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Original Research Paper

Groundwater Quality Assessment Using Geospatial Techniques and WQI in North East of Adama Town, Oromia Region, Ethiopia

Shankar Karuppannan[1]*, Nafyad Serre Kawo[2, 3]

1. School of Applied Natural Science, Department of Applied Geology, Adama Science and Technology University, P.O. Box: 5096, Adama, Ethiopia.
2. Africa Centre of Excellence for Water Management, Addis Ababa University, P. O. Box: 1176, Addis Ababa, Ethiopia.
3. School of Civil Engineering and Architecture, Department of Water Resources Engineering, Adama Science and Technology University, P. O. Box: 5096, Adama, Ethiopia

Abstract

Assessment of groundwater quality is vital for the sustainable use of the resources for domestic and agricultural purposes. In this study spatial variation of physicochemical parameters were analyzed for Northeast Adama Town. Water Quality Index (WQI) and irrigation indices were used to determine the suitability of groundwater for drinking and irrigation purposes, respectively. Further, the physical-chemical results were compared with the Ethiopian standards and the World Health Organization (WHO) standards for drinking and public health. Using GIS interpolation methods in Arc GIS 10.3.1, spatial distribution maps of pH, TDS, EC, Cl^-, HCO_3^{2-}, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+ and K^+, RSC, SAR, Na% were prepared. Results indicated that except ASTU well 2, all samples are below the desirable limits of WHO. The WQI results indicated that 85% of samples and 15% of samples were in good and poor categories, respectively. Irrigation indices show that the most groundwater samples have excellent water classes, indicating that they are suitable for irrigation purposes.

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1 INTRODUCTION

Groundwater is the primary source for drinking, domestic, industrial and agricultural purposes in different parts of the world (Fienen and Arshad, 2016; Wagh *et al*., 2016). Groundwater is widely used for drinking purposes in numerous urban areas (Altchenko *et al*., 2011; Lapworth *et al*., 2017). Rapid population growth, irrigation expansion, and increasing industrialization have prompted an increasing demand for groundwater. In recent decades, there is a rapid expansion of the urban areas, improper waste disposal from domestic and industrial areas. Many cities have no well-developed sewer and drainage systems (Kazi *et al*., 2009). These expansions and increasing demands are resulting in depletion and contamination of the resources. According to Farooq and Ustad, (2015) groundwater pollution has been increasing rapidly in many parts of the world, due to industrial effluents, agricultural fertilizers, municipal wastewater, landfill, and animal waste. Mohanakavitha *et al*. (2019a, 2019b) stated that the discharge of untreated wastewater and leachate from waste disposal site is contaminating groundwater in south India. Anthropogenic activities are causing degradation of groundwater quality and limiting the availability of freshwater resources.

Groundwater is extremely used for drinking water supply in the Main Ethiopian rift (Reimann *et al*., 2003). Many research studies (UNDP, 1973; Chernet, 1982; Wood and Talling, 1988; Halcrow, 1989; Gizaw, 1996, 2002; Kebede *et al*., 2005; Berhanu, 2007; Ayenew *et al*., 2008; Ayenew, 2008; Kebede *et al*., 2008; Demlie and Wohnlich, 2006; Demlie *et al*., 2007a, 2007b, 2008;

* Author address for correspondence
School of Applied Natural Science, Department of Applied Geology, Adama Science and Technology University, P.O. Box: 5096, Adama, Ethiopia.
Tel.: +251 962-10320
E-mails: geoshankar1984@gmail.com (*K. Shankar* -Corresponding author); nafyad.serre@gmail.com (*N. Kawo*).

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Yitbarek *et al*., 2012; Amanial, 2015; Kawo and Shankar, 2018) reported on the groundwater chemistry in the Ethiopian rift. These finding reported that the chemical composition of groundwater in highland and rift valley aquifers are different. Many researchers have already reported high F^- concentrations in the groundwater from rift valley (Ayenew, 2005; Tekle-Haimanot *et al*., 2006; Reimann *et al*., 2003; Rango *et al*., 2010; Furi *et al*., 2011; Haji *et al*., 2018). Mica-based volcanic aquifers; pyroxene and amphiboles are sources of fluoride in the rift valley groundwater (Furi *et al*., 2011). Further, liquid waste discharges from cities found in the rift valley are polluting groundwater. Taye (1988) reported that pollution of groundwater in the Dire Dawa groundwater basin. Tamiru (2004) studies status and groundwater vulnerability in Addis Ababa and reported that pollution of groundwater due to untreated waste discharge to rivers. Water quality studies conducted in the East Shewa Zone reported that pollution of groundwater. For instance, Haile Gashaw, (1999) stated that high TDS and fluoride concentration in the lake Ziway area. Dinka, (2015) studies the hydrochemical properties of different surface water bodies and groundwater available at Matahara region and reported that variations of chemical parameters in different water sources. Dinka, (2017) also stated pollution of groundwater by anthropogenic activities in Matahara region. Eliku and Suleiman, (2015) studied physicochemical and bacteriological parameters in Adama town and reported that water quality degradation due to inadequate sanitation and hygienic practices.

Worldwide, a number of hydrogeochemical studies have been conducted to identify geochemical processes and evolution of groundwater quality (Aravindan *et al*., 2008, 2011; Rango *et al*., 2010; Aravindan and Shankar, 2011a, 2011b; Kumar and Balamurugan, 2018; Wagh *et al*., 2018; Narsimha and Rajitha, 2018). The IDW interpolation method of a geographical information system (GIS) is widely used to map groundwater quality. GIS-based research is the best idea to observe the evolutionary tendency of water quality that keeps changing from time to time. This modern approach allows environment executives and decision-makers in the process of precise monitoring and rapid decision-making, tremendously. Spatial variation of groundwater quality is controlled by geology and anthropogenic activities within a groundwater basin (Subramani *et al*., 2005; Aravindan *et al*., 2010; Aravindan and Shankar, 2011a; Shankar *et al*., 2010, 2011, 2011a, 2011b; Venkateswaran *et al*., 2012; Li *et al*., 2016; Mahlknecht *et al*., 2017; Wu *et al*., 2017; Kawo and Shankar, 2018). Further, water quality index (WQI) has been widely used to evaluate the suitability of groundwater for domestic purposes (Rabeiy, 2017). Details of WQI were presented in Babiker *et al*. (2006), Gebrehiwot *et al*. (2011), Singh and Khan (2011), Selvam *et al*. (2013), Boateng *et al*. (2016), Jhariya *et al*. (2017), Keraga *et al*. (2017), Wagh *et al*. (2017), Ramya Priya and Elango (2018), Kawo and Shankar (2018) and Lad *et al*. (2018).

In this study, major cations and anions were analyzed and IDW interpolation in GIS was used to produce spatial variation map. In addition, spatial variation map of the Water Quality Index and suitability of groundwater for irrigation purposes were analyzed.

2 STUDY AREA

Adama is located in the north-central part of the Main Ethiopian Rift (MER), within the East Showa zone of Oromia National Regional State. It’s located about 100 km southeast of the capital city Addis Ababa. Adama city is one of the largest cities in Oromiya and it’s found between escarpment and the Great Rift Valley in West and East, respectively. Adama is found in the Rift valley area in the upper Awash River Basin. Geographically the study area is located at 8º32′0" N – 8º36′0" N latitude and 39º16′0" E – 39º20′0" E longitude (Figure 1). The areal extent of Northeast Adama is 45 km^2. The location of the map of our study area drawn from a toposheet number of 0839A4 and 0839C2 published in 1975 by the survey and mapping department of Ethiopia at a scale of 1:50,000. It is situated in a flatland area surrounded by sloping hills on all sides except the one facing the south. The soil is light sand and fine clay, which is easily blown into storms during the dry season. Climatically, Adama falls within the kola zone /low land zone and the average annual temperature is about 20 degrees centigrade with maximum temperature slightly exceeding 30-32 degrees centigrade during the month of May. Summer temperatures are low giving mild and pleasant weather conditions. Annual rainfall, which comes during the month of June, July and August, ranges between700 mm and 900 mm.

3 GEOLOGY

The geology of the study area is covered by different types of volcanic rocks with different occurrences and ages. Mafic and felsic volcanic rock are dominant geological units in the study area. These rocks consist of alkaline transactional basaltic lavas, and pantellerite, dacitic and rhyolite, ignimbrite sheets, generally strongly welded, and sporadic lava domes. In general, ignimbrites, slightly welded tuffs, unwelded tuffs, rhyolite lava flows, pumice fall deposits, obsidian flows, and basaltic lava flows and scoria are the main lithological units identified in the study area. The study area is characterized by a number of minors and major normal types of faults running almost parallel to each other in an NNE-SSW direction and is usually arranged in the form of an “en echelon” feature, commonly in a right stepping manner (Furi *et al*., 2011, 2012; Agostini *et al*., 2011). These faults are commonly associated with volcanic activities and in general younger in the central part and get older towards the rift margins. They form steps and local graben-horst structures and dissect almost all lithological units outcropping in the area and recent volcanism has been observed to be associated with these faults. Some faults are reported to be presently buried under the lacustrine sediments. The faults of the floor which are part of the Wonji Fault Belt

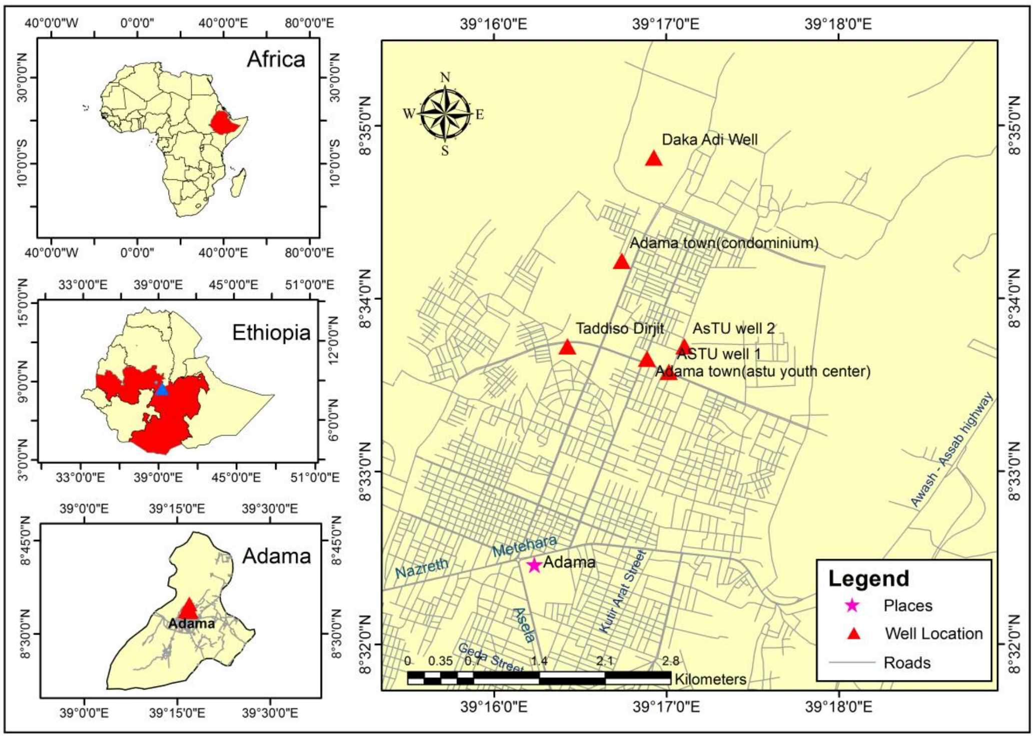

Figure 1. Study area

(Mohr, 1960) form several tectonic depressions like the ones found in the area of Boku, and Wagillo and the orientation of the fault is NNE-SSW direction (Assiged, 2007).

4 METHODOLOGY

To assess groundwater quality in the North East of Adama Town, 7 groundwater samples were collected from existing pumping wells and analyzed in 2017 using standard methods (APHA, 1995). Before filling the bottle with the sample, the water sample bottles (High-density polythene bottles) were washed using dilute HNO_3^{2-} acid and then with distilled water. The bottles were sealed after water sample collection and labeled, systematically. Then, water analyses were carried out by using standard procedures (APHA, 1995). pH, Total dissolved solids (TDS) and electrical conductivity (EC) were measured in the field using portable devices while the concentration of chemical constituents such as Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, HCO_3^{2-}, F^{-} and SO_4^{2-} in groundwater samples were determined in the laboratory. A titrimetric method was used to determine Cl^{-} and HCO_3^{2-} in groundwater samples. F^{-} and SO_4^{2-} were determined using the ion-selective electrode and spectrophotometer, respectively. Na^{+}, K^{+} and Ca^{2+}, Mg^{2+} were determined by flame photometric and EDTA titrimetric method, respectively. In this study, duplicates were used for quality assurance and quality control (QA/QC).

Groundwater types were determined using Piper plot (Piper, 1944). Data were made available in a format that is accessible via GIS (ArcGIS -Spatial Analyst tool). Further, IDW method was used to analyze spatial variation of major cations and anions in groundwater of the study area. Water Quality Index (WQI), Sodium Adsorption Ratio (SAR), Sodium Percentage (Na%), and Residual Sodium Carbonate (RSC) were used to assess the suitability of groundwater for drinking and irrigation purposes, respectively.

5 RESULTS AND DISCUSSION

The descriptive statistics and WHO-Ethiopian standard limits for determined cations and anions were presented in Table 1. The pH values range from 7.3 to 8.4, with a mean value of 8.0. EC and TDS values range from 220.7 to 869.1 μS/cm and 141.2 to 556.2 mg/L, with mean values of 532.1 μS/cm and 340.6 mg/L, respectively. Ca^{2+} and Mg^{2+} ranges from 11 to 116 and 2.4 to 52.3 mg/L, with average values of 50.9 and 12.9 mg/L, respectively. Na^{+} and K^{+} ranges from 57 to 214 mg/L and 5.9 to 31.5 mg/L, with mean values of 101.6 and 14.7 mg/L, respectively. Major anion concentrations in the study area ranges from 7.9 to 263.9 mg/L for Cl^{-}, from 0.8 to 496.1 mg/L for SO_4^{2-}, from 256.2 to 349.6 mg/L for HCO_3^{2-} and from 0.88 to 1.5 for F^{-}.

5.1 Physical Characteristics of Ground Water (pH, Conductivity, TDS)

pH value shows that the groundwater of the study area is mainly alkaline in nature. Figure 2(a) shows an interpolated spatial variation map of pH of the groundwater. The lowest pH is recognized in ASTU Well 2 and the highest pH is observed in the central part of Taddiso Dirjit and ASTU Well 1. According to WHO (2011) standards, the pH of the water should between 6.5 and 8.5 (Table 1). The study area is dominated by the alkaline water due to the presence of alkalies in carbonate ions present (Davis, 1966). If pH < 8.2, it is a measure of bicarbonate ions. Groundwater in the rift valley has high pH values due to Na- rich igneous rock aquifer (Kawo and Shankar, 2018; Haji *et al.*, 2018). The spatial variation map (Figure 2(b)) of EC values indicates that the Southwestern part of Adama town has a high EC concentration. As per WHO (2011), the allowable limit for EC is 1000 µs/cm and all groundwater samples are found to be within the drinking limits.

Table 1. Statistical details and WHO-Ethiopian standard limits for determined hydrochemical parameters

	Hydrochemical Parameters			WHO	Ethiopian
Ions	Minimum	Maximum	Average	2011	limit
pH	7.3	8.4	8.0	6.5-8.5	6.5-8.5
EC (µS/cm)	220.7	869.1	532.1	1000	-
TDS (mg/L)	141.2	556.2	340.6	500	1776
Ca^{2+} (mg/L)	11.0	116.0	50.9	75	200
Mg^{2+} (mg/L)	2.4	52.3	12.9	50	150
Na^{+} (mg/L)	57.0	214.0	101.6	200	358
K^{+} (mg/L)	5.9	31.5	14.7	-	-
Cl^{-} (mg/L)	7.9	263.9	50.5	250	533
HCO_3^{2-} (mg/L)	256.2	349.6	283.5	200	-
SO_4^{2-} (mg/L)	0.8	496.1	83.5	200	483
F^{-} (mg/L)	0.88	1.5	0.95	1.5	3

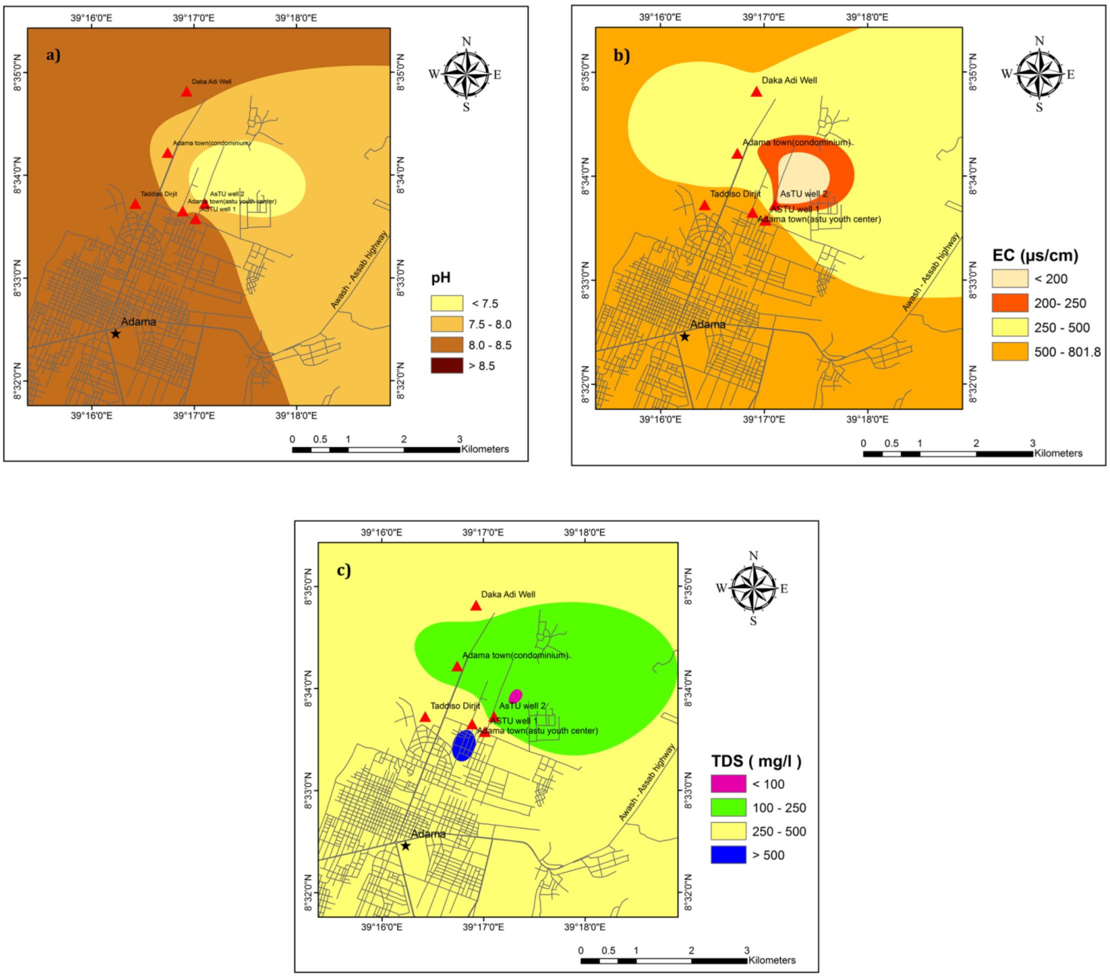

Figure 2. Spatial Variation: pH (a), EC (b) and TDS (c)

The source of high EC values in the study area might be agricultural activities and wastewater discharged from industries and cities (Amanial, 2015). Figure 2(c) shows the spatial variation map of TDS. The larger part of the study area has a TDS value of less than 500 mg/L and falls in the freshwater group except small areas found in the central part (BH4 kebele 03). BH4 kebele 03 shows brackish water type. Higher content of TDS is from the weathered media of the rock and longer residence time of groundwater in the aquifer (Rango *et al*., 2013; Mechal *et al*., 2017).

5.2 Chemical Characteristics of Ground Water

5.2.1 Major Cations

Calcium (Ca^{2+})

As per WHO (2011), the permissible limit for Ca^{2+} is 75 mg/L and 30 mg /L as a safer zone for drinking (Table 1). It is observed that most of the groundwater samples are found to be within the permissible limit of drinking water and fall in good groundwater quality zones except ASTU well 2 (Figure 3a). The possible source of high Ca^{2+} in samples from ASTU well 2 might be due to chemical and mineralogical composition of basic rocks through which it percolates.

Magnesium (Mg^{2+})

As per WHO (2011), the permissible limit for Mg^{2+} is 50 mg/L (Table 1). Spatially, Mg^{2+} in groundwater is above 50 mg/L in and around ASTU well 2 (Figure 3b). Basalt that contains ferromagnesian minerals such as olivine, pyroxenes, and amphibole are source of Mg^{2+} (Hem, 1985; Wagh *et al*., 2019a). On the basis of Mg^{2+} content, almost all the groundwater samples are suitable for drinking.

Sodium (Na^{+})

Sodium concentration is higher in ASTU Well 2. Deep percolating water from the topsoil layers could be a possible source of sodium due to longer residence time and water-rock interaction (Wagh *et al*., 2019b). Spatially, around ASTU Well 2 of the study area has greater than the desirable limit of sodium concentration in drinking water standard (Figure 3c).

Potassium (K^{+})

According to WHO'S standard, potassium concentration < 50 mg/L, 50-100 mg/L and > 200 mg/L is fall in a good zone, moderate zone and poor groundwater quality zones, respectively. Good zone and moderate zone are suitable for drinking purposes. The maximum concentration of potassium in groundwater samples of the study area is 31.5 mg/L (Table 1) which falls in the good zone. Spatial variation map of potassium shows that, groundwater samples fall in the good zone (Figure 3d).

5.2.2 Major Anions

Bicarbonate (HCO_3^{2-})

In the study area, bicarbonate concentration is high. Silicate and carbonate weathering process are sources of bicarbonate (Bala Krishna Prasad and Ramanathan, 2005). According to the WHO standard, HCO_3^{2-} < 100 mg/L is categorized as a poor zone which is suitable only for industrial activity. The larger part of the study area has HCO_3^{2-} concentration greater than 250 mg/L except for few areas in the Western part (Figure 3e). The possible source of HCO_3^{2-} could be the magmatic release of CO_2 by the active fault zones (Mechal *et al.*, 2017; Rango *et al*., 2010).

Chloride (Cl^{-})

The chloride concentration in groundwater of the study area below desirable limit except ASTU well 2 which is exceeding the maximum allowable limit of 200 mg/L (Table 1). The spatial distribution of chloride concentration in the groundwater of the study area is illustrated in Figure 3f. ASTU well 2 of the study area has a poor groundwater quality zone (Figure 3f). The possible source of chloride is agricultural activities and leachate from waste disposal sites.

Sulphate (SO_4^{2-})

The highest desirable limit of Sulphate in drinking water quality is 200 mg/L and 483 mg/L according to WHO, 2011 and Ethiopian standard, respectively. In the study area, most of the samples are found to be within the prescribed limit for drinking purposes except ASTU well 2 (Table 1). This high content of SO_4^{2-} in the basin might be associated with volcanic activity and lacustrine sediments (Ayenew, 2005; Kawo and Shankar, 2018).

Fluoride (F^{-})

The highest desirable limit of fluoride in drinking water quality is 1.5 mg/L and 3 mg/L according to WHO, 2011 and Ethiopian standards, respectively. Fluoride concentration in groundwater is within the desirable limit of WHO standards and Ethiopian standard in the study area (Table 1). Higher concentration of fluoride (1.5 mg/L) is observed at BH4 Kebele 03. The F^{-} in Ethiopian rift groundwater comes from acidic volcanic rocks such as tuffs, fluvio/volcano lacustrine sediments, pyroclastic deposits, ignimbrite and rhyolite (Furi *et al*., 2011; Haji *et al*., 2018).

5.3 Hydrogeochemical Facies

The dominant water type in the study area is Mixed Ca–Na–HCO_3 type facies type (Figure. 4). According to Kawo and Shankar (2018), Na/Ca–HCO_3 water is dominant in escarpment and Na–HCO_3 type of water is dominant in the rift floor. Ayenew, (2005) also reported that hot springs and groundwater in the rift valley has a Na–HCO_3 water type, with high Na^{+} and HCO_3^{2-} concentration. Haji *et al*., (2018), stated that a high concentration of fluoride which is related to Na–HCO_3 type of waters.

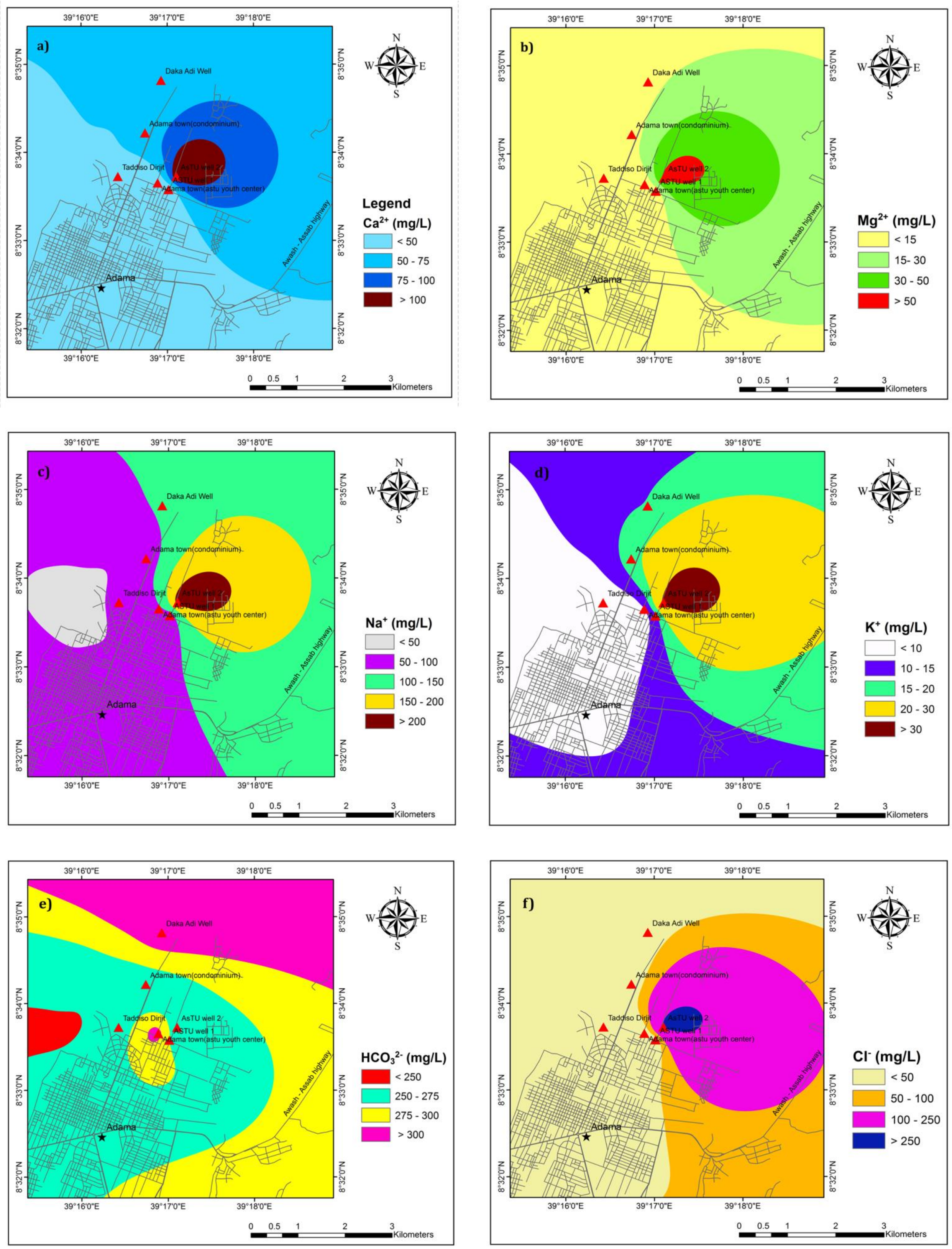

Figure 3. Spatial Variation: Ca^{2+} (a), Mg^{2+} (b), Na^{+} (c), K^{+} (d), HCO_3^{2-} (e) and Cl^{-} (f)

5.4 Suitability of Groundwater for Irrigation Purposes

Irrigation water quality indices such as Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), Sodium Percent (Na%) were used to investigate the suitability of groundwater. Higher concentration of dissolved ions in irrigation water has a negative effect on soil properties and decline productivity (Kaka *et al*., 2011; Li *et al*., 2011). Chemically, irrigation water should contain less dissolved ions and has no poisonous constituents (Shankar *et al*., 2011c).

Sodium Adsorption Ratio (SAR)

The SAR was used to evaluate the suitability of water for irrigation. It measures the proportion of sodium ions to calcium and magnesium in irrigation water (Kalra and Maynard, 1991). In this study, SAR was calculated using equation (equation (1)) (Richards, 1954).

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \qquad (1)$$

According to Richards, (1954) SAR <10, is considered excellent for irrigation (Table 2) and all the groundwater samples fall in the excellent water class. The calculated SAR value in the study area ranges from 2.3 to 7.4 and suitable for irrigation (Figure 5a).

Sodium Percentage (Na%)

High concentration of sodium in irrigation water reduces soil permeability and eventually causes soil to have poor internal drainage (Belkhiri and Mouni, 2012). Hence, it restricts air and water movements in the soil and this type of soils become hard when dry (Saleh *et al*., 1999). In this study, Sodium percentage was computed using equation (equation (2)):

$$Na\% = [(Na^{+}+K^{+})/(Ca^{2+}+Mg^{2+}+Na^{+}+K^{+})]\times 100 \qquad (2)$$

In the study area, the Na% ranges between 49.6 and 84.8 (Table 2). Na% indicates that around 70 % of samples fall in the field of the permissible limit. It was revealed from the analysis that the groundwater of doubtful and bad quality (ASTU well 1 and BH4 Kebele 03) was found 30% of the area (Figure 5b). Na% in irrigation water results in sodium accumulation and calcium deficiency in the soil. Therefore, good drainage, high leaching process and application of organic matter are possible solution to manage property of the soil (Beyene *et al*., 2019).

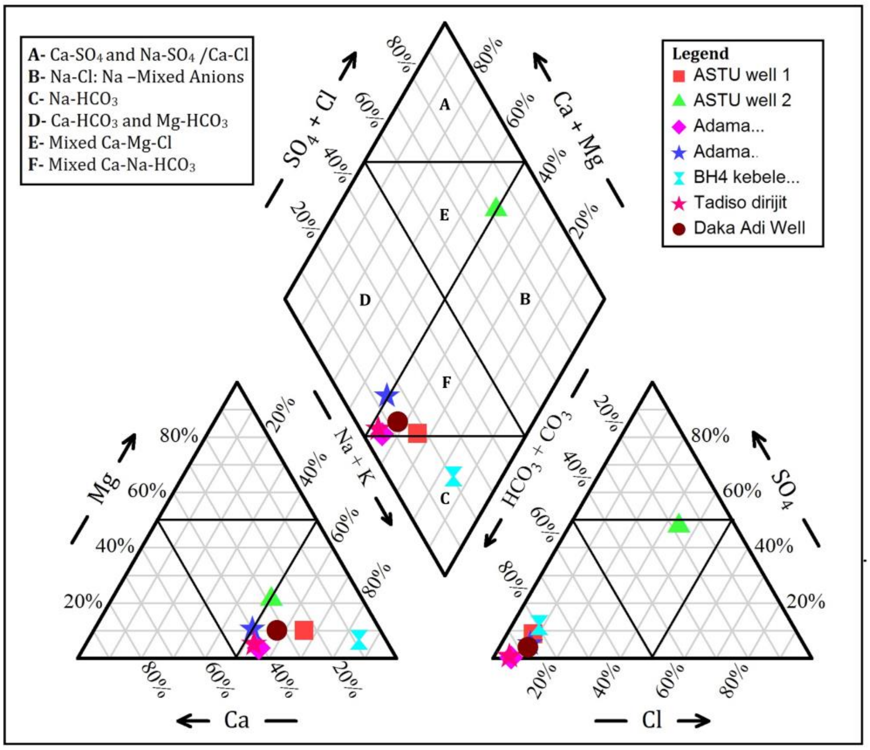

Figure 4. Hill piper plot

Table 2. Classification of groundwater samples for irrigation purposes

Parameters (meq/L)	Sample range			Range	Classification	Number of samples
	Min.	Max.	Average			
Alkalinity hazard (SAR) (Richards 1954)	2.29	7.36	3.64	< 10	Excellent	7
				10 – 18	Good	0
				18 – 26	Doubtful	0
				> 26	Unsuitable	0
Na% (Wilcox 1955)	49.57	84.81	59.36	< 20	Excellent	0
				20 – 40	Good	0
				40 – 60	Permissible	5
				60 – 80	Doubtful	1
				> 80	Unsuitable	1
RSC (Raghunath 1987)	-5.89	4.75	1.04	< 1.25	Good	2
				1.25 - 2.5	Doubtful	3
				> 2.5	Unsuitable	2

Residual sodium carbonate (RSC)

The high concentration of carbonate and bicarbonate in groundwater affects the suitability of groundwater for irrigation (Kawo and Shankar, 2018). High concentrations of bicarbonate in irrigation water causes precipitation of calcium and magnesium in the soil and the soils become more concentrated (Eaton, 1950; Srinivasamoorthy *et al*., 2014). The relative proportion of sodium in the water is increased in the form of sodium carbonate denoted as residual sodium carbonate (RSC) (Eaton, 1950; Ragunath 1987). In this study, RSC was calculated using equation (equation (3)):

$$RSC = \{(HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})\} \quad (3)$$

RSC more than 2.50meq/L of is unsuitable for irrigation purposes (Ragunath 1987). The results of RSC values show that 28.6% of the samples are fall in good quality whereas 42.9 % and 28.6 % of samples fall in the category of doubtful and unsuitable class, respectively (Table 2; Figure 5c) for irrigation purpose.

5.5 Water Quality Index (WQI)

Many researchers have been used WQI to map groundwater quality and its suitability for drinking purposes (Singh, 1992; Subba Rao, 1997; Avvannavar and Shrihari, 2008). In WQI the rating system was used for individual water quality parameters to determine the overall drinking water quality (Mitra *et al*., 2006; Sahu and Sikdar, 2008). In this study, the WHO (2011) guideline for drinking purpose was considered to calculate of WQI. pH, TH, TDS, major cations and anions were given weight (w_i) to compute WQI. The highest w_i was assigned to parameters that has a significant health effect. F^- was assigned the highest w_i followed by pH, TDS, TH, Ca^{2+}, Mg^{2+}, Na^+, and SO_4^{2-} as shown in Table 3. The least weight is assigned for chloride. Then, the relative weight (W_i) for each parameter is computed from the using (equation (4)). A quality rating scale (q_i) for each parameter also calculated using (equation (5)). Finally WQI is calculated using equation (equation (6)). Categories of WQI are presented in Table 4. The categories of WQI for each samples is represented in Table 5.

$$W_i = w_i / \Sigma^n_{i=1} w_i \quad (4)$$

$$q_i = (C_i/S_i) \times 100 \quad (5)$$

$$SI_i = W_i \times q_i \text{ and } WQI = \Sigma SI_i \quad (6)$$

where, W_i is the relative weight, w_i is the weight of each parameter, n is the number of parameters, q_i is the quality rating, C_i is the concentration of each chemical parameter in each water sample, S_i is the WHO standard for each chemical parameter, SI_i is the sub-index of i^{th} parameter.

WQI of the study area ranges between 51 and 114 (Table 5). The result of WQI indicates that 85 % and 15% of water samples fall in the category of good and poor water quality, respectively. The spatial distribution of WQI, (Figure 6) represents most of the regions with good quality groundwater. Except ASTU Well 2 which is fall in poor quality groundwater all other samples fall in good quality for drinking purposes.

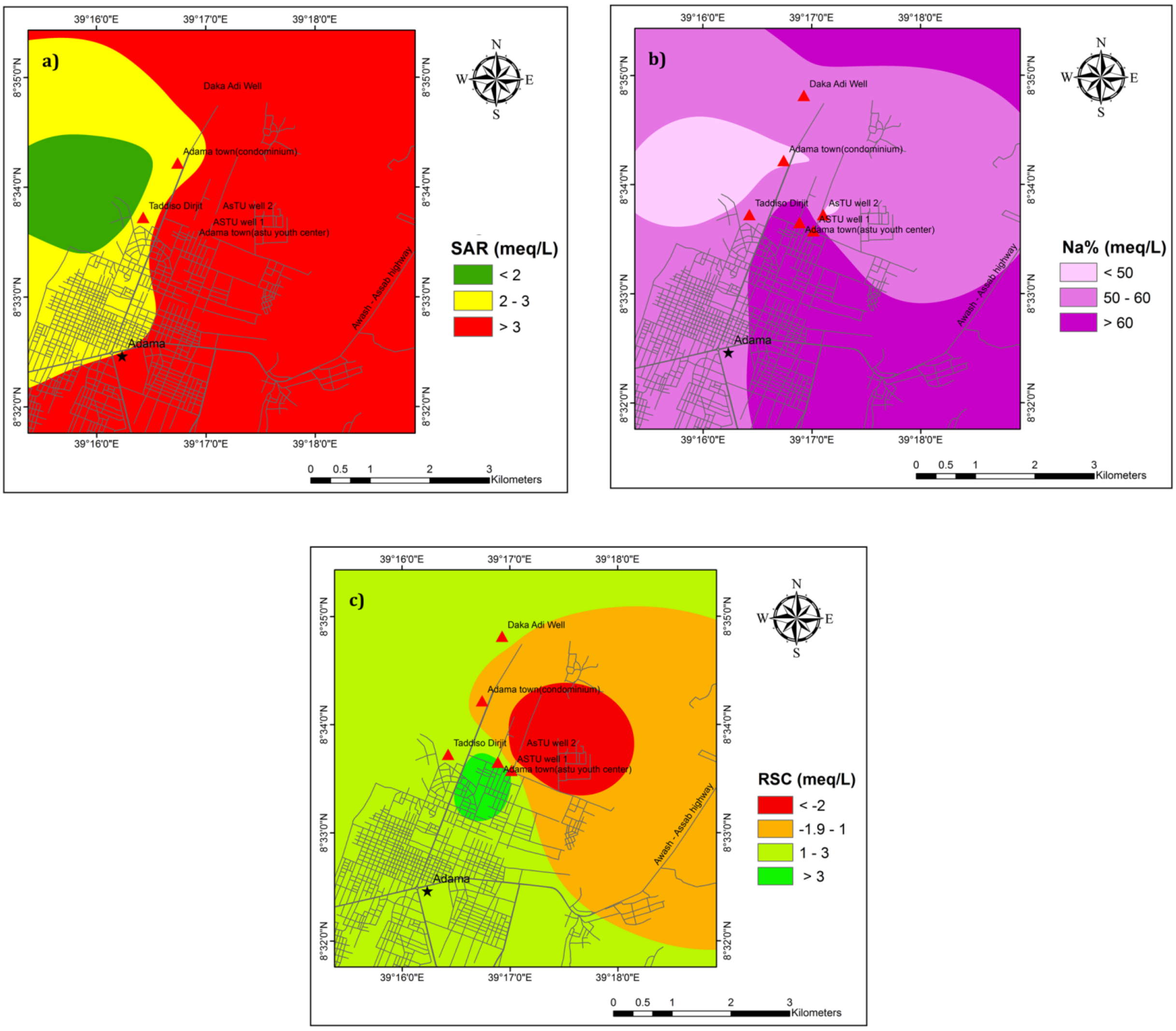

Figure 5. Spatial Variation: SAR (a), Na % (b), and RSC (c)

Table 3. Relative weight of chemical parameters

Chemical parameters	WHO (2011)	Weight (wi)	Relative weight
F^-	1.5	5	0.179
pH	6.5 - 8.5	4	0.143
TH	300	4	0.143
TDS	500	4	0.143
Ca^{2+}	75	3	0.107
Mg^{2+}	50	3	0.107
SO_4^{2-}	200	2	0.071
Na^+	200	2	0.071
Cl^-	250	1	0.036
		$\Sigma w_i = 28$	**$\Sigma w_i = 1.000$**

Table 4. Water Quality Index and their status of groundwater (Sahu and Sikdar, 2008)

Range	Type of water	Number of the samples	% of the samples
< 50	Excellent water	0	0
50 - 100	Good water	06	85
100-200	Poor water	01	15
200-300	Very poor water	0	0
> 300	Unsuitable	0	0

Table 5. Calculation of WQI for individual water samples

Well No.	Well Name	WQI	Classification
1	ASTU well 1	65	Good water
2	ASTU well 2	114	Poor water
3	Adama town (ASTU youth center)	60	Good water
4	Adama town (condominium)	59	Good water
5	BH4 kebele 03	78	Good water
6	Taddiso Dirjit	64	Good water
7	Daka Adi Well	51	Good water

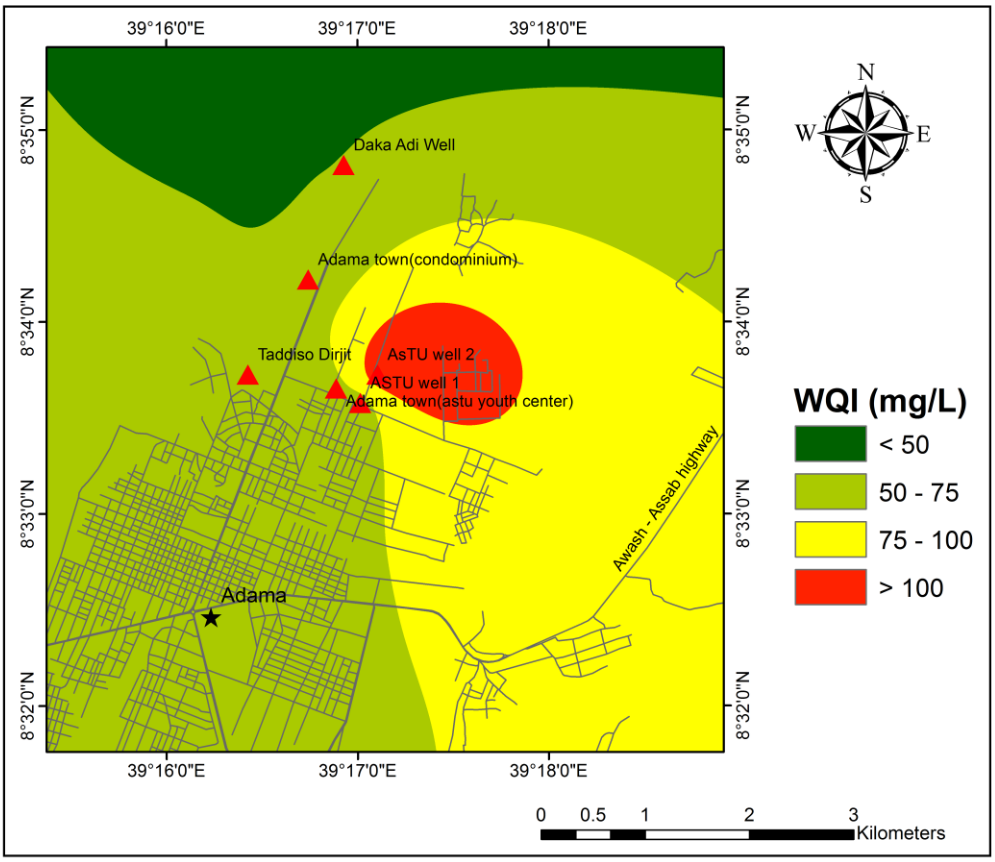

Figure 6. Spatial distribution of WQI

6 CONCLUSIONS

The present study was aimed at groundwater quality assessment using geospatial techniques in Northeast of Adama Town, Oromia Region, Ethiopia. The study draws out the following conclusions:

- The pH of groundwater samples indicate alkaline in nature. EC of groundwater samples are found within the Good limit of drinking and BH4 Kebele 03 is permissible limit. The TDS values within the desirable limit of drinking. BH4 Kebele 03 shows brackish water type.
- The concentration of Calcium, Magnesium, Sodium and Potassium are found within the desirable limit of drinking except ASTU Well 2.
- A larger part of the study area has HCO_3^{2-} concentration greater than 250 mg/L except for few areas in the western part.
- The chloride concentration in groundwater of the study area below the desirable limit except ASTU well 2 which is exceeding the maximum allowable limit of 200 mg/L.
- The Piper Trilinear diagram indicates that most of the groundwater samples fall in Mixed Ca–Na–HCO_3 types.
- The Na% indicates that around 70 % of samples fall in the field of the permissible limit. It was observed that doubtful and bad quality at ASTU well 1 and BH4 Kebele 03, respectively.
- The results of RSC values show that 28.6% of the samples are fall in good quality whereas 42.9% and 28.6% of samples fall in the category of doubtful and unsuitable class, respectively for irrigation purpose.
- The result of WQI indicates that 85% and 15% of water samples fall in the category of good and poor water quality, respectively. Except ASTU Well 2 which is fall in poor quality groundwater all other samples fall in good quality for drinking purposes.

Overall, groundwater quality parameters (major and trace elements) should be monitored in the central part of the study area to avoid problems related to human health and ensure socio-economic development in the area.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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ABBREVIATIONS

APHA: American Public Health Association**; ASTU:** Adama Science and Technology University; **EC**: Electrical Conductivity; **GIS:** Geographic Information System; **IDW:** Inverse Distance Weighting; **MER:** Main Ethiopian Rift; **RSC:** Residual Sodium Carbonate; **SAR:** Sodium Adsorption Ratio; **TDS**: Total Dissolved Solids; **TH**: Total Hardness; **UNDP:** United Nations Development Programme; **WHO**: World Health Organization; **WQI**: Water Quality Index.

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