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REVIEW ARTICLE

Salt affected soils in sub-Saharan Africa: an analysis of distribution from 1970 to the present

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ABSTRACT

Salt-affected soils pose a significant global challenge, impacting approximately 1 billion hectares worldwide, including 80 million hectares in Africa. This systematic review, conducted using the PRISMA framework, focuses on the extent and distribution of salt-affected soils in Sub-Saharan Africa (SSA) from 1970 to the present. The review revealed that salt affects about 65.6 million hectares of SSA's soils. The worst areas are near the coast, in river deltas like the Nile Delta, and in dry areas that get a lot of water from irrigation. Significantly affected areas include Eastern Africa, the Lake Chad Basin, and the West African coast. Ethiopia is the most affected country (11 million hectares) due to inadequate irrigation and poor drainage. The review reveals discrepancies in documentation, favoring coastal regions such as Senegal, Tanzania, and Kenya over inland areas like Chad and Mali. It also identifies the reliance on older FAO reports based on Solonchaks (saline soils) and Solonetz (sodic soils) to estimate the area coverage of salt-affected soils from the FAO/Unesco Soil Map in 1970–1981. The lack of current and updated data highlights the need for an expanded knowledge base on this topic. There is a pressing need to use data from the field and the lab, soil databases like WoSIS and HWSD, and environmental covariates gathered from remote sensing to create digital fine-scale salinity maps. The review also suggests saline agriculture, utilizing brackish water and salt-tolerant crops, as a viable strategy for rehabilitating severely affected areas, such as the Nile Delta and coastal zones.

Keywords: FAO; Irrigation water management; Remote sensing; Sub-Saharan Africa; Salt-affected soils; Solonchaks; Solonetz.

INTRODUCTION

Soil salinization represents a considerable global risk to agricultural productivity (Setia et al., 2013; Butcher et al., 2016; Ivushkin et al., 2019; Corwin and Scudiero, 2019; Hopmans et al., 2021; Khasanov et al., 2023; Rui et al., 2024). Approximately 1 billion hectares of land globally are impacted by salinization (Wicke et al., 2011; Ivushkin et al., 2019; Singh, 2021). Singh (2018) highlighted that more than 3% of global soils have deteriorated due to salinization. Elevated salinity levels are especially observed in India, Pakistan, China, the United States, Argentina, Ethiopia, and Central and Western Asia (Butcher et al., 2016). Currently, 20% of cultivated land and 33% of irrigated land worldwide are affected by salinity, with forecasts suggesting that by 2050, 50% of the global arable land will be harmed, intensifying food insecurity (Mukhopadhyay et al., 2021; Butcher et al., 2016). In 2014, regions afflicted by salinity were associated with global economic losses amounting to $27.3 billion (Smaoui et al., 2024). Approximately 80 million hectares in Africa are salinized, with 68.8 million hectares situated in Sub-Saharan Africa (Smaoui et al., 2024).

Salt-affected soils are typically characterized as soils with elevated salinity or saline soils. Elevated salinity in these soils arises from the presence of significant cations such as sodium (Na+), potassium (K+), calcium (Ca2+), and magnesium (Mg2+), in conjunction with anions including chloride (Cl−), sulfate (SO42−), bicarbonate (HCO3−), carbonate (CO32−), and nitrate (NO3−) in concentrations detrimental to most plants (Shannon and Grieve, 1998; Chhabra, 2005; Bui, 2013; Bernstein, 2019; Munns et al., 2020; Zhao et al., 2020; Hopmans et al., 2021; Stavi et al., 2021; Walche et al., 2023; Donald, 2024; Omar et al., 2024). The effects of soil salinization differ based on climatic and soil conditions, light intensity, and the tolerance of plant species (Acosta-Motos et al., 2017; Shrivastava and Kumar, 2015; Tang et al., 2024). Climate change is anticipated to exacerbate these consequences (Corwin and Scudiero, 2019; Eswar et al., 2021; Wen et al., 2021), resulting in substantial reductions in crop growth and production. In arid and semi-arid areas, yield decreases can surpass 50% (Ivushkin et al., 2019; Anami et al., 2020).

In Sub-Saharan Africa (SSA), soils damaged by salinity are emerging as a more critical concern. Reports suggest that salt-affected soils in Sub-Saharan Africa encompass around 68.8 million hectares (Kebede, 2023; Smaoui et al., 2024), but Tully et al. (2015) documented 19 million hectares. Ivushkin et al. (2019) emphasized a significant deficiency of comprehensive data regarding salt-affected soils at regional and national levels. These soils adversely affect agriculture, transforming fertile terrain into desolate regions and deteriorating water quality and ecosystem services. Research indicates that, with appropriate management, salt-affected soils can yield productivity and economic value (Wicke et al., 2011; Hamada and Hamada, 2020; Hopmans et al., 2021; Li et al., 2023; Marroquin et al., 2023; Navarro-Torre et al., 2023). A comprehensive study of their characteristics, extent, and distribution is crucial for adopting effective management technologies to achieve their economic potential. Nevertheless, in Sub-Saharan Africa, data regarding these soils is scarce and disjointed (Butcher et al., 2016; Ivushkin et al., 2019; Smaoui et al., 2024), obstructing efficient management. This comprehensive research seeks to evaluate the current prevalence and distribution of salt-affected soils in Sub-Saharan Africa from 1970 to the present, offering critical insights for policymakers and sustainable agriculture practices in the region.

METHODOLOGY

This review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, which ensures scientific rigor and transparency in systematic reviews (Page et al., 2021). The modified PRISMA flowchart, a widely recognized checklist for improving reporting quality, guided the process (Mishra and Mishra, 2023). The review consisted of four phases: identification, screening, eligibility, and inclusion. Seven databases—ScienceDirect, Google Scholar, Web of Science, Scopus, AGRIS, African Journals Online (AJOL), and SpringerLink—were used to gather peer-reviewed journal articles and, in some cases, relevant reports. Title keywords helped filter irrelevant papers and reduce the risk of missing important studies. The search identified 272 journal articles and 20 reports. After removing 100 duplicates, 172 articles were screened, and 62 were rejected for not meeting the review's criteria. Further screening eliminated 38 more articles due to a lack of relevant content, leaving 110 articles. Among the 20 reports, 7 were excluded after eligibility screening. In the end, 72 articles and 13 reports were selected to examine various aspects of salt-affected soils in SSA. The process, from the initial search to the final selection, followed the PRISMA approach by Page et al. (2021) as shown in Figure 1.

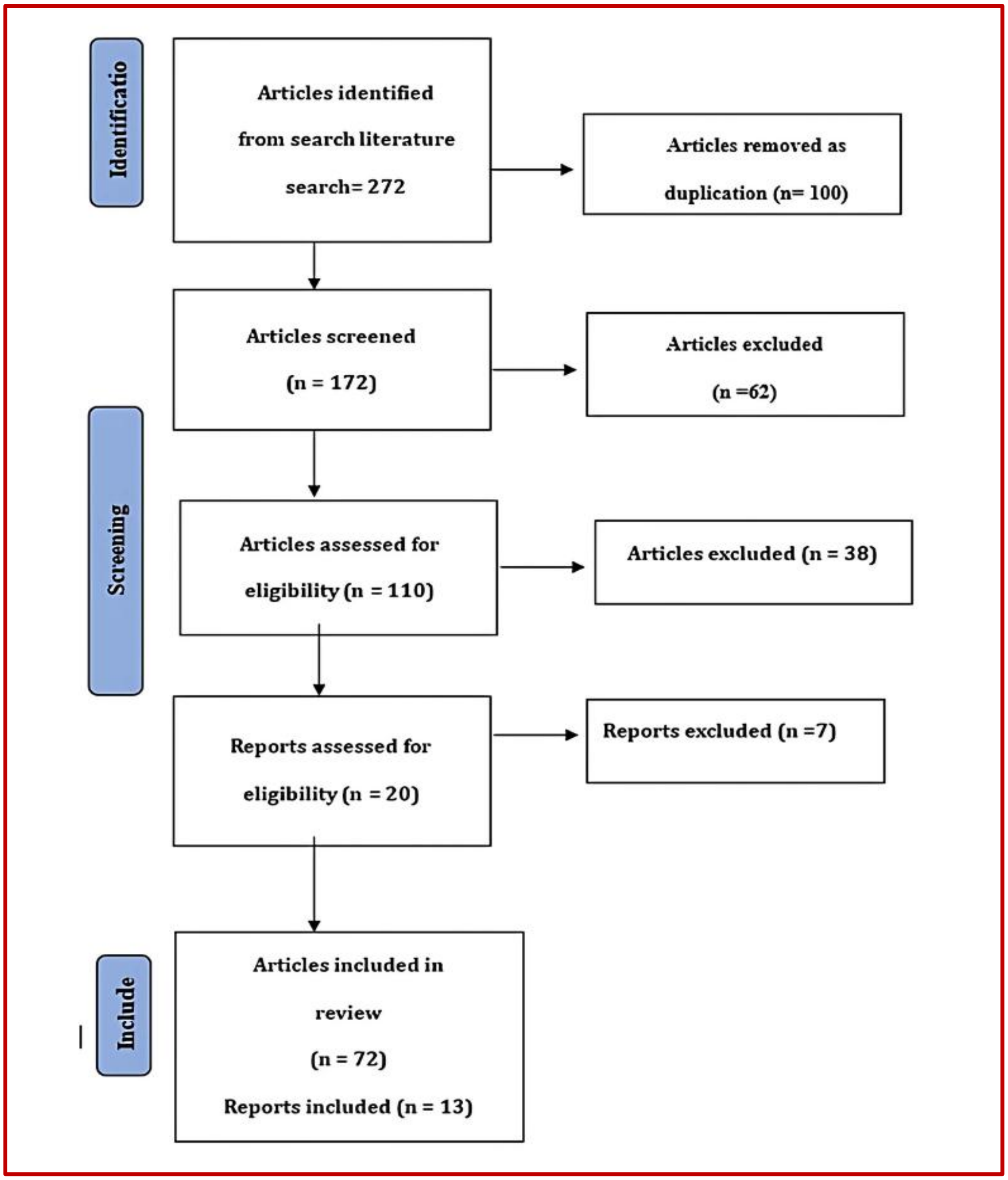

Figure 1. A modified updated guideline for reporting systematic reviews adopted from Page et al. (2021).

PRESENT SCIENTIFIC KNOWLEDGE AND DISTRIBUTION OF SALT-AFFECTED SOILS IN SUB-SAHARAN AFRICA

The extent and distribution of salt-affected soils have been subjects of considerable study, but precise measurements remain uncertain due to unreliable data, with only rough estimates available (Tully et al., 2015). Estimates in Sub-Saharan Africa (SSA) vary from 19 million hectares (Tully et al., 2015) to 68 million hectares (Kebede, 2023), while the FAO (1988) estimated about 63.9 million hectares. This discrepancy, shown in Table 1, highlights the imprecision in current measurements and the lack of comprehensive data.

Scientific knowledge of salt-affected soils is uneven across SSA. Coastal countries such as Senegal, Tanzania, Kenya, and Ethiopia are better documented than inland countries like Chad or Mali. Groundwater-induced soil salinity has been studied in Senegal, Burkina Faso, Kenya, and Ethiopia, but countries like Mali, Chad, and South Sudan lack comprehensive analyses. Coastal areas and river deltas have the most salt-affected soils, with Ethiopia being the most affected (Tessema et al., 2022). However, the scarcity of data on arid and semi-arid inland areas suggests these regions are underrepresented in research. The lack of knowledge about inland areas presents a significant obstacle to accurately estimating the distribution of salt-affected soils in SSA.

This review noted a outstanding consistency between the data from the older FAO (1988) report and recent salinity studies in Sub-Saharan Africa (SSA), which underlines the slow progress in updating the knowledge base. Many studies still reference FAO's 1988 data instead of generating new field observations and mapping recent salt-affected soils. Thus, despite the lack of reliable and comprehensive data, the FAO (1988) report remains a valuable baseline for understanding the extent and distribution of salt-affected soils. The FAO's pioneering work, based on the FAO/Unesco Soil Map of the World, continues to serve as a reference point for salinity studies in various SSA countries. For example, salt-affected soil data for Ethiopia (Tully et al., 2015; Qureshi et al., 2019; Tessema et al., 2022; Walche et al., 2023; Kebede, 2023), Sudan (Salih and Elsheik, 2014), Chad, Nigeria, Botswana, Somalia, Kenya, Mali (Kebede, 2023), and Tanzania (FAO, 2000) align closely with the FAO (1988) findings, reinforcing its dependability even in current literature. This makes FAO's classification of Solonchaks and Solonetz for saline and sodic soils, respectively, remain critical in identifying and mapping salinity in SSA, a view supported by Van Oort (2018). However, the overreliance on FAO (1988) presents challenges, as the data, derived from the FAO Soil Map produced between 1970 and 1981 with a coarse resolution, may be outdated for monitoring recent soil salinity dynamics. Moreover, the lack of time-series data hampers effective monitoring and mapping of salt-affected soils over time.

The Harmonized World Soil Database (HWSD) of 2012 has provided another valuable opportunity for studying the extent and distribution of salt-affected soils in Sub-Saharan Africa (SSA). Van Oort (2018) used the HWSD (2012) to identify soil types such as Solonchaks and Salic Fluvisols (SCFLs) as indicators of salinized areas and combined Solonchaks, Salic Fluvisols, and Solonetz (SCFLsSN) for saline or sodic soils. The electrical conductivity (EC) and exchangeable sodium percentage (ESP) of these soil types correlate closely with salinity. These findings aligned with salinity data in SSA countries like Tanzania, Guinea, Senegal, and Mozambique, particularly in rice-growing areas. However, no comparable salinity studies were available in many countries for verification. Solonchaks and Solonetz were reliable indicators due to their high salt content and poor drainage, which favor salinization.

Despite its usefulness, the HWSD (2012) has limitations. The database consists of soil mapping units, with each unit representing a single value of soil salinity, and some of these units may span hundreds of kilometers, leading to coarse resolution and high generalization. It also relies on the FAO/UNESCO Soil Map of the World (1970-1981), which may be considered outdated due to the dynamic nature of soil salinity. Despite these shortcomings, the results from HWSD and FAO data show significant consistency, confirming Solonchaks and Solonetz soils as critical indicators of salt-affected areas. Therefore, the FAO (1988) and all its sister databases, including the World Soil Information Soil and Terrain (SOTER) database, ISRIC – World Soil Information (WoSIS), and HWSD (2012), serve as important baselines for salinity studies in SSA, providing a solid foundation for future research.

Table 1. Sources of data for salt-affected soils for the entire SSA.

Extent in Million ha	Basis	Source
19	Fertility capability soil classification (FCC) system	Tully et al. (2015)
68	Literature	Kebede (2023)
68.6	Area coverage of Solonchaks and Solonetz soils	Harmonized World Soil Database (HWSD, 2012)
63.9	Area coverage of Solonchaks and Solonetz soils	FAO (1988)

EXTENT AND DISTRIBUTION OF SALT-AFFECTED SOILS IN SSA

The causes of salinity are varied and intricate, including salts released from the weathering of rocks and soils, airborne salts, saline groundwater from subterranean sources, and anthropogenic activities such as mining, railway development, and road construction (McCune, 1991; Khaska et al., 2013; Leppänen et al., 2019; Stavi et al., 2021; Gurmessa et al., 2022; Sparks et al., 2024). The prevalence and distribution of salt-affected soils in Sub-Saharan Africa fluctuate markedly among various countries, with certain areas facing acute salinity challenges while others are mostly unaffected. Ethiopia has the largest prevalence of salt-affected soils in Africa, with approximately 11 million hectares damaged, representing 9% of the total land area and 13% of the irrigated area of the nation (Qureshi et al., 2019; Birhane, 2017). The soils are predominantly found in the Rift Valley, Wabi Shebelle River Basin, Denakil Plains, and several additional lowlands and valleys. Chad, Nigeria, and Botswana have considerable issues, with 8,267,000 hectares, 6,502,000 hectares, and 5,679,000 hectares of salt-affected soils, respectively (Kebede, 2023).

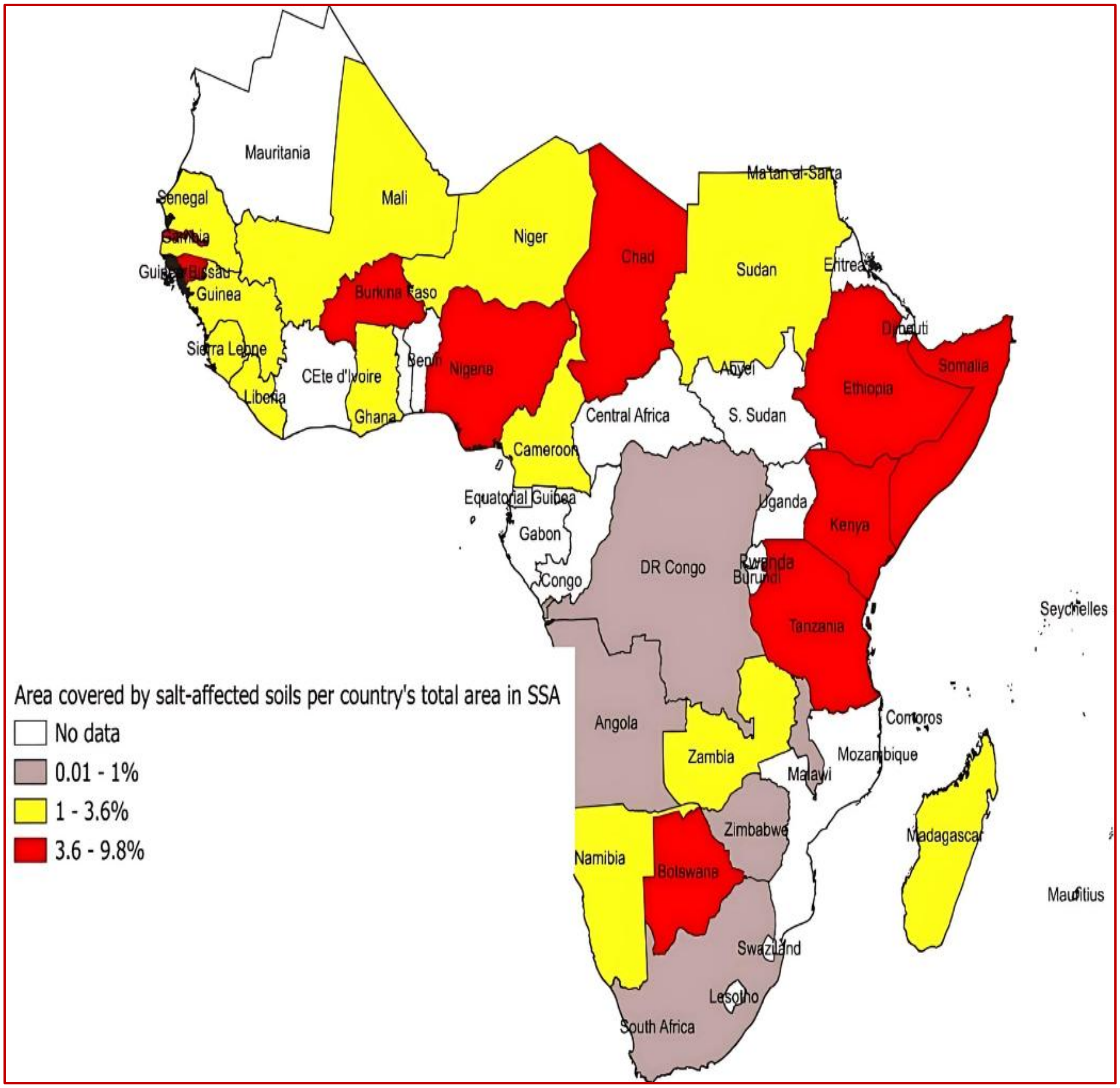

Figure 2. Spatial distribution of salt-affected soils in SSA as per reviewed data

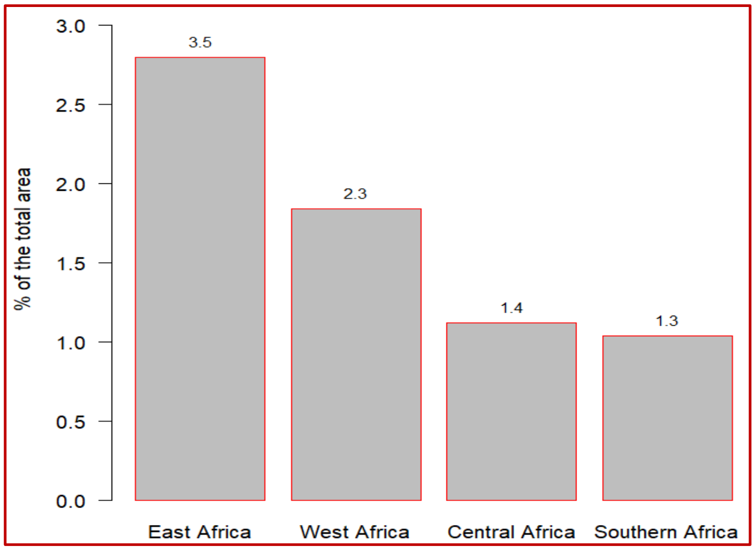

Figure 3. Percent of area coverage of salt-affected soils in SSA sub-regions as per reviewed data

Table 2. The extent of the distribution of salt-affected soils in various SSA countries, listed in descending order from most to least affected (Million ha) as per reviewed data.

Country	Area (Million ha.)			Reference
	Saline	Sodic	Total	
Ethiopia	10.61	0.43	11.03	(FAO, 1988; Kebede, 2023)
Chad	2.42	5.85	8.27	(FAO, 1988; Kebede, 2023)
Nigeria	0.67	5.84	6.50	(FAO, 1988; Kebede, 2023)
Botswana	5.01	0.67	5.68	(FAO, 1988; Kebede, 2023)
Somalia	1.57	4.03	5.60	(FAO, 1988; Kebede, 2023)
Sudan	2.14	2.74	4.87	(FAO, 1988; Salih, & Elsheik, 2014)
Kenya	4.41	0.45	4.86	(FAO, 1988; Kebede, 2023)
Tanzania	2.95	0.58	3.54	(FAO, 1988; FAO, 2000)
Mali	2.77	-	2.77	(FAO, 1988; Kebede, 2023)
Namibia	0.56	1.75	2.31	(FAO, 1988)
Niger	-	1.39	1.39	(FAO, 1988)
Madagascar	0.04	1.29	1.32	(FAO, 1988)
Senegal	1.23	-	1.23	(Diatta, 2016)
Burkina Faso	1.30	0.002	1.302	(Kabore et al., 2021)
Zambia	-	0.86	0.86	(FAO, 1988)
South Africa	0.78	-	0.78	(De Villiers et al., 2003)
Cameroon	-	0.67	0.67	(FAO, 1988)
Angola	0.44	0.09	0.53	(FAO, 1988)
Guinea	0.53	-	0.53	(FAO, 1988)
Liberia	0.36	0.04	0.41	(FAO, 1988)
Ghana	0.20	0.12	0.32	(FAO, 1988; Sackey et al., 2021)
Sierra Leone	0.31	-	0.31	(FAO, 1988)
Guinea-Bissau	0.19	-	0.19	(FAO, 1988)
Gambia	0.15		0.15	(FAO, 1988)

Malawi	0.07	-	0.07	(Kandinga, 2019)
Congo DRC	0.05	-	0.05	(FAO, 1988)
Zimbabwe	-	0.03	0.03	(FAO, 1988)
Total	38.76	26.83	65.59	-

Salt-affected soils in Sub-Saharan Africa (SSA) are primarily located in Eastern African nations, along the western coast of Africa, inside the Lake Chad Basin, and in certain regions of Southern Africa (Figure 2). East Africa, encompassing the Horn of Africa, is the most impacted sub-region in Sub-Saharan Africa (Figure 3). In East Africa, the salinity of lakes and rivers is a primary factor contributing to salt-affected soils in the region. Regions next to lakes and rivers, particularly in East Africa, have some of the most salinized soils in sub-Saharan Africa. Table 2 indicates that Ethiopia, Somalia, Kenya, and Tanzania are among the most impacted nations due to salt from lakes, deltas, and rivers, corroborating findings by Dubois (2011). Schagerl and Renaut (2016) revealed that lakes in Ethiopia, Kenya, and Tanzania display salty conditions that expedite the formation of salt-affected soils in these regions. Certain salty lakes originated from the evaporation of marine water sources, shown as Lake Assal in Djibouti, where geothermal heat facilitated the evaporation process, leading to a highly saline environment (Pérez and Chebude, 2017). Furthermore, salt-affected soils in regions with thermal springs, such as Ga'etel in Ethiopia, have been influenced by seismic activity (Pérez and Chebude, 2017).

Salt-affected soils are prevalent throughout Sub-Saharan Africa (SSA), notably in nations like Angola, Botswana, Burundi, Cameroon, Chad, Ethiopia, Kenya, Madagascar, Malawi, Mali, Mozambique, Niger, Nigeria, Somalia, Sudan, Rwanda, and Tanzania (Kebede, 2023; Qureshi et al., 2019). In the Horn of Africa, encompassing northeastern Kenya, eastern Ethiopia, Djibouti, Eritrea, and Somalia, principal factors influencing soil salinity comprise precipitation patterns, evaporation, low groundwater recharge rates, proximity to the ocean, and fractured geological formations (Gurmessa et al., 2022; Araya et al., 2023). Recurring droughts and arid conditions in numerous nations have exacerbated the incidence of salt-affected soils. Conversely, nations like the Congo DRC, Congo, Gabon, and Ivory Coast exhibit less saline soil presence, underscoring the disparate distribution of salinity challenges throughout the continent (Tully et al., 2015; Van Oort, 2018). The soil types most susceptible to salinity are Solonchaks, Salic Fluvisols, and Solonetz. These soil types exhibit elevated electrical conductivity (EC) and exchangeable sodium percentage (ESP) values, rendering them dependable indicators of salinized soils (Van Oort, 2018). This classification corresponds with salinity data from countries such as Tanzania, Guinea, Senegal, Mozambique, Sierra Leone, and Guinea-Bissau, where these soil types are common.

Low-lying topography and poor drainage are major contributors to the development of salt-affected soils in SSA (Befus et al., 2020; Magnan et al., 2022; Walche et al., 2024). Wetland regions, including river and coastal floodplains, deltas, and depressions, are especially susceptible to salinity problems, with poor drainage exacerbating the issue (Zhang et al., 2011; Islam, 2016; Mastrocicco et al., 2020; Ferreira et al., 2023). These areas, including drylands on upper slopes and wetlands in valley bottoms, trap salts, hindering agricultural productivity (Diatta, 2016). An estimated 30 million hectares of SSA's wetland areas are situated in river floodplains, where moderate to poor drainage further exacerbates salinity issues (Tully et al., 2015). Irrigation practices, particularly in lowland areas with inadequate drainage, contribute to soil salinity development. In Ethiopia, for example, the rise in the groundwater table due to large irrigation schemes in the Awash Valley has led to increased salinity, exacerbated by high evapotranspiration rates (Borena and Hassen, 2022). Similarly, in Sudan, poor soil and water management and inadequate drainage in irrigated areas have contributed to salinity issues, particularly in low-rainfall regions along the Nile River terraces and agricultural schemes near Khartoum and Gezira (Salih and Elsheik, 2014).

The presence of mangrove rice cultivation in coastal areas also contributes to salinity issues in countries like Nigeria, Guinea, Sierra Leone, and Guinea-Bissau (Diagne et al., 2013). While Tanzania does not have mangrove rice, it still faces salinity issues due to inland sodic soils (Van Oort, 2018). The correlation between mangrove rice cultivation and salinity further underscores the need for targeted interventions to manage salinity and reduce its impact on agricultural productivity.Effective irrigation and drainage practices are essential To mitigate salinity in these areas. Improved soil and water management, especially in lowland areas with wetlands and mangrove rice cultivation, can help reduce the development and spread of salt-affected soils in SSA.Climate is another fundamental factor influencing the distribution and extent of salt-affected soils in SSA. The region's arid and semi-arid areas, such as Ethiopia, Somalia, Botswana and even Sudan, are particularly susceptible to soil salinization due to their climatic conditions (Omuto et al., 2024). High temperatures and low rainfall in these areas lead to elevated rates of evapotranspiration, which concentrates salts in the soil as water evaporates. This process is exacerbated by the natural weathering of salt-bearing rocks and the capillary rise of saline groundwater to the soil surface (Borena and Hassen, 2022). In Ethiopia, for instance, the Rift Valley and Wabi Shebelle River Basin experience significant salinization due to these climatic factors, compounded by inadequate drainage systems (Birhane, 2017). Climate change further intensifies the salinity issues in SSA by increasing temperatures and altering precipitation patterns, leading to more frequent and severe droughts (Corwin and Scudiero, 2019). These changes exacerbate salinity problems in already vulnerable regions, such as the Nile River terraces in Sudan and the low-lying topographies of Botswana. In these areas, poor soil and water management practices, combined with climatic stressors, lead to widespread soil degradation. The impacts of climate on soil salinity in these areas necessitate comprehensive management strategies, including improving irrigation efficiency, implementing effective drainage systems, and adopting salt-tolerant crops to sustain agricultural productivity under changing climatic conditions (Tully et al., 2015; Kebede, 2023).

Coastal salinity in certain regions of Sub-Saharan Africa arises from multiple factors, including seawater intrusion, flooding during high tides, river and estuary intrusion, groundwater inflows, and salt-laden aerosols (Suarez and Jurinak, 2012). The coastal zone of West and Central Africa extends from Mauritania to Namibia, while the Eastern African coastal zone encompasses the coastal regions of the island nations of Madagascar, Mauritius, Réunion, and Seychelles. The low-lying topographies and diverse ecosystems, including estuaries, deltas, wetlands, mangroves, and coral reefs, render these areas especially susceptible to salinization (Kebede, 2023). In numerous arid and semi-arid coastal regions, as well as occasionally humid areas, evaporation from shallow water tables intensifies salinization by drawing saline groundwater to the surface via capillary action. (Lian et al., 2021; Naorem et al., 2023). The severity of this process is notable in countries such as Senegal, Sierra Leone, Togo, Ghana, and southern Madagascar (Kebede, 2023). Coastal saline soils in estuaries and deltas of humid tropical regions are characterized by high organic matter content and distinct properties, particularly when associated with mangrove species like Avicennia and Rhizophora (Barreto et al., 2016). Upon drainage, these soils exhibit high acidity and are categorized as Thionic Fluvisols (Barbiéro et al., 2005). These soils are found in countries including Sierra Leone, southern Senegal, the Gambia, Guinea Bissau, Guinea, Liberia, Nigeria, Cameroon, Gabon, Kenya, Tanzania, Mozambique, and western Madagascar, encompassing an estimated area of around 3.35 million hectares (Kebede, 2023). Soluble salts in tidal marshes and recently reclaimed sulfidic soils can impede water and nutrient uptake through osmotic effects, while the toxicity of sodium (Na^+) and chloride (Cl^-) ions is prevalent. In Senegal, the Gambia, and Guinea Bissau, the pronounced dry season and reduced annual rainfall over the past two decades have resulted in a significant increase in topsoil salinity, with ECe values reaching 80 dS m^{-1} (Sylla, 1994). Effective management strategies are crucial for mitigating these impacts and sustaining agricultural productivity in coastal regions.

SALT-AFFECTED SOILS IN IRRIGATED AREAS IN SSA

Irrigated regions in Sub-Saharan Africa (SSA), particularly in the Nile Delta, Ethiopia, and Sudan, are presently the primary salt-affected areas (Balasubramanian et al., 2007; Tully et al., 2015; Van Oort, 2018; Walche et al., 2023). The accumulation of salt in irrigated soils is a significant problem in Sub-Saharan Africa, attributed to seawater intrusion, elevated groundwater levels in low-lying regions, and the application of salted irrigation water (Frenken, 2005). As soil desiccates, salts become more concentrated in the soil solution, exacerbating salt stress. Kebede (2023) emphasizes that although soils in arid, hot regions are inherently saline, inadequate irrigation and substandard drainage intensify the issue by inducing waterlogging, elevating the water table, and drawing salts nearer to the surface. The evaporation of water results in salt accumulation around plant roots, obstructing water absorption and inhibiting plant growth. Irrigation enhances food production but exacerbates soil salinization, resulting in degraded soils, diminished agricultural yields, poverty, and social instability. Dewitte et al. (2013) caution that regions impacted by salinity are expected to proliferate with augmented irrigation practices. Consequently, if irrigation proliferates in the semi-arid parts of Sub-Saharan Africa without adequate precautions, salt issues may exacerbate.

Irrigation-induced salinity is particularly prevalent in low-rainfall areas along the Nile River terraces and agricultural schemes near Khartoum and Gezira (Salih and Elsheik, 2014). Poor soil and water management, along with inadequate drainage, worsen salinity issues. Ethiopia faces significant salinization, with an estimated 13% of its irrigated area affected, especially in the Rift Valley and other lowlands (Birhane, 2017; Borena and Hassen, 2022). In these areas, high evapotranspiration rates and improper drainage contribute to salinity development, leading to crop losses and farmland abandonment (Gebremeskel et al., 2018). These findings suggest that effective irrigation and drainage are crucial for mitigating salinity's impact on agricultural productivity in SSA.

CONCLUSION AND FUTURE OUTLOOK

Salt-affected soils in SSA cover approximately 65.6 million hectares. Key affected regions include Eastern Africa, the Western African coast, the Lake Chad Basin, and some parts of Southern Africa such as Botswana. Notable hotspots include Ethiopia's Rift Valley and Sudan's Nile River terraces. Salt-affected soils are most common in arid climates, low-lying areas, and regions with intensive irrigation. Major causes include natural factors like saline groundwater movement and human-induced issues such as inefficient irrigation and poor water management. Data on salt-affected soils in SSA remain fragmented and rely heavily on old sources, such as the FAO (1988) report. Despite their high generalization, databases like HWSD, FAO Global Soil Map and Database, World Soil Information Soil and Terrain (SOTER) databases, and ECe point data from the WoSIS database are valuable sources of information on salt-affected soils in SSA for both older and current literature. The estimation of salt-affected soil coverage, as represented by Solonchaks (saline soils) and Solonetz (sodic soils) in the FAO World Soil Map and HWSD, has shown strong alignment with findings in recent literature. This consistency suggests that Solonchaks and Solonetz serve as a crucial starting point and foundational baseline for studying and estimating the extent and distribution of salt-affected soils, not only in SSA but globally.

There is a significant lack of new field and laboratory observational data and time-series studies to monitor changes over time, due to the shortage of use of advanced Geographical Information System (GIS) and remote sensing techniques, which could address the limitations of traditional soil mapping. These technologies enable high-resolution and dynamic salinity maps by integrating data on thermal infrared imagery, soil properties, and environmental covariates in a machine learning environment for soil salinity fine-scale mapping. The above conclusions lead to the following future recommendations:

- Improve data collection and mapping by enhancing new field and laboratory observations and utilizing advanced technologies like GIS and remote sensing to achieve accurate and dynamic soil salinity mapping at a fine scale.
- Conduct targeted research in under-explored arid and semi-arid regions to better understand the distribution of salt-affected soils.
- Adopt sustainable irrigation practices by improving irrigation efficiency, using saline water carefully, and upgrading drainage systems to reduce the risks of salinization.
- Implement land management techniques such as promoting mulching and crop rotation to conserve soil moisture and reduce evaporation.
- Encourage saline agriculture by cultivating salt-tolerant crops and employing brackish water irrigation, particularly in high-salinity areas like the Nile Delta and coastal regions, to restore degraded soils.
- Provide policy and institutional support by creating incentives for adopting advanced technologies and sustainable practices to ensure long-term soil health and agricultural productivity.

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AUTHOR CONTRIBUTIONS STATEMENT

FFM: conceptualization, investigation, data curation, formal analysis, methodology, writing- original draft, writing–review and editing, and validation. GRM & BEM: conceptualization, formal analysis, investigation, writing–review and editing. NAA:

conceptualization, formal analysis, supervision, writing–review and editing.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

ETHICS APPROVAL

Not applicable

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