Suitability of Groundwater Quality for Irrigation with Reference to Hand Dug Wells, Hantebet Catchment, Tigray, Northern Ethiopia

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ABSTRACT

The purpose of the project has been to assess the suitability of groundwater quality for irrigation purpose in the Hantebet catchment (24.4 km^2), Tigray region, northern Ethiopia. The total numbers of hand dug wells in the area are 154. Out of these, 110 are functional and the remaining dried out. Stratified and random sampling techniques were utilized to select representative samples of groundwater. Accordingly, twenty groundwater samples were collected from twenty hand dug wells for chemical analysis. Twenty soil samples were also collected from the command area of the hand dug wells from where the groundwater samples were collected. Both groundwater and soil samples were analyzed for Ca^{2+}, Mg^{2+}, K^+, Na^+, CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}, and NO_3^- besides pH and electrical conductivity (EC). Further, the Sodium Adsorption Ratio (SAR) for the both the groundwater and soil samples and Exchangeable Sodium Percentage (ESP) for the soil samples were also computed. Out of the analyzed 20 groundwater samples, 8 show EC values below 0.7 and the remaining between 0.71 and 1.12 dS/m, and pH values from 6.55 to 7.26. Chloride ion concentrations in groundwater range from 0.435 to1.393 (meq/l); bicarbonate from 5.124 to 9.660 (meq/l); and nitrate (NO_3 - N) values below 5 (mg/l) except in one sample that has 5.87 mg/l. In soil samples, EC values range from 1.36 to 4.65 dS/m (at 25°C) (mean 2.487), and pH values range from 6.77 to 7.79 with a mean value 7.20. SAR values are well below 3 in groundwater, except in one sample and in soil it ranges from 0.111-1.571. ESP values in the soil vary from 2.016 to 4.863. The results indicate that the groundwater in general is suitable for irrigation purpose. In the case of soils about 80% of the soil samples indicate no hazard but 20% are saline. The soils are free of sodicity hazards. However, i) to achieve a full yield potential; ii) to sustain it for long period of time; iii) to avoid the possibility of increase in salinity, and iv) to avoid the possibility of occurrence of sodicity and toxicity hazardous in future, proper irrigation scheme is required in the form of crop selection, fertilizer usage and suitable alternative management.

Keywords: Aquifer, Groundwater quality, Hand dug well, Irrigation, Tigray.

1. INTRODUCTION

The main economic means of Tigray region, located in the northern part of the country, 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 as well as natural devastation; the level of land productivity is declined at alarming rate. As a result, because of moisture limitation and the above reasons, 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 country, promotion of irrigated agriculture was given priority in the strategy of the nation. Irrigation is one of the methods used to increase food production in arid and semi-arid regions. It can enhance food security, promote economic growth and sustainable development, create employment opportunities, improve living conditions of small-scale farmers and thus contribute to poverty reduction. Furthermore, it increases subsurface water levels and recharges groundwater. On the other hand, if irrigation is not properly managed, it can have adverse effects on the environment and the users.

Groundwater utilization was considered as a potential option next to surface water harvesting operations in Tigray. Farmers are advised to dig hand dug wells on their farm plot and utilize the groundwater for irrigation. Utilization of groundwater as a source of water for irrigation would boost the farmer's production two to three times in a year. This will help the farmers to attain food security at the household level.

To overcome the water scarcity in Hantebet watershed, the households constructed about 154 hand dug wells for irrigation purpose till now. The households benefited from the intervention by cultivating and producing different high value crops once up to two times per annum due to the availability of water.

Availability of water by itself is not a guaranty for sustainable development, but, its fitness to specific purpose like irrigation, domestic or industrial use should also be verified. Only economic advantage cannot sustain the practice. Other such as ecological and social issues needs to be taken in to account in the development and management of the schemes. Quality of the water is part of the ecological issues required to be considered in the early beginning. Knowledge of irrigation water quality is critical to understanding what management changes are necessary for long-term productivity (Bohn et al., 1985; FAO, 1985; Brady, 2002). Besides these, irrigated agricultural crops need very good quality water.

In the study area, the beneficiaries as well as the extension workers do not have a detailed knowledge on the suitability of the groundwater for irrigation purpose to produce crops. Studies concerning this issue have not yet been done in the area. However, sustainable utilization of groundwater as a source of water for irrigation requires quality and quantity fitness of the groundwater for this purpose. This paper addresses one of these gaps, which is determination of the suitability of the groundwater for irrigation purpose. Therefore, the main center of attention of this paper is mainly to assess the groundwater suitability for irrigation in Hantebet watershed;

to determine the degree of salinity, sodicity, and toxicity of the groundwater; and to examine the extent of soil salinity and sodicity of the irrigated area of the hand dug wells of the watershed.

1.1. Description of the Study Area

1.1.1. Location

The catchment area is located in southern Tigray Regional State in north Ethiopia. Geographically it lies between 1467000 to 1476000 m N and 523000 to 530000 m E, and is estimated to have an areal coverage of 24.4 km^2 (Fig.1).

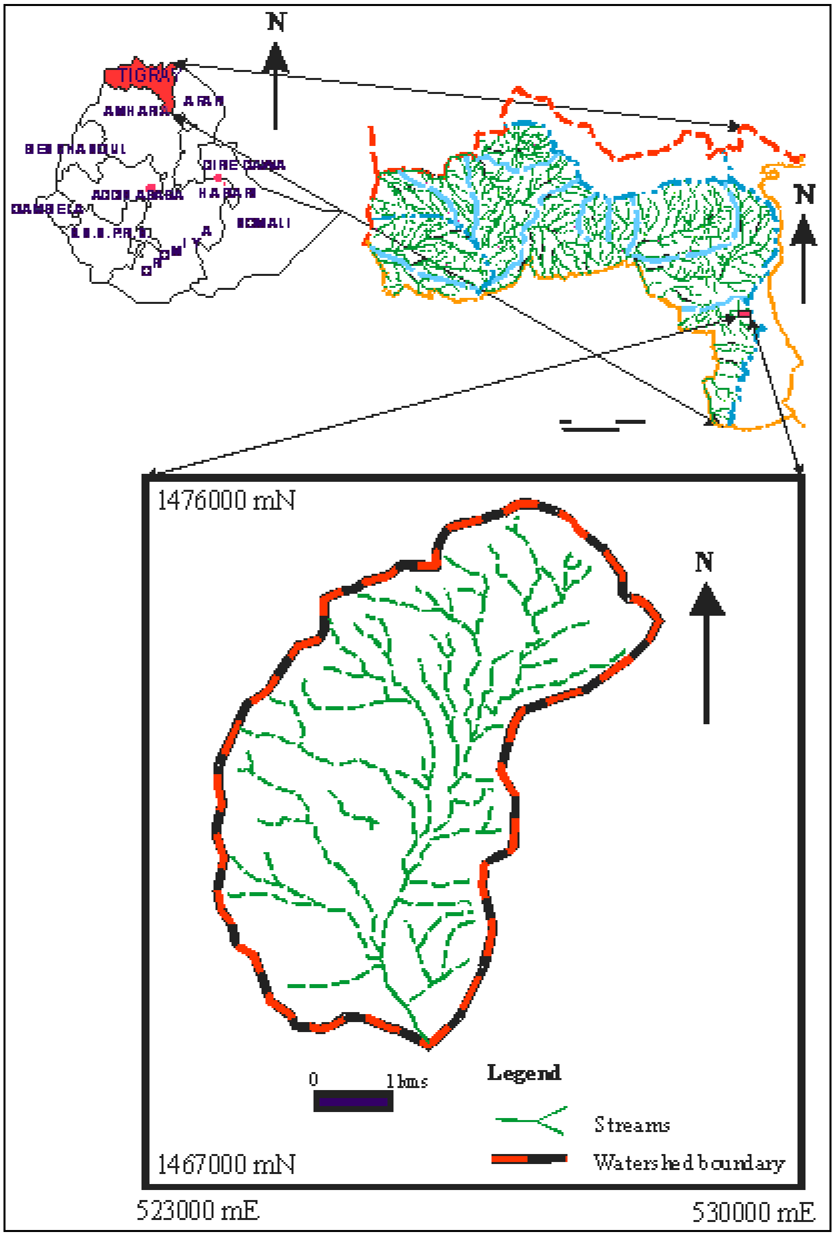

Figure 1. Location map of the study area.

1.1.2. Physiography and Drainage

The basin consists of vast depressed areas that extend from northeast to southwest bounded by adjacent highlands. Altitude ranges from 2000 m above sea level on the lowland to mountain peaks greater than 2600 m above sea level. The average elevation of the basin is 2330 m above sea level with peaks reaching 2660 m above sea level.

The studied area is drained by a perennial river called Hantebet' river. It originates from the northern highlands and flows towards the southern flatlands and finally joins the Tekeze River, which is the main tributary of Atbarah River in Sudan. There are in addition many small intermittent and a few perennial meandering rivers that drain the area. These streams originate from the surrounding highlands. The streams are dense at areas of higher slopes and sparse where the slope is relatively flat. The lengths of the longest and shortest streams are 7145.5 m and 89.8 m, respectively. Most of the longer streams are found on flat plain of alluvial deposits whereas the shorter ones are on the flunk of the mountain covered by mostly dolerite intrusions. Most of the steep well-drained areas usually have numerous small tributaries whereas the gentle slopes and plain areas have long streams in places where the soils are deep and permeable. In general, the studied area has a dendritic drainage pattern (Figure 1.1). The main sources of supply for the streams are precipitation during the rainy seasons and to a lesser extent the shallow perched aquifers during the dry seasons. The basin has no any other inland waters such as lakes and ponds.

The mean annual minimum air temperature of the area is 11.15 ºC. The mean annual maximum air temperature is 23.39 ºC. The mean annual air temperature of the area is 17.3 ºC. The mean annual rainfall is 632.08 mm.

1.3.3. Soils

The soils in the basin are light sandy and highly plastic clay soils, which seem to have different distributions (Table.1). Substantial area of the cultivated land is dominantly covered by fine sandy loam soil with a presence of clay loam and clay soils in very limited areas. A considerable area of the upstream side has sandy clay soil in which no activity is practiced on the hillsides.

Other than these, some part of the homesteads and wood land of the catchment's area has mainly of sandy loam soil. Within this area agriculture is practiced to some extent.

Table. 1. Area coverage of the different soil types (Source: Nata, 2006).

Soil type	Area coverage (km^2)
Fine sandy loam	10.33
Clay	0.42
Sandy clay	8.59
Sandy loam	4.02
Clay loam	1.02
Total	24.38

1.3.4. Land Use

Six major land use types were identified during the field assessment made on the basin. These are cultivated land, grazing land, dense woodland, homestead, sparse woodland and bare land. Of these, cultivated land constitutes 10.16 km^2 (41.67 %), which is the largest portion of the total area. The agricultural practice is largely undertaken in the slope range 0 -15 %. The major agricultural crops produced in the area are wheat, teff, sorghum, maize, and barely.

Grazing land constitutes 1.66 km^2 (6.81 %) of the total area. Forestland covers 1.36 km^2 (5.58 %) of the total area of the catchment. This area which is named as "forest land" (both scattered and densely forested area) includes areas, which are covered with very scattered acacia trees, bushes, cactus and eucalyptus trees. The rest of the land use types cover homestead, 2.67 km^2 (10.95 %), and bare land, 8.53 km^2 (34.99 %), which is the second largest portion of the total area next to cultivated land.

1.3.5. Geology

The major lithological units in the studied area are dolerite, shale, limestone, meta-sandstone and thick alluvial deposits. Stratigraphically, the limestone (which covers 12% of the total area) is found at the base overlying by shale (13.4%) and then followed by meta-sandstone (0.5%). Overlying these successions, the igneous intrusions of dolerite as a sill and dike (45.2%) are exposed on the top parts of hills and plateaus. Alluviums (28.9 %) are found having different thickness overlying all these successions in the lowlands.

1.3.6. Groundwater Development

The investigated area is currently supplied mainly with groundwater from developed hand dug wells. The shallow, mostly unconfined and confined, aquifers in the thin alluvial covers and weathered and fractured upper parts of the rocks are exploited through these hand dug wells. They supply water daily for domestic, irrigation and livestock consumption.

1.3.6.1. Hand Dug Wells

In the studied area, huge amount of groundwater is extracted using dug wells. Around 154 hand dug wells have been inventoried. Out of these, 110 are functional whereas the remaining 44 are dry. These hand dug wells were constructed from 2003 to 2008 for the purpose of irrigation, domestic and livestock's uses. This technique was introduced to the area during 2003 by the Regional government. The households are nowadays benefiting from the intervention by producing different high value crops twice to three times in a year. All most all the hand dug wells are found concentrating around the major river and its tributaries (Fig. 2). The range of spacing of wells varies from less than three meter to above 50 meters. The main cause for the existence of crowding and close spacing of wells is related to land ownership.

With the exception of a few wells, which are closed and fitted with hand pump, most of them are open and equipped with pulley and treadle pump. There is no uniformity in the geometry of the dug wells: circular, rectangular, trapezoidal and irregular shapes are common. The diameter of the circular dug wells range from 5 to 7 m and some of the rectangular dug wells have dimensions up to 7 * 5 m. Generally, the depth of the dug wells range from 1.3 to 6 m. Some of the dug wells have masonry lining and most of them have stone lining.

The yield of the dug wells varies from 1 to 3.5 l/s. The discharge of a dug well is smaller, because (i) dug wells can tap only the top most or at the most the next lower water bearing stratum, and (ii) water from dug wells can be withdrawn only at velocity equal to or smaller than the critical velocity for the soil, so as to avoid the danger of well siltation. In general, the yield characteristics of dug wells depend upon several factors, namely:

(a) Landform - whether located in pediment, buried pediment or valley fill areas.

(b) Regolith - its thickness and permeability.

(c) Fracture characteristics of bedrock.

(d) Local groundwater regime: whether the well is located in groundwater recharge or discharge area.

(e) Depth of water table and its fluctuation.

The depth of static water level varies from 0.2 - 5 m. The wells are rich in water during the rainy season and the water table (in the unconfined aquifers) becomes shallow while during dry season the majority of them will dry up.

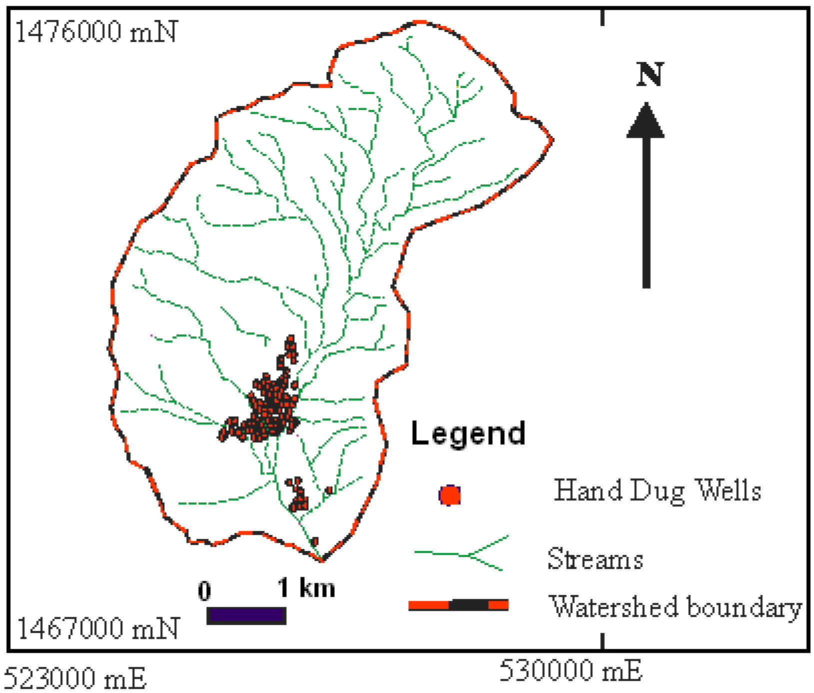

Figure 2. Location of hand dug wells.

2. METHODOLOGY

2.1 Data Collection

To assess the suitability of the groundwater for irrigation purpose, the methods employed comprises of office work and fieldwork. Extensive work was carried out by collecting pertinent primary data of the area in the field and secondary data from different offices. The topographic map of 1:50,000 scale was used as a base map. Geological and hydrogeological maps of the area were prepared using this as a base map.

Collection, analyses and interpretation of topographical, hydrological, meteorological, soil, geological and hydrogeological data and maps, geological and hydrogeological logs and other secondary data were done at the office level.

During fieldwork various activities were carried out. The boundary of the watershed was delineated with the help of GPS in the field and latter on finalize with the help of ArcView GIS 3.3 software at the office. Data for slope, land use, soil, geology and water points were collected in the field with the help of GPS. Inventory of all the available water points and also in situ measurements of their respective electrical conductivity of the groundwater and its corresponding temperature measurement were also carried out.

To determine the suitability of the groundwater of the watershed for irrigation use groundwater and soil samples were collected and analyzed.

2.2 Sampling

Initially inventory of all hand dug wells that are available in the area was carried out. After knowing their total number, all hand dug wells that are functional for irrigation purpose was identified. During inventory, in situ measurement of electrical conductivity and temperature of the groundwater, and air temperature for each well were carried out. Since the electrical conductivity values were measured in situ at a temperature different from the standard 25 °C, an adjustment of the electrical conductivity values of the water was made by multiplying the respective measured electrical conductivity value by the factor corresponding to the temperature at which the measurement was made.

To determine the number of water samples for chemical analyses, stratified and random sampling techniques were utilized. The in situ measured and corrected electrical conductivity values of the groundwater were grouped into different water classes based on Quality Classification of Water for Irrigation (Wilcox, 1955). Then after, twenty groundwater samples were selected randomly from the different water classes for chemical analyses.

Soil samples from the command area of the hand dug wells were also collected for chemical analyses. The samples were collected from the hand dug wells where the water samples were collected. Twenty soil samples were collected for analyses.

2.3. Data Analyses

The groundwater samples were analyzed in the Ethiopian Water Works Design and Supervision Enterprise Laboratory Service, Addis Ababa. The samples were analyzed for calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), sodium (Na^{+}), carbonate (CO_3^{2-}), bicarbonate (HCO_3^{-}), chloride (Cl^{-}), sulfate (SO_4^{2-}), nitrate (NO_3^{-}), and phosphate (PO_4^{-3}). Besides, pH and electrical conductivity in μS/cm at 25 °C were also measured.

The soil samples were analyzed in the Soil Laboratory of the Department of Land Resources Management and Environmental Protection, College of Dry Land Agriculture and Natural Resources Management, Mekelle University. The samples were analyzed for calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), sodium (Na^{+}), carbonate (CO_3^{2-}), bicarbonate (HCO_3^{-}), chloride (Cl^{-}) and sulfate (SO_4^{2-}). Besides, pH and electrical conductivity (EC (1:5)) in μS/cm at 25 °C were also measured. The electrical conductivity of saturation extracts of the soil paste

(ECe) was also determined for each sample. The Sodium Adsorption Ratio (SAR) and Exchangeable Sodium Percentage (ESP) were also computed for each sample. ESP value for each soil sample was computed using the computed value of SAR for each respective soil sample.

Various thematic maps such as location of the study area and location of hand dug well sites were produced by using ArcView 3.3, CorelDRAW 12 software and the data is analyzed using SPSS version 11 software.

3. RESULTS AND DISCUSSIONS

3.1. Suitability of Groundwater for Irrigation Uses

Irrigated agriculture is dependent on an adequate water supply of usable quality. Just as every water is not suitable for human beings, in the same way, every 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.

In the study area since the source of water for irrigation is groundwater, its suitability for irrigation use was determined by evaluating the potential of the groundwater to create soil or crop problems through salinity, water infiltration rate, toxicity and a group of other miscellaneous problems.

The data generated for the groundwater samples are given in table 2 and FAO (1989) guidelines for interpretations of water quality for irrigation are used to evaluate the suitability of the groundwater of the watershed for irrigation.

3.1.1. Salinity Hazard

The salt concentration is generally measured by determining the electrical conductivity of water. For all the analyzed samples, the measured electrical conductivity values are given in table 3. Out of the analyzed twenty groundwater samples, eight samples have an electrical conductivity values below 0.7 dS/m and the remaining twelve samples have an electrical conductivity ranging from 0.71 to 1.12 dS/m. Therefore, based on electrical conductivity values, two types of groundwater are recognized in the watershed: a groundwater that is not hazardous and needs no restriction on use and a groundwater that needs slight to moderate degree of restriction on use. The first type groundwater can be used for irrigation for almost all crops and for almost all kinds of soils. No soil or cropping problems will rise. Very little salinity may develop which may require slight leaching; but it is permissible under normal irrigation practices except in soils of extremely low permeabilities. To achieve a full yield potential using the second type, gradually increasing care in selection of crop and management alternatives are required.

Table 2. Summarized results of the analyzed groundwater samples (CO_3^{2-} values are below detection in all samples).

Well No.	***Sample Code***	***Na^+***	***K^+***	***Ca^{2+}***	***Mg^{2+}***	***Cl^-***	***SO_4^{2-}***	***NO_3^-***	***HCO_3^-***	***pH***	***ECw (µS/cm)***
		(mg/l)									
1	HAGW-S1	33	1.7	114.24	26.5	19.57	148	2.1	399.67	6.64	1010
2	HAGW-S2	128	0.6	84.84	27.03	46.35	136	0.97	550.83	7.26	1020
3	HAGW-S3	47	0.7	93.84	26.52	25.75	47.6	2.09	491.9	6.55	1080
4	HAGW-S4	68	5.3	117.6	33.15	49.44	88.6	0.4	581.57	6.61	1120
5	HAGW-S5	58	0.7	88.2	33.15	22.66	16.3	0.4	589.26	6.65	1090
6	HAGW-S6	29	2	96.6	8.16	17.5	23.6	0.49	391.98	6.76	1010
7	HAGW-S7	61	0.5	79.8	13.26	21.63	65.2	0.64	397.11	6.83	900
8	HAGW-S8	51	0.3	84	15.3	15.45	43.6	0.5	430.42	6.88	900
9	HAGW-S9	48	0.5	84.84	14.79	18.54	44.8	0.55	409.92	6.94	710
10	HAGW-S10	56	0.4	75.6	21.42	23.69	80.3	0.75	384.3	6.68	620
11	HAGW-S11	49	0.5	94.08	5.61	22.66	39.39	0.79	397.11	6.91	680
12	HAGW-S12	38	0.8	93.24	15.81	15.45	64.07	1.7	376.61	6.86	610
13	HAGW-S13	38	0.8	93.24	15.81	15.45	32.46	1.51	376.61	6.98	660
14	HAGW-S14	54	1	79.8	19.38	37.08	90.73	1.23	312.56	6.90	600
15	HAGW-S15	60	0.7	85.68	6.63	26.78	83.29	2.61	345.87	6.80	760
16	HAGW-S16	30	0.4	115.92	4.59	17.51	70.07	4.3	361.24	6.87	680
17	HAGW-S17	22.5	0.9	93.24	11.73	17.51	39.13	0.3	320.25	6.81	840
18	HAGW-S18	56	0.4	105.84	17.34	29.7	80.3	5.87	453.47	6.79	610
19	HAGW-S19	35	0.2	94.92	12.24	18.54	54.62	0.88	381.74	7.22	680
20	HAGW-S20	44	1.1	109.2	18.36	15.45	76.25	0.34	456.04	7.12	760
Minimum		22.5	0.2	75.6	4.59	15.45	16.3	0.3	312.56	6.55	600
Maximum		128	5.3	117.6	33.15	49.44	148	5.87	589.26	7.26	1120
Average		50.3	0.98	94.236	17.339	23.836	66.216	1.42	420.42	6.85	817
Standard Deviation		22	1.11	12.437	8.499	9.915	33.889	1.44	79.1	0.19	183

3.1.2. Infiltration (Sodicity) Problems

An infiltration problem related to water quality occurs when the normal infiltration rate for the applied water or rainfall is appreciably reduced and water remains on the soil surface too long or infiltrates too slowly to supply the crop with sufficient water to maintain acceptable yields. Although the infiltration rate of water into soil varies widely and can be greatly influenced by the quality of the irrigation water, soil factors such as structure, degree of compaction, organic matter content and chemical make-up can also greatly influence the intake rate.

The two most common water quality factors that influence the normal infiltration rate are the salinity of the water and its sodium content relative to the calcium and magnesium content. High salinity water will increase infiltration. Low salinity water or water with high sodium to calcium and magnesium ratio will decrease infiltration. Both factors may operate at the same time. The infiltration rate generally increases with increasing salinity and decreases with either decreasing salinity or increasing sodium content relative to calcium and magnesium - the sodium adsorption ratio (SAR). Therefore, the two factors, salinity and SAR, must be considered together for a proper evaluation of the ultimate effect on water infiltration rate.

Table 3. SAR (computed), EC (measured), chloride, bicarbonate and nitrate values in groundwater, Hantebet catchment.

Well No.	*Sample Code*	*ECw (dS/m)*	*SAR*	*Cl^- (meq/l)*	*HCO_3^- (meq/l)*	*NO_3^- - N (mg/l)*
1	HAGW-S1	1.01	0.722	0.551	6.552	2.1
2	HAGW-S2	1.02	3.095	1.306	9.030	0.97
3	HAGW-S3	1.08	1.102	0.725	8.064	2.09
4	HAGW-S4	1.12	1.425	1.393	9.534	0.4
5	HAGW-S5	1.09	1.335	0.638	9.660	0.4
6	HAGW-S6	1.01	0.760	0.493	6.426	0.49
7	HAGW-S7	0.90	1.664	0.609	6.510	0.64
8	HAGW-S8	0.90	1.342	0.435	7.056	0.5
9	HAGW-S9	0.71	1.263	0.522	6.720	0.55
10	HAGW-S10	0.62	1.463	0.667	6.300	0.75
11	HAGW-S11	0.68	1.326	0.638	6.510	0.79
12	HAGW-S12	0.61	0.957	0.435	6.174	1.7
13	HAGW-S13	0.66	0.957	0.435	6.174	1.51
14	HAGW-S14	0.60	1.405	1.045	5.124	1.23
15	HAGW-S15	0.76	1.679	0.754	5.670	2.61
16	HAGW-S16	0.68	0.742	0.493	5.922	4.3
17	HAGW-S17	0.84	0.583	0.493	5.250	0.3
18	HAGW-S18	0.61	1.328	0.837	7.434	5.87
19	HAGW-S19	0.68	0.897	0.522	6.258	0.88
20	HAGW-S20	0.76	1.025	0.435	7.476	0.34

For all the samples that were analyzed, the SAR values were calculated and are given in table 3. As it is shown in the table, out of these analyzed twenty samples, one sample (HAGW-S2) has SAR value of 3.095, and its respective electrical conductivity value is 1.02 dS/m. This indicates that the groundwater from this well needs slight to moderate degree of restriction on use. The

SAR values of the reaming nineteen samples are ranging from 0.583 to 1.679. However, these nineteen samples are classified into two groups based on their respective electrical conductivity values even though they are grouped in one class according to their respective SAR values; SAR = 0 - 3. Eleven samples (HAGW-S1, HAGW-S3, HAGW-S4, HAGW-S5, HAGW-S6, HAGW-S7, HAGW-S8, HAGW-S15, HAGW-S18, HAGW-S19 and HAGW-S20) have electrical conductivity values of greater than 0.7 dS/m; indicting no hazards of sodicity will rise if the groundwater from these eleven wells is considered for use. The electrical conductivity values of the reaming eight samples range from 0.7 to 0.2 dS/m, indicating that the groundwater from these hand dug wells needs slight to moderate degree of restriction on use.

In general, the groundwater from HAGW-S1, HAGW-S3, HAGW-S4, HAGW-S5, HAGW-S6, HAGW-S7, HAGW-S8, HAGW-S15, HAGW-S18, HAGW-S19 and HAGW-S20 hand dug wells can be used for irrigation with little danger on almost all soils and for almost all crops except those that are highly sensitive to sodium. Sodium-sensitive crops such as stone-fruit trees and avocados may accumulate injurious concentrations of sodium.

The groundwater from HAGW-S2, HAGW-S9, HAGW-S10, HAGW-S11, HAGW-S12, HAGW-S13, HAGW-S14, HAGW-S16, and HAGW-S17 hand dug wells is hazardous for use on fine textured soils that have high cation-exchange capacity. This water may be used on coarse textured or organic soils with good permeability.

3.1.3. Toxicity Problems

As it has been explained above, SAR values were computed for all the analyzed twenty samples. With the exception of sample HAGW-S2 (SAR = 3.095), in all the remaining samples the SAR values are well below 3, indicating no sodium toxicity will rise by using the groundwater from these hand dug wells for surface irrigation. In the sample HAGW-S2, however, the computed SAR value (Table 3) suggests the necessity of slight to moderate degree of restriction on use of the groundwater from this hand dug well for surface irrigation. The likelihood of sodium toxicity hazards is high if the groundwater from this hand dug well is considered for surface irrigation use. The toxicity of chloride depends on its availability in the water. All the samples were analyzed for chloride. As shown in table 3, the chloride concentrations in the groundwater of the watershed range from 0.435 to 0.393meq/l. In all the analyzed samples, the concentrations of chloride are below 3meq/l. This suggests that, if the groundwater of the watershed is considered for both surface and sprinkler irrigation uses, no chloride toxicity will rise.

3.1.4. Miscellaneous Problems

Bicarbonate, although not ordinarily thought to be a toxic ion, is reported to cause zinc deficiency in rice. According to Mikkelson (FAO, 1989), bicarbonate in excess of 2 meq/l in the water used for flooding and growing paddy rice is reported to cause severe zinc deficiency.

As it is shown in table 3, the concentrations of bicarbonate in all the analyzed samples of the groundwater are above 2meq/l. The measured bicarbonate concentrations range from 5.124 to 9.660meq/l. Rice is not a common crop in the study area. Nevertheless, in the future, if it is considered as an alternative crop and groundwater is considered for irrigation, the bicarbonate level in the applied water must be considered to cope with zinc deficiency that might reduce production under prevailing conditions of use. This can be remedied by adding zinc to soil before flooding or at the time of earliest appearance of the chlorosis. Actual zinc of 8 to 10 Kg/ha from zinc oxide or zinc sulfate is surface applied to remain in the upper 5 to 10 cm of soil (FAO, 1989).

Nitrogen (NO_3-N) in the applied irrigation water is generally beneficial to most crops but may cause problems for some. Nitrogen in the irrigation water is readily available and if present should be considered as an important part of the fertilizer program. For most crops, this nitrogen is equivalent to fertilizer nitrogen and should be included in the total nitrogen planned for applications. For a few crops, however, the added nitrogen from the water may be too much and result in excessive and vigorous growth, delayed or uneven maturity, and reduced quality. These sensitive crops include apricots, grapes, sugar beets and cotton, but there are probably others.

The groundwater of the study area was analyzed for NO_3-N. As shown in table 3, the nitrate (NO_3 - N) concentrations of the groundwater of the watershed, with the exception of HAGW-S18, are well below 5 mg/l. This suggests that, if the groundwater of the watershed is considered for irrigation use, no quality problem associated to N will rise. However, in HAGW-S18 the measured NO_3 - N value suggests the necessity of slight to moderate degree of restriction on use of the groundwater from this hand dug well for irrigation. The likelihood of quality problem is high if the groundwater from this hand dug well is considered for irrigation use.

3.1.5. pH

The acidity or basicity of irrigation water is expressed as pH (< 7.0 acidic; > 7.0 basic). The normal pH range for irrigation water is from 6.5 to 8.4. Abnormally low pH’s are not common in the study area, but may cause accelerated irrigation system corrosion where they occur. The measured pH values of the groundwater of the watershed ranges from 6.55 to 7.26 (Table.2). In general, from pH point of view the groundwater of the watershed is safe and can be used for irrigation.

3.2 Soil Analyses

The data generated for soil samples are given in the table 4 and are discussed below.

Table 4. Summarized results of the analyzed soil samples.

Sample code	***pH***	***EC(1:5) (dS/m)***	***ECe (dS/m)***	***Cations (mg/l)***				***Calculated***		***Anions (mg/l)***				
				Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	***SAR***	***ESP***	Cl^{-}	HCO_3^{-}	CO_3^{2-}	SO_4^{2-}	NO_3^{-}
HASS1	7.32	0.208	1.39	28	6	68.11	11	0.491	2.757	0.054	121.8	0.097	105.3	4.57
HASS2	7.13	0.373	2.31	16	3	90.68	10	0.601	2.972	0.099	97.5	0.065	199.8	0.09
HASS3	7.3	0.178	1.36	24	4	98.99	13	0.646	3.060	0.033	66.97	0.066	128.5	20.2
HASS4	7.11	0.172	1.41	18	4	120.9	13	0.721	3.206	0.109	85.29	0.054	220.7	1.24
HASS5	6.77	0.245	4.11	53	3	75.31	9	0.325	2.434	0.102	54.87	0.016	161.7	9.87
HASS6	7.01	0.153	2.13	35	9	38.99	13	0.506	2.787	0.056	58.31	0.043	116.2	9.52
HASS7	6.81	0.834	4.01	31	7	63.88	31	1.307	4.349	0.087	79.25	0.025	176.7	6.41
HASS8	6.92	0.283	2.18	29	11	63.12	14	0.561	2.894	0.124	91.42	0.037	128.1	7.67
HASS9	6.98	0.242	2.38	29	4	81.97	14	0.645	3.058	0.04	85.32	0.004	135.2	3.42
HASS10	7.24	0.171	1.63	58	4	65.38	13	0.445	2.668	0.05	60.89	0.052	125	3.63
HASS11	7.3	0.129	4.49	27	5	76.89	14	0.649	3.066	0.053	66.97	0.066	100.1	9.72
HASS12	7.26	0.192	4.65	60	7	79.03	12	0.390	2.561	0.054	42.62	0.038	201.9	64.5
HASS13	6.98	1.062	1.55	16	1	78.65	24	1.571	4.863	0.124	73.13	0.034	131.5	286.5
HASS14	7.79	0.245	1.9	104	3	70.72	31	0.817	3.393	0.109	133.4	0.405	152.2	35.5
HASS15	7.46	0.215	1.52	449	10	66.94	11	0.140	2.073	0.067	91.24	0.130	161.1	8.8
HASS16	7.34	0.217	1.9	291	6	70.88	7	0.111	2.016	0.076	85.21	0.092	84.6	66
HASS17	7.55	0.352	2.54	155	5	81.98	26	0.560	2.892	0.03	91.18	0.159	108.4	47.3
HASS18	7.49	0.282	2.25	29	3	69.52	14	0.661	3.089	0.041	54.73	0.083	86.73	81.1
HASS19	7.26	0.503	3.09	39	8	66	17	0.647	3.062	0.047	42.62	0.038	161.8	82.1
HASS20	6.99	0.444	2.93	45	0	13	15	0.615	2.999	0.119	97.5	0.047	134.3	72.3
Minimum	6.77	0.129	1.36	16	0	13	7	0.111	2.016	0.03	42.62	0.004	84.6	0.09
Maximum	7.79	1.062	4.65	449	11	120.9	31	1.571	4.863	0.124	133.4	0.405	220.7	286.5
Average	7.20	0.325	2.487	76.8	5.15	72.05	16	0.620	3.010	0.074	79.01	0.078	141	41.02
Std..Dev.	0.26	0.237	1.061	108.6	2.9	21.33	6.9	0.335	0.652	0.032	24	0.086	38.17	64.85

3.2.1 Soil Salinity

To assess the extent of salinity, soil samples from the command area of the hand dug wells were collected and analyzed for EC (1:5). The minimum and maximum EC (1:5) measured value was 0.129 dS/m at 25 °C and 1.062 dS/m at 25 °C, respectively, with a mean EC (1:5) value of 0.325 dS/m at 25 °C. Moreover, the electrical conductivity of saturation extracts of the soil paste (ECe) was also determined. Therefore, the corresponding minimum and maximum ECe value was 1.36 dS/m at 25 °C and 4.65 dS/m at 25 °C, respectively, with a mean value of 2.487 dS/m at 25 °C (Table 4).

3.2.2 Soil Sodicity

Alkali hazard or sodium hazard was evaluated based on the calculated parameters of Sodium Adsorption Ratio (SAR) and Exchangeable Sodium Percentage (ESP). SAR is the proportions of sodium to calcium and magnesium. For all the analyzed soil samples, SAR was computed. Accordingly, the calculated SAR values range from 0.111 - 1.571 with an average of 0.620 (Table 4). By convention, a soil with SAR value greater than 13 is considered as sodic soil (Soil Science of America 1984, cited in Janzen, 1993). In the study area, all the computed SAR values are well below 13. Therefore, the soil of the area is free of sodic hazard.

Exchangeable Sodium Percentage (ESP), the proportion of exchangeable sodium to cation exchange capacity multiplied by 100 %, was also considered as a parameter to evaluate the extent of sodicity of soils. Soil with more than 15 ESP associated with pH value of 8.5 and above is considered as sodic (Brady, 2002).

ESP value for each soil sample was computed using the computed value of SAR for each respective soil sample. There are various relations developed between SAR and ESP. According to USSL staff 1954 cited in Levy (2000), the soil ESP can be estimated from SAR of saturated paste extracts using an empirical relationships of ESP= 1.95 SAR + 1.8, when more dilute extracts are used, such as 1:5 soils: water ratio.

Therefore, from this relation, ESP was computed for the soil samples of the study area. Accordingly, the computed minimum and maximum ESP value was 2.016 and 4.863, respectively. The mean ESP value was 3.010. The pH of the soil for each soil sample was measured in the laboratory. In the watershed the measured pH value of the soil rang from 6.77 to 7.79. The mean pH value is 7.20.

Generally, according to James et al., (1982) soil classification, a soil with electrical conductivity of saturation extracts (ECe) less then 4.0 dS/m at 25 °C, ESP less than 15 %, SAR less than 13 and pH less than 8.5 are classified as normal soil. Therefore, 80 per cent of the soils of the study area are normal soils. In the remaining 20 per cent (soil samples HASS5, HASS7, HASS11 and HASS12), where a soil with electrical conductivity of saturation extracts (ECe) greater than 4.0 dS/m at 25 °C, ESP less than 15 %, SAR less than 13 and pH less than 8.5, the soils of the area are considered as saline soils.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

Generally, in the watershed the groundwater is suitable for irrigation purpose. The soils are free of any soil sodicity hazards. The majority (80 per cent) of the soils are normal soils, free of any soil salinity whereas the remaining 20 percent of the soils are saline but free of sodicity hazards. However, i) to achieve a full yield potential; ii) to sustain it for long period of time; iii) to avoid the possibility of increase in salinity, and iv) to avoid the possibility of occurrence of sodicity and toxicity hazardous in future, proper irrigation scheme is required in the form of crop selection, fertilizer usage and suitable alternative management.

4.2 Recommendations

To maximize the benefits from irrigation activities the following recommendations are suggested.

- Groundwater potential of the watershed should be investigated;
- Since each well is covering around 30 m^2, the existing 154 hand dug wells cover about 4, 600 m^2 of the cultivated land. Keeping in view the small land holdings of the farmers, the close spacing nature the existing hand dug wells and to avoid the wastage of cultivable land, it is suggested to adopt community wells;
- Farmers should be advised on the site selection and drilling of the wells:
- Groundwater utilization and management policies should be formulated and implemented to overcome future conflict in utilization of the groundwater resource in the area and also to maintain the sustainability of the irrigation scheme:
- Groundwater recharging measures needs attention by the community to maintain and maximize the availability of groundwater in the watershed: and,

- With the expansion of water harvesting structures and irrigation in the watershed, health aspect should get serious attention.

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