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Assessment of Corrosion and Scale forming Potential of Groundwater Resources: Case Study of Dire Dawa City, Ethiopia

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

[1] Process, Environmental Engineering and Energy Chair, Institute of Technology Dire Dawa University, P.O. Box 1362, Dire Dawa, Ethiopia (*grhaile@gmail.com).

[2] Geomatic and Geoinformatic Chair, Institute of Technology Dire Dawa University, P.O. Box 1362, Dire Dawa, Ethiopia.

ABSTRACT

Almost 100% of the water supply of Dire Dawa City is from groundwater (including boreholes, dug wells, and springs). Recently, groundwater cause corrosion and scale problems to water distribution systems due to its content of dissolved ions that can cause public health and economic issues. The present paper investigates the corrosion and scale-forming potential of the groundwater in the city and visualize with mapping. Spectrophotometer, EDTA/Acid titration with calculation methods were used fors it water quality parameters analysis. GW Chart Calibration plot applied for the Piper diagram to categorizes the water types. Langelier saturation (LSI), Ryznar (RSI), aggressive (AI), Puckorius Scale (PSI), and Larson-Skold (LRI) indices were manipulated with Excel ® and visualized their spatial distribution using ArcGIS 10®. The mean values of LSI, RSI, PSI, AI, and LRI obtained were 0.29 ± 0.28, 6.4 ± 0.5, 5.10 ± 0.48, 12.20 ± 0.24, and 1.4±1.57 respectively. LSI and RSI results indicate moderate to low scale-forming tendency of groundwater in most parts except the northeastern part with corrosive groundwater. Based on the AI value, the groundwater ranges low corrosion in almost all zones except the edge of the northeast and northwest region. PSI indicated the water tends to form salt-scale at a medium rate. The LSI results showed that chloride and sulphate are unlikely to interfere with the formation of protecting film except in northwestern and northeastern regions where localized corrosion might occur. In conclusion, in almost all distribution system of the city is affected by calcium carbonate scale formation. The groundwater in the northwest and northeast resulted in localized corrosion because of relatively high contents of chlorides and sulphates.

Keywords: Corrosion indices, Scale-forming, Water quality, GIS, Dire Dawa, Ethiopia.

1. INTRODUCTION

Ethiopia gets more than 80% of the drinking water supply from groundwater (Seifu et al., 2018). In the case of Dire Dawa, which is arid part of the country, there are no perennial rivers and streams. For the last 12 years, almost 100% of the water for the urban and rural population of Dire Dawa Administrative Council (DDAC) gets its water supply for domestic, industrial, and irrigation purposes exploited from boreholes, dug wells, and springs. Besides, the increasing water demands, there are other related issues from the source point to the distribution system from public health and economic aspects. This has not been considered a serious

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problem in Ethiopia until recent times (Seifu et al., 2018; Tamiru, 2006; Alemayehu, 1999; WWDSE, 2004 unpubl. data).

Naturally, water contains dissolved hardness-causing ions, iron, sodium, potassium chloride, sulphate, bicarbonate which cause corrosion and scale problems to the water distribution systems. Corrosion and scale add to the cost of water selling price because of high pump operation costs; replacement of failing pumps, pipes, and fittings; short life of water heaters, boilers, and cookers in-house and industries. Corrosion may cause the leaching of contaminants such as lead and copper into the water distribution network that would have hazardous concerns for community health (Mahmoud et al., 2012). It also rises customer complaints and loss of public trust due to water quality, low water pressure (Singley et al., 1984; Dobersek and Goricanec, 2007). There are a public drinking water distribution system and several private bottled water companies in Dire Dawa City which are facing problems related to corrosion and scale forming. According to the technical report (Antonaropoulos and Associates, 2017 unpubl. Data) on the incrustation problems of the city water distribution system stated an average of 2000 m long pipes damage each year. In the 2014-15 year annual reports of the city Water Supply and Sanitation Authority (DDWSSA), it was also presented that the pipe loss estimated 1% of the total distribution network length. The actual production capacity of the existing water sources is estimated at 415 l/s, which corresponds to approximately 70% of their design yield (DDWSSA, 2015 unpubl. data).

It is crucial to monitor the effects of corrosion to deel with related concerns with evidence. The most widely used indirect monitoring methods are water analysis interpretation, consumer complaints and corrosion indices. Water stability indices easily analyze and predict corrosion or scale forming tendencies of water which are very handy in a corrosion control program (Singley et al., 1984; Alam and Sadiq, 1989).

Water corrosion or scale forming effect is related to its pH, alkalinity, hardness, temperature, dissolved oxygen, total dissolved solids, and other factors (Salvato et al., 2003). These water stability indices combine the above-mentioned factors to indicate their contribution to corrosive or scale forming effects. Langelier Saturation (LSI), Ryznar stability (RSI), and aggressive (AI) indices are the most commonly used in the waterworks industry, which can indicate the tendency of water to be corrosive or not. They also predict water tendency to precipitate a corrosion protective salt coater. Scale forming occurs when thick layers of salt are deposited (Singley et al., 1984).

Several researchers have investigated the water situation in terms of scale forming and corrosion. However, so far, almost no studies have been done on corrosion and scale forming potential of drinking water in Ethiopia and Dire Dawa. There was only one study (Gebremedhin et al., 2013) that estimated the corrosiveness of groundwater at different localities in Mekelle City using corrosion indices of Larson index and aggressive index. The results showed that groundwaters were corrosive than spring samples. Tavanpour and Noshadi (2016) showed that the mean value of Langelier, Ryznar, Puckorius, Larson, and Aggressive indices in the water distribution network of Shiraz city. The zones located in eastern, south-eastern, and southern zones had scale-formation problems. Avaz-pur et al. (2008) studied Ilam City-Iran corrosion and scaling effect on water distribution system using Langelier saturation index, Ryznar stability index, and aggressive index. The indices indicated that water source three rivers were all corrosive. Aghapur et al. (2009) studied and indicated the water corrosion and scale-forming levels in distribution facilities of Urmia, Iran, that the corrosiveness was related to low hardness water. This resulted in a risk of heavy metals solution of lead, cadmium, copper, and zinc from pipelines. De Rosa (1993) studied scale formation in the drinking water distribution system of different regions of London, England. The results suggested a significant effect on the accumulation of scale particles. In addition to the lower pipes diameter became the more scale existed in the downstream main pipes of distribution networks.

GIS is useful for mapping the spatial distribution of different regions in water quality studies that several researchers have successfully utilized this tool (Assaf and Saadeh, 2009; Narany et al., 2014; Zarif et al., 2014). Zarif et al. (2014) using LSI, RSI index and GIS software studied the spatial variation of corrosion and scale forming potential of groundwater of 105 wells in the Dezfoul - Andimeshk Plain and the results showed increasing scale-forming tendency from north to south of plain. GIS-based assessment of corrosion and scale formation in Thanjavur, India by Kumar et al. (2014) indicated that most parts of the study area were occupied by moderate calcium and moderate to high corrosion, with more on the northern region of the area than the southern.

The purpose of the present study was to investigate the corrosion and scale forming potential of the groundwater source of Dire Dawa City using the water stability indices and visualize the geographical distribution on the studied area using GIS.

2. METHODOLOGY

2.1. Geographical description and data collection

Dire Dawa City is located in the eastern part of Ethiopia taking the UTM coordinate system as a reference, the location of the city is between 804511m to 816913m west-east direction and 1059754m to 1067650m south-north direction as shown in Figure 1. The City is located 515 km far from Addis Ababa, the capital city of Ethiopia, 311 km west of Djibouti port and 55 km to the north of the historic City of Harar. Dire Dawa City Administration (DDCA) consists of nine urban zones and other rural zones. To analyze the physicochemical parameters, groundwater samples of 15 boreholes were collected from Dire Dawa central area, Tome, Boren and Melka Jebdu as shown in figure 2. Additional secondary data of 67 sample points were obtained from the quality control laboratory of DDWSSA and Federal Water Works Design and Supervision (WWDSE) analyzed from 2004 to 2015 (WWDSE, 2004 unpubl. data; Eyilachew, 2010; MS consultancy, 2016 unpubl. data). For Secondary data, the accuracy was monitored with Ion Balance Error (IBE) calculation within a margin of +/- 5%. The water resources were also located using Garmin Origon-550 GPS (Global Positioning System) in UTM coordinate system as shown in figure 1 and 2.

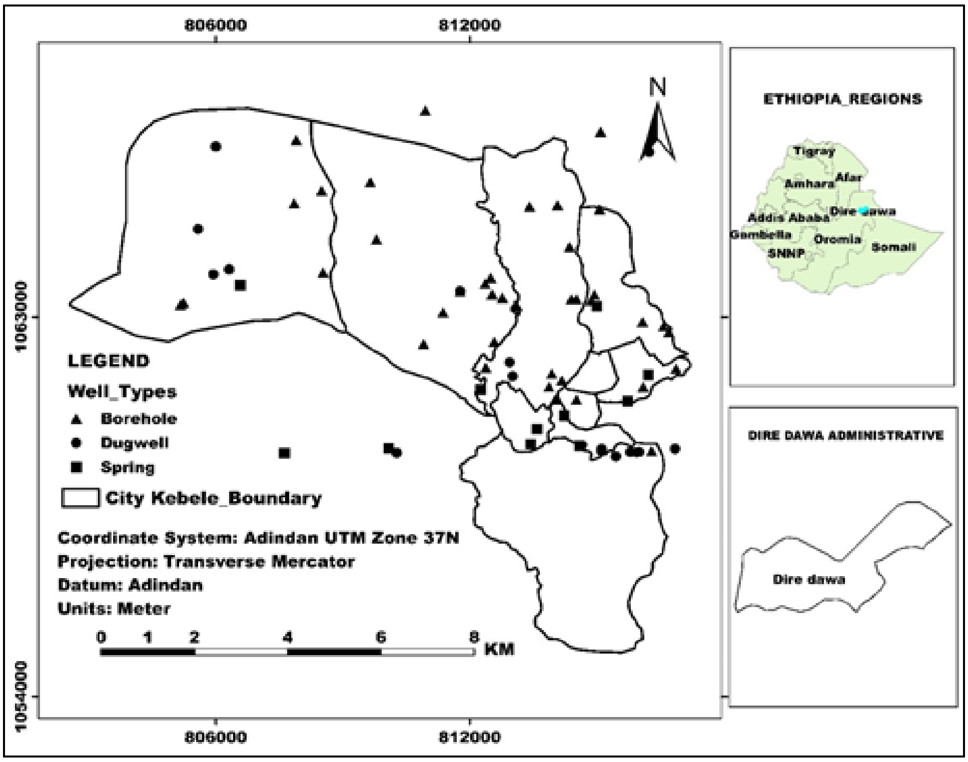

Figure 1. The geographical location of groundwater points, Dire Dawa City, Ethiopia.

2.2. Water Quality Parameters

The samples were collected in pre-washed and rinsed polyethylene bottles. The temperature was measured on-site using portable meter. TDS, alkalinity, total hardness, cations (calcium and magnesium) were measured with acid and EDTA titrimetric, conductivity (EC meter), and calculation. Sulphate and chloride were measured using spectrophotometer at Dire Dawa University Water Sanitation office and Dire Dawa Water Supply and Sanitation Authority, Quality Control Laboratory. The hydrochemical facies of groundwater were understood by constructing Piper (1944) diagram with GW Chart Calibration plot (USGS, 2000).

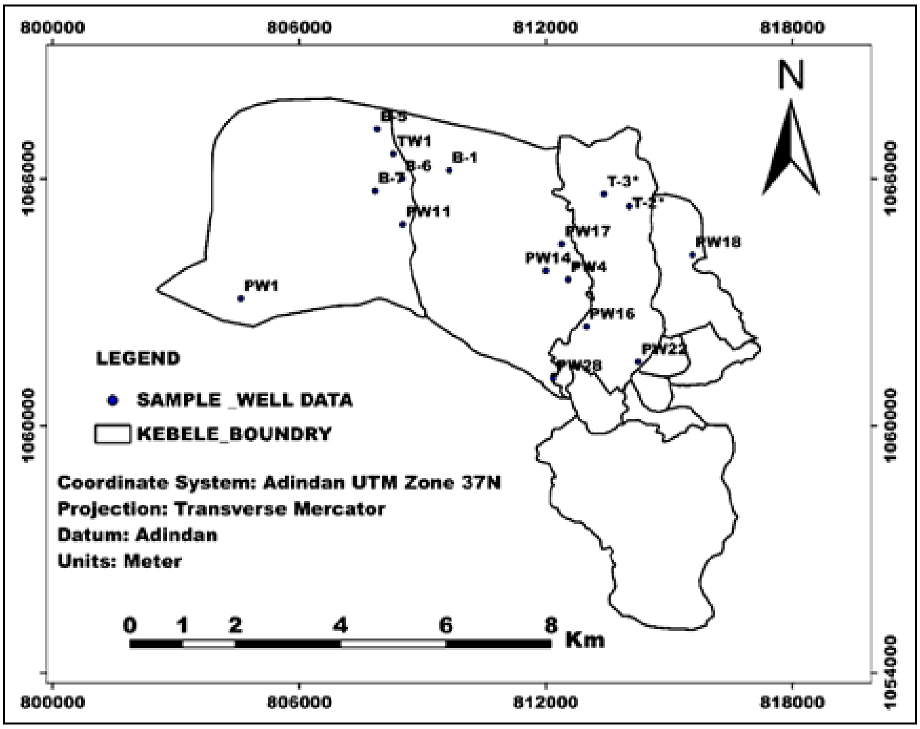

Figure 2. The spatial location of sampled water wells, Dire Dawa City, Ethiopia.

2.3. Water Stability Indices

With the help of the groundwater chemical and physical parameter data, the corrosion and scale forming indices of LSI, RSI, PSI, AI and LRI were calculated Excel ® software for investigation of corrosion or water scale-forming. Summary of the most common indices interpretation and criteria for categorizing the stability of the water presented in table 1.

2.3.1. Langelier Index (LSI)

The Langelier index only shows the tendency of water to dissolve or form carbonate scale. it is only conducive to control the calcium carbonate content in systems (Langelier, 1936).

LSI is expressed as

$\mathrm{LSI} = \mathrm{pH} - \mathrm{pHs}$ …………………………………………………………….…(1)

$\mathrm{pHs} = (9.3 + (\log[\mathrm{TDS}] - 1)/10 - (13.12 * \log(\mathrm{T} + 273) + 34.55)$

$- (\log(\mathrm{Ca}^{2+}) - 0.4 + \log(\text{Total Alkalinity})$ ……………………………………….(2)

T- temperature in °C, TDS in mg/L, Ca^{2+} and Total Alkalinity in mg/L as $CaCO_3$, $\mathrm{pH_s}$ is the pH in saturation state in calcite or calcium carbonate. The index could be efficient for systems at low water speed, TDS and temperature ranges (McNeill and Edwards, 2001; Singley et al., 1984).

2.3.2. Ryznar Stability Index (RSI)

While Ryznar index is experimental, it could only be used for (water inside the pipeline) with a velocity of about 0.6 m/sec. This index is often used in combination with the LSI to improve the accuracy of the prediction. Ryznar index is not suitable for the case of water saturation (Prisyazhniuk, 2007). RSI helps to monitor scale thickness.

RSI is calculated as follows.

$\mathrm{RSI} = 2\mathrm{pH_s} - \mathrm{pH}$ ………………………………………………………………….(3)

2.3.3. Aggressive Index (AI)

The AI is a simplified form of the Langelier index and only approximates the solubility of $CaCO_3$ and water acidity but the corrosion effect.

The index is calculated as

$\mathrm{AI} = \mathrm{pH} + \log\,[(\mathrm{A})(\mathrm{HC})]$…………………………………………………………...(4)

A is Total Alkalinity and HC is Calcium hardness in mg/L as $CaCO_3$

However, it can be a useful tool in selecting materials like asbestos-cement lining pipelines or treatment options for corrosion control (Von Huben, 1995).

2.3.4. Larson-Skold Index (LRI)

This index was developed by Larson and Skold (1958) for examining the extent of corrosion based upon the aggressiveness of chloride and sulphate in water and alkalinity as aggression reducer which is exposed to steel pipelines with light carbonic structure and cast-iron pipes (Singley et al., 1984; Singh and Chakradhar, 1998).

Larson-skold index is calculated as:

$\mathrm{LSI} = \frac{\mathrm{C_{cl^-}} + \mathrm{C_{so4^{-2}}}}{\mathrm{C_{HCO_3^{-1}}} + \mathrm{C_{CO_3^{-2}}}}$……………………………………………………………..(5)

(all ionic concentrations are expressed in mg/L as $CaCO_3$)

2.3.5. The Pockurius Scale forming Index (PSI)

PSI is based on buffer capacity. It is explanatory of the maximum quantity of scale that may bring in water. In this index, the use of equilibrium pH (pH_{eq}) is more than actual pH. To calculate Pockurius index

$\mathrm{PSI} = 2\mathrm{pH_s} - \mathrm{pH_{eq}}$……………………………………………………………..…...(6)

$\mathrm{pH_{eq}} = 1.465 \log(\text{Total Alkalinity}) + 4.54$………………………………………..….(7)

A is Total Alkalinity in mg/L as $CaCO_3$

PSI is a practical index for scale forming. A high salt saturation level is observed if the water contents of high calcium & magnesium ion but less alkalinity and buffering capacity. The number resulting from this index is similar to RSI (Singley et al., 1984; Puckorius and Brooke, 1991).

Table 1. Summary of Corrosion and Scaling Index (Abbasnia et al., 2018; Acharya et al., 2018; Hadi, 2010).

	Index value	***Interpretation***
Langlier Saturation Index	$-4 < LSI < -2$	Mild Corrosion
	$-1 < LSI < 0$	Low Corrosion
	$LSI = 0$	Balanced
	$0 < LSI < 2$	Low to Moderate Scale-forming
Ryzan Stability Index	$RS < 5.5$	Highly scale-forming
	$5.5 < RS < 6.2$	Relatively scale-forming and corrosive
	$6.2 < RS < 6.8$	Balanced
	$RS > 6.8$	Corrosive
Larson Skold Index	$LRI < 0.8$	Formation of protective media without the mediation of Cl^-& SO_4^{-2} ions
	$0.8 < LRI < 1.2$	Formation of scale with the mediation of Cl^- & SO_4^{-2} (corrosion rates more than expected)
	$LRI > 1.2$	High rates of localized corrosion
Aggressive Index	$AI < 10$	High water corrosion
	AI = 10-12	Moderate water corrosion
	$AI > 12$	Lack of water corrosion
Pockurius Saturation Index	$PSI < 5$	The water intended to be scale forming
	$5 < PSI < 7$	Relatively scale-forming
	$PSI > 7$	water tend to dissolve if exist any scale

2.4. Spatial distribution analysis of the indices

The city boundary shapefile data were taken from the city administration. The collected spatial data of bore wells were downloaded with DNR Garmin software in CSV file format and match with the calculated index values. Finally, the geocoded (address matching with other tabular data) was brought into ArcGIS 10.3® software for spatial analysis. Among different spatial analysis tool, interpolation technique which has been used for analyzing the geocoded index of each point. Among different interpolation techniques, the researcher most used IDW and kriging in corrosion and scale forming studies (Webster and Oliver, 2007; Kumar and Gorail, 2013; Zarif et al., 2014).

3. RESULT AND DISCUSSION

According to Habteab and Jiri (2018); Eyilachew (2010); Minalah (2007); Tamiru (2006); WWDSE (2004); and Seife Michael (1982), the city is covered by limestone, sandstone, shale, and chalk of Mesozoic age.

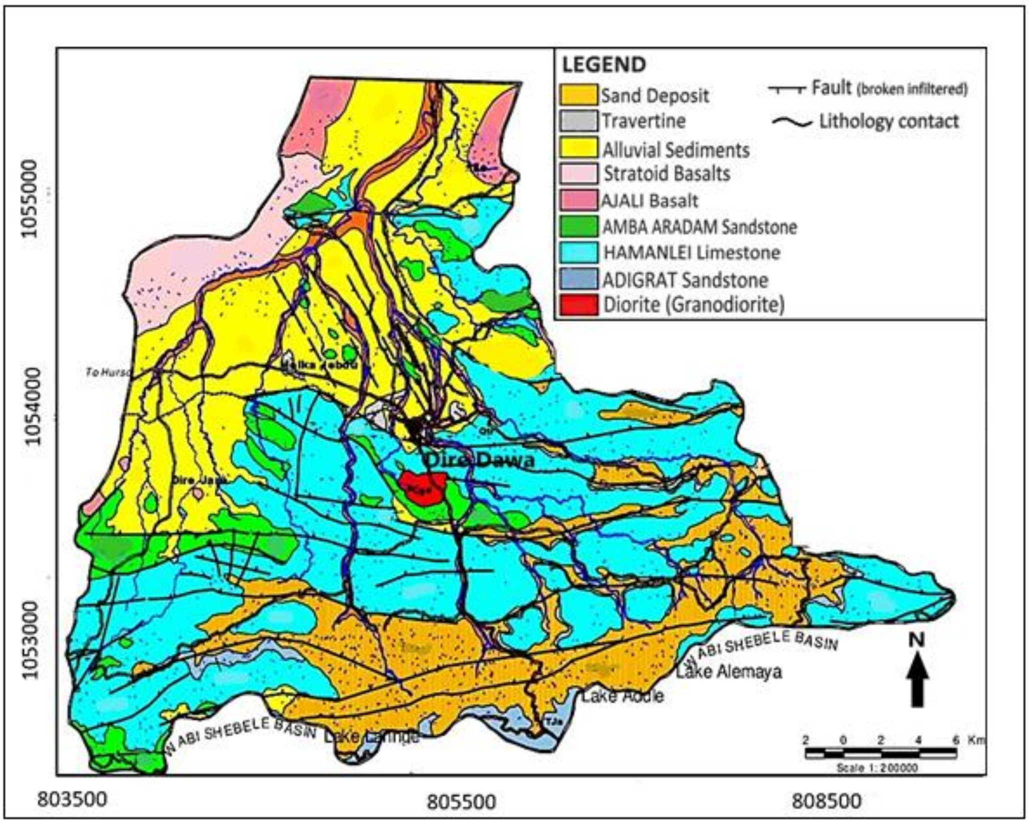

Figure 3. Geological Map of Dire Dawa Basin (WWDSE, 2004; Eyilachew, 2010).

The western part, the upstream, is dominated by sandstone and hamanlei limestone units are the most productive aquifers in the area. Alluvial sediment deposits dominantly cover the east, downstream area, as it unconfined unit composed of clay, silt, sand, gravel and rock fragments in the groundwater basin as shown in figure 3.

The Piper graph (Fig 4) showed that most of the samples related to the high concentration of $Ca(HCO_3)_2$ and $CaMg(CO_3)_2$ the significant amount of $CaSO_4$. The groundwater of $CaHCO_3$, Ca-HCO_3-SO_4 and $CaMg(CO_3)_2$ dominated water types in boreholes and dug well. As observed by Habteab and Jiri (2018), the Ca-Mg-HCO_3 dominant groundwater and springs the southern, and western parts of the study area whereas Ca-HCO_3-SO_4 in the central part of the city due to domestic and industrial waste (chloride and sulphate dominant).

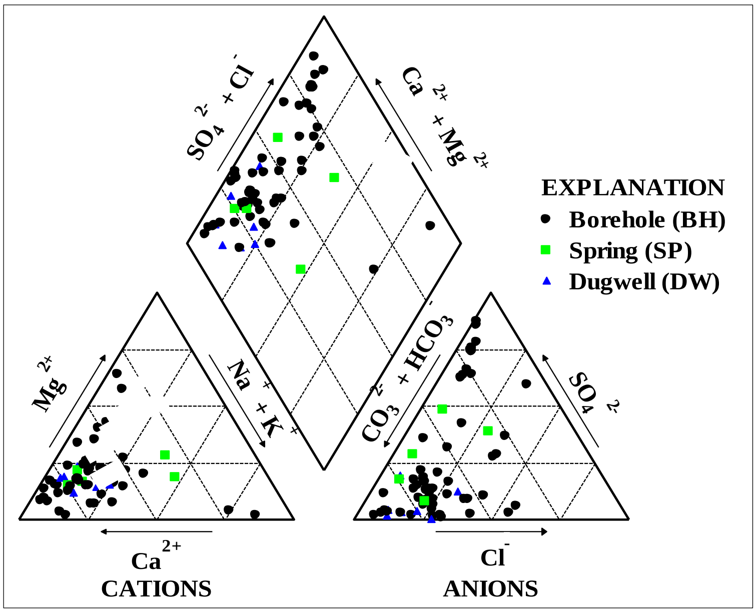

Figure 4. Piper graph of groundwater source of Dire Dawa City.

On the other hand, springs in Melka Jebdu possess Ca-Mg-Na-HCO_3 dominant water types. The sodium originated due to possibly halite from lake connections to Wabi Shebele-Awash River basin and flow towards Dire Dawa plain area (Habteab and Jiri, 2018; Eyilachew, 2010). According to reports and studies, high total dissolved solids from excess calcium and magnesium concentrations, and concentrations sulphates and bicarbonate existed in the groundwater sources (Habteab and Jiri, 2018; Antonaropoulos and Associates, 2017 unpubl. data; DDWSSA, 2015 unpubl. Data; WWDSE 2004).

The high concentration of bicarbonate, sulphate, and chloride causes the incrustation and corrosion action (Sawyer and McCarty, 1967; Aiman and Enab, 2007; Anon, 1983). The values of the groundwater physical and chemical parameters of sample points are presented in appendix 1, 2 and 3.

3.1. Physical and Chemical parameters

3.1.1. Total Dissolved Solids

Total dissolved solids (TDS) is mainly contents of inorganic salts and dissolved organic matter in groundwater (WHO, 2003). A TDS increases conductivity, as result, it facilitates corrosion electrochemical reaction. TDS may also affect the formation of protective films since it was related to the excess calcium-based bicarbonate, sulphate, and chloride. High TDS (>500) result in excessive scaling in water pipes, water heaters, boilers, and household appliances (WHO, 2003). The TDS higher than the desirable level (>500) were observed in boreholes and springs (Habteab and Jiri, 2018; Antonaropoulos, 2017 unpubl. data; Eyilachew, 2010; WWDSE, 2004).

3.1.2. Acidity (pH of water)

Water with pH > 9 tends to reduce corrosion and also tends to stabilize around pH = 6.5 (Health Canada, 2009). The mean values of wells and springs were found to be between 6.7 and 7.2 that were stable enough.

3.1.3. Alkalinity

Alkalinity serves to control the buffer intensity of most water systems. It provides a stable pH, as a result, prevents corrosion of lead, copper, and cement-based linings pipes. The mean values of alkalinity were between 248 to 440 mg/L. If the alkalinity level is higher than 100 mg/L, leads to scale-forming on a pipe wall. Also, the high alkalinity avoids point corrosion which is caused by rapid pH change of the water. The fact that bicarbonate more than 400 mg/l causes incrustation problems (Anon, 1983) that bicarbonate of the PW17, PW18, PW22, T-2, T-3 recorded more than the limit (<400 mg/l). A total of 66% of the samples, more than the limits (<400 mg/l), were all boreholes and dug wells. The groundwater of pH less than 8, had no concentration of carbonate (CO_3^{-2}) so it was bicarbonate dominant (McDonald, 2006).

3.1.4. Hardness (Calcium and Magnesium)

Calcium and Magnesium are responsible for the hardness, originate from limestone and dolomite respectively. The values of calcium (157.6 to 568 mg/L) and magnesium ion (8.9 to 144 mg/L) were relatively high in both spring and wells that all samples were categorized as hard water. The high hardness contributed to the formation of dominated with calcium carbonate protective layer and inhibits the corrosion of pipes. The excessive scale-formation in pipes is mostly responsible for the frequent blockage of water supply systems (WHO, 2011). Hardness also causes high soap consumption, and the deterioration of fabrics at values above 200 mg/L and high alkalinity (John et al., 2012).

3.1.5. Sulphate and Chloride

Sulphate is a strong corrosion catalyst implicated in the pitting corrosion of copper and lead (Health Canada 2009; Ferguson et al., 1996; Berghult et al., 1999). The mean sulphate values were between 68.8 to 1809.1 mg/l. The desirable sulphate ion is limited below 250 mg/L (Anon, 1983) to avoid incrustation in low pH. Only 35.4% of the samples were above the limit of calcium bicarbonate and sulphate with the highest value of borehole PW17, PW18, PW22, and Tome wells T-1 and T-3 in Police Meret and Legahare which are populated and oldest settlement of the city. Chloride is the most active and corrosive ion (Jones, 1996). 87.7% of the wells and springs samples were within the limit (200 mg/l). The aggressiveness of water containing high alkalinity, bicarbonate and sulphate resulted in lower corrosion since the larger percentage of the current carried by SO_4^{2-} or HCO_3^- competing with chloride. A chloride to sulphate mass ratio (CSMR) less than 0.7, is desirable in which the corrosion rate is low (EPA, 2016; Reiber et al., 1997; Nguyen et al., 2011). Value of CSMR of sample TW1, PW17, PW18, PW22, T-3 and T-2 were below 0.7 that the groundwater was less corrosive to galvanized metals. On the contrary, 76% of the well CSMR values were more the limit (> 0.7) that able galvanized corrosion.

3.2. Corrosion and Scale-forming Indices

Since a corrosive or scale-forming tendency of water is a complicated phenomenon, many attempts have been made to develop an index and several of the indices have been useful for prediction purposes (McNeill and Edwards, 2001). There is no single corrosion index applicable to all materials. Corrosion indices, particularly those related to calcium carbonate saturation, have given mixed results. The mean values of LSI, RSI, PSI, LRI and AI obtained as 0.29 ± 0.28, 6.4 ± 0.5, 5.10 ± 0.48, 2.06 ± 0.25 and 12.20 ± 0.24 respectively. The corrosion and scaling forming indices of the sample points were displayed in tables 2,3 and 4 above. Mapping the spatial distribution of the corrosion indices in the study area was best interpolated with kriging method. To validate the map, the real indices values and the predicted ones was cross-checked.

3.2.1. Langelier and Ryznar Indices

The Langelier index values in all zones ranged from -0.37 to 0.98. According to LSI, all the samples were above zero with a minimum value related to point PW 18. Besides, majority of water sources (95%) were supersaturated which could form scale at moderate rate and consequently damaged drinking and other water-consuming and distribution systems. In this regard, as per figures 5 and 6, the groundwater that tendency to form a scale located in most parts of the study area except the north-west and north-east part the city with corrosive groundwater points. While the highest values obtained (most scale-forming) were related to the north-center. The Ryznar index values were in the range of 5.60 to 7.29 while among the samples the maximum value was related Boren borehole B-1, B-5 and B-6 as displayed in appendix tables.

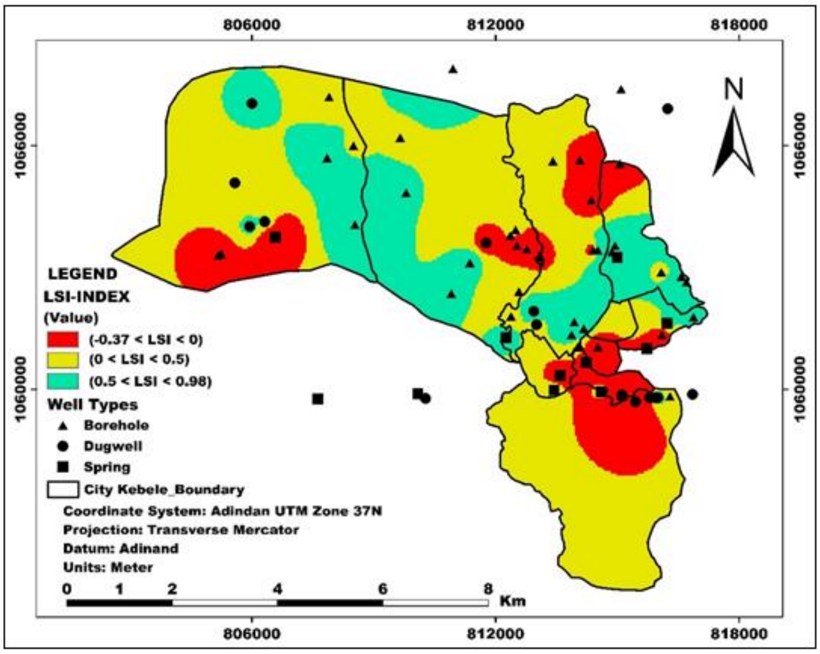

Figure 5. Maps of spatial changes of Langelier Saturation Index of Dire Dawa city.

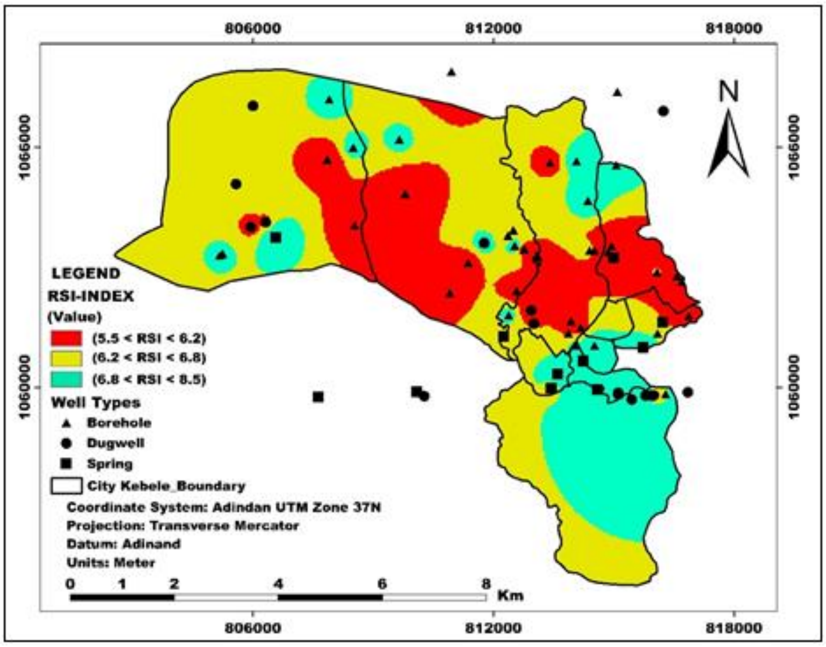

Figure 6. Maps of spatial changes of Ryznar Index of Dire Dawa city.

More than half of the boreholes and dug wells (59.7%) had a scaling tendency on pipeline and water operating equipment and the other 20.8% of groundwater source points were balanced. However, the other 19.5% of the groundwater points were corrosive to metals and deteriorated effects on cement-lined and plastic pipes. The Ryznar index, in figure 6, showed relative scale-forming and saturated north part. However, the edge south and northwest part groundwater had shown corrosion tendency. Langelier index, on one hand, is preferably used for still waters and is used for control of bicarbonate scale formation. In this case, TDS was calcium bicarbonate dominant groundwater. On the other hand, the Ryznar index may be used with moderate to hard water but does not apply to soft or saline waters.

3.2.2. Aggressive Index

The aggressive index mean values in all zones ranged from 11.59 to 12.93. Almost all (87%) data were nonaggressive (AI greater or equal to 12) groundwater. The other 13% exhibited a corrosion rate ranged low to moderate. The wells with minimum AI values were located in the northeastern edge and the maximum values in central and northwestern. AI does not incorporate temperature or TDS effects. The groundwater ranged from low to medium corrosion and its effect is only applicable to asbestos-cement pipelines.

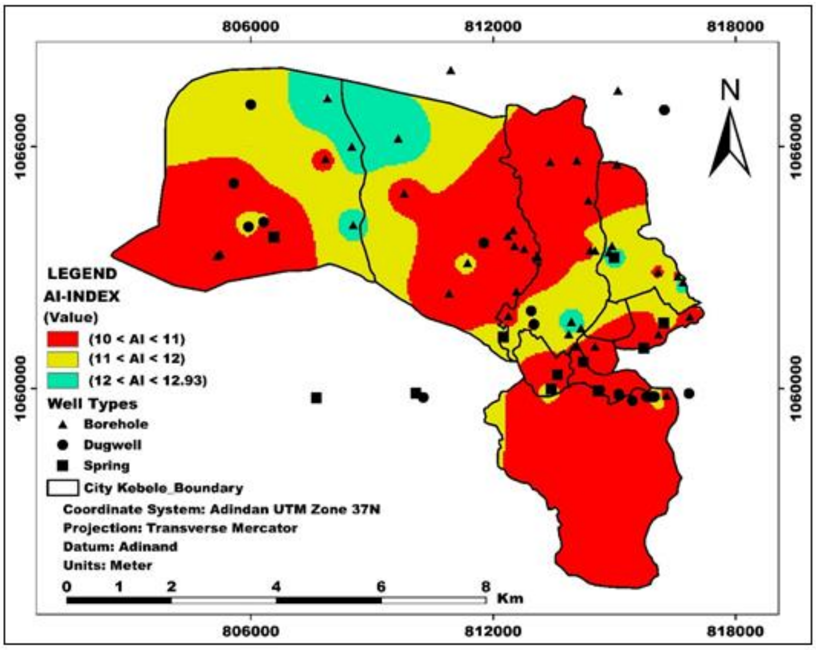

Figure 7. Maps of spatial changes of Aggressive Index of Dire Dawa City.

3.2.3. Puckorius Scale forming Index

The mean values of the index in all zones ranged from 4.23 to 5.87. Based on the results, the water tended to be scale-forming at moderate in most of the regions especially northwestern and central parts. The groundwater has high calcium concentration and high alkalinity consequently possess high buffering capacity. The calcium precipitated from the oversaturation over the less of pH change. The high values PSI in the southern and northeast edges indicated that groundwater was from less scale forming and tended to dissolve any existing scales.

3.2.4. Larson-Skold Index

The groundwater that has high calcium and alkalinity (bicarbonate), possesses high buffering capacity (Sajil Kumar, 2019). So the groundwater aggressiveness containing sufficient buffering capacity and alkalinity is due to the increase in chloride and sulphate (Larson and Skold, 1958).

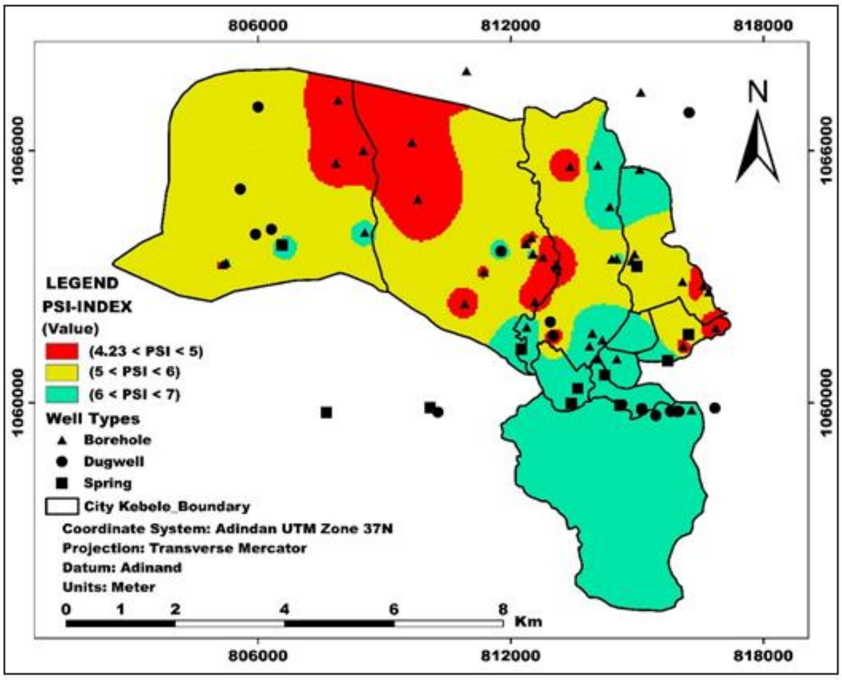

Figure 8. Maps of spatial changes of Pockurius Scaling Index of Dire Dawa City.

The Larson index values in all zones ranged from 0.09 to 6.03. Both the minimum value of the index (i.e. most scale-forming) and the maximum value (i.e. localize corrosion) were related to wells located in northwestern. This index is associated with corrosion of steel, iron-cast pipes and also leaching lead, copper, tin into the water. Chloride and sulphate are unlikely to interfere with the formation of protecting film in most of the city except northwestern and northeastern where corrosion would be expected. Tome mountain well field in northeast exhibited where localized corrosion effect existed. The geology also confirms present of marine sediment rich in sulphate (MS consultancy, 2016 unpubl. data). Melka Jebdu well field in northwest is populated and has poor municipal northwest is populated and has poor municipal waste management. Animal and human waste are also the main source of sulphate and chlorine (Eyilachew, 2010).

In summation, the calcium and magnesium, bicarbonate and sulphate dominant salt in groundwater caused a moderate scale as indicated by LSI, RSI and PSI. On the other hand, the groundwater was also the source of low corrosion problems as indicated by AI and LRI mainly due to high TDS and warm temperature.

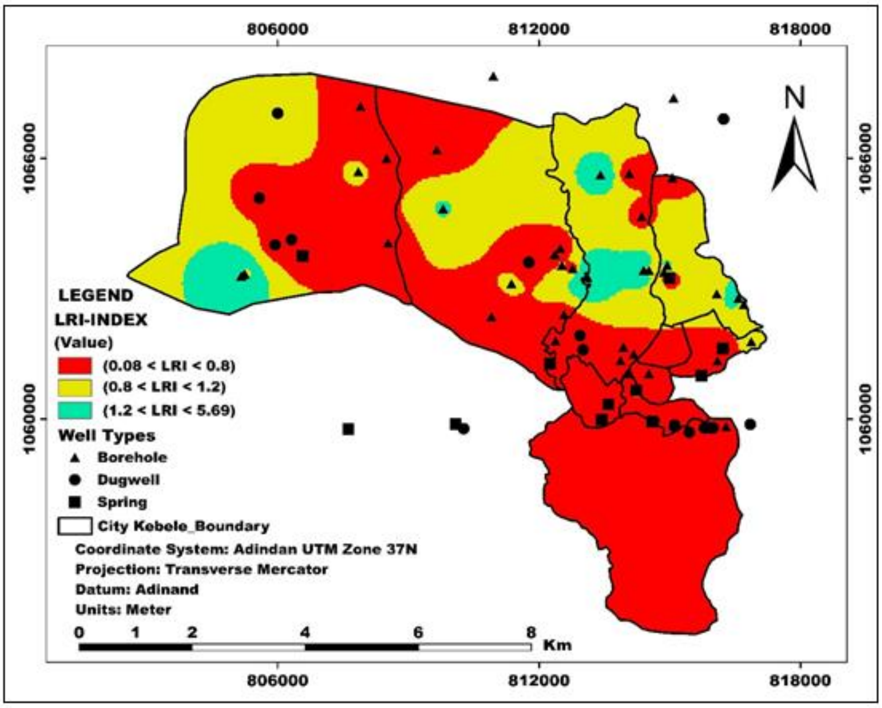

Figure 9. Maps of spatial changes of Larson-Skold Index of Dire Dawa City.

In northeastern and northwestern, the groundwater contained significant amount of chloride and sulphate that dangerous pitting corrosion might exist which is fast and localize according to Larson and Skold (1958). Geographically, the corrosion tendency of groundwater in Dire Dawa City increases from south to north direction. The scaling problem was more aggressive at the center of the city, where most of the groundwater sources exist.

4. CONCLUSIONS

Assessment of the corrosion and scale forming tendency of the groundwater in Dire Dawa City was performed using five water stability indices. These indices prove very helpful to the city public drinking water distribution systems and other industrial water utility supervisors, field engineers, and policymakers in monitoring and manage water corrosion and scale-forming effects. The groundwater stability was mainly influenced by parameters of TDS, total hardness, alkalinity, calcium, magnesium, sulphate and chloride. The piper diagram of the groundwater samples revealed that the samples fall under Ca-Mg-HCO_3, Ca-Mg-HCO_3-SO_4 and Ca-Mg-HCO_3-Cl type water. Finally, according to the indices used in the study, it can be concluded that groundwater sources of Dire Dawa City behave from moderate to low scale. The groundwater contains hardness of mainly calcium, carbonate and sulphate from the natural occurrence. Tome (northeast region) and Melka Jebdu (northwestern region) are highly inhabited and old settlements that the groundwater had localized corrosion tendency due to relatively high content of chloride and sulphate. A recent over-pumping of the drinking water also caused a sudden drop in the groundwater level. Consequently, this increased salinity of the water exceeds limits and also led to carbonates and sulphate precipitation in pipes and water supply systems. This increasing trend requires more protection of the water resources and implementation of water treatment systems.

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6. CONFLICT OF INTEREST

There is no conflict of interests.

7. REFERENCE

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Appendix 1. The physiochemical analysis and corrosion indices of the Borehole of Dire Dawa City.

Index	**X-coor**	**Y-coor**	**T**	**TDS**	**pH**	**Ca^+**	**Mg^+**	**Cl^-**	**HCO_3^-**	**SO_4^{-2}**	**TH**	**AL**	**LSI**	**RSI**	**AI**	**PSI**	**LRI**
BH-05	812378	1061804	22.3	532	7.4	116	28.7	83.6	373.3	18.46	306	409.6	0.4	6.6	12.4	5.9	0.3
BH-06	813870	1061350	25	946	7.6	200	20.9	150	378.2	50	310	587.2	0.7	6.2	12.8	5.6	0.5
BH-08	814520	1063426	26.4	598	7.3	128	34.1	67.1	441.6	47.5	362	462.1	0.4	6.5	12.4	5.6	0.3
BH-10	814020	1061049	27.3	834	7.3	152	30.2	80.6	373.3	39.56	306	505.7	0.4	6.5	12.4	5.7	0.3
BH-12	814172	1061499	26.5	1570	7.5	240	41.3	315	414.8	23.7	340	772.3	0.7	6.1	12.8	5.4	0.8
BH-13	814356	1064666	26.7	790	7.1	112	31.1	160.6	383	14.5	314	409.7	0.1	7.0	12.0	5.9	0.5
BH-14	814865	1063384	28	1245	7.7	240	44.7	215.6	353.8	221.5	290	786.5	1.0	5.8	12.9	5.3	1.2
BH-15	814941	1063539	25	1583	7.3	264	68.1	331.1	412.4	448.5	338	943.8	0.7	6.0	12.7	5.0	1.9
BH-02	816294	1059832	28	470	7.3	140	8.27	28.6	400.2	12.1	328	384.5	0.4	6.5	12.4	5.5	0.1
BH-21	811477	1071736	26.3	780	7.2	140.6	36.8	91.2	468.2	128.6	383.8	504.8	0.5	6.1	12.3	5.0	0.5
BH-43	812491	1063930	19.4	622	7.2	136	30.1	106	424.6	44.8	348	465.7	0.5	6.1	12.3	5.1	0.4
BH-48	810949	1067896	18.7	822	7.5	184.7	11.5	117	447.4	102.6	366.7	509.7	0.9	5.7	12.7	4.8	0.5
BH-50	815089	1067392	35	778	7.2	182.4	27.6	33.25	440.4	219.9	361	571	0.4	6.3	12.4	5.2	0.6
BH-53	813936	1061662	25.3	1092	8.1	214	29.5	166	322	56.7	263.9	657.9	1.1	5.8	13.2	5.8	0.7
BH-56	805241	1063341	23	598	7.3	128	34.1	67.1	441.6	47.5	362	462	0.4	6.5	12.3	5.5	0.3
BH-30	809629	1062713	28.4	910	7.3	144.4	57.5	79.8	573.4	180	600.6	470	0.7	6.2	12.3	5.0	1.8
BH-51	804918	1062924	28.3	1296	7.5	208	65.6	188.1	466	448.4	793.6	382	0.4	6.5	12.6	5.5	1.1
BH-77	804505	1059760	26.5	415	7.5	134	11.5	14.6	392.8	43.5	383	322	0.5	6.3	12.3	5.0	0.5
BH-1	816864	1067498	27.7	619	7.2	100	38	47	388	101	408.3	318	0.5	6.0	12.3	5.1	0.4
BH-04	816835	1067510	29	466	7.9	88	14.1	39.6	363.6	73.8	278.8	298	0.9	5.7	12.7	4.8	0.5
BH-60	813870	1061350	25	946	7.6	200	20.9	149.6	378.2	50.0	587.2	481.3	0.4	5.8	12.0	5.1	0.6
BH-53	813936	1061662	29.8	1092	8.1	214	29.5	165.9	322	56.7	657.9	539.3	1.1	5.2	13.2	5.9	0.7
BH-61	814020	1061049	26.3	834	7.3	152	30.2	80.6	373.3	39.6	505.7	414.5	0.4	6.5	12.3	5.4	0.3
BH-57	814172	1061499	21.8	1570	7.5	240	41.3	314.6	414.8	23.7	772.3	633	0.1	6.6	12.4	6.2	0.8

BH-67	814356	1064666	19	790	7.1	112	31.1	160.6	383.1	14.5	409.7	335.8	0.5	7.0	12.0	5.9	0.5
CBH-12	812527	1063543	29.5	892	7	164	52	194	353	150	289.3	626.7	0.1	6.8	12.1	5.6	0.9
DBh-13	816872	1061784	36	1708	7	238	68	335	438	349	359	878.3	0.6	5.9	12.4	4.6	1.6
FBh-12	814520	1063426	23	1153	7.1	183	48	125	344	95	282	657.5	0.3	6.6	12.2	5.6	0.6
HBH-1	814520	1061049	28	941	6.8	123	37	83	520	40	426.2	461.7	-0.1	7.1	11.8	5.6	0.3
MBh-1	811769	1063611	19	647.4	7.2	110	39	57	443	64	363.1	437.5	0.2	6.7	12.2	5.6	0.3
MBh-10	808534	1064055	24.2	860.9	7.9	132	50	131	437	87	358.2	538.3	1.0	5.9	12.9	5.5	0.5
TBh-3	816080	1062886	26	1649	7.1	240	65	354	403	250	330.3	870.8	0.4	6.3	12.4	5.2	1.5
PW-13	812573	1062411	35	734	6.9	177.6	37.4	97.8	488	80.3	400	600	0.5	6.0	12.2	4.5	0.4
PW-2	805167	1063299	35	2620	6.7	596.8	122	23.5	297.7	1611	244	2000	0.2	6.5	12.1	4.9	5.5
PW-30	813111	1063263	19.7	1712	6.7	352	5.7	88.6	366	733.1	300	904	0.3	6.1	12.1	4.6	2.3
PW-4	812527	1063543	22	923	6.8	137.6	37.4	81.3	478.2	74.5	392	500	0.2	6.4	12.0	4.9	0.3
SBh-1	812491	1063930	18	722	7.1	133	33	88	427	54	350	470	0.4	6.2	12.2	5.1	0.3
SBh-9	813111	1063263	20.9	1101	7.1	171	43	162	372	81	304.9	606.7	0.3	6.6	12.2	5.5	0.7
SnBh-1	814072	1065654	25.5	802.4	7.3	118	48	101	462	99	378.7	495	0.3	6.7	12.4	5.7	0.4
SnBh-2	815062	1065559	35	1039	6.8	302.4	67.9	71.1	463.6	765	1039	380	0.0	7.0	12.0	5.9	0.5
TW1	808291	1066600	28	1600	6.8	169	42	71.1	580.7	89.2	599.9	476	0.5	5.7	12.3	4.2	1.8
PW1	805800	1063087	31	712	6.8	195.8	50.7	88.6	580.7	117	700.8	476	0.5	6.0	12.1	4.5	0.4
PW11	808515	1064885	29	1114	6.8	302.4	67.9	71.1	463.6	765	1039	380	0.5	5.7	12.3	4.2	1.8
PW14	811995	1063764	33	850	6.9	167	38	70.2	492.8	112	575.9	404	0.4	6.1	12.2	4.4	0.3
PW16	812986	1062405	35	680	7.2	288	144	59.7	370.8	1086	1320	304	0.4	6.0	12.1	4.5	0.4
PW17	812384	1064409	29	1892	6.7	358.4	140	65.1	341.6	1300	1480	280	0.7	5.8	12.5	4.7	3.1
PW18	815570	1064147	31	2148	6.7	568	91.2	14.5	302.5	1809	1800	248	0.1	6.5	12.1	5.1	4.0
PW22	814254	1061551	25	2800	7.5	112	12	46.6	536.8	68.8	330	440	0.3	6.1	12.2	4.8	6.0
PW28	812180	1061149	26	1390	6.8	448	46.1	55.5	370.8	1133	1312	304	0.7	6.0	12.5	5.0	1.0
T-2	814034	1065326	26	1968	6.9	427.2	50.8	53.7	375.7	1087	1280	308	0.4	6.1	12.4	4.7	3.0

T-3	813410	1065622	29	1900	6.9	160	24	90.3	434.3	180	480	356	0.6	5.6	12.3	4.2	3.2
B-1	809650	1066200	28	838	6.6	168	36.5	55.4	451	190	572	370	0.5	6.6	13.4	4.9	0.4
B-5	807900	1067200	31	804	7.5	157.6	11.8	53.2	507.7	145	432.6	416	0.4	6.7	13.4	4.8	0.3
B-6	808500	1066000	33	756	6.9	320	28.8	43.7	329.4	855	920	270	0.5	6.6	13.3	5.0	0.4
B-7	807850	1065700	32	1472	7.2	236.7	20.3	48.4	418.5	500	676.3	343	0.7	5.9	12.3	4.9	0.9

Measuring unit of each parameter – T(ºC) -Temperature, TDS (mg/l), Ca^+ (mg/l), Mg^+ (mg/l), Cl^- (mg/l), HCO_3^- (mg/l) SO_4^{-2} (mg/l), Na^+ (mg/l), Total Hardness (TH) (mg/l as $CaCO_3$) and Total Alkaliniy (TA) (mg/l as $CaCO_3$)

LSI: Langlier Saturation Index, RSI: Ryznar Saturation Index, AI: Aggressive Index; LSI: Larson Skold Index, PSI: Pockorous Saturation Index;

Appendix 2. The physiochemical analysis and corrosion indices of Dug wells of Dire Dawa City.

Index	**X-coor**	**Y-coor**	**T**	**TDS**	**pH**	**Ca^+**	**Mg^+**	**Cl^-**	**HCO_3^-**	**SO_4^{-2}**	**TH**	**AL**	**LSI**	**RSI**	**AI**	**PSI**	**LRI**
TDW-1	813009	1061596	19	1135	6.8	168	55	197	508	97	416.4	649.2	0.0	6.9	12.0	5.3	0.6
DW-21	815113	1059868	12.6	526	7.6	120	27	61.6	297.7	147.7	244	416	-0.1	6.9	11.9	5.3	0.5
DW-22	816238	1066909	20.5	884	6.7	184	19.5	160.6	431.8	55.4	354	541	0.6	6.9	12.5	6.8	0.1
DW-11	805579	1065086	22.7	804	7.9	88	29.2	34.1	563.6	200.4	462	341.6	0.4	6.3	12.4	5.1	0.6
DW-12	806000	1067040	25	1416	7.4	144	75.4	249	463.6	448.4	380	674	0.6	6.3	12.5	5.4	1.5
DW-19	806316	1064129	25	670	7.3	168	24.3	83.6	461.2	42.24	378	521.3	0.6	6.2	12.5	5.2	0.3
DW-30	811769	1063611	24.6	989	7.1	183	18	91.2	475.8	65.9	390	532.5	0.6	6.0	12.4	4.8	0.3
DW-32	814113	1056268	23.5	884	6.7	184	19.4	160.6	431.9	55.4	541.1	354	0.5	6.0	12.1	4.5	0.4
DW-31	816574	1067528	36	526	7.6	120	27.8	61.6	297.7	147.7	416.1	244	0.4	6.2	12.2	5.1	0.3
DW-33	814113	1056268	26	884	6.7	184	19.5	160.6	431.9	55.4	541.1	354	0.3	6.6	12.2	5.5	0.7
DW-34	816574	1067528	25	526	7.6	120	27.8	61.6	297.7	147.7	416.1	244	0.7	5.8	12.5	4.7	0.3

Measuring unit of each parameter – T(ºC) -Temperature, TDS (mg/l), Ca^+ (mg/l), Mg^+ (mg/l), Cl^- (mg/l), HCO_3^- (mg/l) SO_4^{-2} (mg/l), Na^+ (mg/l), Total Hardness (TH) (mg/l as $CaCO_3$) and Total Alkalinity (TA) (mg/l as $CaCO_3$)

LSI : Langlier Saturation Index, RSI: Ryznar Saturation Index, AI: Aggressive Index; LSI: Larson Skold Index, PSI: Pockorous Saturation Index;

Appendix 3. The physiochemical analysis and corrosion indices of Dug wells of Dire Dawa City.

Index	***X-coor***	***Y-coor***	***T***	***TDS***	***pH***	***Ca^+***	***Mg^+***	***Cl^-***	***HCO_3^-***	***SO_4^{-2}***	***TH***	***AL***	***LSI***	***RSI***	***AI***	***PSI***	***LRI***
MSP-3	815730	1061000	19	514.7	7.3	111	27	17	445	19	364.8	390	0.3	6.7	12.3	5.7	0.1
SP-1	807621	1059771	26	1268	7.4	184	60.8	281.6	427	290.2	350	713.3	0.5	6.3	12.6	5.5	1.3
Sp12	816904	1073154	37	688	7.7	159.6	31.3	32.3	299	263.7	245	529.3	0.8	6.1	12.7	5.4	1.0
SP-14	812255	1061280	25.3	526	7.6	132	17	94.6	356.2	7.9	292	400.9	0.6	6.4	12.6	5.8	0.3
SP-19	814595	1059950	25.7	680	7.4	152	9.7	105.6	390.4	5.27	320	420.5	0.4	6.5	12.5	5.7	0.3
SP-21	816219	1061625	20.3	570	7.4	140	24.3	56.1	507.5	15.8	416	451.3	0.6	6.2	12.6	5.2	0.1
SP-25	813438	1059985	24.8	570	7.4	140	24.3	56.1	507.5	15.8	416	451.3	0.5	6.3	12.6	5.4	0.1
SP-26	816850	1059880	40	544	7.6	128	26.8	94.6	295.2	50.1	242	431.5	0.4	6.7	12.5	6.3	0.5
SP-3	815449	1059700	25	408	7.1	200	4.8	34.1	231.8	5.27	190	520.3	0.0	7.0	12.1	6.3	0.2
SP-5	815794	1059800	24	270	7.3	64	4.8	34.1	187.9	18.2	154	180.3	-0.4	8.1	11.7	7.6	0.3
SP-7	816000	1059801	37	458	7.5	144	17	28.6	446.5	15.8	366	430.9	0.6	6.3	12.6	5.5	0.1
SP-8	812000	1072000	24.8	528	7.7	129.2	16.1	24.7	419.7	78.3	344	390.1	0.7	6.3	12.8	5.6	0.3
DSP_1	814232	1060663	22.5	1476	7.1	160	70	262	449	234	368	691.7	0.3	6.6	12.3	5.4	1.1
FSP-5	813592	1060342	25.2	720	7	128	23	91	415	40	3402	415.8	0.1	6.9	12.0	5.7	0.3
LSP-6	806574	1063754	28.6	786.7	7	143	30	120	437	63	358.2	482.5	-0.2	7.1	11.8	5.5	0.4

Measuring unit of each parameter – T(°C) -Temperature, TDS (mg/l), Ca^+ (mg/l), Mg^+ (mg/l), Cl^- (mg/l), HCO_3^- (mg/l) SO_4^{-2} (mg/l), Na^+ (mg/l), Total Hardness (TH) (mg/l as $CaCO_3$) and Total Alkaliniy (TA) (mg/l as $CaCO_3$)

LSI : Langlier Saturation Index, RSI: Ryznar Saturation Index, AI: Aggressive Index; LSI: Larson Skold Index, PSI: Pockorous Saturation Index;