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Groundwater Characterization of Raya Valley for Irrigation use: The case of Mehoni Agricultural Research Center/Fachagama Experimental Site, Northern Ethiopia

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Abstract: **Characterization of groundwater quality is crucial to the sustainability of irrigation development. The broad objective of this research was to characterize the groundwater quality of Mehoni agricultural research center experimental site in northern Ethiopia for its suitability for irrigation purpose as an appropriate method to give information for different users through optimal management of this resource. Thus, groundwater sample was collected from irrigation bore-hole pump. Studied selected chemical parameters include pH, electrical conductivity (ECw), dissolved basic cations (Ca^{2+}, Mg^{2+} and K^{+}) and anions ($HCO3^{-}$, $CO3^{2-}$, Cl^{-} and $SO4^{2-}$), sodium adsorption ratio (SAR) and residual sodium carbonate (RSC). The results of the laboratory analysis had shown that the groundwater quality of the Fachagama experimental has no sodicity has hazard (SAR = 4.93) but shows a minimum risk or limited hazard with respect to RSC (RSC = 3. 20 meqL^{-1}). Despite the medium EC value (0.36 dS m^{-1}), the groundwater of the study area is fresh, possibly due to flushing by the rainfall and high quality highland groundwater interactions. Hence, most plants can be produced in this groundwater without any practical salinity control.**

Keywords: **Characterization, Ethiopia, Groundwater quality, Irrigation and Mehoni.**

1. INTRODUCTION

Water is mankind's most vital and versatile natural resource and has always played an essential role in virtually every aspect of human life (Nata *et al.*, 2008). Groundwater potential of Ethiopia is estimated around 40 Billion cubic meter (Abiti, 2011) and plays an important role as a major source of water for domestic uses, irrigation activities, industries and livestock. In rural areas, which cover more than 85% of the population of Ethiopia, the problem of water shortage can be solved by proper development and utilization of groundwater. Moreover, currently groundwater is the only limiting resource for further intensification of agriculture, therefore its rational use should be ensured in terms of quality and quantity (Sarkar and Hassan, 2006).

Raya valley area, located in the northern part of Ethiopia has huge groundwater resources which estimated as 7.2 Billion cubic meter (Evans, *et al.*, 2012). This high groundwater potential is basically derived from highland rainfall (Ayenew *et al.*, 2013). In Raya valley region, the Raya Azebo commune is mainly dependant on agricultural production, in which most of the land is cultivated intensively and commercially by individual investors and local farmers with high-yielding cash crops such as onion, tomatoes, pepper, watermelon, vegetables, banana, mango and grapes for commercial purposes. Cereal crops such as teff, maize and sorghum are also produced in the area (Hagos, 2019).

Now a days, groundwater is the main source of irrigation water of Raya valley and pollution of groundwater is a matter of serious concern. The soils of Raya valley region were being continuously irrigated with ground water over years mainly using furrow irrigation methods, which may results in the significant rise in the salinity of the soil. Groundwater pumping at unsustainable rates has also contributed to the lowering of groundwater tables and to saltwater intrusion in some coastal areas (Cai *et al*., 2006). Such irrigation water needs to be of appropriate quality.

The chemical constituents of irrigation water can affect plant growth directly through toxicity or deficiency, or indirectly by altering plant availability of nutrients (Ayers and Westcot, 1985; Rahman *et al*., 2017). Use of poor water quality can also create four types of problems such as toxicity, water infiltration rate, salinity and miscellaneous(Ayers and Westcot, 1985). In addition, poor irrigation water quality affects both soil quality and crop production adversely and is currently a major environmental issue worldwide (Millennium Ecosystem Assessment, 2005). Regardless of its source, irrigation water contains some dissolved salts. The suitability for irrigation water is assessed in terms of the presence of undesirable constituents. The most important characteristics that determine the suitability of irrigation water are: pH; total concentration of soluble salts assessed through electrical conductivity (EC); relative proportion of Na to other cations such as Ca and Mg, referred to as the sodium adsorption ratio (SAR) and concentration of carbonates and bicarbonates as related to the concentration of Ca and Mg, referred to as residual sodium carbonate (RSC) (Ayenew *et al.,* 2013; Kadyampakeni *et al*., 2018).

In irrigation and drainage development projects, characterization of irrigation water characteristics which are important to irrigation development are crucial and helps for management decisions concerning types of crops to plant, extent of contamination and irrigation scheduling. In addition, under irrigation, soil and water compatibility is very important. If they are not compatible, the applied irrigation water could have an adverse effect on the chemical and physical properties of the soil (Scherer *et al*., 2017). Thus, knowledge of irrigation water quality is critical to the understanding of necessary management changes for long-term productivity (Bauder *et al*. 2004) and understanding of irrigation water characteristics over an area has proved useful for the development of water management plan.

Groundwater quality characterization and classifying contribute to the alleviation of the adverse effect of water contamination and is the main information source for precision agriculture and irrigation scheduling. In Raya valley district of Tigray region in general and Mehoni/Fachagama district in particular where this research was conducted, formal scientific study has not been conducted to characterize the irrigation water characteristics using standard classification and evaluate its suitability for crop production. Hence, the objective of this study was, therefore, to characterize the groundwater quality of the Raya valley/Fachagama experimental site to determine the exact level of physico-chemical parameters with special emphasis on its irrigation suitability in the study area. The knowledge generated from this study will guide irrigation water use, and agricultural policy for sustainable irrigation development in the region.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

2.1.1. Location

The study was conducted at Mehoni agricultural research center experimental site which is located at Raya Valley (Fachagama) district in southern zone of Tigray Regional State, northern Ethiopia. It is 668Kms north of Addis Ababa and about 128Kms south of Mekelle, the capital of the National Regional State of Tigray. Geographically, the experimental site is located between 12°41'50" to 12°41'67" N latitude and 39°42'08" to 39°42'26"E longitude with an altitude of 1578 meters above mean sea level. From the hydrological point of view, the site is located within the Afar drainage basin.

2.1.2. Climate

The area is characterized as semi-arid climate region and hot almost throughout the year, except the cooler short winter season (November, December). The mean monthly minimum and maximum temperatures during the study period were 14.34 ^{o}C and 30.04 ^{o}C, respectively. The study area has also unevenly distributed and erratic annual rainfall amount which ranges between 450 and 600 mm (RVLZ, 2007), with most of the rain falling in July – August. Hence, recurrent drought and long dry spell, especially in the main season, has become a common problem. The combined effect of high temperature and strong solar radiation caused the potential evapotranspiration to be very high and significantly exceeds the rainfall in all months. This means that the soil water available for the plants is deficient and crop production must be based on irrigated farming system according to the requirements of the adapted crops. Due to this there is an increasing trend of using irrigation water through pumping from the deeper ground. Climatic data observed during the season were acquired from the nearby Spanish agricultural investment site automated meteorological station. The station is approximately 3.5 km east of the experimental site.

2.1.3. Soil

The soil texture at the site is mostly clay loam (Hagos, 2019), deep black with better water and nutrient holding capacity. In addition, the soil is deep and suitable for irrigation in particular and for agriculture in general. Vertisols and Fluvisols are the dominant soil types found extensively in farmlands of the study area (Amanuel *et al.*, 2015). Diversified variation in agro-climatic zones, soil types and socioeconomic conditions of the farming communities, has contributed to the evolution of different cropping practices in the region in general and study area in particular.

2.1.4. Hydrogeology

The valley floor is bounded on both west and the east directions by highly fractured and weathered basaltic rocks, mainly Ashange basalt. A groundwater resource is believed to be the huge water resource in the area. The dominant groundwater flow directions are north-south and west-east. The depth of groundwater varies from about 20 m in Waja and Adis-Kigni (south) areas to over 60 m in the northern part of the project area (Water Works Design and Supervision Enterprise, 2008).

2.2. Irrigation Water Sample Collection and Analysis of Parameters

Irrigation water sample was collected using a bottle from irrigation bore-hole pump by mixing several portions at 5 minutes interval. The bore-hole was pumped until steady pH and electrical conductivity were obtained. Before collecting the sample, the bottle was washed properly and rinsed thoroughly with distilled water so as to remove any contamination. Sample was taken only after checking the water being free of foreign materials. The sample bottle was tightly capped, labeled carefully and placed in to box with location and then transported to Mekelle Laboratory for chemical analysis within three hours after collection for the analysis of most popular water quality parameters, such as electrical conductivity of water (ECw), pH, dissolved basic cations (Ca^{2+}, Mg^{2+} and K^{+}) and anions ($HCO3^{-}$, $CO3^{2-}$, Cl^{-} and $SO4^{2-}$) contents. Furthermore, SAR and RSC indices were estimated from the measured parameters. The SAR of a water sample is the proportion of sodium relative to calcium and magnesium.

Electrical conductivity and pH of the water sample were measured using conductivity meter and a digital pH meter with appropriate conversion factors for temperature, respectively (FAO, 1988; FAO, 1999). Dissolved basic cations of Ca^{2+} and Mg^{2+} were directly measured using Atomic Absorption Spectrophotometer (AAS), while Na^{+} and K^{+} were analyzed using flame photometer (USSLS, 1954). Additionally, the anions ($CO3^{2-}$, $HCO3^{-}$, Cl^{-} and $SO4^{2-}$) were determined following the procedures described for their respective methods of determination after saturation paste extract has been made (FAO, 1999). The Residual Sodium Carbonate (RSC) and Sodium Adsorption Ratio (SAR) levels were determined using standard equations from the concentrations of HCO_3^{-}, CO_3^{2-}, Na^{+}, Ca^{2+} and Mg^{2+} using equations 2.1 and 2.2, respectively as:

$$RSC = [(HCO_3^{-} + CO_3^{-2}) - (Ca^{+2} + Mg^{+2})] \qquad (2.1)$$

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \qquad (2.2)$$

where, all concentrations were expressed in meq L^{-1} (Hoffman *et al.*, 2010; USSLS, 1954).

3. RESULTS AND DISCUSSIONS

3.1. Groundwater Quality Characterization

Water quality is assessed from the point of view of its use for irrigation purposes, as that is its primary prospective use. Based on this, the laboratory analysis of groundwater chemical compositions of the study area of Fachagama experimental site is shown in Table 1.

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Table 1: Chemical compositions of groundwater in the study area

Sample code	pH	ECw (dS m^{-1})	Dissolved cations ($meq\ L^{-1}$)				SAR	Dissolved anions ($meq\ L^{-1}$)				RSC ($meqL^{-1}$)
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}		CO_3^{2-}	HCO_3^-	SO_4^{2-}	Cl^-	
Fgw	7.58	0.36	3.58	3.50	9.28	0.48	4.93	Trace	10.28	0.21	7.46	3.20

where: Fgw = Fachagama groundwater, ECw = Electrical conductivity, SAR = Sodium adsorption ratio and RSC = Residual sodium carbonate.

The cation, Na^+ and anion, HCO_3^- were dominant in the study area. The other groundwater quality of the study area explanation based on a few water-quality parameters is also given below separately.

pH

The pH value of the irrigation water of the present study area was 7.58. Therefore, according to Bryan *et al*. (2007) (Table 2) the irrigation water quality of the study area was classified as slight to moderate in degree of restriction on use and could pose a threat to crop production with regard to pH value. However, the FAO acceptable threshold limit for irrigation water quality is 6.80 to 8.40 pH value (Ayers and Westcot 1985) which disagrees with the Bryan *et al*. (2007) range. Accordingly, considering Ayers and Westcot (1985) range the pH of the study area was acceptable within the FAO thresholds. Kadyampakeni *et al*. (2018) reported that the pH is an indicator of the predominant cations and anions and irrigation water with a high pH indicates the potential for the precipitation of calcium carbonate salt, which can plug emitters in a drip system.

Table 2: Water quality guidelines for irrigation use

Potential irrigation problem	Degree of restriction on use		
	None	Slight to moderate	Severe
TDS ($mg\ L^{-1}$) [a]	< 450	450-2000	> 2000
HCO_3^- ($mg\ L^{-1}$) (for sprinkler irrigation) [a]	< 1.5	1.5-8.5	> 8.5
pH [b]	< 7	7-8	> 8

Source = FAO (1988)[a]; Bryan *et al*. (2007)[b]

Electrical Conductivity (EC)

Electrical conductivity is a good measurement of salinity hazard to crop when using groundwater for irrigation purpose (Pathmarajah *et al.*, 2012), and therefore is often used to measure salinity problems related to irrigation of crops. The electrical conductivity of irrigation water (ECw) of the present study area was 0.36 dSm^{-1} and according to USSLS (1954) (Table 3) irrigation water quality classification system, it was classified as class two (C2) indicating medium salinity hazard may be due to groundwater outflow and low alkali hazard.

Table 3: Classification of irrigation water quality based on ECw, SAR and RSC

ECw			SAR hazard			RSC hazard		
Salinity class	Salinity hazard	ECw (dSm^{-1})	Sodicity class	Sodicity hazard	SAR	RSC class	RSC hazard	RSC ($meq\ l^{-}$)
C1	Low	< 0.25	S1	Low	< 10	1	Safe (Low)	<1.25
C2	Medium	0.25-0.75	S2	Medium	10-18	2	Marginal	1.25 - 2.50
C3	High	0.75-2.25	S3	High	26-18	3	Unsafe	>2.50
C4	V. high	>2.25	S4	V. high	>26	-	-	-

Source: USSLS (1954).

Despite the medium EC value, the groundwater of the study area is fresh, possibly due to flushing by the rainfall and high quality highland groundwater interactions. This showed that the ground irrigation water of the study area can be used to

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irrigate all types of soils especially soils with good drainage and most plants can be developed in this groundwater without any practical salinity control.

Ayenew *et al.* (2013) also reported that Mohoni basin has Mg-Ca-HCO3 types of water, and the ionic concentration, expressed as electrical conductivity (EC) or TDS, increases towards the valley floor. In areas where irrigation water quality is doubtful, there is a risk of yield reduction for most of the commonly cultivated crops like tomato, cabbage, cauliflower, potato, onion, carrot, bean, tobacco and grapes (Pathmarajah *et al*., 2012). Therefore, adequate drainage and special salinity control measures may be required to cultivate sensitive crops (Raihan and Alam 2008; Pathmarajah *et al*., 2012).

Sodium Adsorption Ratio (SAR)

In US salinity diagram (U.S. Salinity Laboratory Staff, 1954), SAR is taken as alkalinity hazard and is the proportion of sodium relative to calcium and magnesium. In the present study area SAR was also calculated, which reached 4.93 indicating that the water is safe or suitable for irrigation purpose, pose no threat to crops and therefore will not have physical problems associated with dispersed caly (USSLS, 1954). According to Ayenew *et al.* (2013) report no high sodium levels have been identified in the limited amount of groundwater currently used for irrigation in the Mehoni basin, which agreed with this study.

However, if periodic sampling indicates that the SAR is increasing, say from 6 to 9 it implies a hazard or increment of sodium replacing adsorbed calcium and magnesium ions, decreasing soil porosity, resulting in damage to the soil structure and plant roots (Kadyampakeni *et al*., 2018; Ali, 2002). In this case, you may need to consider corrective action during irrigation. Scherer *et al*. (2017) reported that calcium added to irrigation water can lower the SAR and reduce the harmful effects of sodium. Continued use of water with a high SAR value leads to a breakdown in the physical structure of the soil caused by excessive amounts of collodially absorbed sodium (Ayenew *et al.*, 2013).

In SAR, the Ca^{2+} and Mg^{2+} ions are important since they tend to counter the effects of Na^+ hazard (Dhembare, 2012). Presence of Na^+ in irrigation water reacts with soil to reduce permeability and its repeated uses makes the soil impermeable, while high Na^+ leads to development of alkali soil (Rahman *et al*., 2017). Present study area has Na:Ca ratio less than 3 (Table 1) which demonstrates that there is no possibility of infiltration problem occurring in the groundwater. Arshid *et al.(*2011) also reported a high concentration of sodium is undesirable as sodium is adsorbed on the exchange sites causing soil aggregates to disperse, reducing its permeability. Similarly, Pathmarajah (2012) reported that when the concentration of sodium ion is high in irrigation water, Na^+ tends to be absorbed by clay particles, displacing magnesium and calcium ions.

Residual Sodium Carbonate (RSC)

With regards to residual sodium carbonate, the irrigation water sample of the study area was found as 3.2 meq L^{-1} and according to USSLS (1954) standards of irrigation water quality classification system it was classified as high or unsafe RSC, which indicated that there is tendency for calcium and magnesium to precipitate as carbonates. Therefore, RSC of the study area do not meets irrigation water quality and needs corrective measures.

4. CONCLUSIONS

From the above discussion, it can be concluded that the groundwater quality of the Fachagama experimental area pumped from the well has no sodicity has hazard but it has only limited hazards with respect to RSC. Although the study area has medium EC value, the groundwater of the study area/Fachagama is generally fresh, possibly due to flushing by the rainfall and high quality highland groundwater interactions. This showed that as a general aspect levels of sodicity and salinity of the groundwater of the study area do not pose constraints for agricultural water use and satisfy irrigation water standards. However, to safeguard the long-term sustainability of the groundwater resource it needs to be continuously monitored. Furthermore, care must be taken to prevent or minimize the chances of saline water development during pumping from the ground aquifer for irrigation development. Hence, this will results sustaining irrigated agriculture for food security.

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