Analysis and evaluation of the spatial and temporal variabilities of river water quality parameters

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Abstract

This study aimed to analyze the status and evaluate the spatiotemporal variabilities of water quality in the Awash River, Ethiopia. The study also aims to identify the origin and geochemical composition of the river water. Temporal variabilities of similar water quality parameters in the Lake Beseka, a dramatically rising lake (0.2 m/year) in the Awash River basin, which is being channeled into the Awash River system in order to control the lake level rise, were also considered in this study. To do this, laboratory measurements and a 10-year consecutive record of physicochemical parameters, major ions, nutrients and minor ions of the Awash River and Lake Beseka waters, graphical methods and factor analysis approaches were used. The origin of the Awash River was found to be shallow-medium depth aquifer with a geochemical composition of $\text{Ca}(\text{HCO}_3)_2$ and NaHCO_3 , while the origin of Lake Beseka was found to be deep, ancient groundwater with a geochemical composition of NaCl and NaHCO_3 . However, mixing the lake water with Awash River in the downstream sites shifted the geochemical composition of the river water to a mixture of $\text{Ca}(\text{HCO}_3)_2$, NaHCO_3 and NaCl water types. The results also showed that the river water quality varies spatially and temporally, controlled by three major factors: the combined effects of anthropogenic activities and mineral dissolutions (Factor-1), anthropogenic activities and ion exchange (Factor-2) and ion exchange (Factor-3). While Factor-1 was the main controlling factor of the river water quality, and Factor-3 was the least, all three factors equally controlled the temporal variabilities of water quality in Lake Beseka. The observed temporal and spatial variabilities of the river water quality suggest that frequent water quality evaluations are important in designing appropriate water management strategies in river systems near intensive agricultural, industrial, and urban development areas.

Keywords Awash River basin · Lake Beseka · Major cations · Metahara · Water quality analysis · Wonji

Introduction

Water is the essence of life (Sharma and Kansal 2011). According to the human rights act in relation to water, both the quantity and quality of water are equally important (Palmer et al. 2018). Access for water is a basic human right and critical determinant for life, while the quality of drinking water is a powerful environmental determinant of health (Farooq and Ustad 2015). Therefore, the pledge of drinking water safety is a basis for the deterrence and control of waterborne diseases. This signifies the importance

of analyzing and evaluating the spatial and temporal variabilities of water quality.

Water quality is a measure of the condition of water in relation to the requirements for one or more purposes (WHO 2011). Water quality assessment can be defined as the evaluation of the physical, chemical, biological and radiological nature of water in relation to the natural quality, human effects and intended uses (Ahmed 2010; Shishaye and Nagari 2016; Tiemann 2014). According to the Safe Drinking Water Act (1996), anything other than the water molecules within a water sample is classified as a contaminant. However, this does not necessarily indicate that the presence of contaminants in water poses a health risk (Ahmed 2010; Shishaye and Nagari 2016). In reality, there are harmless contaminants as well, even though some drinking water contaminants may be harmful if consumed at certain levels beyond the guideline values (WHO 2011). Therefore, analyzing the physical, chemical, biological and radiological

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nature of water and comparing it with the guideline values is important for the sake of human health and safety (Srinivasamoorthy 2012; Ahmed 2010; Farooq and Ustad 2015).

The quality of both surface and groundwater resources could be affected by natural and anthropogenic sources (Shishaye and Nagari 2016; Gamvroula et al. 2013; Alexakis 2011). Some of the natural sources of contaminants are the geologic formations and acid rains, while the anthropogenic contaminants include agricultural fertilizers, industrial wastes and farm effluents (Shishaye 2018). Surface water bodies are highly exposed especially to anthropogenic contaminants than groundwater (Farooq and Ustad 2015; Shishaye and Nagari 2016). Of all the anthropogenic activities affecting surface and groundwater quality, agriculture, unplanned urbanization, and dumping of polluted water and other wastes at inappropriate places are the most cited sources of water quality deterioration (Srinivasamoorthy 2012; Alexakis et al. 2012; Shishaye 2018). Musingafi and Tom (2014) showed that anthropogenic impacts highly affected surface water resources including rivers and lakes in South Africa, where they showed that surface water resources are relatively highly exposed to anthropogenic sources of contamination as compared to groundwater resources. Parris (2011), in his study on recent trends and prospects of the impact of agriculture on water pollution in OECD countries, also indicated that surface water resources receive an abrupt impact of agricultural contaminants, while agricultural pollution also affects both the groundwater and marine waters. This implies that anthropogenic activities, including agriculture, disrupt the limited global freshwater systems, both on and underground, tremendously from their pristine states (Moss 2008; Gamvroula et al. 2013; Alexakis 2011).

Rivers, constituting about 0.49% of the world's freshwater (Gleick 1993), are the most easily accessible water sources, while they are relatively highly exposed to contamination, especially to anthropogenic sources (Khatri and Tyagi 2015; Alexakis et al. 2012). Phiri et al. (2005) reported that the receiving rivers in urban areas of Malawi were highly contaminated as a result of industrial effluents, where they showed that the effluents have increased acidity of the river water in both the dry and wet seasons. Strokhal et al. (2016) reported alarming nutrient pollution in Chinese rivers as a result of agricultural transitions, where they found that the total dissolved nitrogen and total dissolved phosphorus inputs to rivers increased from 2- to 45-fold (range for sub-basins) during 1970–2000. Wright et al. (2018), in their study on river water pollution after the closure of Australia's longest operating underground coal mine, reported significant river water contamination with high pH, zinc and nickel in the adjacent Wingecarribee River, with the state of pollution predicted to continue for decades. This implies that regular/frequent river water quality analysis, evaluation

and monitoring are very important to safeguard freshwater resources (Sharma and Kansal 2011).

The Awash River is one of the intensively used rivers in Ethiopia for domestic, industrial and agricultural purposes (Tilahun et al. 2017). Most of the Ethiopian sugar estates, the horticultural crops, fruits and vegetables in the Middle and Lower Awash Valley use water from the Awash River (Shishaye 2015). This has a considerable positive contribution to the growth and economic development of the nation as a whole. In addition to its use for irrigation purposes, the Awash River is also being used for drinking water supply, and it is a major source of hydroelectric power in the area (Tilahun et al. 2017). However, the origin and geochemical composition of the Awash River water are not clearly identified. Further, except the local investigations conducted at different stages of the river course (e.g., Amare et al. 2017; Degefu et al. 2013; Taddese 2019; Yimer and Jin 2020; Adeba et al. 2015) the overall status, and the spatial and temporal variabilities of the river water quality have not been documented, despite all the natural and anthropogenic effects starting from its origin, the highlands of central Ethiopia, to the Rift Valley area in the east, then to its endpoint at Lake Abbe (near Djibouti; Tilahun et al. 2017). This study aimed to investigate the status and evaluate a multi-year (10-years) spatial and temporal trends of the water quality parameters in the Awash River. It also aimed to identify the origin and geochemical composition of the river water based on the measured water quality parameters and assess the suitability of the Awash River for irrigation and domestic uses. The study considered physicochemical parameters, major and minor ions, nutrients and trace metals.

Materials and methods

Study area

The Awash River spans from central to eastern Ethiopia (Fig. 1). It rises on the steep northern escarpment of the Eastern (Great) Rift Valley, and it feeds different lakes in Ethiopia (e.g., Shala, Abiyata, Langano, Ziway and Abbe; Adeba et al. 2015). Starting its way in the central highlands of Ethiopia, Awash River ends in the chain of saline Lake Abbe being an endorheic basin in the Danakil Plains after a northeasterly course of about 1200 km (Fig. 1; Tilahun et al. 2017).

Based on physical and socioeconomic factors, the Awash Basin is divided into Upland (all lands above 1500 m amsl)—Upper Valley, Middle (areas between 1500 and 1000 m amsl), Lower Valley (areas < 1000 m amsl), and Eastern Catchment (closed sub-basins are between 2500 and 1000 m amsl) (Fig. 1). The Upper, Middle and Lower Valleys are part of the Great Rift Valleys systems, with the

Fig. 1 Location of the study area and sampling sites

Lower Awash Valley comprising the deltaic alluvial plains in the Tendaho, Assaita, Dit Behri area and the terminal lakes area (Tilahun et al. 2017). The Rift Valley part of the

Awash River basin is seismically active (Adeba et al. 2015). The international border region of South-Western Djibouti and North-Eastern Ethiopia also named the *Afar Depression* or the *Afar Triangle* or the *Danakil desert* is a result of the separation of three tectonic plates (Arabian, Somali and African) (Shishaye 2017).

In a normal year, a subtle hydrological balance characterizes the lower Awash River basin. This means that inflows are equal to the losses in lakes and wetlands in the area (Dost et al. 2013). Below Dupti in Ethiopia (Fig. 1), no considerable runoff from local rainfall reaches the Awash River. The level of Lake Abbe (Fig. 2a), thus, rises and falls according to the balance between the inflow from Awash River and losses through evaporation. According to Taddese et al. (2009), the annual total rainfall in the Awash River basin is 39,845 (Mm³), where 72% of it (28,383 Mm³/yr) is lost through evapotranspiration, 18% (7386 Mm³/yr) runoff and 10% (4074 Mm³/yr) is rechargeable water.

The major land-use types in the Awash River basin include annual cropland, sparse forest, closed shrubland, settlement and bare soil, with ten other land-use types also available (Fig. 2a). The majority of the croplands and settlements are located in the upstream, while the bare soil is in the lower dry land (Fig. 2a). The river passes through the old perennial croplands (sugarcane farms) in Ethiopia, Wonji and Metahara sugarcane farms (Fig. 2a), where agricultural effluents from these farms were reported increasing river water nutrient concentrations (Shishaye 2015).

Fig. 2 a Land use land cover and b surface geological maps of the Awash River basin

The surface geology of the most upstream areas of the Awash River basin is dominated by the upper Miocene–Pleistocene Magdala group (Fig. 2b). The Magdala group includes rhyolites, trachytes, tuffs, ignimbrites, agglomerates and basalts. The Ashangi group, which includes basalts, tuffs and gabbro intrusive dominate the northwestern portions of the basin, while the alluvial formations including sands, silts and clay cover the majority of the downstream of the Awash River basin followed by the Afar group formations, which includes basalts, subordinate acid lavas and ignimbrites (Fig. 2b). The Shield group, including alkali basalts, tuffs and agglomerates, cover a small portion of the western Awash River basin, while the Amba Aradom formation (i.e., clay, silt, sandstone and conglomerates) covers a similar area in the east (Fig. 2b). The Afar and Ashangi groups are the most fractured formations in the Awash River basin (Fig. 2b).

Field sampling and analytical techniques

Samples had been collected from seven sampling sites, i.e., Wonji, upstream side of the mixing site of Awash River with Lake Beseka (AR_B_LB), Lake Beseka (LB), at the mixing point of Awash River with Lake Beseka (AR_A_LB), Awash water supply site (AWS), Melka Sedi and Dubti (Fig. 1) for 10 consecutive years. Samples were analyzed for total dissolved solids (TDS), electrical conductivity (EC), total solids (TS), turbidity, pH, total hardness (TH), major ions (Na^+ , Ca^{2+} , Mg^{2+} , K^+ , HCO_3^- , SO_4^{2-} , Cl^- , CO_3^{2-}) and some minor ions and nutrients (NO_3^- , total iron, Mn, F^- , Ammonia and PO_4^{3-}).

The pH, EC and TDS values were measured using pH-meter and TDS/EC-meter, respectively, as discussed in Shishaye (2018). The major ions were determined with flame atomic absorption spectrophotometer, while UV–Vis spectrophotometer was used for the determination of PO_4^{3-} (at 880 nm, 4500-P E. Ascorbic Acid Method) and SO_4^{2-} (at 420 nm, 4500- SO_4^{2-} E. Turbidimetric Method) following the procedures discussed in APHA (1999). NO_3^- was determined using the UV absorption at 220 nm according to ‘4500- NO_3^- B (APHA 1999), and F^- was determined using the ion selective electrode method. Details on the step-by-step procedures from the reagent preparations to sample analysis are discussed in APHA (1999), Shishaye (2018) and Shishaye and Nagari (2016).

Data analysis and interpretation

The GW-Chart software (Winston 2000) was used to produce piper diagrams of each sampling site to identify the origin and geochemical compositions of the Awash River and Lake Beseka waters. The concentrations of the major cations (Na^+ , K^+ , Ca^{2+} and Mg^{2+}), major anions (Cl^- ,

SO_4^{2-} , CO_3^{3-} and HCO_3^-) and TDS were used as inputs for the software. The JMP 15 of the SAS software was used to evaluate the correlations among the hydro-chemical parameters, and factor analysis was conducted to identify the factors controlling the water quality parameters of the river and the lake.

Result

Origin and geochemical compositions of the Awash River and Lake Beseka waters

The samples from the upstream sampling site (Wonji), close to the origin of the river, lay at the border of the left and bottom quadrants of the piper diagram (Fig. 3a), indicating $\text{Ca}(\text{HCO}_3)_2$ and NaHCO_3 water types. Similarly, samples from the second sampling site (AR_B_LB), river water before mixing with Lake Beseka, also lay at the border of the left and bottom quadrants, except one sample from 2013 laid at the center of the bottom quadrant (Fig. 3b), indicating NaHCO_3 dominated water type. However, due to mixing of the Awash River water with the NaCl and NaHCO_3 -rich water type of Lake Beseka (samples at the border of the right and bottom quadrants; Fig. 3g), the geochemical composition of the river water changed into NaHCO_3 dominated water types with samples from 2010 and 2011 showing mixed water of NaCl and NaHCO_3 water types and samples from 2008 and 2013 showing a mixture of $\text{Ca}(\text{HCO}_3)_2$ and NaHCO_3 water types (Fig. 3c) at the downstream of the mixing site of the Awash River and Lake Beseka waters (AR-A-LB; Fig. 1). The majority of the samples from AWS (Fig. 3d) and MS (Fig. 3e) also laid in the bottom quadrant of the piper diagram with some bias to the border of the left and bottom quadrants, indicating a majority of NaHCO_3 geochemical composition with a mixture of $\text{Ca}(\text{HCO}_3)_2$ water types. However, the samples from the most downstream (Dubti) were found at the bottom quadrant, but close to the center of the diamond diagram of the piper plot, indicating a majority of NaHCO_3 geochemical composition with a mixed $\text{Ca}(\text{HCO}_3)_2$ and NaCl water types (Fig. 3f).

The TDS values of the Awash River were also spatially and temporally variable (Fig. 3). The highest TDS at Wonji (260 mg/L) was found in 2011 (Fig. 3a), while it increased to ~645 mg/L at AR_B_LB in 2013 (Fig. 3b), with the minimum TDS values at Wonji and AR_B_LB being 178 mg/L and ~207 mg/L, respectively. The highest TDS values of the Lake Beseka (ranging from 3017 to 4529 mg/L; Fig. 3g) increased TDS of the Awash River at the downstream of the mixing site (AR-A-LB) to a maximum of 2062 mg/L (Fig. 3c). TDS of the river water, then, decreased slightly in the downstream sites, with total ranges from 193 to 531 mg/L at AWS (Fig. 3d), 146 to 554 mg/L at MS (Fig. 3e)

Fig. 3 Piper diagrams of the Awash River water at **a** Wonji, **b** AR_B_LB, **c** AR_A_LB, **d** AWS, **e** MS, **f** and Dubti, and **g** the Lake Beseka. The sizes of the symbols refer to the extents of TDS values in mg/L

and 329 to 445 mg/L at Dubti (Fig. 3f). However, the TDS values at the different sampling sites were not consistent temporally. For example, with the highest TDS values of Lake Beseka being in 2011, the highest TDS at AR_A_LB was found in 2011, while it was in 2015 at AWS, in 2010 and 2015 at MS and 2009 at Dubti (Fig. 3c–f).

Spatiotemporal variability of water quality in the Awash River and Lake Beseka

Physicochemical parameters

TDS of the Awash River increased (Fig. 4a) from the upstream (Wonji) to the downstream (Dubti) (Fig. 1).

However, it decreased from 193 mg/L in 2006 to 178 mg/L in 2015 at Wonji, while it increased from 248 mg/L in 2006 to 461 mg/L in 2015 at MS. TDS values of the Lake Beseka showed a decreasing trend, while it still was beyond the guideline values for domestic uses (500 mg/L; WHO 2011). The EC values of the river and the lake were in a similar trend with the TDS values (Fig. 4d), as EC is directly proportional to TDS (i.e., $TDS = 0.67EC$; Shishaye and Nagari 2016). The river water was highly turbid (Fig. 4b). The turbidity (Fig. 4b) and total solids (TS) (Fig. 4c) of the river water were highly variable spatially and temporally, while both showed an increasing trend from upstream to downstream and a decreasing trend from 2006 to 2015. Turbidity of Lake Beseka was by far below the values of the Awash

Fig. 4 Spatiotemporal variabilities of the concentrations of physicochemical parameters in the Awash River and the Lake Beseka

River in all sites, while TS of the lake was higher than the TS of the Awash River. The pH of the river water decreased from 8.1 in 2006 to 7.3 in 2015 at Wonji, while it increased from 7.8 to 8.3 in Dubti (Fig. 4e). The pH of the LB was highly alkaline (averagely 9.5; Fig. 4e). Total hardness (TH) of both the river and LB showed increasing trends temporally (from 2006 to 2015) and spatially (from upstream to downstream) (Fig. 4f). However, TH was below the drinking water standard (500 mg/L CaCO_3 ; WHO 2011) in both the Awash River and Lake Beseka.

Major ions

The concentrations of most of the major ions in the Awash River were far below their concentrations at Lake Beseka, except Mg^{2+} and Ca^{2+} that were relatively higher in the Awash River compared to their concentrations in Lake Beseka (Fig. 5). The concentration of Na^+ at Wonji was ~32 mg/L in both 2006 and 2015, it fluctuated from ~32 to 57 mg/L in the study period, while it increased from ~48 to 189 mg/L at AR_B_LA (Fig. 5a; “Appendix 1”). The concentration of Na^+ also showed an increasing trend in all sites downstream of LB, while it decreased from 1758 in 2006 to 1196 mg/L in 2015 at LB (Fig. 5a; “Appendix 1”). In general, the concentration of Na^+ was below the international guideline values for domestic uses (<200 mg/L; WHO 2011) in all sites, except in Lake Beseka (Fig. 5; “Appendix 1”).

The Mg^{2+} concentration was also found below the guideline values for domestic uses (200 mg/L; WHO 2011) in

all sampling sites, while it showed a slight increase in the study period (Fig. 5b; “Appendix 1”). It increased from 4 to 7 mg/L in the far upstream (Wonji), from 7 to 12 mg/L in the most downstream (Dubti) and 1 to 4 mg/L at LB (“Appendix 1”). The concentrations of Ca^{2+} were also found below the guideline values set for irrigation (200 mg/L) and drinking (40 mg/L) purposes (WHO 2011) in all sites, except one sample from Dubti sampled in 2008 (Fig. 5c). The analysis has also revealed that calcium levels in the lake were found below its concentration in the river (Fig. 5c). Even though there is no designed standard for the K^+ concentration, the levels of K^+ was found < 10 mg/L in all sampling locations in the whole study period, except in Lake Beseka where it was found to be higher, on average > 50 mg/L (Fig. 5d; “Appendix 1”). However, K^+ concentration has shown a decreasing trend in LB within the study period, while it showed a slight increase in all sampling sites in the Awash River (Fig. 5d).

The concentration of Cl^- at Wonji varied from 12 to 17 mg/L, with 12 mg/L in 2006 and 13 mg/L in 2015 (Fig. 5e). However, Cl^- concentration increased from 19 mg/L in 2006 to 66 mg/L in 2015 at AR_B_LB, with > 150 mg/L in 2010 and 2011 (Fig. 5e). Similarly, Cl^- concentration also showed an increasing trend in AWS and MS sites, while it fluctuated between 36 and 54 mg/L at Dubti, with 36 mg/L in both 2006 and 2015. Its concentration was found significantly higher in LB, ranging from ~585 mg/L in 2006 to 412 mg/L in 2015 with a decreasing trend in the study period (Fig. 5e; “Appendix 1”). Cl^- concentration was lower in the most upstream area

Fig. 5 Spatiotemporal variabilities of the concentrations of major ions in the Awash River and Lake Beseka

(Wonji; average 12.5 mg/L) than the most downstream (Dubti; average 36) in the study period (Fig. 5e).

The concentration of HCO_3^- decreased from 141 mg/L in 2006 to 139 mg/L in 2015 at Wonji (upstream), and it decreased from 239 mg/L in 2006 to 220 mg/L in 2015 at Dubti (Fig. 5g; “Appendix 1”). It also decreased from ~1426 mg/L in 2006 to 892 mg/L in 2015 in LB (Fig. 5g). However, HCO_3^- also showed an increase from 170 mg/L at AR_B_LB, 154 mg/L at AR_A_LB, 172 mg/L at AWS and 182 mg/L at MS in 2006 to 409 mg/L at AR_B_LB, 202 mg/L at AR_A_LB, 435 mg/L at AWS and 348 mg/L at MS in 2015. The CO_3^{2-} concentration does not show high variabilities within the sites in the Awash River, except in LB where it was found on average from 50 to 100 times of its concentration in the river water, with a slight increase in the river and a slight decrease in the lake from 2006 to 2015 (Fig. 5f). Sulfate ion (SO_4^{2-}) was also lower in the Awash River (in all sampling sites) than in Lake Beseka (Fig. 5h). In the Awash River, SO_4^{2-} concentration increased from 8.5 mg/L at Wonji to 34.3 mg/L at Dubti in 2006, and from 7.2 mg/L at Wonji to 48 mg/L at Dubti in 2015 (Fig. 5h), with values fluctuating between 6 and 75 mg/L going from upstream to downstream during the study period (“Appendix 1”). However, SO_4^{2-} concentration

in LB remained beyond the guideline values for domestic uses (400 mg/L; WHO 2011) in most of the years, except in 2013 and 2015, where it was measured to be 374 mg/L and 354 mg/L, respectively.

Nutrients, minor ions, and trace elements

Ammonia showed an increase temporally in both the Awash River and Lake Beseka within the study period (Fig. 6a; “Appendix 1”). However, it showed a decreasing spatial trend from upstream (Wonji) to downstream (Dubti), with a decrease from 0.24 mg/L at Wonji to 0.02 mg/L at Dubti in 2006 and from 1.42 mg/L at Wonji to 0.5 mg/L at Dubti in 2015 (Fig. 6a). Ammonia in Lake Beseka showed an increase temporally from 0.12 mg/L in 2006 to 1.22 mg/L in 2015 (Fig. 6a). Nitrate also showed decreasing trends in the most upstream and downstream sites, with concentrations fluctuating between 0.9 and 5.5 mg/L at Wonji and 1.4 and 3.7 mg/L at Dubti. However, it showed no consistent trend in the remaining sampling sites (Fig. 6b). Nitrate in Lake Beseka decreased from 2.9 mg/L in 2006 to 1.1 mg/L in 2015, with exceptionally high in 2007 and 2009 (6.2 mg/L and 7.6 mg/L, respectively; “Appendix 1”). In contrast, PO_4^{3-} increased

Fig. 6 Spatiotemporal variabilities of the concentrations of nutrients, minor ions, and trace metals in the Awash River and Lake Beseka

in all sampling sites in the Awash River and showed a decline in Lake Beseka within the study period (Fig. 6c). It also increased from upstream toward downstream in most of the sampling years, with an exceptional decrease at Dubti in the last two sampling years (2014 and 2015) (Fig. 6c).

Even though it showed no consistent trend, the overall concentration of the total iron showed an increase in both Lake Beseka and the Awash River relative to its concentration at the initial study period (2006; Fig. 6d). The spatial variability of total iron concentration in the Awash River also showed higher concentrations in the upstream sites than the most downstream sites (Fig. 6d). Manganese (Mn) showed a relatively stable concentration in all sites in the whole study period, with an exceptionally high concentration in the upstream sites of the Awash River and the lake in 2013 (Fig. 6e). The higher concentrations of Mn measured in 2013 were beyond the drinking water guideline values (> 0.1 ; WHO 2011), while its concentration remained below the guideline values in the rest of the years ("Appendix 1"). The general temporal variability of the F^- concentration in the Awash River decreased from 2006 to 2015, with an exceptional increase in 2010 and 2011 at AR_A_LB (sampling sites right after the Awash River got mixed with Lake Beseka, a lake with significantly high F^- concentrations) (Fig. 6f). The concentration of F^- in Lake Beseka ranged from 23 times of the drinking water guideline value (1.5 mg/L ; WHO 2011) in 2006 to 10 times in 2015 (Fig. 6f; "Appendix 1"). However, F^- concentration in the lake showed a 56% decline from 2006 to 2015 (Fig. 6f).

Factor analysis

Three water quality governing factors, signifying geochemical and anthropogenic processes, were extracted in each sampling site (Fig. 7) using the variable loadings ("Appendix 2"). The three factors explained a total variance of $> 97\%$ in each sampling sites (Fig. 8). The loadings of each factor were spatiotemporally variable (Fig. 7). However, Factor-1 alone explained 52%, 49%, 38%, 55%, 49%, 41% and 55% at Wonji, AR_B_LB, LB, AR_A_LB, AWS, MS and Dubti, respectively (Fig. 8), making it the major controlling factor in all sites. Based on the variable loadings under each of the three principal components ("Appendix 2"), Factor-1 (high loadings of turbidity, TDS, EC, TS, NO_3^- , total iron, ammonia, HCO_3^- , and CO_3^{2-} ; "Appendix 2") showed a combined effect of anthropogenic activities including land use and urban and industrial effluents, and mineral (mainly carbonate) dissolutions. Factor-2 (positive loadings of Mg^{2+} , Ca^{2+} with and the negative manifestation of Na^+ , and positive loadings of turbidity, ammonia, NO_3^- , total iron, manganese, phosphate and chloride) indicated the combined effects of anthropogenic activities and ion exchange. Factor-3 showed tradeoffs between the major cations, mainly Ca^{2+} , Mg^{2+} and Na^+ ("Appendix 2") indicating ion exchange as a major controlling factor. This factor showed the least loading at the most upstream (Wonji) and downstream (Dubti), AR_A_LB sites, while it showed a relatively higher loadings AR_B_LB, AWS, MS and at the Lake Beseka, which is higher than the factor loadings in all sites (Fig. 8).

Fig. 7 Spatial and temporal variabilities of the rotated factor loading values of the three controlling factors of water quality at **a** Wonji, **b** AR_B_LB, **c** LB, **d** AR_A_LB, **e** AWS, **f** MS and **g** Dubti

Fig. 8 Variances (factor loadings) explained by each of the three factors in all sampling sites

Discussion

Origin and geochemical composition of the Awash River

The geochemical composition of the Awash River water in the upstream (Wonji)—close to the origin of the river was found to be dominated by HCO_3^- (Fig. 3a). The samples from this site in the 10 years study period lay at the border of the left and bottom quadrants of the piper diagram (Fig. 3a), indicating a mixture of $\text{Ca}(\text{HCO}_3)_2$ and NaHCO_3 water types. A sample laying at the top quadrant of the diamond diagram of a piper plot shows calcium sulfate waters mainly originated from gypsum rich water and mine drainage, the left quadrant represents calcium bicarbonate waters mostly originated from shallow fresh groundwater, the right quadrant represents sodium chloride waters originated from marine and deep ancient groundwater, and the bottom quadrant represents sodium bicarbonate waters originated from deep groundwater influenced by ion exchange (Shishaye and Nagari 2016). Accordingly, the piper plot at

the upstream site (Wonji) indicates that the Awash River originates from shallow to medium depth fresh groundwater with a major geochemical composition of calcium bicarbonate and sodium bicarbonate (Fig. 3a). Samples from the AR_B_LB also lay at the same location in the piper plot with the samples in the upstream (Wonji), except samples from 2013 that showed a NaHCO_3 water type (Fig. 3b). This can, therefore, be attributed to the basalt dominated Magdala group formation covering the upstream sites of the Awash River basin. Basalt is rich in Ca^{2+} and HCO_3^- (Chandrasekar et al. 2018). Water that originates from basalt-rich aquifers is mostly $\text{Ca}(\text{HCO}_3)_2$ types (Srinivasamoorthy et al. 2008). This implies that the Awash River originates from the shallow-medium depth aquifers in the central highlands of Ethiopia, where the major geological setting of the aquifer is dominated by basalts of the Magdala group (Fig. 2b). In contrast, the origin and geochemical composition of Lake Beseka were found to be deep and ancient groundwater with a mixture of NaHCO_3 and NaCl rich geochemical nature (Fig. 3g). The lake is located in the siliceous domes and lava flow formations, where the junction between the Ashangi group, the Afar group and the siliceous domes and lava flow formations in the Rift Valley is in its western vicinity (Fig. 2b). The active volcanic activities in the lake vicinity facilitate high chemical reactions, where the groundwater that feeds the lake reacts with the volcanic rocks/formations causing high F^- , HCO_3^- and Na^+ (from the rhyolites) ions in the lake water that are known from the volcanic formation (Rakovan 2005; Chandrasekar et al. 2018; Litchfield et al. 2002).

Mixing the Lake Beseka water with Awash River, however, caused a different geochemical composition of the river water in the downstream sites, shifting it from a $\text{Ca}(\text{HCO}_3)_2$ and NaHCO_3 water types to a NaHCO_3 dominated water type (Fig. 3c–f), with the mixture improved to include $\text{Ca}(\text{HCO}_3)_2$, NaHCO_3 and NaCl water types at the most downstream site (Dubti; Fig. 3g). Therefore, the changes in the geochemical composition of the river water in the downstream sampling sites should be taken as an indicator of the impact of the lake water on the river water quality. The chemical composition of the river water in the downstream sampling locations was found to be dominated by the lake water geochemical composition.

Factors controlling the spatial and temporal variabilities of water quality in the Awash River

The concentrations of the water quality parameters in the Awash River were found spatially and temporally variable (Figs. 4, 5, 6). The spatial and temporal variabilities of the water quality parameters in both Awash River and Lake Beseka were affected by three major factors (Figs. 7, 8). The factors were grouped into three, based on the variable loadings (“Appendix 2”), with factor one including anthropogenic activities and dissolution of carbonate minerals (Fig. 9), factor two referring to the combined effect of anthropogenic activities and ion exchange and the third factor indicating ion exchange effects alone (Figs. 7, 8). The higher loadings of EC, turbidity, TDS, TS, NO_3^- , total iron and ammonia in the first and second principal components

Fig. 9 Conceptual diagram of potential urban, industrial and agricultural effluents as sources of river water pollution. This conceptual diagram was developed using Adobe Illustrator CS6

of all the sites (“Appendix 2”) refer to the impacts of anthropogenic activities such as agricultural land uses, urban and industrial effluents (Thivya et al. 2013), while higher loadings of HCO_3^- , alkalinity and CO_3^{2-} ions refer to dissolution of carbonate minerals, mainly from the basalt-rich Magdala group in the upstream (Figs. 2b, 9). In the third factor, trade-offs among the major cations (Ca^{2+} , Mg^{2+} , Na^+ and K^+) in the second and third principal components (“Appendix 2”) showed that ion exchange is the dominant factor controlling the extents of the water quality parameters (Chandrasekar et al. 2018; Litchfield et al. 2002).

In the most upstream site (Wonji), factor one and two were the major factors controlling the river water quality (Fig. 7a). Most of the tributaries streaming to the Awash River, especially those from the suburbs of Addis Ababa city (Fig. 2a), contain several pollutants. These pollutants, therefore, caused higher loadings of turbidity, EC, TDS, TS, NO_3^- , total iron and ammonia (“Appendix 2”). Turbidity, for example, is caused by waste discharge, urban runoff sediments from erosion and phytoplankton (Huey and Meyer 2010). The wastes from the Addis Abeba city and other small cities/settlements in the course of the Awash River (Fig. 2a) are discharged in open areas where the tributaries of the Awash River can wash them down and affect the river water quality (Fig. 9). These, therefore, yielded turbid water and higher loadings of EC, TDS, TS and total iron. Most of the croplands in the upstream of the sampling site (Wonji; Fig. 2a) use organic and inorganic fertilizers, which caused higher loadings of NO_3^- , PO_4^{3-} and ammonia (“Appendix 2”). Further, the most upstream areas of the Awash River basin (areas from the origin to Wonji) are dominated by basalt (Magdala group; Fig. 2b), which is known to cause high bicarbonate ions in water (Chandrasekar et al. 2018). Therefore, dissolution of carbonate minerals of the basalt formations caused higher loadings of bicarbonate and alkalinity in the river water (“Appendix 2”; Fig. 9). However, ion exchange has decreased the loadings of Ca^{2+} and Mg^{2+} , while basalt was known for higher loadings of these ions (Shishaye et al. 2020, accepted). This led to a conclusion that the three factors control the water quality of the Awash River at this site, with factors one and two being the major controlling factors (Fig. 7a).

Going farther down to the next sampling site (AR_B_LB), the Awash River passes through mechanized farms (e.g., the Wonji sugarcane farm) and other small-scale farms (Fig. 2a). Further, the geology is also dominated by basalt and rhyolites (Fig. 2b). This caused factors one and two to be the dominant controlling factors of the river water quality (Fig. 7b; Thivya et al. 2013). However, because the site is in a lower elevation than Wonji (Fig. 1), the temperature is higher, which increases mineralization and ion exchange (Chandrasekar et al. 2018; Shishaye et al. 2020). This, therefore, causes higher ion exchange (higher loading of factor

three; Fig. 7b) than the Wonji site (Fig. 7a). This was also supported by the positive loading of Ca^{2+} and Mg^{2+} with a negative manifestation of the Na^+ in the third principal component at the AR_B_LB site (“Appendix 2”; Thivya et al. 2013). The temporal variabilities of the waste disposals and fertilizer utilization in the upstream, and variabilities in temperature may have caused the temporal variabilities of the parameters (“Appendix 2”) and factors (Fig. 7) loadings. In their study on the identification of the key factors that affect temporal variability in stream water quality across multiple catchments in the state of Victoria (Southeast Australia) using a Bayesian hierarchical model, Guo et al. (2019) indicated that water temperature and nutrient application were among the major controlling factors of the temporal variabilities of water quality parameters.

The influence of the three factors was, however, almost similar in Lake Beseka (Fig. 7c). Lake Beseka is a naturally contaminated and continuously raising (i.e., ~ 0.2 m/year) lake, located in a volcanically active place within the East African Rift Valley (Shishaye 2017). The high temperature in the area creates a favorable condition for mineralization and ion exchange (Chandrasekar et al. 2018; Litchfield et al. 2002). Further, the nearby towns (e.g., Metahara) dispose of their wastes in open areas where surface runoff washes it out to the lake. Therefore, anthropogenic activities, mineral dissolution and ion exchange equally control the lake water quality (Fig. 7c).

The temporal trends of the controlling factors in the downstream sites (AR_A_LB, AWS, MS and Dubti) showed a complex pattern (Fig. 7d–g). As a measure of controlling the continuous rise of Lake Beseka, the Awash Basin Authority discharges the lake water to the Awash River course, diluting it in a proportion of 2% lake water with 98% of river water (Shishaye 2017). This mixing, therefore, caused chaos on the spatial and temporal trends of the major controlling factors of the river water quality downstream of the Lake (Fig. 7d–g), with insignificant ion exchange processes at the AR_A_LB site in the first 4 years of measurement (Fig. 7d). The influence of the three factors at AWS and MS sites alternates temporally, with factors one and three dominantly controlling water quality at AWS until the last 2 years of the study (Fig. 7e) and factors one and two being the dominant factors at MS in the same study period. This implies that ion exchange processes increased from the AR_A_LB to MS sites. The relatively higher Ca^{2+} and Mg^{2+} concentrations in the Awash River than the lake (Fig. 5b, c) resulted in a favorable condition for ion exchange processes with the Na^+ -rich water from Lake Beseka (Fig. 5a; Chidambaram et al. 2018) in the downstream sites (i.e., from the AWS to MS) (Figs. 7e–g, 8). At Dubti (Fig. 7g), the impact of factor three significantly decreased, leaving factors one and two being the major controlling factors. This could be attributed to the relative decline of Na^+ at Dubti (Fig. 4h)

due to the high ion exchange processes in the long way from AWS to MS sites (Fig. 7e–f). However, the impacts of anthropogenic activities mainly agriculture (Fig. 2a) and mineral dissolution, mainly the basaltic flows and the Afar group formations in the course of the river in the downstream sites (Fig. 2b) still control the river water quality in the most downstream site (Figs. 7, 8).

Therefore, the combined effect of anthropogenic activities and mineral dissolution (Factor 1) was the major controlling factor of water quality in Awash River followed by the combined effects anthropogenic activities and ion exchange (Factor 2) (Fig. 8). The influence of ion exchange was significantly lower ($< 3\%$) at Wonji, AR_A_LB and Dubti sites, while its loading reached $\sim 20\%$ at AR_B_LB and $> 20\%$ at AWS and MS sites (Fig. 8). In Lake Beseka, however, ion exchange (Factor 3) showed higher loading $\sim 30\%$ (Fig. 8). This implies that ion exchange is among the major controlling factors of the lake water quality, while its impact on Awash River water quality is relatively low. In general, starting from its origin (highlands of central Ethiopia) to its end near Lake Abbe (Figs. 1, 2), the Awash River water quality was found mainly affected by different anthropogenic activities, including organic and inorganic nutrients, and mineral dissolutions (Figs. 7, 8; “Appendix 2”). The sources of the anthropogenic contaminants include wastes from settlements, industries, and fertilizers from agricultural farms (Fig. 9). Cities ranging from the capital of the nation (Addis Abeba) to small towns/settlements (Fig. 2a) dispose of their wastes including the urban and industrial effluents within the catchment area of the Awash River (Fig. 9). The upstream catchments of the Awash River basin are also dominantly covered by perennial and annual croplands (Fig. 2a), where inorganic fertilizers are widely used (Fig. 9). Further, the major national sugarcane farms (Wonji and Metahara sugarcane farms) are also located within the upper half of the Awash River basin (Fig. 2a). These activities, therefore, resulted in anthropogenic activities to be the dominant factors affecting the Awash River water quality (Fig. 9). Mixing Lake Beseka and Awash River waters in the downstream, however, affected the composition of the Awash River water in the downstream (Fig. 9). This implies that mixing the naturally contaminated lake with Awash River, the widely used river in the country may cause long-term soil salinization problems in the downstream areas, which could be more complex than the current impacts of the lake on the nearby towns and infrastructures.

Suitability of the Awash River and Lake Beseka waters for irrigation and domestic uses

Turbidity in the Awash River was higher than the international guideline values for domestic uses (5 NTU; WHO 2011). However, turbidity has no considerable effect,

especially in irrigation water. In contrast, the TS, TDS, EC, pH and TH values of the Awash River were found within the drinking water standard (Fig. 4; WHO 2011). However, except the TH, the other four parameters were beyond the guideline values both for irrigation and domestic purposes (WHO 2011) in Lake Beseka (Fig. 4).

The concentrations of the major cations of the Awash River and Lake Beseka were found below the guideline values for both irrigation and domestic uses, except Na^+ concentration of the Lake Beseka, which was far beyond the guideline values (200 mg/L; WHO 2011). However, its concentration decreased by 32% from 2006 to 2015 (Fig. 5a), even though both the causes of the high levels of Na^+ and its decreasing trend in the lake are not clearly known (Shishaye 2017). The concentrations of the major anions, but bicarbonate (the dominant anion), were found to be below the guideline values for irrigation uses in all of the sampling sites within the Awash River (Fig. 5), while they all exceed the guideline values for both irrigation and domestic uses in Lake Beseka (Fig. 5; WHO 2011), even though they all showed a decreasing trend within the study period (Fig. 5). However, the lake water containing the exceeding anion concentrations is being discharged to the Awash River course to control the continuous lake level rise (Shishaye 2017), and the mixed water is used as an irrigation and domestic water supply in the downstream (Fig. 1a). Excess amounts of any of the major ions could cause an adverse effect on human health and agricultural productivity. Excess amounts of carbonate, bicarbonate and sulfate salts can cause plant chlorosis (Taddese 2019). The other most common toxicity of irrigation water is from chloride (Shishaye 2017). Chloride is normally not adsorbed or held back by soils, and it rather moves readily with the soil–water and is used by the crop, moves in the transpiration stream, and is accumulated in the leaves (White 2001). If the chloride concentration in the leaves exceeds the tolerance of the crop, injury symptoms such as leaf burn or drying of leaf tissue can develop (Franco-Navarro et al. 2015). However, the toxicity of chloride salts depends on the cation present. Therefore, the analysis showed that the Awash River can be used for irrigation purposes, unlike Lake Beseka. This implies that mixing the lake water with the river water and supplying it to the downstream farms may cause a long-term consequence on the soil and the groundwater in the area, which will affect the productivity of the farms eventually.

The concentrations of nutrients in both the Awash River and Lake Beseka were within the guideline values for domestic and irrigation uses (Fig. 6; < 45 mg/L for NO_3^- , < 20 mg/L for PO_4^{3-} ; WHO 2011; EPA 2001). Nitrate levels at or above this level have been known to cause a potentially fatal blood disorder called methemoglobinemia, in which there is a reduction in the oxygen-carrying capacity of blood, in infants under 6 months of age (Shishaye

2015). The usual range of PO_4^{3-} in irrigation water is also 0–2 meq/L or 20.66 mg/L (WHO 2011). However, PO_4^{3-} load has appeared to be low in the analyzed water samples (Fig. 6). This could be due to low solubility or high precipitation of other phosphate sources, which contribute to phosphate solubility (Prasanna et al. 2010). Ammonia levels in the study area were also lower in all sampling sites, including Lake Beseka (Fig. 6). This could be because of the higher pH levels in almost all sampling sites (Fig. 4; Shishaye 2018). However, ammonia levels have shown a slight increase during the study period (Fig. 6), mainly due to the potential organic source in the area (Fig. 9).

The concentrations of total iron in the Awash River were found within the standard from 2006 to 2010, while it showed an increase and became beyond the standard (0.3 mg/L Fe^{+3} ; WHO 2011) after 2011 (Fig. 6). This might be one of the reasons causing loss of the availability of phosphorus within the river water, as excess iron can compete with other needed micronutrients, which makes it problematic in irrigation waters. Manganese is often found with iron-rich water resources, and concentrations of Mn^{2+} less than 0.05 mg/L are generally satisfactory for domestic uses (WHO 2011). However, the overall levels of Mn^{2+} obtained in the Awash River and the lake water samples were above the recommended values for domestic uses (Fig. 6). The recommended maximum Mn^{2+} concentrations in irrigation waters are also ≤ 0.2 mg/L (ESB 1972; Kolega and Wooding 1979). However, the Mn^{2+} levels measured in the lake and the river water samples in 2009 and 2013 have shown higher values (Fig. 6). The higher iron and manganese values in the river water can be associated with the urban wastes and industrial effluents in the upper Awash River basin (Fig. 9). Fluoride concentrations of the Awash River were also found above the guideline values for domestic uses (1.5 mg/L; NAS 1974; Pratt 1972), with elevated concentrations at AR_A_LB site (Fig. 6). This was because of the significantly higher fluoride concentrations of Lake Beseka (> 15 mg/L; Fig. 6). The probable reasons for the high levels of fluoride ion concentrations in the lake could be the volcanically active formations (Belay 2009) and the nature of the Rift Valley Zones (Shishaye 2017).

Conclusion

This study used a multi-year (10-years) water quality data to identify the origin and geochemical composition of the Awash River, and to evaluate the spatiotemporal variabilities and the factors controlling the river water quality. The river water quality parameters were also compared with the extents of similar parameters in Lake Beseka to evaluate the influence of mixing the lake water with Awash River in

the downstream areas. The results showed that the origin of the Awash River was shallow-medium depth aquifers with a major geochemical composition of $\text{Ca}(\text{HCO}_3)_2$ and NaHCO_3 , while Lake Beseka originates from deep and ancient groundwater with a major geochemical composition of NaHCO_3 and NaCl . The river water quality was spatially and temporally variable, mainly controlled by anthropogenic activities, mineral dissolutions and ion exchange processes. In the upstream areas, the intensive agricultural practices, urban and industrial effluents caused higher nutrient concentrations, while the dissolution of carbonate minerals resulted in higher bicarbonate ions. In the downstream areas, the concentration of Na^+ increased because of the rhyolite formations, which increased the role of ion exchange. In Lake Beseka, however, the anthropogenic activities, mineral dissolution and ion exchange showed almost equal loadings, indicating that they equally control the lake water quality.

The concentrations of most of the parameters, except fluoride, in the Awash River were within the international guideline values for agricultural and domestic (after mild treatment) uses, while they were beyond the guideline values in Lake Beseka. This implies that discharging the lake water to the river course as a means of controlling the lake water level rise will cause an increase in concentrations of the parameters of concern, leading to long-term problems, such as soil salinity and sodicity, in the downstream agricultural farms that use the mixed water.

The identification of the origin and geochemical compositions of both the river and lake waters was crucial to understand the status and create prospects on the chemical and physical characteristics of the water bodies. Evaluations of the spatiotemporal variabilities of the water quality and the controlling factors are also important to designing appropriate water management strategies. For example, balancing nutrient application rates with plant uptake capacity and effective management of effluents from the nearby settlements and industries can be recommended to reduce the anthropogenic impacts in the upstream areas, while treating the lake water before channeling it to the river is crucial to maintain water quality in the downstream.

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Appendix 1: Laboratory measurements

A 10-year continuous water quality measurements of the Awash River at six different sampling sites (Dubti, Melka Sedi, Awash Water Supply site (Awash 7), Awash River after mixing with Lake Beseka, Awash River before mixing with Lake Beseka, Wonji) and Lake Beseka.

Location	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
TDS (mg/L)										
Dubti	336	430	329	445	377	372	391	407	334	334
MS	248.5	146	194	249	553.5	259	349	356	461	461
AWS	235.4	236	237	250.2	204	193	316	382	530.8	530.8
AR_A_LB	236.14	236	238	260.4	1838	2062	337.2	285	446	446
LB	4528.8	4403	4233	3828.8	4225.6	4074.7	3513.2	3383.2	3017.1	3017.1
AR_B_LB	206.8	206.9	230	218.3	248.9	275	238.73	644.8	232.1	232.1
Wonji	193	188.6	180	219	224.7	260	211	205	178	178
Turbidity (NTU)										
Dubti	1203	529	3788	2768	76	334	93	163	81	81
MS	1874	647	1731	944	288	389.2	423	424.5	1122.2	1122.2
AWS	1434.8	1436	1450	1968	4538	1125	749.1	1234	503.9	503.9
AR_A_LB	508	510	523	2330.6	1702	1670.47	449.2	1404	334	334
LB	8.1	6.2	57	39.3	44.1	49.2	42.1	74.04	47.2	47.2
AR_B_LB	1698.3	356.7	1102	1202	384.2	657.77	277.9	1063.2	413.4	413.4
Wonji	400	151	257	249.4	257.4	179	224	182	198	198
TS at 105 °C (mg/L)										
Dubti	1932	3420	5081	3749	489	848	543	668	503	503
MS	4377	1469	2155	1679.7	1542	3344	3506	1164	1059.4	1059.4
AWS	3873.4	3800	3600	2692	4987	2931	5225	3318.4	1042	1042
AR_B_LB	5255.3	1007.1	605.3	2183	2158.7	3188	754.55	2700.3	511.3	511.3
LB	4621	4420	4325	5617.4	4308	4404	3644.5	3623.8	3497.8	3497.8
AR_A_LB	1175	1190	2500	4543.5	4099	3422	1256.2	1873.4	807	807
Wonji	774	410.4	538.5	503	537.3	381	512	420	334	334
EC (µs/cm)										
Dubti	551	650	495	680	574	568	661	643	609.3	609.3
MS	384	346	288	378	414	392	562	571	591.5	591.5
AWS	371.7	372	375	379.7	315	276	503.6	593	873.8	873.8
AR_B_LB	315.3	323.4	344.5	331.09	380.99	419	380.36	997.9	401.4	401.4
LB	6745	6678.3	6287.5	5531	6067.8	5510	5382	5292	4934.2	4934.2
AR_A_LB	373.43	375	380	394.5	2692	2969.3	544.3	437.4	737.9	737.9
Wonji	296	312	266.5	330.2	342	403	323.2	324	302	302
pH										
Dubti	7.87	8.08	7.9	8.01	8.06	8.11	8.28	8.04	8.32	8.32
MS	7.88	7.82	8.22	7.98	7.62	7.97	8.23	7.88	7.48	7.48
AWS	8.02	8.02	8.02	8.13	7.83	7.8	8.3	7.82	7.39	7.39
AR_B_LB	7.77	7.79	8.29	7.92	7.65	7.65	7.89	7.77	6.79	6.79
LB	9.12	9.52	9.63	9.62	9.39	9.47	9.51	9.32	9.56	9.56
AR_A_LB	8.16	8.16	8.6	8.17	8.28	8.74	8.1	7.44	7.29	7.29
Wonji	8.09	8.25	8.47	8.55	7.71	7.88	8.19	7.76	7.37	7.37
TH (mg/L CaCO₃)										
Dubti	125	109	112	111	115	98.45	103	108.1	208.03	208.03
MS	100	98	98	93.44	106.8	96.16	104.9	109	108.8	108.8

Location	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
AWS	93.07	93	92.8	92.59	82.95	75.1	100.69	114	104.4	104.4
AR_B_LB	9.84	100.9	88.45	91.25	101.27	114	102.01	100.5	102.8	102.8
LB	15.51	19.83	46.28	33.02	15.24	17.73	17.96	21.67	21.55	21.55
AR_A_LB	89.13	89.1	89.2	89.5	63.42	54.25	99.5	114.12	104.99	104.99
Wonji	87.3	8.52	91.18	92.2	88.8	88.9	96.75	98.81	93.57	93.57
Ammonia (mg/L)										
Dubti	0.02	0.5	0.43	0.55	0.45	0.99	0.6	0.58	0.503	0.503
MS	0.5	0.44	0.55	0.57	0.51	0.78	0.7	0.76	1.26	1.26
AWS	0.45	0.45	0.46	0.53	0.55	1.12	0.88	0.59	1.11	1.11
AR_B_LB	0.55	0.53	0.67	0.6	0.41	0.81	0.86	0.84	1.28	1.28
LB	0.12	0.42	0.76	0.61	0.49	0.67	0.77	0.85	1.22	1.22
AR_A_LB	0.41	0.45	0.46	0.56	0.39	2.2	0.9	0.93	1.2	1.2
Wonji	0.24	0.43	0.74	0.54	0.42	0.43	0.83	0.79	1.42	1.42
Na (mg/L)										
Dubti	71	103	73	116	90	91.1	99.5	86.4	86.5	86.5
MS	49.5	50	32.2	50.3	53.1	50.56	84	82.4	134.2	134.2
AWS	46.15	–	–	52.36	37	33.25	72.92	88	197	197
AR_B_LB	35.83	33.29	44	37.85	49	53	43.54	228.88	48.2	48.2
LB	1758	1645	1525	1437	1595	1613.33	1218	1286	1196.3	1196.3
AR_A_LB	47.79	–	–	54.68	70.92	81.95	78.6	55.95	189.2	189.2
Wonji	31.9	32.83	25.88	41.25	38.4	57.25	33.71	31.69	31.89	31.89
Mg (mg/L)										
Dubti	7.2	7.25	13.8	6.6	7.81	5.42	8.63	7	12.09	12.09
MS	5.4	5	7.1	4.85	5.3	5.41	6.07	7.75	11.75	11.75
AWS	3.87	3.88	3.9	4.22	4.59	5.49	5.44	7.26	15.03	15.03
AR_B_LB	3.88	5.41	4.33	3.85	4	9.03	5.12	5.81	12.6	12.6
LB	1.1	1.09	5.9	2.08	1.33	0.9	1.56	1.99	4.31	4.31
AR_A_LB	4.16	4.2	4.1	5.4	3.6	3.87	5.5	7.24	17.61	17.61
Wonji	4.04	3.94	4	4.64	6.12	5.13	5.54	7.86	7.09	7.09
Ca (mg/L)										
Dubti	38	32	53.4	34.9	32.02	30.43	30.6	36.62	34.51	34.91
MS	30.7	31	27.5	29.4	33.9	33.17	31.83	31	32.17	32.28
AWS	30.91	30.2	30.2	30.1	25.62	20.88	31.21	33.66	31.04	28.5
AR_B_LB	30.12	31.62	28.12	34.4	31.54	30.67	32.12	30.6	31.8	41.96
LB	4.5	6.21	8.85	9.77	4.48	5.6	4.55	5.34	6.92	15.59
AR_A_LB	28.87	28.4	28	26.8	19.5	15.2	30.6	33.59	32.44	33.28
Wonji	28.3	28.81	29.92	29.7	28.2	27.04	29.3	26.43	29.26	32.38
K (mg/L)										
Dubti	5.5	6.7	4.72	7.07	6.36	5.7	5.83	6.45	6.21	6.3
MS	7	7.71	5.3	6.72	7.4	20.05	8.91	11.4	11.56	11.2
AWS	6.94	6.93	6.94	6.91	6.1	8.25	8.54	13.48	13.03	13.1
AR_B_LB	6.86	7.9	8.05	7.05	7.84	10.4	8.66	16.71	19.3	19.3
LB	60.14	68	65.13	61	58.98	48.76	46.79	46.86	44.33	44.5
AR_A_LB	7.41	7.5	8	12.4	18.9	7.65	9.7	9.98	16.37	16.4
Wonji	6.3	6.29	6.43	6.49	7.16	8.45	6.95	7.75	6.56	6.7
Cl (mg/L)										
Dubti	36	49.4	28.5	51.21	43.69	34.07	54	49.48	35	36
MS	18.83	19.4	13.9	21.6	23.31	19.84	34.89	31.4	50.05	51
AWS	17.82	18	19	21.42	13.62	14.83	28.41	31.96	65.4	66

Location	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
AR_B_LB	13.74	15.83	17.63	16.74	19.53	22.03	20.1	73.08	18.8	19
LB	584.8	592	530.6	458.1	554.3	422.2	437.5	437.4	411.6	411.8
AR_A_LB	19.32	19	20	23	224.4	250.6	37.63	21.5	61.32	66
Wonji	12.94	14.14	12.4	17.21	17.06	21.84	16	15.6	12.97	13
CO_3^{2-} (mg/L)										
Dubti	9.1	10.4	9.1	55.4	12.6	9.2	15	23.73	23	23
MS	6.6	2.4	7.2	7.2	4.8	24	23.05	18.1	19	19
AWS	14.85	14	13	12.96	14	15	19.37	22.7	19.2	19
AR_B_LB	33.6	13	12	4.8	8.1	9.8	7.5	27.4	21	21
LB	872.5	676	760	645	538.8	365.3	460	546.8	503.9	504
AR_A_LB	13.6	14	15	16	16.12	14.32	16.7	17.64	24	24
Wonji	12	6.24	8	7.2	9.7	9.1	11.3	13.68	14	14
HCO_3^- (mg/L)										
Dubti	239	263.5	204	292	237	190	218	220.94	219	220
MS	182.2	190	145.9	190.08	205.8	188.36	246.1	247.7	347.43	348
AWS	172.15	173	174	186.74	152.44	133.82	210.97	265.5	434.41	435
AR_B_LB	153.86	168.63	169.5	170.05	203.76	218.05	253.43	512	201.1	202
LB	1425.6	1604	1533.4	1360	1594.7	1556.5	1306	1028.3	891.6	892
AR_A_LB	170.45	174	175	181.4	756.4	799	229.93	217.7	408.45	409
Wonji	141.3	144.3	129	173.5	175.2	213.4	155	254.47	137.9	139
SO_4^{2-} (mg/L)										
Dubti	34.3	40.94	58	40	53.2	65.3	58	73.11	74	48
MS	18.92	16.62	19.63	13.09	26.43	24.2	30.6	37.4	69.65	60.4
AWS	16.74	17	15	14.78	19.61	20	27.41	51.82	75.56	53.2
AR_B_LB	16.91	9.55	18.7	7.72	15.86	21.39	15.4	67.9	24.5	6.85
LB	479.51	510.4	397	474.5	553.5	792	427	373.92	473	353.67
AR_A_LB	16.16	17	17	17.84	221.8	281.29	31.24	30.8	64.35	6.8
Wonji	8.5	6.67	7.76	5.62	12.5	9.83	23.04	18.91	21.61	7.2
Total iron (mg/L Fe^{3+})										
Dubti	0.04	0.06	0.25	0.069	0.024	0.08	0.11	0.1	0.11	0.11
MS	0.09	0.11	0.09	0.1	0.12	0.42	0.34	0.26	0.54	0.53
AWS	0.08	0.08	0.08	0.072	0.03	0.63	0.38	0.26	0.31	0.32
AR_B_LB	0.08	0.12	0.19	0.2	0.09	0.28	0.51	0.18	0.76	0.71
LB	0.03	0.12	0.22	0.12	0.06	0.3	0.23	0.15	0.15	0.15
AR_A_LB	0.12	0.12	0.12	0.13	0.04	0.425	0.45	0.27	0.46	0.42
Wonji	0.07	0.12	0.3	0.25	0.09	0.11	0.59	0.26	0.49	0.49
Mn (mg/L)										
Dubti	0.04	0.09	0.04	0.21	0.02	0.02	0.02	0.15	0.04	0.05
MS	0.08	0.07	0.06	0.05	0.03	0.02	0.02	0.04	0.05	0.05
AWS	0.09	0.06	0.07	0.035	0.05	0.06	0.06	0.07	0.07	0.07
AR_B_LB	0.07	0.08	0.06	0.05	0.03	0.02	0.03	0.43	0.01	0.04
LB	0.09	0.04	0.02	0.04	0.04	0.05	0.06	0.72	0.05	0.06
AR_A_LB	0.1	0.06	0.05	0.04	0.07	0.06	0.08	0.9	0.04	0.08
Wonji	0.04	0.05	0.06	0.07	0.02	0.04	0.07	0.9	0.04	0.06
F^- (mg/L)										
Dubti	1.5	1.98	1.31	4.38	1.46	1.15	1.12	0.94	0.99	1.31
MS	1.95	2.19	1.08	1.3	2.14	1.47	1.77	1.3	4.88	1.71

Location	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
AWS	1.83	1.6	1.7	1.5	1.23	0.49	1.27	1.57	2.15	2.86
AR_B_LB	1.78	1.86	1.55	1.45	1.47	1.46	3.21	1.23	0.99	1.06
LB	34.3	35.85	32.8	30.63	33.58	6.9	20	16.96	17.91	15.08
AR_A_LB	2.23	2.2	2.1	1.9	14.44	16.57	1.54	1.14	1.74	2.37
Wonji	1.98	1.89	1.4	1.9	1.42	1.74	1.02	1.01	1.03	1.13
NO_3^- (mg/L)										
Dubti	2.6	2.03	1.62	2.56	3.1	3.71	1.95	2.72	1.35	1.4
MS	3.66	2	2.3	3.69	4.21	5.74	3.45	4.72	2.31	2.5
AWS	2.21	2.2	2.3	2.66	4.7	4.57	4.27	3.12	2.36	2.4
AR_B_LB	2.1	1.71	3.74	5	3.59	1.82	2.91	3	2.2	2.2
LB	2.85	6.15	2.1	7.61	1.29	1.3	1.08	1.04	1.03	1.05
AR_A_LB	2.54	2.5	2.5	4.5	3.7	3.43	3.31	4.6	2.52	2.6
Wonji	2.76	1.72	0.91	2.8	5.1	2.7	5.51	5.26	4.96	5.1
PO_4^{3-} (mg/L)										
Dubti	0.24	0.67	0.26	0.66	0.28	0.4	0.66	0.56	0.3	0.32
MS	0.36	0.315	0.35	0.5	0.38	0.512	0.6	0.66	0.66	0.67
AWS	0.31	0.31	0.32	0.63	0.37	0.78	0.53	0.46	0.73	0.73
AR_B_LB	0.35	0.25	0.49	0.41	0.33	0.39	0.76	0.73	0.41	0.42
LB	3.23	3.27	2.69	2.44	2.84	2.73	2.33	2.48	2.08	2.4
AR_A_LB	0.27	0.3	0.56	0.48	1.41	1.84	0.69	0.69	0.66	0.63
Wonji	0.2	0.28	0.2	0.52	0.36	1.14	0.73	0.48	0.56	0.57

Appendix 2: Principal component analysis of the water quality variables of the Awash River and Lake Beseke

Variables	Wonji			AR_B_LB			LB			AR_A_LB			AWS			MS			Dubti		
	Prin1	Prin2	Prin3	Prin1	Prin2	Prin3	Prin1	Prin2	Prin3	Prin1	Prin2	Prin3	Prin1	Prin2	Prin3	Prin1	Prin2	Prin3	Prin1	Prin2	Prin3
Alkalinity	1.37	-0.37	-0.09	0.33	0.49	-0.42	2.41	-0.34	0.38	0.66	0.79	-0.07	-0.18	0.8	0.01	0.09	0.48	0.21	0.61	-0.81	0.04
Ammonia	-1.93	0.11	-0.01	-1.5	-0.34	0.15	-1.81	0	0	-1.62	-0.28	0.01	-1.25	-0.43	-0.1	-1.39	-0.25	-0.2	-1.67	0.23	-0.1
Bicarbonate	2.19	-0.67	-0.58	0.83	0.66	-0.72	0.73	-0.09	0.21	0.8	0.85	-0.41	0.04	1.1	0.05	0.37	0.62	0.3	1.01	-0.98	0.07
Calcium	-1.23	0.04	0.04	-1.15	-0.17	0.03	-1.79	0.01	-0.01	-1.38	-0.26	-0.09	-1.11	-0.34	-0.09	-1.16	-0.19	-0.17	-1.27	0.05	-0.06
Carbonate	-1.69	0.07	0.02	-1.29	-0.22	0.06	-0.67	0	-0.09	-1.18	-0.03	0.34	-1.17	-0.37	-0.1	-1.3	-0.21	-0.19	-1.51	0.15	-0.07
Chloride	-1.57	0.05	-0.04	-1.28	-0.26	0.08	-0.87	-0.03	-0.05	-1.22	-0.04	0.04	-1.08	-0.19	-0.08	-1.17	-0.12	-0.13	-1.17	-0.02	-0.07
EC	6.24	-1.42	0.32	3	1.81	-1.47	9.38	-0.24	-0.47	4.47	3.05	0.13	1.67	3.28	0.16	2.5	2.56	0.63	5.88	-3.51	0.45
Fluoride	-1.92	0.11	-0.02	-1.49	-0.34	0.15	-1.72	0.01	-0.04	-1.61	-0.28	0.01	-1.24	-0.42	-0.1	-1.38	-0.25	-0.2	-1.66	0.23	-0.1
Magnesium	-1.78	0.04	0.06	-1.41	-0.27	0.09	-1.8	0	-0.01	-1.56	-0.24	-0.02	-1.21	-0.37	-0.09	-1.33	-0.22	-0.19	-1.56	0.16	-0.09
Manganese	-1.95	0.11	-0.02	-1.51	-0.35	0.16	-1.81	0	0	-1.63	-0.29	0.01	-1.25	-0.43	-0.1	-1.39	-0.26	-0.21	-1.67	0.23	-0.1
Nitrate	-1.86	0.09	0	-1.48	-0.34	0.16	-1.76	-0.02	-0.01	-1.61	-0.28	0	-1.24	-0.43	-0.1	-1.37	-0.25	-0.21	-1.64	0.23	-0.09
Nitrite	-1.95	0.12	-0.02	-1.51	-0.35	0.16	-1.81	0	0	-1.63	-0.28	0.01	-1.25	-0.43	-0.1	-1.39	-0.26	-0.21	-1.67	0.23	-0.1
PH	-1.76	0.1	-0.02	-1.43	-0.31	0.14	-1.79	0	0	-1.56	-0.28	-0.01	-1.22	-0.41	-0.1	-1.33	-0.24	-0.2	-1.58	0.18	-0.09
Phosphate	-1.94	0.11	-0.02	-1.51	-0.35	0.16	-1.8	0	0	-1.63	-0.28	0.01	-1.24	-0.43	-0.09	-1.39	-0.26	-0.21	-1.67	0.23	-0.1
Potassium	-1.78	0.09	-0.02	-1.37	-0.25	0.09	-1.7	0	0	-1.54	-0.25	-0.02	-1.21	-0.39	-0.1	-1.32	-0.23	-0.2	-1.6	0.19	-0.09
Sodium	-1.07	-0.07	-0.03	-0.93	-0.11	-0.03	1	0.01	-0.05	-0.86	0.22	-0.36	-0.76	0.3	-0.03	-0.83	0.1	0	-0.59	-0.28	-0.03
Sulfate	-1.64	0.07	-0.02	-1.32	-0.26	0.12	-0.87	0.04	0.05	-1.27	-0.12	0.09	-1.07	-0.2	-0.08	-1.14	-0.09	-0.09	-0.96	-0.14	-0.04
TS	9.43	1.33	-0.23	11.23	-2.11	-0.01	6.34	0.72	0.17	10.63	-1.63	-0.35	11.9	-0.71	-0.95	11.76	-0.59	-1.36	2.86	-1.86	0.18
TDS	3.13	-0.61	-0.09	1.21	0.81	-0.64	5.49	-0.21	0.28	2.16	1.56	0.28	0.48	1.54	0.06	1.23	1.33	0.25	-0.2	-0.51	0.02
TH	0.12	-0.09	0.31	-0.4	0.24	-0.28	-1.65	0.09	-0.26	-0.83	-0.21	-0.3	-0.81	-0.17	-0.07	-0.63	-0.04	-0.07	-1.67	0.23	-0.1
Total iron	-1.95	0.11	-0.01	-1.51	-0.35	0.16	-1.81	0	0	-1.63	-0.28	0.01	-1.25	-0.43	-0.1	-1.39	-0.26	-0.21	9.39	2.46	-0.88
Turbidity	3.54	0.68	0.46	4.49	2.37	1.87	-1.69	0.03	-0.08	4.06	-1.44	0.7	4.46	-0.89	2.08	3.95	-1.37	2.66	2.34	3.31	1.33

References

- Adeba D, Kansal ML, Sen S (2015) Assessment of water scarcity and its impacts on sustainable development in Awash basin, Ethiopia. *Sustain Water Resour Manag* 1(1):71–87
- Ahmed R (2010) Drinking-water contamination and its effects on human health. Water Research Foundation, Denver, pp 1–9
- Alexakis D (2011) Assessment of water quality in the Messolonghi-Etoliko and Neochorio region (West Greece) using hydrochemical and statistical analysis methods. *Environ Monit Assess* 182:397–413
- Alexakis D, Gotsis D, Giakoumakis S (2012) Assessment of drainage water quality in pre- and post-irrigation seasons for supplemental irrigation use. *Environ Monit Assess* 184(8):5051–5063
- Amare SK, Zebene K, Agizew NE (2017) Evaluating water quality of Awash River using water quality index. *Int J Water Resour Environ Eng* 9(11):243–253
- APHA (1999) Standard methods for the examination of water and wastewater, 20th edn. APHA, Washington, DC
- Belay EA (2009) Growing lake with growing problems: integrated hydrogeological investigation on Lake Beseka, Ethiopia. Rheinisch-Friedrich-Wilhelms-Universität Bonn, Bonn, pp 1–10
- Chandrasekar T, Sabarathinam C, Nadesan D, Rajendiran T, Banaja RBP, Keesari T, Viswanathan PM, Utharapathi V, Alagappan R (2018) Geochemical (process-based) characterization of groundwater along the KT boundary of South India. *Geochemistry* 78(1):1–16
- Chidambaram S, Sarathidasan J, Srinivasamoorthy K, Thivya C, Thilagavathi R, Prasanna MV, Singaraja C, Nepolian M (2018) Assessment of hydrogeochemical status of groundwater in a coastal region of Southeast coast of India. *Appl Water Sci* 8:27
- Degefu F, Lakew A, Tigabu Y, Teshome K (2013) The water quality degradation of upper Awash River, Ethiopia. *Ethiop J Environ Stud Manag* 6(1):58–66
- Dost R, Obando EB, Bastiaanssen W, Hoogeveen J (2013) Water accounting plus (WA+) in the Awash River Basin. FAO, Land and Water Division, pp 1–50
- Environmental Studies Board (ESB) (1972) Water quality criteria. National Academy of Science and Engineering, USA. Water Supply Paper 1812 Washington
- EPA (2001) Parameters of water quality interpretation and standards. Environmental Protection Agency, Wexford
- Farooq G, Ustad I (2015) Investigation of physico-chemical properties of groundwater from commercial boreholes in Altamash Colony, Aurangabad. *World J Pharm Pharm Sci* 4:1625–1630
- Franco-Navarro JD, Brumós J, Rosales MA, Cubero-Font P, Talón M, Colmenero-Flores JM (2015) Chloride regulates leaf cell size and water relations in tobacco plants. *J Exp Bot* 67(3):873–891
- Gamvroula D, Alexakis D, Stamatis G (2013) Diagnosis of groundwater quality and assessment of contamination sources in the Megara basin (Attica, Greece). *Arab J Geosci* 6(7):2367–2381
- Gleick PH (ed) (1993) Water in crisis: a guide to the world's fresh water resources. Oxford University Press, New York
- Guo D, Lintern A, Webb JA, Ryu D, Liu S, Bende-Michl U (2019) Key factors affecting temporal variability in stream water quality. *Water Resour Res* 55:112–129
- Huey GM, Meyer ML (2010) Turbidity as an indicator of water quality in diverse watersheds of the Upper Pecos River Basin. *Water* 2(2):273–284
- Khatri N, Tyagi S (2015) Influences of natural and anthropogenic factors on surface and groundwater quality in rural and urban areas. *Front Life Sci* 8(1):23–39
- Kolega J, Wooding NH (1979) Water quality for farm processing. In: Quality water for home and farm proceedings of the third domestic water quality symposium, February 27–March, 1979. ASAE Publication, St. Louis Missouri
- Litchfield N, Craw D, Koons PO, Edge B, Perraudin E, Peake B (2002) Geology and geochemistry of groundwater within the Taieri Basin, east Otago, New Zealand. *New Zeal J Geol Geophys* 45(4):481–497
- Moss B (2008) Water pollution by agriculture. *Philos Trans R Soc* 363:659–666
- Musingafi MC, Tom T (2014) Fresh water sources pollution: a human related threat to fresh water security in South Africa. *J Public Policy Gov* 1(2):72–81
- National Academy of Sciences (NAS) (1974) Subcommittee on nutrient and toxic elements in the water. Nutrient substances in water for livestock and poultry. National Academy of Sciences, Washington, DC
- Palmer R, Short D, Auch W (2018) The human right to water and unconventional energy. *Int J Environ Res Public Health* 15(9):1–28
- Parris K (2011) Impact of agriculture on water pollution in OECD countries: recent trends and future prospects. *Int J Water Resour Dev* 27(1):33–52
- Phiri O, Mumba P, Moyo BHZ, Kadewa W (2005) Assessment of the impact of industrial effluents on water quality of receiving rivers in urban areas of Malawi. *Int J Environ Sci Technol* 2(3):237–244
- Prasanna MV, Chidambaram S, Shahul HA, Srinivasamoorthy K (2010) Study of evaluation of groundwater in the Gadilam basin using hydrogeochemical and isotope data. *Environ Monit Assess* 168:63–90
- Pratt P (1972) Quality criteria for trace elements in irrigation water. California Experiment Station, Riverside, p 46
- Rakovan J (2005) Word to the wise: solid solution. *Rocks Miner* 80(6):449–450
- Sharma D, Kansal A (2011) Water quality analysis of River Yamuna using water quality index in the national capital territory, India (2000–2009). *Appl Water Sci* 1:147–157
- Shishaye HA (2015) Simulations of nitrate leaching from sugarcane farm in Metahara, Ethiopia, using the LEACHN model. *J Water Resour Prot* 7:665–688
- Shishaye HA (2017) Water quality analysis and evaluation using graphical methods: a case of Lake Beseka. *Ethiop J Environ Stud Manag* 10(8):1054–1070
- Shishaye HA (2018) Diagnosing the suitability of lake water for domestic and agricultural uses: a case study in Eastern Ethiopia. *East Afr J Sci* 12(2):101–110
- Shishaye HA, Nagari A (2016) Hydrogeochemical analysis and evaluation of the groundwater in the Haramaya Well Field, Eastern Hararge Zone, Ethiopia. *J Hydrogeol Hydrol Eng* 5:4
- Shishaye HA, Douglas RT, Kevin MB, Damien TM, Reading JM, Jeffrey L, Tewolde G, Tilahun A (2020) Geology and groundwater flow drive high variability of groundwater potential and chemistry of a quaternary aquifer. *Hydrogeol J* 28:1–21 (accepted)
- Srinivasamoorthy K (2012) Hydrochemistry of groundwater from Sarabanga Minor Basin, Tamilnadu. *Int Acad Ecol Environ Sci* 2:193–203
- Srinivasamoorthy K, Chidambaram S, Prasanna MV, Vasanthavirar M, John PA, Anandhan P (2008) Identification of major sources controlling groundwater chemistry from a hard rock terrain—a case study from Mettur taluk, Salem district, Tamilnadu India. *J Earth Syst Sci* 117(1):49–58
- Strokal M, Ma L, Bai Z, Luan S, Kroeze C, Oenema O, Velthof G, Zhang F (2016) Alarming nutrient pollution of Chinese rivers as a result of agricultural transitions. *Environ Res Lett* 11(2):1–11
- Taddese G (2019) Irrigation water quality of middle Awash River basin, Ethiopia. *Int J Hydrol* 3(4):308–312
- Taddese G, Sonder K, Peden D (2009) The water of the Awash River basin: a future challenge to Ethiopia. ILRI, Addis Ababa

- The Safe Drinking Water Act (1996) The safe drinking water act of 1996. U.S. Government Printing Press, Washington, DC, pp 1–128
- Thivya C, Chidambaram S, Singaraja C, Thilagavathi R, Prasanna MV, Jainab I (2013) A study on the significance of lithology in groundwater quality of Madurai district, Tamil Nadu (India). *Environ Dev Sustain* 15:1365–1387
- Tiemann M (2014) Safe drinking water act (SDWA): a summary of the act and its major requirements. Congressional Research Service, Addis Ababa
- Tilahun A, Shishaye HA, Gebremariam B (2017) Sediment inflow estimation and mapping its spatial distribution at sub-basin scale: the case of Tendaho Dam, Afar Regional State, Ethiopia. *Ethiop J Environ Stud Manag* 10(3):1–15
- White P (2001) Chloride in soils and its uptake and movement within the plant: a review. *Ann Bot* 88(6):967–988
- WHO (2011) Guidelines for drinking-water quality, 4th edn. WHO, Geneva
- Winston RB (2000) Graphical user interface for MODFLOW, Version 4. U.S. Geological Survey, Open-File Report 00-315, pp 1–27
- Wright IA, Paciuszkiewicz K, Belmer N (2018) Increased water pollution after closure of Australia's longest operating underground coal mine: a 13-month study of mine drainage, water chemistry and river ecology. *Water Air Soil Pollut* 229(3):1–20
- Yimer YA, Jin L (2020) Impact of Lake Beseka on the water quality of Awash River, Ethiopia. *Am J Water Resour* 8(1):21–30

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