Suitability of Groundwater Quality for Irrigation: A Case Study on Hand Dug Wells in Hantebet Catchment, Tigray, Northern Ethiopia

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Abstract: The study was conducted in Hantebet catchment area which has a total area of 24.5 km^2. The major objective of the study was to assess the suitability of the groundwater quality for irrigation purpose through hydrochemical investigation of the different hand dug wells in the watershed. Having classified the hand dug wells, using the stratified and random sampling techniques, a total of 20 water samples were selected and collected. Water samples were analyzed for alkalinity, sodium (Na^+), potassium (K^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), chloride (Cl^-), bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), sulphate (SO_4^{2-}-S), and nitrate (NO_3^--N) in Water Works Design and Supervision Enterprise Laboratory Service, Addis Ababa. pH and electrical conductivity (EC) were measured in situ. Sodium Adsorption Ratio (SAR) was computed using sodium (Na^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) concentrations in meq/lit. Chemical data of groundwater samples as plotted in trilinear diagram indicated eight water types, Ca-HCO3, Ca-Na-HCO3, Ca-Mg-Na-HCO3, Ca-Na-Mg-HCO3, Na-Ca-HCO3-SO4, Ca-Mg-HCO3-SO4, Ca-Na-Mg-HCO3-SO4 and Ca-Na-HCO3-SO4. Most of the water samples plotted in the Wilcox plot fall in the zone designated C2-S1 and C3-S1 indicating that the groundwater samples generally have low sodium absorption ratio (SAR) and medium to high salinity hazard associated with them. In terms of salinity, eight samples were excellent for irrigation use and twelve samples were with slight to moderate degree of restriction on the basis of ECw. In terms of infiltration, on the basis of ECw and SAR value, eleven samples pose slight to moderate degree of restriction on irrigation. However, nine samples pose none degree of restrictions to its use for irrigation due to its effect on soil infiltration rates. Groundwater in the study area is suitable for surface and sprinkler irrigation use with no chloride toxicity, and with respect to sodium toxicity. Only one sample shows SAR values above 3 (3.095).

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1. Introduction

Irrigation is one of the methods used to increase food production in arid and semi-arid regions. It can enhance food production, promote economic growth and sustainable development, create employment opportunities, and improve living conditions of small-scale farmers and thus contribute to poverty reduction and protects the environment from degradation and pollution (Abraham et al., (2005) cited in Nata et al., (2007),. Furthermore, it increases subsurface water levels and recharge groundwater. On the other hand, if irrigation is not properly managed, it can have adverse effects on environment and public health.

The main economic means of Tigray region is rain fed agriculture. The rainfall is erratic and unreliable. The topography of the area is undulating. Thus with the traditional agricultural practices, natural resources are severely degraded due to human interference as well as natural devastation; the land productivity is declining at alarming rate. As a result, the region is not in a position to cover the annual food requirement of the people. To alleviate the challenges of food insecurity in the region, promotion of irrigated agriculture is given priority in the strategy of the Nation (Mekuria, 2003). As a result hand dug well construction and utilization is practiced in the region as well as by individuals in the processes of food security attaining at the households in sustainable basis. In Hantebet watershed, the households constructed about 154 hand dug wells for irrigation purpose. The households benefited from the intervention by cultivating and producing different high value crops two-three times per annum due to the availability of water. Regardless of its benefit the extension workers as well as beneficiaries do not have any understanding on the suitability of groundwater for irrigation purpose to produce crops and there was no data regarding the suitability of ground water for irrigation purpose in the region, therefore the issue of sustainability related to water quality and quantity has to be addressed early in the process.

Since quality of water is part of the ecological concerns to be considered in the beginning, knowledge of irrigation water is critical to understand what management changes are necessary for long-term productivity (Bohn et al., 1985; Brady, 2002). Besides these, irrigated agricultural crops need very good quality water (FAO, 1985). Therefore, the main purpose of carrying out this research was mainly to assess the groundwater suitability for irrigation in Hantebet watershed of Tigray region.

2. Methodology

2.1. Location

The study area, Hantebet catchment, is located in the southeastern zone of Tigray National Regional State, about 50 km southwest of Mekelle, which is the capital city of Tigray. The catchment is one of the tributary of the Tekeze River, which is a tributary to Atbara. Geographically the study area is located between latitude 13° 16' and 13° 24' N and longitude 39° 12' and 39° 20'E having an area of about 24.5 km^2.

2.2. Data Collection

The water samples were collected in January, 2010 from hand dug wells with the aid of environmental sampler in order to have representative sample free from contamination from sampling tools. After each sample is collected, an insitu measurement was made for conductivity, pH, TDS and temperature using Sension Platinum Series portable pH and Conductivity meter (HACH made). Also measured at the field are coordinates and elevation of each of the locations sampled using GPS. All the water samples were collected in 2 liters plastic bottles which were washed and triple-rinsed with distilled water and with the collection water before sampling and transporting them to the laboratory.

2.3. Sampling

After collecting the EC values at water temperature of all the groundwater in the hand dug wells, it was carefully changed in to the EC at 25°C by using the correction factor, and then all the water points were classified according to their EC values at 25 °C in to five groups adopting the following table (Bauder, et al., 2003).

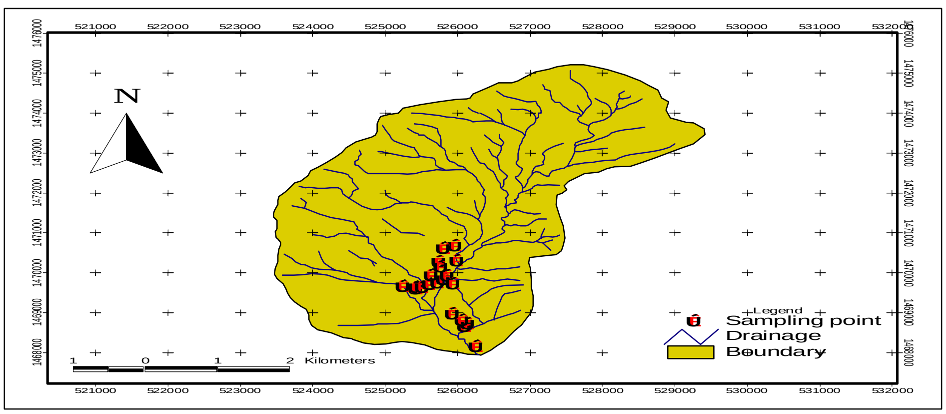

Figure 1: Sampling location of the hand dug wells in the study area

Table 1: Suggested limits for irrigation water use based upon electrical conductivity

S/N	Class	EC(dS/m at 25°C)
1	Excellent	$\leq$ 0.25
2	Good	0.25 – 0.75
3	Permissible[1]	0.76 – 2.00
4	Doubtful[2]	2.01 – 3.00
5	Unsuitable[2]	$\geq$ 3.00

N.B: dS/m at 25°C is equal to mmhos/c, 1 = leaching needed if use, 2 = good drainage needed if used.

Based upon the EC suggested limits for irrigation water use, out of the total 154 hand dug wells, 42 wells were classified to good, 67 wells were classified to be permissible. Since the remaining wells are dried wells, they are not categorized to any one of these classes. Having classified the hand dug wells, using the above stratified classification; random sampling techniques were adopted to take a sample of 20% from each class. Accordingly, 7 samples from good class and 13 from permissible class, a total of 20 water samples were selected and collected approximately with uniform spatial distribution over the study area (Figure 1). The adopted sampling technique was depth integrated sampling.

2.4. Data Analysis

The water samples were analyzed for alkalinity, sodium (Na^+), potassium (K^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), chloride (Cl^-), bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), sulphate (SO_4^{2-}) and nitrate (NO_3^--N) in Water Works Design and Supervision Enterprise Laboratory Service, Addis Ababa.

Sodium Adsorption Ratio (SAR) was computed for each water sample from the analyzed sodium (Na^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) using the derived calculations stated in (Lloyd, 1985).

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

Where the concentration of sodium, calcium and magnesium ions is expressed in milliequivalents per liter (meq/lit)

Cations: sodium (Na^+), potassium (K^+), magnesium (Mg^{2+}) and calcium (Ca^{2+}) were analyzed using AAS (Atomic Absorption Spectrophotometer). Anions such as chloride (Cl^-), sulphate (SO_4^{2-}), and nitrate (NO_3^-- N) were analyzed using UV Spectrophotometer. EC meter and pH meter were used to determine the electrical conductivity and pH of each sample. Titration method was used to determine HCO_3^- and CO_3^{2-} ions.

Water chemistry data has been processed using RockWare (2006) Aq•QA, spreadsheet for water analysis. The quality of the irrigation water is assessed in terms of salinity hazard, sodicity hazard, specific ion toxicity and miscellaneous problems. The salinity hazard of the water is expressed by the electrical conductivity (EC_w). The sodicity hazard of the water is determined by calculating the sodium adsorption ratio (SAR) and electrical conductivity of the groundwater. In addition to the two parameters, the quality of the irrigation water is evaluated on specific Cl^- toxicity and Na^+ and miscellaneous problems of NO_3 – N, HCO_3^- and pH. The chemical quality of irrigation waters was assessed by the classification scheme of FAO**,** (1989) stated in Ayers et al. (1994) (Table 2).

3. Results

3.1. Cations and anions

3.1.1. Major Cations

The cationic concentrations in the groundwater samples of the study area were presented in table 4 and figure 2. The respective ranges for Na^+, K^+, Ca^{2+}, and Mg^{2+} in mg/l are 22.5 – 128, 0.2 – 5.3, 75.6 – 117.6 and 4.59 – 33.15, respectively. The lowest and highest concentrations were collected at HAGW-S17 and HAGW-S2 for Na^+, at HAGW-S19 and HAGW-S4 for K^+, at HAGW-S10 and HAGW-S4 for Ca^{2+} and at HAGW-S16 and HAGW-S5 for Mg^{2+}. The mean concentration values for Na^+, K^+, Ca^{2+}, and Mg^{2+} in mg/l were 50.275, 0.975, 94.236 and 17.339, respectively. In the groundwater samples calcium and sodium were dominant cations.

Table 2: Guidelines for interpretation of water quality for irrigation

Potential Irrigation Problem	**Restriction on Use**			
	Units	**None**	**Slight to Moderate**	**Severe**
Salinity				
EC_w (or)	dS/m	<0.7	0.7 - 3.0	>3.0
TDS	mg/l	<450	450 - 2 000	>2 000
Infiltration (Sodicity)				
SAR =0-3 and ECw=		>0.7	0.7 - 0.2	<0.2
SAR = 3 - 6 and ECw=		>1.2	1.2 - 0.3	<0.3
SAR= 6 - 12 and ECw=		>1.9	1.9 - 0.5	<0.5
SAR= 12 – 20 and ECw =		>2.9	2.9 - 1.3	<1.3
SAR= 20 - 40 and ECw=		>5.0	5.0 - 2.9	<2.9
Specific Ion Toxicity				
Sodium (Na)				
surface irrigation	SAR	<3	3 - 9	>9
sprinkler irrigation	me/l	<3	>3	
Chloride (Cl)				
surface irrigation	me/l	<4	4 - 10	>10
sprinkler irrigation	me/l	<3	>3	
Boron (B)	mg/l	<0.7	0.7 - 3.0	>3.0
Miscellaneous Effects				
Nitrogen (NO_3-N)	mg/l	<5	5 - 30	>30
Bicarbonate (HCO_3) (overhead sprinkling only)	me/l	<1.5	1.5 - 8.5	>8.5
pH		(Normal Range 6.5 - 8.4)		

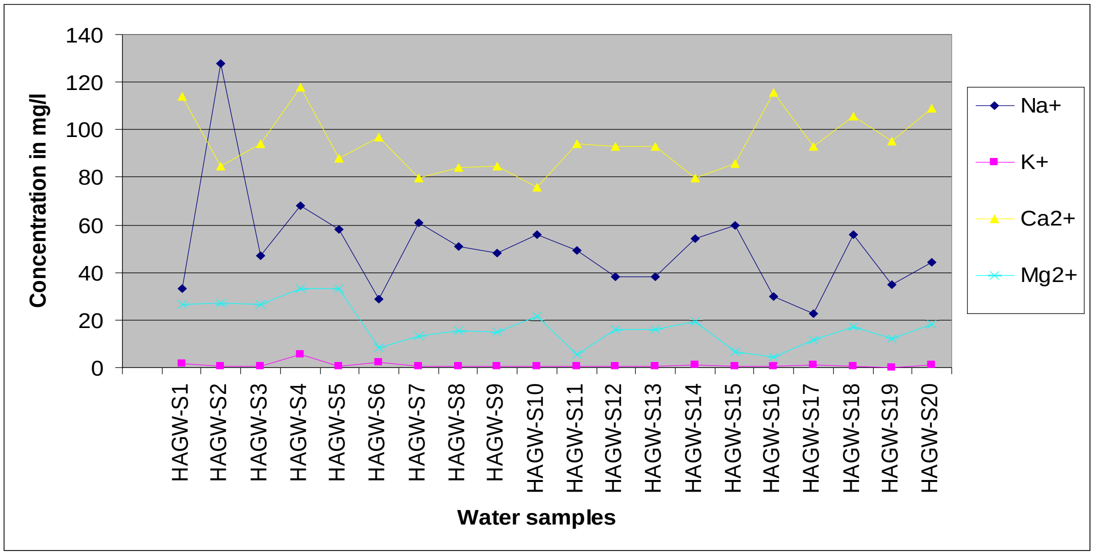

Figure 2: Concentration of major cations in the groundwater sample

3.1.2. Anions

The anionic concentration of Cl^-, SO_4^{2-}, NO_3^- and HCO_3^- in mg/l ranges between 15.45 – 49.44, 16.3 – 148, 0.3 – 5.87 and 312.56 – 589.26 with a mean concentration values of 23.84, 66.22, 1.42 and 420.42, respectively (Table 4 and Figure 3). The anionic concentrations were lowest and highest at HAGW-S8 and HAGW-S4, HAGW-S5 and HAGW-S1, HAGW-S17 and HAGW-S18 and HAGW-S14 and HAGW-S5 for Cl^-, SO_4^{2-}, NO_3^- and HCO_3^-, respectively.

The predominant anions in the study area were bicarbonates and sulphates while carbonates remain nil throughout the groundwater samples (figure 4).

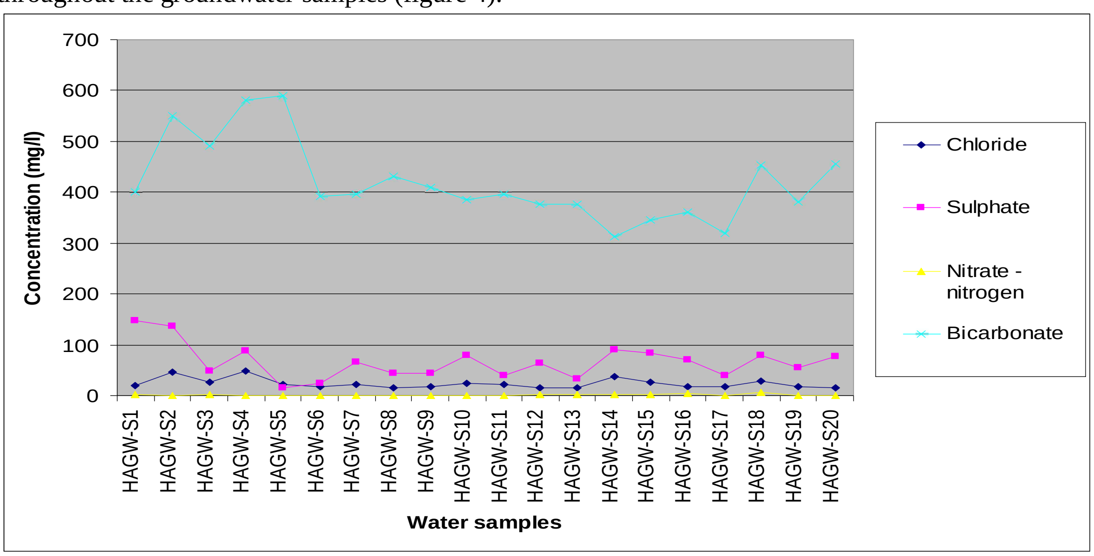

Figure 3: Concentration of anions in the groundwater samples

3.2. ECw, TDS, Alkalinity, pH, Total Hardness and SAR

3.2.1. Electrical Conductivity

The electrical conductivity of the groundwater samples of the hand dug wells used for irrigation ranges from 0.60 dS/m to 1.12 dS/m at 25°C (Table 3). Out of the twenty groundwater samples, six water samples, HAGW-S1, HAGW-S2, HAGW-S3, HAGW-S4, HAGW-S5 and HAGW-S6, had an electrical conductivity value of above 1dS/m with the maximum value of 1.2dS/m obtained at HAGW-S4, while the remaining fourteen water samples,

HAGW-S7, HAGW-S8, HAGW-S9, HAGW-S10, HAGW-S11, HAGW-S12, HAGW-13, HAGW-S14, HAGW-S15, HAGW-S16, HAGW-S17, HAGW-S18, HAGW-S19 and HAGW-S20, had an electrical conductivity value less than 1 dS/m with the minimum value of 0.6 dS/m measured at HAGW-S12.

3.2.2. Total dissolved solids (TDS)

As shown in table 3, TDS values of the groundwater samples of the study area ranges between 300 to 570 mg/l where the lowest value was obtained in the groundwater samples of HAGW-S10 and HAGW-S14 and the highest value was obtained in the groundwater sample HAGW-S5.

3.2.3. Alkalinity

As shown in table 3, the alkalinity of the groundwater samples of the study area ranges from 256.2 to 483 mg/l of $CaCO_3$ where the minimum and the maximum values were observed in HAGW-S14 and HAGW-S5, respectively.

3.2.4. pH

As shown in table 4, the pH value of the groundwater samples of Hantebet basin lied between the ranges of 6.55 to 7.26 at the hand dug wells coded HAGW-S3 and HAGW-S2, respectively.

3.2.5. Total Hardness

Total hardness of the groundwater samples of the study area ranges from 241.5 to 430.5 mg/l of $CaCO_3$ in the HAGW-S15 and HAGW-S4, respectively (Table 3).

3.2.6. Sodium Adsorption Ratio (SAR)

The SAR value of the groundwater samples of the study area ranges from 0.58 to 3.09. The mean SAR value of the groundwater samples of the study area was also found to be 1.25 (Table 3).

Table 3: Computed values of Sodium Adsorption Ratio and measured electrical conductivity (dS/m at 25^{o}C), Alkalinity, Total hardness, Total dissolved solids and Water types for all the analyzed water samples

Sample Code	GPS Location (in UTM)			Alkalinity (mg/l $CaCO_3$)	Total Hardness (mg/l $CaCO_3$)	TDS (mg/l)	ECw at 25^{o}C (dS/m)	SAR	Cl^- (meq/l)	HCO_3^- (meq/l)	Water type
	UTMN	UTME	Elevation (m)								
HAGW-S1	526210	1468122	2198	327.6	394.8	500	1.01	0.722	0.551	6.552	Ca-Mg-HCO3-SO4
HAGW-S2	526046	1468624	2197	451.5	323.4	540	1.02	3.095	1.306	9.030	Na-Ca-HCO3-SO4
HAGW-S3	526085	1468678	2198	403.2	342.3	490	1.08	1.102	0.725	8.064	Ca-Mg-Na-HCO3
HAGW-S4	526016	1468783	2202	476.7	430.5	560	1.12	1.425	1.393	9.534	Ca-Na-Mg-HCO3
HAGW-S5	525877	1468954	2206	483	357	570	1.09	1.335	0.638	9.660	Ca-Mg-Na-HCO3
HAGW-S6	525195	1469634	2212	321.3	275.1	310	1.01	0.760	0.493	6.426	Ca-HCO3
HAGW-S7	525381	1469597	2206	325.5	254.1	400	0.90	1.664	0.609	6.510	Ca-Na-HCO3
HAGW-S8	525459	1469612	2208	352.8	273	390	0.71	1.342	0.435	7.056	Ca-Na-HCO3
HAGW-S9	525557	1469682	2208	336	273	340	0.62	1.263	0.522	6.720	Ca-Na-HCO3
HAGW-S10	525673	1469720	2209	315	277.2	300	0.68	1.463	0.667	6.300	Ca-Na-Mg-HCO3-SO4
HAGW-S11	525753	1469816	2214	325.5	258.3	340	0.66	1.326	0.638	6.510	Ca-Na-HCO3
HAGW-S12	525807	1469894	2213	308.7	298.2	310	0.60	0.957	0.435	6.174	Ca-Na-HCO3
HAGW-S13	525582	1469921	2214	308.7	298.2	330	0.61	0.957	0.435	6.174	Ca-Na-HCO3
HAGW-S14	525719	1470113	2212	256.2	279.3	300	0.68	1.405	1.045	5.124	Ca-Na-HCO3-SO4
HAGW-S15	525700	1470242	2217	283.5	241.5	370	0.76	1.679	0.754	5.670	Ca-Na-HCO3-SO4
HAGW-S16	525761	1470576	2226	296.1	308.7	370	0.68	0.742	0.493	5.922	Ca-HCO3
HAGW-S17	525921	1470646	2222	262.5	281.4	410	0.61	0.583	0.493	5.250	Ca-HCO3
HAGW-S18	525938	1470285	2215	371.7	336	310	0.84	1.328	0.837	7.434	Ca-Na-HCO3
HAGW-S19	525381	1469570	2207	312.9	287.7	350	0.90	0.897	0.522	6.258	Ca-HCO3
HAGW-S20	525891	1469697	2214	373.8	348.6	380	0.76	1.025	0.435	7.476	Ca-Na-HCO3

4. Discussion

4.1. Classification of Groundwater Type

The groundwater types in the area were Ca-Na-HCO3, Ca-HCO3, Ca-Na-HCO3-SO4, Na-Ca-HCO3-SO4, Ca-Na-Mg-HCO3, Ca-Mg-HCO3-SO4, Ca-Na-Mg-HCO3-SO4, and Ca-Mg-Na-HCO3. 40 per cent of the groundwater of the area was Ca-Na-HCO3 (Table 3).

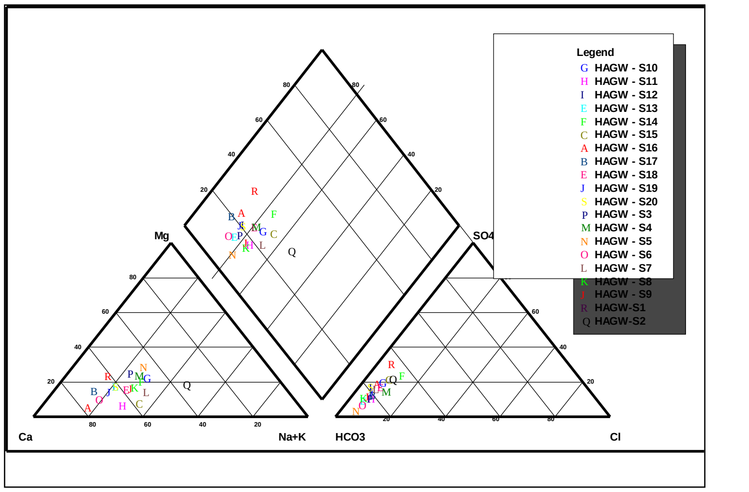

Figure 4: Piper plot of Hantebet groundwater samples

4.2. Suitability of Water for Irrigation Uses

4.2.1. Salinity Hazards

ECw of the groundwater samples of the study area varies widely from 0.6 dS/m to 1.12 dS/m with a mean value of 0.82 dS/m. The greatest and lowest ECw values were obtained at HAGW-S12 and HAGW-S4, respectively (Table 3). Eight groundwater samples are excellent for irrigation use and twelve samples are with slight to moderate degree of restriction since the groundwater samples with < 0.7 dS/m and 0.7 dS/m – 3 dS/m, respectively are none degree of restriction and slight to moderate degree of restriction for irrigation water use (Ayers et al., 1994).

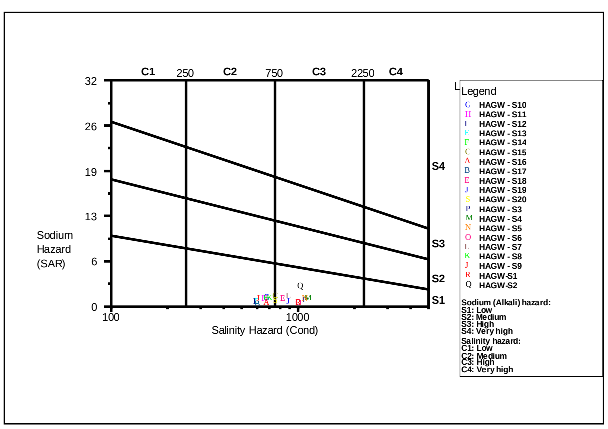

Figure 5: Wilcox plot of Hantebet hand dug well water samples

Furthermore, the Wilcox plot can also be used to quickly determine the viability of water for irrigation purposes Wilcox (1955). The classification of the groundwater of the Hantebet watershed using the Wilcox plot was plotted in the zone designated C2-S1 and C3-S1 indicating that the ground-waters generally have low sodium absorption ratio (SAR) and medium to high salinity hazard associated with them (Figure 5).

4.2.2. Infiltration (Sodicity Hazards)

According to the FAO, (1989) guidelines in table 2, groundwater samples with SAR value 0 – 3 and ECw value of 0.2 – 0.7 dS/m as in the case of eight groundwater samples of the study area (HAGW-S9, HAGW-S10, HAGW-S11, HAGW-S12, HAGW-S13, HAGW-S14, HAGW-S16 and HAGW-S17) and with SAR value 3 – 6 and ECw value of 0.3 – 1.2 dS/m as in two groundwater samples (HAGW-S7 and HAGW-S15) and one groundwater sample (HAGW-S2) with SAR value of 6 – 12 and ECw value of 0.5 – 1.9 dS/m would generally pose slight to moderate degree of restrictions to their use for irrigation due to their effect on soil infiltration rates.

However, nine groundwater samples HAGW-S1, HAGW-S3, HAGW-S4, HAGW-S5, HAGW-S6, HAGW-S8, HAGW-S18, HAGW-S19 and HAGW-S20 have a SAR value between 0 – 3 and ECw value greater than 0.7 dS/m, which pose none degree of restrictions to its use for irrigation due to its effect on soil infiltration rates.

4.2.3. Toxicity Problems

4.2.3.1. Chloride

As shown in table 3, the chloride concentrations in the groundwater samples of the watershed range from 15.45 mg/l to 49.44 mg/l. Though the highest measured chloride 49.44 mg/l occurs in the sample of HAGW-S4 hand dug well, the concentrations of all the groundwater samples are below 4meq/l. This suggests that the groundwater of the study area is suitable for surface and sprinkler irrigation use with no chloride toxicity (Ayers et al., 1994).

4.2.3.2. Sodium

As can be seen from table 4 below, the sodium concentration of the study area ranges from 22.5 mg/l to 128 mg/l in the hand dug wells HAGW-S17 and HAGW-S2, respectively, with a mean value of 50.275 mg/l. The groundwater of the study area is classified into two groups based on their SAR value: nineteen samples have a SAR value of less than 3 and one sample (HAGW-S2) has a SAR value of 3.095, which is greater than 3, with none and slight to moderate degree of restriction of groundwater use for surface irrigation, respectively, based on the FAO, (1989) guidelines stated in Ayers et al., (1994). Nineteen groundwater samples of the study area are suitable for sprinkler irrigation and one groundwater samples (HAGW-S2), which has sodium concentration value of 5.57 meq/l, lies in the slight to moderate degree of restriction for sprinkler irrigation since the water with sodium concentration value of < 3 meq/l has no restriction and > 3 meq/l slight to moderate degree of restriction for sprinkler irrigation (Ayers et al., 1994).

4.2.4. Miscellaneous Problems

4.2.4.1. Bicarbonate

Bicarbonate concentration of the groundwater samples of the study area is greater than 1.5 meq/l. Seventeen have a concentration value of 1.5 – 8.5 meq/l and three groundwater samples (HAGW-S2, HAGW-S4 and HAGW-S5) have a concentration value of greater than 8.5 meq/l (Table 3).

Based on the FAO, (1989) guidelines for irrigation water stated in Ayers et al., (1994), seventeen groundwater samples are with slight to moderate degree of restriction for overhead sprinkler irrigation, however, three groundwater samples are with severe degree of restriction for overhead sprinkler irrigation use because the irrigation water with 1.5 – 8.5 meq/l and > 8.5 meq/l is slight to moderate and severe degree of restriction for overhead sprinkler irrigation (Ayers et al., 1994).

4.2.4.2. Nitrate – nitrogen

Out of the twenty groundwater samples, nineteen groundwater samples had nitrate – nitrogen concentration of < 5 mg/l but only one groundwater sample,HAGW-S18, had a NO_3 – N concentration value of 5.87 mg/l, which was the highest NO_3 – N concentration value in the study area (Table 4). Hence, nineteen groundwater samples were excellent for irrigation but one groundwater sample, HAGW-S18, was with slight to moderate degree of restriction for irrigation.

4.2.4.3. pH

The groundwater of the study area was suitable for irrigation since the pH value lies between the normal ranges of irrigation water given by Ayers et al. (1994) as 6.5 and 8.4 (Table 4).

4.3. Major Cations

4.3.1. Calcium

Irrigation water containing a high proportion of soluble calcium may form scale inside the irrigation component (Pitts et al., 1989) and form scale like deposits on plant parts when overhead sprinkler irrigation system is used (Haman et al., 2000). The highest calcium concentration was observed at HAGW-S4 and value was 117.6 mg/l (5.88 meq/l). The lowest calcium concentration was obtained at HAGW-S10 and its value was 75.6 gm/l (3.780 meq/l) (Table 4). Hence, the groundwater of the study area is suitable for irrigation since the usual range of calcium in irrigation water is 0 – 20 meq/l (Ayers et al. 1994).

4.3.2. Potassium

The minimum and maximum concentration value ranges from 0.2 mg/l to 5.3 mg/l at hand dug wells HAGW-S19 and HAGW-S4. The mean potassium concentration of the study area was found to 0.975 mg/l (Table 5). Hence, nineteen groundwater samples are excellent for long-term irrigation on all soils and crops since the recommended maximum concentrations of K for long-term irrigation use on all soils is 2 mg/l (Ayers et al., 1994 and Duncan et al., 2000). However, only one groundwater sample, HAGW-S4 is normal if used for irrigation since the irrigation water with 5 – 20 mg/l is normal (Duncan et al., 2000).

4.3.3. Magnesium

The concentration of magnesium in the groundwater samples ranges from 4.59 mg/l (0.378 meq/l) to 33.15 mg/l (2.728meq/l) at HAGW-S16 and HAGW-S5 respectively (Table 4). The usual range of magnesium in irrigation water is 0 – 5 meq/l (Ayers et al. 1994). Therefore, the groundwater water of the study area is suitable for irrigation purposes.

Table 4: The major, minor ions, pH and electrical conductivity of water determined in the groundwater samples of Hantebet watershed

Sample Code	Na^+ (mg/l)	K^+ (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Cl^- (mg/l)	SO_4^{2-} (mg/l)	NO_3^- (mg/l)	HCO_3^- (mg/l)	CO_3^{2-} (mg/l)	pH	ECw (µS/cm)
HAGW-S1	33	1.7	114.24	26.5	19.57	148	2.1	399.67	0	6.64	1010
HAGW-S2	128	0.6	84.84	27.03	46.35	136	0.97	550.83	0	7.26	1020
HAGW-S3	47	0.7	93.84	26.52	25.75	47.6	2.09	491.9	0	6.55	1080
HAGW-S4	68	5.3	117.6	33.15	49.44	88.6	0.4	581.57	0	6.61	1120
HAGW-S5	58	0.7	88.2	33.15	22.66	16.3	0.4	589.26	0	6.65	1090
HAGW-S6	29	2	96.6	8.16	17.5	23.6	0.49	391.98	0	6.76	1010
HAGW-S7	61	0.5	79.8	13.26	21.63	65.2	0.64	397.11	0	6.83	900
HAGW-S8	51	0.3	84	15.3	15.45	43.6	0.5	430.42	0	6.88	900
HAGW-S9	48	0.5	84.84	14.79	18.54	44.8	0.55	409.92	0	6.94	710
HAGW-S10	56	0.4	75.6	21.42	23.69	80.3	0.75	384.3	0	6.68	620
HAGW-S11	49	0.5	94.08	5.61	22.66	39.39	0.79	397.11	0	6.91	680
HAGW-S12	38	0.8	93.24	15.81	15.45	64.07	1.7	376.61	0	6.86	610
HAGW-S13	38	0.8	93.24	15.81	15.45	32.46	1.51	376.61	0	6.98	660
HAGW-S14	54	1	79.8	19.38	37.08	90.73	1.23	312.56	0	6.90	600
HAGW-S15	60	0.7	85.68	6.63	26.78	83.29	2.61	345.87	0	6.80	760
HAGW-S16	30	0.4	115.92	4.59	17.51	70.07	4.3	361.24	0	6.87	680
HAGW-S17	22.5	0.9	93.24	11.73	17.51	39.13	0.3	320.25	0	6.81	840
HAGW-S18	56	0.4	105.84	17.34	29.7	80.3	5.87	453.47	0	6.79	610
HAGW-S19	35	0.2	94.92	12.24	18.54	54.62	0.88	381.74	0	7.22	680
HAGW-S20	44	1.1	109.2	18.36	15.45	76.25	0.34	456.04	0	7.12	760
Minimum	22.5	0.2	75.6	4.59	15.45	16.3	0.3	312.56	0	6.55	600
Maximum	128	5.3	117.6	33.15	49.44	148	5.87	589.26	0	7.26	1120
Average	50.275	0.975	94.236	17.339	23.836	66.216	1.421	420.423	0.000	6.853	817.000
Standard Deviation	22.040	1.111	12.437	8.499	9.915	33.889	1.441	79.093	0.000	0.190	182.961

5. Conclusions

The results of analysis and interpretation of groundwater samples from Hantebet Watershed for irrigation purpose indicates that samples lie in the slight to moderate degree of restriction and none degree of restriction for irrigation. Generally, groundwater samples of the study area contained desirable levels of concentrations of Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, NO_3^-, and SAR value, indicating that there would not be any possibility of severe salinity, sodicity, toxicity and miscellaneous problems from irrigation using groundwater. However, Bicarbonate (HCO_3^-) seventeen samples are with 1.5 – 8.5 meq/l and three groundwater samples have a concentration values > 8.5 meq/l which is having severe degree of restriction on irrigation Therefore the groundwater in the study area is fairly suitable for agricultural purposes.

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