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Groundwater quality evaluation for irrigation, Modjo River catchment, a wash basin, Central Ethiopia

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Abstract

Irrigated agriculture is dependent on an adequate water supply of usable quality. Water containing impurities, which are injurious to plant growth, are not satisfactory for irrigation. Water quality for agricultural purposes is determined on the basis of the effects of the water on the quality and yield of the crops, as well as the effects on drainage efficiency and characteristic changes in the soil [16]. This study aims to assess the quality of groundwater in Modjo river catchment for irrigation. Hence, the groundwater samples were collected from well and borehole situated at different site within the catchment to analyze for necessary parameters. Consequently, in-situ measurements such as; EC, pH and TDS were carried out in the field inventory using portable (pH) meters, whereas major ions are analyzed in Sinana Agricultural Research Center Soil laboratory. The chemical analysis of the samples shows that Na-Ca-HCO3 water type in the recharge area, intermediate water type Ca-Mg-Na HCO3 in northern and central part of the area and Ca-Mg-HCO3 water type towards the east of the subbasin. Most of the water in the study area is clustered as Calcium-Sodium-Magnesium-Bicarbonate type, which is characterized by a high concentration of HCO3 and Ca. Generally water quality analysis shows that as the concentrations in the water sample is below the maximum allowable limits for irrigation (i.e.EC<2000 µS/cm and SAR<9) and therefore the groundwater could be used safely for irrigation.

Keywords: Groundwater; Water quality; Irrigation; Modjo subbsin

1. Introduction

Irrigated agriculture is dependent on an adequate water supply of usable quality. Just as any water is not suitable for human beings, in the same way, any water is not suitable for plant life. Water containing impurities, which are injurious to plant growth, is not satisfactory for irrigation, and called unsatisfactory water. Water quality for agricultural purposes is determined on the basis of the effects of the water on the quality and yield of the crops, as well as the effects on drainage efficiency and characteristic changes in the soil [16] Water quality is defined by the physical, chemical and biological characteristics and composition of water sample.

Irrigation waters whether derived from springs, streams, or pumped from wells, contain appreciable quantities of chemical substances in solution that may reduce crop yield and deteriorate soil fertility. The suitability of water for irrigation is determined by its potential to cause problems to soils and crops and related management practices needed. The relevant parameters for appraising the suitability of irrigation water quality in terms of crop production are categorized based on the concentration of dissolved salt (salinity hazard), relative proportion of sodium ions to other cations (sodium hazard soil permeability effects), carbonate and bicarbonate anion concentration as related to calcium plus magnesium concentration (alkalinity) and concentration of specific elements that may be toxic (toxicity) [3].

However, the quality of water, whether good or bad, is not sufficient to decide the suitability of water for agriculture. Several non-water factors must be considered in deciding the usefulness of water for a specific situation. These include

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soil texture and structure, internal soil drainage, gypsum and lime contents of the soil, salt and sodium tolerance of the crop, and irrigation method and management practice followed [1].

Groundwater is one of the most valuable natural resources, which supports in overcoming a rainfall shortage for crop production. However, deterioration of its quality has been observed in many places in last decades. In Ethiopia groundwater quality varies widely. It is primarily influenced by geology, physicochemical factors, biological factors, anthropogenic influences such as pollution from industrial, municipal and agricultural sources, geomorphologic and geographical setting as well as climatic condition [12]. To have sustainable groundwater resource for irrigation; water quality investigation is crucial.

As a result, this study will provides valuable data and baseline information in formulating technically sound groundwater resources management policies in mitigating the deterioration of groundwater quality in the study area. Consequently, this study was carried out with the objective of groundwater quality evaluation for irrigation in the Modjo river catchment.

2. Material and methods

2.1. Description of Study Area

This study was conducted for Modjo River catchment, which is located at upper Awash Basin. The sub-basin covers about 2201 km^2 area and is bounded within 8°75'N-9°05'N latitude and 38°56'E -39°17'E longitude. Elevation for the catchment ranges from 1594 to 3068 meter above mean sea level. The area has a bi-modal rainfall with a short rainy season from March to May and with a long rainy season from June to September. The mean annual temperature of the sub-basin is 19°C and the average annual rainfall is 933 mm. The relief of the study area is generally flat land with an undulation of some ridges and mountains like the eastern part of Yerer and the catchment generally shows an eastward decrease in elevation. The water units found in the study area are Modjo and Gale Wemecha Rivers. Regarding geological setup, the area belongs to the Quaternary rocks of Pleistocene and Holocene which is 70% quaternary volcanic rock and 30% unconsolidated sediment. According to [17], those rocks are highly fractured and resulted in a favorable situation for groundwater recharge and occurrence and are very important hydro-geological formation that is used as a good source of groundwater in Ethiopia.

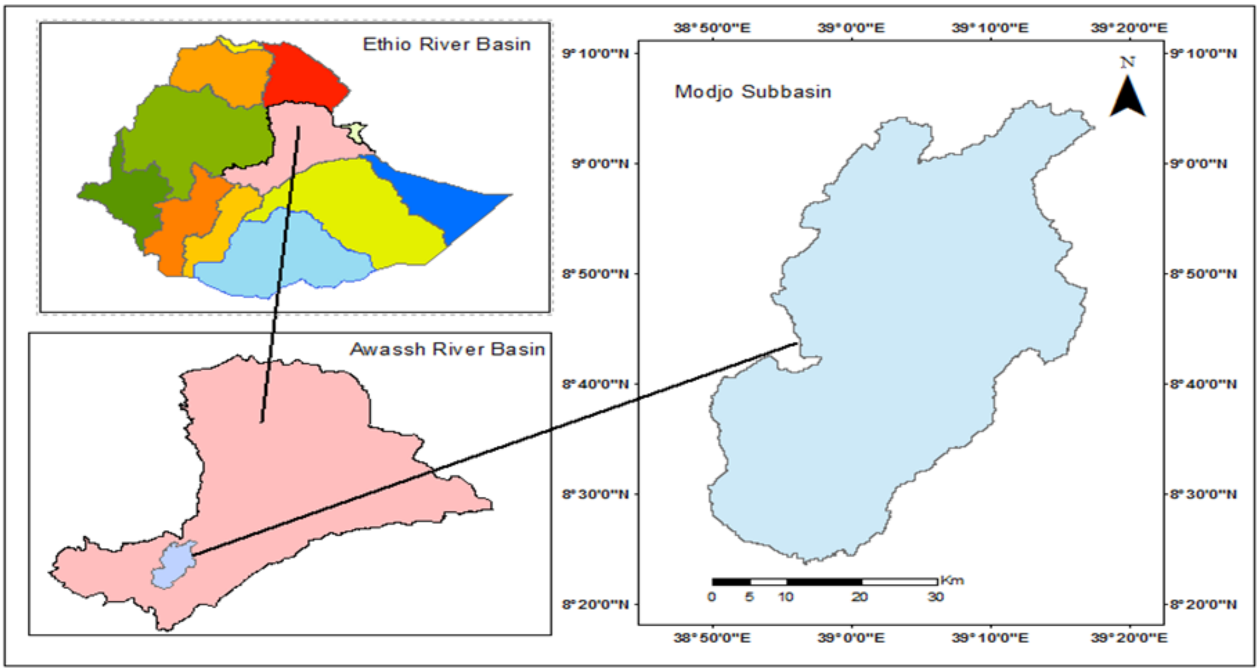

Figure 1 Location map of Modjo Sub-basin

2.1.1. Salinity Hazard (TDS)

Water with high total soluble salts (TDS) content poses a salinity hazard in which high concentrations of salt in the soil result in a physiological drought condition. Excess soluble salts in the root zone restrict plant roots from withdrawing water from the surrounding soil, effectively reducing the plant available water [4]. The most commonly responsible electrolytes in causing salinity in water are the cations of Ca^{2+}, Na^{+}, K^{+} and the anion of HCO^{3-}, Cl and SO_4^{2-}.The contributions of CO_3^{2} is often time negligible but at times they may have to be taken in to account [13].

Table 1 Water classification by salinity

Water type	EC dS/m	TDS mg/litre
Non-saline water	< 0.7	< 500
Saline water	0.7–42	500–30 000
Slightly saline	0.7–3.0	500–2 000
Medium saline	3.0–6.0	2 000–4 000
Highly saline	> 6.0	> 4 000
Very saline	> 14.0	> 9 000
Brin	> 42	> 30 000

Source Based on [9]

2.1.2. Sodicity Hazarded (SAR)

High concentrations of sodium in irrigation water can result in the degradation of well-structured soils. This will limit aeration and soil permeability to water, leading to reduced crop growth [6]. Poor aeration due to poor drainage will reduce the oxygen available to plant roots for respiration and will also cause carbon dioxide to build up in the soil, both further restricting root growth [14]. Sodium in irrigation water can also cause toxicity problems for some crops, especially when sprinkler applied [5]. Soil dispersion is the primary physical process associated with high sodium concentrations [8]. The high alkalinity associated with sodicity cause soil organic matter to disperse, which further weakens soil structure.

Table 2 Potential irrigation problems due to sodium in irrigation water

Salinity level of irrigation water ds/m	No reduction	Slight reduction	Medium reduction	Sever reduction
	SAR	SAR	SAR	SAR
ECw = 0.7	<1	1-5	5-15	>11
ECw = 0.7-3.0	<10	10-15	15-23	>12
ECw = 3.0-6.0	<25	>25	No effect	No effect
ECw = 6.0-14.0	<35	>35	No effect	No effect
ECw = >14.0	No effect	No effect	No effect	No effect

Source Based on [15]

2.1.3. Ionic balance

Magnesium is the 2nd most abundant cation found in highly saline water. However, in low ECiw, Ca^{2+} dominates over Mg^{2+}. Obviously, it can be stated that with an increase in EC

iw, Ca:Mg ratio tends to decrease. It was believed in the past that, when the proportion of Ca^{2+}:Mg^{2+} is high, the sodicity hazard is low. However, this holds good so long as ECiw remains less than 4 dS m-1and Ca:Mg >1. Harmful effects on soils appear when the ratio of Ca:Mg <1. Occurrence of Mg^{2+}in higher proportion than Ca^{2+} tends to increase soil dispersion. Therefore, if the proportion of Mg^{2+} amongst the divalent ions is high, the soil dispensability hazard will be high [2].

2.1.4. Permeability index

Soil permeability is affected by long-term use of irrigation water. Sodium, Ca, Mg and HCO_3^- contents of the soil influence it. [7] evolved a criterion for assessing the suitability of water for irrigation based on the permeability index. Accordingly, waters can be classified as class I, Class II and Class III based on PI. Class I and Class II waters are categorized as good for irrigation with 75% or more maximum permeability. Class III water is unsuitable with 25% of maximum permeability [7].

3. Results and discussion

3.1. Physiochemical parameters

3.1.1. Hydrogen ion activity (pH)

The pH of the water samples obtained varies from 6.88 to 8.3. Water bicarbonate is dominant and in general the water of the study area has an alkaline pH. Alkalinity increases from north east towards the south direction (high rainfall to low rainfall area) of the catchment as shown on Figure 2 below, this is because high rainfall contributes to the formation of acidity lowering the alkaline concentration in the groundwater.

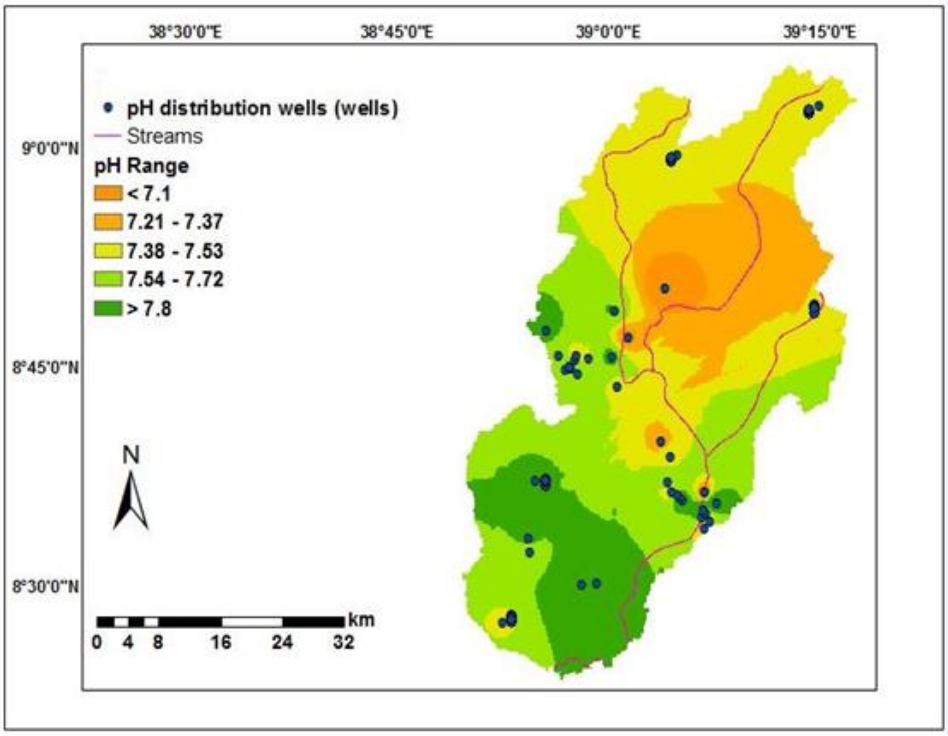

Figure 2 Spatial variation of pH value within the catchment

3.1.2. Total dissolved solid (TDS)

Total Dissolved Solids concentration is approximately equal to the sum of the concentrations of all dissolved ions. From the water quality analysis result TDS of the study area ranges from (175-750) ppm. It increases towards ground water flow direction along the axis of the valley (Fig 3). This implies that as the water goes from the highland through fractured and unconsolidated sediments it acquires dissolved solids more.

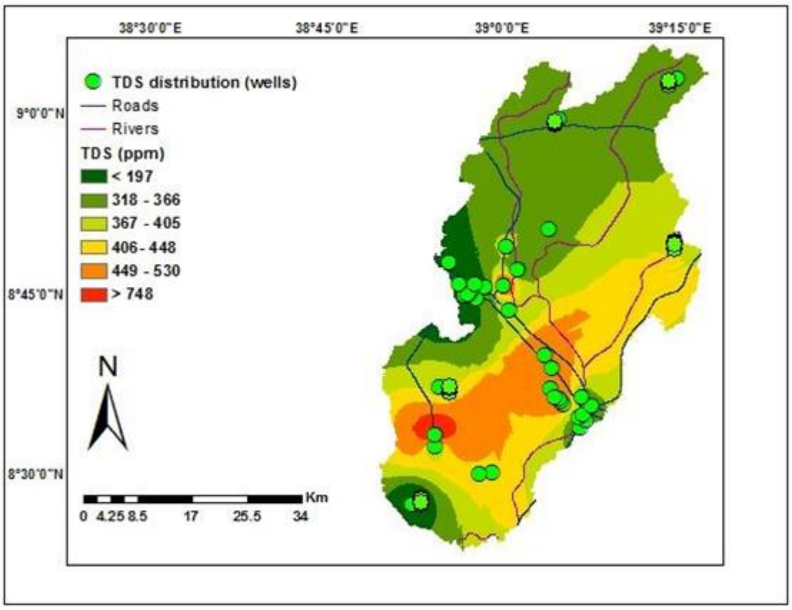

Figure 3 TDS map of Modjo subbasin

3.1.3. Electrical conductivity (EC)

The conductivity of the groundwater in the area ranges from 351µS/cm to 1038µS/cm in both well and borehole. Higher conductivities are observed in wells located in the South eastern along the depression of the subbasin Figure 4. This increase in conductivity towards the axis of the valley could be associated with the geology, the ground water flow direction and possible evaporation. According to[10]. dissolved solid concentrations in groundwater increase along flow paths, from the surface to the saturated zone and through the aquifer, due to the dissolution of minerals. Similarly, the groundwater of the catchment was found to flow from the north eastern escarpment towards the south eastern floor contributing to increase in dissolved solid along its flow path.

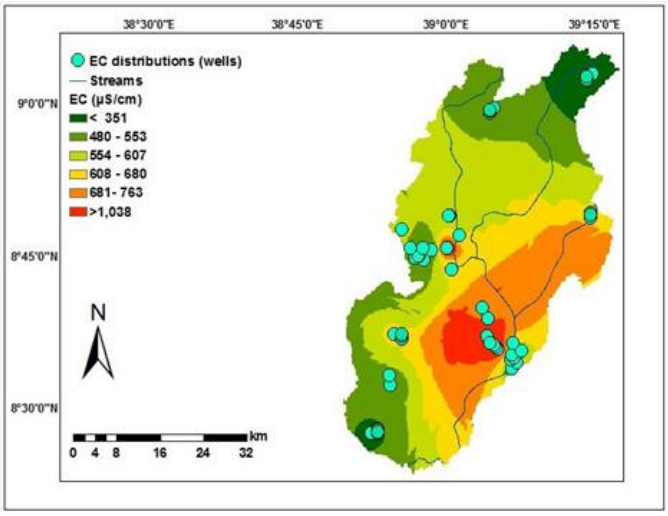

Figure 4 EC map of Modjo subbasin

Electrical conductivity is the ability of a substance to conduct electric current [11]. The presences of charged ionic species in water make it conductive. In other words, EC is a measure of the total concentration of ion. Even though conductivity may not correlate directly to concentration, in this study the water quality results show that electrical conductivity (EC) and total dissolved solid (TDS) have a good correlation of TDS = 0.847EC – 121.2 with R^2 = 0.8094 see (Figure 5).

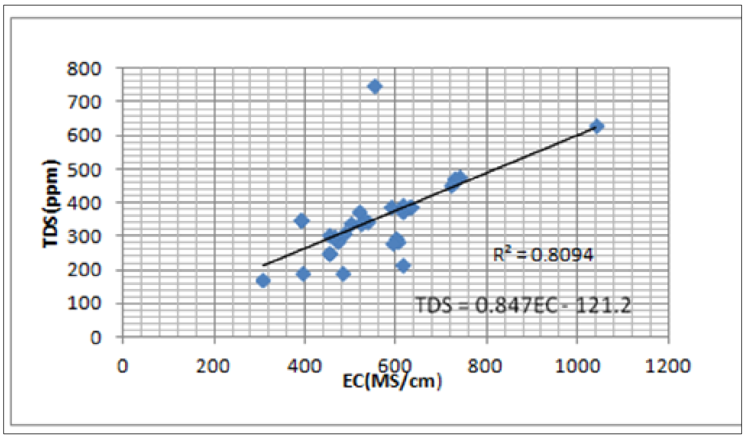

Figure 5 TDS – EC correlation for the water sample

3.2. Major Ions

3.2.1. Sodium and potassium (Na^+ & K^+)

Sodium is the second abundant cation in the subbasin Table 3. The analysis shows that as it ranges from 23 to 135mg/l. The mean is about 54.2mg/l. Most of the samples show a value ranging from 30 to 70mg/l. Sodium concentration shows in general an increasing tendency from the west escarpment towards the eastern tip of the study area. This is because of long time water-rock interactions. The main source of sodium in the study area could be sodium plagioclase (albite) and to some extent sodium may be retained by adsorption on mineral surface of lacustrine deposits having high cation exchange capacities such as clay before directly recharge to groundwater.

The minimum concentration of Na^+ with respect to K^+ is greater by 7mg/l in the groundwater sample Figure 6. Potassium is lower than sodium in the area, because it is resistant to chemical attack while species containing sodium and calcium are more susceptible to weathering. The low concentration of potassium in general could be attributed to the lesser proportion of potassium feldspar.

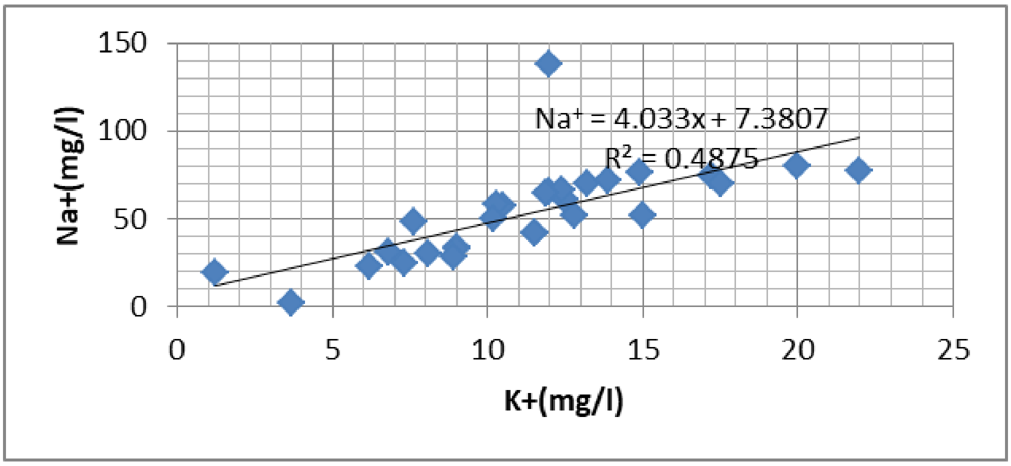

Figure 6 Na+ Vs K+ in the subbasin

3.2.2. Calcium and Magnesium

Calcium is the most abundant cations and magnesium takes the third order in the study area as per concentrations in milligram per litter. Because of their similar geochemical behavior calcium and magnesium are treated together. Most of the samples in the study area are sodium and calcium bicarbonate water types. Calcium ranges from 32mg/l to 78.3mg/l, higher concentrations are found at the centre and south west of the area. Magnesium ranges from 1.2mg/l to 36 mg/l. The main source of Calcium in the study area could be derived from weathering of calcic plagioclase and calcium rich pyroxene since there are no external factors (industries) which can be source of calcium in the area.

3.2.3. Chilorides

Table 3 Summary statistics of the groundwater sample result in the catchment

Constituent	Unit	Minimum	Maximum	Mean
EC	µS/cm	307	1038	554
TDS	mg/l	175	750	352
pH		7.09	8.30	7.60
Ca^{+2}	mg/l	34.2	79.3	57.4
Mg^{+2}	mg/l	1.20	36.0	17.0
Na^{+}	mg/l	23.0	135	54.2
K^{+}	mg/l	6.20	22	12.0
HCO_3^-	mg/l	126	468	360
NO_3^-	mg/l	0.00	17.5	5.20
Cl^-	mg/l	0.15	69	17.0
F^-	mg/l	0.00	2.2	0.84
SO_4^{-2}	mg/l	0.00	29.7	5.50
SAR	mg/l	0.73	6.8	1.90

The mean concentration of chloride is 17 mg/l. It ranges from 0.15 mg/l to 69 mg/l. Only single BH with chloride of 85mg/l. Most of the samples are between 5.5 mg/l and 50 mg/l. The chloride concentration is high at plain areas as the general groundwater flow Direction.

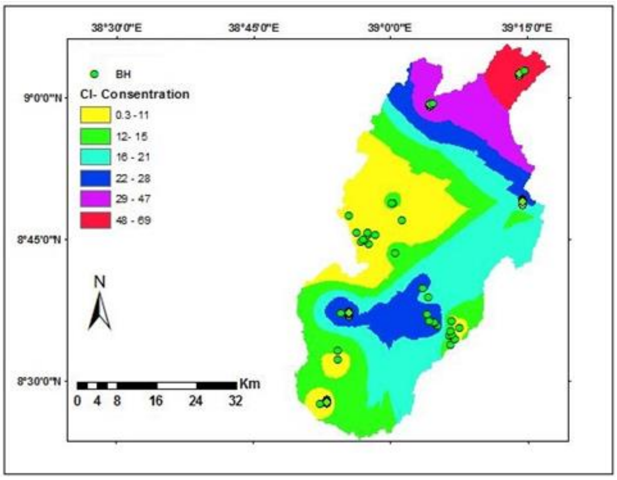

Figure 7 Cl concentration distribution in groundwater of Modjo subbasin

3.2.4. Carbonets

Carbonate in the area is mainly in the form of bicarbonate. Bicarbonate is the major ion in the groundwater. The concentration of bicarbonate in boreholes ranges from 127 mg/l to 468 mg/l. The highest bicarbonate concentrations were detected in Modjo hand dug wells which have more than 461 mg/l of bicarbonate. The mean concentration for the boreholes is about 360 mg/l. Bicarbonate is by far the largest anion in the study area. All samples that show higher TDS with high concentration of HCO_3 and the lower TDS is the vice versa. Higher concentrations of HCO_3 are observed in wells located in the South east of the plain and a kind of decrease to the North and Western tip of the study area.

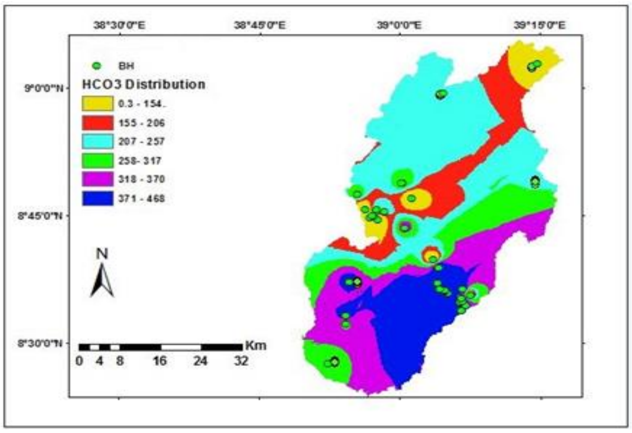

Figure 8 HCO_3 concentration distribution in groundwater the subbasin

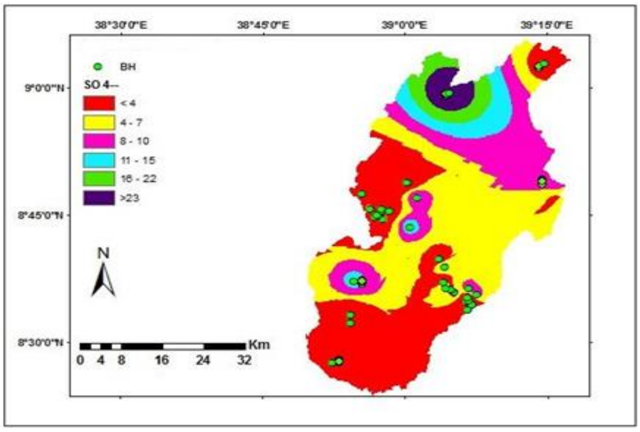

Figure 9 SO_4 concentration distribution in groundwater of Modjo subbasin

3.3. Cluster Analysis

AquaChem 2012.5 software was used for groundwater cluster analysis in this study.

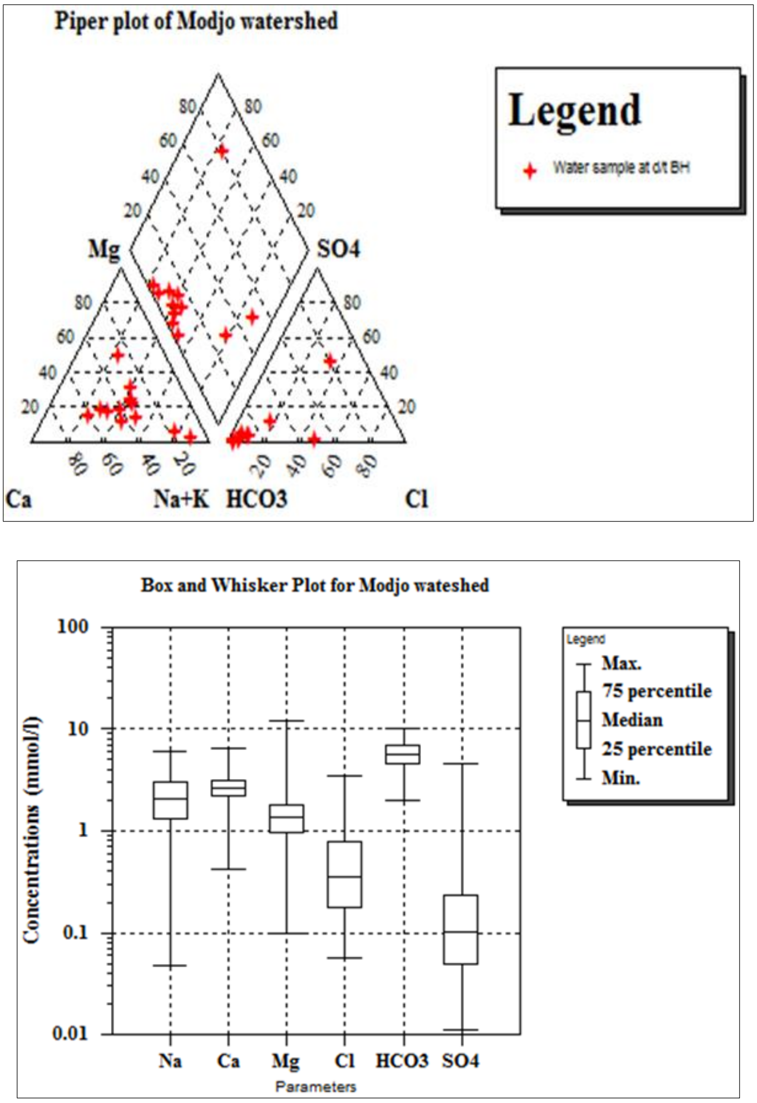

Figure 10 Clusters analysis of hydro-chemical and their statistical summary

Each cluster group is plotted on Piper graph and Box and Whisker summary plot (Figure 10), which shows the relative contribution of major cations and anions on a mill equivalent basis to the total ion content of the water. Calcium and sodium are the dominant cations in all water types. Calcium is the major cation, and bicarbonate is the dominant anion with a concentration of about 43% and 90% of the total cations and anions respectively. In this group, sulphate is found in very small amount which is about 2% of the total anions. Plotting of the chemical analysis of samples analyzed in the area using piper graph show that Ca - Na -HCO_3 water type in the recharge area, intermediate water type Ca-Mg-Na-HCO_3 in northern and central part of the subbasin and Ca-Mg-HCO_3 type towards the east and most of the water is clustered in the left part, suggesting that the water in the study area is a Calcium-Sodium-Magnesium-Bicarbonate type, which is characterized by a high concentration of HCO_3 and Ca whereas Na and Mg are available in minimum quantity.

4. Water quality evaluation for irrigation

The water quality evaluation in this study area was focus on the important parameters and criteria of the chemical water quality suggested for irrigation.

4.1. Salinity hazard

Based on EC as an index of salinity hazard suggested by [5] (Table 5), the water samples of the study area can be classified as good for irrigation Table 4.

Table 4 Suitability of groundwater in the study area for irrigation based on EC

Water samples	Ranges of EC (µS/cm)	Water class
All BH except BH-17	351- 763	Good
Only BH-17	1041	Medium/ permissible

Table 5 Suggested criteria for irrigation water use based upon conductivity

Classes of water	Electrical Conductivity (µS/cm)
Excellent	≤250
Good	250 – 750
Permissible1	750-2000
Doubtful 2	2000-3000
Unsuitable2	≥3000

Source, [5]

4.2. Sodicity hazard (SAR)

The groundwater sample analysis shows that the groundwater of the study area is free of Sodicity hazard based on SAR value as suggested by [*5]*, on table 7 below.

Table 6 Suitability of Groundwater of the study area for irrigation purpose based on SAR

Water samples	Range of SAR	Water class
All BH	0.07-0.68	Excellent

Table 7 General classification of water sodium hazard based on SAR values

SAR values Mg/l	Sodium hazard of water	Comments
1-9	Low	Use on sodium sensitive crops must be cautioned.
10-17	Medium	Amendments such as gypsum and leaching needed

18-25	High	Generally unsuitable for continues use
>26	Very High	Generally unsuitable for use

Source, [5]

Wilcox plot on Figure 11 indicates the correlation of consantration analysis:-

- All samples analysis result fall under S_1 curve of the plot indicating that the groundwater in the area is free of alkalinity (low sodium) hazards
- Most of the sample analysis result fall undercolomon C_2 of the plot suggesting that the groundwater consantration with medium salinity and some under C_3 shows high groundwater salinity is showen in some borehols.

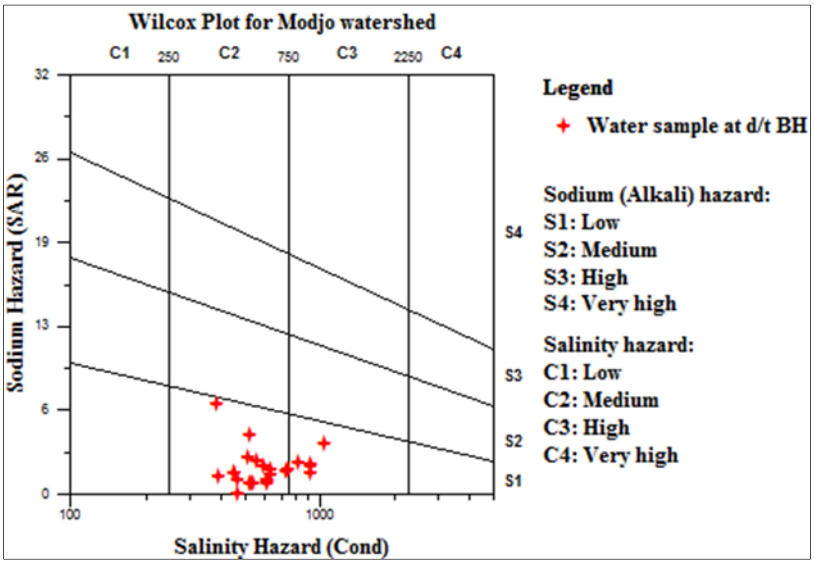

Figure 11 Degree of sodcity and salinity hazard in the groundwater of Modjo subbasin

4.3. Ionic balance

Harmful effects on soils appear when the ratio of Ca:Mg < 1. In this study the ratio of Ca to Mg in the groundwater was found to be 3.2 (Ca:Mg= 3.2); signifying that the groundwater is safe of this problems.

4.4. Toxicity problems

For toxicity problems the ions of primary concern are chloride and sodium. Sometimes toxicity problems may occur even when these ions are in low concentrations. In this study the groundwater in the study area is free of toxicity problems and it is suitable for irrigation in this regard.

5. Conclusion

The hydro-chemical analysis of water samples in the area revealed that the water samples from the north western highland escarpment have relatively lower values of TDS, EC, sodium, chloride etc. Generally, the ion concentrations increase when one is moving from the highland escarpment to the central part of the subbasin indicating the increased dissolution along the flow paths from recharge to discharge areas. The water in the study area is a Calcium-Sodium-Magnesium-Bicarbonate type, which is characterized by a high concentration of HCO3, Ca, Na and Mg. In general, for most of the major constituents the samples show concentrations below the maximum allowable limits for irrigation as indicated by different scholars. Especially groundwater in Modjo subbasin is low in the sodium adsorption ratio (SAR) values making them favorable for all types of irrigation.

Recommendation

The concentrations in the water sample shows below the maximum allowable limits and therefore the groundwater could be used safely for irrigation.

Compliance with ethical standards

Acknowledgments

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References

[1] Abrol IP, SP Yadav, FI Massoud. Salt Affected Soils and their management. FAO.Soils Bulletin 39: FAO, Rome. 1988.

[2] Alvaro. Physical Properties of Magnesium Affected Soils in Colombia. National University of Colombia, Palmira, Colombia. 2003; 6.

[3] Ayers RS, DW Westcot. Water Quality for Agriculture. FAO Irrigation and Drainage Paper. 29 Rev. 1. FAO, Rome, Italy. 1994; 201.

[4] Bauder JW, TA Brock. Irrigation water quality, Soil amendment and crop effects on sodium leaching. Arid Land Research and Management. 2001; 15: 101-113.

[5] Bauder TA, RM Waskom, JG Davis. Irrigation water quality criteria. Colorado State University Cooperative Extension. 2003.

[6] Dehayr R, N Diatloff, I Gordon. Irrigation water quality salinity and soil structure stability. Queensland Government, NRM facts, Water Facts W 55, Brisbane Australia. 2006; 4.

[7] Doneen LD. Notes on water quality in agriculture, Water science and engineering. Depar tment of Water Sciences and Engineering, University of California, Davis. 1996.

[8] Falstad, J. 2000. Soil Condition. Transplant Status in Burger Draw. Billings Gazette. Prepared by D.G. Steward Page. Burger Draw Comments and Recommendations. 6/06/00

[9] FAO. 1985, Water quality for agriculture, 29 Rev.1. 1985.

[10] Freeze RA, Cherry JA. Groundwater. Prentice-Hall, Englewood Cliffs, N.J., USA. 1977; 604.

[11] Hem, J. D., Roberson, C. E., and Fournier, R. B., 1982, Stability of PMnOOH and manganese oxide deposition from spring water: Water Resources Research, v. 18, p. Series, no. 73, Washington, D.C., American Chemical 563-570

[12] International Water Management Institute, Sri Lanka. 2012. groundwater availability and use in sub-saharan africa: PO box no. 2075, 127, Sunil Mawatha, Pelawatte, battaramulla, Sri Lanka.

[13] Keren R. Salinity In: Sumner, M.E (eds.). Hand book of soil science.CRC press. 2000; 126.

[14] Mehreteab Tesfai, V Dawod, Kiflemariam Abreha. Management of salt affected soils in the NCEW 'Shemshemia irrigation scheme in the Upper Gash Valley of Eritrea. 2002.

[15] Rhoades, J.D. (1984). Using saline water for irrigation. In: "Scientific Reviews on Arid Zone Research Scientific Publishers, Jodhpur, India.

[16] Wilcox LV. Classification and use of Irrigation Waters. U.S. Dept. Agric. Circ. 969, Washington, DC. 1995; 19.

[17] WSP. Country Case-Study by theCost-Effective Boreholes Flagship of the Rural Water Supply NetworkFinal Report. June 2006.