Assessment of quality and suitability of groundwater resources for industrial and irrigation purposes, Dire Dawa, Ethiopia

Girmaye Haile Gebremikael[1,*] and Aman Hussien Dawod[2]

[1]Process, Environmental Engineering and Energy Chair, Institute of Technology, Dire Dawa University, Ethiopia
[2]Geomatics and Geoinformatics Chair, Institute of Technology, Dire Dawa University, Ethiopia

ABSTRACT

The groundwater demand of Dire Dawa has increased recently due to the expansion of irrigation and the industrial sector in the city. Groundwater used for irrigation and industry was studied. Eighty-two samples were used to analyze physicochemical using different indices like Langelier index (LSI), Ryznar index (RSI), Aggressive index (AI) and Larson-Skold index (LRI). Parameters of Sodium Absorption Ratio (SAR), Residual Sodium Carbonate (RSC), Dissolved Sodium (%Na), Magnesium hazard (%Mg) statistical and spatial distributions were analyzed and programmed with Excel, Arc GIS, and Diagrams software. Results showed that pH, Mg^{2+}, Cl^- were found to be within the limit for industrial use. The groundwater corrosion indices mean values of LSI, RSI, AI, and LRI obtained were 0.29 ± 0.28, 6.4 ± 0.5, 12.20 ± 0.24 and 1.4±1.57, respectively. LSI, RSI results indicated a moderate scale-forming tendency of the groundwater. AI values were within low to no corrosion rates in all zones. Because of Cl^- and SO_4^{2-}, LSI showed some localized corrosion properties at kebele 01 and 09. Parameters like pH, Conductivity, Na^+, HCO_3^- and Cl^- ion were within permissible limits for irrigation. The irrigation indices (meq/l); SAR, RCS, Na% and Mg Hazard were calculated to be 1.33, -2.17, 21.5%, 45%, respectively. The EC was within the permissible limit but was significant. The low values of SAR, RCS, Na% indicated that the groundwater can cause lower alkalization (Sodium hazard) effect. In conclusion, all the parameters of the groundwater sources were categorized as good for irrigation. However, corrosion indices elaborated the groundwater scaling problems and may also be aggravated with temperature and heat-related industrial equipment.

Keywords: Corrosion indices, Physicochemical, Scaling, Spatial
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*Corresponding author: grhaile@gmail.com; girmaye.haile@ddu.edu.et

INTRODUCTION

In Ethiopia, more than 80% of the drinking water supply is obtained from groundwater (Seifu Kebede *et al.*, 2018). In the case of Dire Dawa, an arid area where no perennial rivers and streams exist, groundwater is the primary source. For the last 12 years, boreholes, dug wells, and springs supplied almost 100% of the city's domestic, industrial, and irrigation water needs.

In addition to the ever-increasing demand for water in the area, deteriorating groundwater quality resources has become an issue from both public health and economic point of view despite the little attention is given to it in Ethiopia until recent times (WWDSE, 2004). Water naturally contains dissolved hardness-causing cations, iron, sodium, potassium and different anions such as chloride, sulphate, bicarbonate which corrode objects and form scales, poisons, and affect food and drink quality. What is contained in the water may also deteriorate soil quality and damage crops during irrigation. Corrosion and scaling of water is related to its pH, alkalinity, hardness, temperature, dissolved oxygen, total dissolved solids (TDS) and other factors. Langelier index (LSI), Ryznar stability index (RSI), and Aggressive index (AI) are the most commonly used corrosion indices in the waterworks, food and other industries.These indices give clues whether the water is corrosive or not. They also help to predict the tendency of the water to precipitate a corrosion protective salt coat (Singley *et al.,* 1984). On the other hand, the irrigation water quality can be determined by (a) salinity hazard, (b) permeability and infiltration problems, (c) specific element and ion toxicity measured with parameters like electrical conductivity (EC) and calculation of sodium absorption ratio (SAR), residual sodium carbonate (RSC), sodium percentage (SSP), and permeability index (PI). The effect on groundwater is an important issue to deal with quality and stability indices that can easily be calculated in monitoring, forecasting and controlling programs (Singley *et al.,* 1984; Singh and Chakradhar,1998).

Several researchers have investigated groundwater suitability for industrial and irrigation purposes using water stability and quality indices. However, extensive study has not been done on groundwater suitability and stability, and on corrosion and scaling potential in Ethiopia particularly in Dire Dawa. Gebremedhin Berhane *et al.* (2013) estimated the corrosiveness of groundwater at different localities in Mekelle. Alsaqqar *et al.* (2014) also evaluated water stability of groundwater in Baghdad City with two indices, namely Langelier and Ryznar index. They concluded that the treated water corrosiveness was related to low alkalinity and high total dissolved solids and warm temperature. Sabaghi *et al*. (2015) studied groundwater corrosion and scaling problems in irrigation hydraulic systems. They considered Langelier saturation index and Ryznar stability index to determine relative corrosiveness and low sedimentation in groundwater in their study. The results showed that the boreholes samples were more corrosive than springs. Yousefi *et al.* (2016) determined the corrosion and scale-forming potential of Ilam City-Iran surface water. The results showed that the corrosion was caused by low pH values. Coating and adjustment of water pH were recommended as a solution. Aghapur *et al.* (2009) examined the water suitability and stability in Urmia, Iran. The results indicated that the corrosiveness of water was related to the low level of hardness which may expose the water to be contaminated by dissolved heavy metals.

The suitability of groundwater for irrigation purposes was studied in many parts of Ethiopia as in Modjo, East Shawa (Karuppannan and Kawo, 2019), in Adama (Amanuel Gidey, 2018), and around Mekelle (Kawo and Karuppannan, 2018). Amanuel Gidey (2018) studied water quality for irrigation purposes around Mekelle City, northern Ethiopia with Conductivity (EC), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), % Na, Cl^-, HCO_3^- along with mapping these parameters with GIS. The study confirmed salinity hazard, hardness problem but no sodium and bicarbonate hazards in the samples. Karuppannan and Kawo (2019) used GIS interpolation and irrigation suitability indices of EC, RSC, SAR, and Na% to study groundwater suitability of Adama City. Most of the groundwater samples were excellent for irrigation because of low sodium content and TDS.

There are no studies that have been carried out in the Dire Dawa region about groundwater suitability for industrial and irrigation purposes. It is known that water is the primary and major input for irrigation and most industries. Investigating the groundwater suitability for such purposes with the help of water stability indices and irrigation suitability parameters is one key issue for Dire Dawa City, particularly for the industry and agriculture sectors. It gives information about groundwater quality and suitability. This study aimed to investigate the stability and suitability of Dire Daw city groundwater for the industry using quality tolerance standards, corrosion and scaling indices as well as to use irrigation water quality parameters to determine the suitability of the city's groundwater source for irrigation use. Many attempts have been made to develop an index, several of which were found useful for prediction purposes (McNeill and Edwards, 2001).

Corrosion and scaling processes are highly complex and interactive. Hence, no single test or index is good enough to indicate the corrosion or scale forming tendency of the water so, multiple indices are used for this purpose. The most widely used indices are Langelier saturation index (LSI), Ryznar index (RSI), aggressive index (AI) and Larson–Skold index (RSI). They can be calculated using the mathematical models involving water quality parameters and their interpretations (Tables 1 and 2) (Davil *et al.*, 2009; Yousefi *et al.*, 2016; Kumar, 2019). The Langelier index (LSI) shows the tendency of water to form scales and it is only conducive to control the calcium carbonate scales. LSI is most effective for waters containing alkalinity > 40 mg/L, sufficient calcium ion concentration, and pH between 6.5 and 9.5 (Langelier, 1946; McNeill and Edwards, 2001; Health Canada, 2009). The Ryznar stability index (RSI) was applied with a water velocity of 0.6 m/sec and for non-saturation water. RSI is scale thickness monitoring index (Prisyazhniuk, 2007). Aggressive Index (AI) only approximates the solubility of $CaCO_3$ and water acidity on corrosion effect. It is derived from calcium hardness, total alkalinity and pH (Kalyani *et al.*, 2017). AI shows TDS and temperature effects. Like AI, Larson and Skold index (LRI) was developed by Larson and Skold (1958) for examining the extent of corrosion based upon the aggressiveness of chlorides and sulphates in water and alkalinity as aggression reducer when it is exposed to steel with carbonic coat and cast-iron pipes (Singley *et al.*, 1984; Ryznar, 1994). LSI and RSI are mostly used to monitor scaling tendency and rate; whereas AI and LRI are used to monitor corrosion effect of water resources. The description of water quality indices for industry and irrigation is presented below (Tables 1 and 2).

Electrical Conductivity (EC) is related to the salt contents of groundwater that elevates the osmotic pressure of the soil solution. Soil with high osmotic pressure, the roots can only absorb insufficient water even if there is plenty of moisture in the soil. Sodium adsorption ratio (SAR) is used to express the activity of sodium ions in reactions with soil and the infiltration hazard which is a measure of water suitability for irrigation (Sappa *et al.*, 2014). The use of high SAR value water leads to a loss of the physical structure of the soil caused by excessive adsorbed sodium. This results in the dispersion of soil clay which then hardens and becomes compacted to smaller particles that clogs its pores. When soil is dry, it increasingly prevents water penetration and then swells when it gets wet (Saleh *et al*., 1999; Singh and Singh, 2008).

Both calcium and magnesium are precipitated as carbonates since the water in the soil becomes more concentrated as a result of evaporation and any residual carbonate or bicarbonate is left in the solution as residual and increased sodium carbonate (Mirza *et al.*, 2017).

Table 1. Summary of interpretation of Indices.

Index	**Index value**	**Interpretation**
Langelier Index	-4<LI<-2	Mild Corrosion
$\mathbf{LSI = pH - pHs}$		
$\mathbf{pHs}$ = (9.3+A+B)-(C+D)	-1<LI<-0.5	Low Corrosion
$\boldsymbol{A} = (\mathbf{log[TDS] - 1})/\mathbf{10}$	LI=0	Balanced
$\boldsymbol{B} = \mathbf{13.12} * (\mathbf{log\,T + 273}) + 34.55$	0.5<LI<2	Moderate Scale-forming
$\boldsymbol{C} = (\mathbf{log(Ca^{2+})} - \mathbf{0.4}$		
$\mathbf{D = log(TA)}$		
Ryznar Stability Index	RSI<5.5	Water has high scaling rate
	5.5 RSI<6.2	Water has scaling tendency
RSI = 2 pHs – pH	6.2 RSI<6.8	Water is balanced
	6.8<RSI<8.5	water dissolve Scale
	RSI>8.5	Water has corrosiveness
Larson-Skold Index	LRI <0.8	Scale formed without meditation of SO_4^{-2} & Cl^-
$\mathbf{LSI} = \frac{\mathbf{C_{cl^-} + C_{so4^{-2}}}}{\mathbf{C_{HCO_3^{-1}} + C_{CO_3^{-2}}}}$	0.8<LRI<1.2	Scale formed with meditation of SO_4^{-2} & Cl^-
	LRI >1.2	High rates of localized corrosion
Aggressive Index	AI<10	High water corrosion
$\mathbf{AI = pH + log[(TA)(HC)]}$	AI=10-12	Moderate water corrosion
	AI>12	Lack of water corrosion

TA- Total Alkalinity, HC-Calcium Hardness (mg/l as $CaCO_3$), T in ºC, TDS, C- Concentration, Ca^{2+}, Ccl^-, $C_{SO4}{}^{-2}$, C_{HCO3-}, $C_{CO3}{}^{-2}$ in mg/l

The water-soluble excess carbonate is also combined with alkaline earth ions to form the $NaHCO_3$. The magnesium hazard was proposed by Szabolcs and Darab (1964). Ca^{+2} and Mg^{+2} are in a state of equilibrium. At equilibrium, the more Mg^{2+} in groundwater adversely affects the soil quality and is considered to be harmful and unsuitable for irrigation (Kumar *et al.,* 2007).

Table 2. Interpretation of Irrigation Water Quality Analysis (Wilcox, 1955).

Parameters	Value and Interpretation
Electrical Conductivity (EC)	< 250 Excellent, 250-750 Good, 750-2000 Permissible, 2000-3000 Doubtful, > 3000, Unsuitable
Dissolved Sodium Ion, Na% $\% \mathbf{Na} = \frac{(\mathbf{Na} + \mathbf{K})}{\mathbf{Ca} + \mathbf{Mg} + \mathbf{Na} + \mathbf{K}} * \mathbf{100}$	< 20 Excellent 20-40 Good 40-60, Permissible 60-80 –Doubtful, > 80 Unsuitable
Sodium Absorption Ratio (SAR) $\mathbf{SAR} = \frac{\mathbf{Na}}{\sqrt{\mathbf{0.5} * (\mathbf{Ca^{2+}} + \mathbf{Mg^{2+}})}}$	0-6 Good, 6-9 Doubtful, > 9 Unsuitable
Residual Sodium Carbonate (RSC) $\mathbf{RSC} = (\mathbf{HCO_3^-} + \mathbf{CO_3^{2+}}) - (\mathbf{Ca} + \mathbf{Mg})$	0-6, Good, 6-9, Doubtful > 9, Unsuitable
Mg hazard $\mathbf{Mg\%} = \frac{\mathbf{Mg^{2+}}}{\mathbf{Ca^{2+}} + \mathbf{Mg^{2+}}} * \mathbf{100}$	< 50% Suitable, 50% Unsuitable

All ionic concentrations are in milliequivalent per liter (meq/L).

MATERIALS AND METHODS

Geographical description and sample collection

Dire Dawa is a city located in eastern Ethiopia between 804511 and 816913 m east and 1059754 and 1067650 m north. It is found 515 km from the capital city (Addis Ababa) and 311 km west of Djibouti. The mean annual temperature is 25.3 °C and the total rainfall is 618 mm (WWDSE, 2004). There are two rainy seasons which run from March to April (short rains), and from August to mid-September (long rains). The study area is characterized by arid climate with minor seasonal variations the whole year. The water wells were identified into six groups of the central area (kebele zone 04, 05, 06), Tome (kebele zone 03, 09), Sabian (kebele zone 01), Melka (kebele 02), Boren (kebele zone 01, 02) and rural area (kebele 10) where most of the borhole and hand dug wells exist. Just

15 groundwater samples were collected between November - January (dry season) in these selected areas (Figure 2).

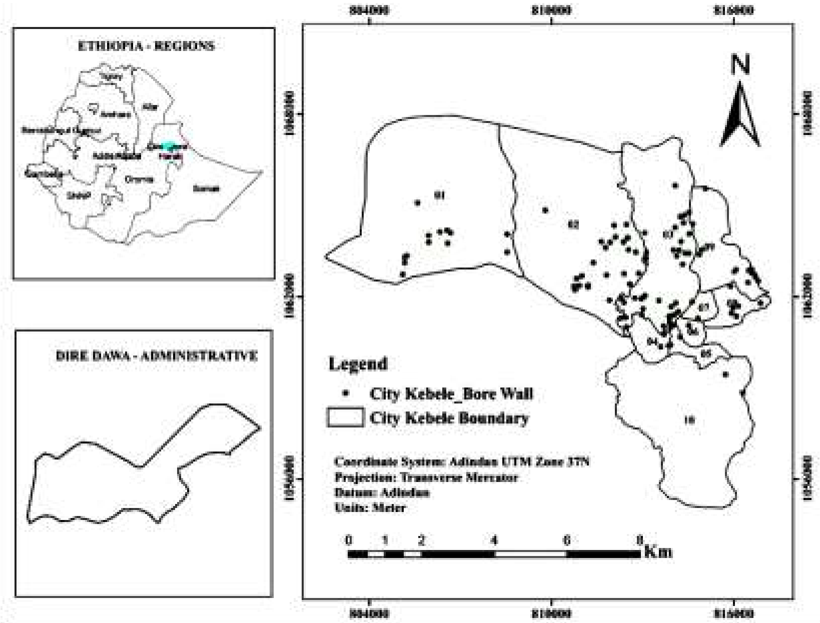


Figure 1. Location of groundwater wells, Dire Dawa, Ethiopia.

Physicochemical analysis techniques

The samples were collected with polyethylene bottles that were initially washed and rinsed with dilute acid and groundwater filtrates and kept in the refrigerator at 4 ºC until analysis. The various parameters were determined using standard procedures (APHA,1995). The physical parameter, such as temperature (T) Electrical Conductivity (EC) and Total Dissolved Solid (TDS) were measured in-situ using portable EC meter.

Chemical parameters of total alkalinity, total hardness, and anions of carbonate, bicarbonate, calcium, magnesium were measured by Acid and EDTA titration and calculation method. Sodium and potassium were measured with flame photometer and sulphate, chloride with spectrophotometer at Water Sanitation

Facility, Dire Dawa University and Dire Dawa Water Supply Authority (DDWSSA) chemistry laboratory.

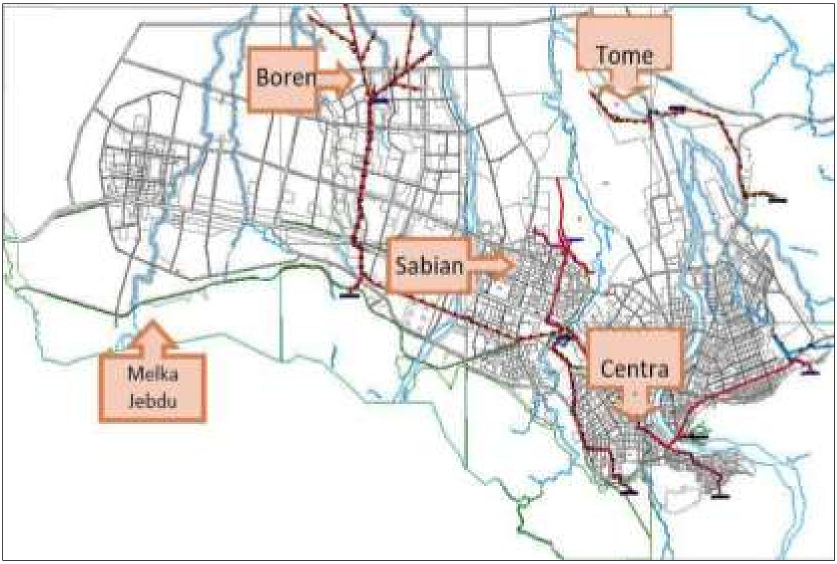


Figure 2. Location of sampled wells, Dire Dawa (WWSDE, 2004)

Additional secondary physicochemical data of 67 wells points, analyzed from 2004 to 2018, were used in this study. These were collected from Ethiopian Water Works Design and Supervision (WWDSE), geological Survey of Ethiopia, DDWSSA and other sources (WWDSE, 2004). data; Eyilachew Yitayew, 2010; WSSRD, 2012) GSE, 2018). For quality assurance, ionic (electrical) balances of the physiochemical data were calculated and checked with the acceptable limit (± 5-10%).

Water quality index and parameter determination

Langelier Saturation, Ryznar Stability, Larson-Skold, Aggressive and irrigation water quality parameters SAR, RSC, %Na, and Mg % of the 82 boreholes and dug wells were calculated using Microsoft Excel®. The Piper trilinear diagram and Wilcox Plot was done with Diagrams software.

Spatial distribution analysis

The city kebele zones boundary shapefile data was taken from the city administration. The collected spatial data of bore wells were downloaded using

DNR Garmin downloading software and changed into CSV file format to match with the calculated LSI, RSI, AI, LRI values of each sample point. Finally, the geocoded (address matching with other tabular data) brought into Arc GIS 10.3® software for spatial analysis. In the spatial analysis tool, an interpolation technique was used for analysing the geocoded index of each bore well. Among different interpolation techniques, most researchers used IDW and kriging interpolation techniques for analysing the spatial variation of water quality effects (Webster and Oliver, 2007; Srinivas *et al.*, 2013; Zarif *et al.*, 2014; Amanuel Gidey, 2018).

RESULTS AND DISCUSSION

Groundwater suitability for industry

Acidity (pH of water)

It is known that at high pH value (> 9), water tends to be less corrosive and also tends to stabilize around a pH of 6.5. Sarin *et al.* (2003) and Karalekas *et al.* (1983) observed that iron concentrations were found to steadily decrease when the pH rose from 6.2 to 9.5. These observations are consistent with the fact that the solubility of Lead, Copper and Nickle pipelines by-products decrease with increasing water pH. The mean values of groundwater acidity in different zones were between 6.7 and 7.2 that were in the desirable range (Singley, 1994; Reiber *et al*., 1996; Health Canada, 2009).

Total dissolved solids (TDS)

High amount of TDS in the groundwater increases conductivity and current flow. It consequently facilitates the electrochemical reaction in which the rate of corrosion may increase. The TDS may also affect the formation of protective films on pipe wall that act a barrier from any corrosion effects. The TDS in the eight kebele zones was higher than the limit (500 mg/l) and that was related to the excess calcium-based bicarbonate, sulphate and chloride (Sawyer and McCarty, 1967; WHO, 2003 a, b). According to related studies on the city groundwater, the existence of significant TDS of these ions in the groundwater was reported (WWDSE, 2004; Eyilachew Yitayew, 2010; Narayanan *et al.*, 2018). Excess TDS with above-mentioned ions result in excessive scaling in water pipes, water distribution and systems. It also interferes with many industrial processes like steel manufacture, causes foaming in boilers and incrustations on equipment especially as the temperature rises.

Sulphate and chloride
Kebele 08 had high sulphate concentration and kebele 10 high chloride. Chloride is the most active and corrosive ion (Jones, 1996). It also has an impact on the taste of food products and beverages prepared from such water (BIS, 1967). The limit of the chloride concentration is set to 200 mg/L (CPCB, 2008) that 87.7% of the samples were within the limit. The rest 12.3% had chloride content higher than the standard limit. Chloride (>200 mg/L) is very corrosive especially aggressive to steel and aluminium (WHO, 1979). These metals can be covered with copper, galvanized steel and cast iron to resist chloride salt corrosion (Shah *et al.,* 2018). The sulphate ion is the second most occurring ion (Table 3) in hard water after bicarbonate. During sugar production and concrete manufacturing, the sulphate ion is limited to 20 mg/L since it can form strong acids that result in the undesired pH change that lower product quality. Excess sulphate precipitates and interferes with the efficiency of dyeing operations in leather, textile and finishing industries (CPCB, 2008; Shah *et al.*, 2018). High levels of bicarbonate, sulphate, and chloride cause incrustation and corrosion. To avoid incrusting under low pH, the limit of the sulphate ion was 100 mg/L (Anon, 1983). Only 35.4% of the samples were above the limit that calcium sulphate scale might exist. Excess sulphate salts (>250 mg/L) were also found on 18.3% of the groundwater that sulphate-reducing bacteria may be involved in the tuberculation of metal pipes. The hydrogen sulphide produced by these bacteria may increase corrosion in both metal and concrete pipes (Sawyer and McCarty, 1967; Anon, 1983; Aiman and Enab, 2007).

Corrosiveness and scaling indices

Langelier and Ryznar indices
Langelier index (LSI), not a quantitative, is the most frequently used index for assessing the water stability mostly related with $CaCO_3$ content. The Langelier saturation index values in all zones ranged from -0.37 to 0.98. According to LSI presented, majority of the samples (95%) were supersaturated which tended to form scale from low to moderate rate. The groundwater had scale-forming tendency as in most part, shown in Figures 4a, b. The highest values obtained (most scale-forming) were related to north- central (kebele zone 02) whereas the north-west part of the city (part of kebele zone 03) had corrosive groundwater.

Table 3. Mean values of the water quality parameter analysis of kebele zones of the city.

Study zones Hardness	**T**	**pH**	**TDS**	**Na^{+}**	**Ca^{2+}**	**Mg^{2+}**	**Cl**	**HCO_3**	**SO_4^{-2}**	**Total**	**Alkalinity**
01-Melka Jebdu	28	7.1	1483	89	158	54	121	448	379	618	383
02-Sabian	31	6.9	1724	79	336	76	75	399	821	1123	329
03 Kezira	33	6.8	1934	75	438	49	55	373	1110	1296	306
04-Ganda Kore	38	6.9	680	40	181	44	79	537	115	638	440
05-Addis Ketema	39	6.9	715	61	158	37	90	483	78	550	400
06-Dacha-tu	37	7.2	1892	80	288	144	60	371	1086	1320	304
07-Afatessa	25	6.7	1653	66	251	75	61	392	682	945	319
08-Laga Harre	36	7.1	1551	259	232	9	278	451	401	617	370
09-Police Meret	26	7.1	2061	90	212	65	223	409	145	796	306
10-Boren	29	6.7	2800	110	568	91	15	303	1809	1800	248

Measuring unit of each parameter – T-Temperature (°C), TDS (mg/l), Ca^{2+} (mg/l), Mg^{+}, Cl^{-} (mg/l), CO_3^{-} (mg/l) SO_4^{-2} (mg/l), Na^{+} (mg/l), TH-Total Hardness (mg/l as $CaCO_3$) and AL- Alkalinity (mg/l as $CaCO_3$)

Ryznar (1994) proposed a modified version of LSI based on pH and pHs values of water was successful to be an improvement over the LSI (Kumar, 2019). The results better quantified the scaling properties of water in numerical value. The Ryznar index values in all kebele zones were in the range of 5.60 to 7.29. More than half of the boreholes and dug wells (59.7%) had scaling tendency and 20.8% of groundwater points had no corrosion and scaling effects (balanced). However, 19.5% of the groundwater points were corrosive. The Ryznar index showed relative scale-forming groundwater in the north-central and southern regions (Figure 4b).

Aggressive index

AI is a parameter of water corrosiveness which is often used as an alternative method for LSI. As with LSI, the AI is not a quantitative measure of corrosion. The mean values of the aggressive index in all zones ranged from 11.59 to 12.93. Much of the groundwater data (87%) was nonaggressive (AI greater or equal 12). The others, i.e., 8% exhibited low corrosion rate ($11.5<AI<11.9$) and 5% moderate ($10<AI<11.4$) rate. The maximum values of the index were related to the city north-western part. Based on this index, the groundwater points varied from nonaggressive to moderate corrosion effect to asbestos-cement pipes and water systems in almost all zones as shown in Figure 5(a).

Larson-Skold index

The groundwater had high calcium and alkalinity (bicarbonate) possessing high buffering capacity (Davil *et al.*, 2009; Kumar, 2019). The groundwater aggressiveness containing sufficient buffering capacity and alkalinity is due to the increase in chloride and sulphate (Larson and Skold, 1958). This index is associated with corrosion of steel, iron-cast pipes and leaching lead, copper, tin into the water.

The Larson index values in all zones ranged from 0.09 to 6.03 indicating the formation of protecting film in most of the study areas. Moreover, in northwestern (kebele 01) and northeastern (kebele 03 and 09) region high corrosion was observed and localized severe corrosion was observed in south of Melka Jebdu. High levels of chloride and sulphate were observed in these areas. These are probably because these zones were inhabited and settlements were old and therefore chlorides and sulphates were expected because of poor waste management.

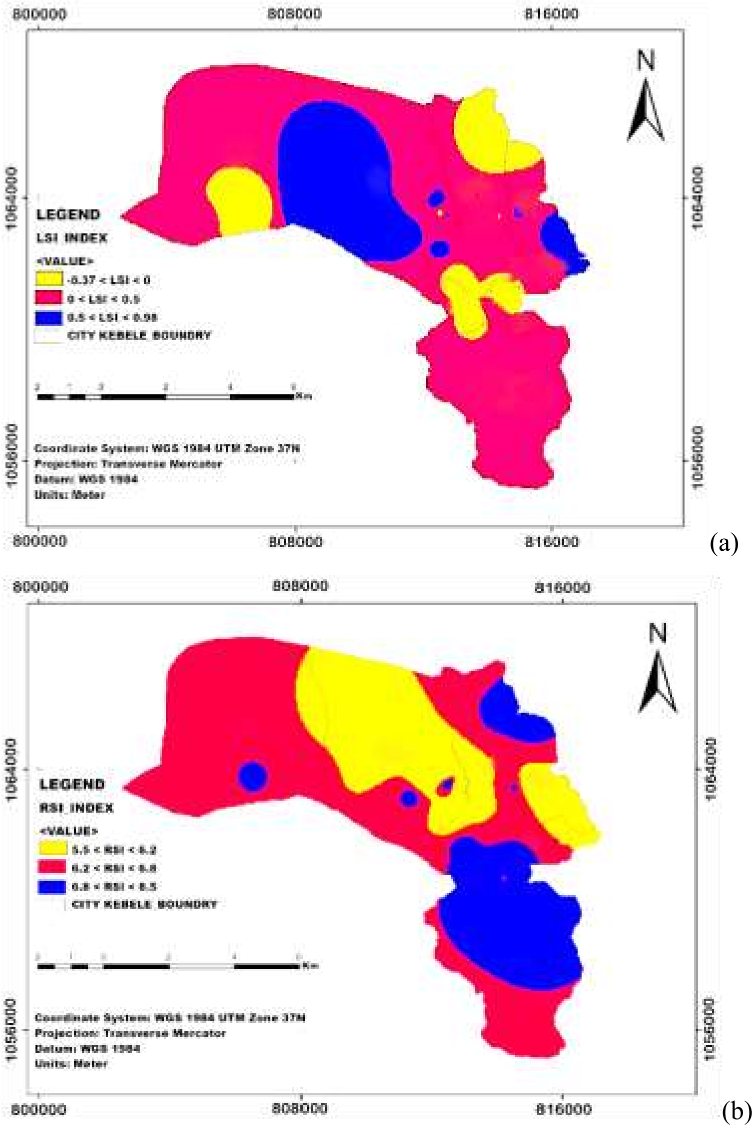
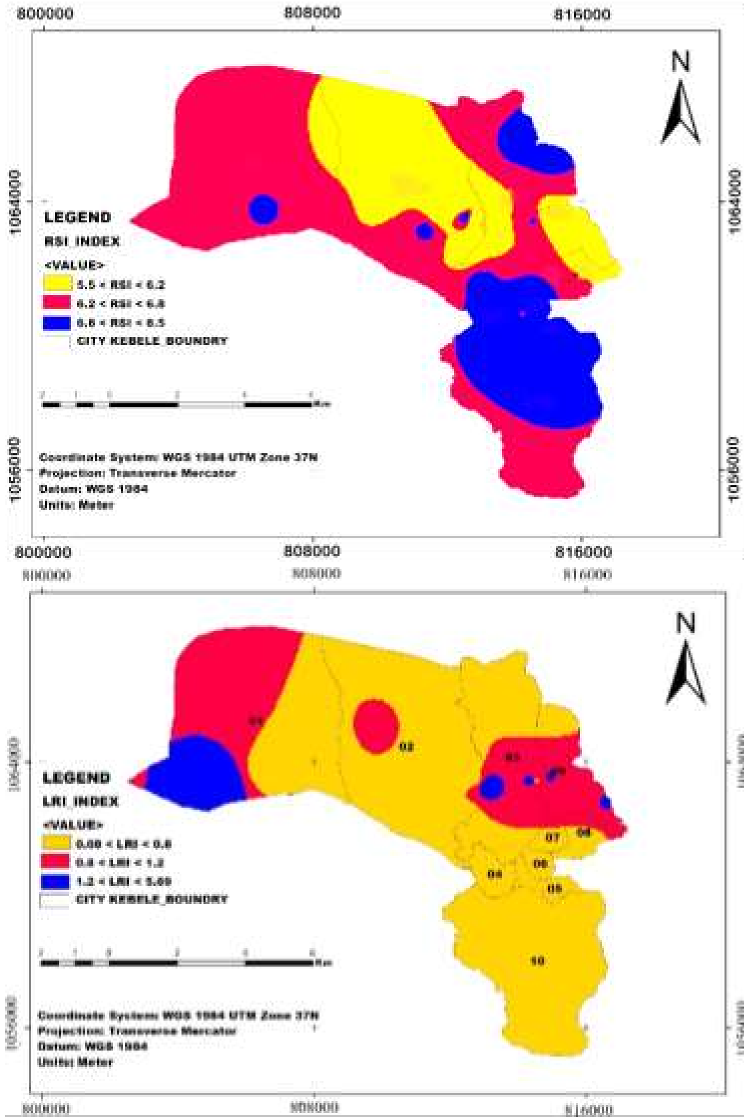


Figure 4. Maps of spatial changes (a) LSI (b) RSI of Dire Dawa groundwater.



(a)

(b)

Figure 5. Maps of spatial changes of (a) AI (b) LRI of groundwater of Dire Dawa.

Suitability for irrigation

Salt hazard

Acidity of water (pH), conductivity, TDS, sodium, bicarbonate, alkalinity, sulphate and chloride ion also lead to loss of soil fertility and crop yield productivity (Kirda, 1997). Both EC and TDS indicate saline groundwater that is completely dissociated ions. More dissolved ions content in irrigation water has negative effect on productivity (Kaka *et al.*, 2011). During irrigation, the excess salt content in the groundwater increases the osmotic pressure of the soil in which insufficient water is absorbed by the roots even under plenty of moisture (Ravikumar *et al*., 2011).

Based on the electrical conductivity (Wilcox, 1955) salinity hazard occurs when EC > 3 dS/m. EC ranged from 466 to 2380 μScm^{-1} that indicated majority of the groundwater sources (94.7%) were within the permissible level in the study area (Table 4).

The acidity of water (pH) also has an impact on the reaction and quality of the soil and water, and hence on plant growth. The pH influences the carbonate equilibrium, heavy metal and other ions in the soil. Acidic water interferes with mineral absorption than basic one which improves the uptake of crucial ions.

The permissible limit of pH groundwater for irrigation is between 6.0 and 8.5 (Ayers and Westcot, 1985). The observed pH values of all groundwater samples were found to be within the limit (Table 4). The average pH of 7.4 means that the dissolved materials were predominant bicarbonates, indicating alkaline nature of the groundwater. Chloride is another common ion in irrigation water. It can cause toxicity to sensitive crops at higher levels. Chloride content below the limit of 140 mg/l (BIS, 1991) is categorized as good quality. Chloride content of 95.5% of the samples was within the permissible limit.

In warm temperatures, high content of calcium and magnesium bicarbonates precipitated into insoluble minerals leaving sodium bicarbonate dominant (Eaton, 1950; Srinivasamoorthy *et al*., 2014). Eighty-seven percent of the wells had bicarbonate content within the permissible limit (< 500 mg/l) for irrigation (Ayers and Westcot, 1985).

Alkali hazard

A high percentage of Na^{+} in relation to Ca^{2+}, Mg^{2+} and K^{+} in irrigation water deflocculates and impairs soil permeability (Saleh *et al*., 1999; Singh and Singh, 2008). An important water quality parameter known as Sodium Absorption Ratio (SAR) is used in the supervision of sodium-affected soils (Alagbe, 2006; Sappa *et al.*, 2014). Continuous irrigation with such water may result in the accumulation of Na^+ compared to divalent ions. This increases the proportion of sodium in groundwater in the form of sodium carbonate (Mirza *et al.*, 2017) as indicated by Residual Sodium Carbonate (RSC). All groundwater samples showed negative RSC values that both carbonate and bicarbonate concentrations were consistent with Ryzan Saturation Index results. Based on the criteria of Sodium Solubility (Na%), SAR, RSC and Mg Hazard, the groundwater samples were good for irrigation purposes (Table 5).

Permeability/ infiltration problems

The city is covered with soil of moderately permeable sandy/alluvial deposit (Hydraulic conductivity of 3-5 m/day) directly overlaid on the main sandstone and limestone aquifer (WWDSE, 2004). This increases the proportion of sodium in groundwater in the form of sodium carbonate (Mirza *et al.*, 2017) as indicated by Residual Sodium Carbonate (RSC). All groundwater samples showed negative RSC values that both carbonate and bicarbonate concentrations were consistent with Ryzan Saturation Index results. On the criteria of Sodium Solubility (Na%), SAR, RSC and Mg Hazard, the groundwater samples were good for irrigation purposes (Table 5).

Table 4. Statistical details of the physicochemicals of the groundwater.

Parameters	Maximum	Minimum	Mean	Standard deviation
EC	2380.0	466.0	1017.5	279.3
PH	8.1	6.7	7.4	0.3
Na, mg/l	240.0	6.0	65.3	60.5
K, mg/l	4.5	0.8	1.9	1.0
Ca, mg/l	302.4	60.0	140.5	42.2
Mg, mg/l	75.4	4.9	24.3	16.8
Cl, mg/l	298.1	23.1	85.5	58.2
HCO_3, mg/l	610.0	187.9	423.3	86.3
SO4, mg/l	65.2	5.3	88.1	147.0
SAR	8.9	0.2	1.9	1.8
RCS	4.4	-13.2	-2.1	2.5
Na %	67.5	3.1	22.0	13.4
Mg Hazard	46.6	8.7	21.5	11.0

Permeability/ infiltration problems

The city is covered with soil of moderately permeable sandy/alluvial deposit (Hydraulic conductivity of 3-5 m/day) directly overlaid on the main sandstone and limestone aquifer (WWDSE, 2004). High concentration of sodium in irrigation water reduces soil permeability and eventually causes poor internal drainage (Belkhiri and Mouni, 2012). Hence, the soil becomes hard when dry and restricts the movement of water and air (Saleh *et al.*, 1999). After continuous use of irrigation water, soil permeability is drastically affected by Na, Ca, Mg and bicarbonate contents in the water (Wilcox, 1955; WHO, 1989). Water type based on Wilcox's (1955) diagram used when the SAR and conductivity of water are known, the classification of water for irrigation can be determined by graphically plotting these values on the Wilcox's diagram (Figure 7).

Table 5. Categorize of the irrigation groundwater suitability.

Parameter	**No of samples**	**Percent of samples**	**Water class for irrigation**
EC (μScm^{-1})	5	13.2	Good
	33	81.6	Permissible
	2	5.3	Doubtful
% Na	33	91.6	Good
	3	7.8	Permissible
	1	2.6	Doubtful
SAR (meq $L^{-1/2}$)	38	100.0	Good
RSC (meq L^{-1})	35	92.7	Good
	3	7.3	Doubtful
% Mg Hazard	38	100.0	Suitable

The Wilcox diagram (Richards, 1954) illustrates that most of the groundwater samples in the field C3S1 had high salinity and low alkaline, which could be used for irrigation for almost all types of soil (Figure 7). Most of the groundwater points (Figure 7) indicated that the values of SAR between 0-3 $meq^{1/2}/l$ and EC of 719-2380 μcms^{-1} was classified suitable for irrigation with medium restriction with low permeable soil. It could be applied for soils with moderate to high permeability values like Dire Dawa with moderately permeable sandy soil (WWDSE, 2004) with no restriction.

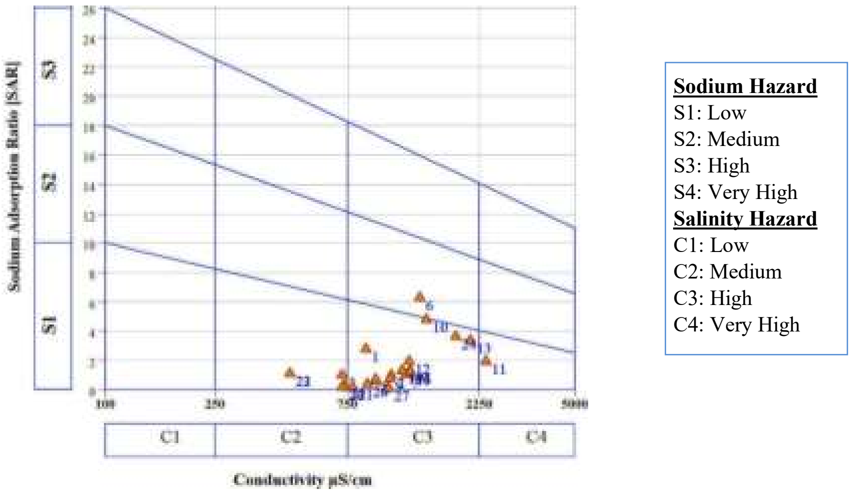


Figure 7. Wilcox plot of classification of irrigation groundwater.

CONCLUSION

The suitability of groundwater of an area should be studied and understood for domestic, irrigation and industrial purposes. The assessment of all the groundwater samples collected from Dire Dawa showed that parameters of pH, sodium, potassium, magnesium and chloride are within the permissible range. In contrast, TDS, total hardness, sulphate, and calcium were above the standard limit. These results were also shown on the piper diagram, that the dominant groundwater type in the city was Ca-HCO_3 followed by Ca-Mg-HCO_3 and Ca-Mg-HCO_3-SO_4. Based on TDS, 85% of the groundwater could cause encrustation and corrosion. The hardness revealed that the city groundwater sources varied from hard to very hard. The mean values of the five indices were 0.29 ± 0.28 for LSI, 6.4 ± 0.5 for RSI, 2.06 ± 0.25 for LRI and 12.20 ± 0.24 for AI. LSI, RSI indicated medium scaling formation from calcium, carbonate and sulphate-based hardness in most of the areas. As per LRI and AI, serious localized corrosion was also presented in Tome (north of kebele 03 and 09) and Melka Jebdu (south kebele 01) due to high content of both chloride and sulphate. As to the groundwater suitability of rural areas for irrigation, the content of significant electrical conductivity (EC) had shown a risk of salt-related problems but no risk of alkaline effects because of low SAR, RSC and Na% values. The groundwater use for irrigation had minor risk of salts, especially for sensitive crops. However, the majority of samples received from groundwater were found to be “suitable” on the basis of EC, SAR, Na%, RSC and Mg Hazard evaluation.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest in relation to this article.

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REFERENCES

Aghapur, A., Mohamadi, A and Boini, A. (2009). The study of corrosion and scale-formation of output water of no.1 treatment center of Urmia City. In**: 12th National Conference of Environmental Safety**, pp.16, Iran.

Aiman, E.A and Enab, M.A. (2007). Assessment of tap water resource quality and its potential of scale formation and corrosivity in Tafila Province, South Jordan. *Desalination* **206**: 322- 332.

Alagbe, S. (2006). Preliminary evaluation of hydrochemistry of the Kal-ambaina formation, Sokoto Basin, Nigeria. *Environmental Geology* **51**: 39.

Alsaqqar, A.S., Khudair, B.H and Ali, S.K. (2014). Evaluating water stability indices from water treatment plants in Baghdad city. *Journal of Water Resource Protection* **6**(14): 1344–1351.

Amanuel Gidey (2018). Geospatial distribution modeling and determining suitability of groundwater quality for irrigation purpose using geospatial methods and water quality index in Northern Ethiopia. *Applied Water Science* **8**(3): 1–16.

Anon. (1983). **Groundwater and Wells**. Johnson Division, 1st ed., Jain brothers. 450 pp.

APHA (1995). Standard methods for the examination of water and wastewater. American Public Health Association, Washington, MWWA & WPCF.

Ayers, R.S and Westcot, D.W. (1985). Water Quality for Agriculture. **FAO Irrigation and Drainage Paper**, pp.29.

Belkhiri, L and Mouni, L. (2012). Hydrochemical analysis and evaluation of groundwater quality in El Eulma area, Algeria. *Applied Water Science* **2**: 127–133.

BIS (1967). Quality tolerances for water for processed food industry- IS 425, Water Section Committee, New Delhi. https://archive.org/details/gov.in.is.4251.1967/page/n3/mode/

BIS (1991). Guidelines for the quality of irrigation water- IS:10500, Irrigation Equipment sectional Committee, New Delhi. https://www.indiawaterportal.org/articles (accessed june, 2019)

CPCB (2008). Use based classification of surface waters in India. In: Guidelines for water quality management. Central Pollution Control Board (CPCB), Parivesh Bhawan, Delhi.

Davil, M.F., Mahvi, A.H., Norouzi, M., Mazloomi, S., Amarluie, A and Tardast, A. (2009). Survey of corrosion and scaling potential produced water from Ilam water treatment plant. *World Applied Sciences Journal* **7**: 1–6.

Eaton, F.M. (1950). Significance of carbonates in irrigation waters. *Soil Science* **69**: 123–134.

Eyilachew Yitayew Abate (2010). Anthropogenic impacts on groundwater resources in Dire Dawa, Ethiopia. MSc Thesis, University of Oslo. https://www.duo.uio.no/handle/ 10852/ 12524?show=full, (accessed in Jan 9, 2019).

Gebremedhin Berhane, Tesfahunegn Abera and Solomon Gebreselassie (2013). Implications of groundwater quality to corrosion problem and urban planning in Mekelle area, Northern Ethiopia. *Momona Ethiopian Journal of Science (MEJS)* **5**(1): 51–70.

GSE (2018). Hydrogeological and hydrochemical maps of Dire Dawa NC 37 – 12 Sheet, Explanatory Notes. Geological Survey of Ethiopia, Groundwater Resources Assessment, Addis Ababa.

Health Canada (2009). Guidance on Controlling Corrosion in Drinking Water Distribution Systems, Ministre of Health, Ottawa, Ontario. Available at www.healthcanada.gc.ca, (Retrieved in Septemeber, 2019).

Jones, D.A. (1996). **Galvanic corrosion. In: Principles and Prevention of Corrosion.** Upper Saddle River, NJ: Prentice Hall.

Kaka, E.A., Akiti, T.T., Nartey, V.K., Bam, E.K.P and Adomako, D. (2011). Hydrochemistry and evaluation of groundwater suitability for irrigation and drinking purposes in the southeastern Volta river basin: Manya Krobo area, Ghana. *Elixir Agriculture* **39**: 4793-4807

Kalyani, D.S., Rajesh, V., Reddi, E.U.B., Kumar, K.C and Rao, S.S. (2017). Correlation between corrosion indices and corrosiveness of groundwater: A study with reference to selected areas of Krishna District, Andhra Pradesh, India. *Environmental Earth Sciences* **76**: 568

Karalekas, P.C., Ryan, C.R and Taylor, F.B. (1983). Control of lead, copper, and iron pipe corrosion in Boston. *Journal American Water Works Association* **75**(2): 92–95.

Karuppannan, S and Kawo, N. (2019). Groundwater quality assessment using geospatial techniques and WQI in North East of Adama Town, Oromia Region, Ethiopia. *Hydrospatial Analysis* **3**(1): 22–36.

Kawo, N and Karuppannan, S. (2018). Groundwater quality assessment using water quality index and GIS technique in Modjo River Basin, central Ethiopia. *Journal of African Earth Sciences* **147**: 300–311.

Kirda, C. (1997). Assessment of irrigation water quality. Economic aspects of water management in the Mediterranean basin, pp. 367-377. CIHEAM - Options Mediterranean: Series A, № 31, Mediterranean Seminars. http://om.ciheam.org/article.php?IDPDF=CI971550 (Accessed February, 2020).

Kumar, M., Kumari, K., Ramanathan, A.L and Saxena, R. (2007). A comparative evaluation of groundwater suitability for irrigation and drinking purposes in Punjab, India. *Environment Geology* **53**: 553–574.

Kumar, P.J.S. (2019). Assessment of corrosion and scaling potential of the groundwater in the Thanjavur district using hydrogeochemical analysis and spatial modeling techniques. *SN Applied Sciences* **1**: 395.

Langelier, W.F. (1946). Chemical equilibria in water treatment. *Journal of American Water Works Association* **38**: 169.

Larson, T.E and Skold, R.V. (1958). Current research on corrosion and tuberculation of cast iron. *Journal of America Water Works Association* **50**(11): 1429–1432.

McNeill, L.S and Edwards, M. (2001). Review of iron pipe corrosion in drinking water distribution systems. *Journal of American Water Works Association* **93(7)**: 88-100.

Mirza, A.T.M., Rahman, T., Saadat, A.H.M., Islam, M.S and Abdullah, A.M.A.S. (2017). Groundwater characterization and selection of suitable water type for irrigation in the western region of Bangladesh. *Applied Water Science* **7**: 233–243.

Narayanan, K., Mesfin Sahele and Moltot Zewdie (2018). Assessment of groundwater nitrate level and source of pollution in Dire Dawa, Eastern Ethiopia. *Resources and Environment* **8**(4): 185–197.

Panaskar, D.B., Wagh, V.M and Muley, A.A. (2016). Evaluating groundwater suitability for the domestic, irrigation, and industrial purposes in Nanded Tehsil, India, using GIS and statistics. *Arab Journal Geoscience* **9**: 615.

Prisyazhniuk, A.V. (2007). Prognosticating scale-forming properties of water. *Applied Thermal Engineering* **27**(8): 1637-1641.

Ravikumar, P., Somashekar, R and Angami, M (2011). Hydrochemistry and evaluation of groundwater suitability for irrigation and drinking purposes in the Markandeya River basin, India. *Environment Monitoring Assessment* **173**: 459–487.

Reiber, S.H., Ryder, R.A and Wagner, I. (1996). **Corrosion assessment technologies. In: Internal corrosion of water distribution systems**. 2nd edn. American Water Works Association, Denver, CO. pp. 445–486.

Richards, L.A. (1954). Diagnosis and improvement of saline and alkali soils. Agri. Handbook 60. U.S. Department of Agriculture, Washington, DC, 160.

Ryznar, J.W. (1994). A new index for determining the amount of calcium carbonate scale formed by water. *Journal American Water Works Association* **36**: 472–494.

Sabaghi, M.M., Sedghi, H., Babazade, H and Khosrojerdi, A. (2015). Studying groundwater corrosion and sedimentation in irrigation hydraulic systems case study: Rafsanjan plain. *Bulletin Environment Pharmacol Life Science* **4**: 155–161.

Saleh, A., Al-Ruwaih, F and Shehata, M. (1999). Hydrogeochemical processes operating within the main aquifers of Kuwait. *Journal Arid Environment* **42**: 195–209.

Sappa, G., Ergul, S and Ferranti, F. (2014). Water quality assessment in Central Italy: a case study for irrigation and drinking purposes. *Applied Water Science* **4**: 115–128.

Sarin, P., Clement, J.A., Snoeyink, V.L and Kriven, W.M. (2003). Iron release from corroded, unlined cast-iron pipe. *Journal American Water Works Association* **95**(11): 85–96.

Sawyer, C.N and McCarty, P.L. (1967). **Chemistry for sanitary engineers**. 2nd edn., McGraw-Hill, Toronto.

Seifu Kebede, Addisu Hailu, Crane, E., Dochartaigh, Ó and Bellwood-Howard, B.É. (2018). Africa groundwater atlas: Hydrogeology of Ethiopia. British Geological Survey, Retrieved (September, 2019) from http://earthwise.bgs.ac.uk.

Shah, M., Sircar, A., Shaikh, N., Patel, K., Thakar, V., Sharma, D., Sarkar, P and Vaidya, D. (2018). Groundwater analysis of Dholera geothermal field, Gujarat, India. *Groundwater Sustainable Development* **7**: 143–156.

Singh, I.B and Chakradhar, B. (1998). Effect of pH and hardness on the scale formation of mild steel in bicarbonate ion containing water. *Corrosion and Its Controls* **97**: 1009-1012.

Singh, V and Singh, U.C. (2008). Assessment of groundwater quality of parts of Gwalior (India) for agricultural purposes. *Indian Journal of Science and Technology* **1**(4): 1–5.

Singley, J.E. (1994). Electrochemical nature of lead contamination. *Journal American Water Works Association* **86**(7): 91–96.

Singley, J.E., Beaudet, B.A and Markey, P.H. (1984). **Corrosion manual for internal corrosion of water distribution systems**. Environmental science and engineering, Inc. Florida, pp.1-67.

Srinivas, Y., Oliver, D.H., Raj, A.S and Chandrasekar, N. (2013). Evaluation of groundwater quality in and around Nagercoil town, Tamilnadu, India: an integrated geochemical and GIS approach. *Applied Water Science* **3**(3): 631-51.

Srinivasamoorthy, K., Gopinath, M., Chidambaram, S., Vasanthavigar, M and Sarma, V. S. (2014). Hydrochemical characterization and quality appraisal of groundwater in Tamilnadu, India. *Journal of King Saudi Science* **26:** 37-52.

Szabolcs, I and Darab, C. (1964). The influence of irrigation water of high sodium carbonate content on soils**. Proceedings of 8th International Congress Soil Science Sodics Soils**, ISSS Trans II, pp.802–812, Bucharest.

Webster, R and Oliver, M.A. (2007). **Geostatistics for Environmental Scientists**. John Wiley & Sons, Chichester.

WHO (1979). Sodium, chlorides and conductivity in drinking-water. Report on a WHO Working Group. EURO Reports and Studies 2, World Health Organization, Copenhagen office.

WHO (1979). Sodium, chlorides and conductivity in drinking-water. Report on a WHO Working Group. EURO Reports and Studies 2, World Health Organization, Copenhagen office.

WHO (1989). Health guidelines for the use of wastewater in agriculture and aquaculture, World Health Organization (WHO), Geneva, pp-74.

WHO (2003a). Total dissolvedsSolids in drinking water support document for development of WHO guidelines for drinking-water quality, World Health Organization, Geneva.

WHO (2003b). Total dissolved solids in drinking water. Background document for development of WHO guidelines for drinking-water quality. World Health Organization (WHO). Geneva.

Wilcox, L.V. (1955). Classification and use of irrigation waters, U.S. Department of Agriculture, circular 969, Washington DC, USA.

WSSRD (2012). Technical report: Incrustation of Dire Dawa water supply distribution network and mitigation measure, Water Supply and Sanitation & Research Development, Addis Ababa, Ethiopia (unpubl.).

WWDSE (2004). Dire Dawa administrative council, integrated resource development master plan study project, vol III: Hydrogeology, final report, Water Work Design & Supervision Enterprise, Addis Ababa, Ethiopia (unpubl.).

Yousefi, Z., Kazemi, F and Mohammadpour, R.A. (2016). Assessment of scale formation and corrosion of drinking water supplies in Ilam city (Iran). *Environment Health Engineering* **3**: 75–80.

Zarif, F., Eslam, H and Afrous, A. (2014). Spatial variation of corrosion and scaling potential of groundwater using kriging (Dezfoul- Andimeshk Plain). *Bulletin Environmental Pharmacology and Life Science* **4**(1): 16-21.