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Original Research Article

Assessment of Irrigation Water Quality Status in Dry Season Wheat Production in Selected Districts of West Hararghe Zone, Ethiopia

Habtamu Hailu[1*], Lemma Wogi[2], Samuel Feyissa[2]

[1]Oromia Agricultural Research Institute, Mechara Agricultural Research Center, Mechara, Ethiopia
[2]Haramaya University, School of Natural Resource and Environmental Sciences, Haramaya, Ethiopia

***Corresponding author:** Habtamu Hailu

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Abstract: Soil salinity problem is predominantly severe in developing countries, particularly in arid and semiarid regions, resulting in short-term damage to people's livelihoods and long-term repercussions on the country's food security. It is also a major challenge in Ethiopia and west Hararghe in particular where small-scale irrigated agriculture is practiced. Against this backdrop, this study was conducted to assess irrigation water quality in dry season wheat production in Dhungeta, Hule Mandhera, and Kinteri irrigation sites in west Hararghe Zone, Ethiopia. Based on an in-situ field survey, 9 composite irrigation water samples were collected by mixing several sub-samples. The mean water pH at Dhungeta (7.00), Hule Mandhera (7.94), and Kinteri (7.45) fields were grouped in the normal range for irrigation water. The salinity hazard of irrigation water at Dhungeta was medium (0.67 dSm^{-1}), Hule Mandhera high (1.03 dSm^{-1}) and Kinteri (0.99 dSm^{-1}). The total mean of dissolved salt showed water has no restriction for use at Kinteri (153.6 mg L^{-1}) and Dhungeta (426.67 mg L^{-1}) while slight to moderate restriction of water for use was recorded at Hule Mandhera (708.27 mg L^{-1}). The sodicity (alkalinity) hazard class of irrigation water was S1 (low sodium hazard). The mean of residual sodium carbonate was a marginal hazard at Hule Mandhera and safe at Dhungeta and Kinteri. Based on the permeability index, magnesium hazard water was found to be suitable for irrigation. Kelley's index, Percentage sodium (Na^+ %), and potential salinity specified that Hule Mandhera water is unsuitable whereas Dhungeta and Kinteri water were suitable for irrigation. Irrigation water is grouped as a low restriction (70-85) based on the irrigation water quality index. Generally, there is a prospect to decide that the irrigation water quality of the study sites is suitable for wheat production.

Keywords: Irrigation Water Quality, Soil Salinity, Wheat Production.

1. INTRODUCTION

In developing nations, particularly in arid and semiarid locations, problems with soil salinity and alkalinity are particularly severe, having an impact both immediately on people's livelihoods and long-term on the nation's food security (Debela, 2017). Aside from these, extensive fertilizer use, poor irrigation water quality, and poor drainage have all contributed to rising groundwater tables, resulting in salinity-induced soil degradation (Qureshi *et al.*, 2013; Sarwar *et al.*, 2015). Ethiopia leads Africa in terms of the number of salt-affected soils caused by both human and natural factors. Although there is no comprehensive nationwide data on the extent of Ethiopia's salinity problem, various studies have stated that 11 million hectares of land are currently salinized (Ashenafi and Bobe, 2016). This equates to 9% of the country's overall landmass and 13% of the country's irrigated area (Birhane *et al.*, 2020). The Rift Valley, Wabi Shebelle River Basin, Denakil Plains, and other lowlands and valleys of the country are particularly rich in these soils (Ayenew *et al.*, 2013). The spread of these soils is jeopardizing irrigated agriculture's long-term viability, as it diminishes the natural biodiversity and farm productivity of the country.

Ethiopia's agricultural production is primarily rainfed, making it very vulnerable to changes in precipitation patterns and other negative climate change effects. Mitigating salinity to increase the productivity of existing salt-affected soils and preventing the expansion of salinity to newly established farms in arid and semi-arid regions is critical for the country's agricultural development. Salinity issues have now expanded across

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the country, affecting landscapes, irrigated regions, rain-fed farmed areas, and rangelands (Qureshi, 2017).

Surface water is not a reliable source because it is prone to seasonal fluctuations and prone to contamination from anthropogenic activities such as point, non-point pollution sources and biological pollution. However, groundwater is quantitatively better suited, readily available and naturally protected from direct contamination from surface anthropogenic activities (Gebrerufael *et al*., 2019). Agricultural water sources may be of poor quality because of natural causes, contamination, or both, and often require improvement before it is acceptable for a given use (Ayers and Westcot, 1985). The suitability of water for irrigation purposes is most affected by the extent of its contamination with inorganic ions and relative concentrations that characterize the salinity, sodicity and toxicity levels of specific ions.

There is relatively little information on the salinity status and distribution of salt-affected soils in Ethiopia (Ashenafi and Qureshi, 2021). Information on the status and distribution of salt-affected soils and irrigation water quality is particularly scarce in the west Hararghe zone, where the government is widely practicing irrigation with surface and groundwater during the dry season. These necessitate examining the status of soil salinity and irrigation water quality to monitor irrigation water-induced salinity to assure sustainable dry wheat crop production. Hence, the objectives of this study were to evaluate the quality of irrigation water and its suitability for wheat production in selected districts of West Hararghe Zone.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

2.1.1. Location

Daro Labu District covered about 156064.72 ha with an altitude of 1040 - 2770 m a. s. l. It is located 435 km to the east of Addis Ababa and 115 km from Chiro (Zonal Capital) to the south on a gravel road, that connects to Arsi and Bale Zones. Geographically location was found between latitudinal and longitudinal positions between 40 ° 20'00" to 40 ° 70'00" E and 08 ° 15'00" to 08 ° 40'00"N respectively and found within Wabe Shebelle river basin catchment areas. The most commonly grown crops include maize, sorghum, groundnuts, coffee, khat, haricot Bean and wheat which were introduced by the government in the last three years.

Miesso is a District in Oromia Region, Ethiopia. Part of the West Hararghe Zone located at 300 km east of Addis Ababa and about 200 km east of Adama and geographically located between 9°19’52” N and 8°48’12” N, and 40º9’30’’ E and 40°56’44” E, a total area 2,573.44 square kilometers with an estimated area of 2,573.44 square kilometers. Dominant crops in the district are sorghum, maize, teff and sesame, Haricot bean and wheat.

Gumbi-Bordode is other District in West Hararghe that was under Mieso District before four years and was reorganized and established as a new District having 28 *Kebeles*. Geographically it is located 9 °9'49"N to 9°37'20"N and 40 °18'39" E to 40 °38'01"E. The livelihood of the district depends on agro-pastoralism and pastoralism. The main crops that are produced in the district are sorghum, maize, teff, wheat, and soybeans. The total area of the district is 104,446.6 hectares. The topography of the Gumbi-Bordode district is dominant plains 80% and mountains 20% (West Hararghe PCDP-III).

2.1.2. Climate

Daro Lebu is characterized by ambient temperature ranges from 14 to 26 °C with an average of 16 °C and mean annual rainfall of 963 mm. The pattern of rain fall is bimodal and its distribution is mostly uneven. The mean annual temperature of Miesso is around 21 °C, whereas the mean annual rainfall is 790 mm (Fekede *et al*., 2016). The mean annual rainfall of Gumbi Bordode is 736 mm as the temperature ranges from 18.9 to 33.7 °C (Figure 2).

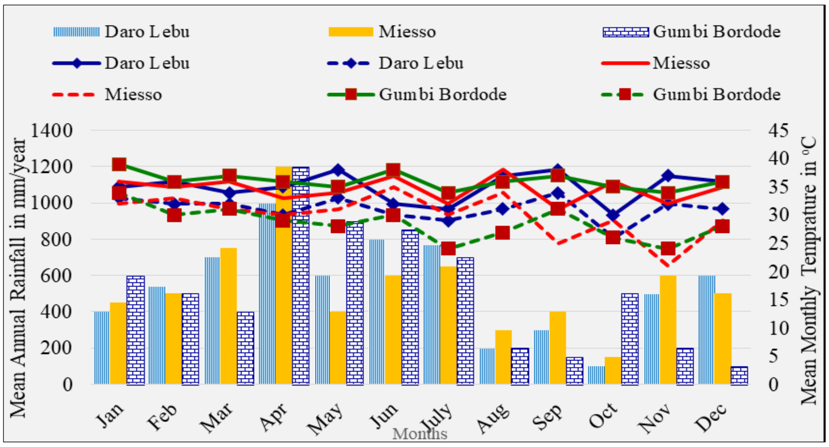

Figure 1: Mean monthly rainfall, maximum and minimum temperatures of the study area (2013-2022)

2.1.3. Topography, Soils and Geology

Most of the land in West Hararghe is characterized by mountainous, with most of the area having an average elevation of 2271.00 masl (Hailu and Biru, 2019). Daro Lebu and Miesso districts are characterized by altitudes ranging from 1350 - 2450 masl and 1107 - 3106 masl respectively. Bayissa *et al.,* (2022) reported that the soil textural coverage of Daro Lebu is sandy clay loam (53.8%), clay soil (21.78%), loam soil (14.28%), clay loam (7.3%), sandy soil (1.9%), and sandy loam (0.9%) with a principal soil type Chromic Cambisols (43.28%), Chromic Vertisols (21.3%), Rendzinas (20.6%), and Vertic Cambisols (9.89%). The dominant soils in Miesso are Cambisol (61%), Leptosol (16%) and Vertisol (Micheli *et al*., 2006) which include Gumbi Bordode since it was part of Miesso.

Geologically Miesso and Gumbi Bordode consist of Alage Formation which contains transitional and subalkaline basalts with minor rhyolite and trachyte eruptives. In addition to this Gumbi bordode is characterized by Amba Aradom Formation (Sandstone, conglomerate and shale) whereas Miesso consists Hamanlei Formation (Oxfordian limestone and shale). The geology of Daro Lebu consists Urandab Formation contain Oxfordian-Kmmerdgian marl and shaly limestone and the Hamanlei Formation that comprises Oxfordian limestone and shale according to the Geological Survey of Ethiopia (1:2000,000).

2.1.4. Farming Systems

The Agricultural activities in the districts are mainly characterized by a subsistence mixed farming system of both crop and livestock production. The livelihoods of the people in the districts depend on livestock and crop production. Crop production is mainly based on rain-fed. The major cereals grown are sorghum (*Sorghum bicolor*), maize (*Zea mays*), and wheat (*Triticum aestivum L.*). Khat and coffee are the main cash crops grown in the study area. Some vegetable crops, such as potato, tomato, cabbage, and onion are grown in the dry season using irrigation where surface water is available. Dry-season wheat production was introduced with irrigation in 2020 using surface and ground water. The main livestock in the study area are cattle, goats, sheep, and poultry which are used as sources of food (meat, milk, and milk products) while their manure is used for soil fertility improvements (Tadele *et al.*, 2021).

2.1.5. Study Sites Selection

Districts with high potential for dry season wheat production were selected through consultation with the Bureau of Agriculture and Rural Development of West Hararghe Zone and the type of irrigation water sources. Accordingly, Daro Lebu (Dhungeta River), Hule Mandhera (Ground water), and Gumbi Bordede (Kinteri River) Districts were selected. Totally 30 farmers' fields, 10 for each site were selected based on the willingness of the farmers.

2.2. Irrigation Water Samples Collection

Before irrigation water sampling, a field survey was carried out. Based on the field observation, irrigation water sampling sources were identified. Accordingly, samples were taken from the selected sources and irrigation canals. Irrigation water samples from irrigation canals were collected by mixing several sub-samples taken at 5-minute intervals at the inlet of the irrigated lands to obtain representative samples. Samples were taken from the groundwater only after it has been pumped for some time and after checking the water was free of mud and foreign materials. Plastic bottles (one liter) were used to collect the water samples from all the water sources and irrigation canals. Before collecting the samples, the bottles were held properly and rinsed thoroughly with distilled water and followed by rinsing with water to be sampled to remove any contamination. Each sample was numbered and labeled carefully and placed into boxes with location and sources indicated.

2.3. Analysis of Selected Irrigation Water Quality Parameters

The electrical conductivity of irrigation water was measured by dipping the conductivity cell assembly in the water sample after it was calibrated by the standard solution (FAO, 1999). Similarly, the pH of the water samples was measured by a digital pH meter after it was calibrated with different buffer solutions (USSLS, 1954). Ca^{2+} and Mg^{2+} of the irrigation water samples were directly measured using AAS, while Na^+ and K^+ were analyzed using a flame photometer (Rowell, 1994). Similarly, the anions (Carbonate and bicarbonate) ions in the sample were determined by titrating it against standard sulphuric acid (H_2SO_4) using phenolphthalein and methyl orange as indicators whereas Cl^- determined $AgNO_3$ titration method in which silver reacts with chloride to form while AgCl precipitate in the presence of sulphuric acid. SO_4^{2-} was determined by the extent of turbidity created by precipitated barium. Boron (B) was determined following the Curcumin analytical method as outlined by Dible *et al*. (1954). Irrigation water salinity, as total dissolved salts (TDS) was determined from EC though multiplied by 640. Sodium adsorption ratio was determined according to equation 1 whereas RSC was determined from the concentrations of HCO_3^-, CO_3^{2-}, Na^+, Ca^{2+}, and Mg^{2+} using equations 2 where all concentrations were in meq L^{-1}.

$$SAR = \frac{Na^+}{\sqrt{\frac{((Ca^{2+} + Mg^{2+}))}{2}}} \text{ Richard (1954) (1)}$$

$$\text{RSC} = [(HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})] \; Richard \text{ (1954) (2)}$$

Magnesium hazard (MH), Kelley index (KI), Potential salinity (PS), and Permeability index (PI), Sodium Percent (%Na^+) were determined from the concentration of Na^+, Cl^-, SO_4^{2-}, Ca^{2+}, K^+, and Mg^{2+} according to equation 3 to 7 respectively while Irrigation Water Quality Index (IWQI) was determined from limiting values of Irrigation water quality parameters (qi) and corresponding weight Wi of each parameter as mentioned in equation 8 whereas qi was determined as stated in equation 9.

$$\text{MH} = \frac{Mg^{2+}}{Mg^{2+} + Ca^{2+}} * 100 \text{ (Doneen, 1964) (3)}$$

$$\text{KI} = \frac{Na^{+}}{Mg^{2+} + Ca^{2+}} \text{ (Kelley, 1963) (4)}$$

$$\text{PS} = Cl^{-} + \frac{1}{2}(SO_4^{2-}) \text{ (Doneen, 1964) (5)}$$

$$\text{PI} = \frac{Na^{+} + [\![\sqrt{(HCO]\!]_3^{-})}}{Mg^{2+} + Ca^{2+} + Na^{+} + K^{+}} * 100 \text{ (Doneen, 1964) (6)}$$

$$\text{Na\%} = \frac{Na^{+} + K^{+}}{Mg^{2+} + Ca^{2+} + Na^{+} + K^{+}} * 100 \text{ (Wilcox, 1955) (7)}$$

$$\text{IWQI} = \sum_{n=1}^{\infty} (\text{qi} * \text{wi}) \text{ (Meireles } et\ al., \text{2010) (8)}$$

$$\text{qi} = q_{max} - \frac{(x_{ij} - x_{inf}) * q_{iamp}}{x_{amp}} \text{ (Meireles } et\ al., \text{2010) (9)}$$

The qi stands for the quality of the i^{th} parameter and wi is the weight of the i^{th} parameter. Value of qi was measured from the upper value of the corresponding class (q_{max}), the observed value of each parameter (x_{ij}), the lower limit value of the class to which the observed parameter belongs (x_{inf}), the class amplitude for qi classes (q_{imap}) and class amplitude to which the parameter belongs (x_{imap}) while wi is the weight given to parameters based their importance for irrigation according to Meireles *et al* (2010).

Gibbs diagram was used to establish the relationship between water composition and aquifer lithological characteristics (Gibbs 1970), USSL salinity diagram was used to represent the relationship between salinity hazards and sodium content in water (expressed in terms of sodium absorption coefficient, SAR; concentrations in meq L^{-1}) and Piper diagram was used to show the classification of water samples from various lithological environment. It also demonstrates the chemical character of the water samples using the dominant cation and anion.

3. RESULTS AND DISCUSSION

3.1. Irrigation Water Quality

3.1.1. Electrical Conductivity and pH

The Mean pH and Electrical conductivity of Dhungeta irrigation water were 7 and 0.24 dS m^{-1}, Hule Mandhera 7.94 & 1.11 dS m^{-1} while 7.45 and 0.24 dS m^{-1} were recorded for the Kinteri irrigation site. According to Lemma *et al*, (2021), the normal pH of irrigation water ranges from 6.5- 8.4. Therefore, based on this range irrigation water of all sites was categorized under the normal range. EC is a good indicator of total soluble solids or salts present in the water and is highly associated with salinity (Corwin and Yemoto, 2017).

In addition to this based on electrical conductivity the quality of irrigation water of the Dhungeta site was class one (C2) which is low in salinity hazard and requires some leaching under normal irrigation practice except for soils with extremely low permeability whereas Kinteri was class two (C1) with medium salinity hazard which can be used if a moderate amount of leaching can occur which is in agreement with Birhane *et al*., (2020) and USSLS (1954). In the case of Hule Mandhera a high (C3) class of salinity hazard was recorded. Natural waters with electrical conductivity typically less than unity when its measurement is performed at a specific temperature and corresponds to the presence of dissolved salts like sodium chloride (table salt), sodium sulfate, calcium chloride, calcium sulfate, magnesium chloride, and others (Pivic *et al.*, 2022).

3.1.2. Concentrations of Major Ions

The most abundant water-soluble cations present in irrigation water are calcium, magnesium, sodium, and potassium. Laboratory analysis revealed that the order of concentrations of these cations in Dhungeta and Kinteri irrigation water were $Na^{+} > Ca^{2+} > Mg^{2+} > K^{+}$. This finding is in line with Sharma *et al*., 2020. On the other hand, orders of concentrations of anions were $HCO_3^{-} > Cl^{-} > CO_3^{2-} > SO_4^{2-}$ (3.54, 1.94, 1.25, 1.16 meq L^{-1}) for the Dhungeta irrigation water whereas $HCO_3^{-} > Cl^{-} > CO_3^{2-} = SO_4^{2-}$ (3.84, 2.36, 1.64 =1.64 meq L^{-1}) in Kinteri irrigation water. In the case of Hule Mandhera, the orders of cations and anions were $Na^{+} > K^{+} > Ca^{2+} > Mg^{2+}$+ and $CO_3^{2-} > HCO_3^{-} > SO_4^{2-} > Cl^{-}$ as indicated in Table 1.

Boron concentration of irrigation water at Dhungeta ranged from 0.36-0.54 mg L^{-1}, in Hule Mandhera irrigation water it ranged from 0.61-0.82 mg L^{-1} and in that of Kinteri from 0.19-0.81 mg L^{-1}. According to Wilcox, (1955) wheat is grouped in semi-tolerant crops for which the suitability of irrigation water is excellent at Dhungeta and excellent to good at Hule Mandhera and Kinteri.

3.1.3. SAR, RSC and TDS

The mean SAR values of irrigation water were 2.51, 2.54, and 5.14 for Dhungeta, Kinteri, and Hule Mandhera respectively. Based on the rating suggested by Richards, (1954) this result was categorized under S1 which is characterized by low sodium or alkali hazard. It can be used for irrigation on almost all soils with little danger of the soil developing harmful levels of exchangeable sodium. However, sodium-sensitive crops such as stone fruit trees and avocados may accumulate injurious concentrations of sodium.

The concentrations of bicarbonate and carbonate than calcium and magnesium, the conditions might be created due to sedimentation of calcium and magnesium carbonates. RSC amount is characteristic of these effects and the remaining sodium carbonate is used to detect the status of irrigation water (Richards, 1954). The RSC extended from -2.28 to -1.37 and -4.12 to -2.64 at the Dhungeta and Kinteri irrigation sites which suggest a little risk of sodium accumulation due to offsetting levels of calcium and magnesium. Birhane *et al.*, (2020) reported that 60% of collected river water has trace RSC. However, the mean of RSC in Hule Mandhera was 2.03 (Table 1) which is categorized under the marginal damage class. On the other hand, a positive RSC value observed at the Hule Mandhera research site indicates that the bicarbonate and carbonate will rescue free calcium and magnesium from the soil, allowing salt to develop.

The Mean of TDS in the Dhungeta, Hule Mandhera, and Kinteri sites irrigation water were 426.67, 708.27, and 153.60 mg L^{-1} respectively. The results of all water samples ranged from 147.2 to 844.8 mg L^{-1} which is categorized under the good quality of water for irrigation practice as rated by Benton, (2012) including Hule Mandhera groundwater. Variation in TDS might be due to anthropogenic factors. Pivic *et al*., (2022) also reported that anthropogenic factors and geological characteristics of the aquifer in the study site can be causes of variations in the TDS of water.

3.1.4. Magnesium Hazard (MH), Kelley Index (KI), and Potential Salinity (PS)

The ranges of MH in the Dhungeta, Hule Mandhera, and Kinteri sites irrigation water were 43.11-48.35, 16.56-59.65, and 31.57-55.06 respectively. For all samples collected from all sources of irrigation water, the mean of MH is below 50 and suitable for practicing irrigation according to the rating of Raghunath (1987). Of the collected water samples 88.89% were categorized under suitable groups of water for the persistence of irrigation based on this parameter. This finding is in line with the study of Pivic *et al*., (2022) and Azhari *et al*., (2023) who recorded 85.12 and 84.62% suitability of surface water for practicing irrigation.

The result of whole samples collected from rivers of Dhungeta and Kinteri indicated Kelley index below one (0.36-0.86 and 0.54-0.65 respectively) and this finding is in agreement with the work of Azhari *et al*., 2023 who reported KI of surface water result <1. According to Kelly's report, the surface water at both locations is suitable for irrigation, and long-term irrigation will not have a detrimental influence on soil permeability due to insufficient cation exchange, resulting in a slight Na^+ excess (Gao *et al*., 2016). But in terms of groundwater, the recorded result of the Kelley index was 0.96-1.18 which is partially categorized under the unsuitable group for persistence of irrigation. The study revealed that based on KI 77.78% of collected samples were grouped under suitable types of irrigation water.

The study also revealed that PS ranges of irrigation water were 2.44 to 2.69 meq L^-, 4.18 to 4.74 meq L^-, and 3.10 to 3.27 meq L^- at Dhungeta, Hule Mandhera, and Kinteri irrigation sites respectively. In terms of this parameter, only water collected from the Dhungeta irrigation site was categorized under Excellent whereas irrigation water from the other sites was grouped under good water for irrigation. Based on this parameter, 33 and 67% of collected samples grouped under excellent and good while a similar finding was reported by Pivic *et al.*, (2022) who reported above 90 % of collected surface water yield PS excellent to good.

3.1.5. Permeability Index and Sodium Percent

The Mean of PI in the Dhungeta, Kinteri, and Hule Mandhera sites was 48.33, 40.26, and 48.84 respectively (Table 1). According to Doneen's (1964) irrigation water classification, the observed results of collected water samples grouped under class II (25-75) which is suitable water for practicing irrigation. In general, it is possible to conclude that sources of irrigation water were suitable for irrigation and continuous irrigation won't impact the permeability of the soil. The range of sodium percent range was extended from 43.81 to 58.78, 60.93 to 67.00, and 44.95 to 56.02 for Dhungeta, Hule Mandhera, and Kinteri prospectively (Table 1). Based on this parameter, the quality of irrigation water for Dhungeta and Kinteri rivers is categorized under good to permissible whereas Hule Mandhera groundwater is grouped as doubtful (60-80) water for irrigation according to the classification of irrigation water quality based on Na^+ % by Wilcox (1955).

Table 1: Selected physicochemical properties of irrigation water

Source IW		pH (H_2O)	EC (dS m^{-1})	Soluble Cations (meq L^{-1})				SAR	B (mg L^{-1})	TDS (mg L^{-1})	RSC (meq L^{-1})
				Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}				
Dhungeta (River)	Range	6.82-7.39	0.49-0.92	3.13-4.25	2.63-3.28	2.21-6.32	2.35-3.46	1.27-3.25	0.36-0.54	313.6-588.8	-2.28 to -1.37
	Mean	7.00	0.67	3.62	2.95	4.59	2.78	2.51	0.46	426.67	-1.77
	SD	0.36	0.23	0.57	0.33	2.13	0.60	1.08	0.09	144.01	0.47
	Median	6.92	0.59	3.47	2.93	5.24	2.52	3.00	0.47	377.6	-1.67
Hule Mandhera	Range	7.68-8.27	0.94-1.32	2.57-7.81	1.55-3.8	7.49-8.96	3.16-7.9	4.1-4.2	0.61-0.82	601.60-844.8	1.62-2.02
	Mean	7.94	1.11	4.95	2.93	8.20	5.57	4.15	0.72	708.27	2.03
	SD	0.28	0.27	2.36	1.34	0.57	1.60	0.03	0.08	171.97	3.93
	Median	7.88	1.06	4.47	3.44	8.16	5.64	4.14	0.72	678.4	3.46
Kinteri (River)	Range	7.26-7.69	0.23-0.25	4.31-5.42	2.50-5.28	4.90-5.19	2.64-4.95	2.33-2.58	0.19-0.81	147.2-160	-4.12 to -2.64
	Mean	7.45	0.24	4.75	4.02	5.08	3.62	2.43	0.42	153.6	-3.30
	SD	0.22	0.01	0.59	1.41	0.16	1.19	0.14	0.34	6.4	0.76
	Median	7.40	0.24	4.52	4.29	5.14	3.28	2.37	0.26	153.6	-3.12

Table 2: Selected chemical properties of irrigation water (*continued*)

Study Sites		Soluble anions (meq L^{-1})				PI	MH	KI	PS (meq L^{-})	NA %	IWQI
		CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}						
Dhungeta (River)	Range	0.27-3.12	3.04-4.16	1.35-2.46	0.45-2.18	37.58-58.2	43.11-48.35	0.36-0.86	2.44-2.69	43.81-58.78	81.66-89.73
	Mean	1.25	3.54	1.94	1.16	48.33	45.01	0.69	2.52	52.03	84.73
	SD	1.62	0.57	0.56	0.9	10.34	2.9	0.28	0.14	7.59	4.37
	Median	0.36	3.42	2.01	0.86	49.19	43.56	0.84	2.44	53.5	82.79
Hule Mandhera	Range	2.36-6.78	4.59-4.9	2.66-2.81	3.04-3.86	42.98-56.89	16.56-59.65	0.96-1.18	4.18-4.74	60.93-67.00	73.50-75.98
	Mean	5.14	4.77	2.75	3.47	48.84	39.9	1.05	4.49	63.5	74.88
	SD	3.13	0.22	0.11	0.58	2.58	19.04	0.05	0.4	4.29	1.19
	Median	6.28	4.81	2.78	3.52	46.64	43.49	1.03	4.54	62.57	75.18
Kinteri (River)	Range	0.57-2.58	3.23-4.37	2.11-2.66	1.00-1.97	38.51-41.79	31.57-55.06	0.54-0.65	3.10-3.27	44.95-56.02	82.27-83.85
	Mean	1.64	3.84	2.36	1.64	40.26	45.11	0.58	3.18	49.7	83.29
	SD	1.01	0.58	0.28	0.55	1.65	12.15	0.06	0.09	5.7	0.89
	Median	1.76	3.93	2.3	1.94	40.49	48.69	0.56	3.16	48.13	83.76

IW= Irrigation water, pH = power of Hydrogen, EC = Electrical Conductivity, SAR = Sodium Adsorption Ratio, RSC = Residual Sodium Percentage, TDS = Total Dissolved Salt, MH= Magnesium hazard, KI= Kelley index, PS= Potential salinity, IWQI= Irrigation water quality index

3.1.6. Irrigation Water Quality Index

The irrigation water quality index (IWQI) was determined using equation 8 from EC, SAR, Concentration of Na^{+}, Cl^{-}, and HCO_3^{-} with their respective weights according to Meireles *et al*., (2010). The mean of IWQI at the Dhungeta, Hule Mandhera, and Kinteri sites were 84.73, 74.88, and 83.29 respectively (Table 2). Relatively, the lowest IWQI was recorded at Hule Mandhera where the source of irrigation water is groundwater which might be due to factors that influence groundwater quality like mineral composition, dissolution and precipitation of minerals, anthropogenic activities, and seawater intrusion. In agreement with this Getahun *et al*., (2014) reported that groundwater contains a higher amount of various ionic constituents than surface water.

According to classes of irrigation water based on existent water quality indexes, risk of salinity problems, soil water infiltration reduction (Meireles *et al*., (2010), as well as toxicity to plants, the observed mean was grouped in the 70 to 85 range. Water use restriction in this range is low and recommended for all crops except salt-sensitive and used for light soil texture with high sand content, and moderate to high permeability.

Table 3: Individual values of each selected chemical parameter (qi) and IWQI

Study site		qi-EC	qi- SAR	qi-Na^+	qi-Cl^-	qi- HCO_3^-	IWQI
Dhungeta	Mean	22.25	14.64	16.52	13.33	17.98	84.73
	SD	0.03	3.62	1.03	0.72	0.41	4.37
	Median	22.25	13.53	16.06	13.49	17.93	82.79
Hule Mandhera	Mean	22.24	8.49	14.97	11.78	17.39	74.88
	SD	0.08	1.25	0.04	0.20	0.06	1.26
	Median	22.24	8.57	14.97	11.73	17.37	75.18
Kinteri	Mean	22.25	13.81	16.60	12.95	17.68	83.29
	SD	0.11	0.27	0.13	0.73	0.20	0.89
	Median	22.25	13.70	16.65	12.84	17.72	83.76

3.1.7. Graphical Presentation of Hydrochemical Data

3.1.7.1. Gibbs Diagram

The Gibbs diagram indicates the origin of solutes and hydrogeochemical processes. Although the Gibbs diagram can be used to determine the role of natural factors, it cannot exclude anthropogenic activities on the chemical properties of water. Water pollutants originating from anthropogenic activities such as mining, metallurgy and chemical industry, and municipal communal services with their actions and contributions, can change the hydrochemical composition of water and increase the concentration of pollutants in water, such as $Cl^−$, $SO_4^{2−}$ and TDS. In addition, people change the hydrodynamic properties of water during the exploitation of water resources and thus affect the interactions of water and geological substrate (rocks) or the intensity of evaporation and change the concentration of individual elements.

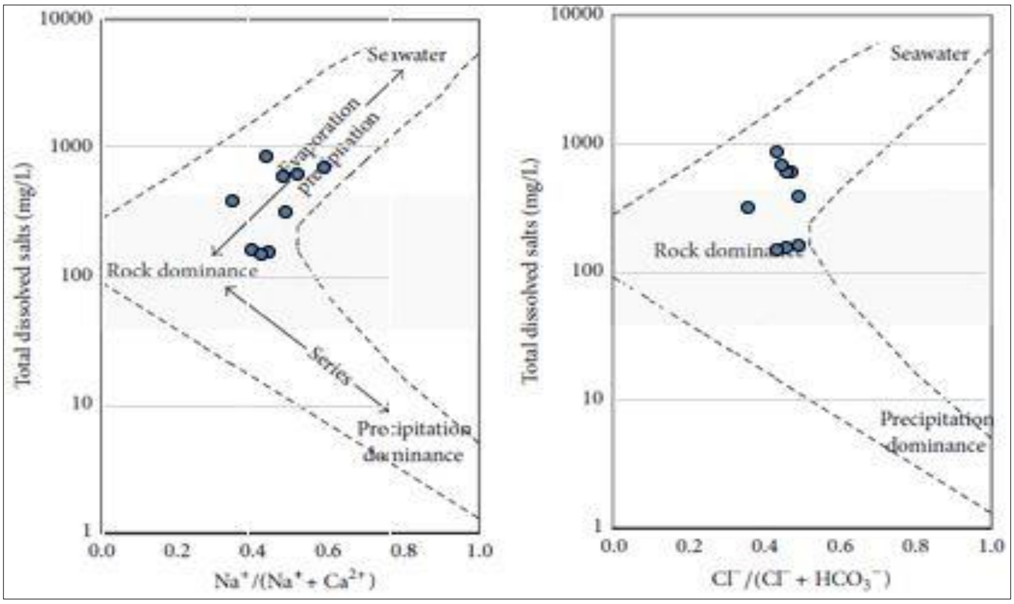

Figure 2: Gibbs diagram: (a) TDS vs. $Na^+/(Na^++Ca^{2+})$; (b) $Cl^-/(Cl^-+HCO_3^-)$

A rock dominance group of irrigation water was recorded for all irrigation sites in terms of both cation and anions which suggests rock weathering and leaching are major geochemical processes influencing water types in Figure 3. The rock–water interaction generally includes the chemical weathering of rocks, dissolution, precipitation of secondary carbonates, and ion exchange between water and clay minerals (Subba Rao 2018). The samples in the rock dominance fall to the left of the Gibbs diagram, with a moderate value of TDS and a lower value of $Na^+/(Na^++Ca^{2+})$ and $Cl^-/(Cl^-+HCO_3^-)$.

3.1.7.2. USSL Diagram

The US Salinity (USSL) diagram represents the relationship between salinity hazard (EC) and sodium content in water (SAR; concentrations in meq L^{-1}). Following (He and Li, 2019), a diagram that appears in Figure 4, a SAR value less than 10 meq L^{-1} is classified as Excellent. SAR values between 10 and 18 meq L^{-1} are classified as good and classified as doubtful if the SAR value is between 18 and 26 meq L^{-1}.

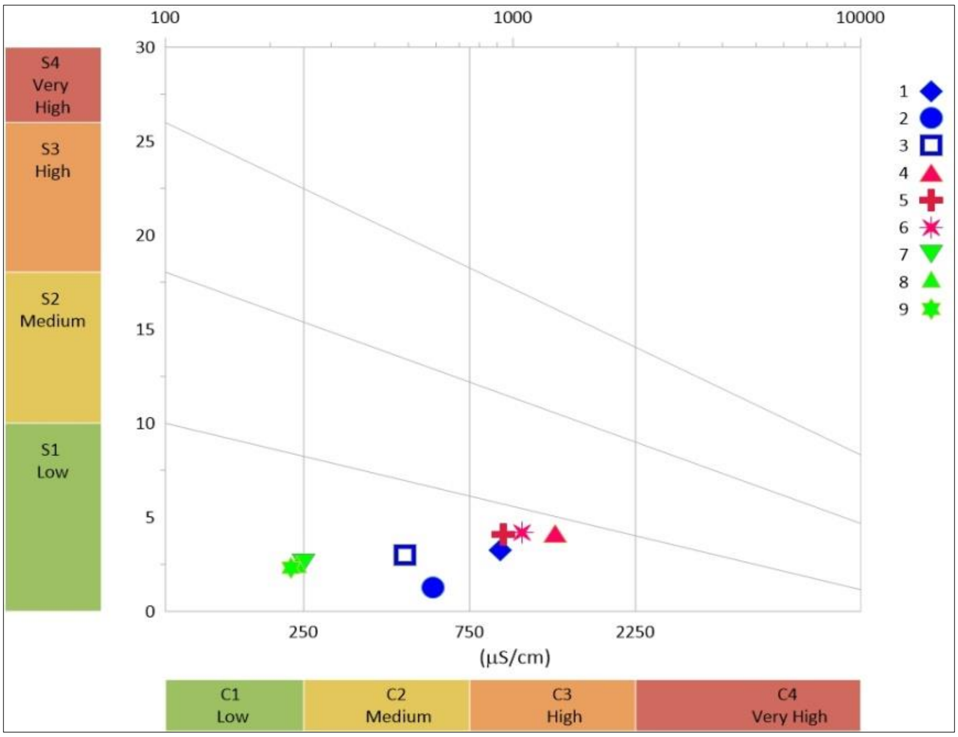

Figure 3: US Salinity (USSL) diagram

1-3 = water samples collected from Dhungeta, 4-6 from Miesso and 7-9 from Kinteri

According to this diagram, clusters of samples located in the regions of C1S1, C2S2, and C3S1 could be considered as very good, a good and medium category of irrigation water. Category C1S1 is characterized by low salinity (used for each type of soil and plant) and low sodicity (used in each type of soil). Similarly, C2S1 is characterized by Medium-salinity water that can be used for all plants if a moderate amount of leaching occurs and low sodicity (which can be used in each type of soil) whereas C3S1 suggests high salinity water (750< EC < 2250 micromho/cm), which cannot be used on soils with restricted drainage, some plants tolerate and low sodicity.

The C3S1-type water cannot be used on soil with restricted drainage. Regarding the suitability of the water zones, C1S1 is suitable for all soil types and crops, and the C2S1 zone could be used to irrigate all types of soils with a modest leaching technique (Subba Rao 2018; Aravinthasamy *et al.*, 2020). The C3S1 zone groundwater samples may be used in areas with appropriate drainage facilities and for salt-tolerant crops.

3.1.7.3. Trilinear Diagram (Piper Diagram)

One of the most common problems with irrigation water is that it comes with an excess of bicarbonates. Bicarbonates get into the water when they pass through a calcium carbonate or magnesium carbonate (limestone or dolomite) rock formation. The stone dissolves into calcium and/or magnesium ions and bicarbonate ions. This sounds innocuous enough, but bicarbonates raise the pH of the water and cause havoc in soil and plants. Bicarbonate only exists when dissolved in water. When water dries out, the bicarbonates in it combine with soluble calcium and magnesium in the soil, locking them up into insoluble calcium carbonate (limestone, $CaCO_3$) and magnesium carbonate (present in dolomitic limestone, $MgCO_3$), the white crust seen around irrigation emitters. This means there will be less soluble calcium and magnesium available for the plants.

Most of the critical issues related to hydrogeochemistry are often estimated based on the percentage concentrations of major cations and anions in meq L^{-1} in the (Piper, 1944) trilinear diagram presented in Figure 5. The Piper diagram is a frequently used and very efficient method for classifying water based on the basic geochemical characteristics of the major ions (Zhang *et al*., 2019). Irrigation water in the study sites was grouped into Mg^{2+} and bicarbonate in terms of cation and anions respectively.

Therefore, the magnesium bicarbonate group of irrigation water is observed at the intersection of the line from cations and anions (Figure 5). The greater calcium and magnesium concentrations are primarily regulated by the hydrolysis of silicate minerals. The anion plots are exclusively clustered around the HCO^-_3, indicating that all of the water samples are bicarbonate type, implying that the study area is in a recharge zone and that weathering and hydrolysis of silicate minerals can be exacerbated by dissolved CO_2 in the area's atmosphere and soils. In general, the principal ionic data plotted in the Figure 5 diagram showed that most of the irrigation water samples were grouped into Mg- HCO^{-}_{3} type water.

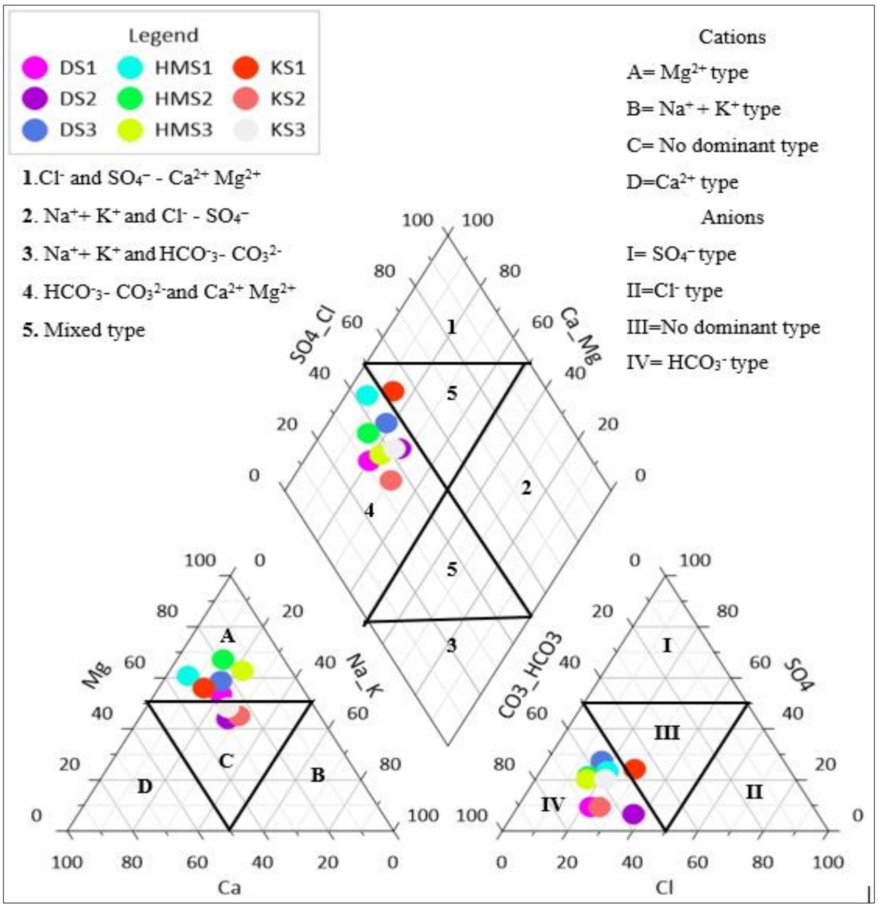

Figure 4: Piper's diagram for water samples

S= Sample, K= Kinteri, D= Dhungeta, HM= Hule Mandhera

3.2. Correlations among Irrigation Water Chemical Properties

The correlation coefficient measures the degree of association that exists between two variables, one taken as a dependent variable. Correlation is the common relationship between two variables. A direct correlation exists when an increase or decrease in the value of one parameter is associated with a corresponding increase or decrease in the value of another parameter (Patil and Patil, 2011). The correlation coefficient (r) among various water quality parameters was calculated and the values of the correlation coefficient were given in (Table 3).

There was highly significant and positive correlation among (P=0.01) (SO_4^{2-}/ Na^+) (r= 0.800) and significant positive correlations ($P \leq 0.05$) (Na^+/ CO_3^{2-}) (r= 0.684). This important correlation may be the result of salt leaching and chemical weathering in surface waters. Similar to this result, Azhari *et al.*, (2023) reported that there is a strong positive correlation between the main cation Na^+ and the bicarbonates (Cl^-, HCO_3^-, and $CaCO_3$), as well as between (Cl^- vs. SO_4^{2-}) and (Na^+ vs. SO_4^{2-}), which provides information on the chemical weathering and leaching of salts in surface waters and suggests salt dissolution in the water.

The significant positive correlations between (EC/Na^+) (r= 0.729) and (EC/Cl^-) (r=0.782) were shown to be related (P 0.05), which provide information on the main parameters controlling the salinity and mineralization of surface water. Since conductivity is caused by the transfer of electricity between ions, the conductivity rises when sodium (Na^+) and chlorine (Cl^-) combine to form sodium chloride in saltwater.

The positive significant correlation between (SO_4^{2-} / K^+) (r= 0.742) may be due to a long history of evaporation and seasonal impacts according to Rajendran *et al*. (2021). At a 5% level of significance, there was also a positive correlation between (SO_4^{2-}/ CO_3^{2-}) (r= 0.677), (SO_4^{2-}/ HCO_3^-) (r= 0.745), and (Boron/CO_3^{2-}) (r=0.720). Similarly, Ahmad (2020) reported a significant positive correlation between SO_4^{2-} and CO_3^{2-}, HCO_3, K^+, and Na^+. The significant correlation between water salinity (EC) and sodicity

(SAR) might designate the potential impacts of various irrigation water qualities on infiltration rates.

Table 4: Pearson's correlation matrix among irrigation water chemical properties

	pH	EC	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SAR	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	RSC	Boron	TDS
pH	**1.00**	0.476	0.527	-0.1	0.542	0.55	0.412	0.457	0.635	**0.782***	0.559	0.281	0.334	0.476
EC		**1.00**	0.267	0.487	**0.729***	0.353	**0.757***	0.56	0.463	0.375	0.528	0.595	0.533	**1.000*****
Ca^{2+}			**1.00**	-0.502	0.486	0.493	0.286	-0.154	0.181	0.181	0.196	-0.405	-0.126	0.267
Mg^{2+}				**1.00**	-0.239	-0.373	-0.251	0.285	0.052	0.192	-0.219	-0.133	0.3	0.487
Na^{+}					**1.00**	0.619	**0.967*****	**0.684***	0.656	0.368	**0.800****	0.538	0.483	**0.729***
K^{+}						**1.00**	0.56	0.429	0.422	0.372	**0.742***	0.325	0.118	0.353
SAR							**1.00**	**0.732***	0.639	0.285	**0.843****	**0.677***	0.496	**0.757***
CO_3^{2-}								**1.00**	0.543	0.618	**0.677***	**0.898****	**0.720***	0.56
HCO_3^{-}									**1.00**	0.447	**0.745***	0.553	0.588	0.463
Cl^{-}										**1.00**	0.346	0.436	0.664	0.375
SO_4^{2-}											**1.00**	**0.692***	0.304	0.528
RSC												**1.00**	0.665	0.595
Boron													**1.00**	0.533
TDS														**1.00**

*, and **, Correlation is significant at $p < 0.05$, and 0.01 respectively, pH = power of Hydrogen, EC = Electrical Conductivity, TDS= Total dissolved salt, RSC= Residual sodium carbonate, SAR= Sodium adsorption ratio

Chloride had a highly positively significant correlation with pH which might be due to Cl^- replacing more OH^- than H_2O when the quantity of Cl^- rises. The elimination of free iron oxides reduces the release of OH^- ions during selective adsorption of Cl^-. This hydroxyl ion release, produced by selective Cl^- adsorption, raises the pH of the soil in a chloride solution. RSC had a high positive significant ($P \leq 0.01$) correlation with CO_3^{2-} (r=0.898) and a nonsignificant positive correlation with HCO_3^- (r=0.553) which indicates the increase of CO_3^{2-} and HCO_3^- concerning Ca^{2+} and Mg^{2+} increases the RSC. TDS correlated with EC (r=1.000***) because TDS is directly determined from EC.

3.3. Suitability of Irrigation Water for Wheat Production

The maximum recorded EC for irrigation water was 1.32 dSm^{-1}. However, USSLS (1954) reported that crops like wheat can grow in EC 8 to 16 dSm^{-1}. The range of irrigation water pH in the study sites was (6.82 to 8.31) which is suitable according to Lemma *et al.*, (2021) who suggested that the normal range of pH for irrigation water (6.5 to 8.4). The mean of B concentration indicated that there was no restriction of irrigation water for use in all irrigation sites. The maximum allowable limits for cations (Ca^{2+}, Mg^{2+}, Na^+, K^+) and anions (HCO_3^-, CO_3^{2-}, Cl^-, SO_4^{2-}) in irrigation water are 80, 35, 200, 30 mgL^{-1} and 250, 15, 250, 180 mgL^{-1} respectively (Sharifi and Safari Sinegani, 2012).

The study revealed that 100% of collected water samples are suitable for irrigation in terms of Cl^- and above allowable in terms of K^+ content for all irrigation sites. In addition to this 100% of Dhungeta water is suitable for irrigation in terms of HCO_3^-, SO_4^{2-}, and Na^+. 33% of collected samples showed suitability at Dhungeta and Kinteri in terms of Ca^{2+} and Mg^{2+} whereas above allowable concentration at Hule Mandhera. 67% of collected samples showed suitability in terms of HCO_3^- and Na^+ at Kinteri while SO_4^{2-} is below allowable concentration. 100% of water samples collected from Hule Mandhera and Kinteri showed unsuitable in terms of CO_3^2. However, the concentration of ions by itself is not enough to assess the suitability of water for irrigation usage. Demelash (2022) also reported that in addition to ions concentration, properties among their exchange should be considered. TDS showed water has no restriction at Kinteri whereas slight to moderate restriction for use at Dhungeta and Hule Mandhera. PI indicated water in all sites grouped to class II which is suitable for irrigation. In terms of MH 100% of water samples collected from Dhungeta and 67% of samples collected from Hule Mandhera and Kinteri were suitable for irrigation.

KI showed 100%, of collected samples from Dhungeta and Kinteri and 33% from Hule Mandhera showed suitability for irrigation. Based on PS irrigation water in all sites was in excellent to good ranges. In the case of Na^+% except for Hule Mandhera, irrigation water was permissible at Dhungeta and Kinteri. The recorded SAR in the study sites was not high enough to cause sodium hazards. A trace RSC was recorded for Dhungeta and Hule Mandhera while it ranges from 1.62 to 2.02

which can cause marginal sodium hazard. IWQI indicated that all sources of irrigation water had low restrictions for use to produce salt-sensitive crops and had no restrictions on semi-tolerant crops like wheat. On the other hand, low-restricted irrigation water is recommended for light soil texture with a high sand content, and moderate to high permeability (Pivic *et al*., 2022; Meirles *et al*., 2010). The soil in all study sites was characterized by high sand content which is suggested for irrigation water with a low restriction use. Therefore, there is the possibility to conclude that the soil and irrigation water quality of the study site is suitable for dry-season wheat production.

4. SUMMARY AND CONCLUSIONS

The study was conducted in Dhungeta and Kinteri where the source of irrigation water is a river and Hule Mandhera where the source of irrigation water is groundwater to evaluate irrigation water quality for dry season wheat production. 9 composite irrigation water samples, three from each site (Hule Mandhera, Dhungeta, and Kinteri) were collected.

Irrigation water pH was extended from 6.82 to 7.39, 7.68 to 8.27, and 7.26 to 7.69 whereas electrical conductivity was 0.49 to 0.92, 0.94 to 1.32 and 0.23 to 1.25dSm^{-1} for Dhungeta, Hule Mandhera and Kinteri respectively. The pH of all collected irrigation water samples was grouped to the normal range (6.5 to 8.4). EC was rated as medium to high, high, and low to high for Dhungeta, Hule Mandhera, and Kinteri irrigation water respectively. The study revealed that a low range of SAR for irrigation water was recorded, 1.27 to 3.25, 4.10 to 7.90, and 2.33 to 2.58 for Dhungeta, Hule Mandhera, and Kinteri respectively.

The hazard of RSC was traced at Dhungeta and Kinteri where the source of irrigation water was surface and a marginal mean (2.03 meq L^{-1}) of RSC hazard was recorded at Hule Mandhera. Permeability index (PI), magnesium hazard (MH), Kelley's index (KI), Percentage sodium (Na^+ %), potential salinity (PS), and irrigation water quality index (IWQI) also used to measure the quality of irrigation water in the study site. Accordingly, based on PI water was found to be class II (25 to 75) for all sources of water which is grouped as a suitable category of water for irrigation. The mean of MH for all sites was below 50 showing suitable water for irrigation. However, 22% of collected water showed MH, 11% for each Hule Mandhera and Kinteri irrigation site. Kelley's index showed that 100% of collected water grouped as suitable water for irrigation at Dhungeta and Kinteri whereas only 33% of collected water became suitable for irrigation at Hule Mandhera, where the source of irrigation water is groundwater.

The potential salinity of irrigation water at Hule Mandhera (4.18 to 4.74 meq L^{-1}) and Kinteri (3.10 to 3.27 meq L^{-1}) was found to be good whereas excellent at the Dhungeta (2.44 to 2.69 meq L^{-1}) irrigation site. Sodium percent in Hule Mandhera ranged from 60.93 to 67.00 which is a doubtful of water for irrigation while it was permissible at Dhungeta (43.81 to 58.78) and Kinteri (44.95 to 56.02) irrigation sites. Irrigation water quality index (IWQI) was measured from five parameters (EC, Na^+, Cl^-, HCO_3^- and SAR) that carry the major factorial load, which defines the best water quality. Accordingly, at Hule Mandhera and Kinteri, the range of IWQI was 73.50 to 75.98 and 82.27 to 83.85 respectively grouped as low restriction for use. In the case of Dhungeta, it ranges from 81.66 to 89.73 with no to low restriction use of water for irrigation. From collected water samples 11% grouped to no restriction for use (85-100) while the rest 89% grouped to low restriction for use (70-85) which is generally suitable for the production of semi-sensitive crops like wheat and other salt tolerant crops.

In addition to evaluating irrigation water quality, analysis of heavy metals in water is required to develop a control approach to limit the negative impacts of irrigation water pollution in the context of sustainable development and water resource protection.

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