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Quality assessment and evaluation of irrigation water and soil used for maize (*Zea mays* L.) production in Boloso Sore district, southern Ethiopia

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ABSTRACT

Poor quality of irrigation water and soil are among the major factors determining maize productivity in Ethiopia. This study assessed and evaluated the quality of irrigation water and soil under maize production in Soke and Woybo irrigation schemes in Boloso Sore district, Ethiopia. Four water samples per site per season were collected from the first point of the irrigation schemes and farm gate for dry and rainy seasons in 2019/2020. Soil samples of 108 were collected from 36 points, from which 18 composited samples were taken for laboratory analysis. Results show that irrigation water of the two schemes is non-saline (electrical conductivity <0.2 dS m^{-1}) and in the normal pH range (6.5–7.5). Maximum concentration of cations in irrigation water was in the order of sodium (22.3 mg l^{-1}) $>$ potassium (7.3 mg l^{-1}) $>$ calcium (6.2 mg l^{-1}) $>$ magnesium (3.1 mg l^{-1}). Moderate to severe sodicity (sodium adsorption ratio of 10.9) was also recorded. Sulfate, nitrate, and phosphate contents in water were trace, and increased during rainy seasons in downstream. Textural classes of soils are clay loam to clay, and less compact to restrict root penetration (bulk density $\leq$1.4 g cm^{-3}), have slow infiltration rate ($\leq$0.13 cm h^{-1}), and medium level of total available water ($\leq$178 mm m^{-1}). Soils are strongly acidic to neutral (pH: 5–6.5), salt-free, and have low soil organic carbon ($\leq$2.1%), low total nitrogen ($\leq$0.1%), low available phosphorus and sulfur, and low Ca^{2+}: Mg^{2+} ratio. It can be concluded that the irrigation water in the study area has cation imbalance (poor quality) which affects soil quality and maize productivity. Likewise, soils of the study area have poor quality. Lime application, efficient fertilizer use, and organic matter applications can be suggested. Further study on optimizing fertilizer rates and irrigation levels has to be conducted to improve maize productivity.

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1. Introduction

Maize production in irrigated soils is dependent on the useable quality and an adequate supply of water [1,2]. Hence, the quality and application level of irrigation water directly affect the quality of soil as well as maize productivity [3,4]. Quality assessment of irrigation water mostly considers its chemical properties whereas soil quality assessment considers the physicochemical properties of soil [5,6]. The widely considered chemical properties of water or soil in the quality assessment include pH, electrical conductivity (ECw or ECe), cations (exchangeable), available phosphors, available sulfur, organic carbon, total (available) nitrogen, and micronutrients. The soil physical properties widely used in quality assessment include soil texture, bulk density, soil moisture content at field capacity (FC) and permanent wilting point (PWP), and infiltration rate.

Acronyms and abbreviations

CEC	Cation Exchange Capacity
CV	Coefficient of Variation
DTPA	Diethylenetriamine Pentaacetic Acid
Ece	Electrical Conductivity of Soil Extracts
ECw	Electrical Conductivity of Water
EDTA	Titrating Aliquot with Ethylenediaminetetraacetic Acid
ERd	Effective Root Depth
FC	Field Capacity
PWP	Permanent Wilting Point
SAR	Sodium Adsorption Ratio
SOC	Soil Organic Carbon
TAW	Total Available Water
ρb	Bulk Density

Maize productivity under irrigated fields is limited by the toxicity of certain ions including sodium, chloride, boron, and nitrate loaded from water into soils [7,8]. High sodium or low calcium content in irrigation water determines their respective levels in soils which reduce infiltration rate [9,10]. The order of bases in quality water or soils is calcium > magnesium > potassium > sodium; deviations from this order create ion-imbalance problems for plants and are categorized as poor quality [9,11]. In addition, a sodium absorption ratio (SAR) beyond 9 causes severe ion imbalance in soil [3].

The cation imbalance in irrigation water or soil results in a low infiltration rate in which sufficient water cannot be infiltrated to supply the crop adequately between irrigation intervals [9,12]. This causes reduced transpiring leaf surface, limited stomatal aperture, and reduced growth and maize productivity [13]. Water infiltration rate refers to the volume flux of water entering into a unit of soil surface area per time, often measured in cm hr^{-1} [7]. Similarly, the nitrification of increased ammonium loaded from water in the soil would serve as a source of hydrogen ions which may lead to soil acidity [14,15]. This could limit nutrient availability to crops as most nutrients are available in the pH range of 5.5–6.5 [16]. Maize productivity is optimal in the pH range of 6–7.2 and electrical conductivity (ECw $\leq$1.1 and ECe $\leq$1.7 dS m^{-1}) [7,17,18].

Likewise, the initial conditions of soils (not from the water) affect maize productivity [19]. Clay content in soils plays a great role in soil quality. Clay content determines soil structure (determines infiltration), retains nutrients against leaching, buffering the soil against extreme pH changes, and is also a source of plant nutrients when it degrades [20,21]. Soil bulk density beyond 0.47 g cm^{-3} for clay and 1.75 g cm^{-3} for clay loams restrict root penetration and development of maize [22]. The soil moisture content at field capacity and permanent wilting points is also an important component of soil quality assessment. Hence, initial soil moisture content determines the amount of plant extractable water in soils, and the level and time of irrigation application [23].

The previous soil quality assessment studies recently conducted in the districts of Wolaita Zone in southern Ethiopia include [5,24,25]. However, the previous studies did not consider irrigation water quality though it significantly affects the soil quality and maize productivity. Likewise, studies [26,27] also indicated that the quality of irrigation water and soil vary from time to time and from place to place. Therefore, this study was undertaken to assess and evaluate the quality of irrigation water and soil under maize production in the Soke and Woybo irrigation schemes of Boloso Sore District in Southern Ethiopia.

2. Materials and methods

2.1. Description of the irrigation water and soil sampling sites

2.1.1. Location

Boloso Sore district is located in Wolaita Zone, southern Ethiopia. This study covered selected *Kebeles* in Boloso Sore district. *Kebele* refers to the lowest administration level in Ethiopia. The capital town (Areka) of Boloso Sore district is located 330 km from Addis Ababa, and 30 km north of Sodo town (Fig. 1). The absolute location of Boloso Sore district ranges from 6°55′ to 7°14′N (latitude), 37°36′ to 37°50′ E (longitude), and at an altitudinal range of 750–1820 m above sea level (source: field survey).

2.1.2. Population and farming systems

The district has a total population of 197,973 (166,565 rural inhabitants), of whom 96,392 are male and 101,581 are female, and it is one of the most densely populated areas in the country [28]. Using the country's average annual population growth rate of 2.9% [29], the district population is projected to be 266,868 by the end of 2019. The district is one of the most densely populated areas in Ethiopia with 653 persons per square kilometer, having a small landholding of less than 0.5 ha on average [29].

The main source of income for farmers in the Boloso Sore district is mixed agriculture (crop production, livestock, and poultry production). Very few farmers are engaged in trading (retailers). Maize is the first preferred annual crop by the farmers and the next one is a common bean. Besides, they produce taro (*Colocasia esculenta* (L.)), *enset* (E*nsete ventricosum*(Welw.) Cheesman), sweet potato (*Ipomoea batatas* (L.)Lam), coffee (*Coffee arabica* L.), ginger (*Zingiber officinale* Roscoe), teff (*Eragrostis tef (Zucc.)*), banana (*Musa acuminate* Colla and M. *balbisiana Colla*), avocado (*Persea americana* Mill.), and mango (*Mangifera indica* L.).

2.1.3. Irrigation schemes and soils of Boloso Sore district

Farmers use both traditional and modern irrigation schemes in Boloso Sore district. The traditional irrigation schemes refer to the diversion of water from rivers and springs through hand-dug furrows whereas the modern irrigation scheme is the water diversion from rivers through canals well prepared from concrete by the Ethiopian Catholic Church Social and Development Commission branch Officie of Soddo. Maize-producing farmers of Achura, Chama Hembecho, Matala Hembecho, Tiyo Hembecho (New *Kebele* extracted from Chama Hembecho and Matala Hembecho *Kebeles*), and Tadisa *Kebele* use irrigation for agricultural production. Farmers of Matala Hembecho *Kebele* use modern irrigation, Tiyo Hemebecho *Kebele* uses both modern and traditional irrigation, and Tadisa *Kebele* uses traditional irrigation only [28].

Boloso Sore district has two modern irrigation schemes namely Soke and Woybo irrigation schemes. The two irrigation schemes cover *Kebeles* of Achura (1678.91 ha), Chama Hembecho (1508.27 ha), and Matala Hembecho including Tiyo Hembecho (1783.26 ha).

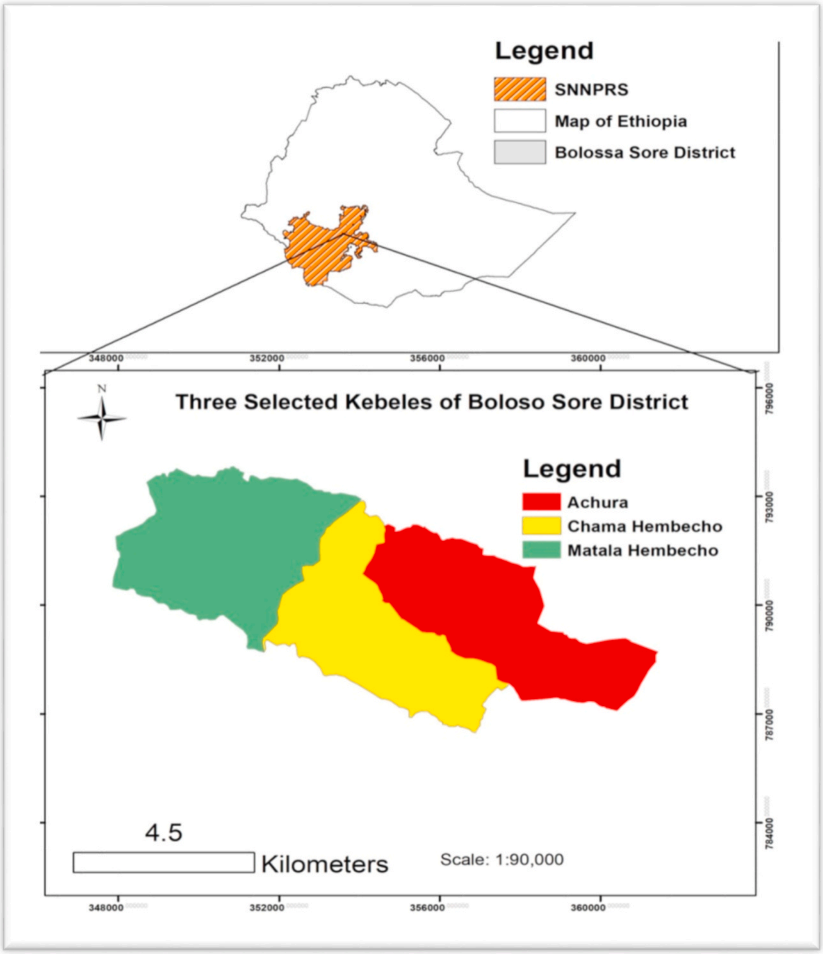

Fig. 1. *Kebeles* using irrigation water in Boloso Sore district, southern Ethiopia.

The Soke and Woybo irrigation schemes are diverted from the Soke River (in 1990 E C/1998 G C) and Woybo River (in 1987 E C/1995 G C.), respectively [28]. The two Rivers are available throughout the year and are the main feeders to the Ajora twin waterfalls of Boloso Bombe district. Soke River is the boundary between Boloso Sore district and Hadero Zuria district of Kembata Tembaro Zone whereas Woybo River is between Woybo *Kebele* and Chama and Matala Hembecho *Kebels* of Boloso Sore district.

The soil (research center) of the district is clay having an average bulk density of 1.2 g cm^{-3} and a pH of 5 [30]. The geological map of Ethiopia developed by the International Groundwater Resources Assessment Centre [31] indicates that the geologic formations of the study area belong to igneous volcanic rocks. The mean annual precipitation of the area is 1328.29 mm with 203.8 mm during *Bega* (dryseason) which needs irrigation for maize production [32]. Mean maximum and minimum temperatures of the area is 25.07 and 13.79 °C, respectively [32].

2.2. Irrigation water sampling and laboratory analyses of chemical properties

Before taking water samples, the residual impurities were removed from the irrigation system. A clean 1L plastic container (bottle) was rinsed three times with the same water to be tested and filled to the top. Water sources are Soke and Woybo irrigation schemes, diverted from Soke and Woybo rivers, respectively. Four water samples per site per season were collected. Water samples were taken from both the diversion point of water from rivers to canals and at farmers' farm gates, in both dry season (November) and rainy season (July) in 2019/2020. Dry and rainy seasons were considered in water sampling, as the chemical properties of water vary with season [33,34], due to factors including soil erosion during the rainy season.

Samples were labeled with identification code, contact information, sample date, and location, to indicate the results are of the sampled point and time. Then, the samples were submitted to the Oromia Water Works Design Enterprise laboratory (Addis Ababa), and the Ethiopian Construction Design and Supervision Works Cooperation laboratory (Addis Ababa) for analysis. The two laboratories were used based on the presence of analysis methods for the selected parameters.

The water samples were analyzed for ten parameters indicated in Table 1. Finally, the ratio of magnesium to calcium, and the sodium adsorption ratio (SAR) as indicated in equation (1), were determined to evaluate the quality of irrigation water. In this study carbonates and bicarbonates were not analyzed as these components are pronounced in the rift valley of Ethiopia and were not expected in Boloso Sore district [6,43].

2.3. Soil sampling and preparation physicochemical properties analyses

For small fields with different cropping histories, IANR [44] suggests Grid soil sampling which divides the field into square or rectangular cells. Similarly, in this study, the square grid cells of 100 m × 100 m were prepared in ArcGIS and supervised with Global Positioning System-GPS points. Based on the gridding outputs, 36 points were identified to collect 108 soil samples as indicated in Fig. 2. The total area of the soil sampling site is 4970.44 ha, from which soil samples were collected from only farming lands used for crop production. Soil samples were collected from the farmlands of both Soke and Woybo irrigation schemes. Soils were sampled to a depth of 60 cm (0–20, 20–40, and 40–60) by opening pits. Similar soil depths were considered by Ref. [45]. Soil samples were collected in December 2019, during which all crops were harvested in Boloso Sore district.

Six (6) samples of similar size from closer points were mixed within their depth and eighteen (18) composite samples (6 from each depth) were taken for laboratory analyses. Besides, a core with a radius (2.5 cm) and height (5 cm) was used to collect core soil samples for bulk density determination. Soil samples were oven-dried at 105 °C for 24 h to obtain a constant weight for bulk density determination. For other parameters analysis, soil samples were removed from the bags and spread out serially on plastic trays checking that

Table 1
Parameters and analysis methods to assess and evaluate quality of irrigation water.

$$SAR = \frac{Na^{+}}{\left[\frac{Ca^{2+} + Mg^{2+}}{2}\right]^{1/2}} \quad (1)$$

S. No	Parameter	Analysis method	Source
1	pH	pH meter	[16]
2	Electrical conductivity (ECw)	Conductivity meter	[16]
3	Calcium (Ca^{2+})	Versenate EDTA titration	[35]
	Magnesium (Mg^{2+})	Versenate EDTA titration	[35]
4	Sodium (Na^{+})	Flame photometer	
5	Potassium (K^{+})	Flame photometer	
6	Phosphate phosphorus (PO_4^{-})	Ascorbic acid/Molybdate blue method	[36]
7	Sulfate sulfur (SO_4^{-})	Turbidimetric method	[37]
8	Nitrate nitrogen (NO_3^{-})	Spectrophotometer	[38]
9	Boron (B)	Curcumin method	[39]
10	Copper (Cu)	Bicinchoninate method	[40]
11	Manganese (Mn)	Periodate oxidation method	[41]
12	Iron (Fe)	A 1, 10 Phenanthroline Method	[42]

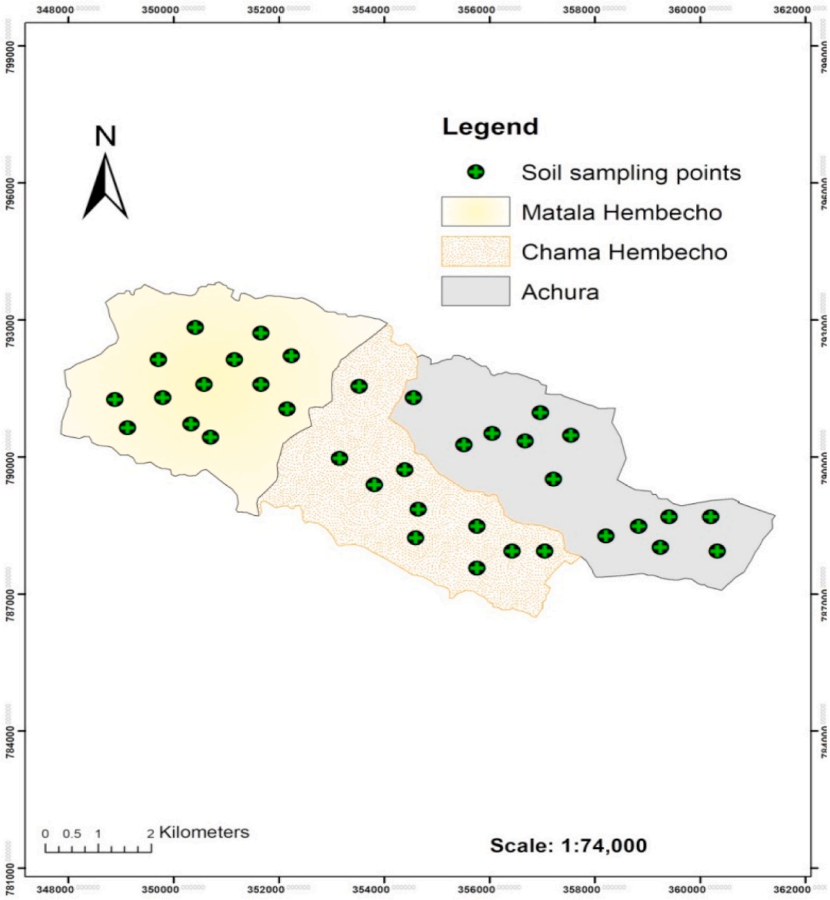

Fig. 2. Sampling points of irrigated fields of the *Kebeles* in Boloso Sore district.

the samples were not mixed and contaminated.

Plant residues like roots were removed and the clods were broken into pieces by hand. The samples were allowed to dry by air, not sunlight. They were dried within 2 weeks. Then, the air-dried soil samples were ground by a mechanical grinder and sieved through a 2

Table 2
Parameters and analysis methods for quality assessment and evaluation of soil.

S. No	Parameter	Analysis method	Source
Soil physical properties			
1	Particle size distribution	Bouyoucos hydrometer method	[46]
2	Texture class	Soil texture calculator	[47]
3	Bulk density	Campbell method	[48].
4	Field capacity	Pressure membrane extractor at a tension of 0.3 bars	[49]
5	Permanent wilting point	Pressure membrane extractor at a tension of 15 bars	[49]
Soil chemical properties			
6	Soil pH (H_2O)	pH meter	[50]
7	Electrical conductivity	Conductivity meter at 25 °C	[16]
8	Total nitrogen	Kjeldahl method	[51]
9	Available phosphorus	Olsen extraction method	[52]
No	Parameter	Analysis method	Source
Soil chemical properties			
10	Available sulfur	Turbidimetric method in barium sulfate precipitation	[53]
11	Exchangeable calcium	Titrating aliquot with Ethylenediaminetetraacetic acid (EDTA) to the endpoint shown by Eriochrome Black T	[35]
12	Exchangeable magnesium	Titrating aliquot with Ethylenediaminetetraacetic acid (EDTA) to the endpoint shown by Eriochrome Black T	[35]
13	Soil organic carbon	Walkley and Black's	[54]
14	Micronutrients (Zn, Cu, Fe, and Mn)	Diethylenetriamine pentaacetic acid (DTPA) was used to extract the available forms of micronutrients and extracts were estimated using atomic absorption spectrophotometer	[55]

mm sieve. The particles >2 mm such as organic debris, gravel, and weathered rock were removed. Finally, the physicochemical parameters of soil samples were analyzed in two separate laboratories, namely; the Ethiopian Construction Design and Supervision Works Cooperation lab, and the Wendo Genet College of Forestry and Natural Resources lab. The two separate laboratories were used based on the presence or absence of equipment and facilities for the required parameters.

2.4. Analyses of soil physicochemical properties

Soil samples were analyzed for the physicochemical properties indicated in Table 2. Then, total available water (TAW) was calculated as the difference between moisture content at field capacity and permanent wilting point (equation (2)). This (TAW) is important to determine the level of supplementary irrigation to fulfill the crop water requirement.

$$\mathrm{TAW}\ (\mathrm{mm}) = \left(\frac{\mathrm{FC} - \mathrm{PWP}}{100} * \rho \mathrm{b} * \mathrm{ERd}\right) * \frac{1}{\rho \mathrm{w}} \tag{2}$$

where ρb is soil bulk density (1.2 g cm^{-3}), ERd is effective root depth (200–600 mm), and ρw is water density (g cm^{-3}).

2.5. Measurement of infiltration rate

The infiltration rate of soils was measured at six points (three points from Soke and three points from Woybo irrigation schemes), spaced 20 m apart from each other. The double ring infiltrometer with the smaller ring with a diameter (28 cm) and length (25 cm) having an area of 615.44 cm^2 was used to measure infiltration in the field. Then, the infiltration rate was calculated as the ratio of change in infiltration to change in time.

2.6. Data analysis

The quantitative data obtained from laboratory analysis and field assessment were recorded in an excel sheet and organized for analysis. Then, the data were analyzed for minimum, maximum, and mean values. Moreover, the coefficient of variation was used to test spatiotemporal variabilities of irrigation water quality and spatial variabilities of soil quality. The R-software, version 4.0.5, was used for analysis.

3. Results and discussion

3.1. Quality of water in Soke and Woybo irrigation schemes

3.1.1. Irrigation water pH and electrical conductivity

Relatively higher pH values of water (6.9–7.5) were observed in the Woybo irrigation scheme (Table 4) than in the Soke irrigation scheme (Table 3). The pH of water showed low spatiotemporal variability in the studied area, as the ratings of [56]. However, relatively higher pH values were observed during the dry season and in downstream in the two irrigation schemes. According to the ratings of [3], the pH of irrigation water in the two irrigation schemes falls in the normal range for irrigation.

The electrical conductivity (ECw) of water is also an important parameter used in irrigation water quality evaluation. Despite the low spatiotemporal variability observed in ECw, the highest ECw (0.185 dS m^{-1}) was recorded in the Woybo irrigation scheme during the dry season. The ECw value of irrigation water falls in the non-saline range of [3] (Appendix 1). The pH and ECw level of water indicate that irrigation water of the two irrigation schemes is in an acceptable range [3] for maize production.

Table 3
Spatiotemporal variations of irrigation water quality in the Soke irrigation scheme.

		Upstream		Downstream		
Parameters	Unit	November	July	November	July	CV (%)
pH	Unitless	6.6	6.5	7.1	6.9	4.1
ECw	dS m^{-1}	0.171	0.170	0.178	0.176	2.1
Ca^{2+}	mg l^{-1}	5	4.7	5	5	2.9
Mg^{2+}	mg l^{-1}	2.6	2.7	2.5	2.6	3.2
K^{+}	mg l^{-1}	6.9	6.8	7.3	6.9	3.2
Na^{+}	mg l^{-1}	21	20	20.5	21	2.3
SAR	Unitless	10.8	10.4	10.6	10.9	2.2
SO_4^{2-}	mg l^{-1}	0.001	0.002	0.001	0.002	38.5
NO_3^{-}	mg l^{-1}	4.4	7.4	5.3	9.2	33
PO_4^{3-}	mg l^{-1}	0.003	0.05	0.07	0.06	64.8
$Fe^{2+,3+}$	mg l^{-1}	1.3	1.2	1.5	1.4	8.3
Mn	mg l^{-1}	0.001	0.002	0.001	0.002	23.1
B	mg l^{-1}	0.001	0.002	0.001	0.002	26.6
Cu	mg l^{-1}	0.001	0.001	0.001	0.001	19.2

where CV is the coefficient of variations, and SAR is the sodium adsorption ratio.

Table 4
Spatiotemporal variations of irrigation water quality in the Woybo irrigation scheme.

		Upstream		Downstream		
Parameters	Unit	November	July	November	July	CV (%)
pH	Unitless	7.3	6.9	7.5	7.1	3.6
ECw	dS m^{-1}	0.18	0.17	0.185	0.174	3.7
Ca^{2+}	mg l^{-1}	6	5	6.2	5.1	11
Mg^{2+}	mg l^{-1}	3	3	2.8	3.1	4.2
K^{+}	mg l^{-1}	7	6	7.2	6.7	7.8
Na^{+}	mg l^{-1}	22.3	20.5	20.7	21.8	4.1
		Upstream		Downstream		
Parameters	Unit	November	July	November	July	CV (%)
SAR	Unitless	10.5	10.3	9.8	10.8	4.2
SO_4^{2-}	mg l^{-1}	0.002	0.003	0.0023	0.003	19.6
NO_3^{-}	mg l^{-1}	3.9	4.5	4.2	6	20.1
PO_4^{3-}	mg l^{-1}	0.0025	0.0032	0.003	0.004	19.6
$Fe^{2+,3+}$	mg l^{-1}	1.4	1.2	1.5	1.23	10.7
Mn	mg l^{-1}	0.001	0.0015	0.0017	0.0018	23.7
B	mg l^{-1}	0.0013	0.0015	0.0018	0.002	18.8
Cu	mg l^{-1}	0.0012	0.0014	0.0015	0.002	22.3

where CV is the coefficient of variations, and SAR is the sodium adsorption ratio.

3.1.2. 2. calcium, magnesium, potassium, and sodium contents in water

The highest contents of calcium-Ca^{2+} (6.2 mg l^{-1}) and magnesium-Mg^{2+} (3.1 mg l^{-1}) were observed in the water of Woybo irrigation scheme (Table 4). These parameters showed low spatiotemporal variability in the studied area. On the other hand, the irrigation water of Soke scheme has higher contents of potassium-K^{+} (7.3 mg l^{-1}) with low spatiotemporal variability. During the dry season, the highest sodium (Na^{+}) content of 22.3 mg l^{-1} was recorded in the water of Woybo irrigation scheme with low spatiotemporal variability. Using the ratings of [7], Na^{+} contents in water are in the acceptable range for irrigation use.

The cations in suitable irrigation water are in the order of $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$ [9]. However, in the case of the studied area, it is in the order of $Na^{+} > K^{+} > Ca^{2+} > Mg^{2+}$. Moreover, Soke irrigation water has the highest sodium absorption ratio (SAR) of 10.9 during the rainy season. Despite the acceptable level of Na^{+} contents in water, its SAR value indicates that it dominated the contents of Ca^{2+} and Mg^{2+} (Table 3, Table 4). According to Ref. [3], the SAR values fall in the range of moderate to severe sodicity levels (Appendix 1). Therefore, the irrigation water of the Soke and Woybo schemes has a cation imbalance which also affects soil quality and water availability to crops [9,12], which limits maize productivity.

3.1.3. 3. Nitrate, sulfate, and phosphate contents in irrigation water

Higher contents of nitrate-NO_3^{-} (9.2 mg l^{-1}) were observed in the irrigation water of the Soke scheme (Table 3). Contents of NO_3^{-} showed medium to very high spatiotemporal variability. This could be associated with nutrient loading from farmlands by erosion. The

Table 5
Particle size distribution and a textural class of soil in Soke and Woybo schemes.

Particle size distribution			Textural class	Site
Sand (%)	Silt (%)	Clay (%)		
Depth (0–20 cm)				
29	34	37	clay loam	Soke
24	32	44	clay	
20	28	52	clay	
24	24	52	clay	Woybo
28	34	38	clay loam	
22	34	44	clay	
Depth (20–40 cm)				
32	25	43	clay	Soke
24	20	56	clay	
25	20	55	clay	
22	24	54	clay	Woybo
26	30	44	clay	
27	23	50	clay	
Depth (40–60 cm)				
32	25	43	clay	Soke
18	20	62	clay	
21	21	58	clay	
20	22	58	clay	Woybo
22	24	54	clay	
26	22	52	clay	

sulfate (SO_4^{2-}) content in irrigation water of Soke and Woybo schemes was trace. However, it showed high to very high spatiotemporal variability using [56] ratings. The high variability could be related to the varied rate of sulfur-containing inorganic fertilizers by farmers that could be discharged to rivers via runoff [57].

Trace contents of phosphate (PO_4^{3-}) were recorded in the irrigation water of the two schemes. However, very high spatiotemporal variability was observed in PO_4^{3-} values of water. It is associated with varying fertilizer use and varying erosion levels loading nutrients to rivers and schemes. In line with these results [58], indicated that the agriculture-dominated surface water has greater total nitrogen, total suspended solids, and pH than the urban and forest land uses due to the use of inorganic fertilizer and runoff from cultivated land. Relatively higher PO_4^{3-} values were recorded in the Soke irrigation scheme than in the Woybo scheme.

3.1.4. 4. micronutrients in irrigation water

Micronutrients except for total iron (Fe) showed trace concentrations in the water of the Soke and Woybo irrigation schemes (Table 3, Table 4). Using the irrigation water standard of [3,59] and, the contents of micronutrients in the irrigation water of Soke and Woybo schemes are below the critical values. This indicates that the concentrations of heavy metals (Fe, Mn, B, and Cu) are not problematic in the irrigation schemes of the studied area (Appendix 1).

3.2. Particle size distribution and textural class of soils of Soke and Woybo irrigation schemes

The results of particle size distribution indicated that the most abundant fraction in both irrigation schemes was clay. The surface soils of the Woybo irrigation scheme had higher clay contents and lower silt contents than that of the Soke irrigation scheme. The textural classes of the soils were clay loam in some locations and clay in the majority of cases (Table 5). The contents of silt and clay showed a consistently decreasing and increasing trend with soil depth, respectively, in both irrigation schemes. Similar results indicating the inverse relationship between clay and silt in response to soil depth were reported by other studies [60,61].

The contents of the sand did not show any monotonic trend with soil depth. This could be due to selective surface erosion of clay, an alluvial accumulation of clay, biological activity, upward movement of coarser particles due to shrinking and swelling, and a combination of two or more of the mentioned processes [62]. In addition [16], indicates that loam or silt loam surface soils, and brown silt clay loams with fairly permeable subsoils are ideal soils for maize cultivation. The study [63] found a strong negative correlation between maize productivity and the clay content of soils. As the textural class of soils of Soke and Woybo irrigation schemes is not heavy clay, they are not limiting factors for maize production.

Table 6

Bulk density and soil moisture content in soils of Soke and Woybo schemes.

	Soil moisture content (mm m^{-1})			Bulk density	Site
	Field capacity	Permanent wilting point	TAW	(g cm^{-3})	
Depth (0–20 cm)					
	352	249	103	1.2	Soke
	385	256	129	1.1	
	343	192	151	1.2	
	321	217	104	1.4	Woybo
	444	266	178	1.1	
	373	254	120	1.1	
CV (%)	11.6	11.9	22.3	9.9	
Depth (20–40 cm)					
	389	286	103	1.1	Soke
	337	225	112	1.1	
	322	123	199	1.1	
	301	200	101	1.3	Woybo
	368	233	134	1.4	
	335	205	130	1.1	
CV (%)	9.3	25.1	28.1	11.2	
	Soil moisture content (mm m^{-1})			Bulk density	Site
	Field capacity	Permanent wilting point	TAW	(g cm^{-3})	
Depth (40–60 cm)					
	349	245	104	1.2	Soke
	402	262	140	1.1	
	301	154	147	1.1	
	421	317	104	1.3	Woybo
	388	241	147	1.2	
	304	180	125	1.1	
CV (%)	14.1	25.1	15.7	7.0	

where TAW denotes the total available water, and CV is the coefficient of variation.

3.3. Bulk density and soil moisture content in soils of Soke and Woybo sites

The bulk density of surface soils of the study area was in the ranges of 1.1–1.4 g cm^{-3} (Table 6). Hazelton and Murphy [64] developed the ratings of bulk density (in g cm^{-3}) as very low (<1), low (1–1.3), moderate (1.3–1.6), high (1.6–1.9), and very high (>1.9). Using this rating, the soils of Soke and Woybo irrigation schemes have low to moderate bulk density. Likewise [22], indicated that soil bulk density for clay (>1.47 g cm^{-3}) and for clay loams (>1.75 g cm^{-3}) restricts root penetration and development. This indicates that the soils of the studied area are not compacted to the extent of restricting root growth of the maize and water movements in the soil. Hence, maize productivity has a strong negative correlation with bulk density [63]. The bulk density of the study area has no monotonic trend with soil depth. This result is similar to the previous finding [61] that indicated the inconsistent trend of bulk density with soil depth.

Relatively higher soil water content at field capacity (FC), permanent wilting point (PWP), and total available water (TAW) were recorded in soils of the Woybo irrigation scheme (Table 6). It is because the soils of Woybo irrigation had higher clay content than that of Soke irrigation scheme, which results in higher water retention. Similarly [65], indicated that soils with higher clay contents have higher water retention. The surface soil moisture content at the field capacity of the study area was 321–444 mm m^{-1} whereas at the permanent wilting point was 192–266 mm m^{-1}. Then, the TAW was estimated as 103–178 mm m^{-1}. Using the ratings [66], the TAW of the surface soils of the studied area was rated as medium (100–200 mm m^{-1}).

As TAW is in the medium range, studies [67–69] suggest mulching, minimum tillage, and compost applications, to improve soil water retention, which could improve maize productivity. A decreasing trend was observed in FC, PWP, and TAW from the surface to the soil depth between 20 cm and 40 cm. However, no monotonic trend was noted on these components with soil depths between the second (20–40 cm) and the last category of soil depth (40–60 cm). In line with this result [65], reported an unclear trend, decreasing or increasing trend of TAW with soil depths. This variation can be associated with variability in organic carbon, soil texture and structure, and rooting depth [70].

3.4. Infiltration rate of soils of Soke and Woybo irrigation schemes

The steady infiltration rate of soils of the Soke and Woybo irrigation schemes was 0.1 cm h^{-1} and 0.13 cm h^{-1}, respectively (Fig. 3). Before the steady state, the infiltration rates of soils between the two irrigation schemes showed huge variations. It could be related to their difference in surface conditions such as clay content, surface crust, surface cracks, and other factors [71]. According to Landon [72], the infiltration rate of soils in the study area falls in the range of slow infiltration rates (Appendix 2). The slow infiltration rate could have caused ponding on level fields, erosion on sloping fields, or inadequate moisture content for maize production [22].

As indicated in Fig. 3, during the initial stage, the highest infiltration rate was observed in soils of the Soke scheme and lowed at a steady state. This is due to a higher percentage of silt and a lower percentage of clay in the surface soils of the Soke scheme than that of the Woybo Scheme (Table 5). In line with this result, the previous studies [61,73] indicated that high content of coarser particles (sand or silt content) have higher initial and steady infiltration rates than soils with larger contents of finer particles (clay loam or clay). The decreasing trend of infiltration rate with time could be due to the gradual weakening of soil structure, the partial sealing of the profile by a surface crust, and the swelling of clay [74].

3.5. Soil pH and electrical conductivity

The pH (H_2O) of the surface soils of Soke and Woybo irrigation schemes ranged from 4.5 to 6.5 (Table 7). In the majority of cases (75%), soil pH showed an increasing trend with soil depth. A similar trend was also reported by Refs. [75,76]. The increasing trend of soil pH with depth could be due to the movement of cations from surface to subsurface soil. Abay and Sheleme [77] confirm that soil

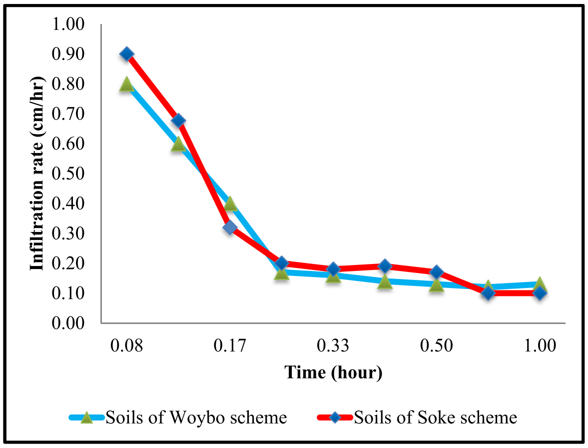

Fig. 3. Infiltration rate of soils of Soke and Woybo irrigation schemes.

Table 7
Soil pH and electrical conductivity of soils in Soke and Woybo irrigation schemes.

	pH (unitless)	Electrical conductivity (dS m^{-1})	Site
Depth (0–20 cm)			
	4.5	0.01	Soke
	6	0.02	
	6.1	0.03	
	4.5	0.02	Woybo
	6.5	0.03	
	6.1	0.03	
CV (%)	15.70	33.28	
Depth (20–40 cm)			
	5.2	0.01	Soke
	6.3	0.02	
	5.2	0.03	
	5	0.02	Woybo
	6.7	0.06	
	4.2	0.03	
CV (%)	16.81	58.65	
Depth (40–60 cm)			
	5.5	0.01	Soke
	6.5	0.02	
	6.5	0.02	
	5.6	0.02	Woybo
	6.3	0.02	
	3.33	0.03	
CV (%)	21.45	35.94	

pH increase with soil depth due to the decrease in H^+ ions released from the organic matter decomposition as organic matter content decreases with depth, and the presence of vertical movements of exchangeable bases.

According to the critical values of soil pH suggested by Ref. [17], the soils of the studied area fall in the range of strongly acidic (25% of the studied area) to moderately acidic (75% of the studied area). Yara [18] rated the soil pH as suitable (5.5–7.3), optimal (6–7.2), and unsuitable (below 5.5) for maize production, as nitrogen, potassium, phosphorus, calcium, and magnesium are readily available in 6.0–6.5 range.

Table 8
Cation exchange capacity and exchangeable bases of soils in Soke and Woybo.

–	CEC (cmol + kg^{-1})	Exchangeable Ca^{2+} (cmol + kg^{-1})	Exchangeable Mg^{2+} (cmol + kg^{-1})	Site
Depth (0–20 cm)				
	7.3	1	0.4	Soke
	8.1	0.8	0.5	
	8.6	0.9	0.4	
	CEC (cmol + kg^{-1})	Exchangeable Ca^{2+} (cmol + kg^{-1})	Exchangeable Mg^{2+} (cmol + kg^{-1})	Site
Depth (0–20 cm)				
	5.4	0.8	0.4	Woybo
	8.9	1	0.5	
	7.2	0.6	0.2	
CV (%)	16.57	17.84	27.39	
Depth (20–40 cm)				
	5.6	0.8	0.2	Soke
	7.1	0.9	0.4	
	7.6	0.7	0.5	
	3.4	1	0.4	Woybo
	6.4	0.9	0.4	
	6.1	0.4	0.3	
CV (%)	24.3	27.28	28.17	
Depth (40–60 cm)				
	5.5	1	0.4	Soke
	7	0.7	0.3	
	7	0.5	0.3	
	2.8	0.6	0.2	Woybo
	3.3	0.4	0.4	
	2.9	0.5	0.2	
CV (%)	42.36	34.65	29.81	

Thus, 25% of the soils of Soke and Woybo irrigation are not suitable for maize production. Hoverer, the pH values of the soils are above intolerable levels for crops, which is below 3 according to Ref. [78]. The roots of a maize crop suffer damage from Aluminum toxicity and limiting nutrient uptake like phosphorous even though fertilizers are applied [18]. Therefore, low maize productivity observed in the study area can be linked with soil acidity.

Relatively, higher electrical conductivity (ECe) was recorded in the surface soils of Woybo irrigation scheme than in the Soke irrigation scheme (Table 7). Using the ratings of [17], the soils of the study area fall in the range of non-saline (Appendix 3). This indicates that the concentrations of soluble salts are below the levels that limit the growth and development of crops including maize [71]. So, salinity is not the factor for the decreasing maize yield reported by farmers in the study area [79].

3.6. Cation exchange capacity and exchangeable bases

Higher cation exchange capacity (CEC) of surface soils was observed in the Soke irrigation scheme than in the Woybo irrigation scheme (Table 8). The CEC of surface soils in both schemes was in the range of 5.4–8.9 cmol $+$ kg^{-1}. No consistent trend was observed in CEC with soil depths. According to Ref. [72] ratings of CEC, the soils of the study area fall into ranges of low CEC (Appendix 3). As the soils of the study area are acidic, low CEC increases the solubility of Al and Fe and it causes deficiencies in cations such as Ca^{2+}, Mg^{2+}, and K^{+} [16,80]. It is related mainly to the continuous cultivation of agricultural fields and nutrient loss by erosion [81,82]. Likewise, it could be related to the low organic matter in the soil indicated by the low content of organic carbon (Table 10), which is confirmed by Ref. [78].

Relatively higher exchangeable Ca^{2+} and Mg^{2+} were observed in the surface soils of the Soke irrigation scheme than in the Woybo irrigation scheme (Table 8). No clear trend was observed on these two exchangeable cations with soil depth. It could be associated with the uneven distribution of parent materials bearing Ca and Mg over the soil depths. Based on the ratings of [78], exchangeable Ca^{2+} is very low (<2) whereas exchangeable Mg^{2+} is very low (<0.3) to low (0.3–1). In productive agricultural soils, exchangeable bases are in the order of $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$; deviations from this order create ion imbalance problems for plants [11].

So, the soils of the study area would cause ion-imbalance problems for plants due to equal values observed both for exchangeable Ca^{2+} and Mg^{2+}, mainly in the lower soil depths. Moreover [72], suggested that the optimum range of Ca: Mg ratio for most crops ranges from 3:1 to 4:1, and less than 3:1 inhibits P uptake and causes Ca deficiency. This is violated in the studied area as a low mean Ca^{2+}: Mg^{2+} ratio (2:1) was recorded. Therefore, the low Ca^{2+}: Mg^{2+} ratio of soils in the study area could cause ion imbalance and limit the magnesium and phosphorus uptake by Maize crops.

3.7. Available phosphorous and sulfur

Relatively higher available phosphorus was observed in the surface soils of the Soke irrigation scheme than in the Woybo irrigation scheme (Table 9). Available phosphorus showed a decreasing trend with soil depth. This could be due to a decreasing trend of organic carbon with soil depth (Table 10). It is related to the applications of animal manure, inorganic fertilizer, and rarely mulching by farmers [79], in response to this, the surface soils have higher available phosphorus than the subsoils. Furthermore [65,83], also indicated that soil organic carbon improves the content of available phosphorus. According to the ratings of [17], the soils of the study

Table 9
Available phosphorus and sulfur in soils of Soke and Woybo irrigation schemes.

	Available phosphorus (mg kg^{-1})	Available Sulfur (mg kg^{-1})	Site
Depth (0–20 cm)			
	12.22	12.64	Soke
	10.82	9.11	
	14.91	8.11	
	7.2	9.28	Woybo
	11.62	14.11	
	12.61	10.1	
CV (%)	21.99	21.96	
Depth (20–40 cm)			
	10.11	3.38	Soke
	11.72	6.4	
	13.13	7.2	
	6.5	5.03	Woybo
	11.02	11.12	
	9.33	11	
CV (%)	22.1	42.8	
Depth (40–60 cm)			
	11.11	19.38	Soke
	7.82	10.2	
	10.15	7	
	5.3	4.88	Woybo
	10.12	7.3	
	8.65	9.07	
CV (%)	23.74	53.03	

Table 10
Soil organic carbon and total nitrogen in soils of Soke and Woybo schemes.

	Soil organic carbon (%)	Total nitrogen (%)	Site
Depth (0–20 cm)			
	0.9	0.03	Soke
	1.6	0.04	
	1.8	0.04	
	1.3	0.02	Woybo
	1.5	0.03	
	2.1	0.1	
CV (%)	26.94	66.35	
Depth (20–40 cm)			
	1	0.03	Soke
	1.4	0.03	
	1.3	0.04	
	1.2	0.02	Woybo
	1.7	0.03	
	1.8	0.09	
CV (%)	21.67	63.2	
Depth (40–60 cm)			
	0.7	0.03	Soke
	1.2	0.03	
	0.9	0.04	
Depth (40–60 cm)			
	0.9	0.02	Woybo
	1.4	0.05	
	1.5	0.09	
CV (%)	28.75	57.77	

area are in the range of very low in available phosphorus (Appendix 3). Conversely, higher available sulfur was observed in the surface soils of the Woybo irrigation scheme than in the Soke irrigation scheme (Appendix 3). Available sulfur showed a decreasing trend with soil depth. This trend is also related to the application of sulfur-containing fertilizers in the surface soils.

Using the ratings of [17], the available sulfur in soils of the studied area falls in the range of very low to low (Appendix 3). This confirms that the available phosphorus and sulfur status of soils in two irrigation schemes are limiting maize productivity. Therefore, amendments of phosphorus and sulfur contents of soils are important to improve maize productivity in the study area.

3.8. Soil organic carbon and total nitrogen

The highest soil organic carbon (2.1%) was observed in the surface soils of the Woybo irrigation scheme than in the Soke irrigation scheme (Table 10). This could be due to varying soil and water management practices between farmers in the study area [79]. Soil organic carbon showed a consistently decreasing trend with soil depth. This is directly related to applications of animal manure, mulching, and also composting on surface soils by farmers though it was not satisfactory [79]. The previous studies [65,83] claimed that applications of organic matter on surface soils directly positively contribute to the organic carbon contents of the soils. Likewise [63], claims that soil organic carbon content has a strong positive effect on maize productivity. Following the ratings of [72], the soils of the study area had very low soil organic carbon.

The total nitrogen content (0.1%) in the surface soils of Woybo irrigation scheme was higher than in the Soke irrigation scheme (Table 10). This could be related to different soil and water management practices applied by the farmers including the inconsistent application rate of inorganic fertilizers. This can be supported by the very high spatial variability of total nitrogen observed in all considered soil depths (>30%), according to Gomes's [56] ratings. The total nitrogen of the studied area falls in the very low to low range in the ratings of [17]. The low contents of soil organic carbon and total nitrogen are related mainly to the continuous cultivation of agricultural fields and the complete removal of maize residues [81,82]. As maize is a high nutrient-demanding crop [78], amending the soils with organic matter and nitrogen-containing fertilizers are important to improve maize productivity.

3.9. Micronutrients in soils

Except for copper, higher micronutrient contents were observed in the Woybo irrigation scheme than in the Soke irrigation scheme (Table 11). It could be due to the medium to very high spatial variability of the micronutrients, according to Gomes's [56] rating. Using the ratings of EthioSIS [17], the soils of the study area had very low Fe, low to optimum Cu, and very low to optimum Zn (Appendix 3). Following the ratings of [71], the soils had deficient to sufficient Mn. A consistently decreasing trend was observed in micronutrient contents with soil depth. This is directly related to the increasing trend of soil pH with soil depth. This is similar to the results of [78] in which increasing concentrations of heavy metal nutrients (Cu, Fe, Mn, and Zn) were observed at lower pH. Fertilizer response is unlikely for values of Fe (>10), Mn (>3), Zn (1.5), and Cu (>1) [84]. Therefore, these micronutrients are not limiting maize

Table 11
Concentrations of extractable micronutrients in soils of Soke and Woybo irrigation schemes.

	Micronutrients (mg kg^{-1})				
	Iron (Fe)	Manganese (Mn)	Copper (Cu)	Zinc (Zn)	Site
Depth (0–20 cm)					
	44	29.2	1	3.8	Soke
	19.5	28.4	1.3	4.2	
	28.2	36.2	0.9	2.6	
	33.4	33.8	1.2	5.5	Woybo
	45.6	30.3	0.8	3.5	
	45.2	36.4	0.8	3.6	
CV (%)	29.95	10.97	20.98	24.79	
Depth (20–40 cm)					
	24.2	16	0.9	2.4	Soke
	17.6	13.3	1.1	3.1	
	20.2	21.2	0.8	1.6	
	19.4	16.2	0.8	1.9	Woybo
	40.4	29.8	0.7	2.7	
	42.1	27.8	0.7	3.1	
CV (%)	40.34	32.78	18.07	25.21	
Depth (40–60 cm)					
	17.2	12.6	0.8	1	Soke
	12.7	12.3	0.6	1.8	
	22.5	19.1	0.7	0.2	
	10.2	5.4	0.9	0.7	Woybo
	35.8	19.9	0.7	1.9	
	39.1	22.7	0.6	2.1	
CV (%)	52.61	41.72	16.31	59.43	

where CV = coefficient of variation.

productivity in the study area, and including them in fertilizer blend is not feasible.

4. Conclusion

Results of the chemical properties of water in Soke and Woybo irrigation schemes revealed that the irrigation water has normal pH levels and is salt-free. Despite this, the cations in the water are in the order of sodium (Na^{+}) > potassium (K^{+}) > calcium (Ca^{2+}) > magnesium (Mg^{2+}) indicating that there is cation imbalance which could also lead to poor soil quality. In addition, the sodium adsorption ratio (SAR) is also at a moderate to severe sodicity level which indicates the dominance of sodium over other cations though its content is low. Further, the increasing trend of nitrate, sulfate, and phosphate concentrations during the rainy season indicates that there were misuses of inorganic fertilizers which are loaded to surface water by erosion. Concentrations of micronutrients (iron, manganese, copper, and zinc) in water are in the normal range; not affecting maize productivity.

With regards to the physical properties of soils, the soils of the study area are categorized as clay loam to clay in texture with slow infiltration rate and less compact bulk density which is not restricting root penetration, and medium water holding capacity. Based on the chemical properties, the soils are categorized as strongly acidic to neutral, salt-free, and have low soil organic carbon, total nitrogen, available phosphorus, and sulfur. Similarly, the soils of the study area had a low Ca^{2+}: Mg^{2+} ratio which indicates that soils have exchangeable cation imbalance which affects maize productivity.

On the other hand, the concentrations of micronutrients in soils were optimum. Based on the results, it can be concluded that the irrigation water in Soke and Woybo irrigation schemes is neutral in pH and have no salinity problem. However, the cation imbalance in water caused a similar problem in soil. Therefore, the irrigation water and soils of the study area are to the extent limiting maize productivity. Thus, lime application (to improve pH level and cation balance), efficient fertilizer use, and organic matter applications can be suggested. Besides, further study on optimizing fertilizer rates and irrigation levels has to be conducted to improve maize productivity in the study area.

Author contribution statement

Alefu Chinasho: Conceived and designed the experiments, performed the experiments, analyzed and interpreted the data, Contributed reagents, materials, analysis tools or data, and wrote the paper.

Bobe Bedadi; Tesfaye Lemma; Tamado Tana; Tilahun Hordofa; and Bisrat Elias: Performed the experiments, Analyzed and interpreted the data, Contributed reagents, materials, analysis tools or data, and Wrote the paper.

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Data availability statement

Data included in article/supplementary material/referenced in article.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors of this manuscript declare that there is no conflict of interest concerning the publication of this article.

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6. Appendices

Appendix 1
Critical levels for irrigation water quality evaluation

Parameters	Units	Degree of restriction on use			Source
		None	Slight to moderate	Severe	
ECw	dS m^{-1}	<0.7	0.7–3.0	>3.0	[3]
Sodium (Na^{+})	me l^{-1}	<2	–	–	[7]
SAR		<3	3–9	>9	[3]
Nitrate (NO_3^{-})	mg l^{-1}	<5	5–30	>30	[3]
Maximum allowable concentration					
Iron (Fe)	mg l^{-1}		5		[7]
Manganese (Mn)	mg l^{-1}		0.2		[7]
Boron (B)	mg l^{-1}		3		[3]
Copper (Cu)	mg l^{-1}		0.2		[7]
pH			Normal range 6.5–8.4		[3]

Appendix 2
Rating of infiltration rates for surface irrigation

Infiltration rates (cm/h)	Suitability for surface irrigation
<0.1	Unsuitable (too slow) but suitable for rice
0.1–0.3	Marginally suitable (too slow); marginally suitable for rice
0.3–0.7	Suitable; unsuitable for rice
0.7–3.5	Optimum
3.5–6.5	Suitable
6.5–12.5	Marginally suitable (too rapid); small basins required
12.5–25	Suitable only under special conditions for very small basins
>25	Unsuitable (too rapid); suggested for overhead methods only

Adopted from Landon [71].

Appendix 3
Critical levels of soil parameters prepared by EthioSIS [17].

Soil parameter	Status	Critical level	Soil parameter	Status	Critical level
Soil pH (water)	Strongly acidic	<5.5	Total	Very low	<0.1
	Moderately acidic	5.6–6.5	Nitrogen	Low	0.1–0.5
	Neutral	6.6–7.3	(%)	Optimum	0.15–0.3
	Moderately alkaline	7.3–8.4		High	0.3–0.5

(*continued on next page*)

Appendix 3 (*continued*)

Soil parameter	Status	Critical level	Soil parameter	Status	Critical level
	Strongly alkaline	>8.5		Very high	>0.5
EC	Salt-free	<2	Copper	Very low	<0.5
(dS m^{-1})	Very slightly saline	2–4	(mg kg^{-1})	Low	0.5–0.9
	Slightly saline	4–8		Optimum	1–20
	Moderately saline	8–16		High	20–30
	Strongly saline	>16		Very high	>30
Phosphorus	Very low	0–15	Zinc	Very low	<1
(mg kg^{-1})	Low	15–30	($mgkg^{-1}$)	Low	1–1.5
	Optimum	30–80		Optimum	1.5–10
	High	80–150		High	10–20
	Very high	>150		Very high	>20
Sulfur	Very low	<10	Iron	Very low	<60
($mgkg^{-1}$)	Low	10–20	($mgkg^{-1}$)	Low	60–80
	Optimum	20–80		Optimum	80–300
	High	80–100		High	300–400
	Very high	>100		Very high	>400
Organic	Very low	<0.2	Boron	Very low	<0.5
matter (%)	Low	2.0–3.0	($mgkg^{-1}$)	Low	0.5–0.8
	Optimum	3.0–7.0		Optimum	0.8–2.0
	High	7.0–8.0		High	2.0–4.0
	Very high	>8.0		Very high	>4.0

Appendix 4

Critical levels of soil organic carbon (OC), and manganese (Mn)

Organic carbon (%)	Rating
>20	Very high
10.0–20.0	High
4.0–10.0	Medium
2.0–4.0	Low
<2	Very low
Manganese (ppm)	
<20	Deficient
20–500	Sufficient
>500	Excessive/toxic

Source: Landon [71]

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