Evaluation of groundwater and surface water quality suitability for drinking and agricultural purposes in Kombolcha town area, eastern Amhara region, Ethiopia

Berihu Abadi Berhe

Received: 25 July 2019 / Accepted: 24 April 2020 / Published online: 8 May 2020
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Abstract
The appropriateness of groundwater and surface water for domestic and agricultural uses was assessed in Kombolcha town located in Amhara region using water quality indexes. The town is one of the fast developing and emerging as a leading industrial town in Ethiopia and is selected as an industrial zone by the government. A total of eighteen groundwater and five surface water samples were collected using 250-ml sampling bottles at selected points and analyzed for major ions (Ca\(^{2+}\), Mg\(^{2+}\), Na\(^+\), K\(^+\), HCO\(_3\)\(^{-}\), SO\(_4\)\(^{2-}\), Cl\(^{-}\)) in the dry season (May 2017) and wet season (Nov, 2017). A water quality index (WQI) method was applied to evaluate the suitability of the groundwater for drinking purposes using eighteen groundwater sampling points and fourteen parameters (EC, TDS, HCO\(_3\)\(^{-}\), Ca\(^{2+}\), Mg\(^{2+}\), Na\(^+\), K\(^+\), Cl\(^{-}\), SO\(_4\)\(^{2-}\), NO\(_3\)\(^{-}\), PO\(_4\)\(^{3-}\), Cu, Fe and F\(^{-}\)), and each parameters were also compared with WHO drinking guidelines. According to WQI, groundwater samples of the present study show excellent (72.2%) and good (27.8%) in the dry season and excellent (83.3%) and good (16.7%) in the wet season. Assessment of groundwater samples from Na\(^+\), Mg\(^{2+}\), K\(^+\), Cl\(^{-}\), SO\(_4\)\(^{2-}\), HCO\(_3\)\(^{-}\), NO\(_3\)\(^{-}\), PO\(_4\)\(^{3-}\), Cu parameters indicates that groundwater of the study area is chemically suitable for drinking purposes. However, some are unsuitable according to the EC, TDS and Ca\(^{2+}\) and all are not suitable with reference to iron (Fe). Groundwater and surface water quality for irrigation were evaluated using SAR, RSC, MR, PI, KI and EC. The results show that most of the groundwater and surface water samples were suitable/excellent for irrigation with some places in the study locations that belong to the good and permissible. The sodium hazard versus salinity hazard of the entire water sample collected in two seasons falls into category C2-S1 and C3-S1, indicating low alkali hazards and excellent irrigation water. Groundwater samples in wet seasons are more suitable than in the dry season for drinking and irrigation purposes, and groundwater samples are less polluted than surface water. The main source of pollution in the study area is the effluents from industries.

Keywords Water quality index · Drinking water · Irrigation water · Kombolcha

Introduction
Hydrochemistry is the primary determinant of domestic, irrigation or industrial water use. Groundwater quality is regulated by various variables, including climate, soil characteristics, lithology type, region topography and on-site human operations (Rajesh et al. 2002; Das Brijraj and Kaur 2007; Cloutier et al. 2008). Surface water and groundwater play a significant role in offering drinking, irrigation and industrial water supply, with approximately 2.5 billion individuals worldwide depending on it (Connor 2015). The quantity and quality issues present a challenge to groundwater management since groundwater is a complement to surface water resources (Van der Gun 2012). The concept of the water quality index (WQI) was firstly used by Horton (1965) and was further developed by Brown et al. (1970).

Water quality index is a rating reflecting the collective impact of different water quality parameters on the whole quality of water, and it is accepted that reasonable evaluation based on single parameter cannot deliver the overall water quality and has been broadly utilized all over the world (Deininger and Maciunas 1971; Tiwari and Manzoor 1988; Li et al. 2010; Pati et al. 2014; Varol and Davraz 2015). Thus,
a comprehensive appraisal of overall water quality using this method is exceptionally imperative.

The chemistry of surface water and groundwater is the main issue determinant water use for domestic, irrigation or industrial functions. Generally, the quality of groundwater is governed by a variety of variables, including climate, soil characteristics, types of lithology, the topography of the area and of course the human activities on the ground (Rajesh et al. 2002; Das Brijraj and Kaur 2007; Cloutier et al. 2008).

Currently, the rapid population increase, the use of agricultural fertilizers and the growth of industrializations and the disposal of industrial waste have all played a significant part in the contamination of surface water and groundwater contamination and have greatly boosted the stress on water quality (Chandra et al. 2015; Verma et al. 2016).

Nowadays, almost in all parts of Ethiopia, the demand for water and consecutive abstraction for groundwater has increased from time to time. This is because surface water bodies are susceptible to pollution and also due to population growth at an alarming rate, thus affecting the resource quality and thus the elevated anticipated cost of the use of contaminated surface water resources. Understanding the water quality used for drinking and irrigation and its potential adverse effects on human life and plant development is very essential to prevent problems and optimize the general public’s health and crop output.

Kombolcha is one of the fast developing and emerging as a leading industrial town in Ethiopia, and it is one of the towns selected as an industrial zone by the government. The town is one of Ethiopia’s towns with comparatively more large-scale manufacturing plants than the size of the town. The town’s major existing industries are Steel Product Industry, Flour Factory, Textile Factory, ELFORA-Meat Processing Factory, BGI-Brewery Factory and Tannery. In this town, industrial wastewater mixed with river water is often used for irrigation industrial wastewaters containing toxic organic and inorganic chemicals that can be taken up by the crops and vegetables (Mohammed 2015).

In Ethiopia, from the increasing human population, uncontrolled urbanization and inadequate sanitation infrastructure cause serious quality degradation of surface waters. Hence, discharging of untreated industrial and municipal wastes to surface water increases with increasing urbanization (Hamere and Eyasu 2017). The quality of groundwater is poorly understood in the Kombolcha town, the eastern part of Amhara region, Ethiopia, whereas it is the only source of drinking and industrial purposes. A detailed study has not been carried out earlier for its suitability for drinking and irrigation purposes and the effect of factory effluents on the surface waters and groundwater has not been investigated well.

Therefore, the current study aims to carry out a comprehensive appraisal of the quality of groundwater resources using the water quality index (WQI) technique to assess its suitableness for drinking and the irrigation water quality of surface water and groundwater within the study was also evaluated by typical water quality index parameters.

**Study area**

It is nearby 23 km from Dessie town and 375 km from state capital Addis Ababa toward North along the road to Mekelle, which covers an area of about 120 km². The groundwater wells were opened in the alluvial plain where it covers about 46% (55 km²) of the study area. The study area is bounded between 571,500 and 583,800 mE longitude and 1,219,000 and 1,234,600 mN latitude (Fig. 1). It is located on the western margin of the Main Ethiopian Rift (MER). The MER is located at the northern termination of the East African Rift System (EARS) and extends from the Afar triple junction in the north to the Turkana Rift in the south (Fig. 1).

Small trees mostly acacia and thorny bushes are common; however, scarce eucalyptus trees are seen along the western in the ridges. Most of the area on the flat topography is used for agricultural farming by local people. June to September is the wet season, while the dry season extends from November to May.

The study area’s mean annual rainfall is 1072.15 mm with the highest rainfall in July and August. The mean annual minimum and maximum temperature of the study area is 12.44 °C and 26.87 °C, respectively, with the mean annual temperature of the area that is 19.66 °C.

The general physiographic map of the study area was prepared from DEM of the study area and is shown in Fig. 1. It is characterized by marked topographic variations and has a very high rugged topography. The altitude ranges from 1759 m.a.s.l on the flat areas, where the Kombolcha town is situated, to 2910 m.a.s.l at Yegof Mountain. The drainage network in this area is almost north–south direction, and major streams in this physiographic area include Borkena River, Eyole and Werka streams (Figs. 1 and 2).

**Geology and hydrogeology**

The geology of the study area is constituted by the rocks ranging in age from Eocene–Oligocene to Recent or Quaternary deposits. Stratigraphically, from bottom to top, they are Ashangie basalts (Eocene–Oligocene), Dessie basalt Formation and Ancharo Rhyolitic ignimbrite (Oligo–Miocene) and Quaternary sediments (GSE 2010) (Fig. 2).

The Ashangie basalts are also exposed as a faulted block along NW–SE trending escarpment. They are found as continuous and patchy outcrops with a sheet and blocky forms (Mengesha et al. 1996; Tesfaye et al. 2010). The Ashangie basalt is exposed along road cuts, stream beds, gentle and steep slopes of undulating mountain chains and low-lying...
flat plains. The unit is unconformably overlain by Dessie basalt formation. Ashangie basalt is found in N and NW, and SW of the highlands of the study area. The Dessie basalt formation is exposed in the western plateau area forming a chain of ridges like Tossa Mountain, cliffs along the escarpment and river cuts (Wolfenden 2003; Tesfaye et al. 2010). The contact with the underlying Ashangie basalt is marked by about 20-m-thick plagioclase phryic basalt marked by
50-cm-thick paleosol from top and bottom as seen along Dessie-Kombolcha road. This unit forms a N–S trending hill in the east part of the study area, which is named after the locality called Ancharo (Tesfaye et al. 2010). The alluvial–colluvial sediments are exposed in the low land plain and the central part of the study and cover about 45% of the mapped area. They are represented by black cotton and reddish-brown silty to sandy soil with few outcrops of diatomite. The black cotton soil is commonly seen along the northern part of the study area around the Kombolcha Airport of the basins. The thickness of the soil is more than 3 m as observed along the Borkena River cut and other streams cuts. The alluvial–colluvial sediments deposited at the valley of the town Kombolcha are characterized by clay, sand, gravel, pebbles and boulders derived mainly from the escarpments (Fig. 2).

Tectonic events that led to the growth of the Rift System control the geological structure of the area. The marginal grabens are slightly elongated depressions bounded on both sides by normal faults facing each other, followed in N–S direction by most of the faults in the study region (Jacques 2018) (Fig. 2). The eastern and western ridges bounding the valley area are characterized by a system of opposite dipping faults oriented parallel to the plateau escarpments (GSE 2010) (Fig. 2).

The alluvial deposits show alternating layers of sands, gravel and clay implying that there are multiple layer aquifers. The alluvial sediment is heterogeneous and their porosity and permeability making them a very good aquifer in the study area. According to pumping test data available the existing wells in the area showed average yield 10 l/s with average transmissivity 210 m²/day (Abraham and the existing wells in the area showed average yield 10 l/s with average transmissivity 210 m²/day (Abraham and Assay 2011). The scoracious basalt is highly porous due to its abundant vesicles and secondary structures such as joints and fractures interconnection of vesicles (Abraham and Assay 2011).

Materials and methods

Streams such as Eyole and Werka, and Borkena River have been used to obtain surface water samples, and wells have been used to collect groundwater samples that were opened by government and private firms and hotels. Hence, a total of eighteen (18) groundwater and five (5) surface water samples were collected during the year 2017 in the dry (May) and wet seasons (December).

The water samples were collected in polyethylene bottles (250-ml plastic bottles), sample containers were washed three times with the sample solution and rinsed three times with distilled water. The containers were sealed and returned to the laboratory, and then, water samples with containers were stored in a refrigerator without freezing to minimize volatilization and biodegradation until analysis at Mekelle University geochemical laboratory (Clesceri et al. 1998).

Water samples were analyzed in Mekelle University, School of Earth Science, geochemical laboratory for major cations and anions. Na, K, Ca, Mg, Fe and Cu were analyzed using the Atomic Absorption Spectrometer. SO₄, and Cl, NO₃, NO₂, SO₄, PO₄, NH₄ and F⁻ were determined by UV–Vis Spectrophotometer Lambda EZ 201 (Double Beam). PH electrical conductivity and total dissolved solid were determined using pH meter 3310 JENWAY, Conductivity meter 4310 JENWAY and Multi-meter 3910, respectively, and total hardness of the water samples was determined by EDTA and concentration of Ca and Mg. Titration method with an indicator of methyl orange and titrant 0.1 N HCl was used to determine bicarbonate and alkalinity (APHA 1989). The credibility of the chemical analyses was assessed through calculation of electrical neutrality between cations and anions, whereby the ionic balances were within ± 5% (Hem 1989) and were calculated using Eq. 1 (Freeze and Cherry 1979).

\[ EN = \frac{\sum \text{Cations} - \sum \text{Anions}}{\sum \text{Cations} + \sum \text{Anions}} \]  

(1)

AquaChem version 4 program was used to draw the Wilcoxon diagram. Statistical descriptive analysis and correlation between different parameters of water chemistry were done by Statistical Package for Social Sciences (SPSS) software package version 20.

Drinking water quality of the current study was evaluated using the water quality index (WQI) method. In this study, the values of WQI for all groundwater samples have been computed using the parameters that included EC, TDS, HCO₃⁻, Na⁺, Ca²⁺, Mg²⁺, K⁺, Cl⁻, SO₄²⁻, NO₃⁻, PO₄³⁻, Cu, Fe and F in both dry and wet season (Table 1). The computation of WQI was carried out in three stages.

First, weights have been provided to the most significant parameters anticipated to play a significant part in deteriorating the general quality of human consumption water. Accordingly, parameters NO₃⁻, F⁻, SO₄²⁻ and PO₄³⁻ are essential in the evaluation of water quality and the maximum weight of five has been allocated; parameters such as EC, TDS, Cl⁻ and Fe weight of four have been allocated; parameters Na⁺ and HCO₃ were assigned three weights; parameters Ca²⁺, Mg²⁺, K⁺ and Cu were assigned two weights depending on their significance for drinking purpose (Khanoranga 2019).

Second, for each sample the relative weight (Wi) is calculated using the following equation:

\[ W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \]  

(2)
where $W_i$ is the relative weight, $w_i$ is the weight of each parameter, and $n$ is the number of parameters selected.

Third, for each parameter, a quality rating scale ($q_i$) is allocated by dividing its concentration in each water sample by its corresponding standard following the guidelines set out in the WHO (2011) and multiplying the outcome by 100:

$$q_i = \left(\frac{C_i}{S_i}\right) \times 100$$

where the $q_i$ is the quality rating, $C_i$ is the concentration of each chemical parameter in each water sample given in a unit of mg/l, and $S_i$ is the WHO standard for each chemical parameter in mg/l according to the guidelines of the WHO (2011).

Finally, SI was calculated for each water quality parameter by multiplying relative weight ($W_i$) with a quality rating scale ($q_i$). The SI amount is equivalent to the index of water quality.

$$SI_i = W_i \times q_i$$

where the $SI_i$ is the sub-index of $i$th parameter, $q_i$ is the rating based on concentration of $i$th parameter, and $n$ is the number of parameters.

$$WQI = \sum SI_i$$

Appropriateness of water quality for agricultural purposes was assessed utilizing the well-known irrigation water quality indicator such as sodium adsorption ratio (SAR), residual sodium carbonate (RSC), permeability index (PI), magnesium ratio (MR), Kelley’s index (KI) and potential salinity (PS) (Table 2).

### Results and discussion

The summarized chemical and physical parameters of the laboratory result of the surface water and groundwater for the dry and wet seasons of the study area are presented in Tables 2 and 3, respectively.

### Surface water and groundwater chemistry

The mean water temperature, pH, TDS and EC values of the surface waters were 28.64 °C, 7.72, 462 mg/l and 758 µS/cm in the dry season and 22.28 °C, 6.74, 316.67 mg/l and 744 µS/cm in the wet season, respectively. However, groundwater samples had 27.16 °C, 7.36, 316.67 mg/l and 519.44 µS/cm in the dry season and 25.09 °C, 6.68, 336.11 mg/l and 531.11 µS/cm, respectively. The pH values of all waters of the study area elaborate a tendency of basic reaction among the groundwater system (Tables 2 and 3).

The high value of TDS in water may originate from natural sources of rock–water interaction, factory and sewage

### Table 1

Assignment of relative weight to the studied groundwater quality parameters and WHO standards used for WQI calculation [explanation: EC (µS/cm) and all concentrations (mg/l)]

| Parameter | WHO standard (2011) | Weight ($w_i$) | Relative weight ($W_i$) |
|-----------|---------------------|----------------|-------------------------|
| EC        | 1000                | 4              | 0.08                    |
| TDS       | 500                 | 5              | 0.10                    |
| HCO₃⁻     | 500                 | 1              | 0.02                    |
| Na⁺       | 200                 | 4              | 0.08                    |
| Ca²⁺      | 75                  | 3              | 0.06                    |
| Mg²⁺      | 50                  | 3              | 0.06                    |
| K⁺        | 12                  | 2              | 0.04                    |
| Cl⁻       | 250                 | 5              | 0.10                    |
| SO₄²⁻     | 250                 | 5              | 0.10                    |
| NO₃⁻      | 50                  | 5              | 0.10                    |
| PO₄³⁻     | 5                   | 1              | 0.02                    |
| Cu        | 2                   | 2              | 0.04                    |
| Fe        | 0.3                 | 4              | 0.08                    |
| F⁻        | 1.50                | 5              | 0.10                    |

$$\sum w_i = 49 \quad \sum W_i = 1$$

### Table 2

Summary of water quality indices for irrigation

| Indices | Formula |
|---------|---------|
| Sodium adsorption ratio (SAR), Richards (1954) | $$SAR = \frac{Na^+}{\sqrt{Ca^{2+}+Mg^{2+}}}$$ |
| Residual sodium carbonate (RSC), Eaton (1950) and Richards (1954) | $$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$$ |
| Magnesium ratio (MR), Raghunath (1987) | $$MR = \left[\frac{Mg^{2+}}{Mg^{2+}+Ca^{2+}}\right] \times 100$$ |
| Kelly’s index (KI), Kelly (1963) | $$KI = \frac{Na^+}{Mg^{2+}+Ca^{2+}}$$ |
| Potential salinity (PS), Doneen (1964) | $$PS = Cl^- + \frac{1}{2}SO_4^{2-}$$ |
| Permeability index (PI), Doneen (1964) | $$PI = \left[\frac{Na^++HCO_3^-}{Ca^{2+}+Mg^{2+}+Na^+}\right] \times 100$$ |

All concentrations were expressed in meq/l.
Table 3 Results of chemical analyses of the surface water and groundwater samples of the study area (date of sampling: May 2017); explanation: EC (µS/cm), concentrations (mg/l), temperature (°C)

| No | Sample Id | T     | pH   | TDS  | EC   | Ca²⁺ | Mg²⁺ | K⁺   | Na⁺  | NH₄⁺ | Cl⁻  |
|----|-----------|-------|------|------|------|------|------|------|------|------|------|
|    |           |       |      |      |      |      |      |      |      |      |      |
| Surface water |           |       |      |      |      |      |      |      |      |      |      |
| 1  | BR-1      | 30    | 8.42 | 346.57 | 486 | 46   | 7    | 0.67 | 15   | 0.001 | 6.89 |
| 2  | BR-2      | 32.5  | 7.04 | 624.68 | 876 | 137  | 7    | 1.01 | 35   | 0.005 | 25.62 |
| 3  | BR-3      | 26    | 8.35 | 464.95 | 652 | 73   | 8    | 0.92 | 32   | 0.005 | 24.69 |
| 4  | ES        | 26.5  | 7.72 | 631.82 | 886 | 102  | 7    | 1.01 | 51   | 0.007 | 41.72 |
| 5  | WS        | 28.2  | 7.76 | 1369.17 | 1920| 182  | 5    | 1.07 | 147  | 0.008 | 39.51 |
| Min | 26    | 7    | 346.57 | 486 | 46   | 5    | 0.67 | 15   | 0.001 | 6.89 |
| Max | 32.5  | 8.4  | 1369.2 | 1920| 182  | 8    | 1.07 | 147  | 0.008 | 41.72 |
| SD  | 2.67  | 0.56 | 399.21 | 560 | 53.4 | 1.1  | 0.16 | 52.4 | 0.003 | 14   |
| Mean | 28.64 | 7.86 | 687.44 | 964 | 108  | 6.8  | 0.936 | 56  | 0.005 | 27.69 |
| Groundwater |           |       |      |      |      |      |      |      |      |      |      |
| 6  | BW-1      | 24.7  | 7.98 | 490.62 | 688 | 59   | 8    | 0.81 | 30   | 0.002 | 21.62 |
| 7  | BW-2      | 24.6  | 8.01 | 418.59 | 587 | 49   | 6    | 0.73 | 36   | 0.003 | 23.83 |
| 8  | BW-3      | 24.3  | 7.23 | 488.48 | 685 | 103  | 9    | 1.05 | 17   | 0.006 | 12.18 |
| 9  | GBI-1     | 29.2  | 8.04 | 301.65 | 423 | 55   | 9    | 1.05 | 17   | 0.006 | 12.18 |
| 10 | GBI-3     | 28.2  | 8.27 | 250.3  | 351 | 29   | 4    | 0.29 | 21   | 0.003 | 22.85 |
| 11 | GBI-4     | 28.1  | 8.32 | 258.86 | 363 | 26   | 4    | 0.52 | 38   | 0.002 | 21.11 |
| Min | 24.3  | 6.93 | 233.90 | 328 | 26   | 4    | 0.62 | 32   | 0.005 | 21.73 |
| Max | 35.4  | 8.32 | 759.46 | 1065| 175  | 11   | 1.07 | 42   | 0.001 | 38.67 |
| SD  | 2.61  | 0.41 | 176.01 | 247 | 44.13 | 2.4  | 0.23 | 8.03 | 0.002 | 5.22 |
| Mean | 27.16 | 7.81 | 435.21 | 610 | 75.22 | 6.39 | 0.81 | 31.9 | 0.004 | 23.98 |
| No | Sample Id | SO₄²⁻ | HCO₃⁻ | CO₃⁻ | NO₃⁻ | NO₂⁻ | PO₄³⁻ | F⁻  | Fe   | Cu   | % Error |
| Surface water |           |       |      |      |      |      |      |      |      |      |      |
| 1  | BR-1      | 75    | 115.84 | 2.92 | 3.61 | 0.03 | 0.003 | 0.002 | 0.31 | 0.42 | −3.6  |
| 2  | BR-2      | 132.51 | 304.66 | 0.164 | 8.17 | 0.05 | 0.007 | 0.002 | 0.47 | 0.42 | 2.05  |
| 3  | BR-3      | 82.81 | 198.81 | 3.29 | 12.32 | 0.05 | 0.005 | 0.003 | 0.51 | 0.43 | −2.26 |
| 4  | ES        | 151.73 | 230.23 | 1.11 | 23.64 | 0.06 | 0.008 | 0.005 | 0.69 | 0.51 | −3.7  |
| 5  | WS        | 169.53 | 673.5  | 3.04 | 15.26 | 0.09 | 0.009 | 0.009 | 0.73 | 0.73 | −0.32 |
| Min | 75    | 115.84 | 0.164 | 3.61 | 0.03 | 0.003 | 0.002 | 0.31 | 0.42 | 2.05  |
| Max | 169.53 | 673.5 | 3.29 | 23.64 | 0.09 | 0.009 | 0.009 | 0.73 | 0.73 | 2.05  |
| SD  | 41.8  | 217   | 1.39 | 7.57  | 0.022 | 0.002 | 0.003 | 0.17 | 0.13 |      |
| Mean | 122.32 | 304.61 | 2.1  | 12.6  | 0.056 | 0.006 | 0.004 | 0.54 | 0.50 |      |
| Groundwater |           |       |      |      |      |      |      |      |      |      |      |
| 6  | BW-1      | 105.00 | 119.19 | 1.47 | 12.33 | 0.05 | 0.004 | 0.003 | 0.49 | 0.51 | −0.65 |
| 7  | BW-2      | 103.37 | 104.22 | 1.46 | 13.42 | 0.04 | 0.002 | 0.005 | 0.62 | 0.63 | −2.9  |
| 8  | BW-3      | 141.63 | 208.01 | 0.341 | 6.29 | 0.04 | 0.003 | 0.001 | 0.67 | 0.45 | −1.17 |
discharges. The maximum TDS (1369.17 mg/l) and EC (1920 µS/cm) values were measured in surface water from sample number WS (Werka Stream). It had been sampled from the direct discharge liquid waste of BGI-Brewery Factory (Tables 3 and 4, and Figs. 1 and 2).

Calcium concentration ranged from 46 to 182 and 61 to 170 mg/l in the dry and wet season for surface waters, respectively, while in groundwater samples it ranged from 26 to 175 and 41 to 178 mg/l in the dry season and wet season, respectively. The average calcium concentration value of all waters was 75.22 and 70.67 mg/l for dry and wet season, respectively. The range of magnesium in surface water varies from 5 to 8 mg/l and 6 to 12 mg/l in the dry and wet season, respectively. However, the concentration in groundwater varies from 4 to 11 mg/l in the dry season and 4 to 25 mg/l in the wet season. Analysis of surface water samples shows that potassium value varies between 0.67 and 1.07 mg/l and 0.95 and 1.03 in the dry and rainy season, respectively, while water samples taken from groundwater vary from 0.29 to 1.09 mg/l in the dry season and 0.54 to 1.57 mg/l in the wet season. The higher Ca$^{2+}$ content can cause abdominal ailments and is undesirable for domestic uses as it causes encrustation and scaling (Sarath Prasanth et al. 2012). The long-term agricultural activities may also directly or indirectly influence mineral dissolution in groundwater (Bohlke 2002).

The expected source of potassium in groundwater is most likely to be the K$^+$ feldspar weathering and the application of artificial fertilizers in agricultural activities. According to Kolahchi and Jalali (2006), the lower potassium concentration in groundwater is owing to its greater resistance to weathering and fixation in the form of clay minerals leading to nutrient loss. Sodium concentration in surface water varied from 15 to 147 mg/l in the dry season and 9 to 18 mg/l in the wet season, whereas in groundwater varied from 17 to 52 mg/l in the dry season and 5 to 33.11 mg/l in the wet season (Tables 3 and 4). The higher resistance of potash feldspars than sodium feldspars to chemical weathering results lower concentration of K$^+$ than Na$^+$ in the study area (Tables 3 and 4).

Relatively, the higher concentration of Na$^+$ and Cl$^-$ is observed from the groundwater sample Tan-W (a well located within the Tannery Factory), surface water WS (effluent discharged from BGI-Brewery Factory) and surface water ES sampled from Eyole stream where it gets discharge from Tannery Factory and ELFORA-Meat Processing Factory (Tables 3 and 4, Figs. 1 and 2).

Bicarbonate, sulfate and chloride concentrations in surface water ranged from 115.84 to 673.5 mg/l in the dry season and 164.7 to 357.95 in the wet season, 75 to 169.53 mg/l in the dry season and 41.85 to 178 mg/l in the wet season and 6.89 to 4.72 mg/l in the dry season and 4.52 to 16.23 mg/l wet season, respectively. The concentrations in groundwater varied from 45.63 to 413.45 mg/l in the dry season and 101.3 to 377.09 mg/l in the wet season, 31.58 to 186.72 mg/l in the dry season and 36.15 to 145.61 mg/l in the dry season and 12.1 to 838.67 mg/l in the dry season and
Table 4  Results of chemical analyses of the surface water and groundwater samples of the study area (date of sampling: Nov 2017); explanation: EC (µS/cm), concentrations (mg/l), temperature (°C)

| No. | Sample Id | T   | pH  | TDS | EC  | Ca\(^{2+}\) | Mg\(^{2+}\) | K\(^{+}\) | Na\(^{+}\) | NH\(_4\)\(^{+}\) | Cl\(^{-}\) |
|-----|-----------|-----|-----|-----|-----|------------|------------|--------|--------|----------|--------|
|     |           |     |     |     |     |            |            |        |        |          |        |
| **Surface water** |           |     |     |     |     |            |            |        |        |          |        |
| 1   | BR-1      | 22.3| 6.51| 348 | 488 | 84         | 6          | 0.96   | 9      | 0.004    | 4.52   |
| 2   | BR-2      | 22.6| 6.68| 527 | 739 | 132        | 8          | 0.98   | 11     | 0.003    | 7.54   |
| 3   | BR-3      | 22.7| 6.91| 601.9 | 844 | 103        | 11         | 0.95   | 16     | 0.003    | 9.88   |
| 4   | ES        | 21.4| 6.64| 670.3 | 940 | 170        | 12         | 1.03   | 18     | 0.005    | 16.23  |
| 5   | WS        | 22.4| 7.74| 355.1 | 498 | 61         | 7          | 0.98   | 11     | 0.006    | 5.31   |
|     | Min       | 21.4| 6.51| 348  | 488 | 61         | 6          | 0.95   | 9      | 0.003    | 4.52   |
|     | Max       | 22.7| 7.74| 670.3 | 940 | 170        | 12         | 1.03   | 18     | 0.006    | 16.23  |
|     | SD        | 0.52| 0.49| 145.1 | 203.46 | 42.46 | 2.59    | 0.03 | 3.81   | 0        | 4.7    |
|     | Mean      | 22.28| 6.9| 500.5 | 701.8 | 110     | 8.8     | 0.98  | 13     | 0        | 8.7    |
| **Groundwater** |           |     |     |     |     |            |            |        |        |          |        |
| 6   | BW-1      | 22.8| 8.07| 340.2 | 477 | 75         | 19        | 0.93   | 16     | 0.002    | 5.12   |
| 7   | BW-2      | 23  | 7.66| 413.6 | 580 | 65         | 50         | 1.02   | 11     | 0.005    | 6.11   |
| 8   | BW-3      | 22.8| 7.59| 489.9 | 687 | 96         | 5         | 0.98   | 12     | 0.006    | 5.01   |
| 9   | BW-1      | 27.5| 7.61| 288.5 | 404 | 45         | 7         | 0.98   | 5      | 0.002    | 4.12   |
| 10  | BW-3      | 26.6| 7.56| 284.5 | 349 | 53         | 5         | 0.69   | 7      | 0.003    | 3.15   |
| 11  | BW-1      | 26.4| 7.77| 260.3 | 365 | 48         | 4         | 0.61   | 8      | 0.002    | 5.72   |
|     | Min       | 22.8| 6.99| 233.2 | 327 | 41         | 4         | 0.54   | 12     | 0.001    | 5.67   |
|     | Max       | 27.6| 8.11| 836.6 | 1233 | 178       | 25        | 1.57   | 32     | 0.002    | 39.61  |
|     | SD        | 1.57| 0.28| 176.3 | 258.17 | 35.79 | 0.81    | 0.648 | 0.668  | 10.64   |
|     | Mean      | 25.09| 7.68| 404.5 | 567.72 | 70.67 | 9.79    | 0.95  | 13.9   | 9.04     |

|     | Sample Id | SO\(_4^{2-}\) | HCO\(_3^-\) | CO\(_3^-\) | NO\(_3^-\) | NO\(_2^-\) | PO\(_4^{3-}\) | F\(^-\) | Fe | Cu | % Error |
|-----|-----------|-------------|-------------|-------------|-------------|-------------|-------------|--------|----|----|--------|
|     |           |             |             |             |             |             |             |        |    |    |        |
| **Surface water** |           |             |             |             |             |             |             |        |    |    |        |
| 1   | BR-1      | 92.49       | 164.7       | 0.029       | 2.67        | 0.04        | 0.003       | 0.006  | 0.63 | 0.59 | 3.15   |
| 2   | BR-2      | 118.15      | 262.3       | 0.537       | 4.11        | 0.06        | 0.002       | 0.004  | 0.52 | 0.61 | 4.76   |
| 3   | BR-3      | 98.77       | 239.1       | 0.16        | 10.76       | 0.05        | 0.004       | 0.004  | 0.76 | 0.82 | 2.59   |
| 4   | ES        | 178         | 357.95      | 0.025       | 6.12        | 0.03        | 0.003       | 0.003  | 0.81 | 0.69 | 0.82   |
| 5   | WS        | 41.85       | 201.79      | 0.122       | 2.56        | 0.05        | 0.002       | 0.004  | 0.52 | 0.63 | 2.88   |
|     | Min       | 41.85       | 164.7       | 0.025       | 2.56        | 0.05        | 0.002       | 0.003  | 0.52 | 0.59 |        |
|     | Max       | 178         | 357.95      | 0.537       | 10.76       | 0.06        | 0.004       | 0.006  | 0.81 | 0.82 |        |
|     | SD        | 49.2        | 73.16       | 0.21        | 3.4         | 0.01        | 0          | 0.001  | 0.13 | 0.09 |        |
|     | Mean      | 105.85      | 245.17      | 0.17        | 5.24        | 0.05        | 0          | 0.004  | 0.648| 0.668|        |
2.41 to 39.61 mg/l in the wet season for bicarbonate, sulfate and chloride, respectively (Tables 3 and 4).

Sources of chloride in groundwater include rainwater, fertilizers and sewage water pollutants (Srinivasamoorthy et al. 2014; Sarath Prasanth et al. 2012). The presence of sulfate to the groundwater and surface water is primarily because of the dissolution of filtering waters, leaching from fertilizers and municipal waste (Singh 1994). High Cl concentration also observed from groundwater sample ELF-W1 (a well located inside ELFORA-Meat Processing Factory) and surface water sample BR-2 sampled from Borkena River which is located just down the factories (Tables 3 and 4, Figs. 1 and 2).

The concentrations of Fe in various parts of the study area are tabulated in Tables 3 and 4. The concentration of Fe in groundwater varied from 0.28 to 0.73 mg/l and 0.25 to 0.89 mg/l in the dry and wet season, respectively (Tables 3 and 4). Its concentration in surface water, however, is higher than groundwater and ranged from 0.31 to 0.73 mg/l and 0.52 to 0.81 mg/l in the dry season and wet season, respectively (Tables 3 and 4).

In most of the groundwater samples, the measured major cations and anions in dry seasons are higher than the wet season due to the rock–water interaction dominancy. During the wet season, as the water level of the groundwater rises, more dilution has occurred and lower concentration than of the dry season was measured. It is obvious that surface water is more susceptible to pollution than groundwater and high concentration of most of the major ions. TDS, EC, Cu and Fe were recorded (Tables 3 and 4). The source of high Fe in all water could have resulted from anthropogenic activities. Untreated effluents are the main cause of increasing some parameters.

**Appraisal of groundwater quality for drinking purposes**

The quality parameters of drinking water have a direct effect on human health. Getting quality water for drinking purposes becomes challenging day by day due to the disturbance by anthropogenic activities.

The groundwater samples from the study were evaluated using the most desirable limit as well as the maximum permissible limit proposed by WHO (2011) (Table 1) for drinking usages.

Out of the 18 groundwater samples of the study area, the TDS value 4 of them (22.2%) in the dry season and 3 (16.7%) in the wet season were above the maximum permissible limit as recommended by WHO (2011). Variations of EC have mainly resulted from a geochemical process such as rock–water interaction, silicate weathering, ion exchange, reverse exchange and oxidation and reduction of sulfate (Ramesh 2008).
The concentration of the major ions (Na⁺, Mg²⁺, K⁺, Cl⁻, SO₄²⁻ and HCO₃⁻), NO₃⁻, PO₄³⁻, F⁻ and Cu of the groundwater samples of the two seasons was fallen within the recommended limit for human consumption. However, in case of the concentration of Ca²⁺ 11 (61.1%) of the groundwater samples were suitable for drinking applications (Tables 1, 3 and 4).

It is found from the study that all the groundwater samples were exceeded the standard levels of Fe of the World Health Organization (WHO) (Tables 1, 3 and 4). These higher amounts of Fe found in the study area may be harmful to the people who are using these water sources for their daily drinking purposes.

Groundwater quality for drinking of the current study was evaluated by the water quality index (WQI) method. The WQI is considerably used to evaluate the quality of water in various countries of the world (Alobaidy et al. 2010; Aghazadeh and Mogaddam 2010; Keesari et al. 2016).

The groundwater samples’ calculated WQI value ranged from 28.03 to 70.75 in the dry season with an average value of 44.31 and from 23.47 to 81.22 in the wet season with an average value of 42.14 (Table 5). The calculated WQI values showed that the study area’s groundwater is categorized into two water types, excellent water and good water for drinking. Thus, among all groundwater samples, the proportion of WQI classifications in the dry season was excellent (72.2%)

![Fig. 3](image-url) The proportion of groundwater samples in the study area classified based on WQI: a dry season, b wet season

| Sample ID | May 2017 | Nov 2017 |
|-----------|----------|----------|
|           | WQI value | Water quality | WQI value | Water quality |
| BW-1      | 45.49     | Excellent   | 41.4      | Excellent   |
| BW-2      | 46.33     | Excellent   | 44.42     | Excellent   |
| BW-3      | 53.69     | Good        | 46.02     | Excellent   |
| BGI-1     | 36.29     | Excellent   | 26.49     | Excellent   |
| BGI-3     | 31.15     | Excellent   | 37.13     | Excellent   |
| BGI-4     | 28.49     | Excellent   | 23.47     | Excellent   |
| ELF-W1    | 67.51     | Good        | 55.38     | Good        |
| SSH-W     | 63.96     | Good        | 37.73     | Excellent   |
| SW-6      | 49.17     | Excellent   | 39.26     | Excellent   |
| SW-8      | 38.01     | Excellent   | 36        | Excellent   |
| Tex-W2    | 41.87     | Excellent   | 45.43     | Excellent   |
| Tex-W5    | 32.24     | Excellent   | 39.44     | Excellent   |
| Tex-W9    | 28.23     | Excellent   | 32.48     | Excellent   |
| Tex-W10   | 28.09     | Excellent   | 26.76     | Excellent   |
| Tan-W     | 70.75     | Good        | 81.22     | Good        |
| KCTW-2R   | 41.35     | Excellent   | 34.89     | Excellent   |
| KO-W2     | 66.89     | Good        | 37.06     | Excellent   |
| YM-2      | 28.03     | Excellent   | 73.85     | Good        |
| Min       | 28.03     |             | 23.47     |             |
| Max       | 70.75     |             | 81.22     |             |
| SD        | 14.80     |             | 15.03     |             |
| Mean      | 44.31     |             | 42.14     |             |

| WQI value | Water quality | Dry season (May 2017) | Wet season (Nov 2017) |
|-----------|---------------|------------------------|-----------------------|
|           |               | # of samples | % of samples | # of samples | % of samples |
| < 50      | Excellent water | 13          | 72.2        | 15          | 83.3        |
| 50–100    | Good water     | 5           | 27.8        | 3           | 16.7        |
| 100–200   | Poor water     | Nil         | Nil         | Nil         | Nil         |
| 200–300   | Very poor water | Nil         | Nil         | Nil         | Nil         |
| > 300     | Unsuitable for drinking water | Nil | Nil | Nil | Nil |
and good (27.8%), while excellent (83.3%) and good (16.7%) in the wet season (Table 6 and Fig. 3).

Comparing the two seasons, water in the wet seasons has a better quality than dry seasons. This may be resulted from the fewer concentration components in the wet season owing to greater water levels in the wells during the wet season than in the dry season (Tables 5 and 6 and Fig. 3). Variation in some of the physicochemical parameters may be also due to anthropogenic and geogenic sources (Khanoranga 2018).

**Appraisal of groundwater and surface water quality for irrigation purposes**

The use of poor irrigation water quality reduces agricultural crop yields. The mineral composition denoted by the quality of irrigational water and the quality proves its effects on plants and soil. It is clear that high-quality and quantity crops yield from the usage of high-quality water.

Groundwater pumped from wells and source water for irrigation purposes may comprise substantial chemical constituents derived from natural processes and human activities that may reduce crop yield and deteriorate soil fertility (Jalali 2009). The chemical composition of irrigation water directly or indirectly impacts crop production by influencing nutrient availability in plants. Irrigation water chemistry varies with the source, local and regional geology. For example, soil water with an elevated salt concentration can be extremely damaging to plants by altering metabolic processes, retarding plant growth. The awareness of irrigation water quality is serious to understand what management changes are necessary for long-standing productivity (Jalali 2011).

Parameters such as sodium adsorption ratio (SAR), residual sodium carbonate (RSC), magnesium ratio (MR), permeability index (PI) and electrical conductivity (EC) were used to evaluate irrigation water quality for two seasons. These parameters are crucial for irrigation purposes in the assessment of groundwater and surface water (Tables 2 and 8).

**Sodium adsorption ratio (SAR)**

Sodium adsorption ratio is the most commonly used parameter to assess the effects of exchangeable sodium on the physical condition of the soil (Richards 1954). The excess sodium in water reacts with soil that changes the composition of the soil and reduces the permeability of the soil. Then, the soil becomes more impermeable and compressed. Richards (1954) categorized irrigation water as suitable based into four groups based on sodium adsorption ratio SAR (Table 8).

The graph of sodium hazard versus salinity hazard (Wilcox 1955) shows that the entire water samples gathered during dry and wet seasons fall into categories C2-S1 and C3-S1, showing low alkaline risks and outstanding irrigation water (Fig. 4).

The Wilcox (1955) sodium hazard versus salinity hazard graph demonstrates that all water samples collected during dry and wet seasons fall into C2-S1 and C3-S1 classifications, demonstrating small alkaline hazards and great irrigation water (Fig. 4).

During the dry season (May 2017), the SAR value of the groundwater sample ranges from 0.43 to 1.83 with an average of 1.04 and the rainy season (November 2017) ranges from 0.18 to 0.80 with an average of 0.39 (Table 7). According to the Richards (1954) classification, all groundwater samples have very low SAR values in both seasons showing that all water samples in the study area are in an excellent category (Table 8). The SAR value of the surface water...
Table 7 Results of water quality indices for irrigation

| No. | Sample Id | Dry season (May 2017) | SAR | PI | RSC | PS | MR | KI | EC |
|-----|-----------|------------------------|-----|----|-----|----|----|----|----|
|     |           |                        |     |    |     |    |    |    |    |
|     |           |                        |     |    |     |    |    |    |    |
| Surface water |         |                        |     |    |     |    |    |    |    |
| 1   | BR-1      | 0.54                   | 57.53 | −0.88 | 0.98 | 20.03 | 0.23 | 486 |
| 2   | BR-2      | 0.79                   | 41.98 | −2.43 | 2.10 | 7.76  | 0.20 | 876 |
| 3   | BR-3      | 0.95                   | 56.08 | −0.94 | 1.56 | 15.28 | 0.32 | 652 |
| 4   | ES        | 1.32                   | 52.70 | −1.87 | 2.76 | 10.15 | 0.39 | 886 |
| 5   | WS        | 2.93                   | 61.08 | 1.63  | 2.88 | 4.33  | 0.67 | 1920 |
|     | Min       | 0.54                   | 41.98 | −2.43 | 0.98 | 4.33  | 0.20 | 486 |
|     | Max       | 2.93                   | 61.08 | 1.63  | 2.88 | 20.03 | 0.67 | 1920 |
|     | SD        | 0.95                   | 7.30  | 1.56  | 0.80 | 6.21  | 0.19 | 559.8 |
|     | Mean      | 1.31                   | 53.87 | −0.90 | 2.06 | 11.51 | 0.36 | 964 |
| Groundwater |         |                        |     |    |     |    |    |    |    |
| 6   | BW-1      | 0.97                   | 55    | −1.61 | 1.70 | 18.25 | 0.36 | 688 |
| 7   | BW-2      | 1.29                   | 63.7  | −1.19 | 1.75 | 16.78 | 0.53 | 587 |
| 8   | BW-3      | 0.43                   | 39    | −2.47 | 1.82 | 12.57 | 0.13 | 685 |
| 9   | BGI-1     | 1.07                   | 61.41 | −1.10 | 1.40 | 13.02 | 0.43 | 423 |
| 10  | BGI-3     | 0.97                   | 66.03 | −0.97 | 1.31 | 18.50 | 0.51 | 351 |
| 11  | BGI-4     | 1.83                   | 79.37 | −0.67 | 1.45 | 20.21 | 1.01 | 363 |
| 12  | ELF-W1    | 0.83                   | 38.85 | −2.78 | 2.88 | 8.60  | 0.19 | 921 |
| 13  | SSH-W     | 0.61                   | 46.3  | −0.78 | 1.43 | 14.25 | 0.17 | 1025 |
| 14  | SW-6      | 0.90                   | 47.83 | −2.31 | 2.07 | 11.94 | 0.29 | 603 |
| 15  | SW-8      | 0.91                   | 54.29 | −1.26 | 1.35 | 11.37 | 0.31 | 503 |
| 16  | Tex-W2    | 1.18                   | 56.56 | −1.28 | 1.75 | 7.19  | 0.39 | 629 |
| 17  | Tex-W5    | 1.16                   | 73.42 | −0.24 | 1.04 | 16.39 | 0.52 | 506 |
| 18  | Tex-W9    | 1.35                   | 72.37 | −0.74 | 1.16 | 15.46 | 0.65 | 328 |
| 19  | Tex-W10   | 1.31                   | 76.95 | −0.31 | 1.05 | 15.46 | 0.63 | 379 |
| 20  | Tan-W     | 0.65                   | 36.13 | −3.20 | 2.35 | 8.92  | 0.15 | 1065 |
| 21  | KCTW-2R   | 0.74                   | 50.29 | −1.63 | 1.32 | 11.50 | 0.25 | 482 |
| 22  | KO-W2     | 1.31                   | 51.03 | −2.20 | 2.66 | 11.05 | 0.38 | 1028 |
| 23  | YM-2      | 1.19                   | 77.91 | −0.07 | 0.96 | 14.77 | 0.57 | 418 |
|     | Min       | 0.43                   | 36.13 | −3.20 | 0.96 | 7.19  | 0.13 | 328 |
|     | Max       | 1.83                   | 79.37 | −0.07 | 2.88 | 20.21 | 1.01 | 1065 |
|     | SD        | 0.33                   | 14.03 | 0.90  | 0.55 | 3.63  | 0.22 | 246.7 |
|     | Mean      | 1.04                   | 58.14 | −1.38 | 1.64 | 13.68 | 0.42 | 610.2 |

| No. | Sample Id | Wet season (Nov 2017) | SAR | PI | RSC | PS | MR | KI | EC |
|-----|-----------|------------------------|-----|----|-----|----|----|----|----|
|     |           |                        |     |    |     |    |    |    |    |
|     |           |                        |     |    |     |    |    |    |    |
| Surface water |         |                        |     |    |     |    |    |    |    |
| 1   | BR-1      | 0.26                   | 40   | −1.99 | 1.09 | 10.52 | 0.08 | 488 |
| 2   | BR-2      | 0.25                   | 33   | −2.94 | 1.44 | 9.07  | 0.07 | 739 |
| 3   | BR-3      | 0.40                   | 39.6 | −2.13 | 1.31 | 14.95 | 0.11 | 844 |
| 4   | ES        | 0.36                   | 31.2 | −3.62 | 2.31 | 10.41 | 0.08 | 940 |
| 5   | WS        | 0.36                   | 56   | −0.32 | 0.59 | 15.89 | 0.13 | 498 |
|     | Min       | 0.25                   | 31.2 | −3.62 | 0.59 | 9.07  | 0.07 | 488 |
|     | Max       | 0.40                   | 56   | −0.32 | 2.31 | 15.89 | 0.13 | 498 |
|     | SD        | 0.07                   | 9.77 | 1.24  | 0.63 | 3.04  | 0.03 | 203 |
|     | Mean      | 0.34                   | 40   | −2.20 | 1.35 | 12.17 | 0.09 | 702 |
| Groundwater |         |                        |     |    |     |    |    |    |    |
| 6   | BW-1      | 0.43                   | 41.3 | −2.13 | 1.24 | 29.43 | 0.13 | 477 |
varies from 0.54 to 2.93 and 0.25 to 0.40 in the dry and wet season, respectively (Tables 7). Irrigation groundwater and surface water with a high concentration of Na⁺ and low Ca²⁺ favors the presence of ion exchange by saturation of Na⁺ and destroys the soil structure owing to the dispersion of clay particles (Todd 1980) resulting in minor production due to difficulty in cultivation (Subba Rao 2006). According to Tables 7 and 8 results, groundwater has better quality than surface water and results from the wet season have better quality than dry season in both groundwater and surface water of the study area.

**Electrical conductivity (EC)**

The concentration of EC is very essential for the classification of irrigation water. As measured by electrical conductivity, the salinity hazard decreases plant productivity (Johnson and Zhang 1990). The mean value of EC of groundwater is 610.2 µS/cm and 568 µS/cm in the dry and wet season, respectively. However, surface water has a mean value of 964 µS/cm and 702 µS/cm during the dry season and rainy season, respectively (Table 7). To classify irrigation water as low, the complete concentration of soluble salts in irrigation water can be demonstrated. Most of the groundwater and surface water samples in the area fall under good and permissible for irrigation purposes (Wilcox 1955) in both seasons (Table 8). The highest value of EC in groundwater and surface water was measured in the wet season, and in general, surface water has high electrical conductivity than groundwater (Table 7).

**Residual sodium carbonate (RSC)**

The calculated RSC was used to assess the dangerous impact of carbonate and bicarbonate concentration on water quality for agricultural usages in the water sample (Aghazadeh and Mogaddam 2010). Higher HCO₃⁻ concentration of in water outcomes precipitation of Ca²⁺ and Mg²⁺ as CO₃²⁻. However, in the study area is geologically composed of basaltic type rocks which are composed of alkali feldspars (non calcareous aquifers). At some stage of the water-rock interaction substantial dissolution of sodium silicate is made by adding of CO₂ to the waters and the reaction of carbonic acid with feldspar minerals in the presence of water releases HCO₃⁻. Thus the high carbonate minerals (HCO₃⁻) in both seasons is resulted from silicate weathering (Chidambaram et al. 2012; Rogers 1989; Elango et al. 2003). When the CO₃²⁻ + HCO₃⁻ concentration exceeds the Ca²⁺ + Mg²⁺ concentration, it will affect the adequacy of irrigation water. Aghazadeh and Mogaddam (2010), based on RSC values, categorized irrigation water into three classifications (Table 8). Table 7 indicates that the computed RSC values

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**Table 7 (continued)**

| No. | Sample Id | Wet season (Nov 2017) | SAR | PI | RSC | PS | MR | KI | EC |
|-----|-----------|-----------------------|-----|----|-----|----|----|----|----|
| 7   | BW-2      | 0.35                  | 47  | −1.06 | 1.00 | 28.84 | 0.11 | 580 |
| 8   | BW-3      | 0.30                  | 44  | −1.11 | 1.07 | 7.90  | 0.09 | 687 |
| 9   | BGI-1     | 0.18                  | 53.9 | −0.80 | 0.65 | 20.39 | 0.08 | 404 |
| 10  | BGI-3     | 0.25                  | 56   | −0.56 | 0.63 | 13.44 | 0.10 | 349 |
| 11  | BGI-4     | 0.30                  | 56.1 | −0.83 | 0.54 | 12.06 | 0.13 | 365 |
| 12  | ELF-W1    | 0.80                  | 48   | −1.27 | 1.75 | 16.22 | 0.23 | 890 |
| 13  | SSH-W     | 0.21                  | 55.3 | −0.75 | 0.69 | 20.75 | 0.09 | 431 |
| 14  | SW-6      | 0.23                  | 54.2 | −0.82 | 0.68 | 23.03 | 0.09 | 434 |
| 15  | SW-8      | 0.57                  | 55.8 | −0.70 | 0.88 | 17.52 | 0.21 | 490 |
| 16  | Tex-W2    | 0.58                  | 49.9 | −0.49 | 1.12 | 18.33 | 0.18 | 701 |
| 17  | Tex-W5    | 0.26                  | 42.5 | −1.84 | 1.26 | 25.83 | 0.10 | 482 |
| 18  | Tex-W9    | 0.22                  | 58.7 | −0.60 | 0.56 | 13.86 | 0.10 | 327 |
| 19  | Tex-W10   | 0.47                  | 62.4 | −0.68 | 0.70 | 13.55 | 0.21 | 343 |
| 20  | Tan-W     | 0.65                  | 34.4 | −3.91 | 2.63 | 9.23  | 0.15 | 1233 |
| 21  | KCTW-2R   | 0.20                  | 58.8 | −0.63 | 0.64 | 16.72 | 0.09 | 429 |
| 22  | KO-W2     | 0.31                  | 46.7 | −0.97 | 0.95 | 22.91 | 0.10 | 528 |
| 23  | YM-2      | 0.69                  | 40.8 | −1.92 | 1.81 | 25.38 | 0.17 | 1069 |
| Min | 0.18      | 34.4                  | −3.91 | 0.54 | 7.90  | 0.08 | 327 |
| Max | 0.80      | 62.4                  | −0.49 | 2.63 | 29.43 | 0.23 | 1233 |
| SD  | 0.19      | 7.65                  | 0.84 | 0.55 | 6.40  | 0.05 | 258 |
| Mean | 0.39  | 50.3                  | −1.17 | 1.04 | 18.63 | 0.13 | 568 |
| Classification index | Ranges | Categories | Groundwater (n = 18) | Surface water (n= 5) |
|----------------------|--------|------------|----------------------|---------------------|
| Sodium adsorption ratio (SAR) (Richards 1954) | < 2 | Very low | 18 100 | 18 100 | 4 80 | 5 100 |
| 2–12 | Low | Nil | Nil | Nil | 1 | 20 | Nil | Nil |
| 12–22 | Medium | Nil | Nil | Nil | Nil | Nil | Nil | Nil |
| 22–32 | High | Nil | Nil | Nil | Nil | Nil | Nil | Nil |
| > 32 | Very high | Nil | Nil | Nil | Nil | Nil | Nil | Nil |
| Electrical Conductivity (EC) (Wilcox 1955) | < 250 | Excellent | Nil | Nil | Nil | Nil | Nil | Nil |
| 250–750 | Good | 14 | 77.8 | 15 | 83.3 | 2 | 40 | 3 | 60 |
| 750–2250 | Permissible | 4 | 22.2 | 3 | 16.7 | 3 | 60 | 2 | 40 |
| 2250–5000 | Doubtful | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil |
| > 5000 | Unsuitable | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil |
| Residual Sodium Carbonate (RSC) (Aghazadeh and Mogaddam 2010) | < 1.25 | Safe | 18 | 100 | 18 | 100 | 4 | 80 | 5 | 100 |
| 1.25–2.5 | Marginally suitable | Nil | Nil | Nil | Nil | 1 | 20 | Nil | Nil |
| > 2.5 | Unsuitable | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil |
| Permeability Index (PI) (Doneen 1966) | < 25 (Class III) | Unsuitable | Nil | Nil | Nil | Nil | Nil | Nil | Nil |
| 25–75 (Class II) | Good | 15 | 83.3 | 18 | 100 | 5 | 100 | 5 | 100 |
| > 75 (Class I) | Excellent | 3 | 16.7 | Nil | Nil | Nil | Nil | Nil | Nil |
| Magnesium Ratio (MR) (Raghunath 1987) | < 50 | Suitable | 18 | 100 | 18 | 100 | 5 | 100 | 5 | 100 |
| > 50 | Unsuitable | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil |
| Kelley’s Ratio (KR) (Kelley 1940) | < 1 | Suitable | 17 | 94.4 | 18 | 100 | 5 | 100 | 5 | 100 |
| ≥ 1 | Unsuitable | 1 | 5.6 | Nil | Nil | Nil | Nil | Nil | Nil |
| Potential Salinity (PS) (Doneen 1966) | < 3 | Suitable | 18 | 100 | 18 | 100 | 5 | 100 | 5 | 100 |
| ≥ 3 | Unsuitable | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil |
for groundwater samples range from −3.2 to −0.07 and a mean value of −1.38 meq/l and from −3.91 to −0.49 and a mean value of −1.17 meq/l in the dry and wet season, respectively. The calculated RSC values for surface water for the two seasons range from −2.43 to 1.63 and a mean value of −0.90 meq/l and from −3.62 to −0.32 and a mean value of −2.20 meq/l in the dry and wet season, respectively. In both seasons, the mean value of groundwater is lower than surface water revealing groundwater better quality than the surface water of the study area (Table 7).

According to Table 8, except for one surface water sample in the dry season, all groundwater and surface water samples of the study area are categorized into the safe quality for irrigation.

**Permeability index (PI)**

The content of sodium, calcium, magnesium and bicarbonate affects soil permeability, and the long-term use of irrigation water affects it. The study area varies from 36.13 to 79.37 and 34.4 to 62.4 during the dry and wet seasons, respectively, and surface water samples range from 41.98 to 61.08 and 31.2 to 56.0 during the dry and wet seasons, respectively (Tables 7). Regarding PI values, three groundwater samples showed class III (excellent) in the dry season. However, the rest groundwater samples and all surface water samples in the study area fall under class II (good) in both seasons (Tables 8).

**Magnesium ratio (MR)**

The excess quantity of magnesium in water affects soil quality, which can lead to a decrease in crop yields (Joshi et al. 2009). In the dry season and wet season, the calculated magnesium risk values from the research area’s surface water vary from 4.33 to 20.03 and 9.07 to 15.89, respectively, and groundwater ranges from 7.12 to 20.21 and 7.90 to 29.43, respectively (Table 7). In total, 100% of the analyzed groundwater and surface water samples are appropriate for irrigation exercise in both seasons based on the Raghunath (1987) classification (Table 8).

**Kelly’s index (KI)**

The Kelly index is also an important parameter measured against sodium ion levels in meq/l against magnesium and calcium ion for irrigation water quality. The statistical analysis of the Kelly index of the present study’s groundwater samples ranges from 0.20 to 0.67 and 0.07 to 0.13 during the dry and wet seasons, respectively, and surface water samples vary from 41.98 to 61.08 and 31.2 to 56.0 during the dry and wet seasons, respectively (Tables 7). According to Kelley (1940) classification, except for one groundwater sample, all groundwater and surface water samples fall into the suitable category in both seasons and are appropriate for irrigation (Table 8).

**Potential salinity (PS)**

Groundwater samples’ prospective salinity has been categorized into 3 classes (Doneen 1966) (Table 8). The study area’s calculated potential salinity (PS) for groundwater varied from 0.96 to 2.88 and 0.54 to 2.63 in the dry and wet season, respectively. Surface water ranged from 0.98 to 2.88 and 0.59 to 2.31 in the dry and wet season, respectively (Tables 7). The mean values of PS in the surface water are greater than groundwater presenting surface water is more polluted than groundwater of the study area (Table 7). However, according to the Doneen (1966) classification, 100% of groundwater and surface water samples are appropriate for irrigation exercise. But wet season results showed better quality (Table 8).

In general, the calculated and evaluated irrigation parameters for groundwater samples are low as compared to surface waters. This is because the surface waters in the study area were polluted by the untreated industrial and municipal wastes. This can be supported, for example, by sample Id of WS and ES, where the highest value of irrigation parameters (SAR, PI, RSC, etc.) was recorded (Table 7). Surface water WS was sampled from Werka Stream, and ES was from Eyole Stream where each stream gets a direct untreated discharge from BGI-Brewery Factory and Tannery factory, respectively (Figs. 1 and 2). Comparing the two seasons, groundwater’s in the wet season is better than in the dry season for irrigation purposes. This is because the concentration of major ions in groundwater is higher in the dry season than in the wet season (Tables 3, 4 and 7).

**Conclusions**

Assessment of surface water and groundwater samples during the wet and dry seasons indicated by higher concentrations of constituents during the dry season, including Ca$^{2+}$, Na$^+$, K$^+$, Mg$^{2+}$, HCO$_3^-$, SO$_4^{2-}$, Cl$^-$ and TDS. The maximum concentration of ions, electrical conductivity and total dissolved solids measured and/or analyzed in surface water were sample number WS (Werka Stream). It was sampled from a direct discharge from a factory nearby.

WQI of the current study was computed by using eighteen groundwater sampling points and fourteen parameters (EC, TDS, HCO$_3^-$, Na, Ca, Mg, K, Cl, SO$_4^{2-}$, NO$_3^-$, PO$_4^{3-}$, Cu, Fe and F) to evaluate the suitability of water for drinking purposes. According to WQI, groundwater samples of the present study show excellent (72.8%) and good (27.8%) in the dry season and excellent (83.3%) and good (16.7%)
in the wet season. It is seen that wet seasons are of better quality than dry seasons. This can explain the decrease in concentration of elements in the wet season because the water level in the wells is higher in the wet season than in the dry season.

TDS, EC and Ca$^{2+}$ concentration values of some of the groundwater samples and all for Fe concentrations are above the maximum permissible limit for drinking as recommended by WHO (2011). However, regarding the Na$^+$, Mg$^{2+}$, K$^+$, Cl$^-$, SO$_4^{2-}$, HCO$_3^-$, NO$_3^-$, PO$_4^{3-}$, F$^-$ and Cu concentrations of the groundwater samples of the two seasons were fallen within the recommended limit for human consumption.

To evaluate the groundwater and surface water for irrigation uses SAR, RSC, MR, PI, KI and EC were used to evaluate irrigation water quality for two seasons. The results reveal that most of the groundwater and surface water samples were suitable for irrigation with some places in the study locations that belong to the good and permissible. However, none of them are unsuitable for irrigation.

According to Table 8, 100% of the calculated values of MR and PS for all groundwater and surface water sample, all SAR and RSC except for one surface water samples and all KI except for one groundwater samples are suitable for irrigational practice in both seasons.

The value of the electrical conductivity of water samples of the study area samples is falling into the good and permissible in both dry and wet seasons for agricultural uses. Graph of sodium hazard versus salinity hazard the entire water sample collected in May and November 2017 falls into category C2-S1 and C3-S1, showing low alkali hazards and waters are grouped under excellent irrigation water.

In general, as the head of the groundwater increases the concentration of most ions decreases, and hence, the concentrations of most ions in the wet season are lower than in the dry season. This leads that waters in wet seasons are more suitable than in the dry season for drinking and irrigation purposes. Effluents from the different factories and industries of the area are the main cause for pollution of groundwater and surface water.

Acknowledgements This work was supported by Wollo University Research Project (WU/125/2017), and the author is grateful to Wollo University for its valuable financial support. The author is grateful for the constructive comments and suggestions of anonymous reviewers for improving the manuscript.

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