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Assessing Soil and Water Salinity in Irrigated Lands of Selected Districts in Borana Zone, Southern Ethiopia

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ABSTRACT

The presence of excessive salts/sodicity in soils, particularly in moisture-stressed areas, can have detrimental effects on agricultural outputs, having in depth knowledge on the salinity/sodicity of the soil and water is essential for managing agricultural fields for sustainable production and productivity of the limited lands. Accordingly, the assessment was conducted to characterize and map the status of soil and water salinity of selected small-scale irrigation schemes in Borana zone and to design appropriate its management systems. The study was conducted at six irrigation schemes including Qadalle, Arganne, Sabba, Sabboqqo, Jirarsa, and Bule Koloba which found at Yabello, Moyale, Miyo, Dillo, Teletelle and Elawayya districts, respectively. Surface soil samples were collected from surface using auger,as well as from opened pits at different depth interval and important parameters such as pH, EC, Na^+, ESP, SAR, Ca^{2+}, Mg^{2+}, K^+, and CEC were analyzed using different methods. The results obtained were classified in to different soil and water salinity classes depending on the standards set by FAO. As a result, 37% of the studied schemes were characterized as saline with very strong salinity contents in opened profile pits. Laboratory results of irrigation water quality of the study area indicated that 36.11% and 27.79% of samples were classified high to very highly saline, whereas, 55.6% was very highly sodic, which confirmed that this water is unsuitable for irrigation purposes. Arganne irrigation scheme is characterized as moderately and slightly sodic respectively. Particularly, very high sodicity was recorded at Qadalle irrigation scheme in Yabello district. Therefore, it is very important to immediately take action to amend and improve them according to their level of severity by various methods.

Keywords: *Salinity/Sodicity, Irrigation, Mapping, Classification*

Introduction

Excessive soil salinity is a significant constraint to crop productivity, particularly in arid and semi-arid regions where moisture availability is already limited. Understanding the salinity and sodicity status of soils, along with the quality of irrigation water, is vital for sustainable land management and improving agricultural output. Soils affected by salinity can impair plant growth through osmotic stress, nutrient imbalances, and ion toxicity. According to the classification by the United States Salinity Laboratory, a soil is considered saline when the electrical conductivity (EC) of the saturation extract exceeds 4 deciSiemens per meter (dS/m) at 25°C, the exchangeable sodium percentage (ESP) is below 15, and the pH remains under 8.5. These parameters serve as diagnostic indicators to differentiate saline soils from sodic or saline-sodic soils, which require distinct management strategies. Accurate assessment of these soil properties is essential for developing effective reclamation approaches, selecting salt-tolerant crops, and optimizing irrigation practices in salt-affected landscapes.

The primary source of salts in the soil is the weathering process of rocks and primary minerals. This natural process can occur in situ or through the transportation of salts by water or wind. As rocks break down over time, they release minerals that contribute to soil salinity [4]. In addition to natural processes, several man made factors contribute to increased salinity levels in soils includes improper irrigation techniques can exacerbate salinity issues. When irrigation water evaporates, it leaves behind salts that were dissolved in it, leading to increased salinity over time. This phenomenon occurs when land use changes such as forest clearance or overgrazing lead to rising water tables [5-6]. As groundwater rises closer to the surface, it can bring saline groundwater with it, further increasing soil salinity.

Materials and Methods

Description of the study area

The study was conducted on purposely selected schemes in some districts of Borana zone namely, Qadalle, Sabba, Sabboqqo, Jirarsa, Arganne, and Bule Koloba irrigation schemes.

Yabello, the administrative capital of the Borana Zone, is located approximately 570 kilometers south of Addis Ababa. The surrounding Borana lowlands, often referred to as the southern rangelands of Ethiopia, are known for their extensive pastoral and agro-pastoral systems.

Table 1. Description of schemes

S.No	Name of scheme	Distract	Source of water	Latitude	Longitude
1	Arganne	Moyale	Surface water	3° 32' 23.95"	39° 3' 10.23"
2	Bule koloba	Elwaya	River	5° 00’	38° 30’
3	Jirarsa	Teltelle	River	5° 00’ 0.00”	38° 14’ 60.00”
4	Qadalle	Yabello	Surface water	4°52'59.99"	38°04'59.99"
5	Saboqqo	Dillo	Ground water	6°24’30″	38°18’30″
6	Saba	Miyo	River	4°N to 5°	37°E to 38°

The annual average temperature across the irrigation schemes in the Borana region ranges between 19°C and 24°C, with annual rainfall varying from 300 mm to 1000 mm. Precipitation in the area follows a bimodal pattern, with approximately 60% occurring between April and May, and about 30% falling during the secondary rainy season from October to November. The natural vegetation is predominantly mixed savanna, characterized by a dominance of perennial grasses such as *Cenchrus*, *Pennisetum*, and *Chrysopogon* species, alongside a variety of woody plant species [6]. Traditionally, the Borana pastoralist communities rely primarily on cattle herding for their livelihoods and household food security. However, small ruminants such as goats and sheep are also integral to their pastoral systems. In recent years, the rearing of camels has emerged to a limited extent, particularly for milk production and resilience to drought, while donkeys and camels are occasionally used for transport purposes.The dominant crops grown in the study areas are cereal (maize, wheat, and sorghum), pulses (haricot bean, green peas), stimulants (coffee, khat), vegetables (tomato, pepper, onion, head cabbage, and lettuce), roots and tubers (potato, sweet potato, and sugar beet), fruits (Mango, Banana, zeyituna, and papaya), etc. Maize is usually cultivated at the near end of the main season to reach supplementary irrigation. Wheat is introduced recently to be cultivated under irrigation as a strategic crop by the government for ensuring food security and export market (Table 1)

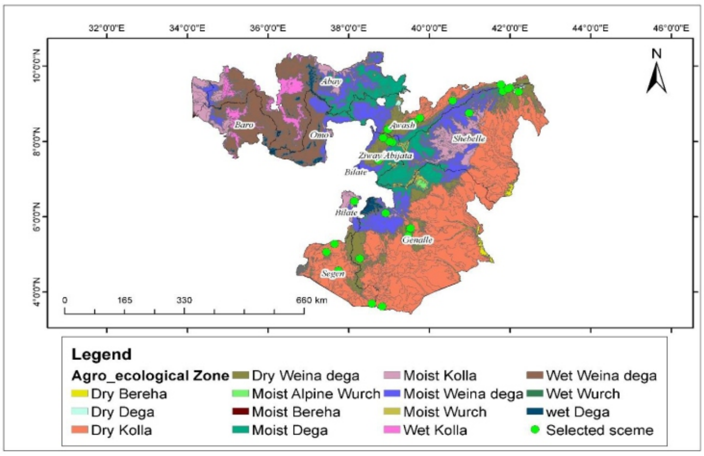

Figure 1: Agro- ecological zone of district selected for data collections

Reconnaissance survey

The preliminary investigation included characterization and description of the potential irrigation schemes. A close reconnaissance survey was done in the selected schemes of Borana zone found in Dillo, Elawayya,Miyo, Moyale Teltelle, and Yabello districts. The assessment was conducted in collaboration with zonal and woreda agricultural and natural resource office. Based on hot spot indicators of salinity and sodicity, six (6) schemes using different irrigation water sources (two schemes from river water source, one groundwater, and three surface water) that are distributed in Borana were finally selected for detail survey (Table 1).

Table 2. Characteristics of selected irrigation schemes from Borana zone districts

Scheme	Actual irrigable area (ha)	Year of start irrigation	Household using the scheme	Major crops
Qadalle	289	2007	275	Maize, tomato, cabbage. mango, papaya and wheat
Jirarsa	85	1988	75	Tomato; Cabbage; Mango; Papaya; Onion; Banana; Lemon; Zayituna and Green Pepper
Saboqqo (GW)	145	2008	575	fodder production
Saba	105	1996	175	Tomato, cabbage; mango, and papaya wheat
Bule koloba	189	1998	875	Tomato, cabbage; mango, papaya and wheat
Arganne	75	2009	200	Khat, Coffee, Banana, Maize, Cabbage, Mango and Papaya

Source: *Zone assessment result: GW- indicates ground water user micro watershed site*

Pit Opening and Soil Sampling

To assess the salinity and sodicity status of the soils across the irrigation schemes, soil pits were excavated based on the slope gradient and variability of soil characteristics within each site. One to two soil profile pits were opened per scheme to a depth of 120 cm. Soil samples were collected at four depth intervals: 0–30 cm, 30–60 cm, 60–90 cm, and 90–120 cm, allowing for a vertical assessment of salinity and sodicity trends. From each depth, approximately 1 kg of air-dried composite soil sample was collected. A total of 24 soil samples were prepared and subjected to laboratory analysis for their physico-chemical properties.

Soil Sample Preparation and Analysis Methods

The collected soil samples were air-dried at room temperature, gently crushed, and sieved through a 2 mm mesh to ensure uniformity. The processed samples were stored in clean, properly labeled polyethylene bags for laboratory analysis [18]. Standard laboratory procedures were employed to determine key chemical properties relevant to salinity and sodicity characterization. These included:

- **Electrical Conductivity (EC)** and **Soil pH**: Determined using a 1:2.5 soil-to-water suspension. A digital pH meter and EC meter were used for the measurements. The measured EC was then converted to electrical conductivity of the saturated paste extract (ECe) using soil-specific conversion factors [15].

- **Cation Exchange Capacity (CEC)**: Extracted using 1M ammonium acetate (NH_4OAc) solution at pH 7.0. The CEC was measured using atomic absorption spectrophotometry.
- **Exchangeable Cations (Ca^{2+}, Mg^{2+}, Na^+, and K^+)**: These were determined through flame photometry and atomic absorption techniques.
- **Exchangeable Sodium Percentage (ESP)**: Calculated using the formula:

$$\text{ESP}\ (\%) = \frac{\text{Exchangeable sodium}\ (Na^+)}{\text{CEC}} * 100 \quad (1)$$

where exchangeable sodium and CEC are expressed in cmol(+) kg^{-1} [12].

These analyses provided a comprehensive understanding of the salinity/sodicity status of the soils, necessary for informing sustainable land and water management interventions in the region.

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

Classification of salinity and sodicity soils

Salinity and sodicity soils were classified according FAO (2008) for salinity and Amrhein (1996)for Sodicity as stated in (Table 2)

Table 3. Criteria for identifying intensity of salinity and sodicity levels in soil

Salinity (ECe in dS/m)		Sodicity (ESP in %)	
Intensity	**FAO (2008)**	**Intensity**	**Amrhein (1996)**
Non saline	0.75	Non-sodic	<6
Slightly saline	0.75-2	Slightly sodic	6-10
Moderately saline	2-4	Moderately sodic	10-15
Strongly saline	4-8	Strongly sodic	15-25
Very Strongly saline	8-15	Extremely sodic	>25
Extremely saline	>15		

Classification of salt affected soils

The soils were classified into various salt-affected categories based on the criteria established by the United States Salinity Laboratory (USSL, 1954), as presented in **Table 3**.

Table 4. Classification of salt affected soils based on their chemical properties

Salt affected soil type	Electrical conductivity of saturation extracts (ECe) at 25 °C (mmhos/cm)	Saturation (%) of Cation Exchange Capacity with Na (ESP)	Soil reaction (pH value)
Saline	> 4	< 15	<8.5
Saline-sodic	> 4	> 15	<8.5 or >8.5
Sodic (Alkali)	< 4	> 15	8.5-10
Non-saline non-sodic	< 4	< 15	About neutral

Methods of Water sampling and preparation

Water samples were collected from various locations along the irrigation canals—including upper, middle, and lower reaches—as well as from the groundwater sources of the study schemes. Each sample was obtained using clean 2-liter glass or polyethylene (plastic) bottles. After collection, the samples were carefully transported to the laboratory for chemical analysis. The procedures for collecting and handling the irrigation water samples followed the standard protocol outlined by [4]. Additionally, each sampling point was georeferenced using a GPS device to ensure accurate location tracking.

Water sample analysis

The collected water samples were subject for the analysis of pH, EC, dissolved cations (Ca, Mg, Na, and K), Alkalinity (HCO_3^- and CO_3^{2-}) and Cl^- contents in the laboratory. EC and pH of the water samples were measured in a laboratory within 24 hours using a conductivity meter and a digital pH meter, respectively[17]. Alkalinity (HCO_3^- + CO_3^{2-} ions) were determined by titrating with standard sulfuric acid (H_2SO4). The Argentometric Method, Soluble Ca and Mg measured chloride were measured using EDTA titration, whilst exchangeable Na and K were analyzed using flame photometer. The General guidelines used for classification of salinity/sodicity hazard of irrigation water based upon ECw and Sodium Adsorption Ratio (SAR) according to USSL staff 1994 described in [1] is presented in Table 4.

Table 5. General guidelines for salinity/sodicity class of irrigation water based onECw and SAR

No.	Salinity class	ECw(mmhos/cm)	Sodicity hazard	Irrigation water with SAR value
1	Low saline	0.1- 0.25	Low Sodicity	<10
2	Medium saline	0.25-0.75	Medium Sodicity	10 to 18
3	High saline	0.75 – 2.25	High Sodicity	18 to 26
4	Very high saline	>2.25	Very high Sodicity	>26

Salinity mapping

Soil salinity mapping conducted a thorough evaluation of soil salinity and sodicity; several steps must be followed systematically. The process involves preparing a database of soil samples, performing statistical analyses, and utilizing geospatial tools like ArcGIS for mapping.The kriging model was used to estimate the electrical conductivity and exchangeable sodium percentage values at un sampled sites[9]; whereas Inverse Distance Weight (IDW) was employed for spatial mapping of the other soil quality parameters[9].

Results and Discussion

Soil salinity class of selected irrigation schemes of Borana zone

Point surface soil salt concentration

From laboratory results of 24 surface soil samples collected from the study irrigation schemes, 68 of samples that share large value (35.79%) were fall under slightly saline and 51 (26.84%) were under moderately saline severity levels. From the studied samples, about 15.27% of them were in the range of highly saline to extremely saline classes, which need immediate management interventions (Table 5). Salinity build-up in irrigation schemes is a significant agricultural challenge, particularly in regions characterized by low rainfall and specific climatic conditions.

The main causes for salinity build-up in those schemes might be mainly due to poor irrigation water management and efficient scheduling that agrees with the finding of [14] that inefficient irrigation practices, absence of adequate drainage systems, locations of the schemes (lowland areas, semi-arid and arid climate where there is limited rainfall to leach down accumulated salts from the plant root zone) are other significant causes of surface soil salinity. '[8] findings also underscore a critical environmental challenge facing Ethiopian agriculture including the widespread of soil and water salinity coupled with sodicity in lowland irrigated areas necessitating immediate attention from concerned bodies.

Table 6. Point surface soil salinity distribution (ECe) of schemes from selected schemes of Borana zone

Depth	Severity	Frequency	Percentage
Surface	Non saline	5	20.83
	Slightly saline	8	33.33
	Moderately saline	6	25.00
	Strongly saline	3	12.50
	Very strongly saline	1	4.17
	Extremely saline	1	4.17
Total Samples		24	100

Profile pit salt concentration

From point sample analysis along soil profile, slightly and moderately saline classes have the highest share along all profile depths (i.e., above 62.62%), whereas the non-saline class fall below 22% of the sample. About 15.35% of the studied sample along soil profile were within salinity class of strongly to extremely saline (Table 6). This result indicated that the salinity source might be from soil parent material, poor groundwater used for irrigation as well as ground water capillarity rise. Those schemes that are highly affected by salinity are from Dillo at Sabboqqo ground water users, Moyale at Arganne and Yabello at Qadalle irrigation schemes.

There was increasing trend of soil salinity along the profile pits from surface to the bottom for some irrigation schemes at Qadalle scheme(Appendix Table 1). This might have resulted from poor irrigation practices like absence of proper irrigation scheduling, water logging, and use of poor-quality water for irrigation, intensive agriculture, and over and or under-irrigation in the study schemes. On the other hand, there observed decreasing trend of soil salinity along soil profile from surface downward for Arganne, schemes. The result is due rising salt-laden groundwater close to the soil by capillary action. Thus, evapotranspiration (ET) between irrigation periods can further increase salinity. This result is in line with the findings of [3] that the irrigated fields of their study areas were affected partly by salinity and the distribution was associated with shallow groundwater.

Table 7. Summary of salinity levels along soil profile of sampled schemes in selected districts

Salinity class	Profile depth (cm)							
	0-30		30-60		60-90		90-120	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Non-Saline	2.00	8.33	1.00	4.17	4.00	16.67	3.00	12.50
Slightly Saline	8.00	33.33	5.00	20.83	6.00	25.00	6.00	25.00
Moderately Saline	5.00	20.83	5.00	20.83	4.00	16.67	2.00	8.33
Strongly Saline	3.00	12.50	7.00	29.17	3.00	12.50	3.00	12.50
Very Strongly Saline	2.00	8.33	1.00	4.17	3.00	12.50	5.00	20.83
Extremely Saline	4	16.67	5	20.83	4	16.67	5	20.83
Total	24	100	24	100	24	100	24	100

Areal surface soil salt concentration

Surface soil analysis results indicated that out of the total area (583.9 ha) of the studied schemes the soil salinity distribution categories fall in to non-saline (24.5%), slightly saline (5.4%), moderately saline (32.7%), strongly saline (21.2%), very strongly saline (12.0%), and extremely saline (4.2%). Qadalle irrigation scheme was the most affected and shared salinity levels of moderately saline, strongly saline, very strongly saline, and extremely saline classes with percent area coverage of 32.3%, 21.1%, 12%, and 4.2%; respectively. Over 37% area of the studied schemes in Borana zone falls within the salinity class of strongly to extreme salinity levels that needs close attention and the rest falls in tolerable salinity limits including the moderate salinity category (Table 7). According to a report in FAO [11] and are under tolerable salinity limits; but needed to practice improved irrigation water and scheme management in order to avoid further development of salinity to higher severity levels.

Table 8. Summary of area coverageof salinity level based on (ECe) selected study schemes

Name of zone of selected schemes	Total Area (ha)	Area coverage per salinity level based on ECe in (%)					
		Non-saline	Slightly saline	Moderately Saline	Strongly Saline	V. Strongly Saline	Extremely Saline
		< 0.75	0.75-2	2-4	4-8	8-15	>15
Arganne	81	6.8	15.5	53.1	3.6	2	0
Bule koloba	125	34.5	8.4	37.7	24.2	14	6.2
Jiraarsa	103.1	22.6	71.9	8.6	0	0	0
Qadalle	121.8	37.8	17	29.3	21.3	12	4.4
Sabbaa	67	21	18	16.2	11	0	0.8
Saboqqo	86	0.4	34	44.4	0.7	5.9	0.6
Total	583.9	123.1	164.8	189.3	60.8	33.9	12

Sodicity Levels of Surface Soils

The laboratory result of soil sodicity (ESP %) of surface composite samples showed that highly sodic soil classes cover the major percentage (35.8%) followed by none-sodic (24.21%) and the lowest share (9.5%) falls under moderately sodic soil class (Table 1). Over 53.7% of the studied samples collected from different schemes fall under highly sodic and extremely sodic classes (Table 8). These large portions of soil sodicity classes need urgent management interventions such as the use of chemicals (e.g., gypsum application with leaching), surface management practices (mulching and manuring), etc.

Table 9. Summary of surface soil sodicity levels (%) of selected schemes in Borana zone

Classes	Frequency of samples	Percentage of total
Non-sodic	6	25
Slightly sodic	3	12.5
Moderate sodic	2	8.33
Highly sodic	9	37.5
Extremely sodic	4	16.3
Total samples	24	100

Soil Sodicity along Soil Profile

Average exchangeable sodium percentage of collected samples from 6 open pit of all schemes at profile depth 0-30 cm, of the region, categorized in the percentage of 33.33%, 10.6%, 18.2%, 16.7% and 21.2% classified as none sodic, slightly, moderately, highly and extremely sodic soil respectively (Table 9).

The laboratory result indicated that soil (ESP %) at surface (0-30 cm) of Bule Koloba value fall at none sodic soil range. In case of the Borana zone, the upper profile indicated that moderately sodic soil. However, highly sodic and extremely sodic soil classes were obtained atSaboqqo ground water user field and scheme. The sodicity of soils occurred due to human made and natural phenomena like: agro ecology and geographic their found, in arid/low land and Semi-arid area, shallow ground water table and over irrigation practice, were the first causes to soil sodicity or salinity initiator at upper profile depth. A first phase assessment report and field observation of this project revealed that Qadalle and Sabboqqo were found at arid climate/low land area; this mean that, there were high soil evaporation on surface soil after irrigation or rainfall. On the other hand, low irrigation water quality (high or low anion and cat-ion concentration) using for irrigation contribution resulted in of high cat- ion and anion accumulation on surface soil. Thus, laboratory result of irrigation water quality of the study area indicated that 36.11% and 27.79% (percentile) of samples were falls as high to very highly saline, whereas, 55.6% was very highly sodic (Table 13), which confirmed that this water is a bad and unsuitable irrigation water due to high its versatile concentration of cat-ion or in-ion. Therefore, using irrigation water might be an important cause of building of soil salinity as well as sodicity. According to [7] the source of soil salinity at lowlands particularly in moisture stress areas where irrigation and/or rainfall are insufficient to leach salts.

The laboratory result of ESP% at profile depth of 30-60 cm, shown that about 30.3% and 25.8% of overall collected samples were none sodic and extremely sodic soil classes respectively. Whereas, both moderately and highly sodic class accounts 15.2% of total samples separately at the same profile depth (Table 8). Similarly, under specific area-based classification, extremely sodic soil was obtained at, Saboqqo. In contrast to those schemes, the results of Bule-koloba, Jirarsa, Arganne and Sabba SSISs and ground water fields shown none sodic soil at 30- 60 cm.

Table 10. Summary of sodicity levels (%) along soil profile of sampled schemes in Borana Districts.

Sodicity Class	Profile depth (cm)							
	0-30		30-60		60-90		90-120	
	Frequency	Percentage	Freq.	Perc. (%)	Frequency	Percentage	Freq.	Percentage
Non	8	33.33	7	30.29	6	22.71	7	28.79
Slightly	3	10.63	3	13.63	4	15.17	3	9.08
Moderate	4	18.17	4	15.17	4	18.17	3	13.63
Highly	4	16.67	4	15.17	4	13.63	5	22.71
Extremely	5	20.83	6	25.75	6	24.25	6	24.25
Total	24	100.00	24	100.00	24	100.00	24	100.00

Similarly laboratory result of soil sample collected at 60 -90 cm profile depth revealed that, moderate and extremely sodic soil class were got as 24.2% of total sample separately, whereas, 13.6% of analyzed samples were highly sodic described in (Table 8). In line with thus, scheme based result shows, Qadalle, was classified under moderate to highly sodic soil at 60 -90 cm profile depth. The highest magnitude, of soil sodicityi.e. extremely sodic class occurred on both ground water users and scheme of Sabboqqo. This may be due water quality and irrigation frequency that resulted in more water deep percolation.

In the case of lowest profile depth (90 -120 cm) the result indicated, around 29.2% none sodic whereas 24.6% of total samples falls under extremely sodic soil, while the remaining sodicity classes found in between moderate and highly sodic soil of total collected samples (Table 8).

Specifically, soil sodicity categorized under this layer covers slightly to moderately sodic classes was observed at Jirarsa, SSIS and groundwater user schemes respectively.

Generally, the result of soil sodium exchangeable percentage (ESP) of study area indicated that none sodic classes throughout profile depth of 0 - 120 cm was obtained in Sabba, Bule-Koloba, Jirarsa and Arganne with negligible sodicity. Moreover, the values of soil ESP % indicate that an increasing 0-30 < 30-60 < 60-90 < 90- 120 cm trends throughout profile. This may be due to agro ecology, irrigation method, shallow ground water table as well as naturally existing soil parent materials. In view of that some of SSISs and ground water-irrigated field soil shows extreme sodicity level throughout the profile depth, particularly at Sabboqqo irrigation scheme.

Areal Distribution of Surface Soil Sodicity

The extent of soil sodicity from total area 583.9 ha of mapped schemes of Borana zone was categorized under non-sodic, slightly sodic, moderately sodic and strongly sodic as 78%, 13.7%, 6.7% and 1.6% respectively (Table 10). The finding of soil sodicity map of selected schemes in Borana zone showed all characteristics; non-sodic, slightly sodic, moderately sodic, strongly sodic and extremely/very strongly sodic as 21.5%, 34.2%, 32.2%, 10% and 2% of total area of 173.1 ha respectively (Table 10). Even though its distribution and severity levels varied, there were soil sodicity problem on entire schemes.

Table 11. Summary of areal distribution of surface soil sodicity in selected schemes

Name of scheme	Total Area (ha)	Area Coverage per sodicity level based on ESP (%)				
		Non-sodic	Slightly sodic	Moderately Sodic	Strongly Sodic	Extremely/V.Strongly sodic
		< 6	6 -10	10 -15	15-25	>25
Qadalle	161.8	6.3	12.9	41.9	11.9	0.0
Bule koloba	81.6	38.0	13.7	4.7	1.3	0.0
Saboqqo	81.1	11.5	14.2	15.2	7.0	10.0
Sabba	80	31.3	13.2	11.4	10.2	1.4
Jiraarsa	88	31.0	13.7	6.7	1.6	0.0
Arganne	91.4	13.1	1.4	0.2	5.0	80.2
	583.9					

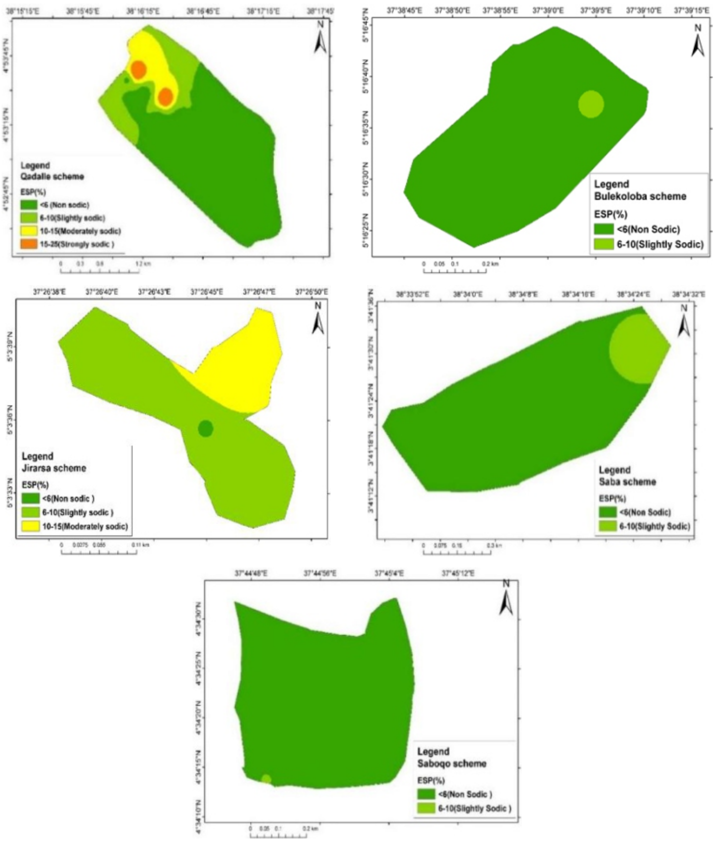

Figure 2. Interpolated map of Soil Exchangeable Sodium Percentage (ESP) of selected SSIS of Districts of Borana zone

Irrigation Water Quality

The concentration and composition of soluble salts in irrigation water are critical factors in determining its suitability for various uses, including human and livestock consumption, and most importantly, for agricultural irrigation. Poor-quality irrigation water can lead to soil degradation, reduced crop productivity, and long-term sustainability issues, particularly in areas where salinity is a pre-existing or potential concern.

In the context of irrigated agriculture, especially in regions prone to salinity buildup, assessing the quality of irrigation water is essential for sustainable land and crop management. This report evaluates irrigation water quality using three fundamental criteria:

1. Total Soluble Salt Content (Salinity Hazard): This indicates the overall concentration of dissolved salts in the water, typically measured by electrical conductivity (EC). High levels of salinity can adversely affect plant growth and soil structure.

2. Sodium Adsorption Ratio (SAR): This index assesses the relative concentration of sodium ions (Na^+) in comparison to calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions. A high SAR value suggests potential risks of soil sodicity, which can impair soil permeability and structure.

3. Specific Ion Toxicity and Composition: While not detailed in this section, it is also important to consider the presence of specific ions such as chloride (Cl^-), bicarbonate (HCO_3^-), and others that may have toxic effects on plants or alter soil chemistry.

These criteria collectively help in determining the long-term viability of using a particular water source for irrigation, and guide the selection of appropriate crops and soil management strategies.

Total soluble salts (salinity hazard)

Irrigation water quality can vary significantly depending on the type and concentration of dissolved salts. Although these salts are typically present in small quantities, they can have substantial long-term effects on soil health and crop productivity. Importantly, there are no universally fixed thresholds that define acceptable water quality for irrigation.

Instead, its suitability is context-dependent, influenced by soil characteristics, crop tolerance, climatic conditions, and irrigation practices, all of which affect how salts accumulate and impact crop yields over time.

To evaluate the appropriateness of water for irrigation, several key parameters are commonly measured:

- **Electrical Conductivity of Irrigation Water (ECw):** Indicates the overall salinity level of the water, which affects plant water uptake and soil osmotic potential.

- **Total Dissolved Solids (TDS):** Represents the total concentration of inorganic and organic substances dissolved in water. High TDS levels can lead to salt accumulation in the root zone.

- **Sodium Adsorption Ratio (SAR):** Assesses the proportion of sodium ions relative to calcium and magnesium ions. A high SAR can degrade soil structure, reduce permeability, and hinder water infiltration.

These indicators collectively provide a comprehensive understanding of water's suitability for irrigation, enabling better management decisions for sustainable agricultural practices.

From the analysis result of irrigation water samples collected from lowland irrigated areas of the Oromia region, there observed some medium to very highly saline classes of irrigation water (Table 11). Out of 7 water samples collected at different schemes of using surface and groundwater sources, about (28.57%) and (42.36%) of samples were found under the category of medium and high salinity of irrigation water quality, respectively necessitating to give great attention to irrigation water quality using for irrigation purposes (Table 12).

Table 12. Summary of salinity classes of irrigation water of selected schemes of Borana zone

EC_{iw} range	Degree of severity	Frequency	Percentage (%)
0.1- 0.25	Low saline	1	14.29
0.25-0.75	Medium saline	2	28.57
0.75 – 2.25	High saline	3	42.86
> 2.25	Very high saline	1	14.29
Total		7	100

Adapted from: (USSL Staff 1994)

Table 13. The chemical analyses (ECw and SAR) of the water collected from schemes at Borana

Scheme Name	Source of water	ECw	Salinity class	SAR	Sodicity Hazards
Bule Koloba	Flood diversion	1.62	High Saline	NA	Very high Sodicity
Saboqo	GW	1.74	High Saline	6.75	Low Sodicity
Arganne	Flood diversion	0.42	Medium Saline	19.26	High Sodicity
Qadalle	Flood diversion	1.07	High Saline	39.2	Very high Sodicity
Jirarsa	Flood diversion	1.27	High Saline	NA	Very high Sodicity
Sabba	Flood diversion	0.57	Medium Saline	NA	Very high Sodicity

Sodium adsorption ratio (SAR)

The parameter that measures the relative concentration of sodium ion to that of Calcium and Magnesium ions of irrigation water were estimated during the study season. The result showed that about 55.56% of samples collected were categorized under very high sodicity hazards and were from schemes and groundwater users in Borana Zone (Bule Koloba, Qadalle, Jirarsa&Sabba) as described on Table 12.

In line with this, (S. A. Shahid et al., 2018) suggest SAR contributes directly to the total salinity existence and may also be toxic to sensitive fruit trees. The above-listed irrigation water from groundwater sources is approximately found at an average of 2m to 3 m feet which is very near to the surface. Thus there is a probability occurrence of very high salinity and very high sodicity at the same time. A similar study indicated that groundwater levels that average about 6 feet or near depth are highly susceptible to salinity or sodicity development [13]. It also indicated as the occurrence of very high sodicity and salinity levels are related to soil genetic factors which are from groundwater of the past than to the current rainfall pattern [16].

Table 14. Summary of sodicity classes of irrigation water of selected schemes

SAR of irrigation water	Sodicity hazard	Frequency	Percent (%)
<10	Low sodicity	1	14.29
10 to 18	Medium sodicity	2	28.57
18 to 26	High sodicity	3	42.86
>26	Very high sodicity	1	14.29
Total		7	100

Adapted from (USSL Staff 1994)

The results of analyzed water samples show high saline and very high sodicity at Qadalle and Jirarsa, and Bule Koloba schemes found in the Borana lowlands. However –[2] demonstrated a positive correlation between EC and SAR with that the source is from ground water.

Conclusion

Depending on soil and water parameters collected to characterize the schemes salinity/sodicity status of soils and irrigation water quality at selected district areas of Borana zone, E Ce of the surface soil was rated from non-saline to extreme at the surface and subsurface soil profiles. The E Ce values of profile soils slightly increased with throughout depth at Bule-Koloba and Qadalle at upper parts of the scheme, whereas vice versa for Arganne scheme in the Moyale district.On the other hand, the rest of the study areas were showed variation of E Ce throughout profile depth. Among the samples of surface soils, 22.10% were not affected by salinity, whereas 35.79% were classified as slightly saline, 26.83% as moderately saline, 10.58% as strongly saline and 3.17% as very strongly saline while the remaining 1.6% showed extremely saline with respect to electrical conductivity. Although out of sampled subsurface soil, 8.33%, 4.17%, 16.67%, 12.50% not affected by salinity through profile depth of 0-30cm,30-60cm,60-90cm,90-120cm respectively. More of the samples percentage were rated slightly to extreme saline only 18.33%, 19.17%, 16.67%, 17.50% on the depths of 0-30cm, 30-60cm, 60-90cm,90-120 cm respectively.In case of irrigation water quality from both ground water and schemes water source results show that, there observed some medium to very highly saline classes and very high sodicity of irrigation water. Out of 6 water samples collected from surface and groundwater sources, about 6.11% and 4.63% of samples were found under the category of high and very high salinity respectively whereas, about 9.26% of samples collected were categorized under very high sodicity hazards. Particularly, very high sodicity were recorded at Qadalle Command scheme in in Yabello woreda.

Recommendations

Based on the assessment of soil and irrigation water quality from selected schemes in the Borana zone, the following general recommendations are proposed:

1. Soil Management Recommendations

• For areas classified as non-saline to moderately saline (based on Ece)

Implement**physical amendments** such as land leveling, sanding, scraping of surface salts, and seedbed shaping. Additionally, adopt **hydrological methods** including efficient use of irrigation water through proper scheduling and measurement techniques.

• For strongly, very strongly, and extremely saline schemes (e.g., Qadalle and Jirarsa)

Apply chemical amendments such as gypsum to reduce sodium levels. Grow salt-tolerant crops and implement leaching practices to flush out accumulated salts.

• For subsoil layers below 30 cm depth

Use an integrated reclamation strategy combining physical methods (e.g., sub-drainage, tillage, sub-soiling, leveling, salt scraping, and sanding) with biological methods such as growing green manure crops (e.g., legumes) to improve soil health and productivity.

• Farmer Training

Provide targeted training programs for farmers on topics such as irrigation water management, irrigation methods, types of irrigation systems, and local irrigation policies to build capacity and promote sustainable practices.

2. Irrigation Water Quality Management

• For shallow groundwater sources already affected by salinity

Adopt a combination of practices including planting intercepting crops, improving physical drainage, cultivating salt-tolerant or better-adapted crops, and using cover crops to mitigate salt impacts.

• For sodic water sources

Carefully assess the economic feasibility of applying soil amendments and improving drainage systems before investing. Cost-benefit analysis is crucial to determine sustainability.

• For water that is both saline and sodic

In such cases, the most practical approach may be to manage the conditions byselecting salt-tolerant cropsrather than engaging in expensive reclamation efforts that may worsen sodicity issues.

• Gypsum Application

The quantity of gypsum required to treat irrigation water should be based on the Residual Sodium Carbonate (RSC)andSodium Adsorption Ratio (SAR) levels, along with the total volume of water needed during the crop's growing season.

Conflict of interests

Authors declare that there is no conflict of interest.

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