of Abyi Adi are summarized in Table 3.

Iron is an essential trace element which exists in significant amount in drinking water. However, it is cited as a health hazard as its shortage causes anaemia, and prolonged consumption of high concentration may also lead to a liver disease [33,34]. The amount of iron recorded in the present study ranged from 0.15 to 0.25 mg/L, which are within the WHO recommended limits for drinking water ($<$0.3 mg/L). However, the amounts of iron from the present finding are a little smaller than the previously reported values (0.432 mg/L) from Abyi Adi [28], (0.726) from Werii catchment [29], (0.04–0.82) from Adigrat [31]. Chromium in its hexavalent (Cr^{VI}) form is recognized as carcinogenic and mutagenic species which can cause lung cancer, kidney, liver and gastric damage. The levels of chromium in the present study ranged from 0.03 to 0.04 mg/L, which are in the WHO recommended limit for drinking water, $<$0.05 mg/L. Similarly, the amounts of chromium from the present finding are a little smaller than the previously reported values (0.098 mg/L) from Abyi Adi [28] and (0.055) from Werii catchment [29].

Manganese dominantly exists in water as a groundwater mineral. The levels of manganese in groundwater may widely vary depending on the leaching process, types of rocks and minerals that exist at the water table. It may impart color, odor, or taste to the water at concentrations above 0.05 mg/L [35]. The maximum amount of manganese recorded in the present study was 0.09 mg/L from Maylomin source. Accordingly, all the results were found to be below the WHO permissible limit for drinking water, 0.5 mg/L. Other scholars have also reported in the ranges of 0–0.12 mg/L [31], which is similar to the present study.

Copper is a trace metal and an essential micronutrient for human life. However, high level of copper in drinking water causes nausea, vomiting and diarrhea leading to health risks to liver and kidney [36]. Lead is another toxic metal which, if absorbed, can lead to serious health problems. The use of lead in pipe lines and the subsequent lead emissions into drinking water becomes a major

Table 2
The levels of cations and anions of Abyi Adi water samples, Mean ± SD (%RSD, N = 9).

Parameter	Sampling sites and average values of physicochemical properties, Mean ± SD (%RSD)				WHO [12]	Ethiopian Standards [25]
	Maylomin	Adibakla	Daram	Chiny		
Na^+ (mg/L)	3.70 ± 0.23 (6.22)	14.77 ± 0.31 (2.10)	13.47 ± 0.30 (2.22)	11.77 ± 0.20 (1.70)	200	200
Ca^{+2} (mg/L)	8.64 ± 0.37 (4.28)	15.77 ± 1.10 (6.98)	8.50 ± 0.15 (1.76)	11.51 ± 0.40 (3.48)	150	75
HCO_3^- (mg/L)	24.56 ± 2.36 (9.61)	40.77 ± 3.92 (9.61)	21.52 ± 2.05 (9.53)	24.93 ± 2.46 (9.87)	500	200
F^- (mg/L)	BDL	BDL	BDL	BDL	1.5	1.5
Cl^- (mg/L)	13.56 ± 1.37(10.10)	40.29 ± 4.03 (10.0)	27.16 ± 2.69 (9.90)	15.51 ± 1.47 (9.48)	250	250
NO_3^- (mg/L)	0.25 ± 0.02 (8.00)	0.24 ± 0.02 (8.33)	0.14 ± 0.01 (7.14)	0.23 ± 0.02 (8.70)	50	50
NO_2^- (mg/L)	0.24 ± 0.01 (4.17)	0.45 ± 0.02 (4.44)	0.55 ± 0.05 (9.09)	0.76 ± 0.06 (7.89)	3	3
PO_4^{-3} (mg/L)	1.11 ± 0.07 (6.31)	0.34 ± 0.01 (2.94)	1.32 ± 0.01 (0.76)	1.17 ± 0.01 (0.85)	2	2
SO_4^{-2} (mg/L)	12.57 ± 0.23 (1.83)	30.58 ± 0.49 (1.61)	14.12 ± 0.25 (1.77)	18.78 ± 0.25 (1.33)	250	250

Table 3
Heavy metal concentrations of Abyi Adi water samples, Mean ± SD, mg/L (%RSD; N = 9).

Parameter	Sampling sites and average values of physicochemical properties, Mean ± SD (%RSD)				WHO [12]	Ethiopian Standards [25]
	Maylomin	Adibakla	Daram	Chiny		
Fe (mg/L)	0.25 ± 0.01 (4.00)	0.22 ± 0.02 (9.09)	0.22 ± 0.01 (4.55)	0.15 ± 0.01 (6.67)	0.3	0.3
Cu (mg/L)	BDL	BDL	BDL	BDL	1–2	2
Cr (mg/L)	0.04 ± 0.00 (0.00)	0.04 ± 0.00 (0.00)	0.03 ± 0.00 (0.00)	0.03 ± 0.00 (0.00)	0.05	0.05
Mn (mg/L)	0.09 ± 0.00 (0.00)	BDL	0.04 ± 0.00 (0.00)	0.05 ± 0.00 (0.00)	0.5	0.5
Pb (mg/L)	BDL	BDL	BDL	BDL	0.01	0.01
Cd (mg/L)	BDL	BDL	BDL	BDL	0.003	0.003

BDL= Below detection limit.

concern. Cadmium is widely distributed in the earth's crust in the form of sedimentary rocks and marine phosphates [37]. It can cause chronic toxicity to human being and the environment [38]. The amount of copper, lead and cadmium obtained in the present study are all below the detection limit of the instrument. Values of copper and cadmium from Abyi Adi groundwater sources, as per reports of other study, also confirm that they exist below detection limits. However, the amount of lead (0.058 mg/L) is comparably higher than the current finding [28].

3.5. Microbiological analysis

The experimental results for microbiological parameters of Abyi Adi's drinking water sources are shown in Table 4. Total coliform ranged from 3.67 to 6.33 MPN/100 mL, with the highest level in Maylomin. Both Maylomin and Chiny exceeded the WHO permissible limit (absent/100 mL), indicating potential health risks. Additionally, *E. coli* levels in Maylomin and Chiny were found to be 1.0 MPN/100 mL, which is also above the WHO limit, absent/100 mL. Thus, the two water sources were contaminated, posing a risk of pathogenic bacteria. However, no coliform and *E. coli* were found in Adibakla and Daram water sources. Other scholars also reported the amount of total coliform in the range of 2–266 MPN/100 mL or CFU/100 mL from water sources collected from different parts of Ethiopia [39,40]. This research further pointed out the Ethiopian water quality has deteriorated mainly due to poor water handling practices. Moreover, the findings were found to be in the range of the literature reported values. Therefore, local communities should further disinfect with chlorination, treat or boil water to protect health risks of microbes from water sources.

3.6. Water quality index (WQI)

The water quality index (WQI) was determined using 30 water quality parameters, and the corresponding results are shown in Table 5. The average WQI values ranged from 6.47 to 35.14, with the highest value recorded at Adibakla site (35.14). According to the WQI rating, Maylomin, Daram, and Chiny water sources scored between 0 and 25, hence classified as excellent or grade "A". Adibakla scored between 26 and 50, hence classified as very good or grade "B" [1,13,14,29]. Despite the favorable WQI ratings, Maylomin and Chiny were found to be infected with coliform and *E. coli*.

4. Conclusion

This study evaluated the quality of water from groundwater sources in Abyi Adi town, Tigrai, Northern Ethiopia, using physico-chemical, biological parameters, and the water quality index (WQI). Most parameters indicated that the groundwater is safe for consumption. However, total coliform levels in Maylomin and Chiny were 6.33 MPN/100 mL and 3.67 MPN/100 mL, respectively, which exceed WHO limits for drinking water. Despite this, WQI results (6.47–35.14) classified the water sources from very good to excellent and/or ranging from grade "B" to "A".

In summary, water sources that are contaminated by coliform and *E. coli* should be treated with boiling and chlorination before consumption to ensure safety. Moreover, in order to maintain the sustainability and quality of the sources, regular monitoring is essential to keep the water sources from the pollution resulted from the anthropogenic activities and geochemical processes. In line with this findings, a comprehensive assessment of seasonal variations of the studied parameters and the geological processes of groundwater are crucial. In addition, if any disparities of water quality occur, the public should be aware of the health risks, and immediate intervention works be made to alleviate the water-borne diseases.

Table 4
Results for the microbiological analyses of Abyi Adi water sources, Mean ± SD; N = 9.

Parameter	Sampling sites and average values of microbiological parameters, Mean ± SD				WHO [12]	Ethiopian Standards [25]
	Maylomin	Adibakla	Daram	Chiny		
Total coliform (MPN/100 mL)	6.33 ± 2.78	–	–	3.67 ± 1.327	absent/100 ml	–
E. coli (MPN/100 mL)	1.00 ± 0.00	–	–	1.00 ± 0.00	absent/100 ml	–

Table 5
Results of the calculated water quality index of the studied water sampling sites.

Parameter	Sampling sites and average values of physicochemical properties, Mean ± SD			
	Maylomin	Adibakla	Daram	Chiny
$\sum wi$	3.08	3.08	3.08	3.08
$\sum Qiwi$	19.95	108.25	31.78	52.43
$WQI = \frac{\sum Qiwi}{\sum wi}$	6.47	35.14	10.32	17.02
Rating in grade	A	B	A	A

Where: A = Excellent water quality and B = Good water quality.

Data availability statement

There is no additional data for this manuscript.

CRediT authorship contribution statement

Abdu Mohammad: Writing – original draft, Formal analysis. **Abraha Gebrekidan Asgedom:** Writing – review & editing, Formal analysis, Conceptualization. **Kebede Nigussie Mokenen:** Writing – review & editing, Supervision, Formal analysis. **Amanual Hadera Tesfay:** Resources. **Tesfamariam Teklu Gebretsadik:** Resources. **Bart Van der Bruggen:** Writing – review & editing, Conceptualization.

Declaration of competing interest

We want to assure you that ALL Authors have no any conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e36173.

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