Information and Knowledge Management
ISSN 2224-5758 (Paper) ISSN 2224-896X (Online)
Vol.13, No.4, 2023

# Assessment of the Spatio-Temporal Trend of Awash River Water Quality to Address Emerging Irrigation Water Quality Issues in Awash Basin, Ethiopia

Melese MINALESHOA
Ethiopian Institute of Agricultural Research; Debre Zeit Agricultural Research Center
P.O.Box 32, Debre Zeit, East Shoa, Ethiopia
Tel. +251 911415773. E-mail: <meleseminaleshoa16@gmail.com>

Girma KASSA*
Ethiopian Institute of Agricultural Research; Debre Zeit Agricultural Research Center
P.O.Box 32, Debre Zeit, East Shoa, Ethiopia
Tel. +251 911349320. E-mail: <girmakaza@google.com>

Lema MAMO
Ethiopian Institute of Agricultural Research; Werer Agricultural Research Center
P. O. Box 2003, Addis Ababa, Ethiopia
E-mail: <emmamamo2006@gmail.com>

Ashenafi WORKU
Ethiopian Institute of Agricultural Research; Werer Agricultural Research Center
P. O. Box 2003, Addis Ababa, Ethiopia
E-mail: <ashuw21@gmail.com>

Melese MULU
Ethiopian Institute of Agricultural Research; Werer Agricultural Research Center
P. O. Box 2003, Addis Ababa, Ethiopia
E-mail: <mele15454@gmail.com>

## Abstract

Awash is the most intensively used river in Ethiopia for agriculture, with irrigation water that spatiotemporally varies in the transport pathways. Ever-increasing anthropogenic activities and climate change have brought challenges, of which, salinity and the degradation of water quality are the prime examples. Information regarding recent water quality and suitability dynamics of the Awash is very limited, and thus, this study was conducted in due time. Samples were gathered from ten water quality monitoring stations, three times a year, for seventeen consecutive years, and analyzed for quality parameters. Results indicate that pH values over the years ranged from 7.4 to 8.4; lying within a slight to moderately alkaline range of water. The EC values ranged from 0.21 to 1.16 dS/m within the 2004–2014 period. The average ion concentrations northwardly spread in the sequence of Ca2+>Na+>Mg2+>K+, HCO3->Cl-> SO42- and Na+>Ca2+>Mg2+>K+. Spatial trend analysis revealed an increasing progression of ECw, SAR, RSC, and ionic constituents. Water quality parameters are found to temporally vary often, with a progressively degrading trend over the study period, confirming the control of water quality mainly by anthropogenic factors. The result further showed a prevalence of slight to moderate sodicity hazards in all samples. The observed space-time variabilities of water quality suggest the proper usage of updated water quality evaluation and spatiotemporal dynamics and trend analysis results in designing appropriate water management strategies in river systems near intensive agricultural, industrial, and urban development areas before unforeseen determinant ground facts hinder development plans in this sub-basin.

Summary of key messages of this paper

- The Awash River is the longest inland river and one of the intensively used rivers in Ethiopia for domestic, industrial and agricultural purposes.
- The water quality of Awash River is under a spatially and temporally continuous and trended change.
- Continuous monitoring and evaluation of water quality are mandatory for timely management actions.

**Keywords:** Temporal trend, Spatial trend, Awash River Basin, water quality, Ethiopia
**DOI:** 10.7176/IKM/13-4-01
**Publication date:**July 31st 2023

## 1 Introduction

Crop production and productivity can be significantly impacted by the quality of irrigation water. Although dissolved mineral salts are present in all irrigation water, the concentration and make-up of the dissolved salts differ depending on the source and the course it is transported from. The term "irrigation water quality" refers to a water supply's qualities that may affect whether or not it is suitable for a certain usage, i.e., how well the quality meets the needs of the user. Without loss of generality, the quality of the irrigation water is known to directly affect chemical and physical soil properties and, consequently, determine crop yield quality and quantity, even if all other conditions and cultural practices are kept optimal. The primary water quality challenge in most irrigation interventions is the incremental dynamics of salinity and sodicity levels. A salinity problem related to water quality occurs if the total quantity of salts accumulated in the crops' root zone is high enough to the extent that yields are affected. If soluble salts build up in the root zone, the crop has more difficulty extracting enough water from the saline soil solution (Ayers and Westcot, 1976).

Szabolcs, (1989) reported that irrigation water sources commonly carry harmful levels of dissolved salts, and the majority of the dissolved salts are left behind on the soil surface following the evaporation of water. The use of poor water quality for irrigation can create problems like salinity, degradation of soil physical properties, and other miscellaneous problems that lead to a reduction in crop production (Banderi *et al.*, 2012) . When the quality of irrigation water is poor, advanced management techniques are needed to stop the water from getting worse and also reduce crop yield loss. In response to differences in climate, soils, geology, land use, and land cover, natural water quality varies spatially and temporally (Ouyang *et al.*, 2006; Jha *et al.*, 2010).  Pollution from sources of all sorts (both point and nonpoint) caused by human activity is another source of concern for water quality(Carpenter *et al.*, 1998).  Surface runoff, as a proxy for the energy involved with soil erosion and sediment movement, causes nonpoint source pollution, moves over land, picks up natural or human-made pollution, and eventually flushes the pollution into water bodies (Kalkhoff *et al.*, 2016).

The Awash River is the longest inland river and one of the most intensively used rivers in Ethiopia for domestic, industrial, and agricultural purposes (Tilahun, Shishaye and Gebremariam, 2017). Water from the River Awash is being utilized to irrigate numerous farms and commodities in the Awash Valley, such as sugar estates, horticultural crops, fruits, and vegetables (Shishaye, 2018). Water quality naturally fluctuates in both spatial and temporal dimensions; spatially along the course of a river, modified by the natural features of both the catchment area contributing to each PowerPoint and the contents and situations such as elevation, geology, connectivity with the floodplain, and the intricacy of the physical habitat surrounding a stream, stream-side wetlands, (Pejman *et al.*, 2009; Juang *et al.*, 2009), while anthropogenic activities including farm effluents, municipal, and industrial waste along the stream transport pathway are the most cited sources of water quality deterioration with varied magnitude in space and time (Shishaye, 2018). Therefore, understanding irrigation water quality trends is crucial for long-term productivity and managing changes, as marginal water use may reduce yields.

Long-term water quality monitoring is the most typical and effective method to evaluate the temporal and spatial water quality trend, understand the impact of increased anthropogenic influences, implement appropriate water management policies, and enforce water resource usage regulations. To this effect, Awash River water quality monitoring activities are being conducted by different institutions, mainly the Werer Agricultural Research Center of the Ethiopian Research Institute and the Awash Basin Authority. Previous studies, based on data generated by the Awash Basin Authority, have shown that water quality, including sediment, nutrients, microorganisms, and physical and chemical properties, has changed both temporally and spatially, often with a declining trend of water quality (SK Amare, Zebene, and Agizew (2017);  Abebe and Jin (2020); Haile Arefayne and Asfaw (2020)). Belay EA. (2009)  reported that the Awash River water may be subject to quality change as a result of the interplay between surface water and groundwater interactions observed in the intermixing of Lake Beseka and the Awash River since the early 2000s. The available water quality trend information so far reported on this river is, however, medium-term, covering periods from 2005 to 2013. Yet, information on the recent dynamics and status of the river's water quality on its course is scanty to nonexistent.

This study is the first of its kind to reveal the spatiotemporal extent and long-term trend of ARWQ through the analysis of multi-year monitoring data that has been generated by WARC during the past 17 years (2004–2020). Besides addressing a multi-year spatial and temporal trend of river water quality parameters and reflecting the most recent water quality status, it is also the first to take into account the use of combining the Irrigation Water Quality Indexing (IWQI) approach and multivariate analysis to assess the status of water quality holistically used for irrigation and provide apparent management needs to help curve emerging irrigation water quality issues. With this framework, the goal and objectives of this investigation were set and run to investigate the spatiotemporal dynamics of River Awash water quality and to evaluate the recent status and trend of the river's water for suitability for irrigation.

## 2 Materials and methods

### 2.1 Description of the Study Area

The spatial extent of the Awash Basin stretches from 7° 53′ 14.2″  N to 12° 3′ 6″ N and 37° 57′ 13″ E to 43° 25′ 6’’E within Ethiopia, as shown in Fig. 1. The basin encompasses a total area of 113,308 km$^2$, with 64,006 km$^2$

situated in the western area that drains into the Awash River or its tributaries. Awash River is approximately 1250 km in length and has an annual flow of 4.59 billion m3 (BCM).

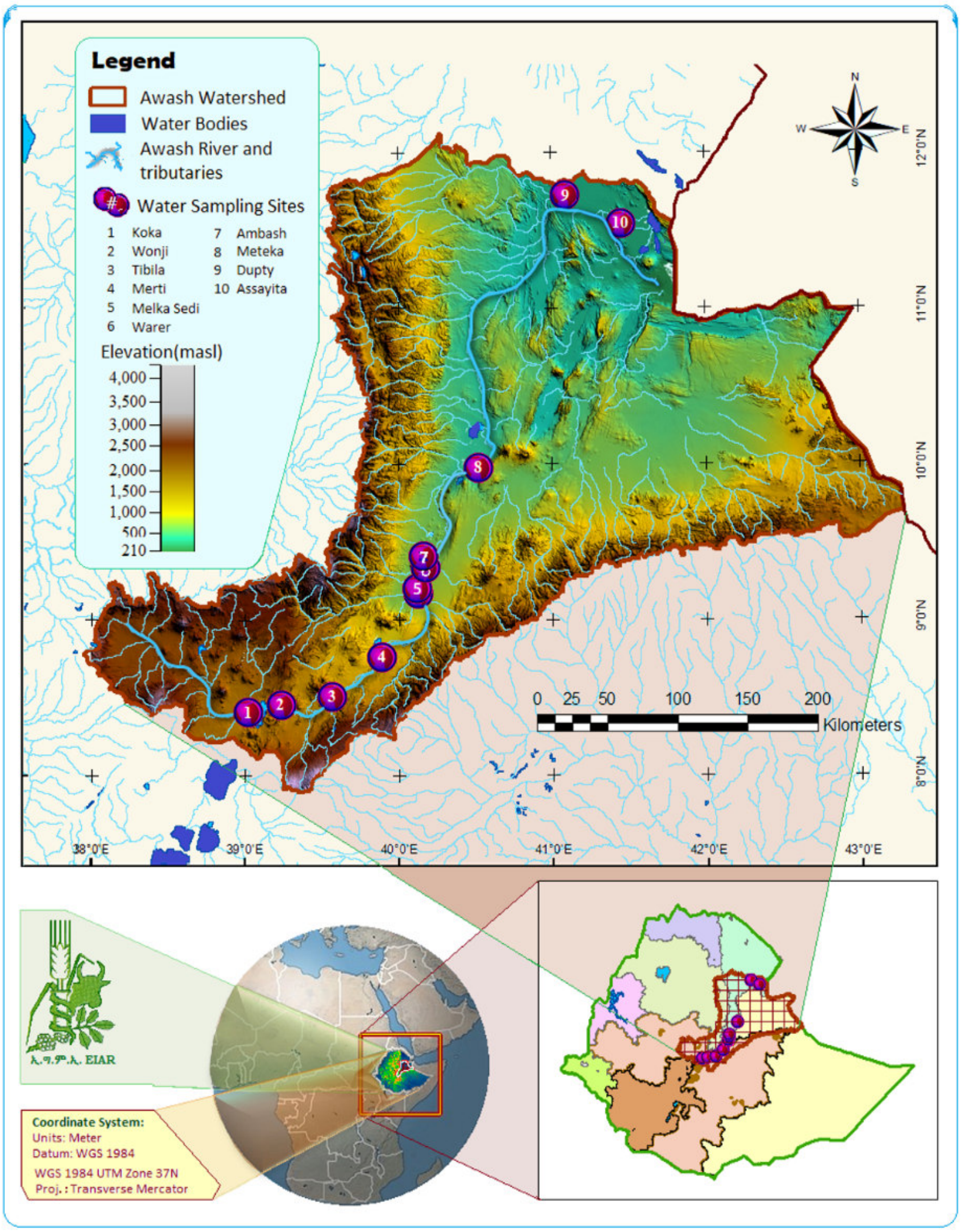


Figure 1. Location map of the Awash River Basin and the sampling sites (1-10)

The river's source is Ginchi, a town 80 km westward from Addis Ababa in the central Ethiopian highlands, roughly 3000m above sea level (m.a.s.l.). It travels along the great rift valley and flows to end at Lake Abe, 250 m.a.s.l., on the border near Djibouti (Degefu *et al.*, 2013; Berhe *et al.*, 2013; Tessema, 2011). In the Rift Valley, the many rift valley lakes, including Lake Beseka, resulting from volcano-tectonic structural depressions are attributed to the intricate volcanic and geotectonic processes. These processes, as well as human intervention, led to the endowment of the basin with wetlands of various types, and, artificial and natural lakes. Lake Beseka is a closed catchment by nature. At present, there are inflows from three big farms located in the Lake Beseqa catchment area: Abadir Farm, Nora Era, and Fentaile irrigation farms. Furthermore, there exists a human-made outflow channel developed by the Awash Basin Authority (ABA) between 2009 and 2010. The River Basin Highlands, the main Ethiopian Rift, and the Afar Triangular Depression are the main physiographic regions characterized by diverse agro-climatic zones with wide ranging ecological conditions, in which grass, shrubs, woodlands, and forests are the main floral units, along with wetlands and artificial and natural lakes of various types.

Awash Basin is divided into four distinct areas based on both physical and socioeconomic factors. (Tilahun, HA and B, 2017). These areas are the Upper Valley (which includes all lands above 1500 m.a.s.l. ), the Middle

Valley (which occupies areas between 1500 and 1000 m.a.s.l. ), the Lower Valley (which encompasses areas below 1000 m.a.s.l. ), and the Eastern Catchment (a closed sub-basin region that ranges from 2500 to 1000 m.a.s.l. Within the Lower Awash Valley, there are alluvial delta plains in the Tendahoo, Ayssaita, and Dit Beihri areas, as well as the terminal lakes region. The Lower, Middle, and Upper Valleys comprise the Great Rift Valley system.

According to Tessema, (2011) and AwBA, (2014), the basin is the most developed and used basin in the nation because it is home to more than 65% of the nation's industries and has a high concentration of large-scale irrigated agriculture, which makes up about 48 to 70% of current practices. Additionally, 77.4% of the basin's irrigable land has been developed for agricultural use. Numerous types of crops are grown, including sugarcane, perennial fruit orchards, cotton, flowers, vegetables, and grains (AwBA, 2014).

### 2.2 Water Sampling and Quality Parameters

Ten water sampling sites identified along the river flow pathway were considered for a long-term water quality monitoring study. Each sampling site was located at diversion weir or pump sites to represent major irrigation scheme sites and capture and reflect respective irrigation water quality status. Each sampling spot was georeferenced (Annex Table 1) and indicated on the location map of the Awash River Basin (Figure 1).

Following the standard procedure of Greenberg, Clesceri, and Eaton, (1992), water samples were taken from ten water quality observing stations three times a year (representing low, high, and medium flow seasons) for seventeen consecutive years (2004–2020). Collected water samples were analyzed at the Werer Agricultural Research Center's (WARC) soil and water analytical laboratory. Table 1 provides a summary of the water quality metrics taken into account in this study, along with their acronyms, units, and common methods of examination.

Table 1. Water quality parameters, their units, and methods of analysis

| Parameter | Abbreviation | Unit | Method |
|---|---|---|---|
| Electrical conductivity | ECw | dS/m | Conductivity meter |
| Power of Hydrogen (pH) | pHw | Scale (1-14) | pH meter |
| Sodium | $Na^+$ | meq/l | Flame photometer |
| Potassium | $K^+$ | meq/l | Flame photometer |
| Calcium | $Ca^{2+}$ | meq/l | Titrimetric method |
| Magnesium | $Mg^{2+}$ | meq/l | Titrimetric method |
| Chloride | $Cl^-$ | meq/l | Titrimetric method |
| Carbonate | $CO_3^{2-}$ | meq/l | Titrimetric method |
| Bicarbonate | $HCO_3^-$ | meq/l | Titrimetric method |
| Sulfate | $SO_4^{2-}$ | meq/l | Titrimetric method |

### 2.3 Data Analysis and Interpretation

#### 2.3.1 Piper-stiff Plotting

A large number of results of analyses can be simultaneously represented by using Piper Diagrams (also known as trilinear diagrams) that identify the hydrochemical facies of the water sample, which can be informative regarding the nature and sources of the pollution. The Piper diagrams, a visual technique developed by Arthur M. Piper (1944), in the form of a diagram plotting and mapping software is used to assist in figuring out the sources, redistribution, and sinks of constituent dissolved salts in water and calculates total dissolved solids (TDS) and charges balances in milligrams per liter (mg/L) concentrations of major ions. The following groundwater modeling and diagram generation software ware utilized for the data analysis and chart production to model piper diagrams of each sampling site and identify the hydrochemical compositions of Awash River water: EASY_QUIM (GHS, 2013), Grapher (GoldenSoftware, 2019), DIAGRAMMES (Adriano MAYER, 2022) and AqQA (RockWare, 2020). The concentrations of the major cations and major anions were used as inputs for the software.

#### 2.3.2 Cluster Analysis

Agglomerative Hierarchical Clustering (AHC) (Forgy, 1965; Rubin, 1967) was used to classify water samples into different groups. Cluster analysis (Swanson *et al.*, 2001) is a very good way of classifying observations into relatively distinct and internally more similar groups. Cluster Analysis (CA), a multivariate statistical technique, is often utilized to enhance the classification of physicochemical parameters in water and improve water quality evaluation by reducing the blurrily shared typical patterns of chemical analyses. The squared Euclidian distance between $Na^+$, $K^+$, $Mg^{+2}$, $Ca^{+2}$, $Cl^-$, $SO_4^{-2}$, $HCO_3^-$, pH and EC values were used to calculate similarity among samples with the furthest neighbor method for linkage. The data analysis and clustering calculations were performed by SPSS-IBM, (2019), PAST-V4.3 (Hammer, Harper, and Ryan 2001) and SAGA v. 7.1.0. (Conrad *et al.*, 2015)

#### 2.3.3 Trend Analysis

Water quality parameters averaged over three seasons of varied stream flow conditions were assessed from the mean analytical values of 2019 and 2020 to reflect the recent state. Temporal trend analysis was done based on annual average values of ECw, SAR, RSC, $Ca^{2+}$ plus $Mg^{2+}$, $Na^{+}$ and $HCO_3^{-}$ averaged over respective sub-basin areas, representing the upper, middle, and lower awash sub-basin areas, across the 2004–2020 study period. Microsoft Excel software with the XLSTAT plugin was used for the data storage, cleaning and partial analysis of both the temporal and spatial water quality trend analysis.

### 2.3.4 Interpretation and characterization of water quality

The standards for irrigation water of the FAO (FAO and ITPS, 2015) and related legislation were used in this study to interpret water quality characterization (Table 2 and Appendix Table 2). The Irrigation Water Quality Index (IWQ) was used as a tool for evaluating water quality fitness for irrigation. The IWQ is a useful index for describing the cumulative effect of the five hazard groups on the water quality used for irrigation. These categories include the harm posed by salinity, the threat posed by permeability, the inherent toxicity of the ions, and the associated aftermaths (Horton 1965; Cude, 2001). The suitability classification for irrigation was calculated by comparison of the measured water metrics with the WQIs values including the SAR, IWQ, KI, PI, Na%, and RSC values (Table 3). Normalization of the various water quality metrics' numerical values was done by an extant mathematical method while the WQIs guideline given in Table 4 was used for the water quality classification. The following surface water modeling and diagram generation software ware utilized for the data analysis and chart production to model piper diagrams of each sampling site and identify the hydrochemical compositions of the Awash River water: SPSS version 22 (SPSS Inc., USA), Grapher (GoldenSoftware, 2019), DIAGRAMMES (Adriano MAYER, 2022) and AqQA (RockWare, 2020). The concentrations of the major cations and major anions were used as inputs for the software.

Table 2. FAO, (1985) Guidelines for Interpretation of Irrigation Water Quality

| Potential Irrigation-Induced Risks | | Restriction level on Use | | |
|---|---|---|---|---|
| Salinity | Unit | None | Slight to Moderate | Severe |
| ECw | dS/m | < 0.7 | 0.7 - 3.0 | > 3.0 |
| TDS | mg/l | < 450 | 450 – 2,000 | > 2,000 |
| Infiltration (affects infiltration rate of water into the soil. Evaluate using ECW and SAR together) | | | | |
| SAR = 0 - 3 and $EC_W$ | | > 0.7 | 0.7 - 0.2 | < 0.2 |
| = 3 - 6 | | > 1.2 | 1.2 - 0.3 | < 0.3 |
| = 6 – 12 | | > 1.9 | 1.9 - 0.5 | < 0.5 |
| = 12 – 20 | | > 2.9 | 2.9 - 1.3 | < 1.3 |
| = 20 – 40 | | > 5.0 | 5.0 - 2.9 | < 2.9 |
| Toxicity of certain ions (affecting sensitive crops) | | | | |
| Sodium (Na): Surface irrigation<br>Sprinkler irrigation | SAR | < 3<br>< 3 | 3 – 9<br>> 3 | > 9 |
| Chloride (Cl): Surface irrigation<br>Sprinkler irrigation | meq/L | < 4<br>< 3 | 4 - 10<br>> 3 | > 10 |
| Bicarbonate ($HCO_3$) | meq/L | <1.5 | 1.5–8.5 | > 8.5 |
| pH | unitless | Normal range: 6.5–8.4 | | |

Table 3. Irrigation Water Quality Indices, formulae, and sources

| Irrigation Water Quality Indices (WQIs) | Formula | References |
|---|---|---|
| Irrigation Water Quality | $IWQ = \sum_{i=1}^{5} Gi$ | (Simsek and Gunduz, 2007) |
| Sodium Percentage * | $Na\% = \frac{(Na + K)}{(Ca + Mg + Na + K)} \text{ x } 100$ | (Todd, 1980) |
| Sodium Absorption Ratio | $SAR = \frac{(Na^{+})}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$ | (L. A. Richards, 1954) |
| Permeability Index | $PI = \frac{(Na + K + \sqrt{Alkalinity})}{(Ca + Mg + Na + K)} \text{ x } 100$ | (Doneen L.D., 1975) |
| Kelley Index | $KI = Na^{+}/(Ca^{2+} + Mg^{2+})$ | Kelley (1940) |
| Residual Sodium Carbonate | $RSC = (CO_3^{2-} + HCO_3^{-}) – (Ca^{2+} + Mg^{2+})$ | Richards, L.A. (1954) |

*All WQIs are estimated in units of meq/L*

Table 4. WQIs-based guideline for classification of water quality.

| Water Quality Indices | Range | Water Class |
|---|---|---|
| Irrigation Water Quality (IWQ) | <22 | Low |
| | 22–37 | Medium |
| | >37 | High |
| Sodium Percentage (Na%) | <20 | Excellent |
| | 20–40 | Good |
| | 40–60 | Permissible |
| | 60–80 | Doubtful |
| | >80 | Unsuitable |
| Sodium Adsorption Ratio (SAR) | <10 | Excellent |
| | 10–18 | Good/safe |
| | 18–26 | Doubtful/moderate |
| | >26 | Unsuitable |
| Permeability Index (PI) | >75% | Good-Class I |
| | 25% - 75% | Good-Class II |
| | <25% | Unsuitable-Class III |
| Kelley Index (KI) | <1 | Good |
| | >1 | Unsuitable |
| Residual Sodium Carbonate (RSC) | <1.25 | Good |
| | 1.25–2.5 | Doubtful |
| | >2.5 | Unsuitable |

## 3 Results and Discussion

### 3.1 Water Facies and Physico-chemical Parameters

The range and mean values of physicochemical parameters, including pH, electrical conductivity (EC), cations and anions, averaged over two years (2019 and 2020) in water samples from ten water sampling points along the River Awash are shown in Table 5. The pH values extended from 7.7 to 8.2, lying within the safe range (6.5 to 8.4), according to R. S. Ayers and Westcot (1985), for irrigation with no anticipated problems. The EC values span between 0.38 and 1.16 dS/m with a mean value of 0.69 dS/m. The minimum and maximum EC values were recorded for samples from the Wonji and Werer sites respectively. According to guidelines for the interpretation of water quality for irrigation (Ayers and Westcot, 1985), river water could be rated as a water type of medium to high salinity.

The Values of $Ca^{2+}$ and $Na^{+}$ varied from 2.07 to 3.11 and 1.30 to 6.95 meq/l, respectively. The river water at upper awash sampling sites was dominated by $Ca^{2+}$ whereas $Na^{+}$ appeared as the dominant cation in the lower sub-basin areas. The $HCO_3^-$ (alkalinity), $Cl^-$ and $SO_4^{2-}$ contents varied from 2.39 to 7.02, 0.49 to 2.05, and 0.30 to 1.65 meq/l, respectively. The result also showed that $HCO_3^-$ was the dominant anion among ionic constituents in Awash River water closely followed by $Cl^-$.

The major ions are effective signals for detecting solute sources; the wide ranges of ions in the water samples collected throughout the stream flow channel reflect the influence of several recharge sources in the spatial domain. The average distribution of concentrations of ions at the upstream sampling sites, including Koka, Wonji, Tibila, and Merti, is in the order of $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$ and $HCO_3 > Cl^{-} > SO_4^{2-}$, indicating that a young stage of evolution is being recharged from the highland catchment areas with the higher release of $Ca^{2+}$ due to weathering of silicate minerals (Srinivasa Moorthy *et al.*, 2008).

Furthermore, detectable $HCO_3^-$ levels in river water samples might be attributed to carbonate dissolution and air silicate weathering. (Obeidatt and Alawneh, 2019). In the study areas; downstream to Lake Beseka including sampling sites from Melka Sedi to Assaiyta, the cationic dominance was in $Na^{+} > Ca^{2+} > Mg^{2+} > K^{+}$ order whereas the anionic dominance remained the same as that in the upstream areas. In line with the work of Gad et.al. (2020), such a shift in cationic dominance (from $Ca^{2+}$ to $Na^{+}$ dominance) accounted for the effect of mixing up of high Na-containing Lake Beseka water to Awash River water. Throughout river water sampling sites, $CO_3^{2-}$ was found in trace amounts.

Table 5. Mean and range values of water quality parameters for the study period of 2019 - 2020

| Parameter | Range | | Mean ± SE |
|---|---|---|---|
| | Minimum | Maximum | |
| pH | 7.6 | 8.2 | 8.0 ± 0.2 |
| EC | 0.38 | 1.16 | 0.69 ± 0.26 |
| $Ca^{2+}$ | 2.07 | 3.11 | 1.46 ± 0.54 |
| $Mg^{2+}$ | 0.85 | 1.27 | 0.22 ± 0.33 |
| $Na^{+}$ | 1.30 | 6.95 | 3.44 ± 1.92 |
| $K^{+}$ | 0.21 | 0.50 | 0.32 ± 0.10 |
| $HCO_3^-$ | 2.39 | 7.02 | 4.08 ± 1.66 |
| $Cl^-$ | 0.49 | 2.05 | 1.04 ± 0.51 |
| $SO_4^{2-}$ | 0.30 | 1.65 | 0.94 ± 0.52 |
| SAR | 1.24 | 4.65 | 2.73 ± 1.23 |
| RSC | 0.26 | 2.68 | 1.17 ±0.92 |

The range values of SAR in the water samples investigated varied between 1.24 and 4.65 and were generally rated as low sodium water (Ayers and Westcot, 1985). RSC values ranged between 0.26 and 2.68 meq/l and were rated as being between the "safe'' and the "unsuitable" suitability class for irrigation. The hydrochemical facies in the River Awash belongs to Ca-$HCO_3$ and Na-Ca-$HCO_3$ type of water throughout sampling points of the upper sub-basin and downstream areas, respectively (Fig. 2).

### 3.2 Spatial Trend

The spatial trend of river water quality parameters was assessed from the mean analytical values of 2019 and 2020 to reflect recent conditions. Figures 2 and 3 present the spatial trend of selected variables, including ECw, SAR, RSC, and ionic content, for 10 monitoring sites along the stream flow pathway. From the trend lines of the respective graphs, the quality parameter values under investigation were shown to vary spatially. In general, the obtained result manifested the spatially changing river water quality. As one moves from the upstream to the mid-basin, ECw, SAR, RSC, and ionic constituents of the river water appear to show an increasing trend, which then follows a slightly decreasing pattern from the Meteka site headwards to the reach of the downstream area. Such a result is in agreement with findings reported by Haile Arefayne and Asfaw (2020). Though there was a detectable water quality trend that spatially varied along the river, the magnitude of change between adjacent sampling sites in each sub-basin followed different patterns. As can be seen from Figures 2a and 2b, spatial variation in quality metrics observed amongst sampling sites of Upper (Koka to Merti) and Lower Awash sub-basins (Dupty to Asaeyta) somehow seemed to be stable as compared to sampling sites within the Middle awash sub-basin area were remarkable spatial water quality variation was seen.

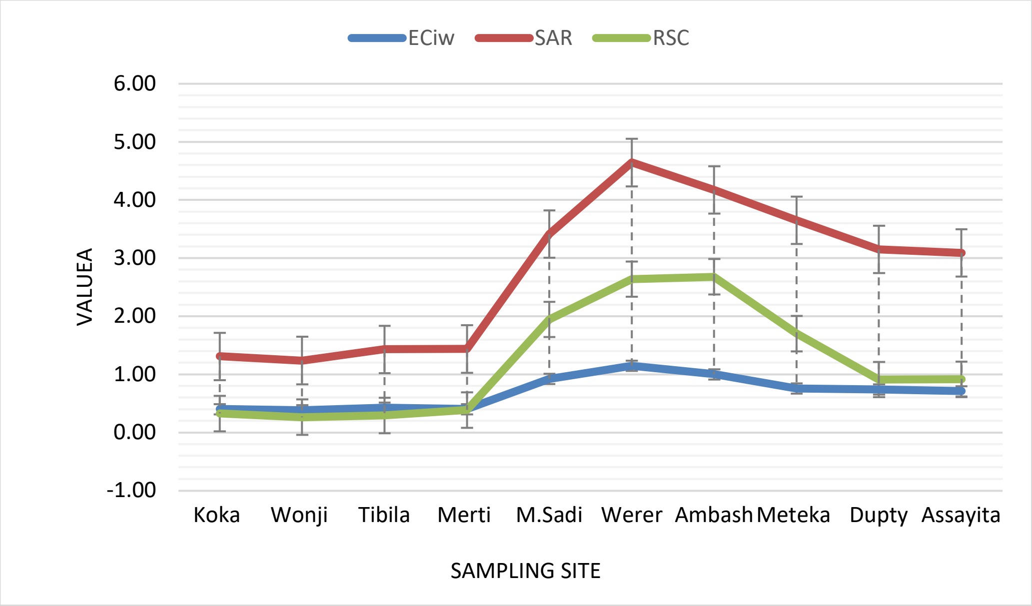


Figure 2. The spatial trend of ECw, SAR, and RSC values in River Awash

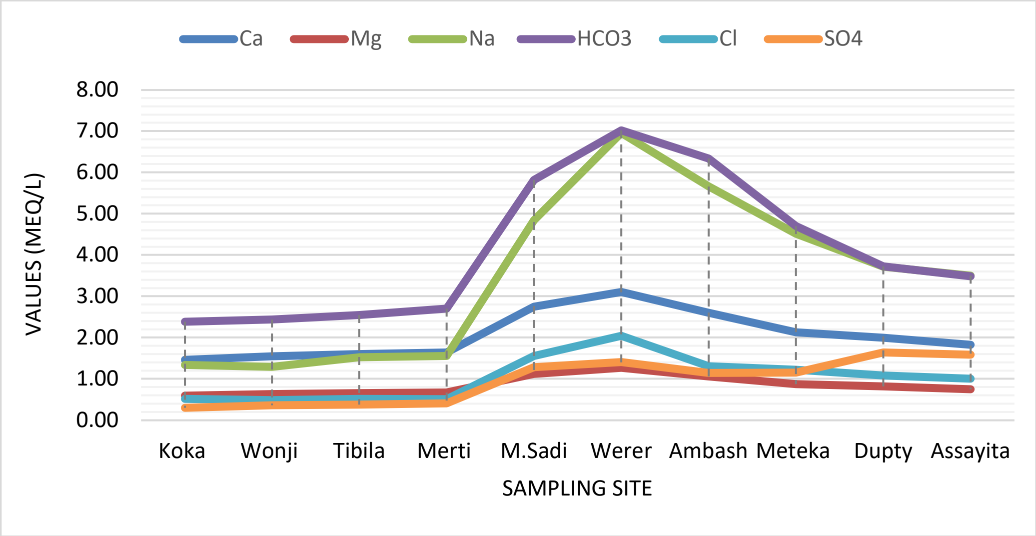


Figure 3. The spatial trend of ionic content in Awash River water

Water quality, by its nature, is a space-time variable that varies significantly over a river's course and is influenced by natural features such as altitude, geology, stream physical habitat complexity, streamside wetlands, and riparian areas, as well as by connectivity with the floodplain and rainstorm seasonal changes (Juang *et al.*, 2009; Pejman *et al.*, 2009), while the anthropogenic activities including farm effluents, municipal and industrial waste along the stream transport pathway are the most cited sources of water quality deterioration with varied magnitude in space and time (Shishaye, 2018). The spatially changing trend in water quality metrics could be attributed to various natural and anthropogenic factors.

Haile Arefayne & Asfaw, (2020) identified major factors governing the spatial variability of Awash River water quality parameters. According to their findings, the factors identified were grouped into three, based on the variable loadings, with factor one including anthropogenic activities and dissolution of carbonate minerals, factor two referring to the combined effect of anthropogenic activities and ion exchange, and the third factor indicating ion exchange effects alone. They concluded that spatially variable river water quality was mainly controlled by anthropogenic interventions, dissolutions of minerals, ion exchange, and related processes.

The most important water body responsible for the water quality spatial redistribution of the River Awash was indicated to be Lake Beseka (Amare, Kiflie, and Agizew Nigussie, 2017; Haile and Asfaw 2020). From their study on natural and anthropogenic salinity sources in the River Awash, Abebe and Jin (2020) have reported it to be from the significant contribution of Lake Beseka discharge that caused elevated salinity in the River Awash. The concern is that a large volume of such a brackish water type is being discharged (as a measure to stabilize lake water expansion) into the relatively much better-quality water of the Awash River, which is the source of irrigation downstream. Such a practice, however, is not without affecting the quality and hence, the suitability of the River Awash's water for irrigating the downstream areas. The effect imposed by water discharging from Lake Beseka into the Awash River could be evidenced by altered river water properties (Figures 2a and 2b) that have been manifested in the nearby downstream sampling site of Melka Sadi (receiving discharge from Lake Beseka) compared to that before the Beseka Lake water mix (Merti sampling site).

Appreciable discharges of natural inflows from saline thermal springs with some of the resultant marshy areas with brackish water located in the Middle Valley table could also be of another irrigation water quality concern to the middle and downstream irrigated farm areas.

For instance, a recent investigation conducted by WARC on spring and drainage water quality status (unpublished) regarded Deho hot spring water as containing higher values of ECw (2.40 dS/m), SAR (25) and RSC (11.5 meq/l) than Awash River water, which could be rated as a water type with severe salinity and sodicity hazards. In this regard, discharge from Lake Beseka and natural inflows from saline thermal springs could be considered as possible principal causes explaining the observed substantial increase in salinity and sodicity parameters and ionic contents of water samples within the middle awash. The slightly decreasing trend in water quality parameter values from peak values at the middle reach towards the lower reach could be accounted for by the dilution effect from tributary streams and other water bodies.

Accounting for the varied factors causing spatially changing hydro-chemical properties of the river resulted in an altered water salinity class of medium salinity (C2) upstream to high salinity water (C3) at downstream areas. Even though there exists a spatially increasing trend in SAR values, water sodicity status remained within low sodium class (S1) water, while RSC values at middle and downstream areas are found to be beyond the safe limit for irrigation use. Observed spatially changing river water quality attributes, often associated with the deteriorating trend, imply the need for timely implementation of site-specific water quality controlling measures together with appropriate irrigated soil management practices to ensure sustainable irrigation in the respective areas with high water salinity and potential alkalinity hazards (RSC).

### 3.3 Water quality metrics in response to stream flow change

Water quality and flow regime change go hand in hand in many aspects, and thus, by transitivity, the River Awash is strongly affected by the Inter-Tropical Convergence Zone (ITCZ) and shows a peculiar seasonal rhythm, with strong flows from July to September and low flows then after. Figures 4(a–d) depict river water quality trends corresponding to three flow seasons, i.e., high, medium, and low flow seasons. The results of the current study indicate that there were noticeable variations in pHw, ECw, and SAR values paralleling the stream flow variations. Higher values of ECw, pHw, and SAR were recorded during the low flow season (dry season) compared to those recorded during the high flow season (rainy season), manifesting an inverse relationship with stream flow.

When stream flow increases due to rainstorm runoff, pHw values at all sampling locations decrease. It decreased from a mean pH value of 8.1 to 7.8 as the flow season changed from low to high. The decrease in pHw during high stream-flow conditions likely results from the decline in concentration of some alkaline-forming ions with subsequent changes in H+ and OH- equilibrium. Rainwater is naturally slightly acidic, with an average pH of about 5.6, which is caused by carbonic acid from the dissolving of atmospheric CO2 in water (Chien *et al.*, 2018). The values of ECw recorded during the high flow season were consistently lower in all water samples, contrary to the low flow season values. Overall mean ECw values during high, medium, and low flow seasons were 0.60, 0.73, and 0.82 dS/m, respectively.

High flows are generally considered vital for reducing levels of various elements in rivers due to the dilution effect (Chien *et al.*, 2018). From the present result, it can be seen that the water salinity (ECw) of the Awash River had shown a decreasing trend as stream flow changed from low to high flow conditions, resulting in a decline in mean ECe values of 0.09 at the upper sub-basin, 0.38 at the middle sub-basin, and 0.17 dS/m at the lower sub-basin areas. The dilution influence may explain the decreased conductivity with increased stream flow in the Awash River. Moreover, previous related studies showed that water quality variations could be caused by the dilution influence of storm events(Pike *et al.*, 2010; Whitfield et al., 1993).

Low flow periods are integral and essential components of many rivers' hydrographs (Smakhtin, 2001) and are necessary for many processes in the riverine ecosystem's functioning (Postel and Richter., 2003). Low-flow conditions are prone to continuously injected water quality stressors such as those from drainage returns, sewage effluent, inflows of salty springs, etc. that ultimately increase the salt load in river streams and might reach toxic levels. Elevated values of EC in Awash River water during low-flow seasons can be explained by an increased content of ions due to the offset of the dilution effect. A similar result was reported by LCRA (2014) who stated that as the water level drops, the ions become more concentrated, which raises the conductivity levels. VIMS, (2005) also indicated that ECw values often increase in the summer (low rainfall season) due to lower flow volume and evaporation. Seasonally changing stream flow regimes are shown to result in water with varied properties.

At monitoring sites in the middle and downstream areas, stream flow changes from high to low result in a concomitant change in ECw from C2 (medium salinity) to C3 (high salinity) water classes. A similar result was reported b Gedion (2009) indicating that the Awash River water contains significant amounts of salts during a low flow period. Similar to EC, SAR for most water samples were also found to have higher records during low flow season.

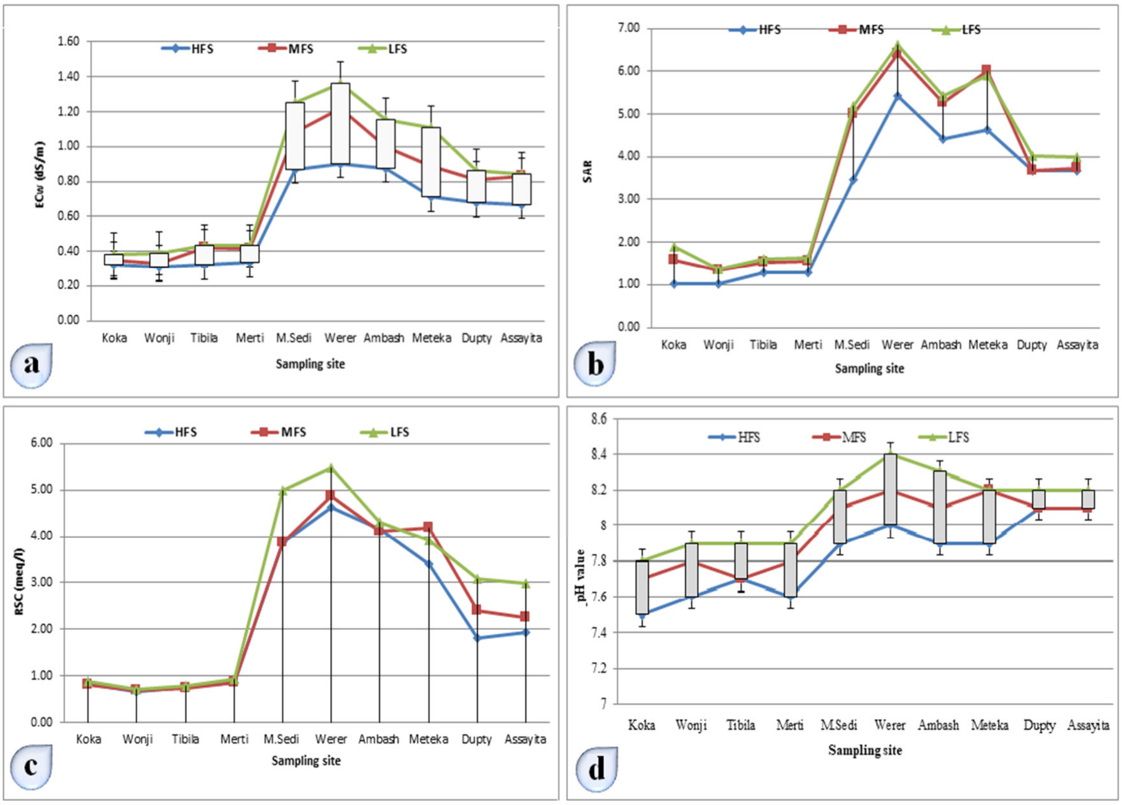


Figure 4 Response of water quality variables; EC (a), SAR (b), RSC (c) and pH (d) values to changed stream flow

As the stream flow declined from high to low flow conditions, mean SAR values increased from 0.92 to 1.55 at the upper sub-basin areas, 2.69 to 3.26 at the middle sub-basin areas, and 1.77 to 2.54 at the lower sub-basin areas, respectively. Calculated RSC values for river water samples in upstream areas appeared low and were within the safe range for irrigation. Previous studies in other areas of the world have shown that water quality, including physical and chemical properties, can change significantly during storm events (Göransson, Larson, and Bendz, 2013; Chen and Chang, 2014; Rostami, He and Hassan, 2018). The water quality-stream flow paralleling changes and possible adverse effects in future scenarios would be greater during low flows than during high flows due to less dilution. It is also evident that the impact of stream flow size fluctuations is pronouncedly significant for the immediate downstream area from Lake Beseka. For instance, immediately after the discharge at Lake Beseka, the EC value at Melka Sadi reach had risen to about 1.50 dS/m, with an approximately 92% difference from the low flow months compared to the high flow conditions, whereas at Merti just before Lake Beseka discharge, the percent increase due to seasonal flow change was only 38.

### 3.4 Spatial clustering

All the 10 study sites under investigation were grouped by Agglomerative Hierarchical Clustering (AHC) analysis into three statistically significant clusters at (Dlink/Dmax) ×100<20. The resulting clusters as can usually be best visualized by the dendrogram, are shown in (Fig. 4). The dendrogram clearly depicts the grouping of the sites based on the similarity of water quality metrics. Accordingly, Awash River at Koka, Wonji, Tibila and Merti sites were grouped as *Cluster 1;* Melka Sadi, Werer, Ambash and Meteka sites were grouped as *Cluster 2* while Awash River at Dupty and Assayita sites were grouped as *Cluster 3*. Sampling sites grouped as clusters 1, 2, and 3 were found to be located in the upper, middle and lower awash sub-basin areas, respectively.

Cluster 1

The first hydro-chemical cluster was typified by a *$Ca\text{-}HCO_3$ (Fig. 5)* type of water. Calcium was the dominant cation, closely followed by sodium, which comprised 40 to 44 and 35 to 41% of the total cationic constituents, respectively. In this group, $HCO_3$ appeared to be the dominant anion, accounting for about 78% of the total anion. This hydro-chemical cluster had ECw and SAR values that ranged between 0.35 and 0.39 dS/m and 1.25 and 1.51, respectively, and was generally perceived as relatively medium salt and Na-containing water. According to the widely used guidelines for classification and interpretation of irrigation water quality (L. Richards, 1954) and (Booker Tate, 1991), water samples from all sites categorized under cluster 1 can be regarded as water types of medium salinity (C2) and low sodium (S1)water type at (Dlink/Dmax)*100

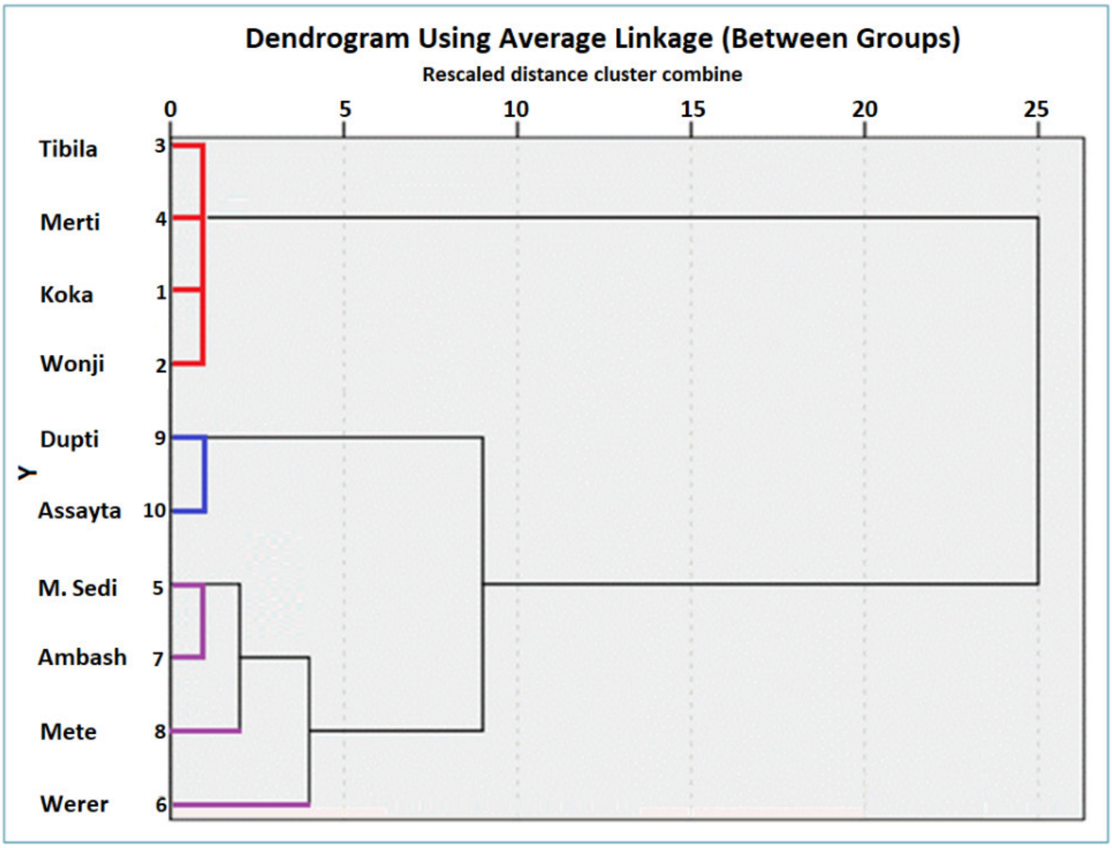


Figure 5 Dendrogram showing cluster analysis of samples based on water quality characteristics

Cluster 2

The second cluster was identified in a mixed Na-Ca-$HCO_3$ (Fig. 5) type of water where sodium was found to be the dominant cation with a concentration range of 60 to 68%. In this group, bicarbonate was found in considerable amounts, reaching up to 70 to 73% of the total sum of anions. This hydro-chemical cluster had exceptionally high ECw values between 1.01 and 1.16 dS/m, which could be classified as high salinity water (C3) (Annex Table 3). Samples from Melka Sadi, Werer, Ambash, and Meteka irrigation water abstraction sites were grouped in this cluster (Fig. 4). The RSC value was also found to be high, ranging between 1.95 and 2.68 meq/l. These sampling sites are located in the Middle Awash sub-basin area, where the River Awash has been subjected to both anthropogenic and natural water quality degrading factors. These factors include the discharge and mixing of brackish Lake Beseka water to the Awash River, inflows from thermal springs in Deho, Bilen, and Meteka; expansion of irrigated agriculture; and abstraction of river water at the upstream end of the upper Awash sub-basin area.

Cluster 3

The third cluster included Dupty and Assaiyta sampling sites located at the lower level reaches of the river under investigation *(Fig. 5)*. It was typified by *Na-Ca-*$HCO_3$ *(Fig. 6)* types of water. Sodium had been recognized as the dominant cation comprising 55 to 58% of the total cation. Among anionic constituents, bicarbonate was seen being dominant with concentrations ranging between 64 and 65 percent of the total anions. The unique characteristic of the water samples grouped in cluster 3 was that it behaves as a property between clusters 1 and 2. Besides, sulfate was found to exist in a significant concentration of about 20% of the sum of the anion.

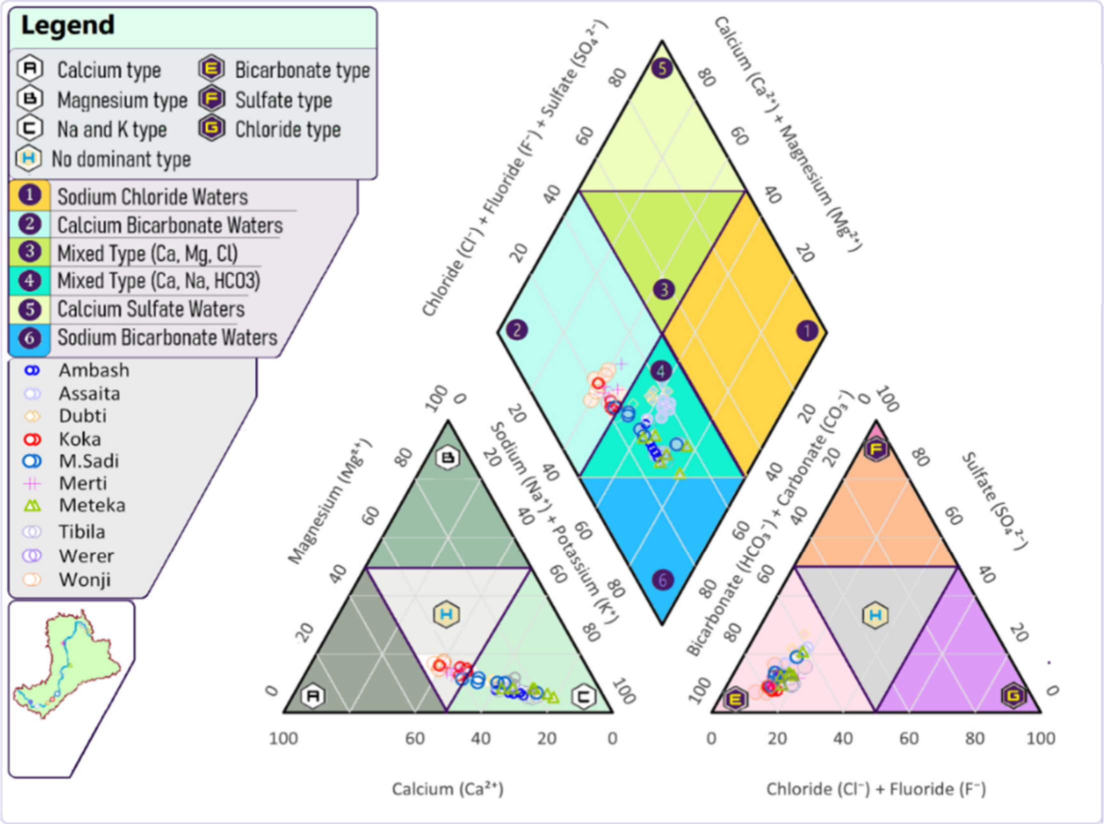


Figure 6. Piper diagram of Awash River reflecting hydrochemistry faces for all sampling sites

### 3.5 Temporal trend analysis

Results from temporal trend analysis show that the river water quality has changed temporally, resulting in altered water types differing in hydrochemical composition. Hydrographs representing multiyear (17 years) river water quality trends based on ECw, SAR, RSC, Ca2+ plus Mg2+, Na+, and HCO3- values across sub-basin areas over the 2004–2020 study period are depicted in Figures 7a–f. Mean ECw values linearly increased over the years with a coefficient of determination (R2) of 0.71*, 0.76*, and 0.91**, respectively, in the upper, middle, and lower awash sub-basin areas. At the middle Awash (Fig. 7a), a noticeable increasing pattern in EC values of water samples was taking place from the year 2007 with a gradual increment until 2010, continuing with an accelerated increase until 2015, which then experienced a slowly declining trend to the end of the study period. The magnitude of the temporal change in water salinity (EC) was exceptionally high at sampling sites within the middle area. It increased from 0.49 dS/m in 2004 to 1.35 dS/m in 2015, i.e., about a 176% increase.

The rate at which ECw has increased during the study period differs among sub-basin areas, as evidenced by their varied slope values of 0.01, 0.05, and 0.02, respectively, representing upper, middle, and downstream areas, indicating apparent temporal trends with spatially dissimilar patterns of water quality change. The temporal trend of ECw at the lower awash sub-basin follows a similar pattern to that at the middle awash, except that the increase-decrease trend was somehow gradual. ECw at the upstream area was found to be more stable over the 2004–2020 study period, showing an increase from an ECw value of 0.24 dS/m in 2004 to 0.39 dS/m in 2015 (about a 63% increase). EC is a measure of salinity that directly relates to the quantity of dissolved salts, and thus, salinity hazards increase with an increase in EC or the total quantity of dissolved salts in the water (TDS).

In this regard, the temporally increasing trend of EC observed in Awash River water indicates that the salinity hazard has increased with time. Conversely, irrigation is observed to amass saline content of unchecked irrigated fields over the season as many irrigation water sources are already overladen with substantial amounts of salt. With the consequence of the temporally increasing trend of ECw that had been taking place during the study period, the river water salinity had altered from medium salinity water (C2), which was until 2010, to high salinity water (C3) class since then at middle awash sub-basins. Water salinity (EC) at the upper awash area was also changed from C1 in the early period (2004) to C2 in progress. At the lower sub-basin area, ECw had generally shown an increasing trend over the 2004–2020 study period; however, the corresponding water salinity status remained within the medium water salinity rating (C2). The result further indicates that values of SAR, RSC, and ionic contents (Fig. 6b-f) varied with time, often reflecting a similar temporal trend seen in EC resulting in a changed geochemical composition of the river water. Over the study seasons, values of Na+, SAR, RSC and HCO32- were found to show significant increases, while the change in Ca2+ plus Mg2+ was not remarkable, indicating a temporally increasing degradation of water quality degradation with respect to alkalinity, sodicity, and ion toxicity hazards.

Water quality could vary in the same location over time due to changes in climate and anthropogenic activities (Vannote *et al.*, 1980; Newbold *et al.*, 1982). Different human activities that have been taking place in the past along the river basin areas could be mentioned as conceivable factors inducing the concomitant river water quality change so far detected in the present study. The mixing of Lake Beseka water with the Awash River (beginning in 2007) and the expansion of irrigated agriculture in the upper and middle catchment areas of the Basin (since the late 2008's) were among the important anthropogenic activities being undertaken during this study period. These factors combine to different degrees to create diverse water types with compositions that vary with time. The linear diversity observed in the Stiff diagram plates below (Figures 7a and 7b) demonstrates the progression of compositional shift: flattening, areal elongation of the horizontal Cation-Anion axis and enlargement of content by incrementing ionic concentrations over the years.

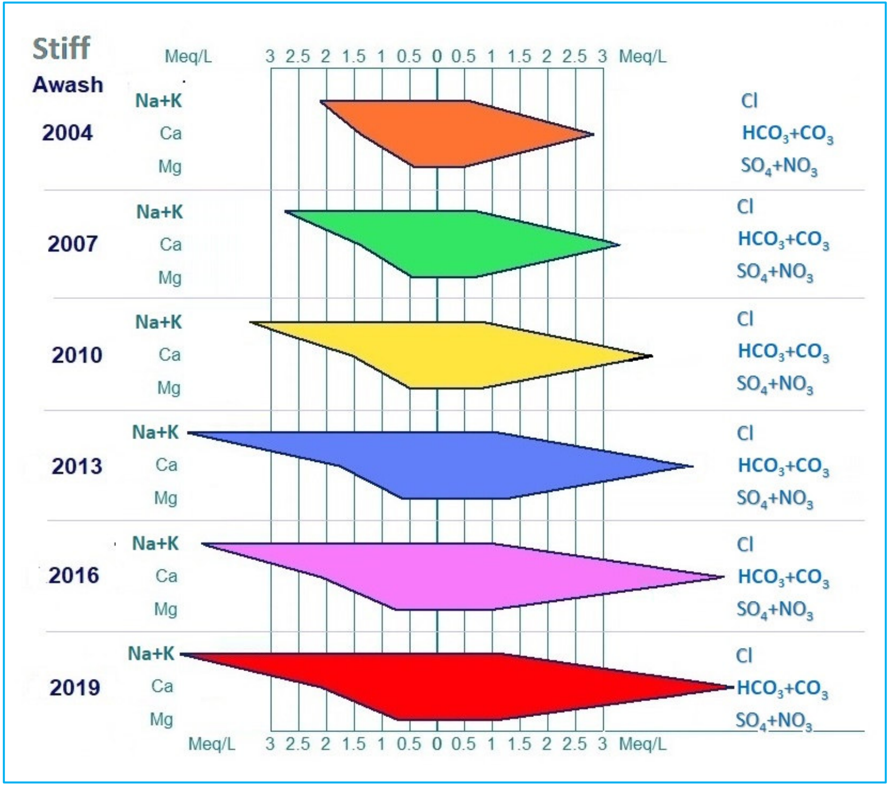


Figure 7a. Stiff Diagram of Awash River plotted from the concentration of major ions

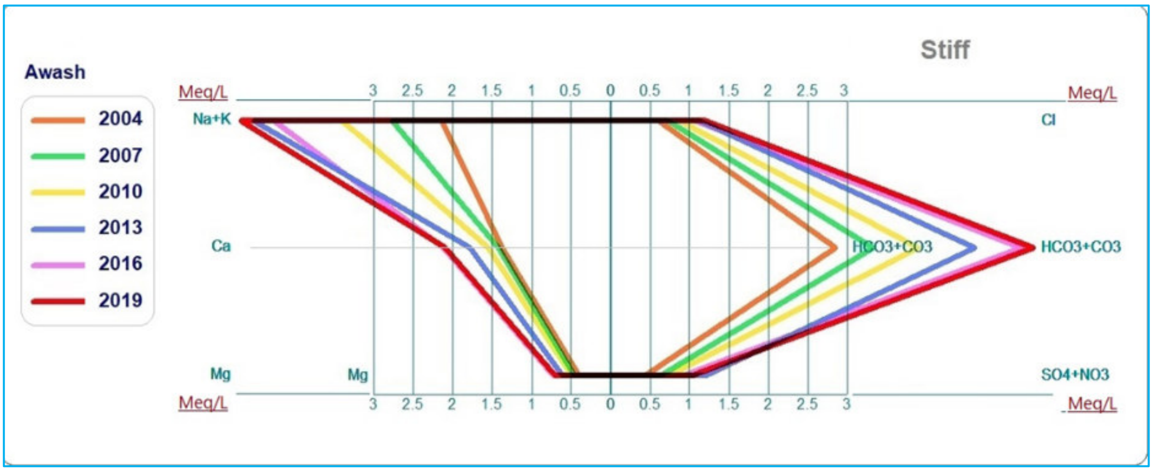
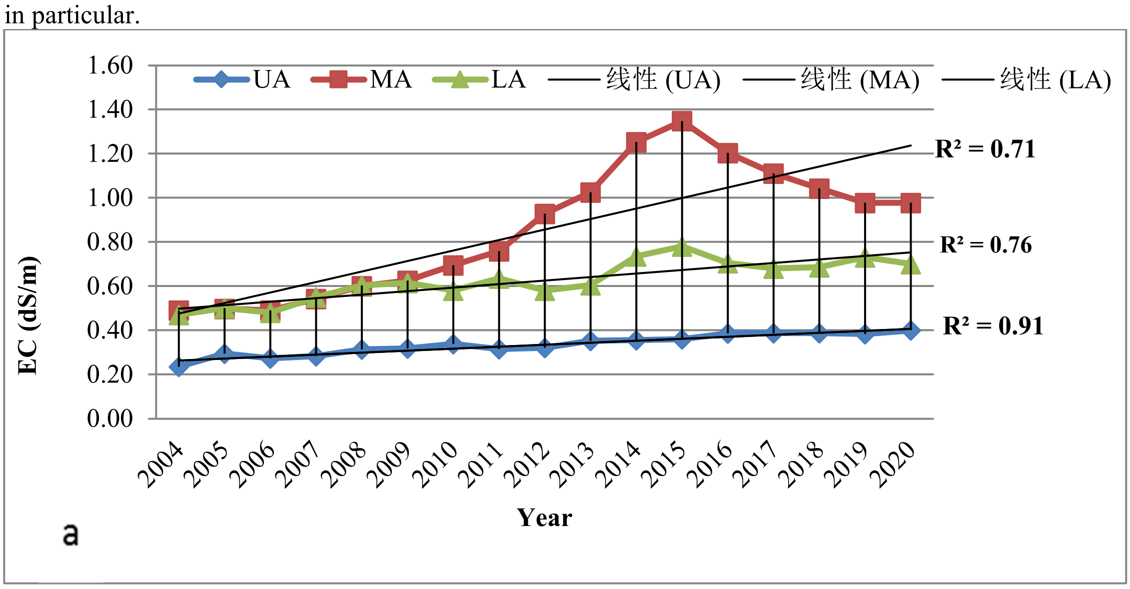


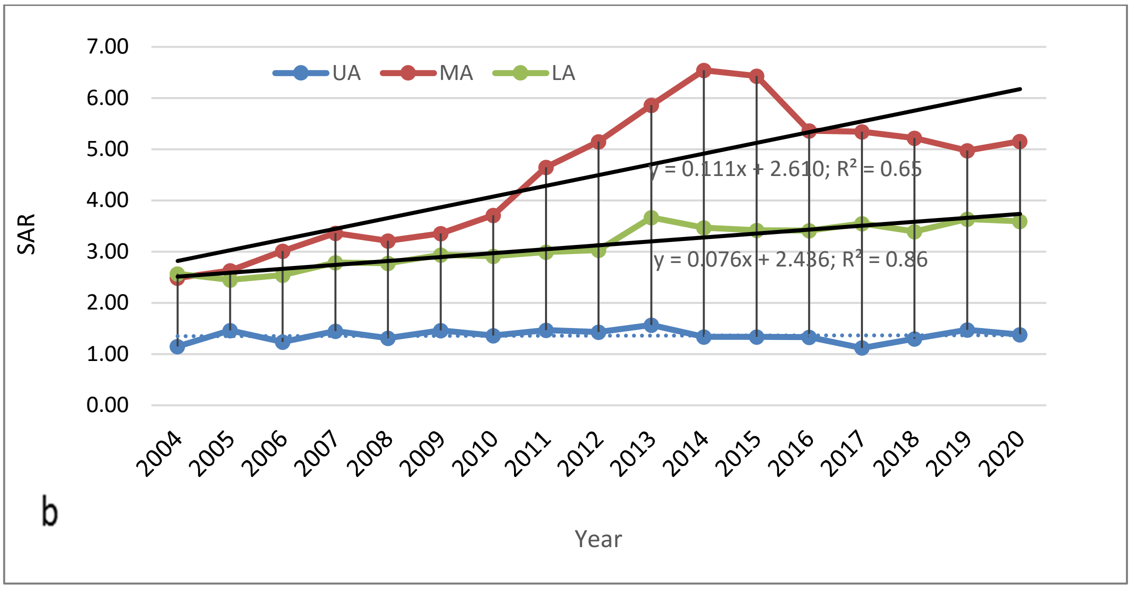
Figure 7b Overlay of Stiff Diagrams of Awash River, 2004–2019

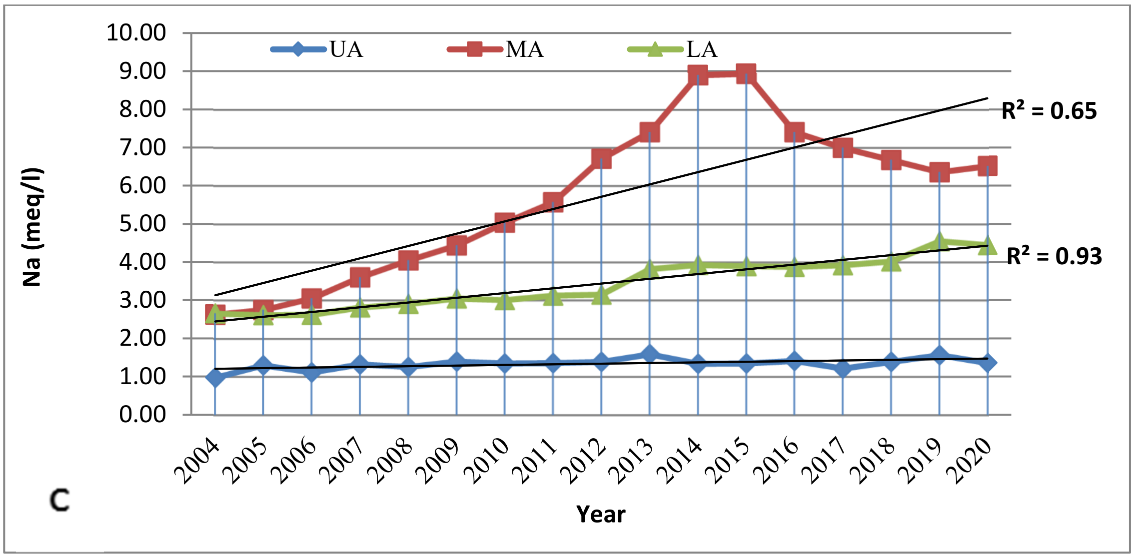
Overlay of Stiff Diagrams of Awash River over the years 2004–2019, shows the pronounced linear temporal progression of incremental HCO3+c3 and Na+K concentrations while a relatively slow change is exhibited on the rest of the other ions as observed on the respective vertices (Figure 7b).

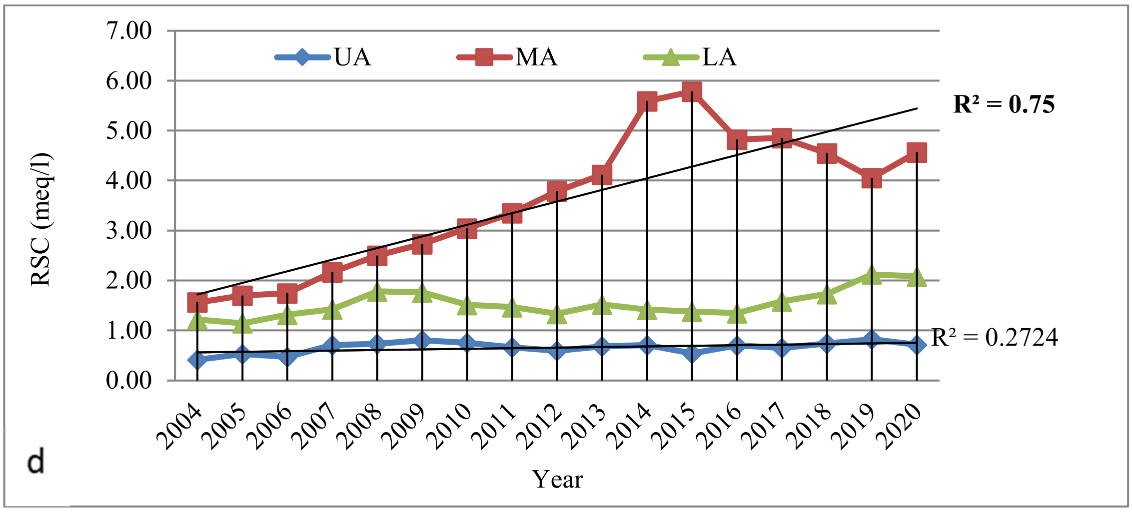
The mixing of Lake Beseka water with the Awash River was carried out as a measure to stabilize the rapid expansion of Lake Beseka before upsetting the surrounding environment. The recommended blending ratio during the early period was 2%. Since the end of 2011, however, Lake Beseka water has been discharged in excess of 10%. According to Belay, (2009) the annual mixing ratios of the Lake water with the Awash River were 6.67%, 13.98%, 45.83%, 27.67%, and 18.73% from 2013 to 2017. Beseka water is generally characterized as brackish quality containing high values of pHw, ECw, SAR and RSC; water of very strongly alkaline type with sever sodicity and salinity hazard (Belay and Eleni, 2009).

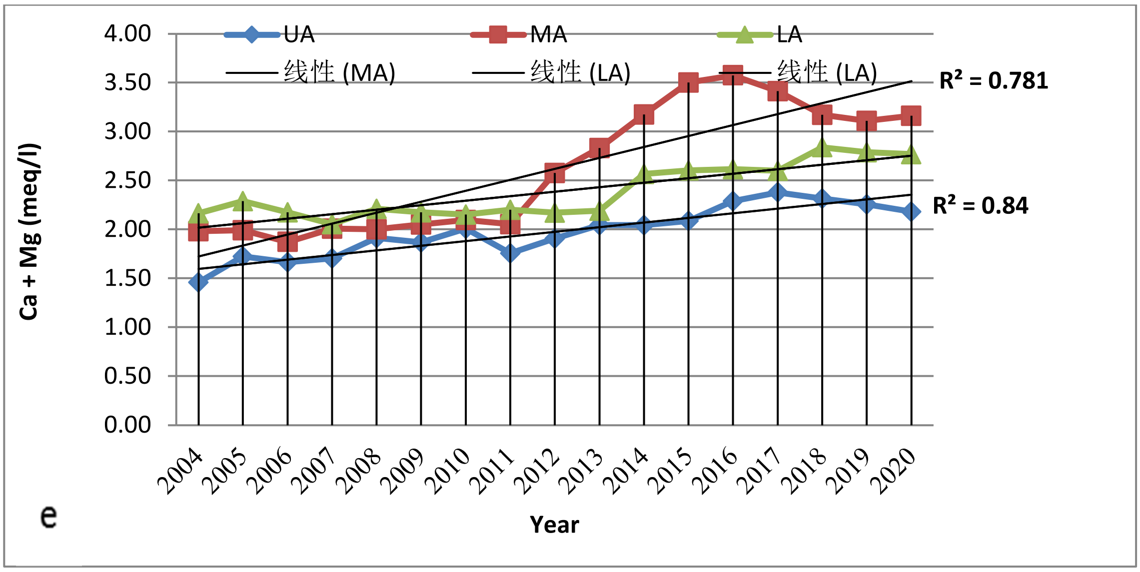
Furthermore, the Fentale and Kesem large-scale irrigation schemes, established in early 2010, were believed to exert an obvious effect in lowering the flow regime of the Awash River, which could ultimately reduce the corresponding dilution effect. Water abstraction for irrigation purposes changes hydrological conditions in rivers(Graf, 2006), or overexploited aquifers (Custodio, 2002). These pressures have both quantitative and qualitative effects on water resources (Kurunc, Yurekli, and Okman, 2005). From the analysis of the temporal trends, it could be realized that Awash River water quality variables had generally shown an increasing trend since the beginning of practicing mixing Lake Beseka water with Awash River water, in general, and from 2010 to 2016, in particular.






10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
UA
MA
LA
R² = 0.65
R² = 0.93
Na (meq/l)
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Year
c


7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
UA
MA
LA
R² = 0.75
R² = 0.2724
RSC (meq/l)
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Year
d


4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
UA
MA
LA
线性 (MA)
线性 (LA)
线性 (LA)
R² = 0.781
R² = 0.84
Ca + Mg (meq/l)
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Year
e

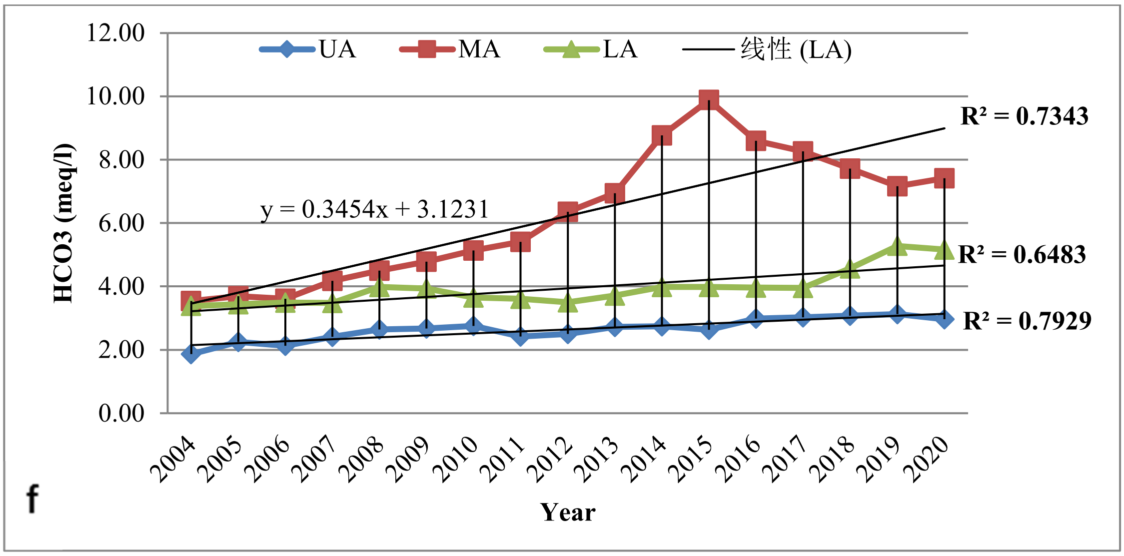


Figure 8. Temporal trend of ECw (a), SAR (b), NA(me/l)(c), RSC (d), Ca+Mg (me/l)(e) and $HCO_3$ (f) at the 3 sub-basins of Awash

From the hydrographs depicted in Figures 8a–f, it can be seen that water quality metrics values at the lower and middle Awash areas have shown a linearly decreasing trend since 2016 onwards, indicating water quality improvement. As indicated above, the discharging and mixing up of water from Lake Beseka to the River Awash had been regarded as the principal factor polluting the downstream areas. According to Eleni (2009) and (Haile and Asfaw 2020) Lake Beseka water had shown remarkable progressive improvement in recent years. In support of their findings, data from regular monitoring work of Werer Agricultural Research (unpublished) also indicated progressive improvement in Lake Beseka's water quality. For instance, a reduction in ECw value of about 0.33dS/m was recorded in 2020 than its value in 2016.

During the same period, a reduction in SAR and RSC values of 1.57 and 1.53 meq/l, respectively, was also noted. A remarkable reduction in cationic and anionic constituents was also seen since 2016. The result clearly illustrates that the observed improvement in water quality coincided with the improvement in lake water. The declining trend of lake water quality point source metrics suggests that observed river water quality improvements can be explained by changing the hydro-chemical properties of lake water, which has been regarded as a point source contaminant.

### 3.6 Geochemical composition

The hydrochemical water-quality concentration data from water samples of the River Awash were graphically evaluated through the Piper Stiff diagrams (Figure 9). Generally, the classification of a river's water into different water facies and water types is done based on the concentration of various predominant cations and anions and the interrelationships of ions. The samples from the upstream sampling sites (Wonji to Merti) throughout the study period lie at the border of the left quadrants of the diamond diagram (Fig. 8a), indicating a Ca-$HCO_3$ water type. River water samples downstream to Lake Beseka were found to have a hydrochemical composition dominated by Na, closely followed by Ca, among cations, and $HCO_3$, among anions. These samples lay in the upper part of the bottom quadrant of the piper plot, indicating a mixed Na-Ca-$HCO_3$ type of hydrochemical facies.

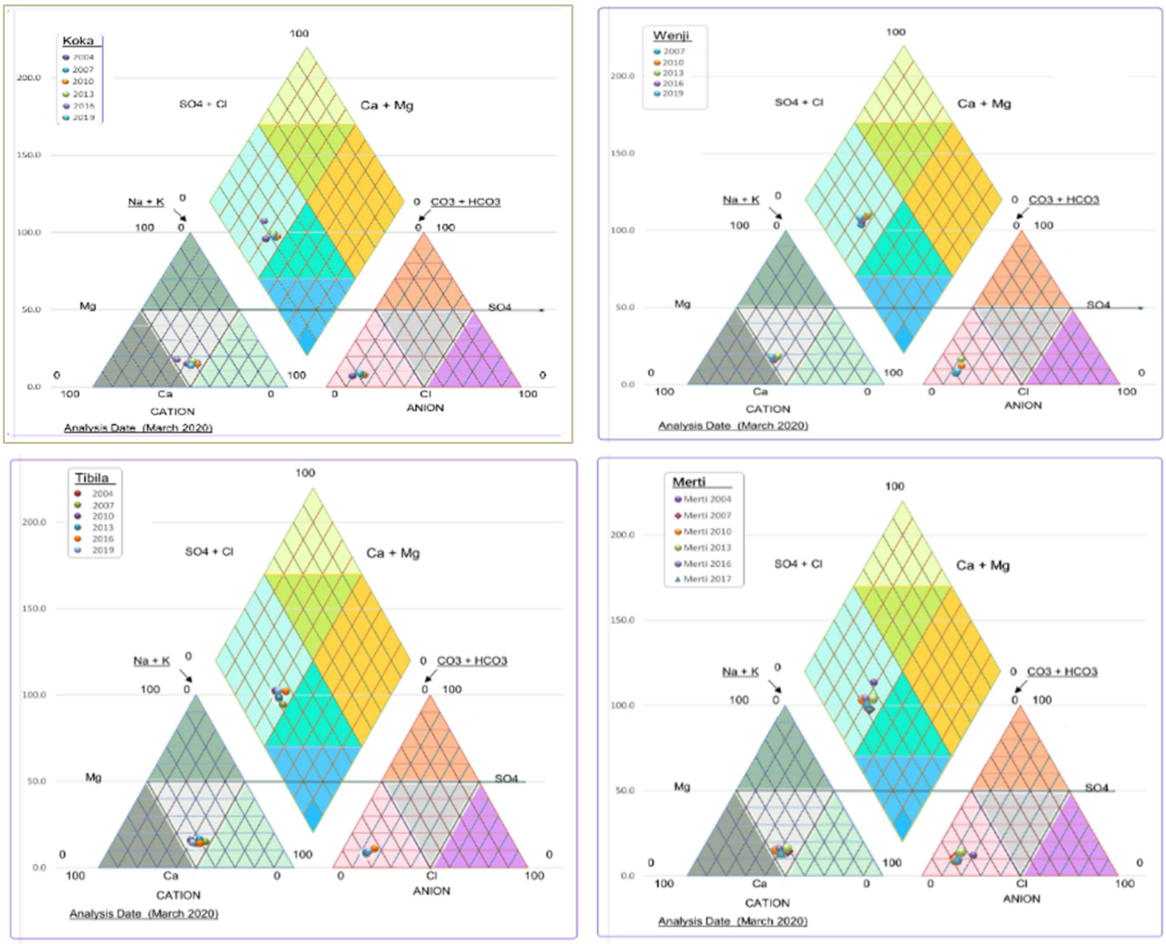


Figure 9. Piper diagrams of the River Awash water at a Koka, Wonji, Tibila and Merti

The chemical composition of certain river water is primarily dependent on the geology, geochemical processes, and, anthropogenic activities that take place within the basin. According to Shishaye and Nagari, (2016), a sample laying in the left quadrant represents calcium bicarbonate waters mostly originating from shallow fresh groundwater, and the right quadrant represents sodium chloride waters originating from deep ancient groundwater and marine groundwater, with sodium bicarbonate waters originating from deep groundwater impacted by ion exchange in the lower quadrant. The calcium bicarbonate water type identified in all water samples from the upstream area suggests that the River Awash originates from a shallow to medium-depth calcium bicarbonate-laden fresh groundwater of the geologically basalt-dominated Magdala group formation at the upstream of the basin. Basaltic parent materials are rich in $Ca^{2+}$ and $HCO_3^{\ -}$ (Chandrasekar *et al.*, 2018), and consequently, associated aquifers mostly yield $Ca(HCO_3)_2$ water types (Srinivasa Moorthy *et al.*, 2008), implying that the predominant origin of water quality determinants for the Awash River is the shallow-medium depth central highland aquifers that are dominated by Magdala group basalts.

The combination of Lake Beseqa water with River Awash led to a distinct geochemical makeup of the downstream river water, transforming it from a Ca-$HCO_3$-laden water type to a Na-Ca-$HCO_3$ dominated mixture (Fig. 8c–f). Thus, the change in the geochemical composition of the downstream sites is demonstrably attributed to the impact of the lake water. It was discovered that the geo-chemical constituents of lake water dominantly modified the water quality values in the downstream sample locations.

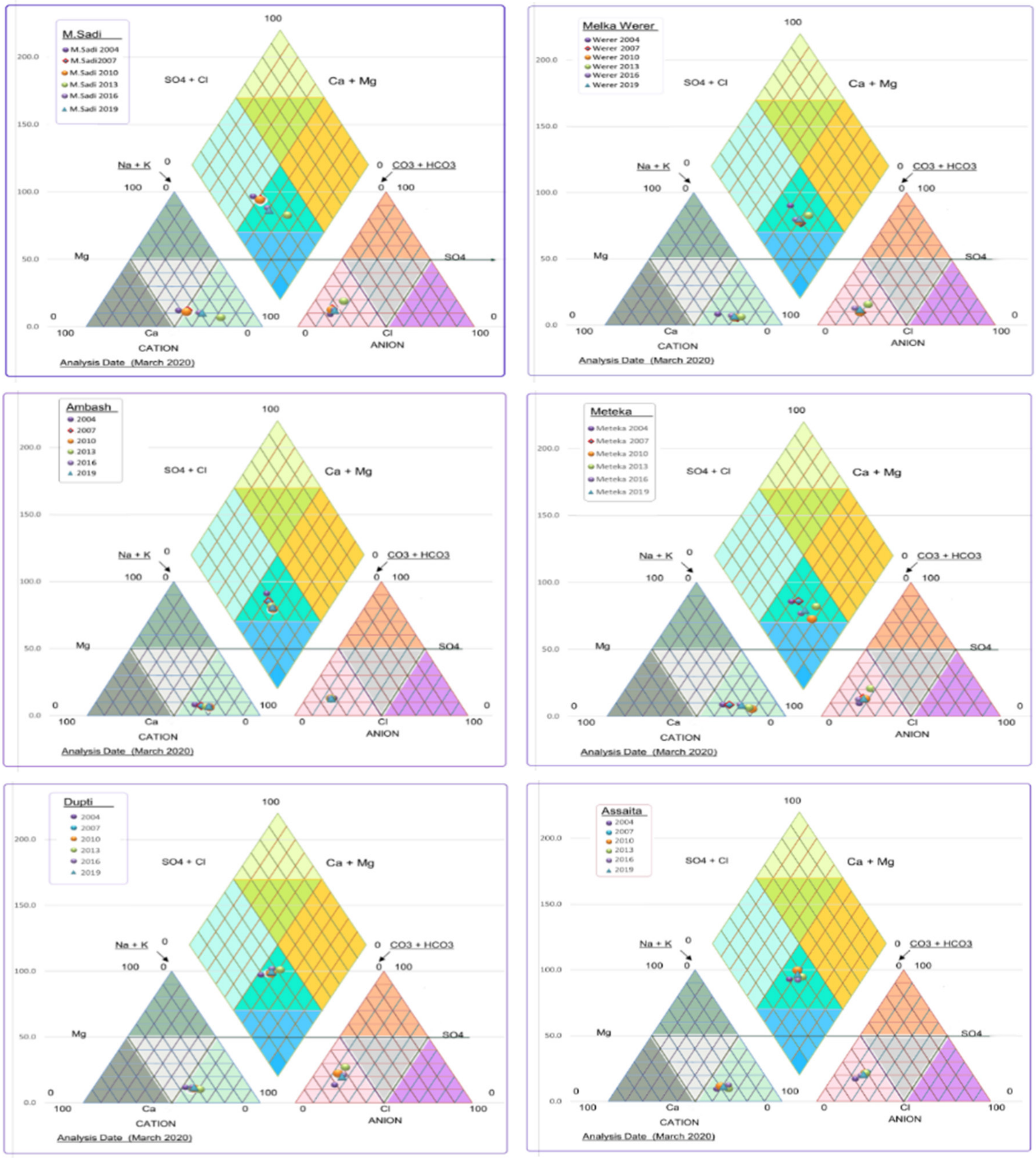


Figure 10. Piper diagrams of Melka Sadi, Werer, Ambash, Meteka, Dubty, and Asaiyta water samples

### 3.7 Present status of irrigation water suitability from the river Awash

Any irrigation water is prone to dissolved mineral salt contaminants with varying concentrations and compositions depending on the source and course. Irrigation water quality and quantity delivered to the agricultural fields account for all potential problems that may occur as a result. The system for the evaluation and characterization of water quality (chemical property) embraces three principal parameters. These parameters include salinity, sodicity, alkalinity, and toxicity hazards. Mean and range values for selected physicochemical variables of river water samples are presented in Tables 6 and 7.

Table 6. Mean and range values of major water salinity/sodicity parameters of Awash River water

| Sub-basin | Sampling site | pHw | ECw (dS/m) | SAR | RSC (meq/l) |
|---|---|---|---|---|---|
| Upper Awash | Awash River at Koka dam | 7.6 | 0.40 | 1.31 | 0.33 |
| | Awash River at Wonji Pump site | 7.8 | 0.38 | 1.24 | 0.26 |
| | Awash River at Tibila | 7.8 | 0.43 | 1.43 | 0.29 |
| | Awash River at Merti Weir site | 7.8 | 0.40 | 1.44 | 0.39 |
| | Minimum | 7.6 | 0.38 | 1.24 | 0.26 |
| | Maximum | 7.8 | 0.43 | 1.44 | 0.39 |
| | Mean | 7.7 | 0.40 | 1.35 | 0.32 |
| | SD | 0.07 | 0.02 | 0.10 | 0.05 |
| Middle Awash | Awash River at M.Sedi Weir site | 8.1 | 0.92 | 3.42 | 1.95 |
| | Awash River at Werer Pump site | 8.2 | 1.16 | 4.65 | 2.64 |
| | Awash River at Ambash Pump site | 8.1 | 1.00 | 4.18 | 2.68 |
| | Awash River at Meteka Pump site | 8.1 | 0.76 | 3.65 | 1.70 |
| | Minimum | 8.1 | 0.76 | 3.42 | 1.70 |
| | Maximum | 8.2 | 1.16 | 4.65 | 2.68 |
| | Mean | 8.1 | 0.96 | 3.97 | 2.24 |
| | SD | 0.04 | 0.17 | 0.55 | 0.49 |
| Lower Awash | Awash River at Dupty Pump site | 8.1 | 0.74 | 3.15 | 0.91 |
| | Awash River at Assaiyta Pump site | 8.1 | 0.71 | 3.09 | 0.92 |
| | Minimum | 8.1 | 0.71 | 3.09 | 0.91 |
| | Maximum | 8.1 | 0.74 | 3.15 | 0.92 |
| | Mean | 8.1 | 0.73 | 3.12 | 0.91 |
| | SD | 0.04 | 0.02 | 0.04 | 0.00 |

### 3.7.1 pHw (Alkalinity/Acidity)

Water samples from the Awash River contain a mean pHw value of 8.0 with extreme minimum and maximum values of 7.7 and 8.2, respectively, which could be regarded as a slight to moderately alkaline range. The water pHs recorded from the majority of the different sampling points along stream flow were within the values are considered normal (6.5 to 8.4) as described by R. S. Ayers and Westcot (1985). The pH, by in large, determines the solubility and ultimate availability of many plant nutrients and potentially toxic ions. Soil is much more strongly buffered against changes in pH than water. Except in extreme conditions, irrigation water will cause soil pH to change slowly with time and does not present a problem in itself over the short term. However, some problems can still occur within the pH range considered "normal" or "acceptable." For instance, alkaline water with a pH of 8.0 and above may enhabit high volume of bicarbonates.

### 3.7.2 Salinity Hazard (ECw)

Water salinity hazard is one of the primary water quality standard indicators that have the largest bearing on agricultural yield. Electrical conductivity (ECw) is used as a proxy measure that is in direct proportion to the concentration of ions in water. Table 6 presents the range and mean ECw values of water samples averaged over three flow seasons. All the ECw values across the Upper Awash sampling sites varied between 0.38-0.43 with mean values of 0.40  0.02 dS/m, which indicates a fresh or slightly freshening water type, as indicated in Figure 11, and was at the acceptably optimal level for irrigation. Range values of ECw were found to vary between 0.76 and 1.16 dS/m, at sampling sites in the middle awash area and 0.71 to 0.71 dS/m at lower awash sampling sites laying within a slight to moderate level of restriction (Ayers and Westcot, 1985). Water quality-induced salinity problems occur when the root zone salts accumulate due to intensified irrigation and exceed the biological tolerance and assisted resistance, leading to crop loss.

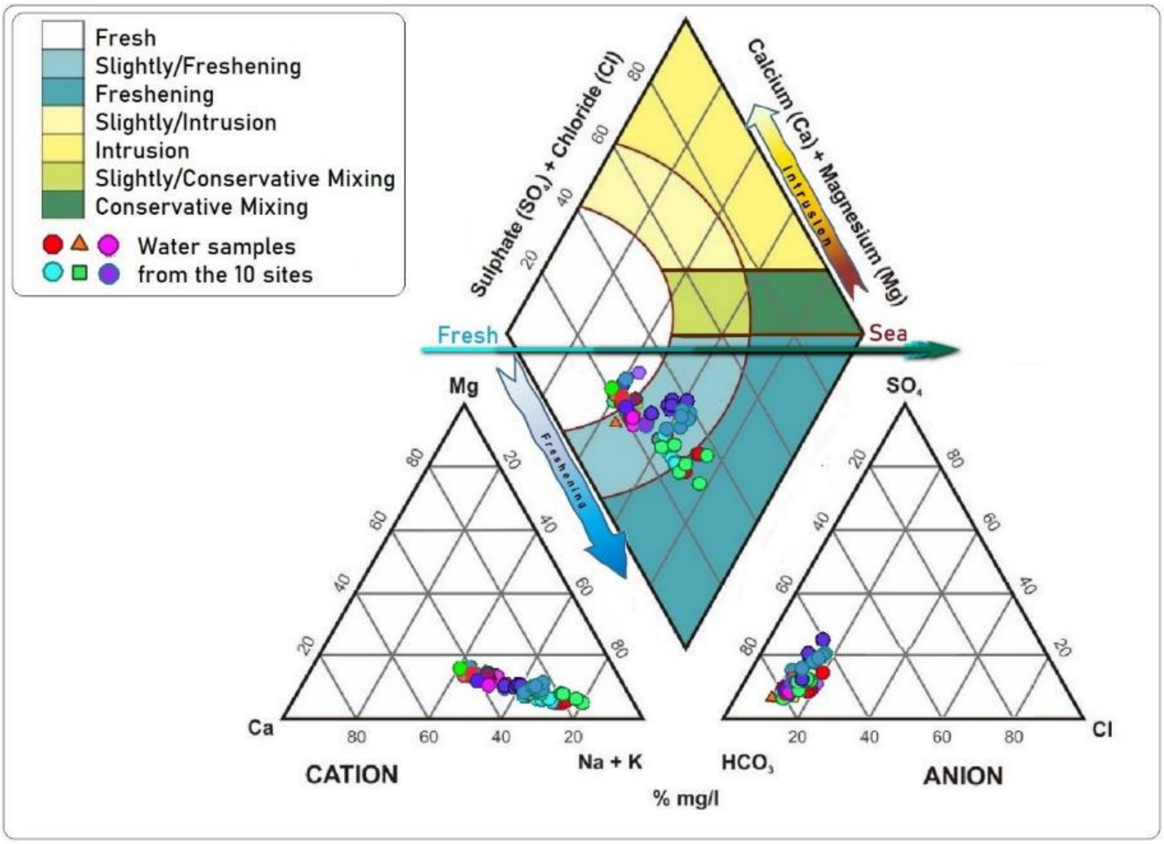


Figure 11. Water sample freshness level on Piper diagram-based grading criteria

Results of this investigation revealed that the salinity (ECw) for all water sampling sites in the upper and lower sub-basin areas was water of good quality class (C2) and was at the optimal level for agriculture purposes; whereas all water samples within the middle Awash sub-basin area were rated as of permissible (C3) water quality class with slight to moderate level of restriction(Ayers and Westcot, 1985). Even though there was remarkable spatiotemporal variation in ECw values, the water from the River Awash could generally be considered water of a slight to medium salinity class

As irrigation water is utilized to meet a range of plants' water needs at vastly variable intensification levels, with a range of different distribution and application systems, and diverse soil types, overall climatic ranges prevail in the Awash Basin, and a wide spectrum of problems might be encountered from long-term use unless associated management actions such as leaching practices are not followed. Moderate leaching may suffice to make medium-salinity water (C2) to be used for fair irrigation. Moderately salt-tolerant plants can be grown in such areas with limited salinity control practices. High-salinity water (C3), on the other hand, shouldn't be used on flat land or soils with no drainage. Along with the installation of drainage systems, relevant operational treatment, and husbandry must be supplemented to control salt. Furthermore, the selection of salt-tolerant plants should be the normative approach for sustained use.

Even though the immediate adverse effect on soil and crops might not be anticipated from the use of C2 and C3 water, the most likelihood of excess salt accumulation might occur from long-term use, aggravating the existing situation of irrigated farms in the Basin. For instance, water with an ECw of 1.15 dS/m contains approximately 2,000 pounds of salt for every acre-foot of water, implying that irrigation can contribute a substantial amount of salt to a field over the season. A cumulative salt load even within a decade of irrigation practice with C3 class irrigation water could exert severe salinity problems with prevailing poor irrigation water management practices, with no leaching and drainage systems in the middle and lower Awash areas where buildup and expansion of soil salinity had already taken place while remaining farm areas are considered prone to secondary salinization

### 3.7.3 Sodicity Hazard

#### 3.7.3.1 Sodium Adsorption Ratio –(SAR)

Some water quality problems are associated not only with the mere presence of a constituent but also with the interactions among them. Sodicity/alkali hazards are one of the problems that often confront the long-term use of a given irrigation water source. It relates to preserving sufficient soil permeability to allow water to permeate and flow freely through the soil. The Sodium Adsorption Ratio (SAR), as a water sodicity index, relates the relative concentration of Na to the combined concentration of Ca and Mg. The issue arises when irrigation water has a disproportionately higher sodium ion content than calcium and magnesium divalent ions, while the total salt concentration is still limited. The coincidence of low salt (low ECw) and high SAR is known to impede percolation of water across the profile, an indirect hindrance of soil permeability or water infiltration capacity. A high SAR or low ECw value can, separately or in synergy, act to disperse soil aggregates to cause soil sealing and crust formation, which reduce large pores and holes in number and size where aeration and drainage are accommodated

Table 7. Ayers and Westcot, (1985) Water quality interpretation guidelines for irrigation.

| Sampling site | ECiw (dS/m) | SAR | Salinity Class | Degree of restriction on use | Sodicity Class | Degree of Restriction on Use |
|---|---|---|---|---|---|---|
| AR at Koka dam | 0.40 | 1.31 | C2 | None | S1 | Slight to Moderate |
| AR at Wonji PS | 0.38 | 1.24 | C2 | None | S1 | Slight to Moderate |
| AR at Tibila | 0.43 | 1.43 | C2 | None | S1 | Slight to Moderate |
| AR at Merti WS | 0.40 | 1.44 | C2 | None | S1 | Slight to Moderate |
| AR at MS W.S | 0.92 | 3.42 | C3 | Slight to Moderate | S1 | Slight to Moderate |
| AR at Werer PS | 1.16 | 4.65 | C3 | Slight to Moderate | S1 | Slight to Moderate |
| AR at Ambash PS | 1.00 | 4.18 | C3 | Slight to Moderate | S1 | Slight to Moderate |
| AR at Meteka PS | 0.76 | 3.65 | C3 | Slight to Moderate | S1 | Slight to Moderate |
| AR at Dupty | 0.74 | 3.15 | C2 | Slight to Moderate | S1 | Slight to Moderate |
| AR at Assayita | 0.71 | 3.09 | C2 | Slight to Moderate | S1 | Slight to Moderate |

The SAR values for all water samples varied between 1.24 (at Wonji) and 4.65 (at Werer), with mean values of 2.75 (Table 7). SAR had shown to increase from upstream to the middle reach (Werer), then tend to decrease towards downstream areas. With the increase in SAR value, ECw value had concomitantly increased, and vice versa. Evidence suggests that the connection between the potential for soil problems and the SAR values is directly associated with the ECw of the water. Based on both ECw and SAR and their interaction (Ayers and Westcot, 1985), the water quality of the River Awash in terms of sodicity hazards and potential water infiltration problems appeared to lie within the class of a slight to moderate degree of restriction on use (Table 7 and Appendix Table 2

### 3.7.3.2 Sodium Percentage (Na%)

The percentage of Na is frequently used to estimate the appropriateness of certain water for agricultural use. When the relative concentration of $Na^+$ contents in surface water exceeds $Ca^{2+}$ and $Mg^{2+}$, it reacts with the soil and declines its permeability. Low permeability in turn disrupts the soil structure that results in the development of stunted plantations (Purushothman *et al.*, 2012; Sudhakar and Narsimha, 2013). The Na ratio over the study years ranged from 41.15 to 62.85, with an average value of 53.52 (Table 6). Based on the recorded Na% values, water samples from Koka, Wonji, Tibila, Merti, Melka Sadi, Dupty, and Assaiyta were in a permissible suitability class for irrigation, while the remaining water samples from Werer, Ambash, and Meteka sites fell into a doubtful suitability class (Table 5, Figures 5 and 6)

### 3.7.3.3 Permeability Index (PI)

The PI is frequently used to evaluate the suitability of water altered by high levels of Na+, $Ca^{2+,}$ $Mg^{2+}$, and $HCO_3$-emersions for irrigation (Ravikumar, Somashekar, and Angami, 2011). Across all the sampling sites, PI values varied between 22.48 and 42.83 (Appendix Table 4). Based on the PI values, the river water samples were classified into two classes: 1/ Good-Class II, which represents Koka, Wonji, Tibila, Merti, Melka Sadi, Dupty, and Assaiyta and 2/Unsuitable-Class III, which represents Werer, Ambash, and Meteka sites (Table 5), indicating that river water represented by samples with Good-Class II could be validated for irrigation.

### 3.7.3.4 Kelley Index (KI)

The KI irrigation suitability assessment (Sudhakar and Narsimha, 2013) conducted along with the PI revealed the presence of sodium in excess. The KI values varied from 0.60 to 1.59b across two years, with an average value of 1.12. As a result, only river water samples from the upper Awash area are qualified for the good class, while samples representing river water from the lower and middle Awash areas are considered unsuitable. A KI below one (KI < 1) indicates that the water is appropriate for irrigation, whereas a KI value over one (> 1) denotes the abundance of Na in the water(Kelley, 1940; Sundaray, Nayak and Bhatta, 2009).

### 3.7.3.5 Irrigation Water Quality (IWQ)

Irrigation water quality class of water with IWQI value less than 22 is considered as low suitability, 22–37 is regarded as moderate suitability, and those above 37 are regarded as high suitability (Dutta, Dwivedi, and Kumar, 2018). The computed mean IWQ values over two years period varied from 25 to 32, with average value of 29

(Appendix Table 4); showing that all the water samples were in a moderate IWQ suitability class.

### 3.7.4 Alkalinity Hazard (RSC)

When establishing and categorizing the irrigation suitability of a given water, the reference to the alkalinity content is also crucial. The alkalinity ($CO_3^{2-}$+ $HCO_3^-$) concentration greater than the alkaline earth metals ($Ca^{2+}$ and $Mg^{2+}$) is known as the 'Residual Sodium Carbonate' (RSC) (Sundaray et al., 2009). The RSC value is a proxy for the irrigation water quality hazard due to alkalinity. The RSC values of all sampling sites from the upper to the lower reach of the river varied from 0.26 to 0.39, 1.70 to 2.68, and 0.91 to 0.92 meq/l. According to these RSC values, all the water samples representing the upper and lower sub-basin areas with values less than 1.25 (Table 5, Figures 5 and 6), fell into a good class—acceptable for irrigation. The RSC At the middle reach, RSC values in Melka Sedi and Meteka sampling sites were found to lie in a doubtful class, whereas water samples from Ambash and Werer pump sites contained RSC values greater than 2.50 meq/l and were generally regarded as unsuitable. According to Sudhakar and Narsimha (2013), soil water movement may be deterred by sustained usage of alkali-laden irrigation water with an RSC of more than 2.5 meq/l by clogging soil pores with the accumulated salt. Such marginal waters are believed to be used for successful irrigation, but only with the necessary ameliorative or amendment measures and proper management practices

### 3.7.5 Specific-Ion Toxicity Hazard

Bicarbonate, chloride, sodium, and ions are among the major dissolved constituents of water. In addition to their role in the salinization of water and the soil beneath, chloride and sodium at high concentrations can pose harm to crop plants. Potential toxicity due to sodium hazards is based on SAR values. The SAR values for all water samples varied between 1.24 and 4.65 and were within a slight to moderate degree of restriction for use. The content of Cl for all water samples was found to exist within the threshold limit set by FAO (1985), indicating that the water from all sampling sites is safe for irrigation usage under both surface and sprinkler irrigation conditions with no restriction. Range values of $HCO_3^-$ varied between 2.39 to 7.02 meq/L at Koka and Werer sampling sites, respectively (Appendix Table 4). The values of $HCO_3^-$ recorded for water samples from all sampling points along the stream flow were found to lie between a slight and moderate degree of restriction for irrigation use. High bicarbonate levels in water can cause calcium to precipitate, deplete it from the soil, and consequently let it sod. This raises soil sodicity and lowers the exchangeable calcium content of the soil. Magnesium may also deteriorate alike and be lost. In severe circumstances, soil calcium and magnesium depletion will impair plant development. Bicarbonates may also cause the loss of many tree species due to lime deposit damage on the root.

Table 6. Values of WQIs in sampling locations of the River Awash

| Sampling site | EC (dS/m) | SAR | RSC | KI | %Na | PI (%) | IWQ |
|---|---|---|---|---|---|---|---|
| Koka | 0.40 | 1.31 | 0.33 | 0.65 | 43 | 43 | 30 |
| Wonji | 0.38 | 1.24 | 0.26 | 0.60 | 41 | 42 | 31 |
| Tibila | 0.43 | 1.43 | 0.29 | 0.68 | 45 | 39 | 32 |
| Merti | 0.40 | 1.44 | 0.39 | 0.67 | 44 | 40 | 32 |
| Melka Sadi | 0.92 | 3.42 | 1.95 | 1.25 | 60 | 25 | 26 |
| Werer | 1.16 | 4.65 | 2.64 | 1.59 | 63 | 22 | 25 |
| Ambash | 1.00 | 4.18 | 2.68 | 1.55 | 63 | 24 | 26 |
| Meteka | 0.76 | 3.65 | 1.70 | 1.50 | 62 | 25 | 26 |
| Dubty | 0.74 | 3.15 | 0.91 | 1.32 | 58 | 29 | 27 |
| Assaiyta | 0.71 | 3.09 | 0.92 | 1.36 | 58 | 29 | 28 |
| Minimum | 0.38 | 1.24 | 0.26 | 0.60 | 41 | 22 | 25 |
| Maximum | 1.16 | 4.65 | 2.68 | 1.59 | 63 | 43 | 32 |
| Mean | 0.69 | 2.75 | 1.21 | 1.12 | 54 | 32 | 29 |
| SD | 0.28 | 1.29 | 0.96 | 0.42 | 9 | 8 | 3 |

Table 7. *Classification of water quality across sampling sites according to WQIs*

| Sampling site | Salinity hazard | Sodicity hazard | Permeability/infiltration problem | | | Alkalinity hazard | IWQ |
|---|---|---|---|---|---|---|---|
| | EC *** | SAR/EC* | KI | Na% | PI%** | RSC | |
| Koka | Class 2 | S to M | Good | Permissible | Class II | Good | Medium |
| Wonji | Class 2 | S to M | Good | Permissible | Class II | Good | Medium |
| Tibila | Class 2 | S to M | Good | Permissible | Class II | Good | Medium |
| Merti | Class 2 | S to M | Good | Permissible | Class II | Good | Medium |
| Melka Sadi | Class 3 | S to M | Unsuitable | Doubtful | Class III | Doubtful | Medium |
| Werer | Class 3 | S to M | Unsuitable | Doubtful | Class III | Unsuitable | Medium |
| Ambash | Class 3 | S to M | Unsuitable | Doubtful | Class III | Unsuitable | Medium |
| Meteka | Class 3 | S to M | Unsuitable | Doubtful | Class III | Doubtful | Medium |
| Dubty | Class 2 | S to M | Unsuitable | Permissible | Class II | Good | Medium |
| Assaiyta | Class 2 | S to M | Unsuitable | Permissible | Class II | Good | Medium |

**Class II in PI (%) indicates a good class for irrigation and Class III indicates an Unsuitable class for irrigation*
***S to M in SAR/EC indicates slightly to moderate sodicity hazard*
****Class 2: medium salinity water and appraised as a good class; Class 3: high salinity water appraised as permissible*

## 4 Conclusion and Recommendations

Based on multi-year monitoring data, the present study investigated the spatiotemporal trend of water quality of River Awash and evaluated the recent suitability status of the irrigation water. From the result, the following concluding remarks were drawn;

- The water quality had changed temporally, resulting in altered water types differing in hydrochemical composition. Water quality metrics showed an increasing trend over the 2004–2020 study period, with a spatially dissimilar pattern of water quality change. The magnitude of temporal change in water quality parameters was exceptionally high around the middle Awash sub-basin area, while in the upstream areas, it appeared more stable over the study period.
- Water quality parameters assessed also showed a spatially increasing trend from the upstream Koka site towards the Meteka reach of the middle basin, which then tends to show a slightly decreasing trend in downstream areas. Different human activities that have been taking place in the past along the river basin areas can be stated as conceivable factors inducing concomitant river water quality change in temporal and special dimensions so far detected in the present study. In response to stream flow change from high to low, values of ionic constituents, salinity, and sodicity parameters increased, revealing an inverse relationship of water quality with stream flow change, signifying possible adverse effects in future scenarios would be more intensified during low flow times than during less dilution high flow times. It is also evident that the impact of stream flow size fluctuations is more pronounced in the immediate downstream area of Lake Beseka.
- Based on hydrochemical composition, river water at upstream flow areas was typified by a $\text{Ca-HCO}_3$ facies with medium salinity (C2) and low sodium (S1), whereas river water in downstream areas was recognized by a mixed $\text{Na-Ca-HCO}_3$ type of water with exceptionally high salinity and alkalinity Irrespective of seasonal flow variation, river water salinity at all sampling sites in the upper awash area remained to be found as water of good quality class (C2) and was at an acceptable or optimal level for agricultural purposes. River water at the lower awash sub-basin area was regarded as water of good quality (C2) during the high flow season (late June to late September), which then altered to a water class of permissible quality (C3) throughout the medium and low flow seasons (October to early June), whereas in the middle awash area, river water had a salinity class of permissible quality (C3), which remained unchanged regardless of seasonal change in stream flow. The result further showed a prevalence of slight to moderate sodicity hazards in all samples.

  Recent Awash River water quality status at the upper sub-basin area was found to lie within the acceptable or optimal level for agricultural purposes, and hence it is recommended that it is worth to upraise for use. In cases where there is moderate leaching, medium-salinity water (C2) may be employed. For the most part, plants that have moderate salinity tolerance can be grown without necessitating specialized techniques for salinity control. However, high-salinity water (C3), shouldn't be used on soils with no or restricted drainage. Along with the installation of drainage systems, relevant operational treatment and specialized husbandry must be supplemented to control salt. Furthermore, the selection of salt-tolerant plants should be the normative approach for sustained use of such soil and water.

From the results of this study, we recommend more specifically that:

- As irrigation water is utilized to meet a range of plants' water needs at vastly variable intensification levels, with a range of different distribution and application systems, and a variety of soils and overall climatic ranges in the basin, a wide spectrum of problems might be encountered from long-term use of river water, particularly with high salinity and a slight to moderate sodicity hazard; unless associated management actions such as leaching practices have not been followed.
- This study also indicated that most of the water-quality problems are associated with reduced flows in rivers. To maintain a water system that can be supportive of natural ecosystems and human societies, competent and innovative management is required. Flow monitoring and control plans should be created to prevent prolonged low water conditions. The specific pollution sources should be identified and remedial solutions should be taken. Further investigation on the sources' presence and severity of heavy metals in irrigated soils and the produce is highly needed. On top of these, close evaluation, monitoring and control of different water sources blending with the main river is very important.

## 5 References

Abebe, Y. and Jin, L. (2020) 'Impact of Lake Beseka on the Water Quality of Awash River', *American Journal of Water Resources*, 8(1), pp. 21–30.

Adriano MAYER (2022) 'DIAGRAMMES'. Laboratoire d'Hydrogéologie d'Avignon. Available at: http://www.lha.univ-avignon.fr/.

Amare, S., Kiflie, Z. and Agizew Nigussie (2017) 'Spatial and temporal water quality dynamics of Awash River using multivariate statistical techniques.', *African Journal of Environmental Science and Technology*, 11(11), pp. 565–577.

Amare, S., Zebene, K. and Agizew, N. (2017) 'Evaluating water quality of Awash River using water quality index', *Int J Water Resour Environ Eng*, 9(11), pp. 243–253.

AwBA (2014) 'Strategic River Basin Plan for Awash Basin, Melka Werer, Ethiopia.', *Awash Basin Authority* [Preprint].

Ayers, R. and DW, W. (1994) 'Water quality for Agriculture', *FAO Irrigation and Drainage Paper*, 29 Rev. 1(FAO Rome).

Ayers, R.S. and Westcot, D.W. (1976) 'Water Quality for Agriculture', *FAO Irrigation and Drainage Paper 29. Rome.* [Preprint].

Ayers, R.S. and Westcot, D.W. (1985) 'Water Quality for Agriculture', *Food and Agriculture Organization of the United Nations: Rome, Italy* [Preprint].

Banderi, A. *et al.* (2012) 'Water quality assessment of Amir Kabir sugarcane agro-industry with respect to agricultural and drinking views.', *Journal of Environment and Ecology*, 3(1):, pp. 11–28.

Belay, E.E.A. and Eleni, A.B. (2009) 'Growing lake with growing problems: integrated hydrogeological investigation on Lake Beseka', *ZEF, Germany.* [Preprint], (64).

Belay EA. (2009) 'Growing lake with growing problems: integrated hydrogeological investigation on Lake Beseka, Ethiopia', *Rheinis- chen Friedrich-Wilhelms-Universität Bonn, Bonn*, pp. 1–10.

Berhe, F. *et al.* (2013) 'MODSIM-based water allocation modeling of Awash River Basin, Ethiopia.', *Catena*, 109, pp. 118–128.

Booker Tate (1991) 'Booker Tropical Soil manual: A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics. Longman Scientific and Technical, Essex, New York.'

Carpenter, S.R. *et al.* (1998) 'Nonpoint pollution of surface waters with phosphorus and nitrogen', *Ecological Applications*, 8(3), pp. 559–568. Available at: https://doi.org/10.1890/1051-0761(1998)008[0559:NPOSWW]2.0.CO;2.

Chandrasekar, T. *et al.* (2018) 'Geochemical (process-based) characterization of groundwater along the KT boundary of South India. Geochemistry 78(1):1–16'.

Chen, H.J. and Chang, H. (2014) 'Response of discharge, TSS, and E. coli to rainfall events in urban, suburban, and rural watersheds.', *Environmental Science: Processes & Impacts*, 16(10), pp. 2313–2324.

Chien, H. *et al.* (2018) 'Impacts of Changed Stream Flow on Selected Water Quality Parameters in the Upper Esopus Creek Watershed of New York, USA', 6(1), pp. 71–78. Available at: https://doi.org/10.15640/jges.v6n1a5.

Conrad, O. *et al.* (2015) 'System for Automated Geoscientific Analyses (SAGA) v. 2.1.4', *Geoscientific Model Development*, 8(7), pp. 1991–2007. Available at: https://doi.org/10.5194/gmd-8-1991-2015.

Cude, C.G. (2001) 'Oregon Water Quality Index a Tool for Evaluating Water Quality Management Effectiveness'', *Journal of the American Water Resources Association*, 37(1), pp. 125–137. Available at:

http://www.deq.state.or.us/.

Custodio, E. (2002) 'Aquifer overexploitation: what does it mean?', *Hydrogeology Journal*, 10, pp. 254–277.

Degefu, F. *et al.* (2013) 'The water quality degradation of upper Awash River, Ethiopia. Ethiop. J. Environ. Stud. Manag. 6(1):58-66.', *Ethiop. J. Environ. Stud. Manag.*, 6(1), pp. 58–66.

Doneen L.D. (1975) 'Water quality for irrigated agriculture', in Plants in Saline Environments, eds A.', *Poljakoff-Mayber & J. Gale, Springer–Verlag, Berlin.* [Preprint].

Dutta, S., Dwivedi, A. and Kumar, M.S. (2018) 'Use of water quality index and multivariate statistical techniques for the assessment of spatial variations in water quality of a small river', *Environ. Monit. Assess. [CrossRef] [PubMed]*, 190, p. 718.

FAO (1985) 'FAO Water Quality for Agriculture', *Rome, Italy* [Preprint].

FAO and ITPS, FAO and ITPS (2015) 'Status of the World's Soil Resources (SWSR) – Main Report. FAO and ITPS, Rome, Italy.', *FAO (Food and Agriculture Organization) and ITPS (Intergovernmental Technical Panel on Soils).* [Preprint].

Forgy, E. (1965) 'Cluster Analysis of multivariate data: efficiency vs. interpretability of classifications', *Biometrics*, 21, p. 768.

Gedion, T. (2009) Surface Water–Groundwater Interactions and Effects of Irrigation on Water and Soil Resources in the Awash Valley. AAU.

GHS (2013) 'EASY_QUIM'.

GoldenSoftware (2019) 'Grapher ® 14.4.420 (64-bit) Jul 13 2019, 2D & 3D Graphing Software, , LLC graphersupport@goldensoftware.com ',. Available at: www.goldensoftware.com.

Göransson, G., Larson, M. and Bendz, D. (2013) 'Variation in turbidity with precipitation and flow in a regulated river system &ndash; river Göta Älv, SW Sweden.', *Hydrol. Earth Syst. Sci.,* 17(7), pp. 2529–2542.

Graf, W.L. (2006) 'Downstream hydrologic and geomorphic effects of large dams on American rivers.', *Geomorphology, 79, 336–360.* [Preprint].

Greenberg, A.E., Clesceri, L.S. (eds. . and Eaton, A.D. (1992) 'Standard methods for the examination of water and wastewater, 18 ed. American Public Health Association, American Water Works Association, Water Environment Federation, Washington (D.C.).'

Haile Arefayne and Asfaw, A.T. (2020) 'Analysis and evaluation of the spatial and temporal variabilities of river water quality parameters', *Applied Water Science*, 10(6), pp. 1–20. Available at: https://doi.org/10.1007/s13201-020-01222-2.

Hammer, 0., Harper, D.. T. and Ryan, P.D. (2001) 'PAST: Paleontological Statistics software package for education and data analysis.', *Palaeontologia Electronica*, 4(1): 9pp.

Horton, R. (1965) 'An Index Number System for Rating Water Quality', *J. Water Pollut. Control Fed.*, 37, pp. 300–306.

Jha, R.B. *et al.* (2010) 'Study of agricultural impacts through fish base variables in different rivers.', *International Journal of Environmental Science Technology*, 7 (3), pp. 609–615.

Juang, D.F., Lee, C.H. and Sueh, S.C. (2009) 'Chlorinated volatile organic compounds found near the water surface of heavily polluted rivers.', *International Journal of Environmental Science Technology*, 6 (4), pp. 545–556.

Kalkhoff, S.J. *et al.* (2016) 'Effect of variable annual precipitation and nutrient input on nitrogen and phosphorus transport from two Midwestern agricultural watersheds', *Science of the Total Environment*, 559(3), pp. 53–62. Available at: https://doi.org/10.1016/j.scitotenv.2016.03.127.

Kelley, W.P. (1940) 'Permissible composition and concentration of irrigated waters.', *Proc. Am. Soc. Civ. Eng. ,* 66, pp. 607–613.

Kurunc, A., Yurekli, K. and Oakman, C. (2005) 'Effects of Kilickaya am on concentration and load values of water quality constituents in Kelkit stream in Turkey.', *Journal of Hydrology*, 317, pp. 17–30.

LCRA (2014) *Water quality indicators. In: Colorado River watch network.* Available at: http://www.lcra.org/water/quality/colorado-river-watch-network/Pages/water-quality-indicators.aspx.

Newbold, J.D. *et al.* (1982) 'Nutrient spiraling in streams: implications for nutrient limitation and invertebrate activity.', *American Naturalist*, 120 ., pp. 628–652.

Obeidatt, A. and Alawneh, M. (2019) 'Hydrochemistry and groundwater quality assessment in Mafraq Province', *Jordan. Open Access Libr. J.*, 6, pp. 1–10. [CrossRef].

Ouyang, Y.N. *et al.* (2006) 'Assessment of seasonal variations in surface water quality.', *Journal of Water Research*, 40 (20), pp. 3800–3810.

Pejman, A.H. *et al.* (2009) 'Evaluation of spatial and seasonal variations in surface water quality using multivariate statistical techniques.', *International Journal of Environmental Science and Technology*, 6 (3), pp. 467–476.

Pike, R.G. *et al.* (2010) 'Water Quality and Forest Management (Chapter 12). In: R.G. Pike, T.E. Redding, R.D. Moore, R.D. Winker and K.D. Bladon (Editor), Compendium of forest hydrology and geomorphology in British Columbia. B.C. Min. For. Range, For. Sci. Prog., Victoria, B.C. an'. Available at:

https://www.for.gov.bc.ca/hfd/pubs/docs/lmh/Lmh66/Lmh66_ch12.pdf.

Piper, A.M. (1944) 'A graphic procedure in the geochemical interpretation of water-analyses. Eos, Transactions, *American Geophysical Union*, 25(6), pp. 914–928.

Postel, S. and Richter., B. (2003) 'Rivers for life: managing water for people and nature.', *Island Press, Washington, D.C., USA* [Preprint].

Purushothman, P. *et al.* (2012) 'Drinking and irrigation water quality in Jalandhar and Kapurthala Districts, Punjab, India: Using hydrochemistry.', *Int. J. Earth Sci. Eng.*, 5, pp. 1599–1608.

Ravikumar, P., Somashekar, R.K. and Angami, M. (2011) 'Hydrochemistry and evaluation of groundwater suitability for irrigation and drinking purposes in the Markandeya River basin, Belgaum District, Karnataka State, India.', *Environ. Monit. Assess.*, 173, pp. 459–487. [CrossRef].

Richards, L. (1954) 'Diagnosis and improvement of saline and alkali soils. In L. A. Richards (Ed.), USA Department of Agriculture Handbook 60 (pp. 98-105).', *Washington, DC: US Government Printing Office.* [Preprint].

Richards, L.A. (1954) Diagnosis and Improvement of Saline and Alkali Soils, U.S. Department of Agriculture. Washington, DC, USA,.

RockWare, I.A. (2020) 'AqQA, The Spreadsheet for Water Analyses"'. Rockware, Inc... Rockware® AND Aq•QA® are registered trademarks of Rockware, Inc.Copyright C 2003-2020. Available at: https://www.rockware.com/product/aqqa/.

Rostami, S., He, J., and Hassan, Q.K. (2018) 'Riverine Water Quality Response to Precipitation and Its Change.', *Environments,* 5(8). Available at: http;//doi.org/10.3390/environments5010008.

Rubin, J. (1967): (1967) 'Optimal Classification into Groups: An Approach for Solving the Taxonomy Problem', *J. Theoretical Biology*, 15, pp. 103–144.

Shishaye, H. (2018) 'Diagnosing the suitability of lake water for domestic and agricultural uses: a case study in Eastern Ethiopia.', *East Afr J Sci*, 12(2), pp. 101–110.

Shishaye, H. and Nagari, A. (2016) 'Hydrogeochemical analysis and evaluation of the groundwater in the Haramaya Well Field, Eastern Hararghe Zone, Ethiopia.', *J Hydrogeol Hydrol Eng*, 5(4).

Simsek, C. and Gunduz, O. (2007) 'IWQ index: A GIS-integrated technique to assess irrigation water quality. Environ', *Monit. Assess.*, 128, pp. 277–300. [CrossRef].

Smakhtin, V.U. (2001) 'Low flow hydrology: a review.', *Journal of Hydrology*, 140, pp. 147–186.

SPSS-IBM (2019) 'IBM SPSS Statistics for Windows'. Armonk, NY: IBM Corp: IBM. Available at: https://www.ibm.com/analytics/spss-statistics-software.

Srinivasa Moorthy, K. *et al.* (2008) 'Identification of major sources controlling groundwater chemistry from a hard rock terrain—A case study from Mettur taluk, Salem district, Tamil Nadu, India.', *J. Earth Syst. Sci.,* 117, pp. 49–58. [CrossRef].

Sudhakar, A. and Narsimha, A. (2013) 'Suitability and assessment of groundwater for irrigation purpose: A case study of Kushaiguda area, Ranga Reddy district, Andhra Pradesh, India.', *Adv. Appl. Sci. Res.*, 4(75–81).

Sundaray, S., Nayak, B. and Bhatta, D. (2009) 'Environmental studies on river water quality with reference to suitability for agricultural purposes: Mahanadi river estuarine system, India—a case study', *Environ Monit Assess*, 155, pp. 227–243. Available at: https://doi.org/10.1007/s1066 1-008-0431-2.

Swanson, S. *et al.* (2001) 'Two-way cluster analysis of geochemical data to constrain spring source waters.', *Elsevier Science B.V., Chemical Geology*, 179Ž2001, pp. 73–91.

Szabolcs and Szabolcs, I. (1989) 'Salt-affected Soils', *CRC Press, Boca Raton, FL*, p. 274.

Tessema, S. (2011) Hydrological Modelling as a Tool for Sustainable Water Resources Management: A Case Study of the Awash River Basin, Licentiate Thesis Environmental Management and Assessment Research Group Department of Land and Water Resources Engineering, Royal Institut.

Tilahun, A., HA, S. and B, G. (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), pp. 1–15.

Tilahun, A., Shishaye, H. and 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), pp. 1–15.

Todd, D.K. (1980) *Groundwater Hydrology*, *Wiley*. New York, NY, USA,.

Vannote, R.L. *et al.* (1980) 'The river continuum concept. Canadian', *Journal of Fisheries and Aquatic Sciences*, 37, pp. 130–137.

VIMS (2005) '(Virginia Institute of Marine Science). Physical characteristics: salinity in shallow Water habitats.' Available at: http://web.vims.edu/bio/shallowwater/physical_characteristics/salinity.html.

Whitfield, P.H., Rousseau, N. and Michnowsky, E. (1993) 'Rainfall induced changes in the chemistry of a British Columbia coastal stream.', *Northwest Science*, 67(1).

## 6 Appendix

Appendix Table 1 Name of water sampling stations and respective geo-reference data

| Sub-basin | Water sampling site name | Geo-reference | | Elevation (masl) |
|---|---|---|---|---|
| | | Easting | Northing | |
| Upper Awash | M. Kuntre (Koka) | 8.40668 | 39.02050 | 1591 |
| | Wonjji pump site | 8.45570 | 39.23098 | 1550 |
| | AR near Tibilla village | 8.50880 | 39.56480 | 1237 |
| | Merti weir site | 8.76248 | 39.88520 | 980 |
| Middle Awash | M/Sedi weir site | 9.20540 | 40.11854 | 747 |
| | Werer pump site | 9.33448 | 40.17136 | 739 |
| | Ambash pump site | 9.41112 | 40.15846 | 733 |
| | Meteka pump site | 9.97479 | 40.51849 | 576 |
| Lower Awash | Dupty | 11.72571 | 41.08581 | 376 |
| | Assayita | 11.54376 | 41.44975 | 358 |

Appendix Table 2 Classification of IWQ for surface water samples

| Class of Water | Irrigation Water Salinity | Range of ECw (dS/m) | Degree of Restriction on Use |
|---|---|---|---|
| Class 1 (C1) | Low salinity water | < 0.25 | Excellent |
| Class 2 (C2) | Medium salinity water | 0.25-0.75 | Good |
| Class 3 (C3) | High salinity water | 0.76-2.00 | Permissible |
| Class 4 (C4) | Very high salinity water | 2.01-3.00 | Doubtful |
| Class 5 (C5) | Excessively high salinity water | >3.00 | Unsuitable |

Source: Richards (1954) and Booker Tropical Soil Manual (Booker Tate, 1991)

Appendix Table 3. Classification of Irrigation Water (Salinity) & Sodicity)

| Sodium Class | Irrigation Water Sodicity | SAR |
|---|---|---|
| S1 | Low sodium water | < 10 |
| S2 | Medium sodium water | 10 -18 |
| S3 | High sodium water | 18 - 26 |
| S4 | Very high sodium water | > 26 |

Source: Richards (1954) and Booker Tropical Soil Manual (Booker Tate, 1991)

Appendix Table 4. Mean values of selected water quality parameters for the period 2019 and 2020

| Sub-basin | Sampling site | pHiw | ECiw (dS/m) | Cations (meq/l) | | | Anions (meq/l) | | | SAR | RSC (meq/l) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Ca+Mg | Na | K | $HCO_3$ | Cl | $SO_4$ | | |
| Upper Awash | Koka dam | 7.63 | 0.40 | 2.06 | 1.34 | 0.21 | 2.39 | 0.52 | 0.30 | 1.31 | 0.33 |
| | Wonji PS | 7.75 | 0.38 | 2.18 | 1.30 | 0.23 | 2.44 | 0.49 | 0.36 | 1.24 | 0.26 |
| | Tibila | 7.78 | 0.43 | 2.25 | 1.52 | 0.31 | 2.54 | 0.52 | 0.38 | 1.43 | 0.29 |
| | Merti WS | 7.78 | 0.40 | 2.31 | 1.55 | 0.23 | 2.70 | 0.51 | 0.41 | 1.44 | 0.39 |
| | Minimum | 7.63 | 0.38 | 2.06 | 1.30 | 0.21 | 2.39 | 0.49 | 0.30 | 1.24 | 0.26 |
| | Maximum | 7.78 | 0.43 | 2.31 | 1.55 | 0.31 | 2.70 | 0.52 | 0.41 | 1.44 | 0.39 |
| | Mean | 7.74 | 0.40 | 2.20 | 1.43 | 0.24 | 2.52 | 0.51 | 0.36 | 1.35 | 0.32 |
| | SD | 0.07 | 0.02 | 0.11 | 0.13 | 0.04 | 0.14 | 0.02 | 0.05 | 0.10 | 0.05 |
| Middle Awash | MS W.S | 8.08 | 0.92 | 3.87 | 4.84 | 0.40 | 5.82 | 1.55 | 1.28 | 3.42 | 1.95 |
| | WARC PS | 8.16 | 1.16 | 4.38 | 6.95 | 0.45 | 7.02 | 2.05 | 1.41 | 4.65 | 2.64 |
| | Amb. PS | 8.08 | 1.00 | 3.66 | 5.66 | 0.50 | 6.34 | 1.31 | 1.14 | 4.18 | 2.68 |
| | Meteka PS | 8.10 | 0.76 | 3.00 | 4.51 | 0.25 | 4.70 | 1.22 | 1.15 | 3.65 | 1.70 |
| | Minimum | 8.08 | 0.76 | 3.00 | 4.51 | 0.25 | 4.70 | 1.22 | 1.14 | 3.42 | 1.70 |
| | Maximum | 8.16 | 1.16 | 4.38 | 6.95 | 0.50 | 7.02 | 2.05 | 1.41 | 4.65 | 2.68 |
| | Mean | 8.10 | 0.96 | 3.73 | 5.49 | 0.40 | 5.97 | 1.53 | 1.25 | 3.97 | 2.24 |
| | SD | 0.04 | 0.17 | 0.57 | 1.09 | 0.11 | 0.98 | 0.37 | 0.12 | 0.55 | 0.49 |
| Lower Awash | Dupty | 8.13 | 0.74 | 2.81 | 3.71 | 0.21 | 3.72 | 1.08 | 1.65 | 3.15 | 0.91 |
| | Assayita | 8.07 | 0.71 | 2.57 | 3.50 | 0.37 | 3.48 | 1.00 | 1.59 | 3.09 | 0.92 |
| | Minimum | 8.07 | 0.71 | 2.57 | 3.50 | 0.21 | 3.48 | 1.00 | 1.59 | 3.09 | 0.91 |
| | Maximum | 8.13 | 0.74 | 2.81 | 3.71 | 0.37 | 3.72 | 1.08 | 1.65 | 3.15 | 0.92 |
| | Mean | 8.10 | 0.73 | 2.69 | 3.60 | 0.29 | 3.60 | 1.04 | 1.62 | 3.12 | 0.91 |
| | SD | 0.04 | 0.02 | 0.17 | 0.15 | 0.12 | 0.17 | 0.06 | 0.04 | 0.04 | 0.00 |