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ORIGINAL RESEARCH ARTICLE

Variations in Water Quality among the Different Municipal Supply Sources of Gondar City, Ethiopia

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Abstract

Gondar city is one of the highly populated cities in Ethiopia. Due to the recent rapid urbanization and the associated population growth, meeting the public demand for drinking water has become a critical challenge. To alleviate this problem, the city has started to use the different available sources including rivers, ground water and springs. The public however, has resentments on the poor quality of the supplied water and its frequently appeared bad taste. The objective of this study was, therefore, to determine the quality of water extracted from the different sources (Angereb reservoir, Angereb boreholes, Koladiba boreholes and springs), and to assess the water supply temporal variations. To achieve these objectives different physicochemical and biological water quality parameters were evaluated on a monthly basis for a year. Water supply from Koladiba boreholes was found to be significantly high in amount ($p < 0.05$) in Cl^- (122–163 mg/L), F^- (0.74–0.80 mg/L) and Ca (150–193 mg/L) than water supply from the other sources. The high level of chloride requires its consideration during water chlorination treatment process. Water supply from Angereb reservoir was more turbid with higher concentrations of PO_4^{3-}(27.7–47.7 mg/L) and SO_4^{2-} (31.1–35.2 mg/L) as well as coliforms (18–47 CFU per 100 mL). All of these water properties increased during the rainy seasons (June, July and August). This suggested that they originate mainly from surface run off water containing chemicals from the neighboring agricultural fields and urban domestic effluents. Hence, devising and implementing an effective management strategy to protect the reservoirs from the influence of the adjacent agricultural and urban residential areas is critical.

Keywords: Water quality, Physicochemical, Nutrient, Coliform, Gondar City

Introduction

Water is one of the natural resources that have critical importance to both the natural ecosystem and human development. It is essential for agriculture, industry and human existence. Because of the rapid industrialization and population growth, supplying adequate water to humans has become a critical challenge for many countries (Agnes *et al*., 2021; Miyittah *et al.,* 2020**)**. Besides to the supply of adequate amount of water, the quality of drinking water supplied to a community is vital for human health. Poor water quality causes adverse health effects on humans. In developing countries it is estimated that around 80% of all diseases are directly related to poor drinking water quality and unhygienic conditions (Firdissa*et al*., 2016; Vadde *et al.,* 2018).

The quality of water may deteriorate due to contamination with various chemicals or biological microorganisms originated from either anthropogenic or natural sources. Currently, anthropogenic sources have become increasingly the main causes of water quality degradation globally. These sources include urban domestic and industrial effluents containing various chemicals as well as agricultural wastes such as fertilizers and pesticides (Al-Maliki *et al*., 2021; Ligatea *et al*., 2021).

In order to keep the quality of drinking water within a predefined standard limits set by different countries and international organizations (Anderson *et al*., 2002), treating the water with an appropriate system before distribution to the public is required. To attain an efficient treatment condition, optimizing the system with respect to the various physicochemical and biological quality indicators is needed. The common water quality indicators include: physicochemical characteristics, such as pH, temperature, dissolved oxygen (DO), turbidity, electric-conductivity (EC), total dissolved solids (TDS), alkalinity, total hardness, major and minor nutrients like ammonia, nitrate, nitrite, phosphate, sulphate, chloride, fluoride, calcium and magnesium, and microbiological constituents which include total and faecal coliforms (Meride & Ayenew, 2016;Venkatesharaju *et al*., 2010). Additionally, the assessment and monitoring of these parameters is essential to identify the magnitude and source of any pollution level (Damotharan *et al*., 2010), and to suggest appropriate management strategies.

Gondar city is one of the highly populated cities in Ethiopia. The city is rich in historical sites that attract tourists from all over the world. As a result of rapid urbanization and fast population growth, demand for drinking water has increased dramatically over the recent years. This, on the other hand, brought a sever drinking water shortage in the city. In order to reduce the problem, the city administration has constructed water supply reservoirs in different available water sources. The public, however, has low confidence on the quality of the supplied water and its rarely appeared bad taste. Additionally, there are variations in the taste quality of the water depending on the time of the year and the location of the sources. The objective of this study was, therefore, to identify water quality parameters and then to estimate the quality status of the water from the different sources (Angereb dam, Angereb boreholes, Koladiba boreholes and Gondar Springs) and to assess their temporal variations.

Materials and Methods

Description of the Study Area

The study was conducted on the four different drinking water supply sources in Gondar city (Angereb reservoir, boreholes in Angereb, boreholes in Koladba, and spring waters in Gondar city). The three sources (Angereb reservoir, boreholes in Angereb and the springs) are located within Gondar city, while the fourth (boreholes in Koladba) is located in Koladiba town (Fig. 1).

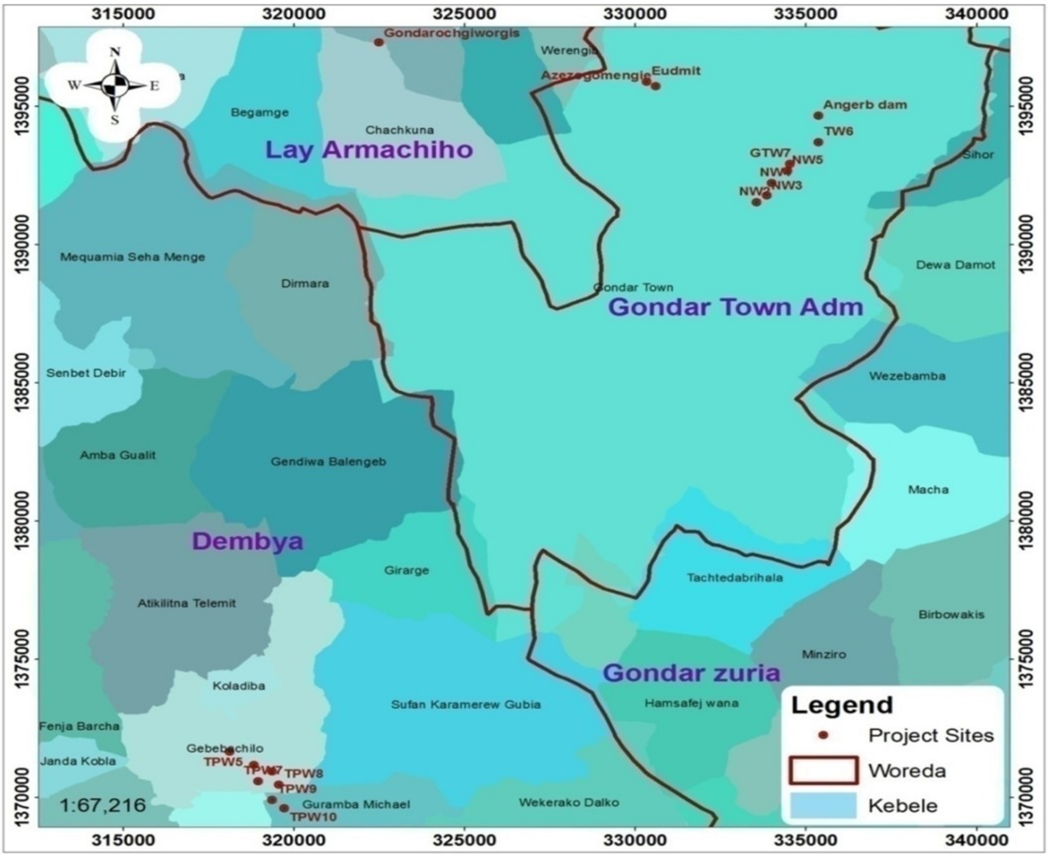

Figure 1. Map of the study area showing the sampling sites (red dots).

Angereb dam, having an area of 76.54 km^2 is located at the eastern outskirts of Gondar city, between 37° 25’to 37° 31’E and 12°00’to 12°34’N with an elevation of 2133 m above sea level. Angereb dam (here after called Angereb reservoir) is the main source of drinking water to the city. The reservoir is not well buffered and protected from the surrounding effluents and run offs. Furthermore, the reservoir is affected by pollution both from rural and urban areas.

The major sources of contamination to the reservoir have been siltation, non-point source agrochemicals such as fertilizers and the bathing and washing activities of humans living in the upstream of the Angereb River. In addition, as the reservoir is located at a lower altitude compared to the nearby residential areas of Gondar city, untreated domestic waste water effluents usually end up to the reservoir carried by various streams. The effect is visible from the colour, odour and turbidity of the water from the reservoir.

Groundwater wells that are constructed within the Angereb River watershed, at the downstream side of Angereb reservoir, are the other sources of drinking water to Gondar city (here after called Angereb boreholes). A total of six groundwater wells are constructed at different locations along the watershed.

Four spring water boreholes (here after called springs) are constructed at different locations around Gondar city (Azezo gomengie, Sanita, Eudmit, Gondaroch Giworgies), have also been used as additional sources of public water supply to the city.

Since the storage capacity of Angereb reservoir and the discharge amount (water level) of Angereb boreholes have been decreasing with time, additional ground water wells have been constructed near Koladiba town in Dembya district (here after called Koladiba boreholes) which is about 38 kilometres away from Gondar city. A total of seven ground water boreholes are available in different locations in Koladiba. Koladiba boreholes are found in the main parts of farming areas, and the major causes of contamination are supposed to be fertilizers, animals and humans excreta.

Chemicals and Equipment

The chemicals used in this study to assess the quality of water were Palintest tablet reagents (Halma, UK) nitric acid and M-lauryl sulfate broth (Sigma-Aldrich, Germany). Equipment used in this study were turbid meter (2100AN, Hach, USA), UV-7100 photometer (Halma, UK).

Water Samples

In this study, water samples from 18 public supply sources, i.e. 1 Angereb reservoir, 6 Angereb boreholes, 4 Springs and 7 Koladiba boreholes were collected and analyzed for physicochemical and biological characteristics, major nutrient and anions. Samples of Angereb reservoir constituted samples from the inlet and outlet of Angereb River as well as the opposite sides of the dam.

Water samples from all of the supply sources were collected and analyzed in the first week of every month for a period of one year from April 2017 to March 2018. Samples were collected using polyethylene bottles which were previously washed thoroughly with distilled water and transported in ice-box to the laboratory of Angereb Water Treatment Plant for analysis.

Analysis of Water Samples

For the analysis of the physicochemical characteristics and total and fecal coliform contents, standard methods were used for the analysis of water (APHA, 1998). All samples were analyzed in triplicates.

Data Analysis

Data was analyzed using the statistical soft ware package SPSS 20 (IBM Corp, USA). One-way analysis of variance (ANOVA) was used to compare the mean values of observations based on sampling areas and seasons. Differences in mean values were considered significantly when $p < 0.05$. Principal component analysis (PCA) was applied to explore sample trends and identify the main distinguishing characteristics among samples.

RESULTS AND DISCUSSION

The physicochemical characteristics of water from the four studied different public water supply sources to Gondar city are discussed in relation to monthly variations across the year, as well as variations across the four seasons in Ethiopia, i.e. pre-rainy season (March, April and May), rainy season (June, July and August), post-rainy season (September, October and November), and dry season (December, January and February).

Physicochemical Characteristics

pH

The measured pH varied in the ranges 6.40 –9.30 across the four water sources and the year (Table 1). Both the lowest and the highest pH values were recorded for Angereb reservoir in August and April, respectively. August is the peak of the rainy season while April is in the middle of pre-rainy season in Ethiopia. In the pre-rainy season, except Angereb reservoir (9.13) the mean pH values of all water samples were within the permissible range of WHO drinking water guideline values and Ethiopian Environmental Protection Agency (ETHEPA) standard values for drinking water quality (6.5–8.5) (Desye et al., 2021).

Except for water from Angereb reservoir, no statistically significant seasonal variation was observed in the pH of water from the different sources. In contrast, water samples from Angereb reservoir exhibited higher pH during the dry and pre-rainy seasons than the other seasons of the year. In the dry and pre-rainy seasons there is no much inflow and outflow of water from the reservoir. Hence, together with the high air temperature during these seasons, there may be increased decomposition rate by microorganisms living in the stored water to change the pH of the reservoir water. On the other hand, the water in the groundwater boreholes and springs are filled by the passage of water in different layered soil stratum and aquifers. As the water flows through such soil formation, the particles and microorganisms will be filtered out through adhesive and cohesive forces. As shown in Table 1, lower pH value of the ground water in the boreholes may be attributed to the presence of a mixture of volcanic gases and gaseous emanations in geothermal (Okhuebor, Izevbuwa, 2020),which is consistent with the study reported by Sorlini et al. (2013).

Temperature

The temperature of the water samples varied from 17.3 to 26.8 °C across the year and source types. The lowest temperature was recorded for Angereb reservoir in July while the highest temperature for both Angereb and Koladiba boreholes was recorded in April. For the water from Angereb reservoir, therecorded temperature was higher during the pre-rainy season. This may be due to the decreased water level of the reservoir during this season. The temperature of water from Koladiba boreholes, Angereb boreholes and the Springs did not show much variation across the months of the year.

Table 1. The mean, minimum (Min) and maximum (Mix) values of the physicochemical characteristics measured for water from the four public supply sources of Gondar city across the four seasons of the year 2018.

Water Source	Season		pH	T (°C)	TRB	EC (µS/cm)	TDS (mg/L)	DO (mg/L)	TH (mg/L)	ALK (mg/L)
Koladiba Boreholes (n = 7)	Dry	Mean	7.72	25.2	0.19	364	185	3.16	130	248
		Min	7.58	24	ND	349	165	3.13	118	242
		Max	8	26.3	0.286	377	203	3.24	140	253
	Post-rainy	Mean	7.63	25.7	1.048	381	190	3.08	129	253
		Min	7.38	25.4	0.429	380	190	2.81	127	253
		Max	7.9	26.2	1.714	382	191	3.41	131	253
	Pre-rainy	Mean	8.14	26.4	0.714	393	201	2.89	130	259
		Min	7.82	26.2	ND	385	192	2.76	124	253
		Max	8.6	26.5	2.143	408	206	3.06	135	264
	Rainy	Mean	7.97	25.5	2.448	383	187	2.62	129	256
		Min	7.94	24.9	2	381	178	2.58	127	252
		Max	8	26.2	3.2	385	193	2.71	131	261
Angereb Boreholes (n = 6)	Dry	Mean	7.57	24.8	0.048	362	187	3.4	115	233
		Min	7.53	23.3	ND	348	178	3.37	111	231
		Max	7.61	25.9	0.143	383	193	3.41	118	235
	Post-rainy	Mean	7.38	25.2	0.286	381	191	3.72	119	238
		Min	7.17	24.9	ND	379	190	3.46	118	236
		Max	7.5	25.6	0.571	383	191	3.87	121	240
	Pre-rainy	Mean	7.86	26.6	0.381	393	198	3.38	120	235
		Min	7.8	26.4	ND	383	197	3.37	120	231
		Max	7.97	26.8	0.857	398	199	3.39	121	240
	Rainy	Mean	7.29	25.1	1.714	404	221	3.42	121	232
		Min	7.07	24.7	1.286	375	207	3.35	118	221
		Max	7.5	25.6	2.286	424	245	3.46	125	240
Springs	Dry	Mean	7.43	22.2	0.25	408	207	3.51	101	236
		Min	7.41	22.1	ND	388	204	3.49	98	232
		Max	7.44	22.4	0.75	419	210	3.52	105	241
	Post-rainy	Mean	7.26	22.3	1.5	424	212	3.66	110	237
		Min	6.95	21.4	1	423	211	3.46	108	234
		Max	7.43	23.1	2	427	213	3.81	112	243
	Pre-rainy	Mean	7.83	24.2	0.583	404	215	3.08	112	240
		Min	7.65	24	ND	387	206	2.98	109	234

Table 1. The mean, minimum (Min) and maximum (Mix) values continued ....

Water Source	Season		pH	T (°C)	TRB	EC (µS/cm)	TDS (mg/L)	DO (mg/L)	TH (mg/L)	ALK (mg/L)
Springs	Pre-rainy	Max	7.93	24.6	1	421	221	3.16	114	244
	Rainy	Mean	6.97	22.1	2.333	421	228	3.37	107	243
		Min	6.9	21.3	1.75	401	201	3.07	105	242
		Max	7.02	22.6	3	434	268	3.55	110	245
Agngereb Reservoir (n = 4)	Dry	Mean	8.28	18.3	50.7	62.7	31.3	3.36	61	121
		Min	7.31	17.9	49	60	30	3.35	59.7	117
		Max	9.02	19	53	65	32.5	3.39	61.7	125
	Post-rainy	Mean	7.04	18.3	68.3	57.4	28.7	4.05	62.2	35.7
		Min	6.9	18	55	53	26.5	3.94	61.9	34
		Max	7.13	19	90	60	30	4.13	62.8	37
	Pre-rainy	Mean	9.13	23.7	47.7	328	124	3.16	65.1	120
		Min	8.9	23	30	201	91	2.97	59.6	119
		Max	9.3	24.2	62	392	160	3.4	68.3	120
	Rainy	Mean	7.27	18.3	95.2	164	134	3.65	62.2	62.8
		Min	6.4	17.3	90.6	50.2	91	3.2	54.6	35.5
		Max	8.9	20	98.9	392	160	3.92	69.4	117
	ETHEPA		6.5-8.5	NS**	5	NS	1000	NS	300	200

*TRB is turbidity, EC is electrical conductivity, TDS is total dissolved solids, DO is dissolved oxygen, TH is total hardness, ALK is alkalinity, ETHEPA is Ethiopian Environmental Protection Agency. **NS is not stated.

During all of the seasons, the temperature of water from Angereb reservoir was lower than that from the other sources which may be due to the fact that the reservoir is open for air cooling.

Turbidity

The turbidity of the water samples varied from below detection at Koladiba and Angereb boreholes and Springs during the dry and pre-rainy seasons to 98.9 NTU for Angereb reservoir in July. The turbidity of the water from Angereb reservoir was by far the highest throughout the year as compared to the other municipal water supply sources (Fig. 2).Throughout the year, the turbidity of the reservoir water (30.0–98.9 NTU) was above the standard limit value of ETHEPA (5 NTU) (Table 2). Turbidity is a measure of pollution level of water which is mainly caused by the presence of suspended soil particles. Higher levels of turbidity indicate the presence of several problems. Turbidity interferes with water treatment process especially with filtration. Suspended soil particles may also carry nutrients, pesticides, and other pollutants. In view of this, Angereb reservoir requires protection especially from the adjacent area soils and from the neighboring agricultural fields.

Water samples from the groundwater wells and springs exhibited very minimal turbidity when they are evaluated from the ETHEPA standard limits point of view. This may be because of the filtration effect of the rain water in the course of its passage to the ground that traps the silt, clay and other suspended soil particles by the geological layers of the earth.

The turbidity of Angereb reservoir reaches its peak value in the middle of the rainy season (July).This is because during rainy season runoff water containing silt, clay and other suspended soil particles contributed to the turbidity of the water. The turbidity of water from Koladiba and Angereb boreholes and springs did not show significant variations across the months of the year (Fig. 2).

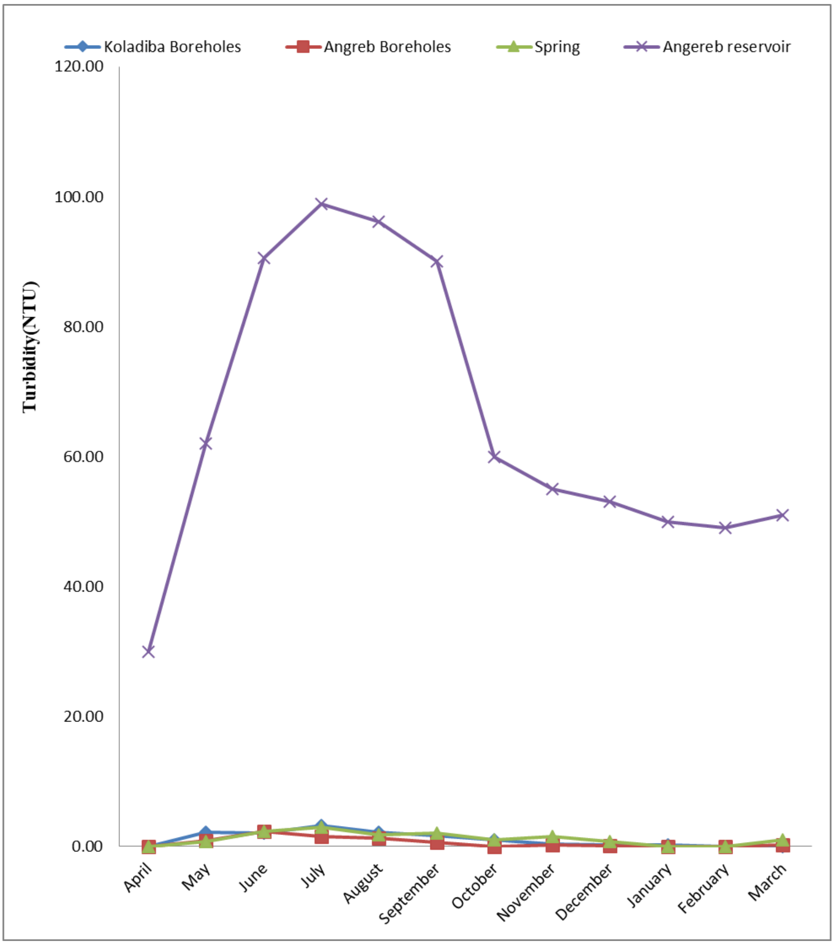

Figure 2.The measured turbidity values of water samples from the four public drinking water supply sources of Gondar city across the months of the year.

Electric conductivity

Electrical Conductivity (EC) is a measure of the ability of an aqueous solution to carry electric current which also depends on the presence and total concentration of ions, their mobility and valance. The EC is a valuable measure of the amount of ionic species dissolved in water (Clesceri *et al*., 1998).

Electric conductivity was recorded in the ranges between 50.2 µS/cm (for Angereb reservoir water in August) to 434 µS/cm (for the Spring water in April). Only little seasonal variation was observed in the electrical conductivity of water from the different water supply sources except for water from Angereb reservoir that showed significantly higher EC during pre-rainy (average 328 µS/cm) season than the other seasons with average in the ranges between 57.4–164µS/cm (Table 1).

Across the different seasons, water from Angereb reservoir had significantly lower EC than water from the other sources with average EC in the ranges 371–429 µS/cm. This may be due to the charging of groundwater by minerals washed from rocks while water passes through the earth's crust.

Table 2. Ethiopian Environmental Protection Agency (ETHEPA)* standard values for drinking water quality.

Parameter	Value	Parameter	Value	Parameter	Value
T	NS**	TH	300	PO_4^{3-}	NS
pH	6.5–8.5	ALK	200	F^-	1.5
Turbidity	5	NO_2^-	NS	Cl^-	250
EC	NS	NO_3^-	NS	Ca	75
TDS	1000	NH_3	1.5	Mg	50
DO	NS	SO_4^{2-}	250		

*ETHEPA standards are indicated in CSAE (2017). **NS is not stated.

Total dissolved solids

The total dissolved solids (TDS) in water consist of inorganic salts and dissolved organic materials. In natural water, salts are comprised of anions such as carbonates, chlorides, sulfates and nitrates, and cations such as potassium, magnesium, calcium and sodium. In ambient conditions, these compounds are present in proportions that create a balanced solution. If there are additional inputs of dissolved solids to the system, the balance is altered and detrimental effects may be seen. Inputs include both natural and anthropogenic sources.

The recorded total dissolved solids (TDS) varied from the lowest in water from Angereb reservoir in September (26.5mg/L) to the highest in water from Springs (268 mg/L) in July. Water samples from all of the different sources were found to contain TDS within the WHO (2011) and ETHEPA standard limits.

Generally, for every month of the year, water from Angereb reservoir was found to contain significantly lower TDS than water from the other sources (Fig. 3). This is similar to the observed variation with EC and which may be explained from the charging of the groundwater sources and springs by minerals washed from rocks in the course of water passing through the earth's crust.

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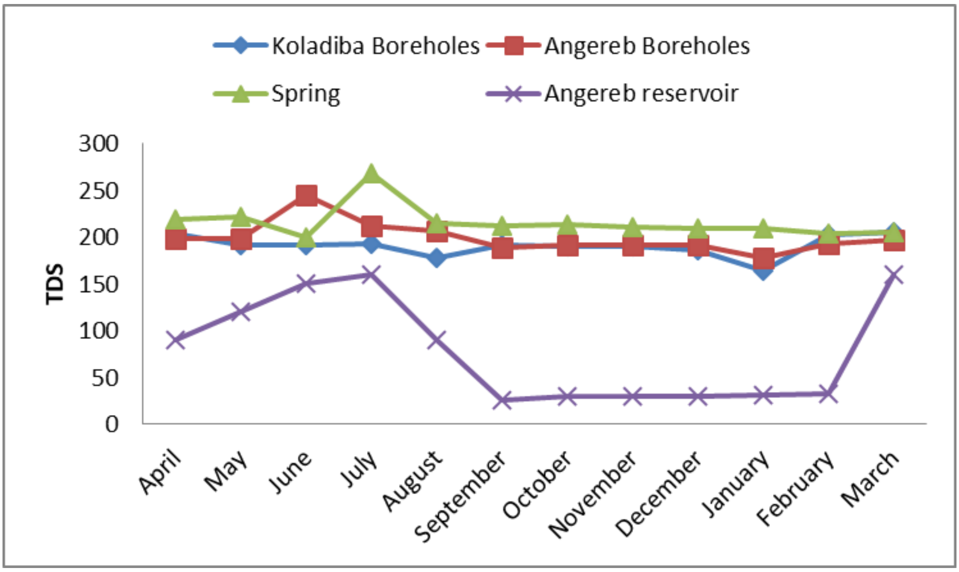

Figure 3. Total dissolved solid values of temporal and source variations

Dissolved oxygen

Dissolved oxygen is the amount of oxygen dissolved in water. Oxygen enters into water from the air and as a by-product of photosynthesis by aquatic plants. The concentration of dissolved oxygen in a water body is affected by temperature (Walker*et al*., 2006) and the amount of decomposition and decay of organic matter (Fair*et al*., 1971). Normal DO levels in freshwater are between 8 and 10 mg/L (APHA, 1992).

The average value of dissolved oxygen (DO) varied in the ranges 2.62–4.05 mg/L across the different sample types and seasons. Low DO mainly results from excessive algae growth caused by nutrients like phosphorus and Nitrogen.

As the algae died and decomposed, the process consumes dissolved oxygen. The decomposition of submerged plants also contributes to low DO.The condition in Angereb reservoir may be because of excessive nutrients primarily nitrogen and phosphorus from the adjacent agriculture fields and residential areas. The groundwater sources are expected to be naturally low in DO. The highest DO level was found in water from Angereb reservoir during post-rainy season. This may be due to the fact that the water reservoir can easily be contacted with air, compared to groundwater sources. Generally, the average DO measured in all of the water samples tends to be high in post-rainy season and low in pre-rainy season (Table 1). Water samples from Koladiba boreholes registered lower levels of DO in all of the months of the year than samples from the other sources. This may be because Koladiba boreholes are deeper than the other boreholes and springs. This indicates that the dissolved oxygen amount of water decreases as the depth of boreholes increased (Araoye 2009).

Total hardness

Hardness in water is mainly caused by the presence of dissolved calcium and magnesium. The widespread abundance of calcium and magnesium in rock formations result in hardness of surface and ground waters.

Total hardness comprises the calcium and magnesium concentrations of water expressed as $CaCO_3$. Across the seasons of the year, water from Angereb reservoir (average 61–65 mg/L) showed significantly lower total hardness than that (average 101–130 mg/L) from Koladiba and Angereb boreholes as well as Springs. This is because the source of water to the reservoir is surface runoff water, and it may not get the washable carbonate rock at the earth's surface. It is known that the chemical composition of water is directly related to the chemical composition of intervening rocks through which the water flows.

The degree of hardness in water may affect its acceptability to the consumer in terms of taste and scale of deposition (WHO, 2011). Depending on pH and alkalinity, hardness which is above 200 mg/L can result in scale deposition which reduces contamination of water by heavy metal from the pipe. However, long term consumption of extremely hard water may cause cancer and cardiovascular disorders (Shigut et al., 2017; Wokem et al., 2015).

The total hardness of water samples from the different sources did not show significant variation across the months or seasons of the year. This shows that the calcium and magnesium which are the dominant components of water hardness do not vary temporally in a significant manner in the studied sites.

Alkalinity

Alkalinity is the capacity to neutralize acids. The alkalinity of natural water is derived mainly from carbonates and bicarbonates. The alkalinity in the studied water sources varied from source type to source type. The ground water sources had significantly higher values than the surface water of Angereb reservoir. The average alkalinity was in the ranges of 35.7–121 mg/L for water from Angereb reservoir across the four seasons of the year while it ranged between 232–259 mg/L for water from the other sources (Table 1). With the exception of water from Angereb reservoir, all the water samples from the remaining three sources contain alkalinity that exceeds the ETHEPA guideline value of 200 mg/L.

Generally, there is no significant variation among the samples except for water from Angereb reservoir which showed alkalinity across seasons of the year. For Angereb reservoir, water alkalinity was found to be higher in the dry (121 mg/L) and pre-rainy (120 mg/L) seasons than the rainy (62.8 mg/L) and post rainy (35.7 mg/L) seasons. This may be due to the fact that during rainy and post rainy seasons, the reservoir develops algal bloom. The algae require carbon dioxide for its development and photosynthesis processes. As the carbon dioxide is consumed by photosynthesis, alkalinity increases.

Inorganic constituents

A number of different nonmetallic nutrients (PO_4^{3-}, SO_4^{2-}, NO_3^-, NO_2^-, NH_3, Cl^- and F^-) and metals (Ca and Mg) constituents were determined in the water samples (Table 3). All of the nonmetallic nutrients, except Cl^- and F^-, were found in significantly higher levels in water from Angereb water reservoir than water from the other sources. The phosphate and sulfate levels of Angereb reservoir were found to be comparable to each other, and which were significantly higher than the other analyzed nonmetallic species, except Cl^-. The lowest concentrations of phosphate and sulfate were recorded in water samples from Koladiba and Angereb boreholes respectively.

The higher concentrations of the nonmetallic nutrients except Cl^- and F^-, found in water from Angereb reservoir can be explained from the fact that the reservoir receives water from the various streams and rivers that flow through agricultural fields and urban residential areas carrying different inorganic species used in fertilizers and household detergents.

Regarding the four seasons, the concentrations of phosphate, nitrate and nitrite in Angereb water reservoir tends to increase during the rainy season reaching its maxima in July. In contrast, no significant seasonal variation was observed for water from the other three municipal supply sources.in the concentrations of any of the nonmetallic nutrients. This may be due to the nature of the sources. Unlike the surface water of Angereb reservoir, they are groundwater sources which are more protected from surface runoff water that contain the inorganic pollutants.

Regarding Cl^- and F^-, significantly higher concentrations were measured in water samples from Koladiba boreholes than from the other sources. The concentration of Cl^- in particular was very high across all the seasons (average 122–163 mg/L), compared to the other sources (average 5.53–12.2 mg/L). This means that the water of Koladiba boreholes is 10 to 30 times richer in chloride than that of the other sources. This may be for the fact that groundwater (borehole) contains high concentration of chlorides as compared to surface water bodies (Springs and reservoirs) (Mohsin et al., 2013), which exhibited comparable levels of chloride that remain nearly the same across the seasons. The Cl^- concentrations were found within the permissible limits for human consumption (250 mg/L).

The measured concentration of fluoride (average 0.74–0.84 mg/L) in water from Koladiba boreholes was by far lower than that of chloride from other sources. However, the fluoride amount of water from Koladiba boreholes was significantly higher than that from the other sources.

The chloride and fluoride levels of water from Koladiba boreholes did not show significant variation among seasons of the year. This indicates that the sources of the ions are mainly minerals from the underlying rocks rather than inputs from surface runoff water.

Table 3.The concentration (mg/L) of different inorganic constituents determined in water samples from the four different public supply sources of Gondar city across different seasons.

Water Source	Season		PO_4^{3-}	SO_4^{2-}	NO_3^-	NO_2^-	NH_3	Cl^-	F^-	Ca	Mg
Koladiba Boreholes	Dry	Mean	7.71	14.2	0.772	0.037	0.034	163	0.754	89.8	174
		Min	6.91	14.0	0.763	0.034	0.011	132	0.733	79.2	142
		Max	8.31	14.7	0.777	0.040	0.057	225	0.769	109	204
	Post-rainy	Mean	7.13	14.5	0.736	0.041	0.011	129	0.839	84.1	150
		Min	6.06	13.7	0.704	0.040	0.006	128	0.836	82.8	149
		Max	8.43	15.6	0.753	0.043	0.021	131	0.841	85.1	151
	Pre-rainy	Mean	8.13	14.7	0.655	0.033	0.075	129	0.738	102	193
		Min	7.40	14.5	0.604	0.031	0.016	118	0.726	82.9	180
		Max	9.27	14.9	0.721	0.037	0.126	135	0.756	112	218
	Rainy	Mean	8.00	15.2	0.699	0.041	0.021	122	0.771	83.8	171
		Min	7.91	14.9	0.637	0.038	0.020	119	0.743	83.1	145
		Max	8.10	15.6	0.779	0.043	0.023	128	0.806	85.1	219
Angereb Boreholes	Dry	Mean	18.4	0.265	0.768	0.029	0.697	12.2	0.006	63.8	71.3
		Min	15.6	0.226	0.719	0.026	0.581	11.6	0.003	60.8	67.7
		Max	20.3	0.297	0.843	0.032	0.787	12.7	0.009	69.7	77.2
	Post-rainy	Mean	14.9	0.210	1.049	0.046	0.033	9.92	0.034	70.9	68.6
		Min	13.0	0.174	0.820	0.035	0.009	7.69	0.004	58.9	65.8
		Max	16.1	0.266	1.449	0.054	0.053	14.4	0.061	92.4	70.9
	Pre-rainy	Mean	15.7	0.626	1.416	0.059	0.050	9.46	0.017	77.7	82.4
		Min	14.3	0.199	1.394	0.059	0.039	8.04	0.013	72.1	78.4
		Max	18.5	1.398	1.450	0.060	0.056	10.4	0.021	80.9	85.1
	Rainy	Mean	15.0	0.201	1.305	0.051	0.194	10.7	0.006	93.3	73.2
		Min	14.9	0.184	1.114	0.035	0.051	10.1	0.003	59.0	66.7
		Max	15.0	0.214	1.432	0.060	0.459	11.3	0.009	139	86.0
Angereb Boreholes	Dry	Mean	18.4	0.265	0.768	0.029	0.697	12.2	0.006	63.8	71.3
		Min	15.6	0.226	0.719	0.026	0.581	11.6	0.003	60.8	67.7
		Max	20.3	0.297	0.843	0.032	0.787	12.7	0.009	69.7	77.2

Table3.The concentration (mg/L) of ....

Water Source	Season		PO_4^{3-}	SO_4^{2-}	NO_3^-	NO_2^-	NH_3	Cl^-	F^-	Ca	Mg
Angereb Boreholes	Post-rainy	Mean	14.9	0.210	1.049	0.046	0.033	9.92	0.034	70.9	68.6
		Min	13.0	0.174	0.820	0.035	0.009	7.69	0.004	58.9	65.8
		Max	16.1	0.266	1.449	0.054	0.053	14.4	0.061	92.4	70.9
	Pre-rainy	Mean	15.7	0.626	1.416	0.059	0.050	9.46	0.017	77.7	82.4
		Min	14.3	0.199	1.394	0.059	0.039	8.04	0.013	72.1	78.4
		Max	18.5	1.398	1.450	0.060	0.056	10.4	0.021	80.9	85.1
	Rainy	Mean	15.0	0.201	1.305	0.051	0.194	10.7	0.006	93.3	73.2
		Min	14.9	0.184	1.114	0.035	0.051	10.1	0.003	59.0	66.7
		Max	15.0	0.214	1.432	0.060	0.459	11.3	0.009	139	86.0
Springs	Dry	Mean	25.5	12.3	0.953	0.038	0.218	9.06	0.017	60.8	94.6
		Min	21.3	11.9	0.868	0.025	0.133	8.78	0.000	60.2	93.9
		Max	28.5	12.6	0.998	0.053	0.353	9.38	0.050	61.2	95.1
	Post-rainy	Mean	33.4	12.3	0.913	0.067	0.167	8.76	0.010	60.8	96.7
		Min	31.7	12.1	0.875	0.065	0.118	8.73	0.008	60.5	96.0
		Max	36.4	12.6	0.948	0.068	0.198	8.83	0.013	61.3	97.2
	Pre-rainy	Mean	23.5	12.7	0.778	0.019	0.203	9.66	0.000	72.9	109
		Min	21.6	12.5	0.710	0.013	0.005	9.45	0.000	70.7	103
		Max	26.0	13.0	0.870	0.023	0.325	10.0	0.000	74.6	113
	Rainy	Mean	29.1	12.7	0.783	0.043	0.239	9.63	0.019	66.5	102
		Min	20.4	12.1	0.710	0.028	0.158	9.04	0.000	60.5	96.5
		Max	36.8	13.5	0.833	0.055	0.348	10.4	0.035	76.8	112
Angereb Reservior	Dry	Mean	27.8	35.2	1.90	0.075	0.713	6.95	0.173	28.3	76.3
		Min	27.0	34.3	1.87	0.065	0.700	6.91	0.100	25.0	68.0
		Max	29.0	36.0	1.95	0.088	0.720	7.00	0.300	30.0	88.0
	Post-rainy	Mean	34.7	31.7	1.80	0.072	0.767	5.53	0.103	31.9	73.3
		Min	32.0	31.0	1.70	0.069	0.640	5.26	0.080	23.8	72.0
		Max	39.2	32.0	1.90	0.075	0.980	6.00	0.140	37.0	74.9
	Pre-rainy	Mean	27.7	35.1	2.00	0.083	1.680	8.67	0.303	46.3	97.3
		Min	26.9	34.3	1.90	0.081	1.280	8.00	0.280	39.0	91.0
		Max	28.1	35.9	2.10	0.086	1.930	9.00	0.340	53.0	103
	Rainy	Mean	33.7	31.1	2.53	0.095	0.950	6.09	0.090	35.2	83.3
		Min	25.0	30.3	1.90	0.092	0.930	5.96	0.080	30.8	70.0
		Max	38.1	32.0	2.90	0.098	0.960	6.30	0.100	42.0	109
			NS	250	NS	NS	1.5	250	1.5	75	50
	ETHEPA		NS	250	NS	NS	1.5	250	1.5	75	50

Despite the observed variations among the different water sources and seasons, the concentration of the nonmetallic nutrients found in the water samples were generally within the ETHEPA standard limits. One exception to this is that the water from Angereb reservoir contained higher NH_3 (average 1.68 mg/L) than the ETHEPA standard limit of 1.5 mg/L. during the pre-rainy season. Higher value of ammonia concentrations in water is an indicator of possible bacterial swage and animal waste pollution (Adekola et al., 2015).

The presence of high amount of ammonia in water compromises disinfection efficiency, result in nitrite formation in distribution systems, causes the failure of filters for the removal of manganese and cause taste and odor problems (WHO, 2003).

The concentrations of PO_4^{3-} measured in the water samples across the four seasons (average 7.13–34.7 mg/L) were above the European Union drinking water standards of 5 mg/L (Anteneh et al., 2017). Since there is no much industrial activity in the studied areas, phosphate reach both the surface and ground waters as a consequence of the application of fertilizers in agricultural activities and from domestic wastewater disposal.

Across all the seasons, the highest concentration of Ca was found in water from Koladiba boreholes (average 150–193 mg/L) followed by Springs (average 94.6–109 mg/L).These concentrations are above the standard limited values of Ca (75 mg/L) for drinking water set by ETHEPA. Water samples from Angereb boreholes (average 68.6–82.4 mg/L) and Angereb reservoir (average 73.3–97.3 mg/L) were found to contain comparable concentrations of Ca which are within the standard values.

Water from Koladiba boreholes also exhibited significantly higher concentrations of Mg than from the other sources. Except water from Angereb reservoir, all the water samples contained higher concentration of Mg than the ETHEPA standard limits of 50 mg/L. Water from Angereb reservoir exhibited the lowest concentration of Mg across all the seasons. The observed low concentration of Ca and Mg in water from Angereb reservoir agree with that found for total hardness. This indicates that rather than inputs from surface runoff water, Ca and Mg are acquired more from minerals in underground rocks.

Fecal and total coliforms

The abundance of fecal coliform and total coliform bacteria is one of the most important water quality indicators. Water needs to be free from coliforms which are the main indicators of pathogenic diseases. There are three different groups of coliform bacteria, i.e. total coliform, fecal coliform and E. coli. The total coliform group is a large collection of different kinds of bacteria. The fecal coliform group is a sub-group of total coliform and has fewer kinds of bacteria. E. coli is a subgroup of fecal coliform. Total and fecal coliform were determined for the water samples from the different sources (Rodrigues and Cunha, 2017).

Regarding total coliforms across all the seasons of the year, water from Angereb reservoir exhibited the highest level (average 18.3–47.3CFU per 100 mL) than that from the other sources (Fig. 4). Water samples from the other sources were found to contain very minute total coliforms (from not detected to 4.33 CFU per 100 mL) that tend to increase during the rainy season. The observed low total coliform can be expected as they are groundwater sources that are relatively less prone to contamination with human and animal waste. However, the tendency of the total coliforms to increase during the rainy season indicates that the water sources are not fully protected from contamination since surface runoff water contains human and animal feces.

Comparing the three groundwater sources, water from Angereb boreholes contained relatively much amount of total coliform during the rainy and post-rainy seasons than from the others. Angereb boreholes are located at the downstream side of Angereb reservoir adjacent to urban residential areas. Hence, domestic wastes carried by runoff water would seep and percolate down during the rainy seasons.

The total coliforms in Angereb reservoir water showed a clear monthly variation (Fig. 4). The highest values were recorded during the late stages of the dry season (February) and pre-rainy season (March to May). This is because during these months, there is little or no inflow and outflow of water from the reservoir and the temperature in these months is high. This enhanced chemical reaction and biological activities which took place and increased the total coliforms. The total coliforms in Angereb water reservoir were also relatively high during the early months of the rainy season (June and July).

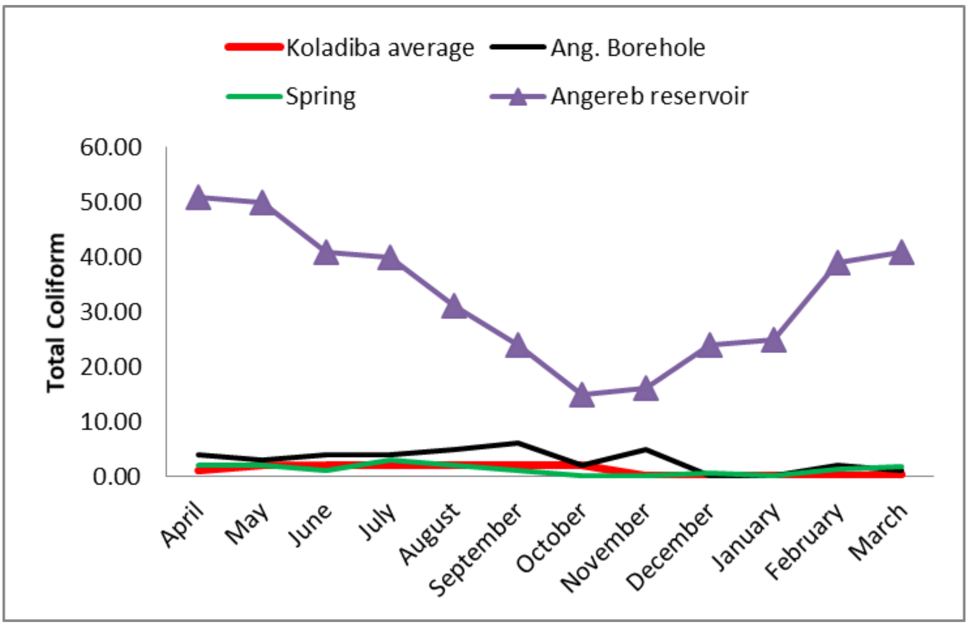

Figure 4. Monthly variations of the concentration of total coliform determined in water samples from the four water supply sources of Gondar city, Ethiopia

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The levels of fecal coliforms were also determined in the water samples. The presence of fecal coliforms in a water supply is an indicator that fecal contamination has occurred, and it is an indication of the risk that pathogens may be present. Water from Angereb reservoir contained higher levels of fecal coliform (1.0-3.0 CFU/100 mL) than from the other water supply sources. The fecal coliform content of Angereb water reservoir was high during the rainy and post-rainy seasons. Water samples from the other water supply sources were almost free from fecal coliform throughout all the seasons with the exception of Angereb boreholes for which some fecal coliforms were recorded during the rainy and post-rainy seasons.

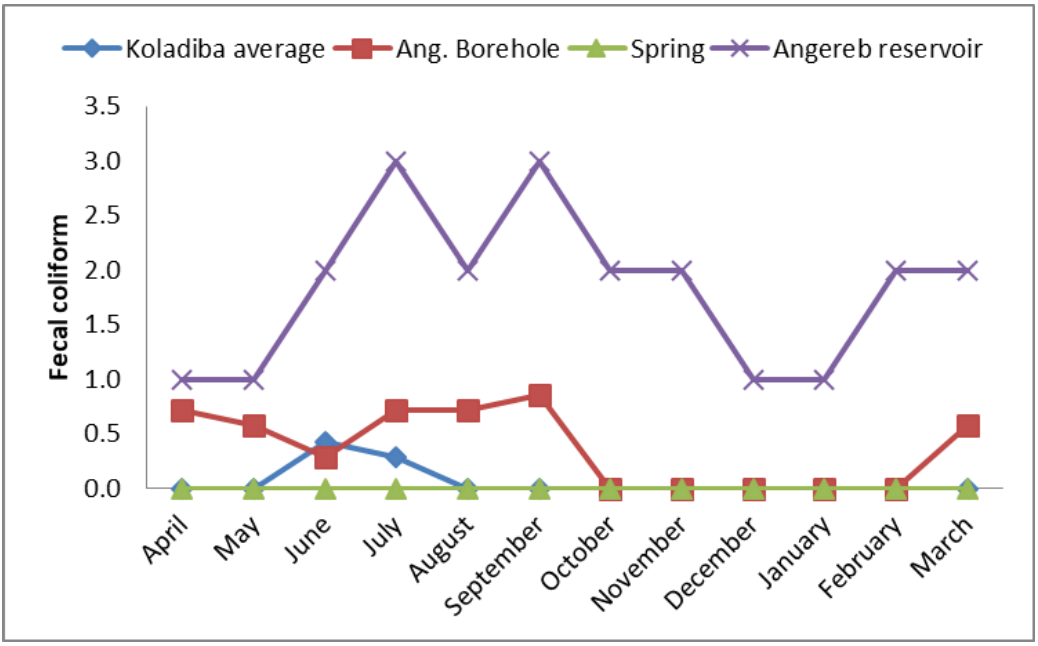

Figure 5. Monthly variations of the concentration of fecal coliform determined in water samples from the four water supply sources of Gondar city, Ethiopia

The ETHEPA standard for drinking water requires that both fecal and total coliforms to be none detectable in 100 mL of water. This requirement was not met by the water of Angereb reservoir throughout all the seasons of the year. However, fecal coliforms were not detectable in the water samples from the remaining three different sources during the rainy season except from Angereb boreholes. On the other hand, with the exception of the dry season, water samples from all of the three sources contained measurable amounts of total coliforms.

Principal Component Analysis

Principal component analysis (PCA) was applied to the whole data set in order to assess the overall variations and to identify the most distinguishing characteristics among the water samples from the four different sources studied. PCA with Varimax rotation, was applied to the data matrix represented by 48 samples (the 12 monthly recordings corresponding to each of the four water supply sources) and the 19 physicochemical and biological water quality parameters determined (pH, temperature (T), turbidity (TUR), electric conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), total hardness (TH), alkalinity (ALK), PO_4^{3-}, SO_4^{2-}, NO_3^-, NO_2^-, NH_3, Cl^-, F^-, Ca, Mg, total coliform and fecal coliform).

Three principal components (PCs) each with eigen value ≥ 1 were extracted. The three PCs together explained 84.4% of the variation in the data. The first two PCs accounted for 59.3% and 17.6% of data variability respectively. As shown by the scores plot of the two PCs (Fig. 5A), water samples from four supply sources are clustered in to three distinct groups. Samples from Angereb boreholes and Springs together constitute one group while those from Angereb reservoir and Koladiba boreholes constitute their respective separate groups.

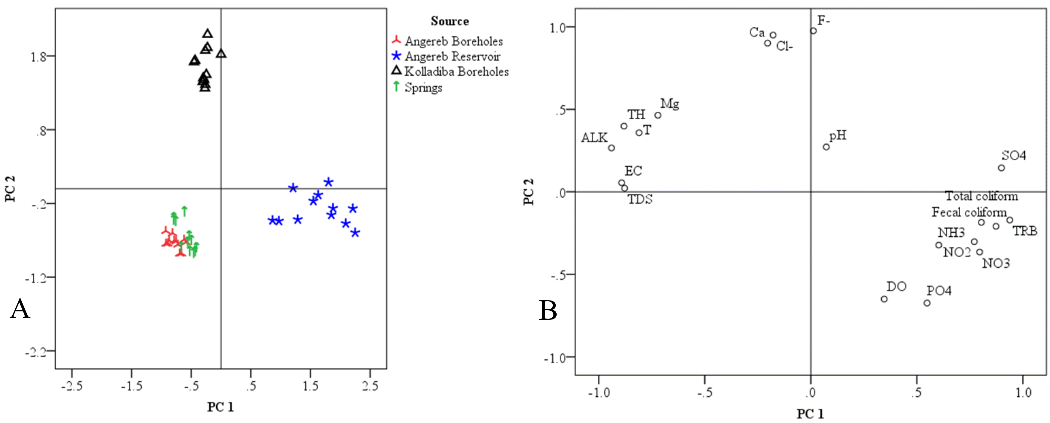

Figure 6. Scores plot (A) and Loadings plot (B) for the first two principal components of the PCA model constructed from the physicochemical and microbiological characteristics of water samples from the four different municipal water supply sources of Gondar city.

Cross examination of the scores plot (Fig. 6A) and loadings plot (Fig. 6B) reveals that the water of Angereb reservoir is characterized by high levels of turbidity, major nonmetallic nutrients (PO_4^{3-}, SO_4^{2-}, NO_3^-, NO_2^-, NH_3) and coliforms. This calls for an effective environmental management strategy to protect the reservoir from eroded soil that affects its turbidity, agricultural and domestic effluents that loads nutrients and human and animal wastes that adds coliforms.

The water of Koladiba boreholes is best distinguished by its content of Cl^-, F^- and Ca (Fig. A and B). As the boreholes are located in areas where there is no industrial activity, these constituents are likely from natural sources. Hence considering the amounts of chloride and fluoride present in the water of Koladiba boreholes is important during chlorination and fluoridation processes.

Conclusion

In this study groundwater sources (Koladiba and Angereb boreholes), springs and a surface water dam (Angereb reservoir) were investigated for their water qualities. Water from Angereb reservoir was found to be more turbid with higher levels of the major inorganic nutrients (PO_4^{3-}, SO_4^{2-}, NO_3^-, NO_2^- and NH_3) as well as coliforms than the other sources. All of these increased during the rainy season, and this calls for an effective management strategy to protect the dam. On the other hand, the water of Koladiba boreholes contained considerably large amount of chloride, fluoride and calcium presumably from minerals in rocks than that of the other sources. These require consideration of the available chloride and fluoride during water treatment processes.

References

Adekola, O., Bashir, A., Asimu, A. (2015). Physico-chemical characteristics of borehole water quality in Gassol Taraba State, Nigeria. *Afri. J. Env. Sci. Techno*. 9:145-154.

Agnes, E., Matchawe, C., Nsawir, B., Manuela, B., Adjele, J., Hippolyte T. Mouafo, Mbanga Baleba,M., Romuald, E., Ngonde, M., Noni, L. (2021). The use of alternative water sources as a means of adaptation to water shortages in Nsimeyong, Yaounde city: a quality assessment. Sci. Afr. 13:1-9.

Al-Maliki, L., Farhan, S., Jasim, I., Al-Mamoori, S., Al-Ansari, N., (2021). Perceptions about water pollution among university students: A case study from Iraq, *Cogent Engin*., 8:1-17.

Anderson, D., Gilbert, P., & Burkholder, J. (2002). Harmful Algal Blooms and Eutrophication: Nutrient Sources, Composition, and Consequence. *Estuaries*, 25: 704–726.

Anteneh, Y., Zeleke, G., & Gebremariam, E. (2018). Assessment of surface water quality in Legedadie and Dire catchments, Central Ethiopia, using multivariate statistical analysis. *Acta Ecologica Sinica*, 38: 81–95.

APHA. (1992). Standard methods for the examination of water and wastewater, 18th Ed. American Public Health Association (APHA), American Water Works Association, Water Environment Federation, Washington, DC, USA.

APHA. (1998). Standard methods for the examination of water and wastewater. American Public Health Association, American Water Works Association, Water Environment Federation, 20th Ed, Washington DC, USA. https://beta-static.fishersci.com/content/dam/fishersci/en_US/documents/programs/scientific/technical-documents/white-papers/apha-water-testing-standard-methods-introduction-white-paper.pdf. Accessed on July 1, 2021.

Araoye, P. (2009).The seasonal variation of pH and dissolved oxygen (DO2) concentration in Asa lake Ilorin, Nigeria. *Int. J. Phys. Sci.* 4: 271-274.

Clesceri, L., Greenberg, A., & Eaton, A . (1998). Standard methods for the examination of water and waste water. 20th ed. American Health Association: Baltimore (USA), 3–17.

Damotharan, P., Permal, N., & Perumal, P. (2010). Seasonal variation of physicochemical characteristics of Point Calimere coastal waters (South east coast of India). *Middle-East J. Sci. Res.*, 6: 333–339.

Fair, G. M., Geyer, J. C., & Okun, D. A. (1971). Elements of water supply and wastewater disposal, 2nd edition. John Wiley & Sons, New York. ISBN 10: 0471251151 / ISBN 13: 9780471251156.

Firdissa, B., Solomon, Y., & Soromessa, T. (2016). Assessment of the Status of Industrial Waste Water Effluent for Selected Industries in Addis Ababa, Ethiopia. *J. Nat. Sci. Res.*, 6: 1–6.

Ligatea, F., Ijumulana, J., Ahmad, A., Kimamboa,V., Irunde, R., Mtamba, J., Mtalo, F., Bhattacharya, P. (2021). Groundwater resources in the East African Rift Valley: Understanding the geogenic contamination and water quality challenges in Tanzania. *Sci. Afri.* 13:1-14.

Meride, Y., Ayenew, B. (2016). Drinking water quality assessment and its effects on residents' health in Wondo genet campus, Ethiopia. Environ Syst Res 5:1-6.

Miyittah, M., Tulashie, S., Tsyawo, F., Sarfo, J., Darko, A. (2020). Assessment of surface water quality status of the Aby Lagoon System in the Western Region of Ghana. *Heliyon*, 6: 1-9. Venkatesharaju, K., Ravikumar, P., Somashekar, R. & Prakash, K. (2010). Physico-chemical and Bacteriological Investigation on the river Cauvery of Kollegal Stretch in Karnataka. *J. Sci. Engin. Technol,* 6: 50–59

Mohsin, M., Samira Safdar, S., Asghar, F., Jamal, F. (2013). Assessment of Drinking Water Quality and its Impact on Residents Health in Bahawalpur City. *Int. J. Hum. Social Sci*., 3:114-128.

Okhuebor, S., Izevbuwa, O. (2020). The Quality and Effect of Borehole Water Proliferation in Benin City, Nigeria and its Public Health Significance, *Adv. Microb. Res*. 4:1-5.

Rodrigues, C., Cunha, M, (2017).Assessment of the microbiological quality of recreational waters: indicators and methods, *Euro-Mediterr J Environ Integr*, 2:1-18.

Shigut, D., Liknew, G., Irge, D., Ahmad, T. (2017). Assessment of physico-chemical quality of borehole and spring water sources supplied to Robe Town, Oromia region, Ethiopia. *Appl Water Sci*. 7:155–164

Sorlini, S., Palazzini, D., Sieliechi, J., Ngassoum, M. (2013). Assessment of Physical-Chemical Drinking Water Quality in the Logone Valley (Chad-Cameroon). *Sustainability,* 5, 3060-3076

Vadde, C., Wang, J. Cao, L., Yuan, T., McCarthy, A., Sekar, R. (2018). Assessment of Water Quality and Identification of Pollution Risk Locations in Tiaoxi River (Taihu Watershed),*Water* 10, 183:1-18.

Walker, Zipper, J. L., Shabman, C. E., Younos, L. A., Tamim, M. (2006). A literature Review for use in nutrient criteria development for freshwater streams and rivers In Virginia. Virginia Water Resources Research Centre Virginia Tech. DOI:http://hdl.handle.net/10919/49474

WHO (2003) *Ammonia in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/1).

WHO (2011) Hardness in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality. Geneva, World Health Organization (WHO/ HSE/ WSH/10.01/10/Rev/1).

Wokem, G., Lawson-Jack, T., (2015). Physicochemical quality of borehole water in abonnema and its public health importance. *Global J. Pure .Appl. Sci*., 21: 2015: 97-104.