Project Report 8

FINAL REPORT OF THE RAMSAP PROJECT IN ETHIOPIA AND SOUTH SUDAN





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REHABILITATION AND MANAGEMENT OF SALT-AFFECTED SOILS TO IMPROVE AGRICULTURAL PRODUCTIVITY (RAMSAP) IN ETHIOPIA AND SOUTH SUDAN

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Rehabilitation and management of salt-affected soils to improve agricultural productivity in Ethiopia and South Sudan (RAMSAP)

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ACRONYMS

ADF	Acid Detergent Fiber
ANOVA	Analysis of Variance
A/TVET	Agricultural Technical and Vocation Education and Training
AGP	Agricultural Growth Program
BoA	Bureau of Agriculture
CASCAPE	Capacity Building for Scaling up of Evidence-Based Best Practices for Increasing Agricultural Production in Ethiopia
CDSF	Capacity Development Support Facility
CEC	Cation Exchange Capacity
CP	Crude Protein
CISEAU	Centre Virtuel de l'eau agricole et ses usages
CRBD	Completely Randomized Block Design
CSA	Central Statistical Agency
DAs	Development Agents
EARO	Ethiopian Agricultural Research Organization
ECe	Electrical Conductivity of the soil saturation paste extract
EIAR	Ethiopian Institute of Agricultural Research
EPRDF	Ethiopian People's Revolutionary Democratic Front
ESP	Exchangeable Sodium Percentage
ETo	Reference Evapotranspiration
FFS	Farmers Field Schools
FREGs	Farmer Research and Extension Groups
FTC	Farmer Training Centre
GTP	Growth and Transformation plan
HPP	High Potential Perennial
ICBA	International Center for Biosaline Agriculture
ILRI	International Livestock Research Institute
IvDMDC	invitro Dry Matter Digestibility Content
IPTRID	International program for Technology and Research in Irrigation and Drainage
LGP	Length of Growing Period
LLRP	Lowland Livelihood Resilience Project
LPC	Low Potential Cereal
ME	Metabolizable Energy
MGT	Mean Germination Time
MoARC	Mekhoni Agricultural Research Center

MRS	**Mekhoni Research Station**
MoA	**Ministry of Agriculture**
MoP	**Ministry of Peace**
MoSF	**Ministry of State Farms**
MoWIE	**Ministry of Water Irrigation and Energy**
NDF	**National Detergent Fiber**
PED	**Pre-Extension Demonstration**
PRA	**Participatory Rapid Assessment**
RAMSAP	**Rehabilitation and Management of Salt-Affected Soils to Improve Agricultural Productivity**
RARIs	**Regional Research Institutes**
RC	**Research Centers**
SAR	**Sodium Adsorption Ratio**
SMSs	**Subject Matter Specialists**
TDS	**Total Dissolved Salts**
TOT	**Training of Trainers**
WARC	**Werer Agricultural Research Center**
WRC	**Werer Research Station**

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The future food security and livelihood of poor rural communities in Ethiopia and South Sudan are threatened by the increasing soil salinity and low agricultural productivity. The soil salinity problems stem from poor quality water coupled with the intensive use of soils for irrigation, poor on-farm water management practices, and inadequate drainage facilities. Therefore, restoring salt-affected lands into productive lands and protecting newly developed areas from the spread of salinity through improved irrigation and crop management is paramount. In the high salinity areas where the growth of typical field crops is limited due to salinity problems, bioremediation methods, including planting halophytic forages, can help.

The International Center for Biosaline Agriculture (ICBA) started a four-year project on 'Rehabilitation and management of salt-affected soils to improve agricultural productivity". This project was funded by the International Fund for Development (IFAD) and implemented with the Ministries of Agriculture in Ethiopia and South Sudan. This project aimed to develop strategies and approaches for rehabilitating and managing salt-affected soils to improve agricultural productivity and livelihood of rural poor in both countries. The project first diagnosed the salinity problems by adopting an integrated land, water, and crop management approach. It then developed short-term and long-term mitigation, management, and rehabilitation strategies at the farm and regional levels. Since rehabilitating saline soils through engineering (drainage systems) interventions or chemical amendments is expensive and time-consuming, this project explores adaptive and mitigation approaches to rehabilitate salt-affected soils. It was expected that improved crop yields and reduced loss of land to degradation would enhance the resilience of farming communities.

It gives me immense pleasure to present this project's findings and salient achievements. The project has evaluated the feasibility of more than 25 genotypes of salt-tolerant food and forage crops for the agro-climatic conditions dominant in these countries. The project has successfully distributed about 35 tons of seeds of the salt-tolerant crops to over 50,000 smallholder farmers for use and further multiplication. The project introduced improved on-farm water management techniques to improve water use efficiency and control soil salinity. This will indirectly benefit more than 250,000 people covering 100,000 ha. More than 1500 irrigation and extension workers were trained on different aspects of land and water management for salinity control through a comprehensive capacity building program under this project. Several farmer field days were organized to educate farmers and extension workers about the newly introduced salt-tolerant crops. The project has reviewed the technical, institutional, and policy constraints for adopting innovative technologies developed under this project. The potential policy interventions to enable the scaling-up of these technologies have also been suggested.

I want to take this opportunity to express my sincere gratitude to the International Fund for Agricultural Development (IFAD) for their generous grant for this project. I hope that our genuine partnership with IFAD will realize our shared vision of ensuring food security and improved livelihood in marginal environments. The support and collaborative efforts from our partner country are also highly commendable. I acclaim the commitment of ICBA's professional and support staff involved in this project. I believe that the findings of this project will be helpful for the farmers, scientists, and policymakers in improving the agricultural productivity of salt-affected soils in Ethiopia and South Sudan.

Dr. Tarifa A. Al-Zaabi
Acting Director-General

EXECUTIVE SUMMARY

Increasing salinity remains a challenge to the sustainability of irrigated agriculture in Ethiopia and South Sudan as it reduces natural biodiversity and farm and livestock productivity. Ethiopia's estimated 11 million ha (Mha) land is exposed to salinity and sodicity. The salt-affected areas in Ethiopia are in the Tigray region and Awash River basin. The situation is expected to exacerbate further in the future due to climate change-induced factors. The salt-affected lands in South Sudan are in the White Nile irrigation schemes. Yet, the area has hardly been utilized for agricultural production despite having great potential due to water from the Nile. In other parts of South Sudan, low soil fertility and the non-availability of good quality seeds for crops and forages are the major bottlenecks in the development of agriculture. About 18% of the land is not cultivated due to a shortage of seed and another 9% due to low soil fertility. With a 3% average population growth in these countries, future food security and the livelihood source for a considerable portion of the population remains a challenge to the governments. The soil salinity problems in both countries stem from poor on-farm irrigation practices and inadequate drainage facilities. Therefore, restoring degraded lands into productive lands and protecting newly developed areas from the spread of salinity through improved irrigation and crop management is paramount. In high saline areas where the growth of regular field crops is difficult, bioremediation methods developed by ICBA, including planting halophytic forages, could be a potential solution to reclaim these soils. This is particularly important for Ethiopia and South Sudan, considering their large livestock sector.

Considering this situation, the International Center for Biosaline Agriculture (ICBA) started a four-year project on 'Rehabilitation and management of salt-affected soils to improve agricultural productivity”. This project was funded by the International Fund for Development (IFAD) and implemented with the Ministries of Agriculture in Ethiopia and South Sudan. The main objective of this project was to develop strategies and approaches for the rehabilitation and management of salt-affected soils to improve agricultural productivity and livelihood of rural poor in both countries.

The project adopted an integrated soil and water management approach to tackle the salinity problems in the irrigated areas of both countries. The project strategy was first to diagnose the issues and then develop long-term mitigation, management, and rehabilitation strategies at the farm and regional level relevant to the problem using proven and high-level international salinity science and management. Since rehabilitating saline soils through engineering (drainage systems) or chemical amendments is expensive and time-consuming, this project worked on adaptive and mitigation approaches to rehabilitate salt-affected soils in Ethiopia and South Sudan. Through improved crop yields and reduction of loss of land to degradation, the project will empower farmers by improving their resilience, thereby reducing migration to cities and health problems due to stress on families suffering from the impact of salinity on their livelihoods.

Farming and livestock are the primary sources of household income in both countries. The direct impacts of soil salinity include abandoning land, reduced crop production, and declining farm incomes. The indirect effects are linked to food insecurity and increased dependence on food aid programs. The decreased household income increases poverty, forcing male members to migrate to nearby towns and cities to seek off-farm jobs. This situation has put enormous pressure on female members, carrying the extra burden of household activities. White crust and dark brown soil color are the primary indicators used by households to identify salinity in their farmlands. The majority of the families believed that poor irrigation management and the absence of drainage systems are the leading causes of salinity development in their fields. Drainage systems are not present in most irrigated areas. The three-decades-old existing drainage systems are either malfunctioning or abandoned due to neglect and poor maintenance.

In salt-affected areas, farmers are witnessing production losses from 10% to 70% depending on the salinity level of the soils, availability of agricultural inputs, and management capacity of the farmers. This situation makes them food insecure and dependent on food aid programs. On average, more than 50% of the population is food insecure during different times of the year. Due to the increasing dependence of farmers on food aid programs, the capacity of the donor organizations is declining. Farmers sell their livestock and household items to buy food and other utilities for their families. Therefore, urgent attention is needed from respective governments to address salinity problems to ensure future food security.

Appropriate and low-cost irrigation systems at affordable costs may help local smallholder farmers to improve agricultural productivity. The establishment of agriculture extension services for the farmers should be one of the priorities for the government and stakeholders. Local vegetable-growing farmers should be trained on modern irrigation methods such as drip and sprinkler irrigation systems. The state and national governments concerned with agriculture development should provide seeds and loans to the vegetable growers to improve their crop production and cultivation of crops during the dry period.

Bioremediation methods such as biosaline agriculture are economical and practical to using unproductive lands to grow different food and feed crops. This approach emphasizes using highly saline water and lands on a sustained basis through the profitable and integrated use of the genetic resources embedded in plants, animals, fish, and insects; and improved agricultural practices. This approach promotes reclamation using salt-tolerant plants, bushes, trees, and fodder grasses. Plants, particularly trees, are commonly referred to as biological pumps and play an essential role in the overall hydrological cycle in a given area. If prudently adapted, this approach can help improve the livelihood of rural and pastoral communities of the salt-affected areas by enhancing feed and fodder production. The project reveals a largely unexplored and unexploited genetic variation that can be harnessed to improve the salt tolerance of field crops. By adequately identifying field crop and fodder species and varieties that can tolerate soil salinization and poor irrigation water quality, the productivity of marginal lands can be maximized.

The ICBA-RAMSAP project introduced and tested more than 25 genotypes of different food and fodder crops and shrubs that produce excellent biomass yield under high soil salinity levels where no output is expected from cultivating other field crops. These include Sorghum, Barley, Cowpea, lablab, and three forages (i.e., Rhoades grass, Panicum, and Cinchrus grasses). These recommended genotypes have shown superior performance in production potential, nutritious values, and increased economic returns under salt-affected conditions than the existing local crop varieties. The scalable experiences gained and best practices validated need to be scaled out to more areas where saline soils are prevalent.

The seed multiplication units were established in both countries to produce seeds of different crops for distribution among farmers as a scaling-up strategy. More than 18 tons of seed was produced in Ethiopia through seed multiplication of different crop varieties. Interested farmers from selected woreda of different regions were chosen to work with the extension workers to scale up the recommended seed. Each farmer was given 500 grams of seed to cultivate a 100 m2 area. The harvest from this area would then be sufficient for 2-3 ha of land. The produced seed was distributed among 30,000 farmers. In South Sudan, about 16 tons of seed was produced and was distributed among 21,000 farmers in different regions. Therefore, about 35 tons of seed were distributed to more than 50,000 farmers. The seed produced by these farmers would indirectly benefit 250,000 people covering more than 100,000 ha of land. All the seed recipient farmers agreed to provide seed to their neighboring farmers for further multiplication. As the farm size in both countries is 0.2-0.5 ha, it is anticipated that the farmer-produced seed after the first harvest will be enough to cultivate more than 500,000 ha of land. The Ministries of Agriculture in both countries promised to take care of the seed distribution after the formal termination of the RAMSAP project.

Despite the water shortage and lack of adequate drainage facilities, farmers tend to over-irrigation, whereas the opposite should be accomplished. Due to poor land leveling and use of basin and flooding methods of irrigation, water use efficiencies are around 35%. Un-even water distribution due to poor leveling of fields produces patches of low and high infiltration rates, making patches of low and high salinity within the same area. Therefore farmers should be facilitated through extension services to level their fields and adopt water conservation measures to increase water use efficiency. In water deficit environments such as Ethiopia and South Sudan, water conservation strategies can save up to 25% of the irrigation water without reducing crop yields. Improved cultural practices such as precision land leveling, zero tillage, and bed and furrow-bed planting methods have shown water savings of up to 40% and reduced salinity development.

The use of saline water, to a large extent, is still confined to growing salt-resistant grasses for fodder, bushes, and trees. Due to minimal economic benefits, farmers are not very interested in adopting these practices and prefer to leave their lands and look for off-farm income employment. Due to the increasing dependence on irrigated agriculture, developing strategies to use different quality irrigation water for agriculture is crucial. The major problem in persuading farmers to use saline water for agriculture is the lack of proper guidelines on mixing ratios of different quality waters, irrigation amounts and frequencies, and cultural practices that can be instrumental in avoiding salt accumulation in the root zone. Therefore, the government needs to prepare strategic plans to improve research and extension services, leading to better solutions for the rehabilitation of salt-affected soils.

The irrigation potential of Ethiopia is not fully exploited. The total irrigation potential is about 7.5 million ha, of which only about 1.2 million (16%) is currently irrigated. Of the total area irrigated, an estimated area of about 260,000 ha (about 22%) is from large and medium scale irrigation, and the remaining 940,000 ha (78%) is from small-scale and micro-irrigation schemes. The performance of existing irrigation schemes is deficient, characterized by inappropriate operation, poor O&M of infrastructure, inefficient conveyance and field irrigation systems, inequitable water distribution, low water, land productivity, etc. A sizeable land area can be brought under cultivation by expanding small-scale irrigation. The current irrigation practices include ridge planting, improving irrigation efficiency, leaching, adopting more frequent irrigation, using localized drip irrigation whenever suitable to leach out salts from the root concentration areas, and pre-plant irrigation. The semi-(arid) regions are more susceptible to salinity development. It is high time to introduce suitable management interventions in saline areas to ensure sustainable irrigated agriculture in Ethiopia.

South Sudan has a substantial amount of surface and groundwater resources. The cultivable land brought under irrigation by smallholders and commercial farming is estimated at 1.5 Mha divided between the Nile-Sobat river basin, the Western and Eastern Flood Plains, the Mangala region the Green Belt zone. However, despite rich water resources present in the country, only 5% of the total area is irrigated due to a lack of irrigation infrastructure. There were several plans for irrigation development in Southern Sudan in the 1970s and 1980s. However, because of the instability, the development of irrigated agriculture was constrained and never fully operational and is still essentially non-functional. The current area for complete control irrigation is only 38,100 ha, and irrigation is mainly done using surface irrigation methods with 30-35% efficiencies. Currently, South Sudan's water sector is also impaired by a lack of updated data and information for surface water and groundwater resources. Apart from customary laws, no formal system for allocating water resources to a sector or user exists. Intense competition for water in the dry season often leads to disputes between farmers and pastoralists, who travel long distances depending on water availability. Several other initiatives need to be taken to strengthen the agricultural sector to achieve maximum benefits from irrigation development. These may include increased access to fertilizer, provision of extensive extension services, increased adaptive research facilities, enhanced private investment, increased agricultural mechanization, and modification of land-tenure laws.

In both countries, women are aware of salinity problems and their impacts on their lives. They are mainly concerned with increasing production costs, reduced yields, farm incomes, and health problems. The overall impact of this situation is increased food insecurity and household poverty. Women's involvement in agriculture largely depends on the societies' attitude towards women empowerment, which is not always as favorable as it should be. The attitudinal analysis done under this project shows that respondents have a positive attitude towards engaging women in farming and empowering them financially, socially, and politically in all regions. However, gender gaps in agricultural productivity in Ethiopia are still 11%, which is much lower than in many neighboring countries. It is estimated that, in Ethiopia, closing the gender gap can increase crop production by 1.4% that can add US$ 221 million in agricultural GDP. In South Sudan, women are more involved in agriculture. This shows a great potential to improve agricultural productivity in Ethiopia by increasing the contribution of women in agriculture. However, this should include better access to agricultural land and credit facilities to buy agricultural inputs, assistance in reclaiming their salt-affected lands, and better access to local and regional markets to sell their produce at competitive prices.

During this project, twenty-two formal trainings were organized to educate farmers, and extension workers were organized at the project locations in Ethiopia and South Sudan. These trainings were attended by 1500 participants including, farmers, irrigation technicians, and extension workers. The trainings covered wide-ranging topics related to different aspects of the rehabilitation and management of salt-affected soils. The trainings were given by the ICBA staff, prominent scientists from the partner countries, and the staff of local and international partners. These trainings also focused on soil and water analysis, crop management, irrigation, water management, scaling up strategies, seed multiplication, and production.

Farmer field days were organized regularly to demonstrate newly introduced technologies to farmers of the target areas. The cooperating farmers were trained in sowing, weeding, and irrigation practices. During these events, farmers' perception and preference among demonstrated crops and respective genotypes were also evaluated. Farmers reveal that they face feed and food shortages and show interest in adopting these practices, mainly forage crops. Farmer field days showed that the economical use of marginally productive soil resources through the cultivation of salt-tolerant food and forage crops as an alternative to existing salt-sensitive crops could help a great deal in optimizing land use. By promoting integrating crop-forage-livestock production systems, poverty in rural areas can be reduced.

In addition to trainings, workshops, and farmer field days, manuals for the farmers and extension workers were prepared. The manuals were prepared in English and local languages. Therefore, these manuals are prepared to educate farmers on appropriate agronomic practices for growing Quinoa, Sorghum, Lablab, Sesbania, and Cowpea crops in salt-affected areas. In addition, the manual will help agro-pastorals and extension workers in the salt-affected areas of Ethiopia. The main events and achievements of the project were shared on ICBA-managed social media regularly. The project team also participated in conferences, workshops, and seminars to present the project outcomes to the more extensive scientific and research communities. The project team in South Sudan managed to deliver speeches on local FM radio to broadcast project-related messages. The project achievements were also highlighted in internationally reputed newspapers to reach a wider audience. Sixteen papers/book chapters were published in internationally reputed journals to share the scientific outcome of the project to the larger scientific community.

01 INTRODUCTION

Soil salinization is a major threat to the sustainability of irrigated agriculture in Ethiopia and South Sudan as it reduces natural biodiversity and farm and livestock productivity. Ethiopia stands first in Africa in salt-affected soils. Current estimates suggest that over 11 million ha (Mha) land is exposed to salinity and sodicity. About 8 Mha have combined salinity and sodicity problems, and the rest 3 Mha are sodic. This relates to 9% of the total landmass and 13% of the country's irrigated area. Most of the saline soils are concentrated in the plain lands of arid, semi-arid, and desert regions of the Rift valley system, including Afar, the Somali lowlands, the Denakil Plain, and valley bottoms throughout the country. Most export crops such as cotton, sugarcane, citrus fruits, and vegetables are produced in the Rift valley. The expansion of irrigation schemes in the Rift valley in the absence of appropriate drainage systems has resulted in the rapid growth of salinity problems leading to the complete loss of land for crop cultivation in these areas. The growing occurrence of these soils reduces natural biodiversity and farm and livestock productivity.

Ethiopia is heavily dependent on the agriculture sector for its overall economic growth and social sector development. It accounts for 40% of the GDP, 80% of the total employment, and 70% of the export earnings. During the last decade, the growth of the agriculture sector has brought food self-sufficiency to the country, with grain production reaching up to 27 million tons. The semi-arid and dry sub-humid agro-ecological zones, which account for 47% of the country's 113 Mha, are highly vulnerable to droughts. A large proportion of the population continues to rely on food aid and safety net programs. Significant causes of low agricultural productivity are declining soil fertility and increasing soil salinity, lack of improved crop varieties, and lack of irrigation water. Other problems related to lower agricultural productivity are the limited crop varieties tolerant to soil salinity and water stress.

Despite this alarming situation, attempts to resolve land degradation problems could not get due attention. With a 3% average population growth, future food security and the livelihood source for a large portion of the population remains a challenge. Ethiopia's soil salinity problems stem from poor quality water coupled with the intensive use of soils for irrigation, poor on-farm water management practices, and inadequate drainage facilities. Therefore, restoring salt-affected lands into productive lands and protecting newly developed areas from the spread of salinity through improved irrigation and crop management is paramount. In the high salinity areas where the growth of typical field crops is limited due to salinity problems, bioremediation methods, including planting halophytic forages, can help.

In the Ethiopian Rift valley agricultural system, the primary sources of salts are shallow groundwater tables, natural saline seeps, and marine origin. The development of large irrigation schemes at middle and lower Awash Valley without appropriate drainage systems and poor management practices has caused the continuing rise of saline groundwater. Due to high temperatures, water evaporates from the soil surface, leaving the salt behind, causing secondary salinization in many areas in Ethiopia. If the current irrigation practices continue in the salt-affected soils, salinity problems will further exacerbate in the future. Salinity problems in Ethiopia have increased to the extent that farmers are experiencing huge crop losses while many farms have gone out of production over the last decade. Due to continuously decreasing land productivity and incomes, male members of the farming families are migrating to the nearby towns and cities to look for off-farm jobs to increase their income to meet their livelihood needs. This has created social problems as women have to take care of farm activities and household responsibilities. Currently, soil salinity is the most critical problem in the country's lowlands, resulting in reduced crop yields, low farm incomes, and increased rural poverty. Among others, farmers' poor knowledge about salinity development and suitable coping strategies is the primary reason for rapidly growing salinity problems.

Agricultural production in Ethiopia is predominantly rain-fed; it is highly susceptible to rainfall patterns and other adverse impacts of climate changes. Mitigating soil salinity to increase crop productivity of existing salt-affected soils and preventing further spread of salinity is therefore of paramount importance for agricultural development in the country. There is also a need to identify the best adaptation and mitigation practices for salinity management, increase farmer incomes, and improve poor rural communities' livelihood. This is particularly important for Ethiopia, considering its large livestock sector. The financial and technical resources needed to reclaim these soils for crop production are beyond the capacity of smallholder farmers. Therefore, there is every motivation to designate more resources by the government agencies to tackle this problem to ensure future food security and poverty reduction for millions of rural poor. This paper reviews the status and characterization of salt-affected lands in Ethiopia and recommends alternative cropping systems to increase crop productivity and reclamation of these lands.

In South Sudan, about 95% of the land is suitable for agriculture, out of which 50% has high production potential. The livestock sector accounts for 15% of the total GDP. Forest cover is about 30% of the entire area. The fertile lands are suitable to grow all sorts of crops. However, land productivity is generally low due to a lack of agricultural inputs such as seeds, fertilizer, pesticides, agricultural machinery, and higher labor costs. Farmers use traditional seed and grain storage methods, which increases post-harvest losses and poor seed quality. The timely availability of labor at reasonable prices is another major issue limiting crop production. Energy for cooking is one of the most challenging things for farmers.

In South Sudan, agriculture accounts for 36% of the non-oil GDP, with 80% of the population living in rural areas dependent on subsistence farming and 75% of the households consuming cereals as a central part of their daily diet. Only 5% of 30 Mha arable land is cultivated despite abundant water supplies. Crop yields are generally low, which negatively affects the incomes and livelihood of farmers. Lack of inputs such as seed and fertilizer, poor advisory services, and inefficient irrigation management are significant barriers. Although South Sudan has the highest livestock per capita globally, with 23 million head of cattle, sheep, and goats, there is little use of improved seed varieties or breeds of livestock. There is a strong need for salt-tolerant forage varieties to enhance livestock productivity. The salt-affected lands in South Sudan are in the White Nile irrigation schemes. The agricultural potential of these areas has hardly been utilized despite having great potential due to freshwater availability from the Nile. Furthermore, poor groundwater quality around Malakal and isolated regions also cause salinity.

The land holdings in South Sudan are generally small, and not all land is cultivated simultaneously due to a shortage of water and other agricultural inputs. The significant challenges perceived by farmers include poor land leveling of fields, lack of irrigation management, loss of land due to salinity, and low water use efficiency due to seepage and runoff losses. Lack of agricultural inputs such as improved seed, fertilizer, farm machinery, shortage of arable land, and lack of technical knowledge are significant constraints for low productivity. The non-availability of pesticides results in the expansion of invasive weeds.

To address land degradation challenges, the International Center for Biosaline Agriculture (ICBA), with the financial support of the International Fund for Agricultural Development (IFAD), launched a project "Rehabilitation and management of salt-affected soils to improve agricultural productivity (RAMSAP)" in Ethiopia and South Sudan. This project was started in 2016 to understand the extent and causes of soil salinity and develop strategies to rehabilitate and manage saline lands by introducing improved water management practices, salt- and drought-tolerant crops, forages, and halophytes. This project aimed to develop linkages between farmers and different extension and research organizations to identify and adopt the best strategies for managing salt-affected soils, increasing farmer incomes, and improving the livelihood of poor rural communities.

Considering this situation, the International Center for Biosaline Agriculture (ICBA) started a four-year project on 'Rehabilitation and management of salt-affected soils to improve agricultural productivity". This project was funded by the International Fund for Development (IFAD) and implemented with the Ministries of Agriculture in Ethiopia and South Sudan. The main objective of this project was to develop strategies and approaches for the rehabilitation and management of salt-affected soils to improve agricultural productivity and livelihood of rural poor in both countries.
The project adopted an integrated soil and water management approach to tackle the salinity problems in the irrigated areas of both countries. The project strategy was first to diagnose the issues and then develop long-term mitigation, management, and rehabilitation strategies at the farm and regional level relevant to the problem using proven and high-level international salinity science and management. Since rehabilitating saline soils through engineering (drainage systems) or chemical amendments is expensive and time-consuming, this project worked on adaptive and mitigation approaches to rehabilitate salt-affected soils in Ethiopia and South Sudan.

This report summarizes the major findings and achievements of the project in Ethiopia and South Sudan. This document is based on seven reports developed on different land and water management aspects to restore and rehabilitate salt-affected soils in the target countries. These reports have been written by ICBA experts and the national partners in both countries. The information presented in these reports provides a scientific basis for the strategies and practices recommended to rehabilitate and manage salt-affected lands in Ethiopia and South Sudan. This report is organized into eight interconnected chapters. These include:

1. Introduction
2. Baseline survey in Ethiopia ad South Sudan
3. Characterization of saline soils in Ethiopia and South Sudan
4. Irrigation water management in Ethiopia and South Sudan
5. Field evaluation of salt-tolerant food and fodder crops
6. Scaling up of recommended technologies
7. Gender differentials in salt-affected soils of Ethiopia
8. Project meetings, capacity building knowledge sharing

02 BASELINE SURVEY IN ETHIOPIA AND SOUTH SUDAN

A comprehensive baseline survey was conducted in the target areas of Ethiopia and South Sudan to collect data on the socio-economic characteristics of farmers. During the survey, information on the extent of saline lands and their impact on the livelihood of farming communities and limitations and constraints faced by farmers in adopting innovative technologies and approaches to improve agricultural productivity was collected. The role of women in agriculture and their problems in providing household food security was also addressed. The survey was conducted in the selected districts of different regions of both countries in collaboration with the local partners. Field teams were trained, and the questionnaire was field-tested before commencing the actual survey. The collected data was analyzed to understand farmer perceptions about salt-affected lands and crop productivity and suggestions for improvement.

The baseline survey was conducted to document the socio-economic and livelihood conditions of the farming communities living in the selected project sites. It was anticipated that the results of this survey would provide helpful information in understanding the status of salt-affected lands in both countries and their impact on the livelihood of farming communities. This survey also included information about the extent and causes of salinity development and farmers' irrigation and salinity management strategies. The survey also identified limitations and constraints in adopting innovative technologies and approaches for managing saline soils and improving agricultural productivity. The role of women in agriculture was stressed, and the problems they faced in ensuring household food security were addressed.

Multistage random sampling techniques were used to select study sites and sample respondents. The study districts were selected based on the prevalence of salinity problems due to long-term mechanized irrigated state farms and commercial agricultural practices. In this study, both primary and secondary data were used. Secondary data were collected from different sources like district agriculture and pastoral development offices and published and unpublished documents. This survey collected qualitative and quantitative information using different survey tools like structured questionnaires, key informant interviews, and focus group discussions. Discussions were also conducted with the government representatives and farmers to understand the socio-economic constraints of the farmers in diversifying their cropping patterns and increasing agricultural productivity through the adoption of new and promising technologies. In addition, information on socio-economic aspects was also collected from both countries.

The survey was conducted using a questionnaire developed by the socio-economic teams of ICBA, South Sudan, and Ethiopia. Focus group discussions and key informant interviews were also conducted as a survey tool. The questionnaire was tested in the field. The field teams of both countries were trained before the start of the study. Discussions were also held with the government representatives and farmers to understand the socio-economic constraints of the farmers in diversifying their cropping patterns and increasing agricultural productivity through the adoption of new and promising technologies.

Besides focus group discussions, key informant interviews were also held with selected individuals, including both men and women household heads. For this survey, a well-structured questionnaire was developed by the socio-economic teams of ICBA and partners. The developed questionnaire was pre-tested by trained enumerators to obtain necessary feedback and make corrections accordingly. The survey was conducted at regional and household levels. 25–30 respondents from each selected site with a mix of big and small farmers were selected for this survey. Consideration was also given to owner and tenant farmers (50/50, wherever possible).

2.1 Findings of the baseline survey in Ethiopia

The study was conducted in five districts of Ethiopia. These include Amibara, Dubti, Raya-Alamata, Ziway-Dugda, and Kewet districts from the Afar, Tigray, Oromia, and Amhara regions. These areas were selected based on the large tracts of salt-affected soils in the irrigated areas and the demonstrated crop production potential. The general characteristics of the selected districts are given in Table 1.

Table 1. Characterization of selected sites in Ethiopia

Districts	Climate	Mean annual rainfall (mm)	Main crops grown	Salinity problems
Amibara	Semi-arid	570	cotton, wheat, maize, vegetables	Widespread salinity in irrigated areas
Dubti	Hot and dry	220	wheat, sorghum, vegetables	High water table, high salinity in farms
Raya-Alamata	Semi-arid	660	*teff*, sorghum, cereals, vegetables	Shallow water table, low to medium salinity
Ziway-Dugda	Arid	760	fodder, cereals	Shortage of water, widespread salinity
Kewet	Hot & humid	1000	*teff*, maize, tobacco, and vegetables	High water table, high salinity, low yields

In the Amibara district, about 33% of the total area is saline. In the Dubti district, more than 80% of the site is affected by salinity and sodicity. The significant reasons for this salinity development are poor irrigation water management practices and lack of drainage facilities. The Raya-Alamata district of the Tigray region is characterized by shallow groundwater levels, which is the leading cause of salinity development. In Ziway-Dugda and Kewet districts, soils are sodic. This problem harms soil fertility which, in turn, reduces crop yields and farm income. The map of the selected districts is given in Figure 1.

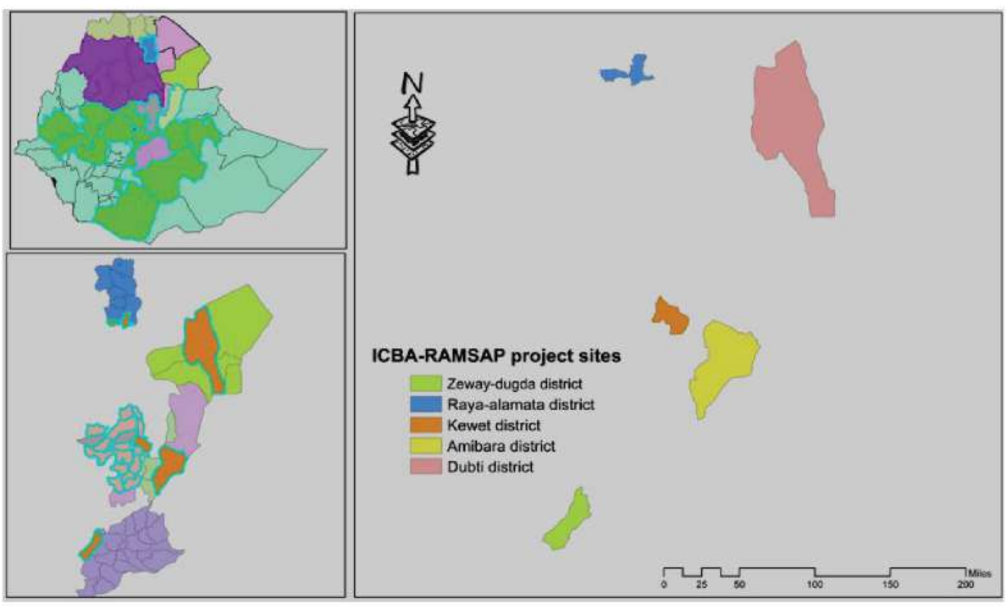


Figure 1. Location of selected sites in Ethiopia

2.1.1 Demographic and socio-economic characteristics of respondents

The demographic and socio-economic characteristics of respondents include gender, family size, marital status, education level, landholding, and livestock ownership. Table 2 shows that 86.7% of the respondents were male and 13% female. The highest number of female respondents belongs to Raya-Alamata district and the lowest to Kewet district. More than 85% of the respondents were married. About 42% of the respondents have formal education, 17% are educated up to secondary school level, whereas 41% were illiterate. The most illiterate respondents were from the Raya-Alamata district, followed by Amibara and Dubti districts. The average household land holding is 2.2 ha, lowest in Amibara (1.2 ha) and highest in Kewet (4.2 ha).

Table 2. Demographic and socio-economic characteristics of the respondents.

Parameters	Amibara (N = 67)	Dubti (N = 35)	Raya-Alamata (N = 88)	Ziway-Dugda (N = 65)	Kewet (N = 45)	Average (N = 300)	SD
Male (%)	92	88.5	70.4	87.7	95.0	86.7	9.6
Female (%)	8.0	11.5	29.6	12.3	5.0	13.3	9.6
Single (%)	8.4	17.0	27.6	37.0	2.2	18.4	14.1
Married (%)	91.4	83.0	72.4	63.0	97.8	81.5	14.1
Illiterate (%)	50.8	48.6	51.4	16.9	35.6	41.0	14.8
Formal school (%)	33.2	42.9	42.8	50.8	40.8	42.0	6.3
SSC school (%)	16.0	8.5	5.5	32.3	23.4	17.0	11.0
Landholding (ha)	1.2	2.0	2.0	1.6	4.2	2.2	1.2
Livestock (TLU)	15.3	15.0	14.6	3.70	3.70	10.4	6.2

2.1.2 Sources of households' income

The agricultural production system of the selected districts is a mixed farming system in which farmers practice both livestock and crop production. However, farmers emphasize crop production to secure food supply and satisfy the cash needs of their families. The different sources of income reported by the sample households include livestock herding, crop cultivation, off-farm wage employment, petty trade, permanent employment, food aid, and others. The survey results show that although livestock and livestock-related income sources were the dominant means of living in pastoral and agro-pastoral livelihood systems, farming (crop sale), off-farm employment, and permanent employment also contributed significantly to the incomes of the respondents.

Table 3 shows that except in Ziway-Dugda, the share of crop sales was the largest in household incomes, followed by livestock. In Ziway-Dugda, the most significant contribution in household income comes from livestock farming and less from agriculture. Due to intensive agro-business activities, there are substantial off-farm wages and permanent employment opportunities in Amibara and the Dubti districts. This makes households of these districts less dependent on food aid programs. Household incomes from permanent employment are substantial (20%) in the Ziway-Dugda district. However, in Raya-Alamata, Ziway-Dugda, and Kewet districts, the chances of off-farm wages and permanent employment are the lowest. More people are dependent on petty trade and food aid programs of national and international organizations. This clearly shows that households of salt-affected areas in these districts cannot rely solely on farming and must engage in multiple activities to earn their living and meet their daily food requirements.

Table 3. Sources of household income

Parameters	Amibara (N = 67)		Dubti (N = 35)		Raya-Alamata (N = 88)		Ziway-Dugda (N = 65)		Kewet (N = 45)	
	N	%	*N*	%	*N*	%	*N*	%	*N*	%
Livestock	56	83.6	28	80.0	19	21.6	37	56.9	29	64.4
Farming (crop sale)	67	100	31	88.5	53	60.2	14	21.5	30	66.7
Off-farm wage	31	46.3	7	20.0	4	4.5	4	6.2	2	4.4
Permanent employment	19	28.4	9	25.7	1	1.2	13	20.0	1	2.2
Petty trade	2	3.0	3	8.57	3	3.4	9	13.8	4	8.9
Food aid	2	3.0	0	0.00	10	11.4	3	4.6	6	13.3

2.1.3 Farmers' perception about the existence and causes of salinity

During this survey, farmers were asked about the indicators they use to identify salinity in their farmlands. According to survey results, 36% of the respondents use white crust on the soil surface, 22% consider dark brown color of the soil, whereas 42% use both the white crust and dark brown color of the soil as an indicator to identify salinity in their fields. Based on these indicators, farmers were asked to classify salinity in their farmlands on a low, medium, high, and very high and the results are presented in Table 4.

Table 4. Farmer perceptions about farmland salinity

Parameters	Amibara (N = 67)		Dubti (N = 35)		Raya-Alamata (N = 88)		Ziway-Dugda (N = 65)		Kewet (N = 45)	
	N	%	*N*	%	*N*	%	*N*	%	*N*	%
Classification of farmland salinity										
Low	10	14.9	4	11.4	7	8.0	2	3.1	3	6.7
Medium	28	41.8	13	37.1	28	32.0	10	15.4	16	35.6
High	23	34.3	15	42.9	31	35.0	18	27.7	13	28.9
Very high	6	8.9	3	8.6	22	25.0	29	44.6	6	13.3
Causes of salinity development										
Parent material	12	17.9	17	42.9	10	11.4	58	89.7	30	66.7
Irrigation water quality	59	88.1	29	82.9	76	86.4	29	44.6	14	31.1
Irrigation methods	23	34.3	23	65.7	37	42.0	4	6.2	8	17.8
Climatic conditions	5	7.5	9	25.7	16	18.2	6	9.2	3	5.3
Land leveling problem	32	47.8	15	42.9	8	9.1	7	10.8	6	13.3
Irrigation frequency	5	7.5	4	11.4	40	45.5	4	6.2	4	8.8
Irrigation water quantity	14	20.9	11	31.4	39	44.3	12	18.5	13	28.9
Drainage problem	34	50.8	18	51.4	53	60.2	58	89.2	37	82.2

The results show that most farmers believe that salinity levels in their farmlands range from medium to high. The high salinity levels in Amibara and Dubti districts are attributed to dry and hot weather conditions and low irrigation water availability. The presence of parent salts and excessive salts due to poor quality groundwater for irrigation are significant causes of higher salinity in these areas. Furthermore, drainage problems are more severe in Amibara and Dubti districts. Poor irrigation management practices and the absence of a drainage system have resulted in a rapid rise in groundwater levels, leading to soil salinization.

The survey's consolidated results revealed that most of the farmlands possessed by respondents of these areas are of poor fertility. About 43% of the respondents consider their farmland inferior (infertile), 51% rated their farmland as average, and 6% termed the fertility of their farmland as good (fertile). Table 4 illustrates that the majority of the farmers consider poor irrigation water quality and inadequate drainage facilities as the leading causes of salinity development in their farmlands, followed by irrigation methods and land leveling issues. Despite all the scientific progress and mounting water shortages, irrigation applications by farmers are not based on actual crop water demands. Fields are poorly leveled, and farmers generally use basin/ ooding irrigation methods. This practice results in low and high water application patches after each irrigation event, leading to uneven crop growth and low yields.

2.1.4 Farmers' perceptions about crop productivity losses due to salinity

The crop productivity losses from soil salinization in the study areas ranged from a complete loss to less than 10% loss. Most of the respondents (54.3%) in the Dubti district reported a 50% loss in their crop production, followed by Amibara (38.8%), Ziway-Dugda (32.5%), Kewet (28.9%), and Raya-Alamata (20.8%). The highest crop productivity losses of 25% were reported in Amibara (35.8%) and Dubti (25.7%) districts (Figure 2). Nearly 15% of the respondents in the Amibara district reported a complete loss of their crop production in multiple cropping seasons. However, total production losses were less than 10% in the other four districts. High productivity losses in Amibara and Dubti districts are understandable given the area's dry, hot and saline environment.

The low crop productivity in salt-affected areas directly impacts the income and livelihood of households. In the highly saline areas of Amibara and Dubti, farmers are abandoning their lands and migrating to nearby cities and towns in search of off-farm jobs. Declining farm incomes has forced households to do extra work to earn cash to meet their daily needs, which has created severe health problems, especially for women and children. Farmers complain about losing their livestock due to drought and diseases, making it impossible to nurture their families. We are entirely dependent on food aid programs for more than six months a year. Due to low productivity in salt-affected areas, farmers send their animals to other areas searching for feed. This situation further increases their vulnerability.

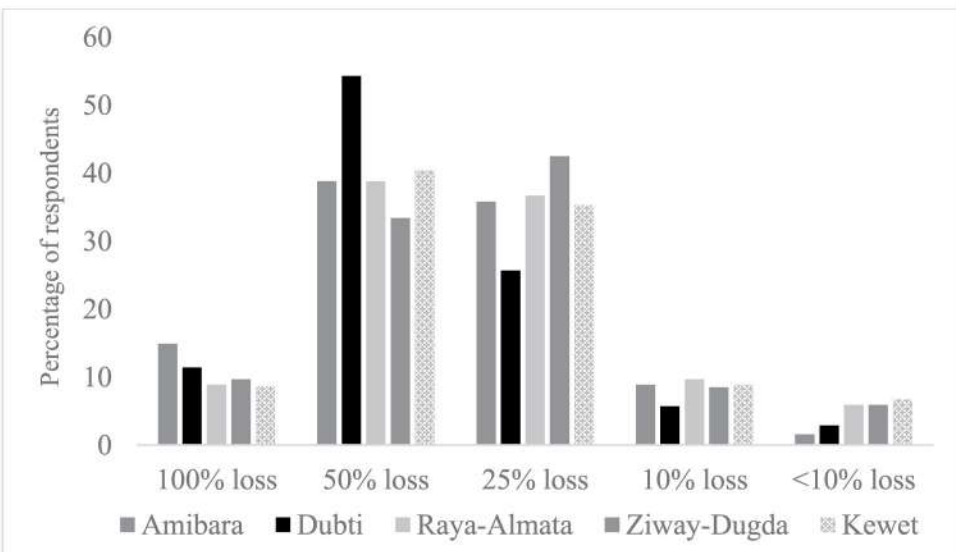


Figure 2. Production losses due to soil salinity in different districts

2.1.5 Farmers' perception about production and marketing constraints

The primary production and marketing constraints reported by farmers for improving their agricultural productivity are lack of farming inputs such as improved seed, fertilizer, and farm machinery, shortage of arable land, lack of technical knowledge, scarcity of irrigation water, and increasing salinity (Table 5). Consistently lower land productivity in the study areas results in reduced farm incomes, food insecurity, and poverty. Due to the constraints mentioned above, crop yields are generally low, and after meeting domestic needs, very little is left for sale in the market to earn cash for other family needs. In addition to low productivity, farmers face many marketing constraints to get the actual value of their produce. The lack of market information and poor infrastructure are significant marketing constraints.

Table 5. Production and marketing constraints faced by farmers in Ethiopia

Parameters	Amibara (N = 67)		Dubti (N = 35)		Raya-Alamata (N = 88)		Ziway-Dugda (N = 65)		Kewet (N = 45)	
	N	*%*	*N*	*%*	*N*	*%*	*N*	*%*	*N*	*%*
Production constraints										
Lack of agricultural inputs	64	95.5	27	77.1	86	98.9	13	20	2.0	4.4
Shortage of arable land	50	74.6	15	42.9	86	98.9	1	1.5	1.0	2.2
Lack of tech. knowledge	51	76.1	25	71.4	85	97.7	32	49.2	14	31.1
Shortage of irrigation water	30	44.8	6	17.1	82	94.3	62	92.3	31	68.9
Increasing soil salinity	67	100	34	97.1	83	95.4	43	66.2	30	66.7
Growth of invasive weeds	52	77.6	25	71.4	70	80.5	22	33.8	18	40.0
Marketing constraints										
Lack of market information	53	79.1	29	82.8	77	88.5	4	6.2	3.0	6.7
Lack of infrastructures	38	56.7	19	54.3	32	36.8	32	49.2	5.0	11.1
Involvement of brokers	18	26.8	6	17.1	27	31.0	2	3.1	24	53.3
High transaction costs	35	53.3	19	54.3	43	49.4	5	7.7	7.0	15.6

2.1.6 Household food security in salt-affected areas

Salt-affected lands are directly and indirectly affect the livelihoods of the households. The direct effects of salinity are related to decreased farm productivity and household income. The indirect effects are linked to food insecurity and increased dependency on donor aid programs. The survey results indicate that about 93% of the households in Raya-Alamata and 98.5% of the households in Ziway-Dugda are food insecure during different times of the year. In the Kewet district, 42% of the households are food insecure for the whole year, especially in August and September. The remaining 58% of the households are food secure. About 44.8% of the households in Amibara and 48.6% in Dubti are food insecure for from March through June, as these are the driest and hottest months. During these months, farmers usually shift their livestock to other areas where fodder and water availability are guaranteed. Therefore, households do not have access to milk and other dairy products, making it challenging to meet their food demands. In addition, crop production is at the lowest due to a water shortage and high temperatures.

Households use different adaptive strategies to ensure food security. Traditionally, the mutual support system was the most used strategy in pastoral and agro-pastoral communities used at the time of shocks and risks. However, with the weakening of the traditional pastoral system, this mutual support strategy system has broken down in recent years. As a result, the communities have adopted other copping strategies either by themselves and/or with the support of internal and external bodies (governmental and non-governmental organizations). According to aggregate survey results, 42% of the food deficit households of all districts participate in "food for work activities," while 13% rely on food aid programs of national and international organizations. The remaining 45% of food-insecure households cope with this situation by doing off-farm income-earning activities and even selling livestock and other household items. Figure 3 shows the percentage of food secure respondents in each region.

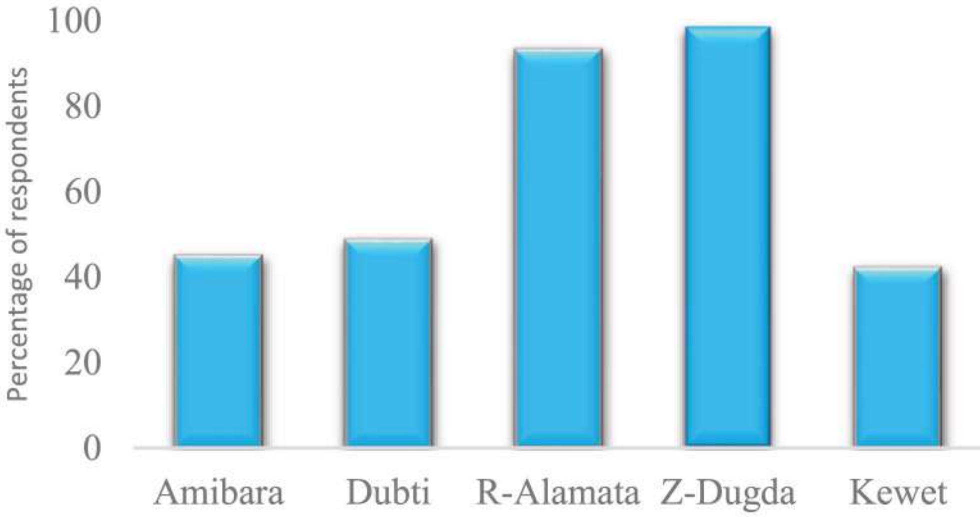


Figure 3. Food security in salt-affected areas of different districts

2.1.7 Summary of findings for Ethiopia

Agricultural farming followed by livestock is Ethiopia's primary source of household income. The direct impacts include abandoning land, reduced crop production, and declining farm incomes. The indirect effects are linked to food insecurity and increased dependence on food aid programs. The decreased household income increases poverty in salt-affected areas, forcing male members to migrate to nearby towns and cities to seek off-farm jobs. This situation has put enormous pressure on female members, carrying the extra burden of household activities.

Farmers use different indicators to identify salinity in their lands. Observing white crust and dark brown soil color are the primary indicators used by households to identify salinity in their farmlands. The majority of the families believed that poor irrigation management and the absence of drainage systems are the leading causes of salinity development in their fields. Drainage systems are not present in most irrigated areas. In some irrigated areas, drainage systems were installed about three decades ago. These systems are either malfunctioning or abandoned due to neglect and poor maintenance.

In salt-affected areas, farmers are witnessing production losses from 10% to 70% depending on the salinity level of the soils, availability of agricultural inputs, and management capacity of the farmers. This situation makes them food insecure and dependent on food aid programs. On average, more than 50% of the population is food insecure during different times of the year. Due to the increasing dependence of farmers on food aid programs, the capacity of the donor organizations is declining. Under these conditions, farmers sell their livestock and household items to buy food and other utilities for their families. Therefore, the government needs to take immediate measures to improve salt-affected areas to address food insecurity and poverty-related problems.

2.2 Findings of the survey in South Sudan

South Sudan is in East Africa, extending over 640,000 km2. It borders Ethiopia, Kenya, Uganda, and the Democratic Republic of Congo in the south and the Central African Republic in the west. The rainfall patterns are zone-dependent, ranging from 500–2000 mm, which provides 130–300 days of the growing season. The temperatures are variable and range from 25oC to 35°C. The dry, hot conditions trigger human and livestock migrations to more permanent water sources, which serve as dry season grazing and fishing areas. The primary water resources are the Nile, its tributaries, and groundwater. The lowlands of the White Nile Valley have great potential for irrigation due to the availability of fresh water from the Nile River. Still, these lands have not been used for agriculture. Despite abundant water resources, only 5% of the total area is irrigated due to a lack of irrigation infrastructure. Surface irrigation methods such as basin and/or ooding are commonly used, resulting in 30–35 percent water use efficiencies.

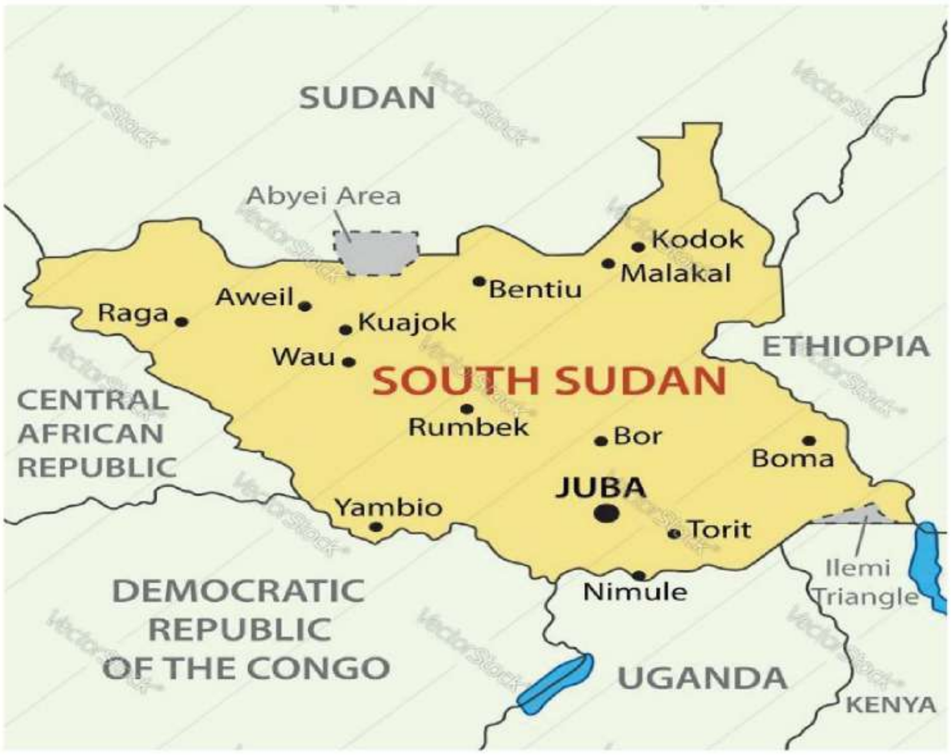


Figure 4. Location of the selected sites in South Sudan

About 95% of the land is suitable for agriculture, out of which 50% is prime land with high suitability to grow all sorts of crops. South Sudan has the highest per capita livestock holding in Africa. The livestock sector accounts for 15% of the total GDP. Land productivity is generally low due to a lack of agricultural inputs such as seeds, fertilizer, pesticides, agricultural machinery, and higher labor costs. Nearly all farmers use traditional methods for seed and grain storage. This increases post-harvest losses, compromises the quality of seeds, and affects crop yields and the nutritional value of the produce. Most farmers are not aware and do not have access to modern irrigation technologies. The primary reasons for low land and water productivities include poor agronomic and irrigation practices, costly land reclamation, deforestation because of logging and charcoal burning, overgrazing, and bush burning, Lack of good quality seeds and improved farm technologies, climate variability, and lack of soil and water analysis facilities.

For South Sudan, five states were selected for conducting a baseline socio-economic survey. The chosen states include Jubiek, Jongule, Aweil, Nayamurnang, and East Nile state. These locations were chosen after consultation with the Ministry of Agriculture and Food Security representatives, research organizations, and research scientists. For each selected state, there is several sites as listed below:

1. Jubeik State (Juba) - Juba, Luri, and Rajaf
2. Jongule state (Bor) - Bor town, Panliet and Cuei Nyok)
3. Aweil State (Aweil) - Nyalith, Awulic, Rice Scheme Nogwe, and Kuom
4. Namurnang state (Kapoeta) - Kapoeta, Katico, Lomilmil and Kotomo
5. East Nile state (Renk) - Renk, Rumeila, Mangara, Khor Ajais, Abu Khadra and Feyuer.

These sites were selected using the following criteria:

- Degraded lands with low productivity due to poor agronomic and water management practices
- A large number of poorly resourced farm-households including women and youth with mainly rare cattle and small ruminants
- Availability of local partners and state government staff.
- Shallow groundwater levels and poor quality in Jonglei (Bor) and Unity (Bentiu) states

Table 6. General characteristics of selected sites in South Sudan

No	Site	Zones	Type of Crops
1	Aweil	Western Flood Plains	(Agro-pastoralism): livestock and agriculture predominant. Main crops are sorghum, pearl millet, vegetables, cow pea
2	Bentiu	Nile-Sobat Rivers	(Agro-pastoralism and fishing): prone to seasonal flooding. Major crops, sorghum, beans, and vegetables.
3	Bor	Nile-Sobat Rivers	(Agro-pastoralism and fishing): prone to seasonal flooding. Major crops include sorghum, beans, and vegetables.
4	Torit	Hills & Mountains	Agriculture and livestock husbandry. Crops include cassava, sweet potatoes, sorghum, maize, finger, pearl millet.
5	Juba	Hills & Mountains	Agriculture and livestock husbandry. Crops include cassava, sweet potatoes, sorghum, maize, finger, pearl millet.

2.2.1 Socio-economic characterization of the respondents

The demographic and socio-economic characteristics of respondents include gender, family size, marital status, education level, landholding, and livestock ownership. About 80% of the respondents were aged between 20 and 50 years, whereas the age of the remaining 20% was above 50 years. This shows that most of the respondents in this survey were active farmers and represent a good mixture of experienced and young emerging farmers. Out of the total sample of 200 respondents, 135 (67.5%) were male, and 65 (32.5%) were female. This disproportion was because the male respondents were readily and easily accessible, whereas female respondents were limited due to their busy schedules at home. The survey results indicate that 55% of respondents were married. They practice irrigated farming to earn food and other necessities such as health and education for their families and children. Single emerging young and widowed/divorced farmers are mainly subsistence farming. Food security and livelihood challenges are more significant in divorced/widows.

Livestock ownership is considered a proxy for wealth in rural areas of South Sudan. In the survey areas, livestock is a primary source of food, income, and security in hardship for the communities. Although the agricultural production system is a mixed farming system (crops and livestock), farmers prefer to grow crops to secure food supply and satisfy the cash needs of their families. The different sources of income include livestock herding, crop cultivation, off-farm wage employment, permanent employment, and food aid. More than 80% of farmers earn their living through crop selling and off-farm jobs, whereas permanent work contributes significantly to the respondents' incomes.

Farmers reduce production costs and increase farm income by performing most farm activities using family labor. Men mainly perform farm labor activities such as land clearing, plowing, and irrigating, whereas women contribute more to winnowing and harvesting. Other activities such as sowing, weeding, bagging, and transporting are primarily shared among male and female household members. Household poverty is very pervasive in the selected areas because low crop productivity directly impacts the income and livelihood of households. The household income of more than 60% of the respondents is less than one US$ per day. Declining farm incomes has forced families to do extra work to earn cash to meet their daily needs resulting in serious health problems, especially for women and children. Farmers occasionally lose their livestock due to drought and diseases. This situation made them entirely dependent on food aid programs of national and international organizations for more than six months a year.

The consolidated results of the survey revealed that most of the lands owned by respondents are poor infertile. About 43% of respondents consider their lands infertile, 51% rated them as average, and about 6% termed the fertility of their land as good (fertile).

2.2.2 Farmers' perceptions about the importance of irrigation

The landholdings are generally small, and not all land is cultivated simultaneously due to a shortage of water and other agricultural inputs. About 70% of farmers have one hectare of land, whereas 16% own less than 3 ha and 14% have more than 4 ha of land. Figure 5 indicates that 42% of farmers cultivate vegetables and 28% legume crops to meet their household needs and earn little money by selling the excess produce in local markets. Cereals and oil crops are grown by 17.5% and 12.5% of farmers, respectively. Other crops are grown in small quantities, including groundnuts, vegeta-bles, and cassava.

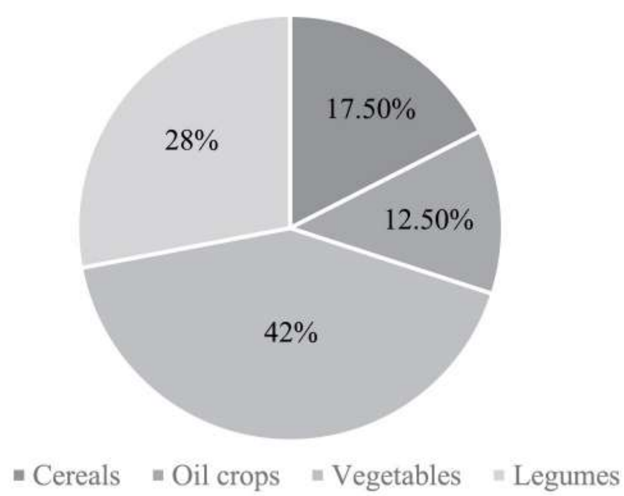


Figure 5. Commonly grown crops in South Sudan

Farmers' knowledge about irrigation management is limited, and most of them are unaware of salinity problems. They usually relate low crop productivity to water shortage and the attacks of insects and diseases. In general, farmers (87%) are aware of the importance of irrigation for sustainable crop production as the rainfall is neither reliable nor sufficient. More than 85% of the respondents believe that the irrigation systems need further development, whereas 15% think the priority should be rehabilitating the existing irrigation systems. About 73% of farmers use surface irrigation methods, and 9% have installed drip systems, whereas the 18% rely on traditional flooding methods. Farmers consider surface irrigation as an income source because it improves their livelihoods through increased crop yield and cultivation of cash crops such as vegetables and fruits both during rainy and dry seasons for the local markets.

More than 87% of the farmers prefer lift irrigation because it is reliable and easy to pump water from surface canals and groundwater wells. In addition, they are less expensive and have minimum operational and maintenance requirements. Many respondents use mechanical pump engines, hand pumps, and water-buckets to lift water from the river and small dug wells for irrigating their fields.

Table 3 shows that 76% of the surveyed farmers have access to one or more irrigation equipment such as pipes, pumps, diesel generators, and watering cans. The remaining 24% of the farmers do not own any equipment because of low purchasing power. These farmers either rent or borrow this equipment from their fellow farmers. Most farmers (36%) use 'rotodynamic" type of pumps due to their low cost, high efficiency, and ease of installation. However, the drawback of these pumps is that they need skilled labor to ensure regular maintenance and better operation. The poor farmers look to government and donor agencies for financial assistance to buy these pumps.

The farmers were found to have limited knowledge of crop water demands. In the absence of scientific irrigation scheduling information, farmers' irrigation applications largely depend on the availability of water and visual plant stress indicators. Most farmers apply irrigation when the soil surface becomes dry, and the crops start showing signs of stress (e.g., dry leaves, changed the color of leaves, etc.). Resultantly, their irrigation applications are much higher than the actual crop demand. The water applied more than crop demand is wasted through surface runoff that damages neighboring fields. During the survey, 80% of the respondents admit that irrigation applications generate surface runoff, whereas 20% do not consider it a big issue. To prevent runoff, farmers use different methods such as land leveling, widening of channels, and raising the bunds of their fields.

The survey results indicate that farmers having access to sufficient irrigation water and own pumps tend to apply irrigation twice a day to save their crops from extra water stress. This is essential irrigation practice because low discharges and high temperatures make the soil dry due to the fast depletion of applied water. Farmers had no access to pumps and irrigation water, applied random irrigations depending on the access to water (Figure 6). The results show that 17% of farmers irrigate daily, 11% twice a week, whereas 19% can only afford irrigation three times a week. These unscheduled irrigation applications produce low water use efficiency and crop yields. This demonstrates that timely access to irrigation water is the biggest constraint in improving agricultural productivity in South Sudan. Mamba et al. (2015) have also stressed the need to match irrigation applications to cover the vagaries of climate changes.

Farmers prefer the basin irrigation method because they consider it better to control surface runoff. However, excessive irrigation applications through this method cause depletion of soil nutrients, which exacerbate existing poor soil fertility problems. Farmers complain that they do not get any information from the extension workers or irrigation technicians regarding the timing and amount of irrigation water application for different crops.

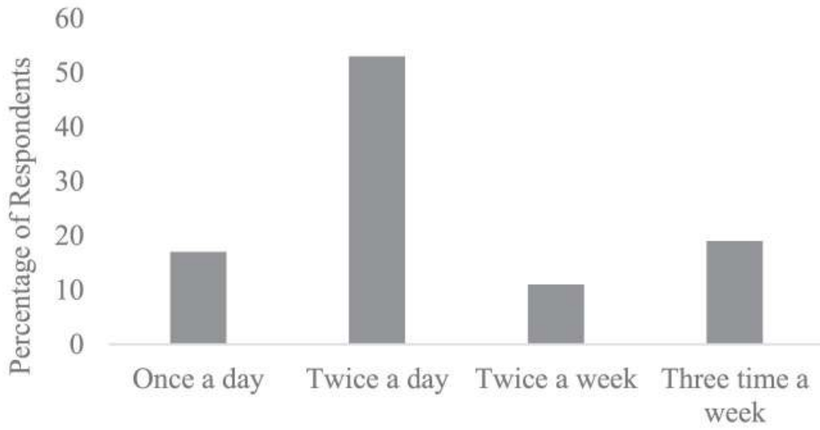


Figure 6. Irrigation schedules adopted by farmers.

2.2.3 Farmers' perceptions about the production and market constraints

The information collected from secondary sources revealed that average crop productivities in the selected districts were consistently low. The major challenges of irrigation management include poor land leveling of fields, lack of irrigation management, less irrigation time, loss of land due to salinity, and low water use efficiency due to seepage and runoff losses. More than 95% of the respondents consider lack of agricultural inputs such as improved seed, fertilizer, farm machinery, lack of technical knowledge, scarcity of irrigation water, and increasing salinity as the significant constraints for low productivity

Figure 7 shows that 38% of farmers consider lack of irrigation equipment as the major challenge for improving crop production followed by less irrigation time (27%), low water use efficiency (18%), poor land leveling (12%), and salinity problems (5%). For the leveling of their fields, farmers have to hire the services of companies as they do not have the skills and equipment to do it themselves. This makes this task difficult for them. Low water use efficiency is caused by excessive seepage and surface runoff due to the ooding irrigation method. Salinity problems are not widespread in the study areas except in the Bore district.

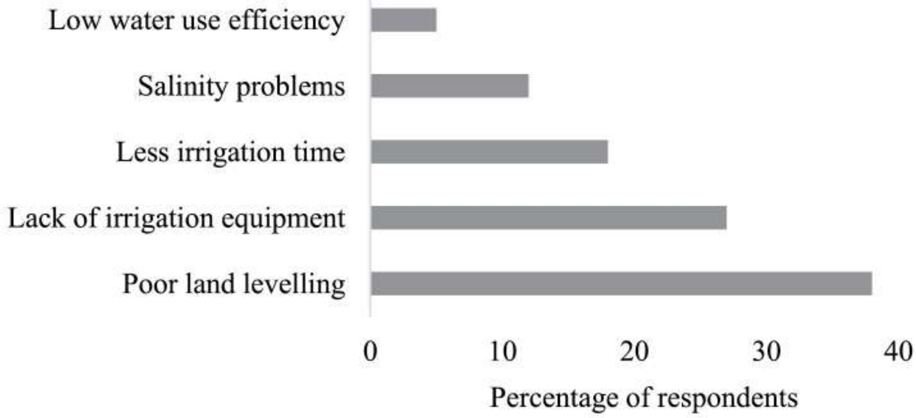


Figure 7. Challenges of irrigation management as perceived by farmers

In South Sudan, farmers hire annual labor for land preparation, planting, weeding, and harvesting purposes. The cost of hiring labor ranges from 200-1000ssp per day (IUS$ = 130 ssp). Meanwhile, the daily income of the respondents from the sale of their farm products ranges from 1500-5000ssp per day. This shows that farmers earn a good income from irrigation farming to cover these costs. However, income levels are low without irrigation, and it becomes hard for them to cover these expenses. Farmers' first preference is to use surface water for irrigation because of its low cost and better quality. However, their ultimate choice is groundwater for irrigation without surface water. Some farmers prefer groundwater because of its on-farm availability. During the survey, farmers demanded training to increase their awareness of irrigation practices, crop water requirements, and soil management. They suggest that government and/or other agencies should arrange this training regularly. Farmers think that government organizations and NGOs should take appropriate steps for improving irrigation management in South Sudan.

Consistently lower land productivity in the study areas results in reduced farm incomes, food insecurity, and sway in poverty. Due to the constraints mentioned above, crop yields are generally low, and after meeting domestic needs, very little is left for sale in the market to earn cash for other family needs. In addition to low productivity, farmers face many marketing constraints to get the actual market value of their produce. During the field survey, farmers rated lack of market information (42%) and poor infrastructure to access regional markets (32%) as the marketing constraints. Farmers also consider the involvement of brokers (18%) and high transaction costs (8%) as the primary constraint for marketing their products. Due to the poor product quality and lack of storage facilities, farmers prefer to sell their produce soon after harvesting. The brokers take advantage of the situation, and farmers must compromise on the price.

2.2.4 Recommendations for improving agricultural productivity

Household poverty is very pervasive in the selected areas of South Sudan. The landholdings are generally small, and not all land is cultivated simultaneously due to scarcity of water and other agricultural inputs. Farmers were unanimous in declaring the low availability of irrigation water as the biggest challenge for improving agricultural productivity in South Sudan. In the absence of irrigation water, farmers depend on seasonal rain, which results in severe food shortages during most of the year. Therefore, installing public wells to increase groundwater availability and establishing rainwater harvesting structures to store rainwater need to be introduced to solve irrigation water problems and overcome food shortages.

Farmers mostly use locally produced seed for growing crops. These seeds are of poor quality and mostly infected, which results in low crop productivity. Therefore, farmers should be provided with quality seeds to improve crop yields. Lack of agricultural machinery is also one of the major causes of low crop productivity. Farmers suggest that the government take the necessary steps to provide equipment such as tillage equipment, planters, sprayers, levelers, harvesters, threshers, and transport trailers to farmers at subsidized rates. Farmers commonly use wide disc planters for land preparation, which uses fuel and damages soil due to excessive tractors and other machinery. The maintenance and availability of spare parts for these machines are a problem in South Sudan.

The locally produced drip and furrow irrigation systems are helpful for smallholder farmers for increasing water use efficiency by minimizing non-beneficial use of water. The benefits of these systems can be maximized if they are appropriately designed, managed, and maintained. Therefore, farmers should be provided consultancy services to design drip irrigation systems properly. The easy access to manuals and guidelines developed by different manufacturers on different design factors may help farmers improve their skills for adequately designing a drip irrigation system.

The establishment of agriculture extension services for the farmers should be one of the priorities for the government and stakeholders. Training vegetable growers on modern irrigation methods such as drip and sprinkler irrigation systems and providing irrigation equipment to the farmers can help increase water use efficiency and agricultural productivity. The government should give high-quality seeds and loans to the vegetable growers to improve their crop production and cultivation of crops during the dry periods.

There is a need to develop a marketing mechanism for farmers' agricultural products at their actual prices. This will encourage them to increase crop production and improve their incomes. Effective extension programs should disseminate information on soil, water, and salinity management practices to farmers. Farmers should also be linked with national research and extension organizations to benefit from their intervention programs to improve land and water management and increase agricultural productivity. Providing accessible credit facilities for farmers might also be a step in the right direction.

2.2.5 Summary of finding for South Sudan

Generally, farmers are aware of irrigation development and its importance and are well informed about the necessity of irrigation in South Sudan to improve crop production and agricultural productivity. Most farmers use surface irrigation methods and recognize the need for training and appropriate designs to optimize irrigation water use efficiency and crop production in South Sudan.

The availability of appropriate and low-cost irrigation systems using local materials in South Sudan received the attention of farmers. They were attracted to this system because of its low cost and ease of installation, especially for low-income smallholder farmers. The locally produced drip and furrow irrigation systems may help local smallholder farmers due to their affordability. These systems had high water use efficiency because plants were supplied with a precise amount of water. Water applications were made directly to the root zone for the drip system and through the furrow for the furrow system. Non-beneficial use of water was reduced to the minimum.

The benefits of drip irrigation systems can be maximized when they are appropriately designed, managed, and maintained. Farmers should be provided the consultancy services to properly develop a drip irrigation system since the drip design is complex. The manuals produced by different manufacturers on different design factors may also help farmers to ensure properly designed drip irrigation systems.

The establishment of agriculture extension services for the farmers should be one of the priorities for the government and stakeholders. Local vegetable-growing farmers should be trained on modern irrigation methods such as drip and sprinkler irrigation systems. The state and national governments concerned with agriculture development should provide seeds and loans to the vegetable growers to improve their crop production and cultivation of crops during the dry period.

03 CHARACTERIZATION OF SALINE SOILS IN ETHIOPIA AND SOUTH SUDAN

3.1 Extent and causes of salt-affected soils in Ethiopia

The arid and semi-arid agro-ecologies, which account for nearly 50% of Ethiopia's land area, are considered marginal crop production environments mainly due to soil and water salinity. Low annual rainfall and high temperatures have resulted in excessive water evaporation rates, contributing to high concentrations of soluble salts in these lowland areas. About 11 million hectares (Mha) are potentially susceptible to salinity problems in Ethiopia. They are mainly concentrated in the Rift valley. The soils of the Melka Sedi-Amibara Plain of the Middle Awash Valley are highly saline, with ECe ranging from 16-18 dSm-1. Generally, Na+, Ca2+, Cl-, and SO42- are the dominant salts (mainly NaCl and CaSO4) contributing to the higher salinity levels in the soils. This has resulted in the degradation of natural habitats and ecosystems and threatened the productivity of irrigated lands, producing more than 40% of the total food requirement of the country.

According to the recent estimates, about 80% of Dubti/Tendaho state farm is affected by soil salinity (i.e., 27% saline, 29% saline-sodic, and 24% sodic soils). The historical trend shows that the extent of salt-affected soils has increased significantly from 1972 to 2014 due to poor irrigation practices, use of poor quality irrigation water, and lack of drainage facilities. In irrigated areas of arid and semi-arid regions, the ascending motion of capillary water is generally more significant than the descending motion. The high evapotranspiration rates facilitate the buildup of salt in soil profiles. Due to poor drainage conditions in the Middle Awash Valley of the Rift Valley System, the giant state-owned irrigated farms are also fast going out of production due to increasing soil salinity. Somali lowlands in the Wabi Shebelle River Basin and the Denakil Plains, and various other lowlands and valley bottoms throughout the country are also heavily affected by soil salinity.

The source of soluble salts in the saline soils of the Rift Valley System is weathering of Na, Ca, Mg, and K-rich igneous rocks and their primary minerals occurring in the volcanic regions of the country. These parent materials undergo severe disintegration and decomposition when exposed to natural waters. Carbonic acid forms large quantities of mobile silica, alumina, and free bicarbonate and carbonate ions of alkali and alkaline earth bases. However, salt-affected soils in Ethiopia, particularly the Awash River Basin, are more diverse and complicated. It is also estimated that the total land area covered by salt-affected soils in the former Hararghe Administrative Region (eastern region) is 1,159,300 ha, which is about 12.9% of the arable land area in the region. They have also stated that out of 4,000 ha of irrigated lands at Melka Sedi, about 40% is saline, 17% is saline-sodic, and 0.02% is sodic. Due to the prevalence of salt-affected soils at the Middle Awash, a large land area has been abandoned for cultivation. Furthermore, about 39% of the Abaya State Farm (southern regional state) are salt-affected.

The Rift Valley Zones and South-Eastern (Somali) country's lowlands are the most valuable agricultural lands as they offer vast potential for multiple cropping. Most irrigated State Farms, where export crops, i.e., cotton, sugarcane, citrus fruits, banana, and vegetables, are also located in the Rift Valley Zone. However, the lack of adequate drainage systems is converting large tracts of land to saline and saline-sodic soils annually. They have shown a considerable salt buildup in the soils of the lower Wabi Shebelle basin of Gode (Somali Region), where small-scale irrigation systems by taking water from the Shebelle River have been introduced. This implies that the development of large-scale irrigation projects in the Wabi Shebelle and other river basins without proper drainage has resulted in the expansion of soil salinity and sodicity problems. A map of soil groups in different parts of Ethiopia is shown in Figure 8.

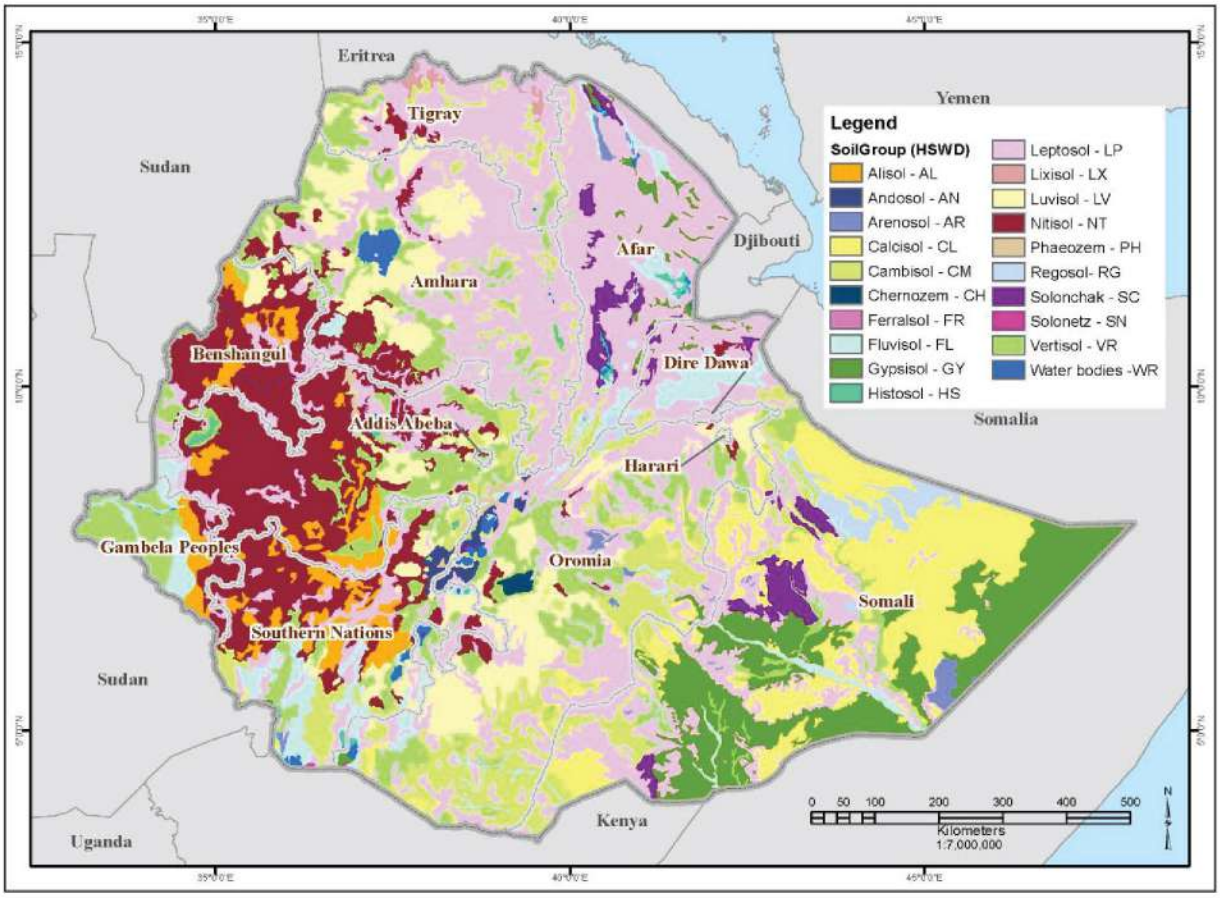


Figure 8. Soil groups in different regions of Ethiopia

Under the ICBA-led project on "Rehabilitation and management of salt-affected soils to improve agricultural productivity (RAMSAP)", the spatial variability of soil salinity (ECe) for the four target regions was assessed using the geo-statistical technique. The soil survey data was used to characterize and develop surface salinity (0-30cm) maps for Afar, Oromia, Amhara, and Tigray regions. The surface salinity was classified as non-saline (<2 dS m-1), low saline (2-5 dS m-1), medium saline (5-10 dS m-1), high saline (10-15 dS m-1) and extreme saline (>15 dS m-1). An optimal interpolation method, "ordinary kriging (OK)" was used to interpolate the values of non-sampled locations for producing maps. The spatial variation in (ECe) was categorized based on standard ratings for data management purposes. Universal Transverse Mercator (UTM), Zone 37N projection, and Datum of WGS_1984 were employed for map projection.

All tasks were completed using GIS software (Arc Map version 10.3). The soils of all regions were classified based on the WRB-FAO 2014 soil correlation/classification system and mapped at 1:500,000 scale at the reference group level. The data was also used to develop surface salinity (0-30cm) maps for Amhara, Oromia, Afar, and Tigray regions. The characterization of saline soils in the four regions is discussed below.

3.1.1 Characterization of the Afar region

Sixteen Reference Soil Groups (RSGs) were identified for the Afar region, covering 82% of the area (Table 7). The major RSGs include Leptosols (30.68%), Cambisols (11.43%), whereas Fluvisols (8.15), Solonchaks (7.08%), Regosols (7.02%), Arensosols (5.25%), Vertisols (4.65%), Gypsisols (2.96%), Solonetz (2.62%), and Calcisols (2.28%) are minor groups. The dominant soil types and their locations are shown in Figure 9.

Table 7. Area covered by different RSGs in the Afar region

No.	Soil Types	Area		No.	Soil Types	Area	
		Km^2	%			Km^2	%
1	Leptosols	29,821	30.68	9	Gypsisols	2,882	2.96
2	Rockoutcrop/Lava	14,541	14.96	10	Solonetz	2,544	2.62
3	Cambisols	11,108	11.43	11	Calcisols	2,221	2.28
4	Fluvisols	7,870	8.10	12	Luvisols	1,670	1.72
5	Solonchaks	6,882	7.08	13	Durisols	699	0.72
6	Regosols	6,829	7.02	14	Andosols	362	0.37
7	Arenosols	5,108	5.25	15	Water Body	143	0.15
8	Vertisols	4,523	4.65	16	Acrisols	2.38	0.002
					Total	97,205	100

The results indicate that the ECe of the surface soils (0-30 cm) ranges from non-saline (<2 dSm-1) to extremely saline (>15 dSm-1). In the Afar region, 58% of the soils are affected by different salinity levels (Table 8). Low and medium surface soil salinity classes cover 38% of the area and are found in the region's central and southern parts. High and highly saline surface salinity levels cover 20% of the region and spatially cover the north-eastern part of the Region (Figure 10). The severity and spatial coverage of sub-surface soil salinity are presumed to be higher than the upper 30 cm soil layer. Therefore, it is recommended to conduct deep soil profile salinity analysis to properly select salt-tolerant species for these regions.

Table 8. Distribution of surface (0-30 cm) soil salinity levels in the Afar region

Soil salinity Levels	Area	
	km^2	%
Non-saline/Waterbody/Rockoutcrop (<2 dS m^{-1})	40,787	42
Low saline (2-5 dS m^{-1})	26,916	28
Medium saline (5-10 dS m^{-1})	9,798	10
High saline (10-15 dS m^{-1})	5,618	5
Extremely saline (>15 dS m^{-1})	14,085	15
Total	97,204	100

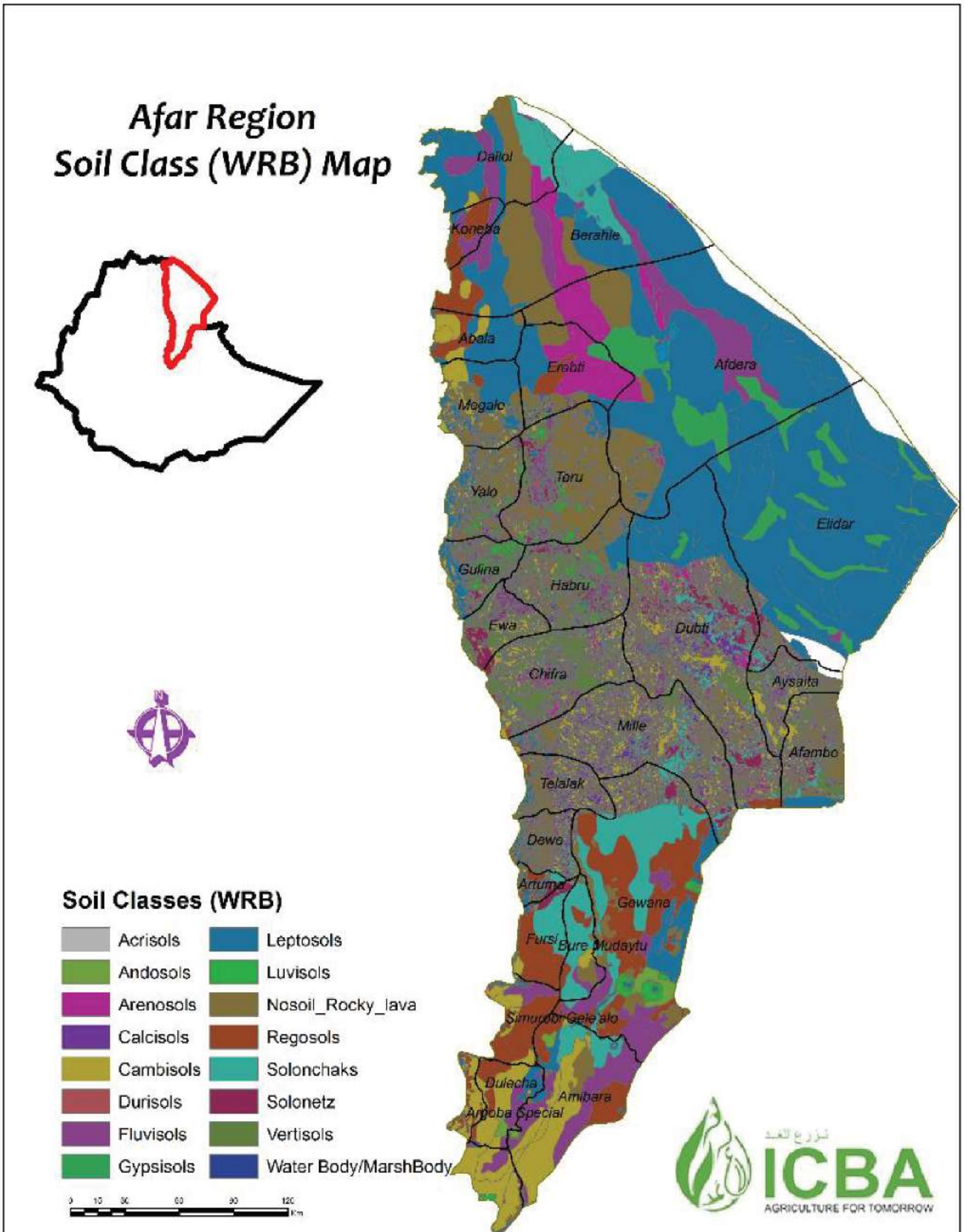


Figure 9. Distribution of surface (0-30 cm) soil salinity levels in the Afar region

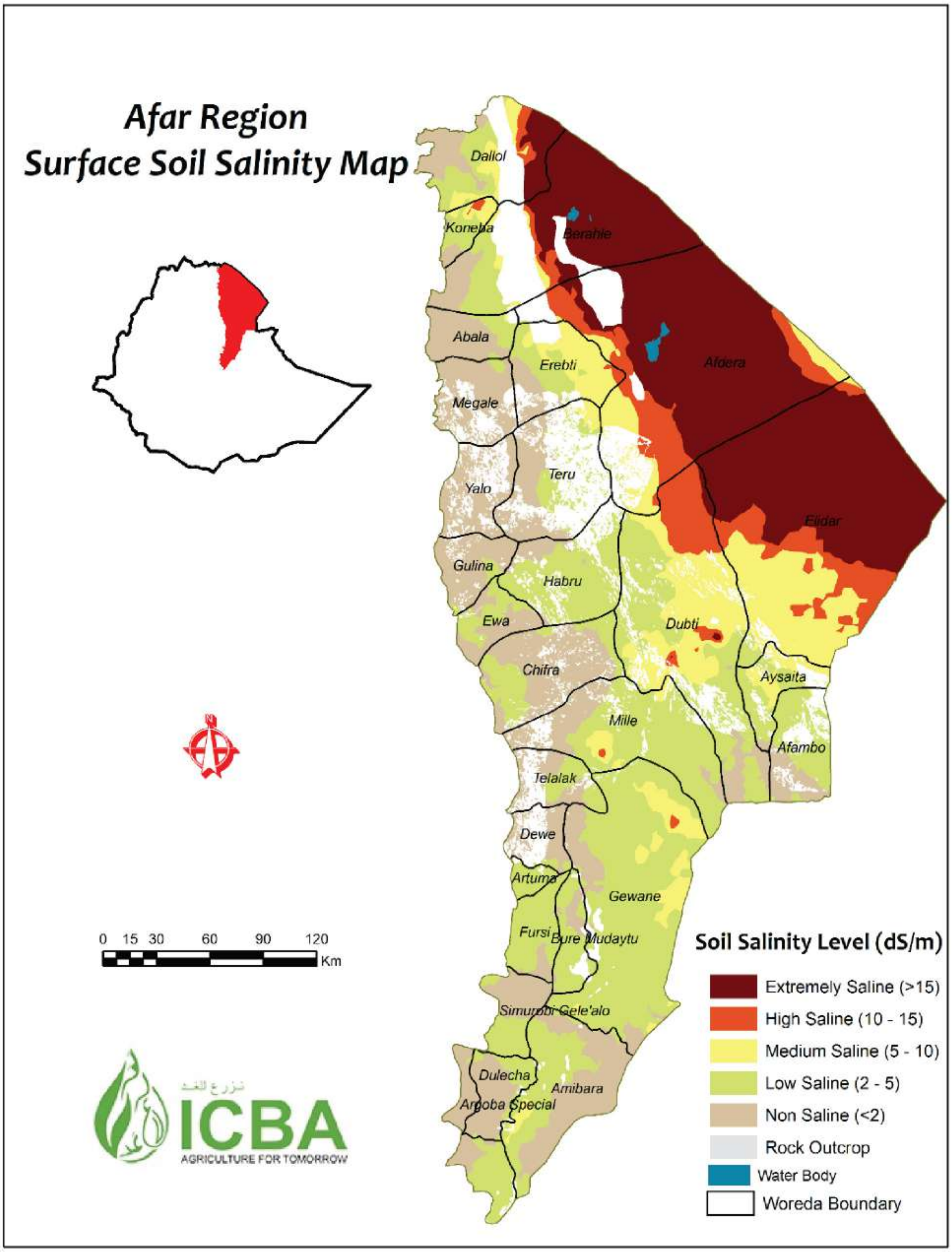


Figure 10. Surface salinity map of the Afar region

3.1.2 Characterization of the Amhara region

Eighteen Reference Soil Groups (RSG) have been identified in the Amhara region, covering 96.6% of the area. The area covered by each RGS is shown in Table 9. Leptosols (38.2%) are dominant in the region, followed by vertisols, cambisols, and luvisols.

Table 9. Area covered by different RSGs in the Amhara region

No.	Soil Types	Area		No.	Soil Types	Area	
		Km²	%			Km²	%
1	Leptosols	59,635	38.32	10	Fluvisols	908	0.58
2	Vertisols	30,444	19.56	11	Arenosols	472	0.30
3	Cambisols	18,258	11.73	12	Acrisols	431	0.28
4	Luvisols	15,972	10.26	13	Andosols	223	0.14
5	Alisols	12,320	7.92	14	Umbrisols	38	0.02
6	Regosols	5,926	3.81	15	Solonetz	36	0.02
7	Calcisols	4,068	2.61	16	Lava/Rock	34	0.02
8	Nitisols	3,683	2.37	17	Chernozems	8.	0.01
9	Water Body	3,180	2.04	18	Gleysols	0.9	0.0006
				19	Phaeozems	0.4	0.0003
					Total	155,638	100

The surface soil salinity (0-30 cm) in the Amhara region ranges from non-saline (<2 dS m-1) to extremely saline (>15 dS m-1). About 12% of the soils are saline to various degrees. Low and medium surface salinity classes cover 11% of the region and are found in the central, south, south-west, and eastern part of the region. High and extreme soil salinity levels cover only 1% of the region and spatially cover the south and south-eastern part of the Region (Figure 11). Table 10 shows the surface salinity in the top 0-30 cm depth. The surface salinity map of the Amhara region is shown in Figure 12.

Table 10. Distribution of surface soil salinity (0-30cm) in the Amhara region

Soil salinity levels	Area	
	km²	%
Non-saline/Waterbody/Rockoutcrop (<2)	137,428	88
Low saline (2-5 dS m^{-1})	4,903	3
Medium saline (5-10 dS m^{-1})	11,892	8
High saline (10-15 dS m^{-1})	1,230	0.8
Extremely saline (>15 dS m^{-1})	202	0.2
Total	155,648	100

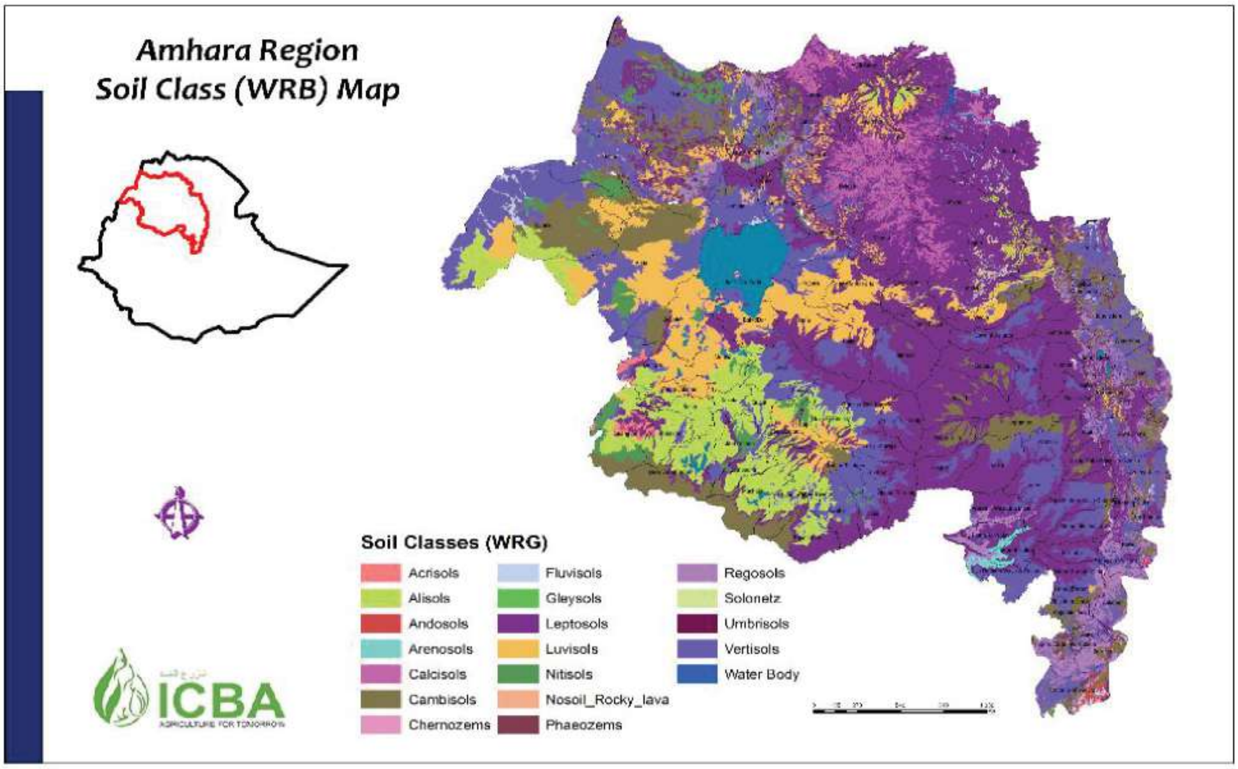


Figure 11. Dominant RSGs in the Amhara region

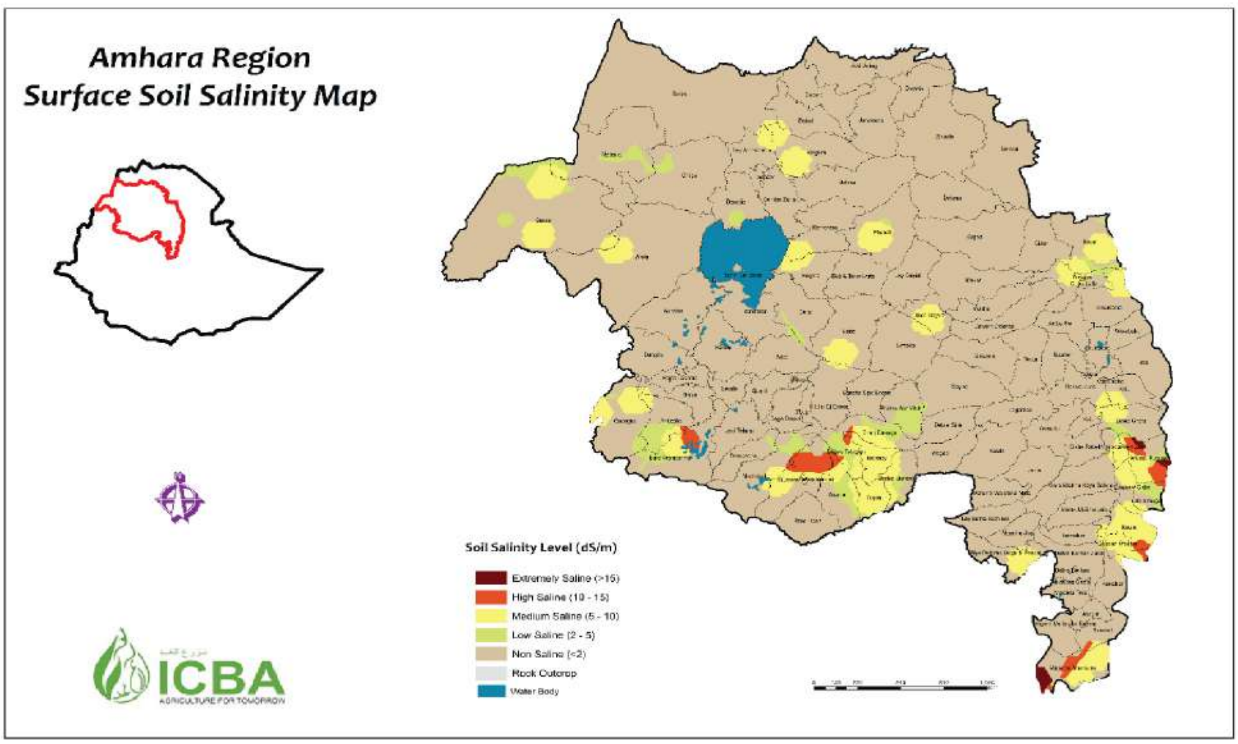


Figure 12. Surface salinity maps of the Amhara region

3.1.3 Characterization of the Oromia region

Fourteen Reference Soil Groups (RSG) have been identified in the Oromia region, covering about 96.55% of the area (Table 11; Figure 13). The soil surface salinity (0-30 cm) in the Mahara region ranges from none-saline (<2 dSm-1) to extremely saline (>15 dS m-1). It is estimated that 11.33% of the soils in the region are affected by salinity (Table 12). Low (5.33%) and medium (5.29%) salinity soils cover 10.62% and are located in the central, south, central-eastern parts of the region. High and highly surface salinity soils cover only 0.71% and spatially cover the south and south-eastern part. Figure 14 shows surface soil salinity (0-30 cm depth) in the Oromia region.

Table 11. Area covered by each RGS in the Oromia region

No.	Soil Types	Area		No.	Soil Types	Area	
		Km^2	%			Km^2	%
1	Cambisols	68,891	21.23	13	Regosols	2,388	0.74
2	Leptosols	51,113	15.75	14	Solonchaks	1,854	0.57
3	Nitisols	46,363	14.29	15	Chernozems	1,612	0.50
4	Vertisols	43,883	13.53	16	Phaeozems	1,400	0.43
5	Luvisols	36,091	11.12	17	NosoilRockylava	1,051	0.32
6	Alisols	15,508	4.78	13	Solonetz	982	0.30
7	Fluvisols	12,523	3.86	14	Gypsisols	595	0.18
8	Acrisols	9,504	2.93	15	Planosols	576	0.18
9	Lixisols	6,184	1.91	16	Water Body	456	0.14
10	Calcisols	5,649	1.74	17	Plinthosols	192	0.06
11	Gleysols	5,379	1.66	18	Lake	79	0.02
12	Andosols	5,319	1.64				
					Total	324,429	100

Table 12. Distribution of surface (0-30cm) soil salinity in the Oromia Region

Soil salinity levels	Area	
	km^2	%
Non-saline/Waterbody/Rock out crop (<2 dSm^{-1})	28,7768.25	88.70
Low saline (2-5 dS m-1)	17,292.05	5.33
Medium saline (5-10 dS m-1)	17,152.54	5.29
High saline (10-15 dS m-1)	1,576.72	0.49
Extremely saline (>15 dS m-1)	713.74	0.22
Total	324,428.69	100

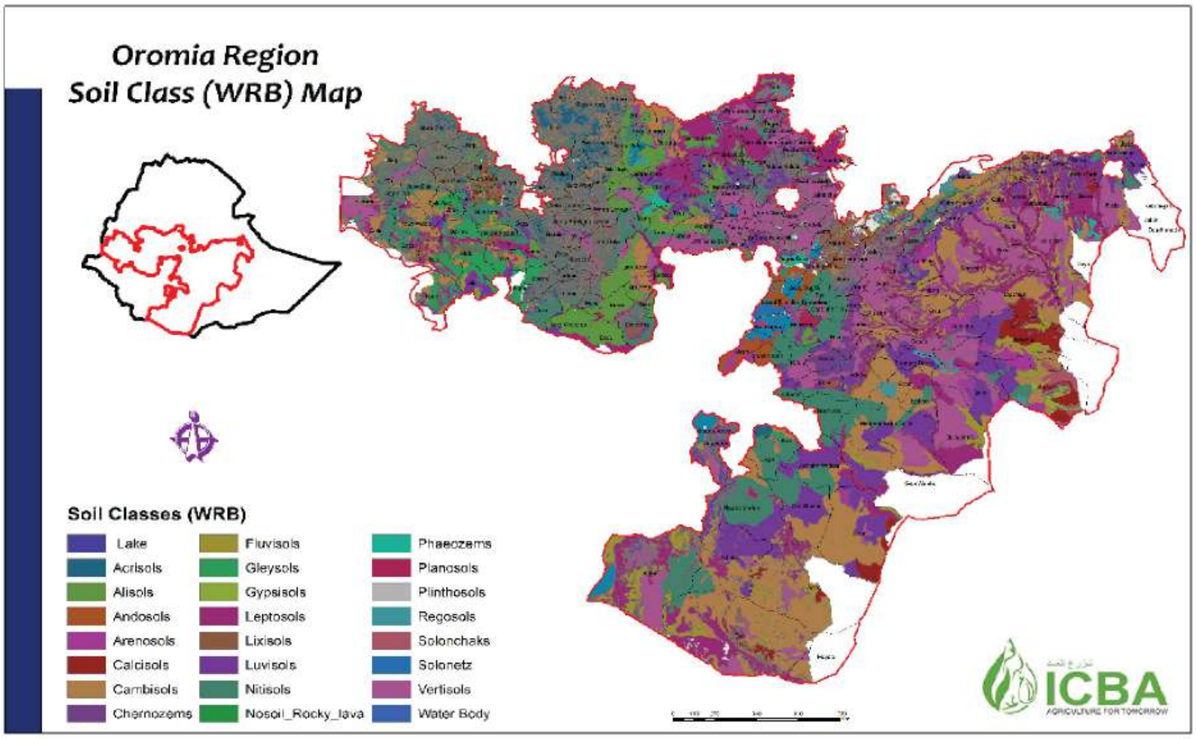


Figure 13. Soil group types in the Oromia region.

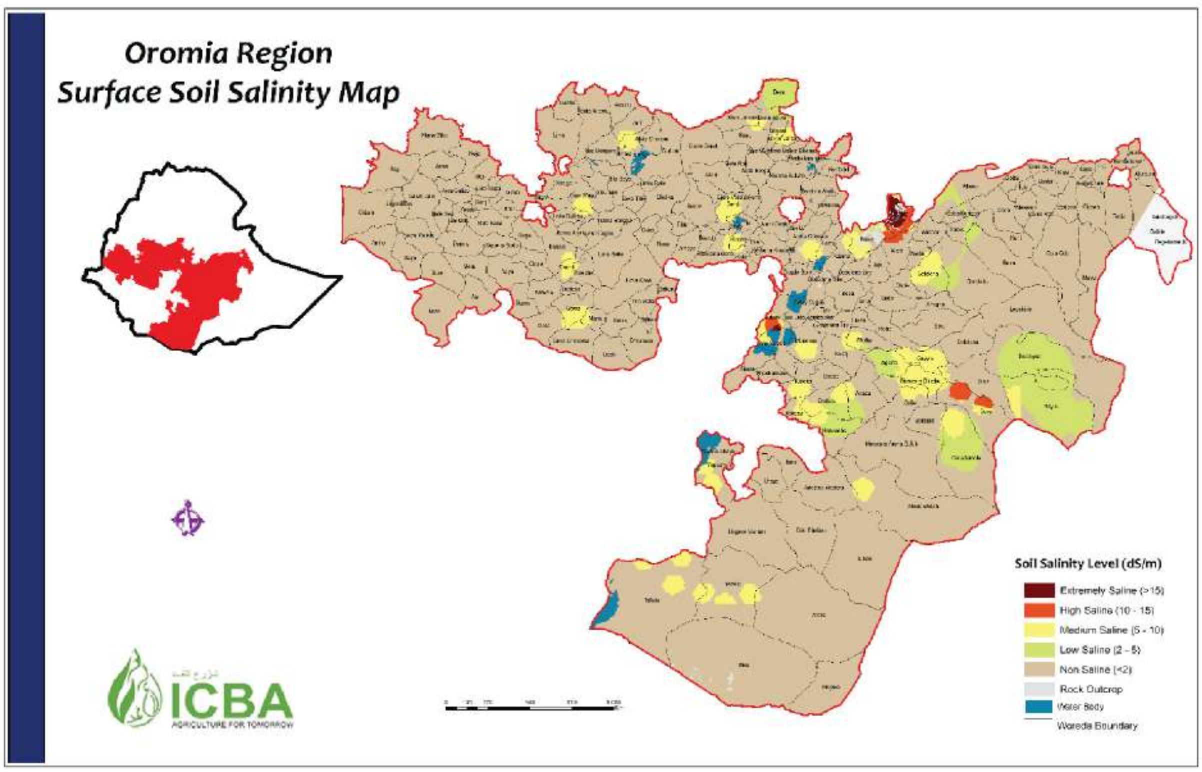


Figure 14. Surface soil salinity (0-30 cm) map of the Oromia region

3.1.4 Characterization of the Oromia region

Eleven Reference Soil Groups (RSG) were identified for the Tigray region covering about 94% of the area. The major groups are leptosols, cambisols, and vertisols (Table 13; Figure 15). The results indicate that ECe of the surface soils (0-30 cm) ranges from none-saline (< 2 dS m-1) to extremely saline (>15 dS m-1). It is estimated that 2.71% of soils of the region are medium saline (Table 14). These soils are located in the central, south, south-west, and eastern part of the region.

Figure 16 shows the Tigray region's surface soil salinity classes (0-30 cm). The salinity of the deeper layers may be higher due to variation in soil properties. Therefore, it is suggested to do a detailed subsurface salinity analysis before offering the most-suited cropping systems for these areas.

Table 13. Area covered by each RGS in the Tigray region

No.	Soil Types	Area		No.	Soil Types	Area	
		Km^2	%			Km^2	%
1	Leptosols	28,490	58	8	Calcisols	422	0.85
2	Cambisols	9,307	19	9	Fluvisols	67	0.14
3	Vertisols	7,120	14	10	Regosols	47	0.10
4	Luvisols	1,673	3	11	Rocky Surface	44	0.09
5	Alisols	980	2	12	Nitisols	34	0.07
6	Arenosols	626	1	13	WaterBody/MarshLand	23	0.04
7	Lixisols	572	1				
					Total	49,406	100.00

Table 14. Distribution of surface (0-30) soil salinity in the Tigray region

Soil Salinity Levels	Area	
	km^2	%
Non-saline/Waterbody/Rockoutcrop (<2)	48,067	97.29
Low Saline (2-5)	0	0
Medium saline (5-10)	1339	2.71
High saline (10-15)	0	0
Extremely saline (>15)	0	0
Total	49,406	100

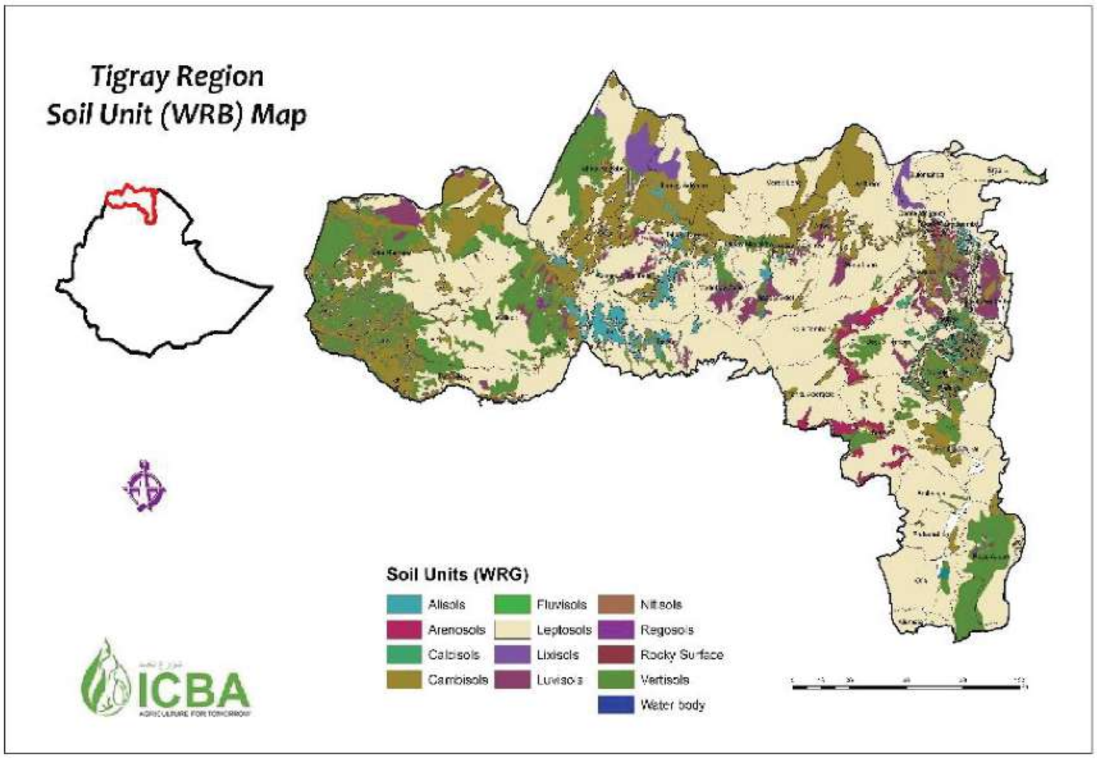


Figure 15. Soil groups types in the Tigray region.

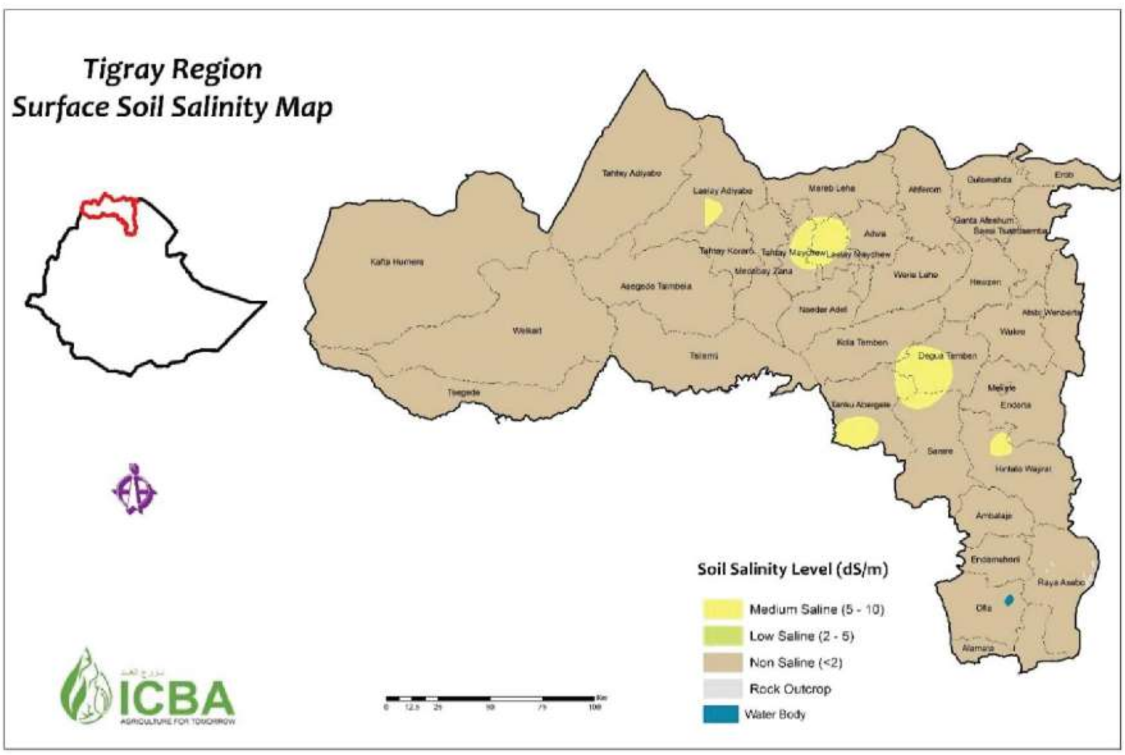


Figure 16. Surface soil salinity (0-30 cm) map of the Tigray region.

3.1.5 Regional analysis of soil salinity in Ethiopia using remote sensing technique

In addition to the soil salinity analysis of field data collected from different sample points, remote sensing images were used to classify salt-affected soils in different regions and the country. The maps generated for this task were produced using solely Landsat-8 images of 2017 courtesy of the U.S. Geological Survey. A total of 49 imagery were selected in December 2017: Afar, nine images, Amhara 11, Tigray 6, and Oromia 23 images. The images were stored and preprocessed to calculate the reflectance values at ground level then the commercial ATCOR software was used to correct ground reflectance by removing atmospheric effects. Hence, it is possible to merge the satellite imagery acquired on various dates under different atmospheric conditions and standardize the physical value of ground reflectance.

The used workflow generated reflectance images at ground level, corrected from atmospheric effect (e.g., aerosol type and water vapor) and terrain effects. Once atmospheric correction was done and the integrity of radiometric value preserved, a mosaicking phase followed to join for each region (Afar, Amhara, Oromia, and Tigray) the overlapping images to form a single, uniform image; an ortho-mosaic. The latter was adjusted and cut using administrative boundaries of each region to keep only valuable data within the borders. A semi-empirical salinity model was used to develop salinity maps. This model uses the Soil Salinity and Sodicity Index 2. The model relies on Short Wave Infrared spectral bands and is sensitive essentially to surface salinity and sodicity in various soil types and conditions. Due to the limited number, space coverage, and time, the available EC (dS/m) and experts' opinions were used to classify salinity levels. These are only qualitative estimates based on the ground-truthing of scarce historical data.

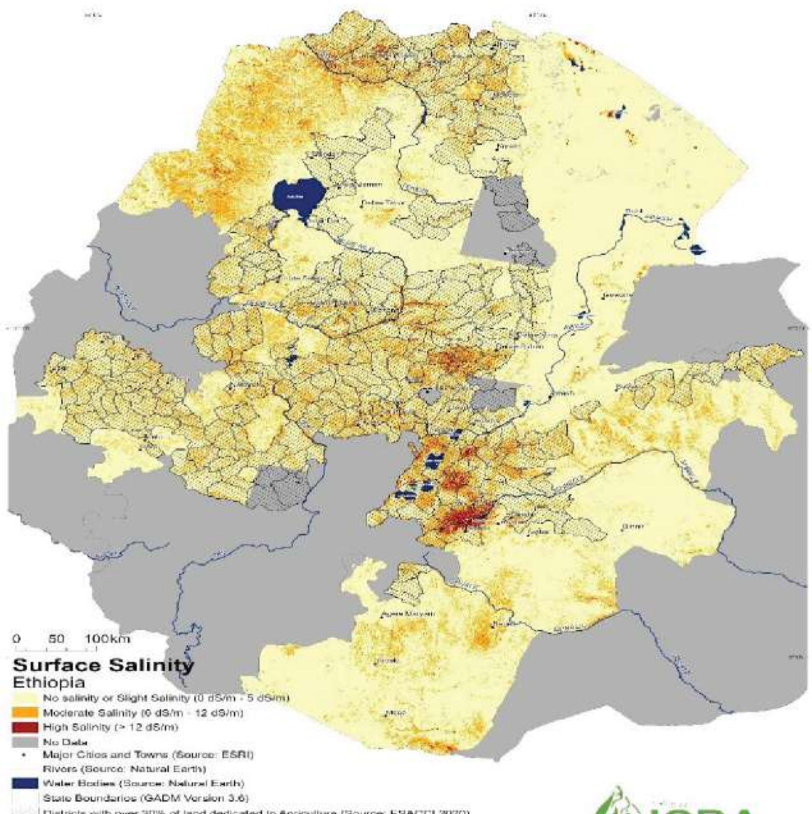


Figure 17. Surface soil salinity map for Ethiopia

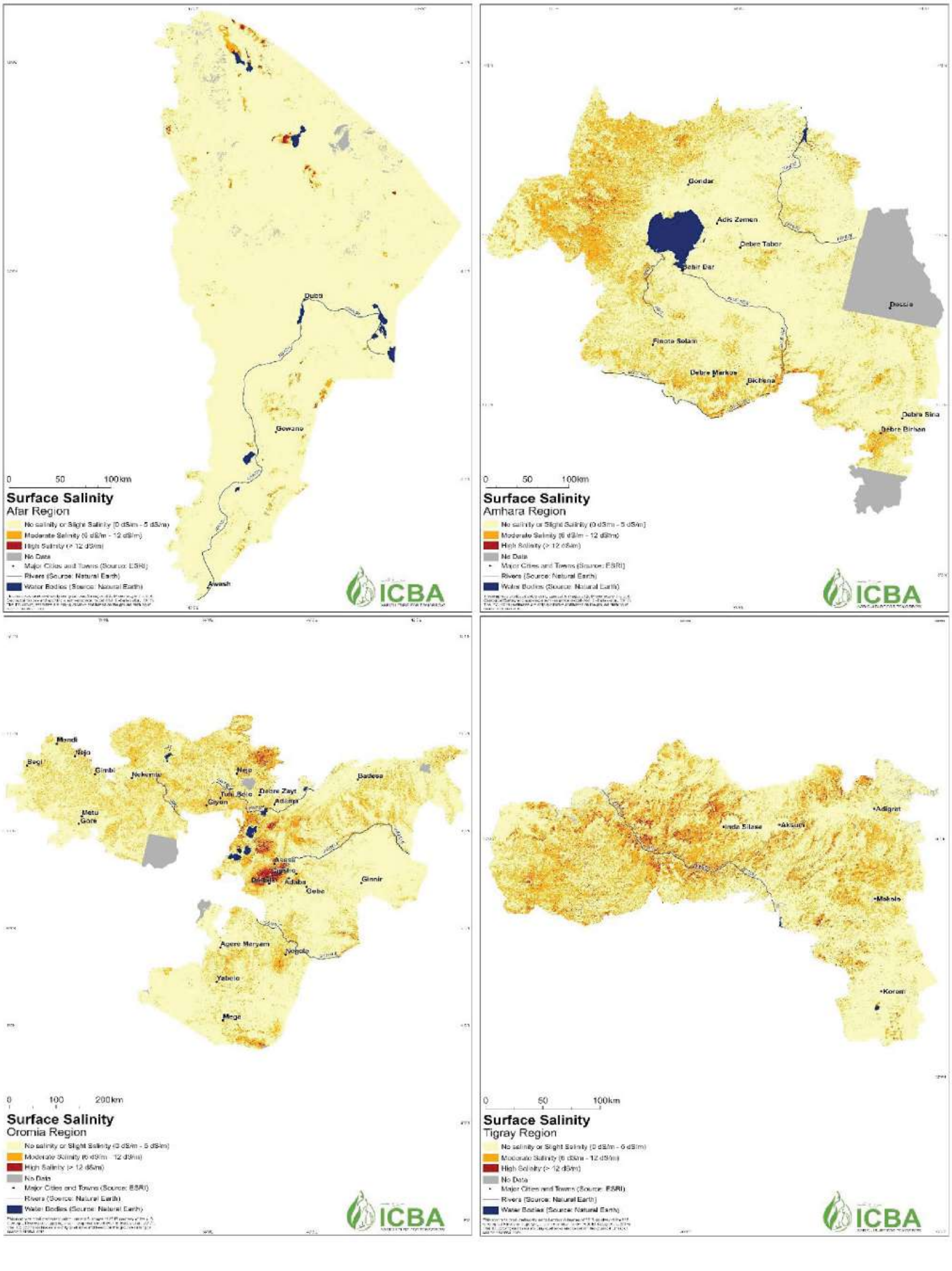


Figure 18. Surface soil salinity maps for the four regions of Ethiopia

3.2 Extent and nature of salt-affected soils in South Sudan

Three hundred seventy-five composite auger samples were collected from the nine targeted areas in South Sudan. These samples were marked with the farmer's name and coordinates collected with the help of GPS. The soil samples were collected at three depths, i.e., 0-30, 30-60, and 60-90 cm, and analyzed for PH, EC, Na, Ca, Mg, K, and H. The soil samples were analyzed in Uganda as there was no capacity in South Sudan to tackle this enormous task. Five researchers and field staff were specially trained to collect soil and samples. The samples were collected and preserved using standard protocols. The preliminary soil investigations include site observation, variations in Physiography, land use, and visually observable soil features (drainage condition, salt crust at soil surface, soil texture, and others).

The results of soil sample analysis from different locations were used to generate GIS maps. The results show that soil texture at these locations is silt loam (SL), silty clay loam (SCL), and clay loam (Cl). The average profile salinity at all areas (ECe = µS/cm) is shallow at all depths, which shows that these soils are not saline. However, due to clay, they have workability and permeability problems. The Ca, Mg, and Na values are low, reducing any chances of sodicity in these soils. The data were also obtained from different sources to perform quantitative and qualitative analyses of soil quality in the selected areas of South Sudan. Data acquired and processing techniques are briefly discussed below:

Land Use and Land Cover (LULC)

The Land Use and Land Cover (LULC) data were obtained from the Climate Change Initiative (CCI) and Land Cover (LC) teams for Africa. It is a high-resolution data at 20 m according to sentinel-2A observations. World Geodetic System 84 (WGS84) reference ellipsoid was the coordinate used. LULC was classified into ten classes. These include cropland; trees cover areas, grassland, shrubs cover areas, built-up areas, vegetation aquatic or regularly flooded, bare areas, open water, lichen, and mosses/sparse vegetation, and snow and ice. Nine classes were captured except for snow and ice land cover.

Analysis of historical precipitation data

Sixty years of precipitation data (1958-2018) of each selected site were processed. The precipitation data was obtained with the help of TEERA high-resolution precipitation maps. It was processed with the use of ArcGIS 10.7.1 through special analysis tools. Data were obtained from the Climate Research Unit (CRU) and the Japanese 55-year Reanalysis (JRA-55) to generate monthly wind speed values, vapor pressure, precipitation, maximum and minimum temperature, and solar radiation. The spatial-temporal outputs of TerraClimate were validated using data on annual temperature, rain, and estimated reference evapotranspiration from ground stations, in addition to yearly runoff data from flow stream gauges. Their findings revealed that TerraClimate datasets indicated significant improvement in overall temperature and precipitation mean of poor correlations about p= 0.8 and 0.90, respectively. Therefore, the TerraClimate dataset is recommended as inputs for ecological and hydrological research at global levels that need high spatial resolution and time series climate and water balance data.

3.2.1 Analysis of water samples

Water samples from different sources were collected from several locations in the five target areas. The analysis of water samples shows that the pH and EC values are low in most of the sites (Table 15). This indicates that agricultural productivity can be significantly enhanced by improving the farmers' accessibility to water and introducing innovative on-farm water management strategies.

Table 15. Results of water samples from different locations in five regions

Region	Locations	pH			EC (µS/cm)		
		Min	Max	Avg.	Min	Max	Avg.
Renk	Awolai stagnant water	6.0	6.1	6.0	10.3	110.7	107.0
	Gozrum stagnant water	6.6	6.8	6.7	99.8	109.9	103.8
	Payuer Tap water	6.8	6.8	6.8	101.2	107.1	103.3
	Payuer stagnant water	7.1	7.7	7.4	100	100.1	100.0
Bor	Panaper borehole 1	8.4	8.5	8.5	192.3	199	195.1
	River Nile	7.6	7.9	7.7	109.9	196.2	167.1
	Tibek borehole	7.1	8.0	7.6	185.0	193.0	190.2
	Panaula 1 borehole	7.3	7.8	7.6	110.1	110.9	110.8
Aweil	B15A	6.7	7.3	7.1	183.5	188.5	186.1
	Rice scheme 1	7.2	7.6	7.4	88.1	99.6	92.5
	Nyalth borehole 1	7.0	7.2	7.1	124.3	127.4	126.1
	Kuom river	7.9	8.2	8.0	110.0	199.9	142.1
Jubek	Kurrola river	7.3	7.5	7.4	103.7	125.5	112.8
	Rajaf East Tokiman borehole	7.3	7.5	7.4	102.0	118.0	110.0
	Rajaf East Mogoro borehole	7.3	7.5	7.4	170.8	181.3	176.1
	Luri river	6.8	6.9	6.8	100.9	109.9	106.9
	Khor William	7.6	7.6	7.6	102.7	110.0	107.5
Kapoeta	Hai Tarawa borehole	7.0	7.3	7.2	183.6	191.4	188.4
	Nalingoro	7.0	7.2	7.1	100.0	110.0	106.3
	Rie North William borehole	7.0	7.5	7.3	103.2	113.5	108.9
	Rie North school borehole	6.9	7.2	7.1	101.1	110.1	105.0
	Palakan Joseph Laguwe borehole	7.1	7.6	7.3	100.1	120.0	109.7
	Morongora borehole	7.1	7.5	7.3	100.0	120.3	107.2
	Napecheke	7.5	7.7	7.6	102.9	110.0	107.6

The soil salinity mapping results at nine selected South Sudan locations are presented below.

3.2.2 Aweil filed site

Table 16 shows that trees cover more than 70% of the area, whereas 17.46% is occupied by grassland and 9.39% by shrubs. The area covered by crops is marginal (2.65%). The spatial distribution of vegetation classes is given in Figure 19. Map related to soil salinity is shown in Figure 20.

Table 16. Land use and land cover data for Aweil field site.

No.	Vegetation classes	Area (km^2)	Percentage (%)
1	Tree cover areas	14,747	70.30
2	Shrubs cover areas	1969	9.39
3	Grassland	3662	17.46
4	Cropland	555	2.65
5	Vegetation aquatic or regularly flooded	18.0	0.09
6	Lichens Mosses / Sparse vegetation	0.0	0.00
7	Bare and built areas	5.0	0.02
8	Open Water	22.0	0.10
Total Area		**20,978**	**100**

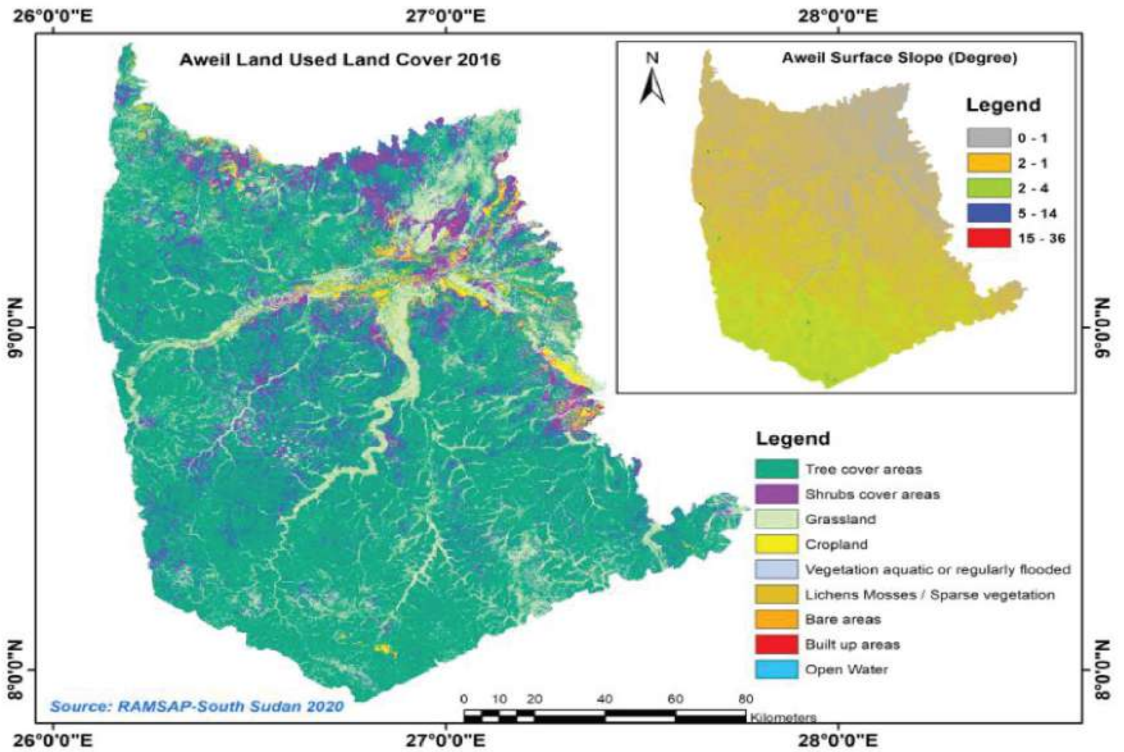


Figure 19. Land use and land cover map for the Aweil field site.

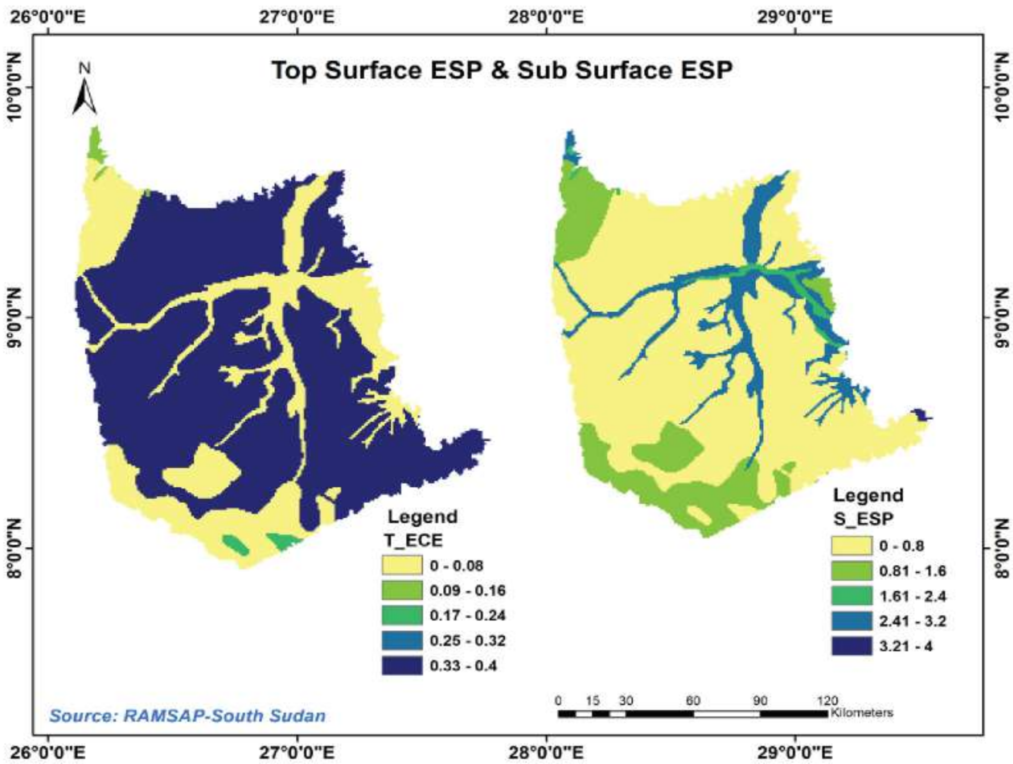


Figure 20. ECe of top-soil and ESP of sub-surface soil in Aweil field site.

3.2.3 Bor field site

Table 17 shows that 44.29% area is under grass while 31.78% and 19.48% are covered by shrubs and trees, respectively. The area covered by crops is marginal (3.89%). The spatial distribution of vegetation classes is given in Figure 21. Map related to soil salinity is shown in Figure 22.

Table 17. Land use and land cover data for Bor field site

No.	Vegetation classes	Area (km^2)	Percentage (%)
1	Tree cover areas	2431	19.48
2	Shrubs cover areas	3966	31.78
3	Grassland	5527	44.29
4	Cropland	485	3.89
5	Vegetation aquatic or regularly flooded	10	0.08
6	Lichens Mosses / Sparse vegetation	0	0.00
7	Bare and built areas	9	0.07
8	Open Water	51	0.41
	Total Area	**12,478**	**100**

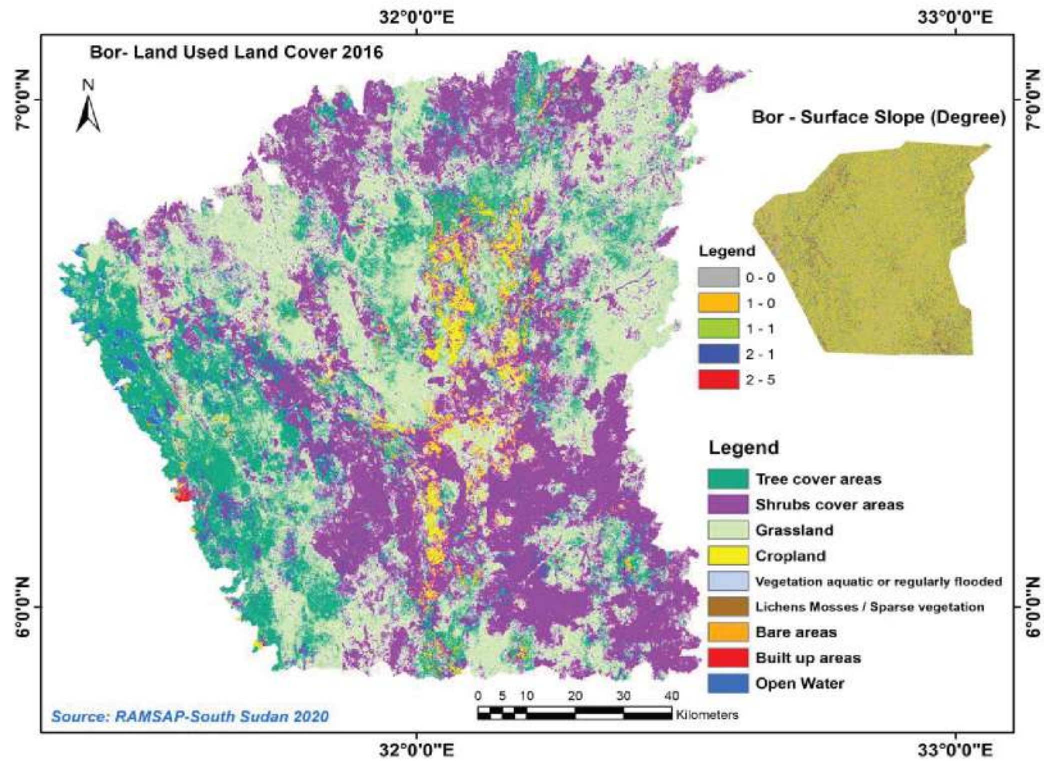


Figure 21. Land use and land cover map for the Bor field site.

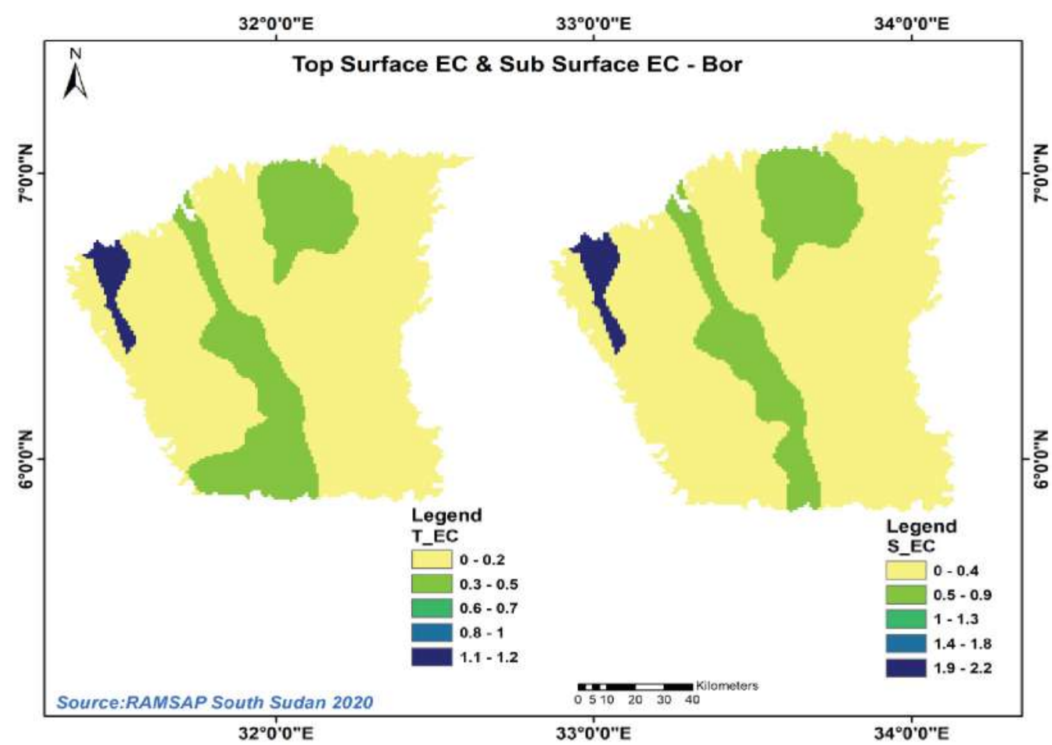


Figure 22. ECe of surface and sub-surface soils at Bor site.

3.2.4 Kapoeta field site

Table 18 shows that 50.70% area is under grassland while 29.58% and 11.56% are covered by shrubs and trees, respectively. The area covered by crops is 7.86%). The spatial distribution of vegetation classes is given in Figure 23. Map related to soil salinity is shown in Figure 24.

Table 18. Land use and land cover data for Kapoeta field site

No.	Vegetation classes	Area (km^2)	Percentage (%)
1	Tree cover areas	4520	11.56
2	Shrubs cover areas	11566	29.58
3	Grassland	19822	50.70
4	Cropland	3071	7.86
5	Vegetation aquatic or regularly flooded	11	0.03
6	Lichens Mosses / Sparse vegetation	74	0.19
7	Bare and built areas	36	0.09
8	Open Water	0	0.00
	Total Area	**39,099**	**100**

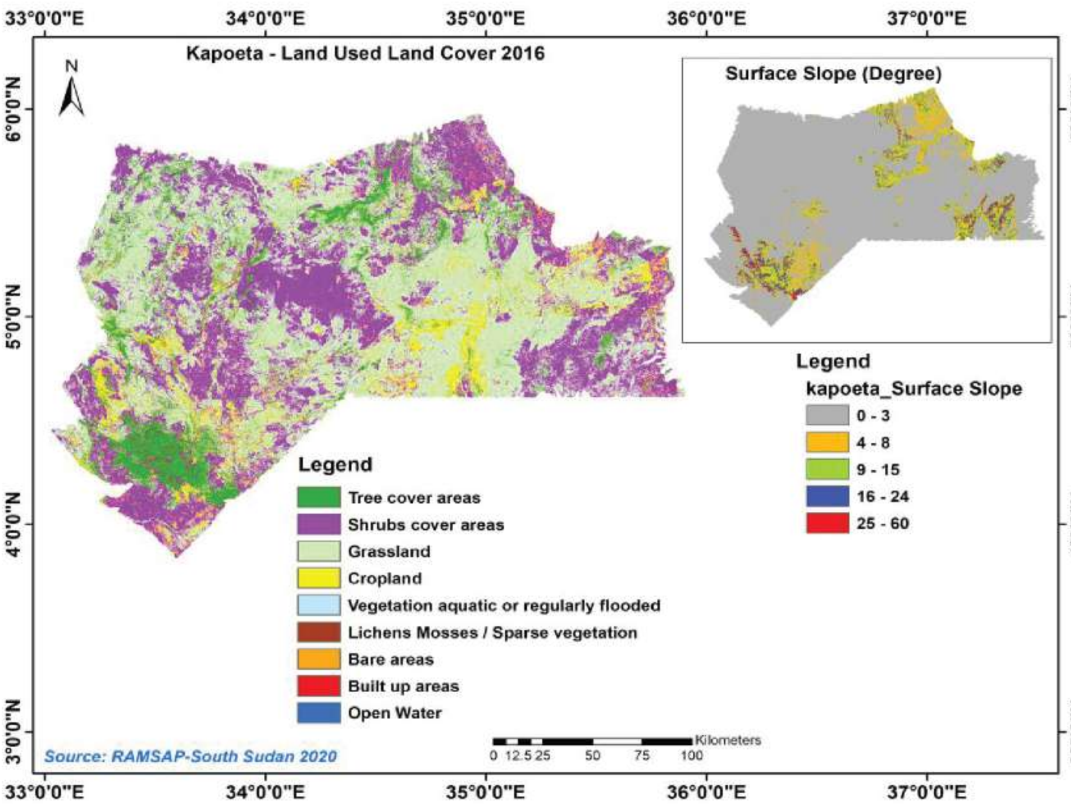


Figure 23. Land use and land cover at the Kapoeta field site.

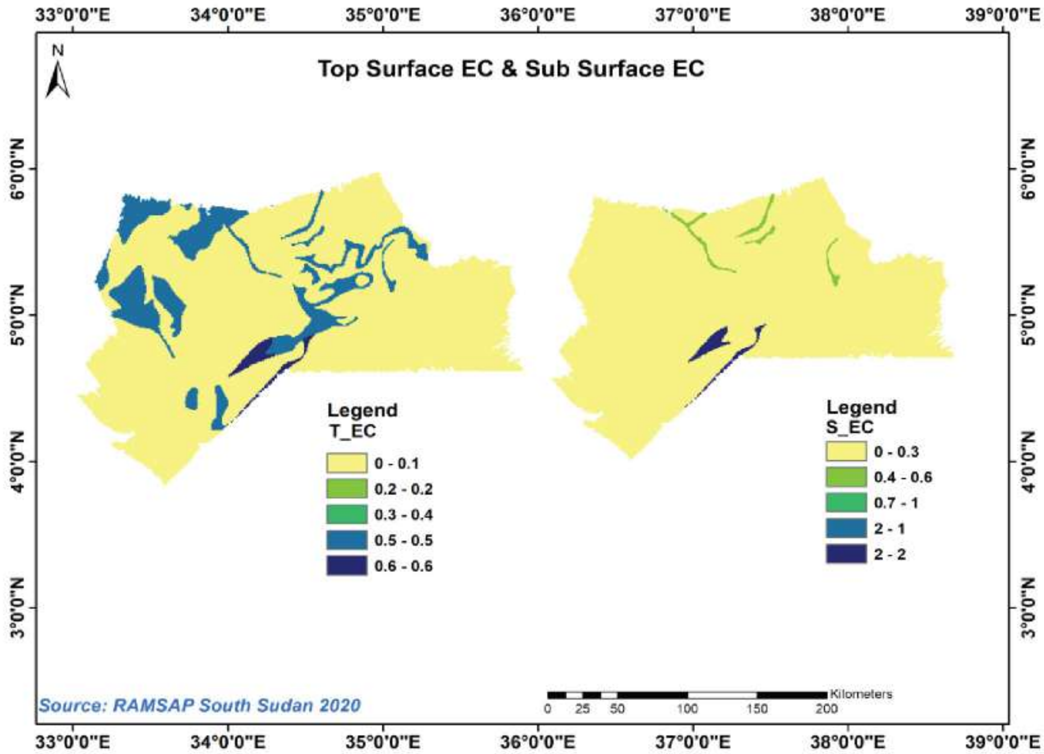


Figure 24. ECe of surface and sub-surface soils at Kapoeta field site.

3.2.5 Renk field sites

Table 19 shows that 25.66% area is under grassland while 17.65% and 13.60% are covered by shrubs and trees, respectively. The area covered by crops is 42.90%. The spatial distribution of vegetation classes is given in Figure 25. Map related to soil salinity is shown in Figure 26.

Table 19. Land use and land cover data for Renk field site.

No.	Vegetation classes	Area (km^2)	Percentage (%)
1	Tree cover areas	1239	13.60
2	Shrubs cover areas	1608	17.65
3	Grassland	2338	25.66
4	Cropland	3907	42.90
5	Vegetation aquatic or regularly flooded	11	0.12
6	Lichens Mosses / Sparse vegetation	0	0.00
7	Bare areas	4	0.05
8	Built up areas	2	0.02
9	Open Water	0	0.00
	Total Area	**9108**	**100**

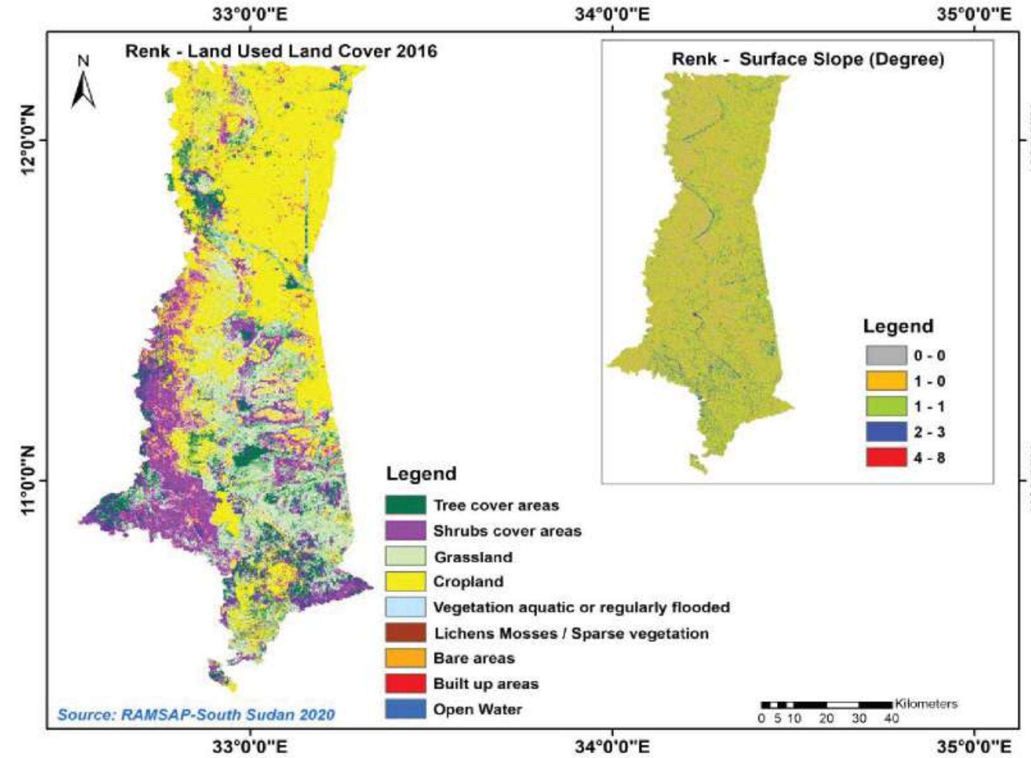


Figure 25. Land use and land cover at Renk field site.

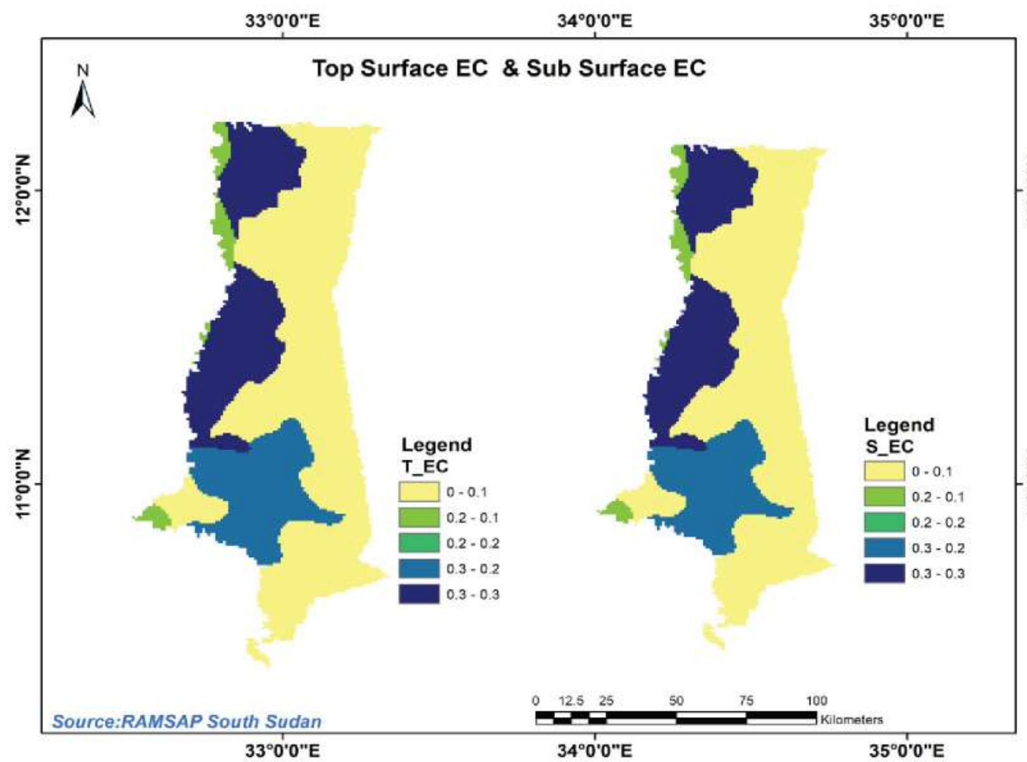


Figure 26. ECe in surface and sub-surface soils at Renk field site.

3.2.6 Torit field site

Table 20 shows that 13.77% area is under grassland while 24.66% and 58.44% are covered by shrubs and trees, respectively. The area covered by crops is marginal (3.05%). The spatial distribution of vegetation classes is given in Figure 27. Map related to soil salinity is shown in Figure 28.

Table 20. Land use and land cover data for Torit field site.

No.	Vegetation classes	Area (km²)	Percentage (%)
1	Tree cover areas	3034	58.44
2	Shrubs cover areas	1281	24.66
3	Grassland	715	13.77
4	Cropland	159	3.05
5	Vegetation aquatic or regularly flooded	0	0.00
6	Lichens Mosses / Sparse vegetation	0	0.00
7	Bare and built areas	4	0.08
8	Open Water	0	0.01
Total Area		**5192**	**100**

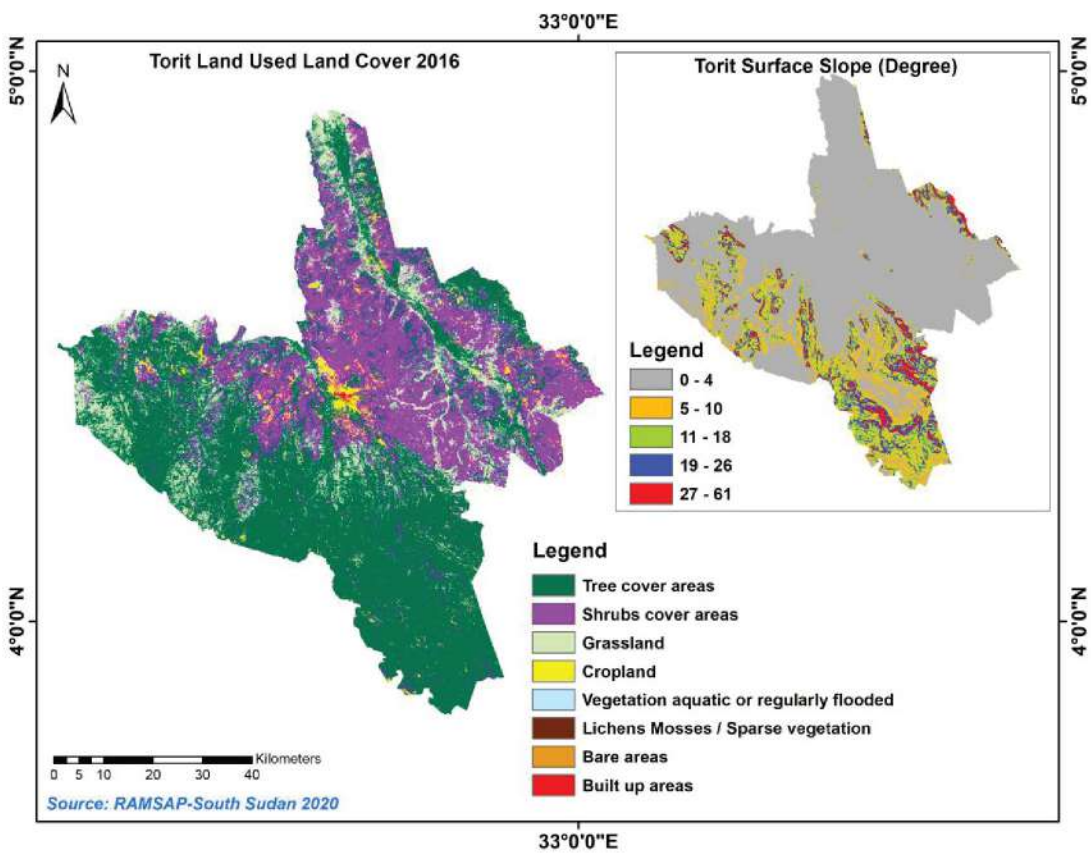


Figure 27. Land use and land cover at Torit field site

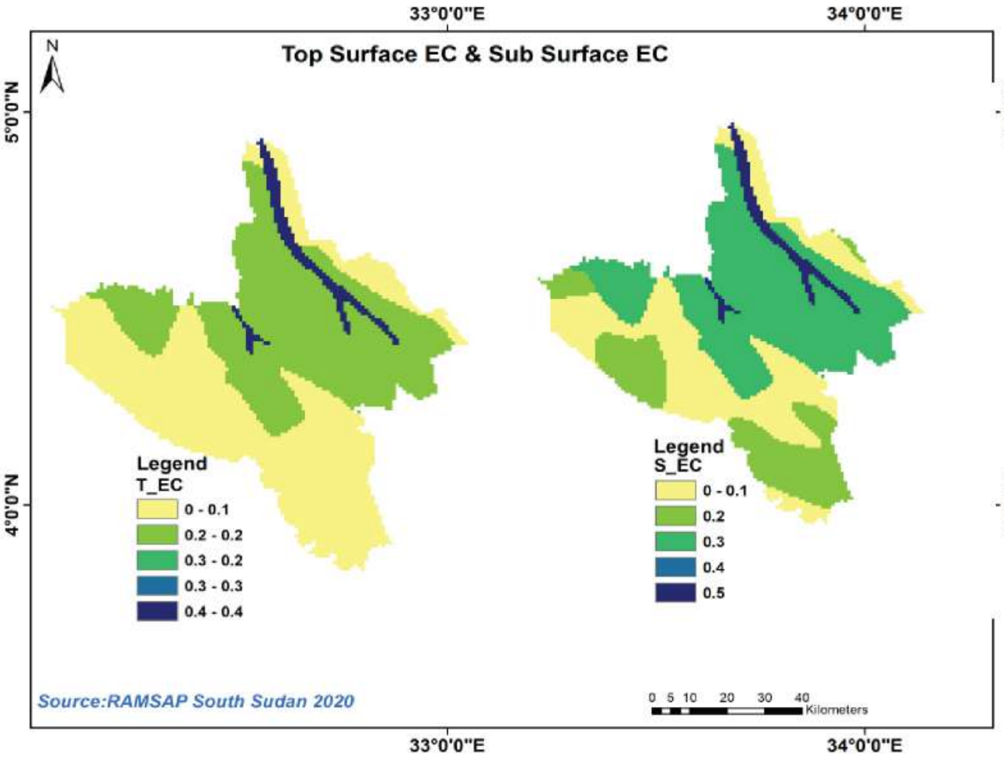


Figure 28. ECe in surface and sub-surface soil at Torit field site.

3.2.7 Wau field site

Table 21 shows that 19.50% area is under grassland while 4.47% and 75.12% are covered by shrubs and trees, respectively. The area covered by crops is almost nil (0.76%). The spatial distribution of vegetation classes is given in Figure 29. Map related to soil salinity is shown in Figure 30.

Table 21. Land use and land cover data for Wau field site

No.	Vegetation classes	Area (km^2)	Percentage (%)
1	Tree cover areas	20,578	75.12
2	Shrubs cover areas	1224	4.47
3	Grassland	5342	19.50
4	Cropland	209	0.76
5	Vegetation aquatic or regularly flooded	12	0.04
6	Lichens Mosses / Sparse vegetation	0	0.00
7	Bare and built areas	28	0.10
8	Open Water	0	0.00
Total Area		**27,393**	**100**

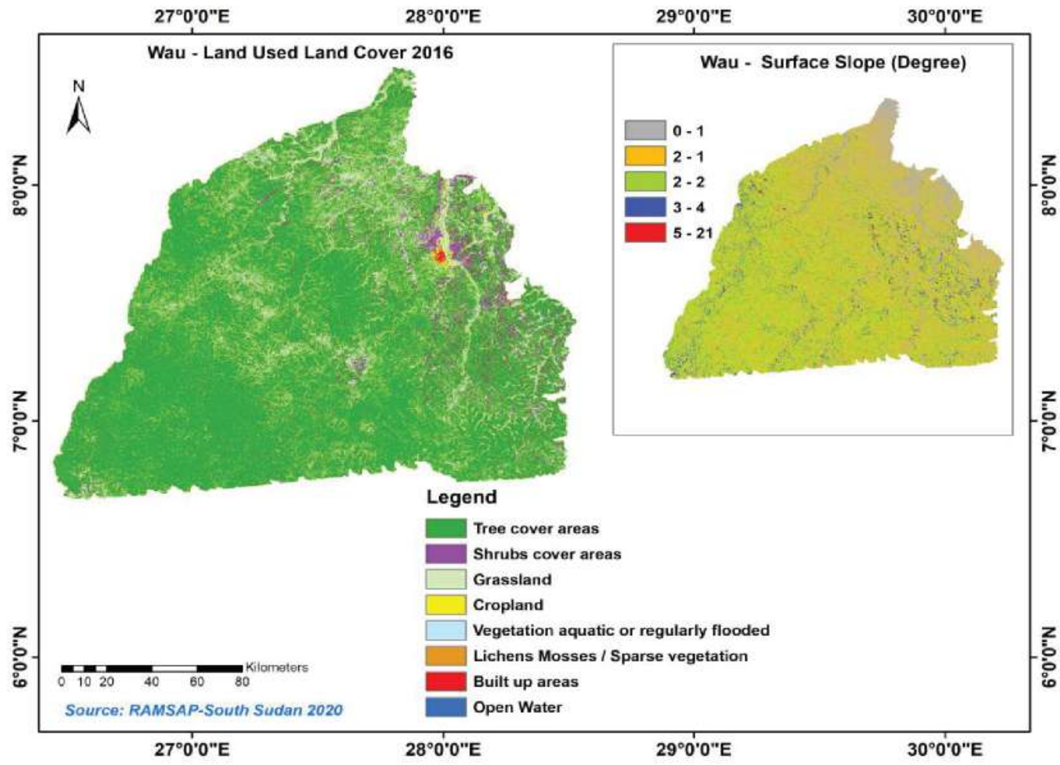


Figure 29. Land use and land cover at Wau field site.

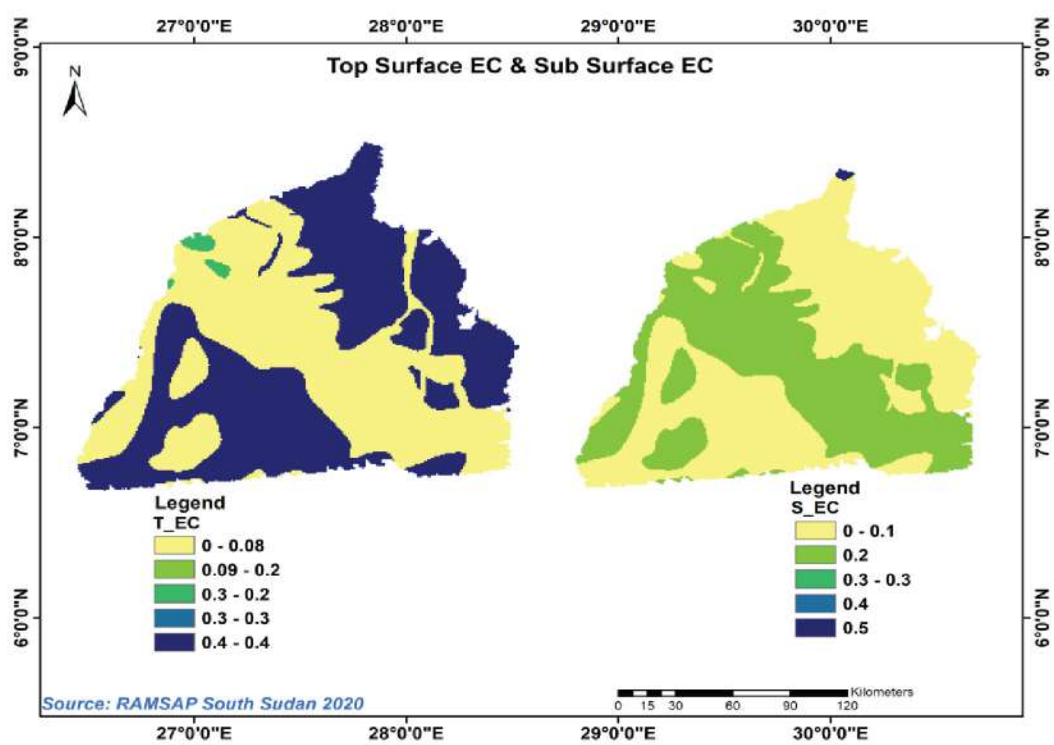


Figure 30. ECe of surface and sub-surface soil at Wau field site.

3.2.8 Yambio field site

Table 22 shows that 5.56% area is under grassland while 2.25% and 91.97% are covered by shrubs and trees, respectively. The area covered by crops is almost nil (0.76%). The spatial distribution of vegetation classes is given in Figure 31. Map related to soil salinity is shown in Figure 32.

Table 22. Land use and land cover data for Yambio field site

No.	Vegetation classes	Area (km^2)	Percentage (%)
1	Tree cover areas	7,239	91.97
2	Shrubs cover areas	177	2.25
3	Grassland	437	5.56
4	Cropland	13	0.16
5	Vegetation aquatic or regularly flooded	0	0.00
6	Lichens Mosses / Sparse vegetation	0	0.00
7	Bare areas	5	0.07
8	Open Water	0	0.00
	Total Area	**7,871**	**100**

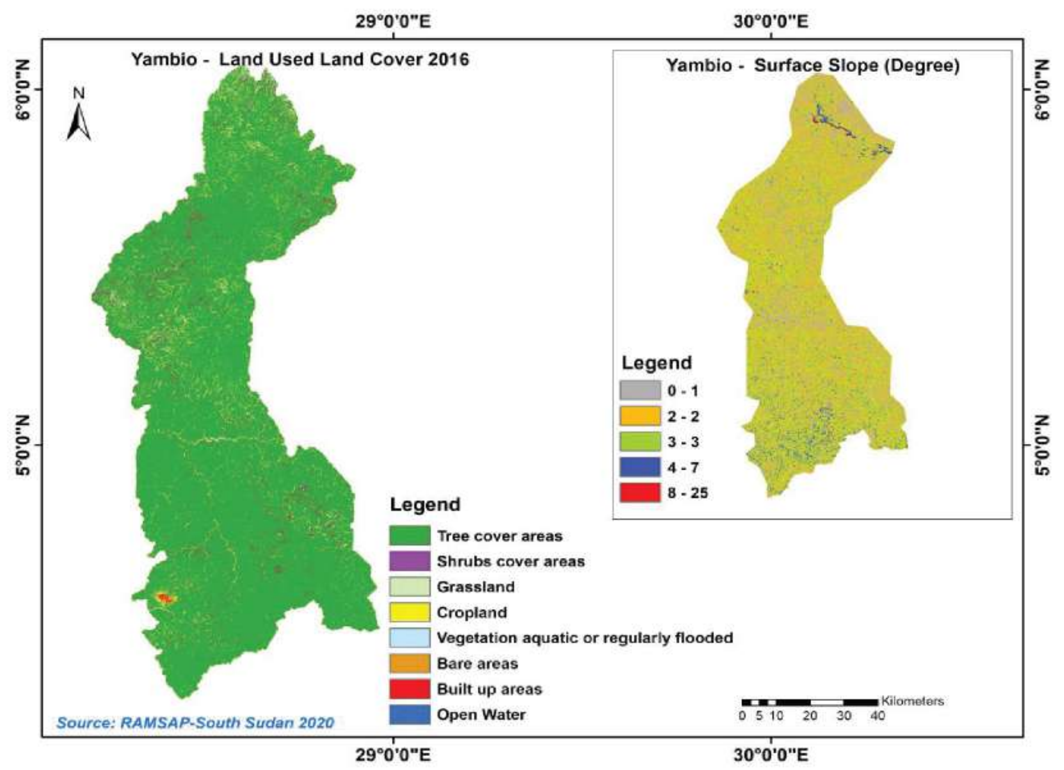


Figure 31. Land use and land cover at Yambio field site

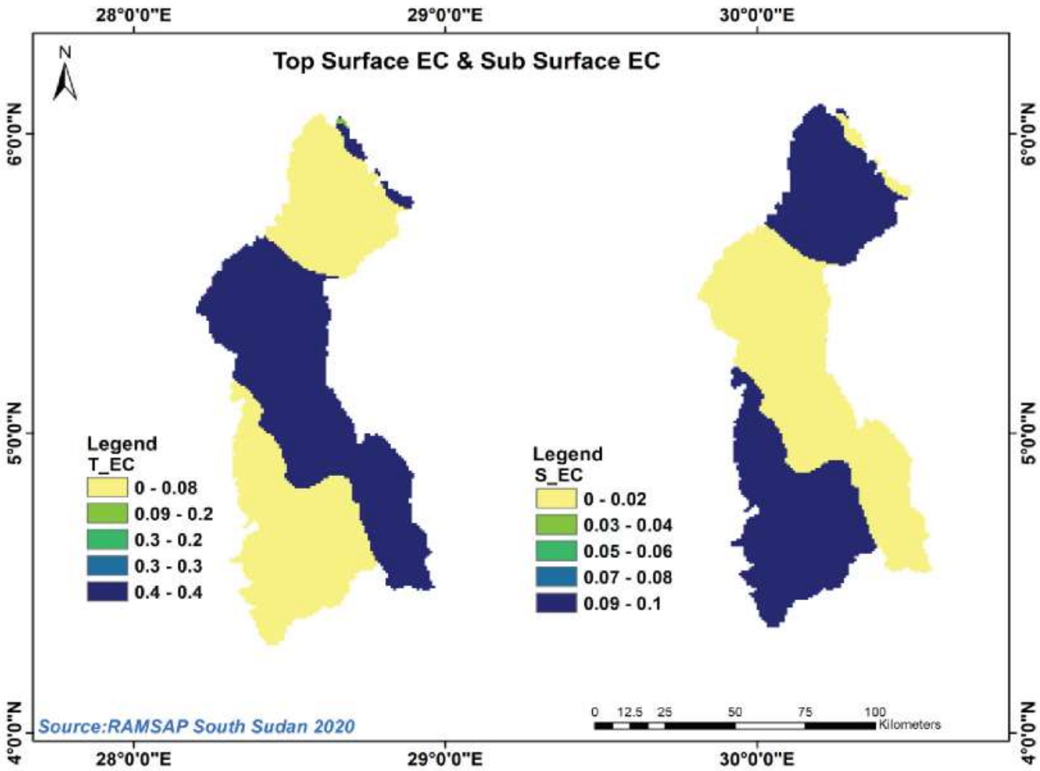


Figure 24. ECe of surface and sub-surface soil at Yambio field site.

3.2.9 Rumbek field site

Table 23 shows that 5.56% area is under grassland while 2.25% and 91.97% are covered by shrubs and trees, respectively. The area covered by crops is almost nil (0.76%). The spatial distribution of vegetation classes is given in Figure 33. Map related to soil salinity is shown in Figure 34.

Table 23. Land use and land cover data for Rumbek field site.

No.	Vegetation classes	Area (km^2)	Percentage (%)
1	Tree cover areas	2654	25.33
2	Shrubs cover areas	2918	27.85
3	Grassland	4534	43.27
4	Cropland	318	3.03
5	Vegetation aquatic or regularly flooded	40	0.38
6	Lichens Mosses / Sparse vegetation	2.4	0.03
7	Built up areas	5.2	0.05
8	Open Water	4.4	0.42
Total Area		**10,476**	**100**

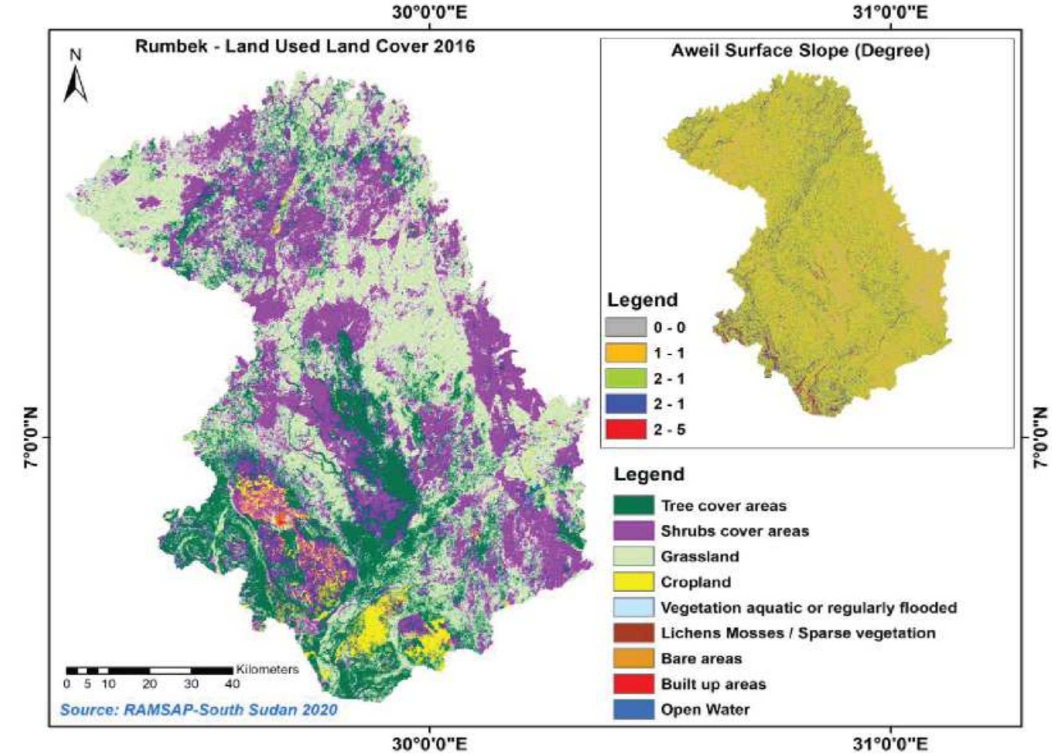


Figure 33. Land use and land cover at Rumbek field site.

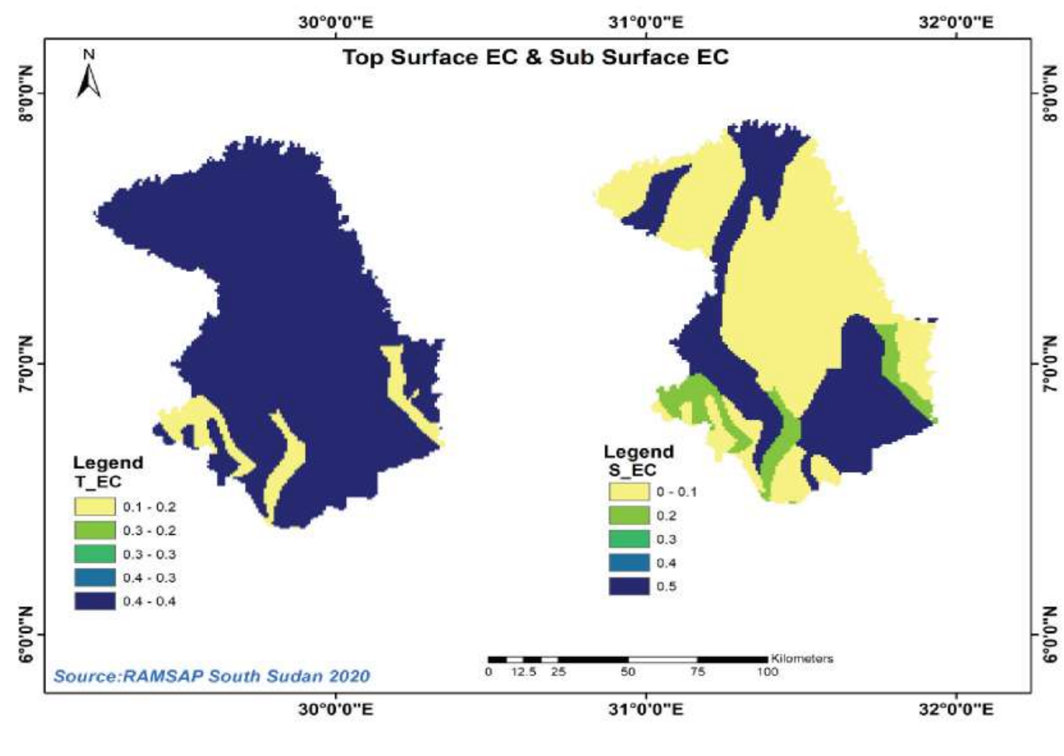


Figure 34. ECe of surface and sub-surface soil at Rumbek field site.

3.2.10 Jubek field site

Table 24 shows that 5.56% area is under grassland while 2.25% and 91.97% are covered by shrubs and trees, respectively. The area covered by crops is almost nil (0.76%). The spatial distribution of vegetation classes is shown in Figure 35. Map of soil salinity is shown in Figure 36.

Table 24. Land use and land cover data for Jubek field site.

No.	Vegetation classes	Area (km^2)	Percentage (%)
1	Tree cover areas	5629	32.32
2	Shrubs cover areas	2688	15.43
3	Grassland	8657	49.71
4	Cropland	352	2.02
5	Vegetation aquatic or regularly flooded	5.3	0.03
6	Lichens Mosses / Sparse vegetation	0.0	0.0
7	Built-up areas	42	2.41
8	Open Water	41	2.40
	Total Area	**17,413**	**100**

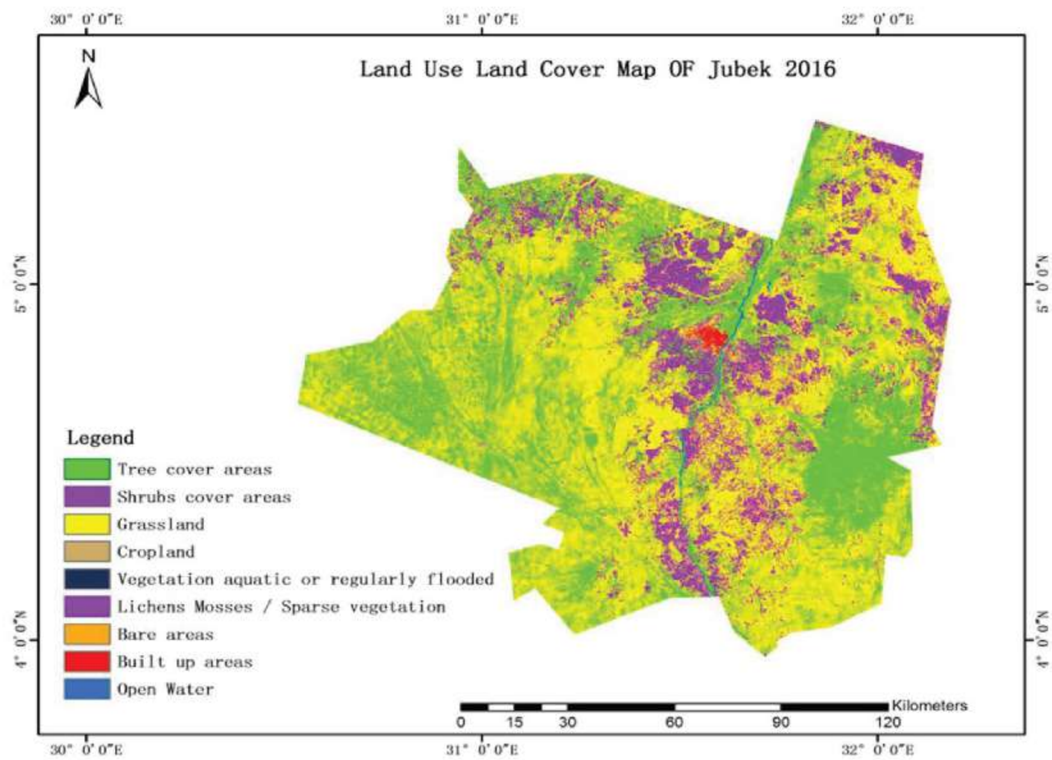


Figure 35. Land use and land cover at Jubek field site.

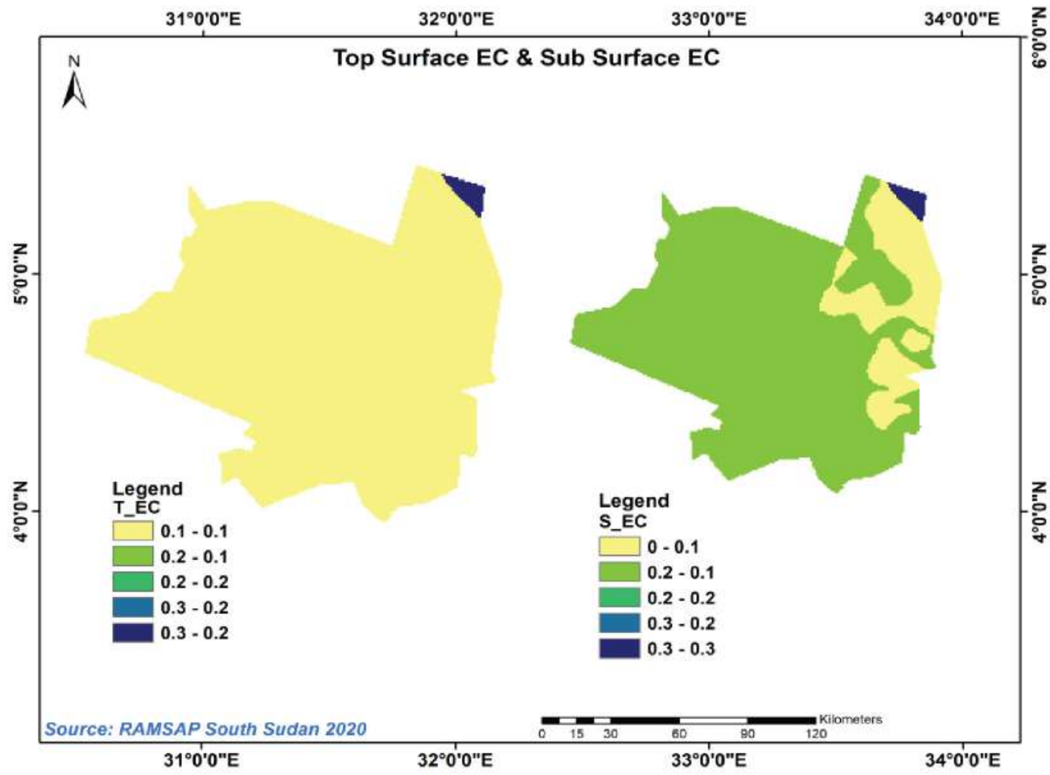


Figure 33. Land use and land cover at Rumbek field site.

3.2.11 Summary of findings

The increasing population in South Sudan after the Comprehensive Peace Agreement (CPA) in 2005 resulted in high demand for food. Despite having fertile lands and sufficient water resources, only 5% of the area is cultivated. In addition to other factors, the lack of accurate data and information about the potential developed areas that can grow food and feed crops are challenging issues that need immediate attention. Recent famine reported by some international agencies and later confirmed by the government of South Sudan is evidence that such information is required urgently for timely decision-making to reduce or eliminate such threats in the future. It is estimated that about 46.7% of the population in South Sudan is severely food insecure. Field data collection on land use, identification of suitable locations for different types of irrigation, the establishment of stream networks, and potential areas for rainwater harvesting is an expensive, time-consuming, and laborious task. Therefore, modern tools such as remote sensing and GIS can develop datasets and information that policymakers can use to make timely policy decisions.

The land use and land cover map of South Sudan show that the biggest cropland is in Renk (42.9%), followed by Kapoeta (7.9%), Bor (3.9%), Torit (3.1%), Aweil (2.6%), Wau (0.8%) and Yambio (0.2%). Apart from Renk, the other parts of the targeted areas show small land under cultivation. However, there is a high potential to transform shrub and grasslands into farmlands. The results of DEM model revealed that most of the surface land of the study areas has a slope angle between 00 – 40, which means that the sites are appropriate for most agricultural practices using different irrigation methods. This requires expansion of irrigation network and training of farmers on improved on-farm water management strategies. Similar studies should be conducted in other parts of the country to develop a strategic policy framework to enhance agricultural productivity, increase food security, and reduce poverty.

3.3 Strategies for the management of sat-affected soils

Saline soils have a high accumulation of soluble salts and low exchangeable sodium. Saline-sodic soils contain an excess accumulation of soluble salts and exchangeable sodium in their solution. The pH value of these soils seldom exceeds 8.5. Sodic soils contain excessive exchangeable sodium (ESP >15) in their exchange complex and have a pH value greater than 8.5.

On salt-affected soils, crop yield is reduced to the extent that the land becomes abandoned for agricultural use. High soluble salts and exchangeable sodium reduce the soil's osmotic or water potential and limit water availability to plants. In addition, the soil's physical properties, such as hydraulic conductivity, infiltration, air circulation, and root penetration, are also affected. Also, the concentration of specific ions can be increased to develop toxic characteristics that might affect plant metabolism. In most cases, this situation can lead to forceful abandonment of lands that cannot be used for any agricultural purposes.

Despite salt-affected soils with the high possibility of expansion, research and development endeavors to alleviate these problems have been minimal in Ethiopia and South Sudan. Therefore, the extent of salt-affected soils is not precisely known. The causes are not investigated to the desired level and documented. The economic implication of the problem is not known to the policymakers to take timely and appropriate actions. There are no autonomous and full-fledged institutions to inventory the natural resources to assess the extent of degradation at the national level. Moreover, the extension services to educate farmers on the strategies to reclaim salt-affected soils are either missing or insufficient. As a result, farmers continue to manage these soils using indigenous methods but with limited success.

Currently, available information and data are not exhaustive. They are based on preliminary studies and field observations that are incomplete and lack systematically analyzed results regarding the chemical composition of soil and water in salt-affected areas. Thus extrapolations and usage of research findings conducted elsewhere are common to convince federal and regional governments. This indicates the urgent need to embark on a sustained research endeavor to characterize salt-affected soils, quantify the extent of damage, and develop technologies to reclaim and halt further expansion of soil salinity in the country. To rehabilitate and manage salt-affected soils, we need to work on both short-term and long-term strategies.

3.3.1 Short-term strategies

To reclaim, restrict expansion, and make successful use of salt-affected soils, any recommendations must be based on detailed studies, investigation, and thorough analysis of the factors affecting salt built-up. The following technical measures can be adopted to desalinize salt-affected soils.

- Introducing proper land drainage to lower groundwater tables and incipient soil salinization. Controlling the quantity of irrigation water practically and economically could be another alternative.
- Practice minimum tillage to avoid soil compaction, maintain good soil structure, improve surface and internal drainage, and facilitate deep leaching.
- Practice surface mulching, organic matter, and crop residue management to reduce evaporation, develop desirable soil structures that improve water movement and root penetration, facilitate deep leaching, and reduce salt accumulation.
- Avoid irregular water intake to prevent the accumulation of salts beneath the high spots or ridges through proper or regular land leveling.
- Use good quality irrigation water, practice proper irrigation, apply the required amount of water (ETo based) depending on crop type and growth stages (crop-coefficient based), soil type, level and quality of groundwater, and climatic conditions of a given locality.

- Practice pre and post-plant leaching to remove the accumulated salts from the root zone of saline soils through a heavy application of good quality irrigation water (using LR concept) to ensure adequate surface and sub-surface drainage.

  Salt-affected soils must be surface mulched during the dry periods of the year to avoid capillary movement of mineralized groundwater that will finally evaporate from the soil, leaving behind crystallized salts on the surface.

- Avoid over-irrigation and/or ooding of farmlands using permanent and standard dams or dikes while permitting adequate soil moisture storage during periods of plentiful water supply that can be drawn by the crops during the periods of water scarcity. This could be achieved through deep tillage that facilitates water movement and storage at the desired depth.
- Maintain enough water available in the root zone during critical crop growth stages.
- Select proper seeding and planting methods and shape seedbeds properly to avoid salt accumulation in the root zone of seeds and growing seedlings; establish optimum plant population to prevent competition among plants and to assure average growth of crops. Eradicate weeds to avoid nutrient and water competition with the crops.
- Proper land selection, i.e., avoids cultivating lands with a high water table and hardpans that will perch added water and impede drainage. If the land is to be used/cultivated, one has to make sure that there is a proper drainage system and/or the condition of the soil should favor fast movement of water within it and on the surface without causing erosion.
- Avoid bringing sub-soil with high sodium and salt accumulation to the surface during land leveling; if needed, spread a uniform layer of salt-free soil on the surface after land leveling.
- Use lined canals or other salt-free conveyance or waterways for primary and secondary irrigation canals crossing soil layers with high salt accumulation.
- Avoid mixing drained water from lands containing high levels of sodium and dissolved salts with the irrigation water sources; avoid reusing water from the drainage system provided that it includes undesired salt levels and type.

Using biological and agronomic practices, the adverse effects of salinity and sodicity on soils and crops can also be minimized. These include:

- Select crop species that are salt or sodium-tolerant and sensitive crops or crop species in rotation.
- Grow ameliorating crop species and/or perennial forage grasses where the latter in turn may initiate livestock farming, such as beef fattening.
- Use high salinity or sodic fine soils to improve pasture under ood irrigation systems. The lands with courser texture, low soil salinity, or sodicity should grow food and industrial crops.
- Adverse effects of excessive salts and exchangeable sodium on plant growth can be minimized by increasing the availability of plant nutrients through the application of less available elements such as P, K, Fe, Mn, Zn, Cu, and in some cases, Ca and Mg due to the high CaCO3 content, high exchangeable sodium, and alkaline soil reactions.
- Improve the soil N content, the water holding capacity, the drainage, and other physical properties by proper maintenance and management of organic matter and crop residue.
- Initiate reclamation of saline and sodic soils through chemical amendments where calcium sources such as gypsum (Ca SO4.2H2O) are available and usable.
- Promote and uphold proper soil, irrigation water, and crop management practices and enforce strict and practical rules and regulations regarding the use of salt-affected soils.
- Monitor, evaluate, and regulate the establishment and expansion of irrigated farms in all parts of the country in general and dry areas in particular.

3.3.2 Long-term strategies

The salinization process is manifested through the adverse effect on crop growth, leading to reduced yield and abandonment of the land at the end. In addition, the physical and chemical properties of the soil are affected beyond the point of no return, which means that the soils might never be reclaimed and put under alternate use. This will have long-term consequences on agricultural productivity and food security. Therefore, developing a long-term policy framework for rehabilitating and managing salt-affected soils is needed to avoid socio-economic and environmental implications.

Reclamation of salt-affected soils, halting the future expansion, proper management of soil and water requires profound knowledge in natural resources conservation and optimum utilization. One of the most cardinal soil reclamation and management problems in arid and semi-arid regions is the lack of locally amendable technologies. The scientific knowledge gained will help understand the complex physical environment, and the technology generated will improve the productive capacity of the soil and water. Thus, a continuous search into the truth and accumulation and dissemination of knowledge and technology is necessary. Hence, research has a vital and pivotal role in generating science and technology that will change the lives and livelihoods of millions on the planet earth. In this regard, Ethiopia cannot be exceptional. The following are recommended for future research to manage saline and sodic soils.

- Observational and diagnostic studies must be made in salt-affected areas.
- Investigations into physical, chemical, biological, environmental, economic, and other social factors affecting soil salinity to be made, and their relationships must be established.
- Field and laboratory studies are to be conducted to characterize salt-affected soils.
- Create awareness among farmers about salinity and sodicity problems and develop preparedness plans to combat these issues.
- Map salt-affected soils at zonal, regional, and national levels through reconnaissance and a large-scale survey of irrigated and dryland areas.
- Investigate the quality of the country's irrigation water and classify the same based on their chemical characteristics related to salinity and sodicity.
- Study the harmful effects of salt-affected soils and irrigation water on soil-forming processes, soil properties (morphological, physical, and chemical), including their fertility and productivity, and monitoring the effect on plant growth and land value.
- Determine suitable systems, methodologies, irrigation and drainage methods, leaching, groundwater management, and cultural practices to control salinity and sodicity.
- Evaluate biological/agronomical methods, such as selecting salt-tolerant crops, forage, grass, and tree species. These grass and tree species will be used to reclaim and manage salt-affected soils.
- Conduct research to address the practical problems of sodicity and reclamation methods. For sodic soils, the type, rate, and quality of gypsum, process of application, and depth of incorporating or mixing the amendments into the soil need to be investigated.
- The quality and quantity of leaching water, system of water application, and drainage during leaching after applications of amendments should be studied.
- Develop and establish appropriate soil, water, and crop management practices for all classes of salt-affected soils in the country.
- Develop agricultural water management manuals, bulletins, and yers as guides for better water management practices.
- Impact on the environment and socio-economic aspects must be assessed to establish a system to sustain agricultural production and protect the environment.

3.3.3 Bioremediation

Bioremediation methods such as biosaline agriculture are economical and practical approaches to using unproductive lands to grow different food and feed crops. The biological approach emphasizes using highly saline water and lands on a sustained basis through the profitable and integrated use of the genetic resources embedded in plants, animals, fish, and insects; and improved agricultural practices. This approach promotes reclamation using salt-tolerant plants, bushes, trees, and fodder grasses. Plants, particularly trees, are commonly referred to as biological pumps and play an essential role in the overall hydrological cycle in a given area.

If prudently adapted, this approach can help improve the livelihood of rural and pastoral communities of the salt-affected areas by enhancing feed and fodder production. The above discussion reveals a largely unexplored and unexploited genetic variation that can be harnessed to improve the salt tolerance of field crops. By adequately identifying field crop and fodder species and varieties that can tolerate soil salinization and poor irrigation water quality, the productivity of marginal lands can be maximized. In Ethiopia, this approach is of particular importance due to the following reasons:

- Shortage of fodder is among the primary reasons for low productivity gains from the livestock sector. Forage production under saline soil conditions without competition with farmland for field crops is essential for Ethiopia for pastoral and agro-pastoral communities in the moisture stress dry regions. In addition to their tolerance to salinity and ameliorative effect. This makes them promising candidates for the diversification of the production system and the economical use of marginal soil and water resources.
- Irrigated agriculture in Ethiopia faces the problems of waterlogging and soil salinization. Engineering solutions to overcome these problems are expensive and technically complex and often cause water pollution and environmental degradation. Therefore, bio-drainage can be a viable option to control the rising groundwater tables.
- Exploring the possibility of bio-drainage for waterlogged saline can reduce the volume and cost of drainage.

  In Ethiopia, large tracts of agricultural lands have become barren and abandoned due to poor soil and water quality conditions. Since the growth of regular crops in these areas is restricted, the plantation of halophytes can be a viable solution to produce food, fuel, fodder, fiber, essential oils, and medicine. Halophytes can also help desalinate and restore saline soils through phytoremediation. Through these strategies, unused marginal lands can be brought under cultivation to improve the livelihood of rural communities.

Despite the above advantages, bioremediation systems have certain shortcomings that restrict their adoption under certain circumstances. The selection of plant species for bioremediation depends on environmental conditions. For non-agricultural tree and bush species, reliable information is limited and difficult to obtain. The efficiency of different plant species for the reclamation of saline-(sodic) soils is highly variable. In general, species with higher biomass production and tolerance against ambient salinity are more efficient in soil reclamation.

The production systems based on salt-tolerant grasses and forage crops are considered more sustainable for bioremediation. If these systems are linked with a livestock production system, economic benefits can increase manifolds, and environmental problems of disposal of saline ef uent can be minimized. Therefore, for the success of bioremediation systems, selecting plants capable of producing adequate biomass is vital. The above discussion shows that bioremediation can effectively assist in lowering the groundwater table to reduce waterlogging and consequent salinity problems in irrigated and non-irrigated areas. The involvement of communities in the rehabilitation process through bioremediation can significantly contribute to rural development and the well-being of rural communities. The bioremediation systems are beneficial to produce timber, fruits, oils, fuelwood, contribution to carbon sequestration, diminishing the effects of wind erosion, provision of shade and shelter, function as windbreaks, yield organic matter for fertilizer, enhancement of biodiversity, as flora and fauna flourishes, diminishing air pollution.

One of the significant disadvantages of bioremediation is that it requires much more land to be effective, which might not be possible for an individual smallholder farmer to afford. Therefore, in countries like Ethiopia and South Sudan, where unique landholdings are very small, farmers must make joint efforts to succeed in bioremediation. Bioremediation is also less effective in removing salts from the root zone and does not allow controlled drainage. Therefore these systems need to be complemented with the conventional drainage system for removing salts from the root zone.

3.3.4 Management of different quality irrigation waters

Despite the water shortage and lack of adequate drainage facilities, farmers tend to over-irrigation, whereas the opposite should be accomplished. Due to poor land leveling and use of basin and flooding methods of irrigation, water use efficiencies are around 35%. Un-even water distribution due to poor leveling of fields produces patches of low and high infiltration rates, making patches of low and high salinity within the same area. Therefore, farmers should be facilitated through extension services to level their fields and adopt water conservation measures to increase water use efficiency. In water deficit environments such as Ethiopia and South Sudan, water conservation strategies can save up to 25% of the irrigation water without compromising the crop yields. Improved cultural practices such as precision land leveling, zero tillage, and bed and furrow-bed planting methods have shown water savings of up to 40% and reduced levels of salinity development. These resource conservation techniques are now widely used in arid and semi-arid areas to grow various crops.

The use of saline water, to a large extent, is still confined to growing salt-resistant grasses for fodder, bushes, and trees. Due to minimal economic benefits, farmers are not very interested in adopting these practices and prefer to leave their lands and look for off-farm income employment. Due to the increasing dependence on irrigated agriculture, developing strategies to use different quality irrigation water for agriculture is crucial. For leaching of salts, good quality irrigation water should be used because excessive leaching with low-quality water needs extensive drainage systems to flush out salts from the system. However, before deciding about options, it is essential to do economic and environmental analysis to evaluate trade-offs between risks and costs. Salinity management and drainage control measures are adopted when soil salinity and groundwater levels have reached alarming levels. However, drainage should be considered a complementary activity to irrigation for sustainable management of irrigated lands. Installation of suitable drainage systems in newly developed or under-development irrigated areas will help in delaying or even eliminating the onset of drainage and associated soil salinity and sodicity problems.

The major problem in persuading farmers to use saline water for agriculture is the lack of proper guidelines on mixing ratios of different quality waters, irrigation amounts and frequencies, and cultural practices that can be instrumental in avoiding salt accumulation in the root zone. Considerable work has been done to develop strategies for using different quality waters for irrigation under other climatic and crop conditions. However, these findings need to be refined and tested for local climatic, soil, and crop conditions. Farmers alone cannot tackle the enormous task of rehabilitating degraded land and water resources. Therefore, the government should prepare strategic plans to improve research and extension services, leading to better solutions for the rehabilitation of salt-affected soils.

04

IRRIGATION WATER MANAGEMENT IN ETHIOPIA AND SOUTH SUDAN

4.1 Surface water resources of Ethiopia

Ethiopia has substantial water resources comprising 12 river basins, 11 fresh lakes, nine saline lakes, four crater lakes, and more than 12 significant swamps and wetlands (Figure 37). The total mean annual runoff volume from the 12 river basins is 122 billion m3 (Bm3), with the Abbay basin (in central and northwest Ethiopia) accounting for 45% of this amount. Much of this run-off could be used for irrigation or other purposes. Out of 12 river basins, eight are wet river basins, while the remaining four are dry basins with insignificant surface water resources contributions. The surface water systems of the wet river basins flow into two main directions based on their position from the Great Rift Valley that dissects the country into two major sections: West and East. The rivers that originate from the western side of central highlands and western plateaus of the country are flowing to the west and joining the Nile system. These include the Abbay, Baro-Akobo, Mereb, and Tekeze basins. The second section contains the basins originating from the Eastern Highlands and flowing toward the east, including Wabi Shebelle and Genale Dawa Basins. River systems flow along the Great Rift Valley, including Awash and the Rift Valley Lakes basin rivers.

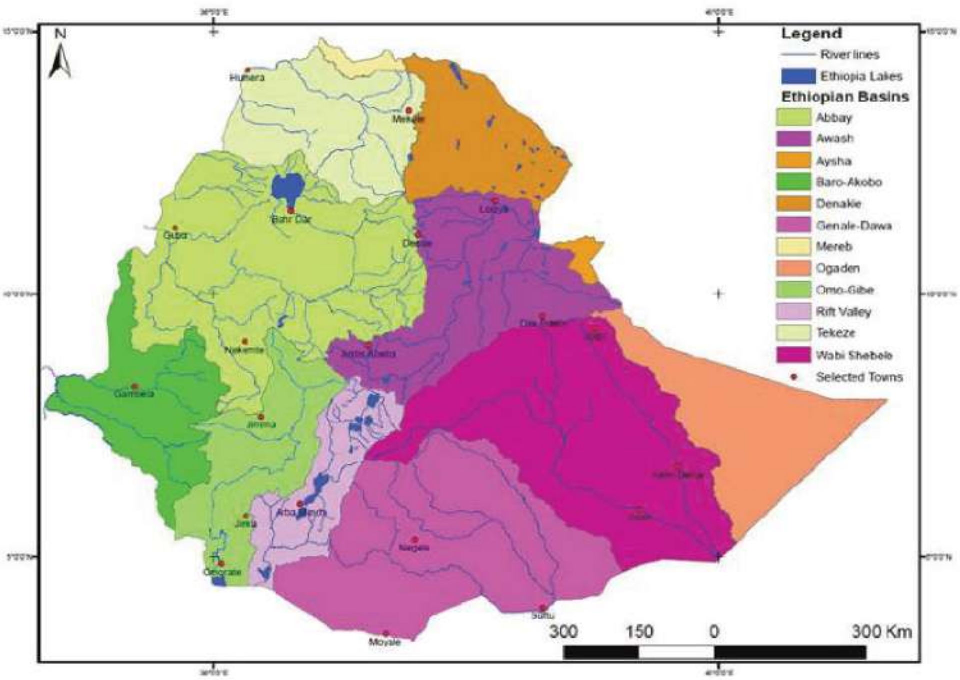


Figure 37. Major river basins of Ethiopia

The surface water resources can irrigate 3.7 million hectares (Mha). However, due to limited water infrastructure and storage capacity, this potential has not been fully utilized for the socio-economic development of its people. There is substantial temporal and spatial variability in the surface water resources. For almost all the major rivers, about 80% or more of the flows occur in just four months (June-September), while flows are minimal over the rest of the months. Due to lack of control and storage, devastating floods are significant water management challenges during the peak flow period, particularly in Awash, Omo, Baro Akobo, and Abbay basins (Figure 38). For example, Ethiopia's current per capita water storage capacity is only 160 m3.

The spatial variability of the surface water resource is even worse. The vast Eastern, North-eastern and southern, southern parts of the country are arid and semi-arid with little rainfall, covering about 40% of the country's landmass. There is severe water scarcity in these regions for domestic, agricultural, and livestock watering. About 60% of the country's water resources occur over areas where only 40% of people live. In 40% of the total land mass (semi-arid and arid), agriculture is mainly not possible without irrigation. If it exists in limited semi-arid areas, crop failures commonly occur due to the lack and unreliability of the natural rainfall. In addition to the deteriorating water quality, reducing the water volumes (river flows) has been witnessed in several basins and sub-basins over the last few decades. This, in combination with a fast-growing population, has been a cause for ever reducing per capita water availability in Ethiopia. Ethiopia's per capita water availability is about 1,100 m3 per year, close to the threshold value of 1000 m3 per year for water scarcity. On top of this, more than 91% of the surface water resources flow in transboundary water courses, so the amount of 124 Bm3 is not an accurate available volume for utilization. Therefore, Ethiopia is not a water-rich country but a nation approaching a water stress situation.

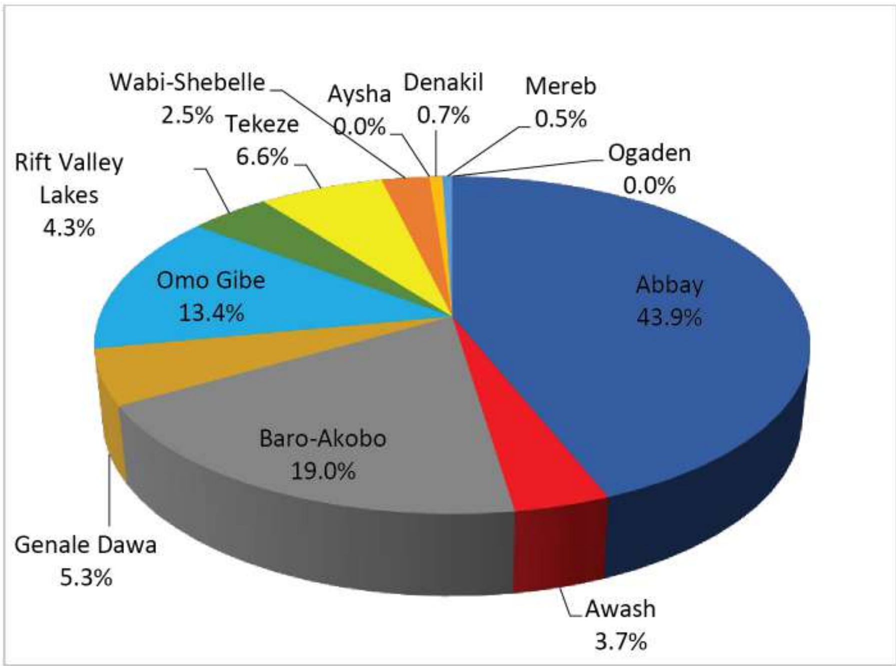


Figure 38. Surface water contributions of major river basins in Ethiopia

4.2 Groundwater resources

Ethiopia's groundwater potential has not been widely studied. Initial estimates suggest that groundwater potential varies from 2.6 to 13.5 Bm3. The groundwater resources potential of Ethiopia was also recently estimated to be about 40 Bm3. Despite this vast potential, groundwater exploitation for agriculture has been prolonged for multiple reasons, including hydro-geological complexity and high drilling costs. It is estimated that over 70% of Ethiopia's domestic water supply comes from groundwater. Regardless of its importance as a source of domestic water supplies in many parts of the country, groundwater is not uniform because it depends on various environmental, physical, and geological factors. Total irrigation potential from groundwater resources is estimated at 1.1 Mha. Figure 39 shows the preliminary ground-water potential map based on elevation, aquifer productivity, and moisture availability.

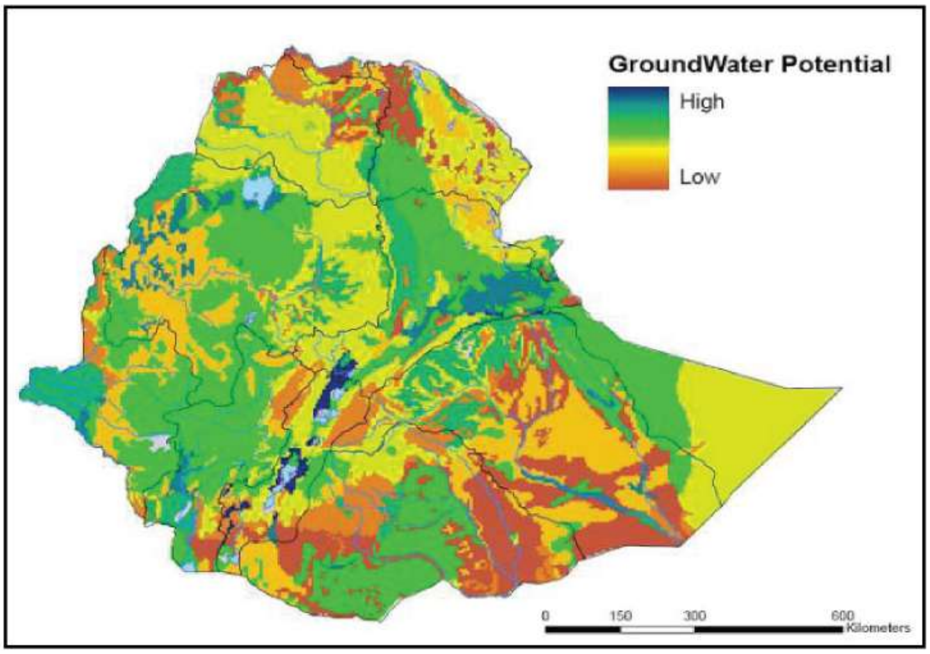


Figure 39. Map of groundwater potential in Ethiopia

The groundwater table depth in most parts of Ethiopia is relatively shallow, ranging from 0 to 25 meters. However, it can be up to 100m in other areas, resulting in higher drilling costs and low productivity. Groundwater productivity is deficient in many parts of Ethiopia (0-5 l/sec), making it economically unfeasible to exploit. The low groundwater productivity is attributed to most of Ethiopia's insufficient groundwater storage. Due to the factors mentioned above, groundwater irrigation development in Ethiopia has been slow compared to many Asian regions where conditions are more suitable for groundwater extraction.

The expansion of irrigation in Ethiopia is constrained by several factors, including policy, institutions, technologies, capacity, infrastructure, and markets. Moreover, irrigated agriculture in Ethiopia is also challenged by soil salinity, lack of adequate drainage, and poor on-farm irrigation practices. As a result, many irrigated areas perform lower than their potential. Most of the 791 irrigation schemes do not have functional drainage systems and lack appropriate water management strategies. This situation has led to a gradual rise of the saline groundwater table that contributed to secondary salinization in large irrigation projects in the Rift Valley, Awash, Wabi-Shebele River Basins, and other places.

Most of the irrigation schemes in the country are performing below their defined potential. Primary reasons for this poor performance include inappropriate irrigation scheduling, inadequate operation plans, lack of adequate institutional setups, inadequate physical water control facilities, canal sedimentation, lack of sufficient maintenance and appropriate asset management. Some of these challenges are critical to small-scale community-managed schemes, while others are fundamental to large-scale projects. The challenges of small-scale irrigation schemes are related to low levels of expertise, knowledge, and capacity to develop and manage irrigation systems. Initial investment costs for installing small-scale irrigation technologies (pumps and motors) and the operational costs (fuel and O&M costs) are also considered the major problems in adopting these innovative irrigation technologies by smallholder farmers. Most installed irrigation schemes are currently not operational due to poor maintenance. This situation has undermined the expected benefits of irrigation for the country's socioeconomic development. Besides, this has also been a cause of wastage of scarce financial resources allocated to the sector.

4.3 Current irrigation practices in Ethiopia

The impacts of salinity are particularly more pronounced in irrigated areas in Ethiopia. This is mainly because human activities such as irrigation modify the agricultural water balance and the chemical balance in the root zone. Awash Basin is the most utilized river basin in Ethiopia for irrigation, with about 30% of the total irrigated areas by large and medium scale irrigation being in the same basin. Salinity is more severe in the Rift Valley system. So, irrigated areas in the Rift Valley (including Awash and Rift Valley Lakes basins) are the most affected by salinity. Some of these irrigated areas under salinity threats are shown in Table 25, and their potential irrigable areas are highly threatened due to salinity.

Table 25. Saline area in the irrigation schemes of different river basins.

No	Schemes	Planned areas (ha)	Actual area (ha)	River Basins
1	Ziway-Meki	12,000	4,400	Rift Valley Lakes
2	Metahara	12,800	12,000	Awash, Upper Valley
3	Amibara	16,000	8,000	Awash, Middle Valley
4	Gewane	3,000	1,500	Awash, Middle Valley
5	Dupti/Tendaho	25,000	10,800	Awash, Lower Valley

Ziway-Meki irrigation scheme is in the Rift Valley Lakes Basin, part of the central rift valley. This area is famous for growing horticultural crops such as tomato, onion, and chili through private irrigation systems and commercial schemes. The total irrigated area in this sub-basin is 4,381 ha, making it most intensively irrigated corridor in Ethiopia. The Meki-Ziway scheme was constructed in 1986 with a planned command area of 3,000 ha, but currently, only 222 ha is irrigated. Another irrigation scheme is also called Meki-Ziway to irrigate about 2,000 ha using water from Lake Ziway.

Flow division structure with missing control gates at Meki Ziwai irrigation scheme

The irrigation schemes in the Middle Awash, mainly the Amibara scheme, are the most affected by soil salinity and sodicity. The soils of the system are highly saline, with ECe ranging from 16 to 18 dS/m in the profiles. The middle and lower Awash valley is a central agricultural corridor, particularly industrial crops. About 64% of the total seed-cotton production of the country was produced from this area, including Amibara, Gewane and Dupti areas (Ethiopian Investment Agency, EIA). The leading causes of salinity are (i) lack of drainage systems, (ii) poor natural drainage of the soils, (iii) poorly controlled and inefficient irrigation practices, (iv) recent increases in salinity of irrigation water due to the mixing of Lake Beseka.

The following are the leading irrigation and related practices and interventions causing and aggregating the salinity problems in saline areas in Ethiopia.

- **Expansion of small-scale irrigation using marginal water:** irrigation is a crucial source of livelihoods, food security, and poverty alleviation for Ethiopian smallholder farmers. As such, small-scale household irrigation practices are widely expanding. These smallholder irrigators often give little or no care to irrigation water quality as long as the water is available. Irrigation with marginal quality water is therefore commonly practiced.
- **Lack of know-how:** There is no clear understanding of the relationship between irrigation practices and soil salinity in several areas, particularly for smallholder irrigators. The risks of poor irrigation practices on soil salinity are not well understood among the irrigators.
- **Increased use of groundwater for irrigation:** In recent years, groundwater has hugely expanded in areas where surface water is scarce and unreliable. However, groundwater is generally more saline than surface waters, posing more salinity risks.

  Little consideration is given to irrigation water quality: In general, little emphasis is given to water quality for irrigation starting from water sources identification to water management.
- **Lack of alternative water sources for irrigation:** Often availability of a reliable water source for irrigation is a challenge for particularly small-holder farmers. There often exist no alternative water sources, and farmers are left with no options but to use poor-quality water.
- **Drainage systems are overlooked:** Drainage systems are complementary parts of irrigation systems. However, in Ethiopia, drainage systems are generally given very little attention from planning to implementation and operation of irrigation schemes. While proper drainage systems are almost non-existent in irrigation schemes, they fail or are poorly functional in major large-scale irrigation schemes due to poor management and maintenance.
- **Over irrigation:** Excess and inefficient water application is expected in irrigated farms in Ethiopia. Farmers lack understanding of the risks of excess irrigation on soil properties and thus to crop productivity. As a result, waterlogging is observed in several irrigated farms endangering sustainability due to salinity and lack of aeration.
- **Lack of irrigation water measurement:** Matching irrigation demands with water diversions is a crucial challenge among irrigators. They lack the facilities for correctly measuring irrigation water diversions from the sources. So, irrigators rely on estimations of water diversions and continually be on the higher side if water is available.
- **Wrong use of leaching water:** Leaching is effective with drainage systems or good natural drainage of the soils. Excess water use for leaching in areas with no drainage causes rising groundwater levels, further aggravating the salinity problem. Farmers usually use poor-quality water for leaching purposes. This practice adds more salts to the soil profile. Therefore, leaching should be done with good quality water.

4.4 Opportunities for irrigation development in Ethiopia

Irrigation development is crucial to improve agricultural productivity and reduce vulnerability to climate variability and changes. Irrigation in Ethiopia could contribute up to US$ 6 billion to the economy and move up 6.0 million households out of poverty. Ethiopia has an essential opportunity in water-led development, but it needs to address critical challenges in the planning, design, delivery, and maintenance of irrigation systems to maximize the benefits. By doing so, Ethiopia can boost its irrigated agriculture sector to ensure food security and improve the livelihood of smallholder farmers and pastoralist communities. This transition will also enable the country to harness considerable labor resources for the operation and maintenance of small-scale irrigation schemes, creating employment opportunities while extending the reach of its water infrastructure. This intervention in small-scale schemes will enable the country to use its abundant labor to reach fragmented households and communities.

4.5 Surface water resources of South Sudan

The River Nile is the dominating geographic feature in South Sudan, flowing across the Country. The Blue Nile and its tributaries flow down from the highlands of Ethiopia. In contrast, the White Nile and its tributaries flow from Uganda and the Central African Republic into the low clay basin to form the world's largest contiguous swamp on their way to Sudan and Egypt (The Sudd Region). South Sudan is home to the World's Largest Swamp, covering 30,000 km2. The surface water resources of South Sudan comprise the Nile River system and the Rift Valley basin. About 20% of the Nile basin lies within South Sudan and includes (1) the White Nile system; upstream of Sobat River originating on the Great Lakes Plateau; (2) the Baro/Sobat River system originating from the Ethiopian highlands; and (3) the Bahr El Ghazal basin, an internal basin in the west of South Sudan and extending to Sudan in the north. The Sobat and Bahr El Ghazal rivers are seasonal rivers, whereas the Nile River is perennial. The annual renewable surface water resources of South Sudan are 26 Bm^3. The major waterway network of South Sudan is Shown in Figure 40. The irrigation potential based on surface water availability in South Sudan is shown in Figure 41.

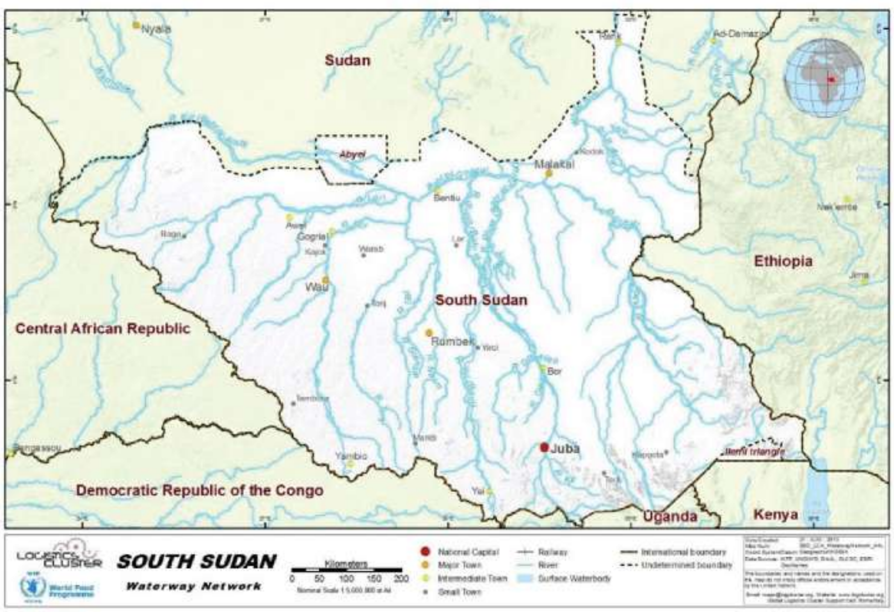


Figure 40. Waterway network of South Sudan

4.6 Groundwater resources of South Sudan

The primary groundwater formation in South Sudan is the Sudd basin, also known as the Umm Rwaba basin. Its extent and its relationship with the overlying surface water are unknown. The Sudd is the only Ramsar-listed wetland in South Sudan. It is an inland delta of the White Nile and comprises lakes, swamps, marshes, and flood plains. Its extent fluctuates from 10,000 km^2 to more than 35,000 km^2 depending on rainfall and evaporation, which is exceptionally high. An estimated 50% of the inflow to the Sudd, mainly through the White Nile system, is lost to evaporation. It is one of Africa's most extensive swamps. Internal renewable groundwater resources are estimated to be 4,000 million m^3 per year, which is overlap feeding the base flow of the river system. The irrigation potential based on groundwater availability in South Sudan is shown in Figure 42.

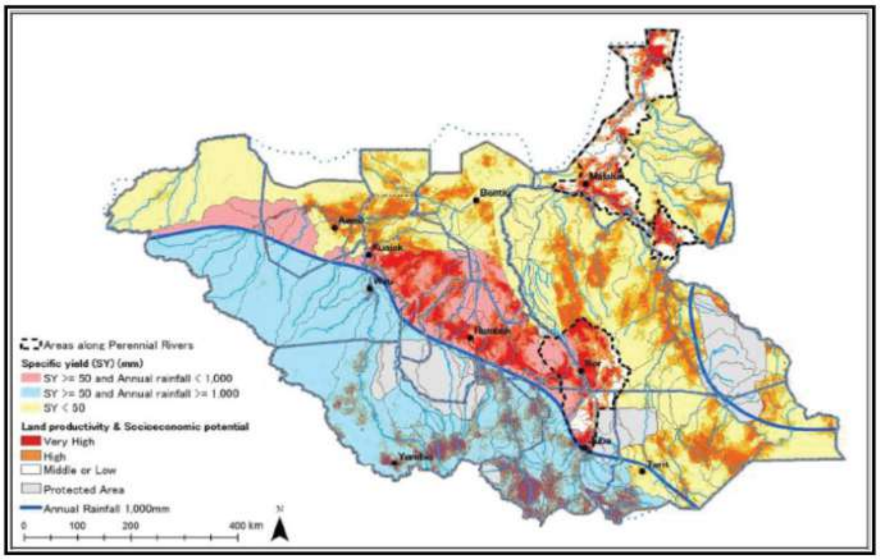


Figure 41. Irrigation potential based on surface water resources

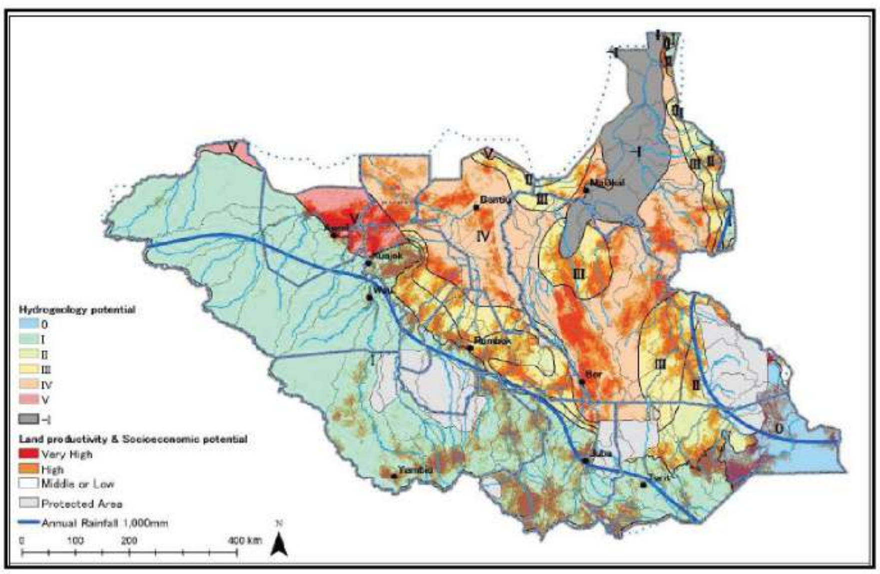


Figure 42. Irrigation potential with groundwater resources

4.7 Irrigation development in South Sudan

Based on Sudan's share from the Nile waters (as measured at Aswan dam in Egypt) and the Nile waters agreement with Egypt in 1959, the area specified for irrigation development is about 1.95 Mha. This includes large-scale modern schemes and small-scale schemes that include traditional irrigation holdings. Before the second war broke out in 1983, the plan for irrigation development was to irrigate about 270,000 ha. These plans were not realized because of the ensuing conflict, and no significant development was done to increase irrigated areas. The current irrigated area occupies only 32,100 ha – less than a tenth of one percent of national land space. About 12,700 ha of the irrigated cropland is in Upper Nile state; irrigated areas in Jonglei and Western Equatoria states are 300 and 500 ha, respectively, with the remaining 18,600 ha in small parcels of land across the country. In addition, about 6,000 ha of flood land, confined primarily to Northern Bahr el Ghazal, is used for rice production. Eastern Flood Plains has most of the irrigated cropland by livelihood zones, followed by the Green Belt and Nile Sobat River Basin.

The development of modern irrigation schemes in South Sudan started in the middle of the 20th Century during the British Colonial era. The major irrigation schemes developed during that time include the Aweil Irrigation Rice Scheme (AIRS) and the Northern Upper Nile Irrigation Schemes (NUNIS). Mongolia-Gemmeiza sugar plantation was also a planned large-scale irrigation scheme. Mongolia-Gemmeiza sugar plantation has been abandoned, and there is no existing schedule yet for its revitalization. Furthermore, pump stations in the Northern Upper Nile irrigation scheme have stopped working due to high operational costs and lack of appropriate repair and maintenance. As a result, farmers in the area still cultivate small-scale farmlands mainly by using rainwater. Generally, despite rich water resources, only 5% of the total area is irrigated due to a lack of irrigation infrastructure. Irrigation is mainly done using surface irrigation methods, and irrigation efficiencies are as low as 30-35%.

The studies done in South Sudan have shown great potential to increase irrigated areas using surface and groundwater resources if the proper infrastructure is provided. Irrigation is critical in traditional farming systems to secure food supplies, especially in drought-prone areas. In the floodplain areas, irrigation is traditionally used in small vegetable gardens cultivated with additional water from hand pumps, storage ponds, or lakeside moisture. In the wet season, floodwaters are diverted into rice and sugarcane fields, and bananas are grown on the dikes protecting fishing camps and lowland settlements.

In the dry season, vegetables and tobacco are irrigated along the river through manual and minor pump-driven lift irrigation, and maize and cowpea are grown using receding floodwater. Currently, the main irrigated crops are rice, fruit trees, and tree plantations. Two harvests are possible each year in the bimodal rainfall area of Western and Central Equatoria, where the growing season is long. Still, generally, only one crop is viable in the unimodal rainfall areas further north except where water is readily available for irrigation.

4.8 Challenges of irrigation management in South Sudan

Given the country's rich land and water endowment, the potential for irrigated agriculture is significant. By expanding irrigation, South Sudan can significantly increase agricultural production. The Ministry of Water Resources and Irrigation (MWRI) has identified irrigation as a means for attaining food security and addressing the problems of recurrent droughts and periodic floods. The locations for potential irrigation development include the following: (i) the lowlands, where farmers make use of flooding to supplement water for growing rice; (ii) areas adjacent to river floodplains, where farmers cultivate short-maturing varieties of sorghum; (iii) areas around swamps/marshes where extension of the growing season is possible by planting in moist soils left by receding floods; (iv) drought-prone eastern mountainous semi-arid areas with low water storage and infiltration capacity; and (v) southwest and western (Green Belt zone) whose agricultural output usually exceeds subsistence level and where modern irrigation techniques can further increase agricultural production, enhance food security and supply agro-industries.

The choice of locations for irrigation development should be guided by the prospects and potential to increase cropland and cropping season. This includes areas where irrigation schemes can convert unutilized arable to cropland. The analysis of the classification of aggregated land use in South Sudan shows that 27% of existing cropland is in areas where the farm potential is high. In comparison, 42% is in areas with medium to low farm potential. Furthermore, the areas with medium to low farm potential have high population densities. On this basis, the best opportunities for expanded smallholder and commercial irrigated-based agriculture appear to be in parts of the Eastern and Western Flood Plains, the Nile-Sobat Rivers area, and the Green Belt zone. Nile-Sobat River Basin Irrigation Schemes.

The potential area irrigated in the Nile-Sobat River Basin is about 654,700 ha. On average, the annual rainfall in the Basin area is between 200 to 400 mm. However, with the introduction of irrigation, the area acquires enormous potential for increased agricultural production. This potential would significantly contribute to agricultural output, enhance food security, and boost export earnings. It is anticipated that cereals (sorghum, rice, maize), oilseeds (groundnuts sesame, sunflower), and gum acacia would feature prominently in these programs because of soil suitability and great unmet domestic, regional, and global demand. Along with the introduction of large-scale commercial irrigation, there are opportunities for the development of small- to medium scale irrigation schemes (primarily for production of rice and possibly sugar cane) in the following areas of the Nile-Sobat Basin:

In South Sudan, water user associations (WUAs) are not formed to regulate water allocations to farmers and routine repair and maintenance. These organizations were not even developed in the Aweil rice scheme during its rehabilitation, although they were planned. This causes an uneven water distribution to different users and low crop productivities. In addition, lack of ownership of irrigation schemes results in poor maintenance with consequences on reduced life and efficiency. Lack of interest from government organizations further complicates the problem.

In South Sudan, the responsibilities in water management and irrigated agriculture are shared between the following three Ministries: (1) the Ministry of Electricity, Dams, Irrigation and Water Resources (MEDIWR); (2) the Ministry of Agriculture and Food Security (MoAFS); and (3) the Ministry of Lands, Housing and Physical Planning (MLHPP). At the state level, Ministries of Agriculture, Animal Resources, and Irrigation (MAARIs) have been established along with the water and sanitation directorates. In addition, the South Sudan Urban Water Coordination (SSUWC) is responsible for developing access to improved water supply under the responsible Ministry. As a result, the institutional water sector is challenged by a lack of clarity for respective missions between MEDIWR and MLHPP and by weak capacity at the state level regarding the availability of qualified staffing, equipment, management, and operational systems. The ambiguity in roles and responsibilities of different Ministries needs to be resolved to improve the country's groundwater and surface water resources management.

There is a critical environmental concern in South Sudan related to water resources and their management. Water levels in rivers decrease due to increased erosion and siltation caused by land-use changes and overexploitation: forest clearing, over-grazing, and fires. Former permanent rivers became seasonal in the last decade, especially Lol, Jur, Gal, and Peyia rivers found along the border with the Central African Republic. A drop in the groundwater table is also observed in Northern Bahr el Ghazal State.

The private investment in small-scale irrigation development in South Sudan is negligible. In addition to the economic constraints of smallholder farmers, existing land tenure laws also restrict farmers from investing in small-scale irrigation development. Furthermore, several provisions in the current land law prohibit foreigners from owning land in South Sudan. Under the 2009 Land Act (i) foreigners are not permitted to own land in South Sudan; they can, however, conditionally, lease land (for a maximum of 99 years); (ii) community lands may be allocated for investment purposes, but that investment must reflect an "important interest of the community" and contribute to the economic and social development of the local community; and (iii) land acquisition of 250 fedans (state authorities must approve 104 hectares). If South Sudan is to transit from traditional farming to commercial farming, then access to land must be equitably liberalized. Having a uniform national land law and a clearly defined and transparent ownership right and obligations will facilitate the decision of potential foreign investors in agricultural land. In addition, given the predominant role that women play in farming in South Sudan, the laws must be gender-sensitive and accord women unfettered right to own and develop the land. Therefore, the government needs to adopt land development policies that allow potential investors to acquire, develop land and reap the benefits of their investment in commercial agricultural land.

4.9 Prospects of irrigation development in South Sudan

There is an urgent need to establish policies and strategies to promote efficient water use to meet the growing water demand for irrigation and avoid potential conflicts between competing users. This is also important because water will be an essential component of future strategies for achieving food security and agriculture-based economic growth. The first step towards effective water management could be assessing and mapping the available water resources. Special attention is needed to evaluate groundwater resources' availability, quality, and occurrence because they are mainly untapped.

Currently, there are some efforts to identify and map the country's irrigation potential more precisely, and a national Irrigation Master Plan was prepared to prioritize investments for the development of irrigated agriculture for the coming decade. This master plan aimed to increase the irrigated area from 38,100 ha to 400,000 ha by 2020. However, this plan has not been implemented due to a lack of irrigation knowledge and financial constraints. The same happened to the improvement in access to water and sanitation. According to this plan, the water supply will increase to 70% in urban areas and 65% in rural areas by 2020. However, this has not been achieved due to organizational and financial limitations. Finally, with the significant livestock activities and difficulty accessing water in dry periods, developing water resources for livestock is also an essential objective for the country.

The irrigation potential suggests that 1.5 Mha of land could be brought under irrigation by smallholders and commercial farming. The World Bank has noted that experience in Sub-Saharan countries indicates that economic returns on small-scale schemes have averaged 26% compared to 17% for large-scale systems. These results depend on keeping investment costs down to best-practice levels of $3,000 per hectare for the water distribution component of large-scale irrigation and $2,000 per hectare for small-scale irrigation. For every 100,000 hectares of smallholder and medium and large-scale irrigation brought into production at these best practice costs, the investment costs would be $200 million and $300 million, respectively. However, these studies indicate that the price of public irrigation has been excessively high.

Many schemes failed to capture higher yield levels and could not transition to higher-value crops. Another critical consideration drawn from experience in Sub-Saharan Africa is that, in most cases, irrigation is only viable for cash crops or high-value food crops (such as horticulture). Experience has shown that the economic viability of irrigation for staple food crops is often doubtful. These concerns about financial viability, farm-level profitability, and sustainability should guide investment decisions in the decade ahead. The country's development and growth will also benefit from the enhanced use of the Nile and its tributaries as water sources for irrigation and transport. However, the country's immense irrigation potential will need to be undertaken within a national strategy for agricultural water development.

A master plan for irrigation development should be prepared in developing this irrigation potential. The master plan will need to give particular attention to the amounts of existing or potential cropland to be brought under smallholder irrigation schemes, the amount to be developed under medium- and large-scale commercial farming, and the likely investment cost per hectare. Construction costs in South Sudan are known to be high. This plan should include the development of 400,000 ha of irrigated agriculture. The underlying assumption is that 50% would be smallholder farm development, and 50% large-scale commercial farming linked to smallholder farmers. Assuming application of best practice investment costs, the water-related component of the program would cost $1.0 billion. The $600 million for commercial farm operations would be mobilized from private investment. The $400 million required for smallholder development would have to be funded from public sources using Government and donor resources. Assuming that the program is successfully implemented to produce high-value crops that yielded $2,000 per hectare, gross revenues would amount to about $1 billion per year.

4.10 Conclusions and recommendations

The irrigation potential of Ethiopia is not fully exploited. The total irrigation potential is about 7.5 million ha, of which only about 1.2 million (16%) is currently irrigated. The development of large and medium irrigation schemes is the responsibility of the Ministry of Water Irrigation and Energy. At the same time, the Ministry of Agriculture is responsible for the development of small-scale irrigation schemes. Of the total area irrigated, an estimated area of about 260,000 ha (about 22%) is from large and medium scale irrigation, and the remaining 940,000 ha (78%) is from small-scale and micro-irrigation schemes. The performance of existing irrigation schemes is deficient, characterized by inappropriate operation, poor operation & maintenance of irrigation infrastructure, inefficient conveyance and field irrigation systems, inequitable water distribution, low water, land productivity, etc.

The current irrigation practices include ridge planting, improving irrigation efficiency, leaching, adopting more frequent irrigation, using localized drip irrigation whenever suitable to leach out salts from the root concentration areas, and pre-plant irrigation. The semi-(arid) regions are more susceptible to salinity development. It is high time to introduce suitable management interventions in saline areas to ensure sustainable irrigated agriculture in Ethiopia.

South Sudan has a substantial amount of surface and groundwater resources. The cultivable land brought under irrigation by smallholders and commercial farming in South Sudan is estimated at 1.5 Mha divided between the Nile-Sobat river basin, the Western and Eastern Flood Plains, the Mangala region the Green Belt zone. However, despite rich water resources present in the country, only 5% of the total area is irrigated due to a lack of irrigation infrastructure. There were several plans for irrigation development in Southern Sudan in the 1970s and 1980s. However, because of the instability, the development of irrigated agriculture was constrained and never fully operational and is still essentially non-functional. The current area equipped for complete control irrigation is only 38,100 ha, and irrigation is mainly done using surface irrigation methods with 30-35% efficiencies.

There are also critical environmental concerns in South Sudan related to water resources and their management. Water levels in rivers decrease due to increased erosion and siltation caused by land-use changes and overexploitation: forest clearing, over-grazing, and fires. Former permanent rivers are becoming seasonal. A drop in the groundwater table is also observed in Northern Bahr el Ghazal State. Decreasing rainfall, attributed to local environmental changes and climate change, might also explain groundwater level drops. Furthermore, salinity issues in the groundwater around Malakal and isolated villages and water pollution from industrial oil wastes in Unity and Upper Nile states.

Currently, South Sudan's water sector is also impaired by a lack of updated data and information for surface water and groundwater resources. Apart from customary laws, no formal system for allocating water resources to sector or user exists. Intense competition for water in the dry season often leads to disputes between farmers and pastoralists, who travel long distances depending on water availability.

Several other initiatives need to be taken to strengthen the agricultural sector to achieve maximum benefits from irrigation development. These may include increased access to fertilizer, provision of extensive extension services, increased adaptive research facilities, enhanced private investment, increased agricultural mechanization, and modification of land-tenure laws.

05 FIELD EVALUATION OF SALT-TOLERANT FOOD AND FODDER CROPS

5.1 Field trials in Ethiopia

For Ethiopia, five locations were selected to establish field trials under this project, as shown below. These locations were chosen after due consultation with the representatives of the Ministry of Agriculture, research organizations, and research scientists. The selected areas include:

1. Amibara and Dubti in Afar regional state,
2. Zeway-Dugda in Oromia regional state,
3. Shewa-Robit in Amhara regional state and
4. Alamata in Tigray regional state.

These sites are located within the East African Rift-Valley system representing different agro-climatic zones, which offer various options to test and grow potential salt-tolerant crops, forages, and cereals. The trials were conducted at the Werer Agricultural Research Center (WARC), Amibara district of the Afar region, and Mekhoni Agricultural Research Center (MoARC), Raya-Alamata district of the Tigray region. (Figure 1). The WARC is semi-arid, with mean annual temperatures ranging between 19°C and 34°C. The mean yearly Class A pan evaporation is 2800mm, five times higher than the mean annual rainfall (570mm). Similarly, the MoARC is classified as dry land climates of semi-arid and arid types. The annual rainfall, minimum and maximum temperatures are 663mm, 14°C, and 28°C, respectively.

The field trials in Amibara were conducted in soils with ECe values ranging from 14.39-32.89 dSm-1, and ESP ranges from 15.45 to 24.28%. In contrast, in Field trials, the Raya-Alamata and Fentale district of Oromia was conducted at the soil with ECe values of 7 to 12 dSm-1 and ESP >15. ICBA and locally available seeds of different crops were sown. Soil samples were collected from the experimental plots at a soil depth of 0-30 and analyzed for the different salinity and sodicity parameters.

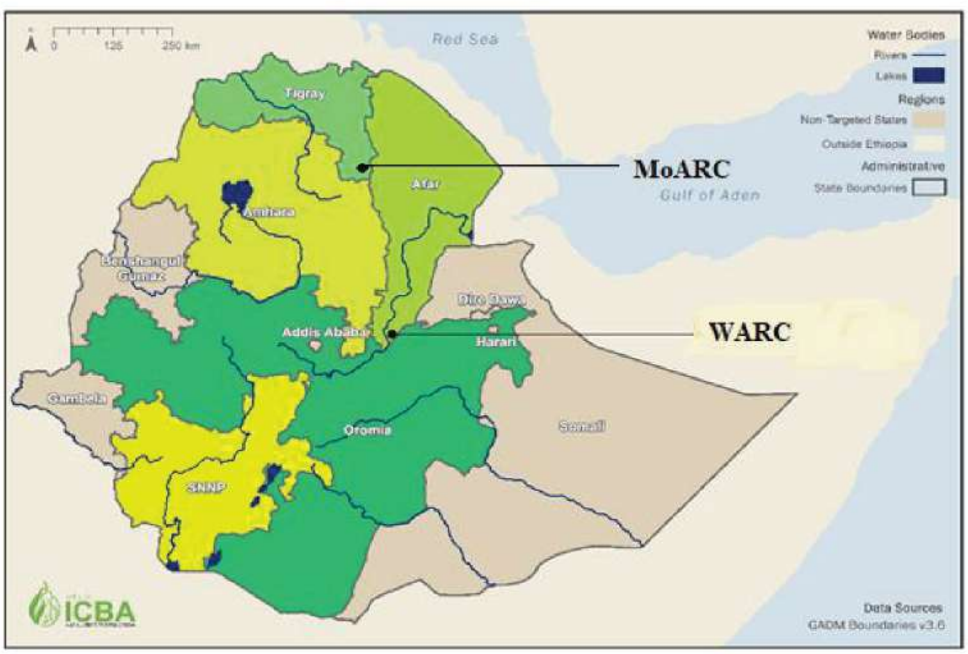


Figure 43. Map of Ethiopia with regional boundaries.

The following information from field trials was collected for screening genotypes of various crops.

- Information about soil salinity/sodicity levels in the potential areas
- Water salinity/sodicity levels (irrigation water)
- Irrigation system available or to be installed
- Sources of irrigation water (groundwater, river water, or rainfed)

Steps for the screening trials and data collection

Step 1: Set up of field trial of selected genotypes

- The site selection and preparation (leveling, making beds, etc.) are based on the experimental design as suggested below.
- Selected field trial sites with different salinity levels, e.g., ECe of 3, 6, and 9 or 2, 4 and 8
- Record salinity (ECe) of the experimental plot up to a depth of 1 m (15, 30, 60, 90 cm depths).
- Arrangement of water and set up of irrigation system
- Sowing of seeds of different genotypes
- Apply recommended doses of fertilizers (NPK) – band placement

Step 2: Water application

- Calculate evapotranspiration (ET) of the crop/plant for different plant growth stages using standard methods and apply irrigation water based on these ET values
- Develop irrigation schedules and irrigate crops according to this schedule
- Measure each irrigation (discharge, time of application, source of water)
- Note down the date and volume of each irrigation.
- Note down the quality of irrigation water applied (freshwater, saline water----ECw)

Step 3: Agronomic parameters

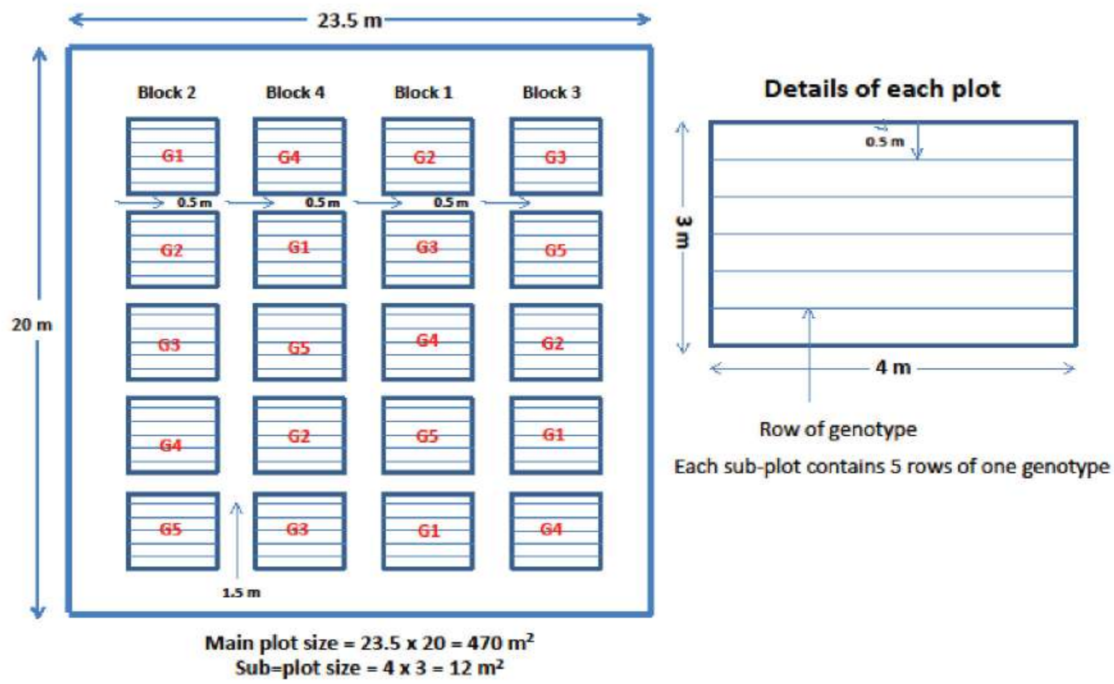
- Record sowing date, harvesting date, soil preparation records, amounts and timing of fertilizer and seed application, soil amendments if any, etc.)
- Record plant growth parameters (tillers, height) on a regular interval (e.g., after every 15 days)
- After harvesting, record fresh and dry biomass and weight of grains

Step 4: Economics of experiment

- Record total cost of establishing field trail. This should include soil preparation, costs of fertilizer, cost of irrigation application, labor costs, land rent if any, etc.
- Record also running cost of field experiment (labor needed for weeding, harvesting, fencing etc.)
- In the end, we will perform benefit/cost analysis

A plot size of 3m x 4m was prepared for each genotype. There were five rows of genotype plants in each sub-plot. A Completely Randomized Block Design (CRBD) with three replications was used for the field trials. Each subplot was separated by 0.5 m distance, and each row of sub-plots was separated by 1.5 m to minimize the influence of different treatments.

Genotype screening experiment layout



ICBA provided the seeds of the salt-tolerant food and fodder crops for testing under local soil and climatic conditions before being recommended for scaling up. In addition, three genotypes of Rhoades grass and three genotypes of Lablab purpuerus were also tested in the field. The salt-tolerant grasses such as Cenchrus ciliaris and Blue Panicum were also introduced to farmers through farmer field days.

Common name	Scientific name	ID	Origin
Barley	*Hordium vulgare*	CM72	Egypt, Ethiopia, Tibet
Barley	*Hordium vulgare*	58/1A	Egypt, Ethiopia, Tibet
Cowpea	*Vigna unguiculata*	TVU9716	Africa, Latin America, South Asia
Cowpea	*Vigna unguiculata*	ILRI-9643	Africa, Latin America, South Asia
Cowpea	*Vigna unguiculata*	ILRI-9334	Africa, Latin America, South Asia
Cowpea	*Vigna unguiculata*	ILRI-12713	Africa, Latin America, South Asia
Sesbania	*Sesbabia sesban*	ILRI 9643	Tropical Africa and Asia
Sesbania	*Sesbabia sesban*	ILRI 1178	Tropical Africa and Asia
Sesbania	*Sesbabia sesban*	ILRI 1198	Tropical Africa and Asia
Sorghum	*Sorghum bicolar*	ICSV700	Northeastern Africa
Sorghum	*Sorghum bicolar*	ICSR93034	Northeastern Africa
Pearl Millet	*Pennisetum glauccum*	IP13150	Sahel zone of West Africa
Pearl Millet	*Pennisetum glauccum*	IP19586	Sahel zone of West Africa
Quinoa	*Chenepodium quinoa*	ICBA-Q1	Latin America
Quinoa	*Chenepodium quinoa*	ICBA-Q2	Latin America
Quinoa	*Chenepodium quinoa*	ICBA-Q3	Latin America
Quinoa	*Chenepodium quinoa*	ICBA-Q4	Latin America
Quinoa	*Chenepodium quinoa*	ICBA-Q5	Latin America

5.2 Results of field trials in Ethiopia

5.2.1 Barley

Under field conditions, barley genotypes showed significant differences in grain yield, dry biomass yield, and spike length. However, differences in days to 50% emergency, days to 50% maturity, number of tillers per plant, and plant height were non-significant (Table 26). The CM-72 genotype performed superior in grain yield compared to CM-58/1A. However, the highest dry biomass yield was recorded in CM-58/1A. Both genotypes performed better at MoARS compared to WRS.

Table 26. Field evaluation of salt-affected barley genotypes

Barley genotypes	DE (days)	DM (days)	PH (cm)	NT (#)	SL (cm)	DBY (tha^{-1})	GY ($Kgha^{-1}$)
Werer Research Station (Amibara)							
CM-58/1A	9.33	84.33	72.33	4.67	6.80^{b}	4.23^{a}	0.70
CM-72	7.67	93.67	76.26	6.00	8.07^{a}	3.54^{b}	1.16
LSD ($P<0.05$)	NS	NS	NS	NS	1.24	0.44	NS
CV (%)	14.80	10.20	14.58	13.57	7.65	9.14	13.18
Mekhoni Research Station (Raya-Alamata)							
CM-58/1A	8.00	87.95	32.50	6.00	3.00	52.50	1.49
CM-72	9.00	99.50	32.00	3.00	5.25	23.95	3.36
LSD ($P<0.05$)	NS	NS	NS	4.75	6.42	5.20	5.11
CV (%)	9.60	10.04	12.68	22.22	17.45	24.15	24.90

DE= Days to 50% Emergency; DM= Days to 50% Maturity; NT = No. of Tillers per plant; PH = Plant Height; SL = Spike Length; DBY= Dry Biomass Yield; GY= Grain Yield.

Barley field trials on the salt-affected lands in Ethiopia

5.2.2 Quinoa genotypes screening under field conditions

The Quinoa genotypes showed a significant difference in grain yield and other biophysical parameters at WRS. ICBA-Q3 gave higher grain and dry biomass yield, followed by ICBA-Q4 (Table 27). The poor performance of other genotypes was probably due to the limited supply of metabolites to young growing tissues because metabolic production occurs within the leaves and is significantly perturbed at high salt stress either due to the low water uptake or the toxic effect of NaCl concentration. ICBA-Q3 produced a higher grain yield at both research stations than other genotypes. However, the grain yield of ICBA-Q3 at the Werer station was about 75% higher than the Mekhoni research station.

Table 27. Field evaluation of five salt-tolerant Quinoa genotypes.

Quinoa genotypes	DE (days)	DM (days)	PH (cm)	NPPP (days)	NDMS (days)	NDPG (days)	DBY (tha^{-1})	GY ($kgha^{-1}$)
Werer Research Station (Amibara)								
ICBA-Q1	12.33	93.00	138.60	8.00	80.00	90.67	1.239	464
ICBA-Q2	12.00	94.33	148.77	8.00	78.33	89.67	1.291	499
ICBA-Q3	9.00	86.33	144.00	11.67	72.33	84.00	7.211	2965
ICBA-Q4	8.67	89.00	152.13	10.00	75.67	88.00	5.885	1644
ICBA-Q5	8.67	86.00	156.13	9.00	71.33	78.66	4.023	1559
LSD (P<0.05)	1.49	3.94	NS	1.41	NS	6.68	0.572	152
CV (%)	7.85	12.33	23.61	8.06	16.85	14.11	8.61	15.67
Mekhoni Research Station (Raya-Alamata)								
ICBA-Q3	8.66	84.66	110.67	8.33	71.00	84.00	5.444	1696
ICBA-Q4	10.00	91.00	118.67	7.33	77.67	89.33	4.185	1044
ICBA-Q5	9.66	78.33	93.00	9.00	69.33	79.00	3.556	1326
LSD (P<0.05)	NS	2.35	NS	NS	NS	NS	NS	80.70
CV (%)	9.34	5.98	22.00	23.63	8.23	8.76	39.45	11.72

DE = Days of 50% Emergence; DM = Days of 50% Maturity; PH = Plant Height; NPPP= No. of Panicles per Plant; NDMS = No. of days to Milky Stage; NDPG= No. of Days to Pasty Grain; DBY= Dry Biomass Yield; GY= Grain Yield.


Quinoa genotypes at the Werer research station, Ethiopia

5.2.3 Sorghum

Sorghum genotypes showed significant differences in all parameters except panicle length in both studied areas. All genotypes were affected more at high salt stress. A similar result was observed. Among the newly introduced sorghum genotypes, Melkam was superior in terms of grain yield than ICSR-93034 and ICSV-700. However, ICSR-93034 and ICSV-700 genotypes produced a higher dry matter than the Melkam genotype (Table 28). This made them highly attractive for animal feeds. Farmers prefer these two varieties because they produce reasonable grain yields and significantly higher biomass. Higher biomass yields are attractive for farmers because of their dependence on livestock.

Table 28. Field evaluation of salt-tolerant Sorghum genotypes at WRS.

Sorghum genotypes	DF (days)	DM (days)	PH (cm)	PL (cm)	DBY (ton/ha)	1000 seed wt (gm)	GY ($Kgha^{-1}$)
Melkam	73.00	97.33	146.07	26.86	10.56	36.30	3286.7
ICSR-93034	91.33	123.67	184.51	20.28	18.37	29.33	2327.5
ICSV-700	94.67	125.67	202.53	19.72	20.84	30.63	1948.6
LSD (P<0.05)	4.13	4.59	50.23	NS	7.70	6.35	415.15
CV (%)	12.11	17.54	12.46	20.71	22.02	8.68	7.26

DE = Days of 50% Emergence; DM = Days of 50% Maturity; PH = Plant Height; NPPP= No. of Panicles per Plant; NDMS = No. of days to Milky Stage; NDPG= No. of Days to Pasty Grain; DBY= Dry Biomass Yield; GY= Grain Yield.


Sorghum genotypes at the Werer research station, Ethiopia

5.2.4 Pearl Millet genotypes screening under field conditions

The pearl millet genotypes showed a statistically significant difference in days of 50% flowering, panicle length, dry matter biomass, and grain yield. However, no significant differences were found in days of 50% physiological maturity, the number of tillers per plant, dry biomass yield, and 1000 seed weight. The IP-13150 genotype performed superior grain and dry biomass yields than the IP-19586 genotype (Table 29). The highest dry biomass yield was recorded in IP-13150, which is very important for animal feeds.

Table 29. Field evaluation of salt-tolerant Pearl Millet genotypes

Pearl Millet Varieties	DF (days)	DM (days)	PH (cm)	NT (#)	PL (cm)	DBY (tha^{-1})	1000 seed wt. (g)	GY ($kgha^{-1}$)
Werer research station								
IP-13150	96.67	127.33	163.86	5.33	21.12	11.72	11.58	1200
IP-19586	102.75	131.67	175.86	4.67	14.97	9.46	11.62	1042
LSD (P<0.05)	2.89	NS	15.01	NS	4.97	NS	NS	101.5
CV (%)	14.52	13.10	14.09	21.60	14.01	13.95	13.71	10.54
Fentale farmers field (Oromia)								
IP-13150	92.09	129.67	198.90	5.96	26.60	11.43	13.29	1136
IP-19586	103.04	136.67	188.90	4.40	16.06	8.467	12.25	1008
LSD (P<0.05)	3.21	NS	NS	NS	5.92	NS	NS	137.8
CV (%)	14.52	13.10	12.31	19.97	7.90	13.95	3.37	3.65

DF = Days of 50% Flowering; DM = Days of 50% Maturity; PH = Plant Height; PL= Panicle Length; RL= Root Length; DBY= Dry Biomass Yield; GY= Grain Yield.

Under high saline conditions, pearl millet varieties produced more than 1.0 tha-1 grain yields and 10 tha-1 dry biomass yields. These are very encouraging results for the highly saline areas of Ethiopia. This shows that these two ICBA introduced pearl millet varieties can successfully be grown to improve the productivity of saline lands in Ethiopia. The soils of the Werer research station are also high in ESP, which means that these pearl millet genotypes can also survive in alkaline soils. Therefore, these varieties should be introduced to farmers of saline and saline-sodic areas.


Pearl Millet genotypes at the Werer research station, Ethiopia

5.2.5 Cowpea genotypes screening under field conditions

The cowpea genotypes showed significant differences in all growth parameters at the Fentale district. However, differences in the Mekhoni research station were non-significant except for dry biomass yield. The ILRI-9643 genotype produced superior grain and biomass yield than the other two genotypes at both locations. The grain and dry biomass yields were higher in MoARS than WRS (Table 30). This shows that these cowpea varieties are suitable for high lands with lower temperatures and higher rainfall.

Table 30. Field evaluation of salt-tolerant cowpea genotypes.

Genotypes	DF (days)	DM (days)	PH (cm)	DBY (tha^{-1})	GY ($kgha^{-1}$)
Mekhoni research station					
ILRI-9643	67.67	97.67	42.67	29.55	2345
ILRI-9334	70.67	97.67	36.00	22.16	2318
ILRI-12713	71.67	93.33	42.33	24.55	2297
LSD (P<0.05)	NS	NS	NS	1.25	NS
CV (%)	5.05	2.27	7.91	9.43	11.35
Fentale farmer field (Oromia)					
ILRI-9643	75.67	76.33	64.96	17.30	1047
ILRI-9334	75.67	95.33	55.40	12.72	582
ILRI-12713	55.33	95.33	63.13	12.53	754.4
LSD (P<0.05)	0.77	1.31	8.74	4.44	154.9
CV (%)	0.48	0.64	6.30	13.81	8.59

DF = Days of 50% Flowering; DM = Days of 50% Maturity; PH = Plant Height; PL= Panicle Length; RL= Root Length; DBY= Dry Biomass Yield; GY= Grain Yield.

5.2.6 Sesabinia sesban

Salinity stress affected plant height of Sesabinia sesban genotypes with varying magnitude. A significant difference ($p < 0.05$) in plant height was recorded for both harvesting times between tested Sesabinia sesban species. The ILRI-1178 was relatively taller (379.67 cm) than the Local genotype (366.50cm) and ILRI-1198 genotype (324cm) at first harvesting (Table 31). A similar observation was made at the second harvesting. The highest dry biomass yield was recorded for the local check than other genotypes.

Table 31. Plant height, fresh and dry biomass yields of three Sesabinia sesban genotypes.

Genotypes	Plant height (cm)		Biomass Yield (tha^{-1})			
			Fresh		Dry	
	1st harvesting	2nd harvesting	1st harvesting	2nd harvesting	1st harvesting	2nd harvesting
Local	366.00ba	357.00a	143.69ba	139.93	44.45	45.72a
ILRI-1198	324.00b	321.00b	141.29b	138.69	43.11	39.56
ILRI-1178	379.67a	366.33a	148.16b	137.48	42.39	43.19
LSD (P<0.05)	45.72	33.76	6.01	NS	NS	3.71
CV (%)	15.65	14.27	15.28	7.11	12.28	13.82

5.2.7 Rhoades grass genotype screening under control conditions

Figure 42 shows the impact of different salinity levels on shoot and root dry matter of three Chloris gayana genotypes. The highest shoot dry matter (71.2 g/pot) was obtained in ILRI-6633, whereas the lowest (60.3 g/pot) was recorded in ILRI-7384. The reduction in dry shoot matter was more pronounced at salinity levels of 15 dSm-1 and 20 dSm-1. Overall reduction in dry shoot matter from 0 to 20 dSm-1 was 18.0 g/pot for ILRI-6633, 21.5 g/pot for ILRI-7384, and 27.5 g/pot for CV-massaba. This demonstrates that the ILRI-6633 genotype has the lowest reduction in dry shoot matter with increasing salinity. The root dry matter ranged between 10.4–17.4 g/pot at 0 dSm-1, 14.2–18.4 g/pot at 5 dSm−1, 12.5–18.3 g/pot at 10 dSm−1, 12.2–16.4 g/pot at 15 dSm−1, and 10.0–12.2 g/pot at 20 dSm−1.

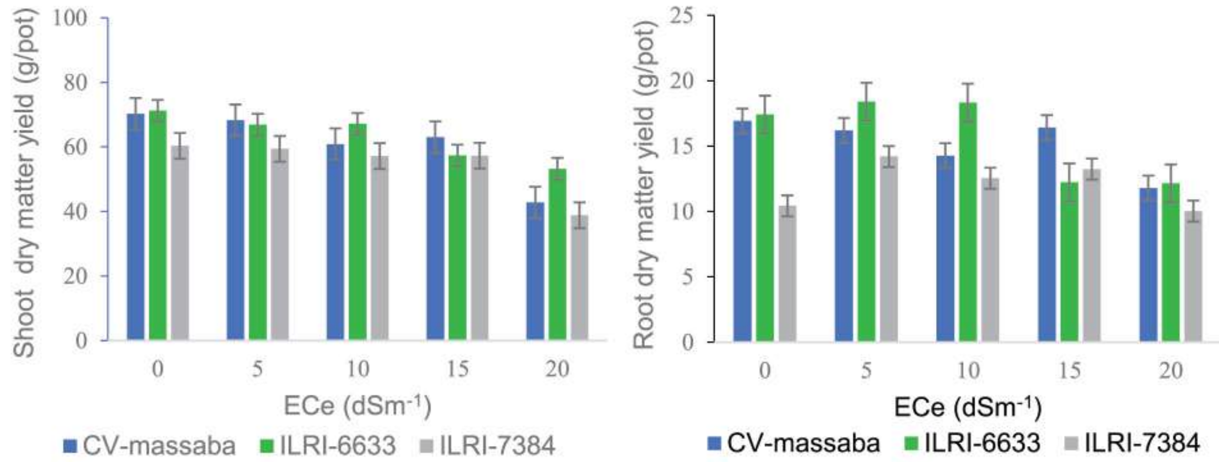


Figure 44. Shoot dry matter and root dry matter of three selected Chloris gayana genotypes.

The highest root dry matter was achieved for ILRI-6633, followed by CV-massaba at all salinity levels. The maximum root dry weight for ILRI-6633 and CV-massaba was obtained at 5-10 dSm-1. The average reduction in dry root matter ranged from 11.3-16.3 g/pot with an increase in salinity from 5-20 dSm-1. These declining trends could be because plants spend more energy to get water and nutrients from the soil under saline conditions. This situation negatively affects the yield and quality of the plant.

Forage grasses are the most remunerative form of animal feed in semi-arid regions. The nutritional value of forages mainly depends on their nutritional composition, such as crude protein (CP) and fiber and ash contents. Crude protein is an essential element of the animal diet that enhances their milk-producing capacity and maintains meat quality. Both CP and ash contents of three Chloris gayana genotypes exhibited a decreasing trend with increasing soil salinity. The highest CP (6.1%) and ash (15.5%) contents were obtained in ILRI-6633 and ILRI-7384 genotypes at low salinity levels (5 dSm-1). In contrast, CV-massaba reported the lowest crude protein (3.8%) and ash content (12.4) at the same salinity level (Figure 43).

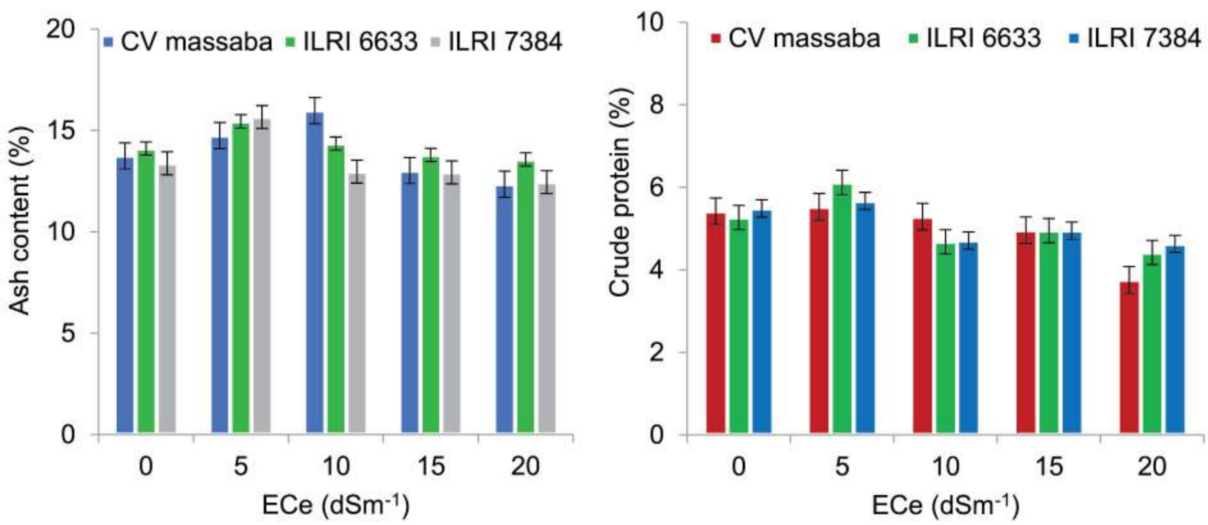


Figure 45. Effect of salinity on Ash content and Crude Protein on three Chloris gayana genotypes

Neutral Detergent Fiber (NDF) consists of hemicellulose, cellulose, and lignin. From the feeding point of view, lower NDF values are desirable for fodder and grains. The NDF values for all three genotypes showed an increasing trend with the growing salt stress. Differences in NDF among the Chloris gayana genotypes show a similar trend for CP. ILRI-6633 reported the highest NDF (70.9–73.9%) value, whereas the lowest values (67.5–72.9%) were observed in CV-massaba for all salinity levels. The average Invitro Dry Matter Digestibility Content (IvDMDC) was 42.9% for control, 41% at 5 dSm-1, 41.6% at 10 dSm-1, 40.2% at 15 dSm-1, and 36.1% at 20 dSm-1.

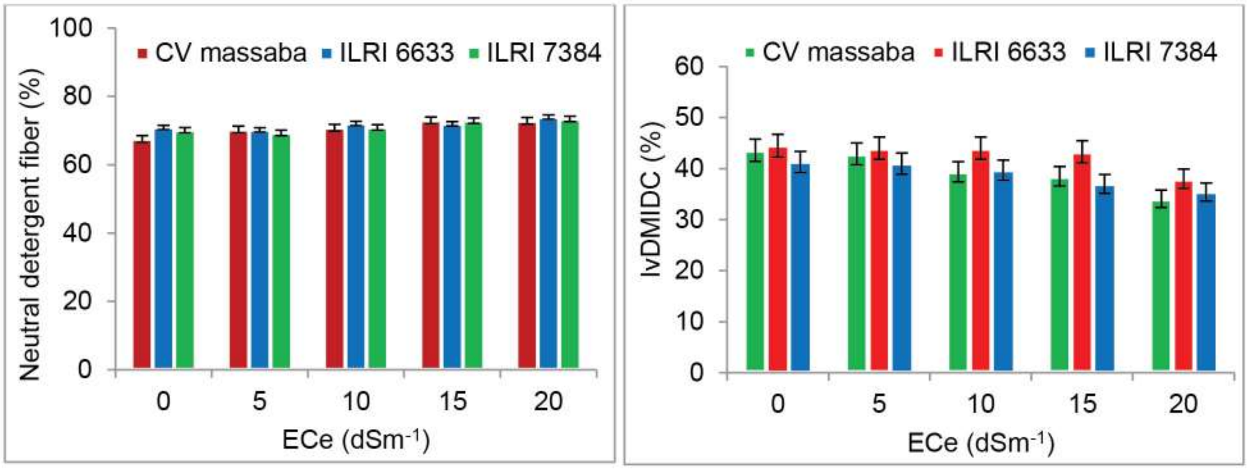


Figure 46. Effect of salinity on NDF and IvDMDC on three Chloris gayana genotypes.

5.2.8 Lablab purpure genotype screening under control conditions

The shoot and root dry matter yield was negatively affected by inflated salinity values (Figure 23). At control, ILRI-6529T showed maximum shoot biomass (44 g/plant) followed by ILRI-184T and local cultivar. The shoot biomass for ILRI-6529T was reduced to 39 and 35 g/plant at salinity of 15 to 20 dSm-1, respectively. The local cultivar was the lowest shoot biomass (35 g/plant at 15 dSm-1 and 30 g/plant at 20 dSm-1). ILRI-6529T genotype proved best for salt tolerance for above-ground shoot biomass.

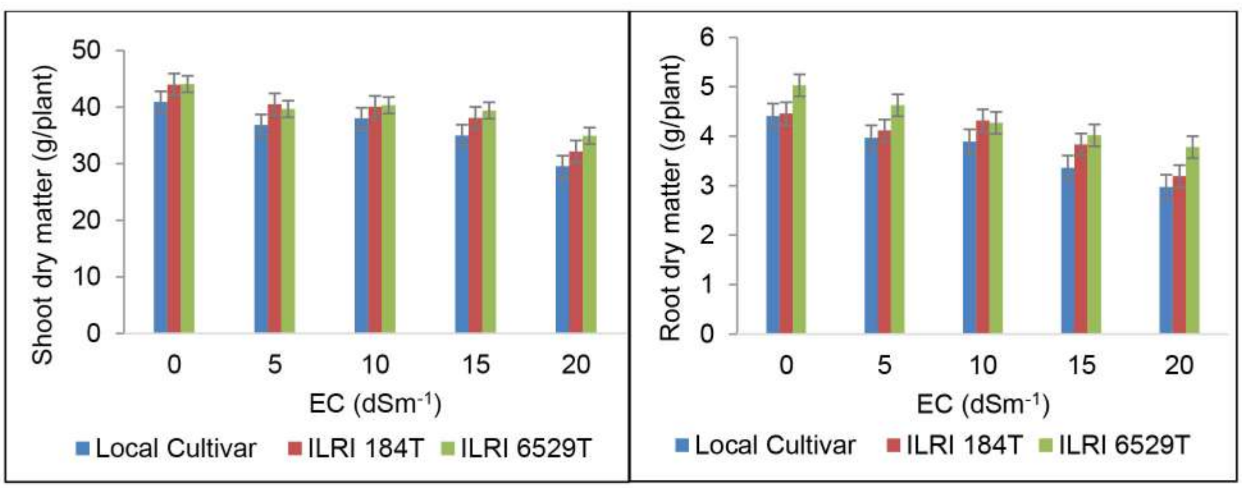


Figure 47. Shoot and root dry matter yield of three Lablab genotypes at different salinity levels.

The root dry matter yield trends were like that of shoot dry matter yield. ILRI-6529T showed the highest root dry matter for all salinity levels, followed by ILRI-184T and local cultivar. The maximum root dry weight for ILRI-6529T and ILRI-184T genotypes was obtained at 5-10 dSm-1. The performance of the local cultivar was the poorest of the other two genotypes. The reduction in dry root matter ranged from 1.2 to 3.9 g/plant with salinity increase from 5 to 20 dSm-1.

The forages legumes are the cheapest form of animal feed available in quantity and quality. The feeding value of forages is mainly dependent on the crude protein and ash contents. Crude Protein (CP) and Ash content of Lablab purpureus genotype were highly affected by salinity. The highest crude protein content (20.91%) and Ash content (20.76%) was obtained in ILRI-6529T genotype at 0 dSm−1. At the same time, the lowest crude protein (15.93%) and ash content (16.45) were analyzed in the local cultivar of Lablab purpureus (Table 32). However, the local cultivar of Lablab purpureus produced lower CP content at salinity levels of 10-15 dSm-1. Generally, low dry matter producing genotypes have higher nutritional value, and higher dry matter producing accessions have lower nutritional value in terms of CP at lower salinity. The effect of salinity on CP content of ILRI-184T was less pronounced than ILRI-6529T and local cultivar.

Table 32. Effect of salinity on Ash, CP, and NDF on three Lablab genotypes.

Parameters	Genotypes	NaCl salt level (dSm^{-1})					LSD ($p < 0.05$)	CV (%)
		0	5	10	15	20		
Ash (%)	Local Cultivar	19.16	18.98	18.20	17.16	16.45	2.45	13.51
	ILRI 184T	20.08	19.98	19.44	18.32	17.43		
	ILRI 6529T	20.76	20.08	19.4	18.29	16.55		
CP (%)	Local Cultivar	18.49	18.31	17.34	16.52	15.93	2.31	16.37
	ILRI 184T	19.67	18.98	18.35	18.21	17.18		
	ILRI 6529T	20.91	19.20	18.15	17.84	16.77		
NDF (%)	Local Cultivar	69.05	68.79	64.42	62.13	59.76	3.87	19.21
	ILRI 184T	74.97	73.23	69.96	66.72	62.16		
	ILRI 6529T	75.93	74.01	70.49	66.11	64.41		

LSD = Least Significant Difference; CV = Coefficient of Variation

Neutral Detergent Fiber (NDF) mainly consists of hemicellulose, cellulose, and lignin. From the feeding point of view, low NDF is a desirable parameter of fodder and grains. Neutral detergent fiber (NDF) showed an increasing trend with the growing salt stress. The genotypes with lower CP tend to have higher NDF values. ILRI-6529T has the highest NDF (64.41–75.93%), whereas the lowest NDF (59.76–69.05%) was found in CV-massaba for all salinity levels (Table 32).

The highest In vitro dry matter digestibility content (IvDMDC) was obtained in ILRI-184T at control, while the lowest was observed in the local cultivar of Lablab purpureus at 20 dSm-1 (Table 33). The ME content (MJ kg-1 DM) ranged from around 8.10 for local cultivar at 20 dSm-1 to 10 for ILRI-184T of Lablab purpureus genotype at 0 dSm-1, with a mean of 9.47. Generally, forage legumes like Lablab purpureus are of comparable quality with high CP, IvDMDC, and ME levels and low detergent fiber fractions.

Table 33. Effect of salinity on IvDMDC and ME on three Lablab genotypes.

Parameters	Cultivar	NaCl salt level (dSm^{-1})					LSD (p<0.05)	CV (%)
		0	5	10	15	20		
IvDMDC (%)	Local Cultivar	66.68	66.09	63.04	58.9	54.02	3.78	14.69
	ILRI 184T	69.19	68.86	65.14	60.16	57.44		
	ILRI 6529T	67.33	68.15	64.07	61.33	56.53		
ME (MJ kg $^{-1}$)	Local Cultivar	10.00	9.91	9.46	8.84	8.10	1.53	13.97
	ILRI 184T	10.38	10.33	9.77	9.02	8.62		
	ILRI 6529T	10.10	10.22	9.61	9.20	8.48		

(IvDMDC = in vitro dry matter digestibility content; ME = metabolizable energy; LSD = Least Significant Difference; CV = Coefficient of Variation)

5.3 Field trials in South Sudan

Field trials in South Sudan were conducted in five regional states. These sites were selected in collaboration with the Ministry of Agriculture and Food Security representatives, local research organizations, and research scientists. The chosen locations include Juba, Bor, Aweil, Kapoeta, and Renk regions (Figure 48). For each selected state, the number of sites was chosen as listed below:

1. Jubeik State (Juba) - Juba, Luri, and Rajaf
2. Jongule state (Bor) - Bor town, Panliet and Cuei Nyok)
3. Aweil State (Aweil) - Nyalith, Awulic, Rice Scheme Nogwe, and Kuom
4. Namurnang state (Kapoeta) - Kapoeta, Katico, Lomilmil and Kotomo
5. East Nile state (Renk) - Renk, Rumeila, Mangara, Khor Ajais, Abu Khadra and Feyuer

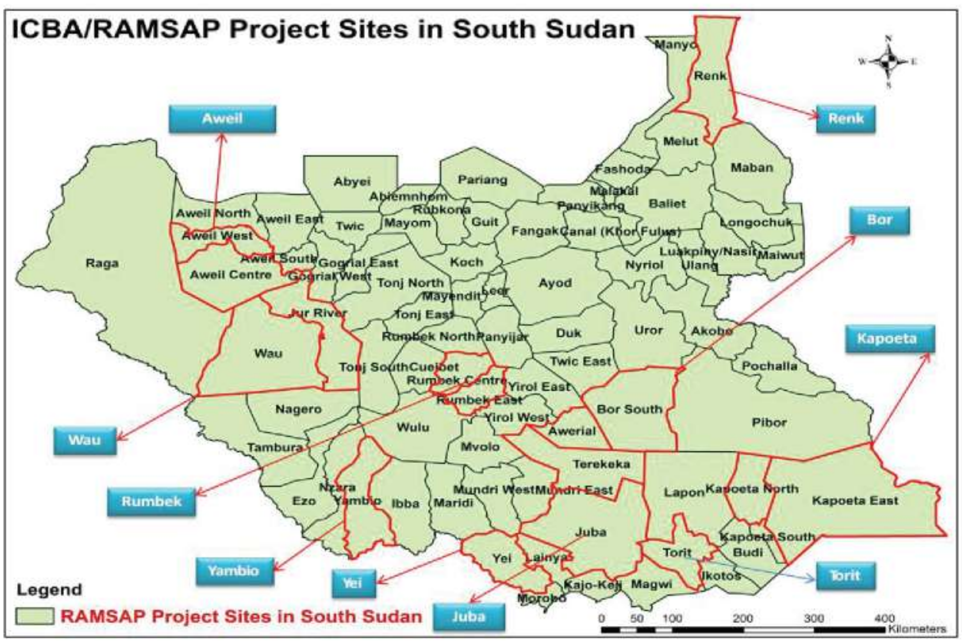


Figure 48. Location of the selected sites in South-Sudan.

Table 34. General characterization of selected sites in South Sudan.

No.	Site	Zone	Type of Crops
1	Aweil	Western Flood Plains	(Agro pastoralism): livestock and agriculture predominant. Main crops are sorghum, pearl millet, vegetables, cow peas.
2	Bentiu	Nile-Sobat Rivers	(Agro-pastoralism and fishing): prone to seasonal flooding. Major crops sorghum, beans, and vegetables.
3	Bor	Nile-Sobat Rivers	(Agro-pastoralism and fishing): prone to seasonal flooding. Major crops include sorghum, beans, and vegetables.
4	Torit	Hills & Mountains	Agriculture and livestock husbandry. Crops include cassava, sweet potatoes, sorghum, maize, finger, pearl millet.
5	Juba	Hills & Mountains	Agriculture and livestock husbandry. Crops include cassava, sweet potatoes, sorghum, maize, finger, pearl millet.

During the field trials, different genotypes of Barley, Sorghum, Cowpea, Sesbania, and Peal Millet were tested on farmer fields. These genotypes were provided by ICBA as listed in Table 35.

Table 35. List of food and fodder crop seeds imported from ICBA gene bank.

Common name	Scientific name	ID	Origin
Barley	*Hordium vulgare*	CM72	Egypt, Ethiopia, Tibet
Barley	*Hordium vulgare*	58/1A	Egypt, Ethiopia, Tibet
Cowpea	*Vigna unguiculata*	TVU9716	Africa, Latin America, South Asia
Cowpea	*Vigna unguiculata*	9333A	Africa, Latin America, South Asia
Cowpea	*Vigna unguiculata*	11114A	Africa, Latin America, South Asia
Sesbania	*Sesbabia sesban*	ILRI 9643	Tropical Africa and Asia
Sesbania	*Sesbabia sesban*	ILRI 1178	Tropical Africa and Asia
Sesbania	*Sesbabia sesban*	ILRI 1198	Tropical Africa and Asia
Sorghum	*Sorghum bicolar*	ICSV700	Northeastern Africa
Sorghum	*Sorghum bicolar*	ICSR93034	Northeastern Africa
Pearl Millet	*Pennisetum glauccum*	IP13150	Sahel zone of West Africa
Pearl Millet	*Pennisetum glauccum*	IP19586	Sahel zone of West Africa

Different crops grown on farmer fields in South Sudan

5.4 Results of field trials

Testing improved varieties was considered among the best strategies to improve production faster and obtain information about different crop varieties for specific areas. Therefore, ICBA varieties of cowpea, pearl millet, sorghum, and the various grasses could be grown in all the States in South Sudan where the demonstrations were established to maximize the yield potential for the smallholder farmers. They recorded high clean seed weight, low severities for major common diseases. They were relatively more stable throughout the vegetative and maturity stages than the local varieties used as checks. It is worth mentioning that South Sudan has trends of preferences both for cereals and legumes; therefore, the varieties that resemble the farmers' preference may be essential in promoting adoption.

The performance of the ICBA varieties is highly dependent on the farmer management and cropping system. This was noted on the differences in the performance of the varieties under on-farm demonstrations within different seasons. The wide range of growth habits among ICBA varieties has enabled the crops to be cultivated successfully under different agro-ecological environments of South Sudan. Most of the varieties were favored by farmers because of their early maturing uniqueness that enables households to get cash returns essential to pay for food and other household needs when other crops have not matured. Thus, it is essential to educate and create awareness to farmers to cultivate ICBA seeds or grains as a business rather than just for subsistence use.

Field preparation for demonstration and field trials

These crop genotypes were planted on farmer fields in all selected regions under the supervision of local agriculture and extension departments. The field size of the trial site was 3x3 feddans, with 48 blocks sized 5x5m. The trial was designed in a Randomized Complete Block Design (RCBD) with three replications. These trials were also used as demonstration fields to neighboring farmers.

During the field trials, ICBA genotypes recorded higher seed weight, low severities for common diseases, and more stability throughout the vegetative and maturity stages than the local varieties used as checks. It is worth mentioning that South Sudan has preferences for cereals and legumes; therefore, the crops that resemble the farmers' choice may be significant in promoting adoption (Table 36). The performance of the ICBA varieties is highly dependent on the farmer management and cropping system. The wide range of growth habits among ICBA varieties has enabled the crops to be cultivated successfully under different agro-ecological environments of South Sudan. Farmers favored these varieties because of their early maturing uniqueness that allows them to get cash returns essential to pay other household needs. Thus, farmers should cultivate ICBA seeds or grains as a business rather than for subsistence use.

At the same time, seed multiplication of the selected genotypes was done for scaling up in the designated areas. These activities were carried out along the River Nile and where the water source was available. Two locations such as Rajaf-East and Kapuri, were selected around Juba. In the Rajaf-East area, field activities were conducted on farmer fields by selecting active farmers. In Kapur, field demonstrations were carried out in the Farmers' Training Center. Farmers were provided all inputs, i.e., the entire operation cost (Land preparation, sowing, weeding, irrigation, pesticides in case of any infection, technical supervision, and harvest). Farmers were responsible for field operations.

Table 36. Selected results of field trials on different crops.

Site	Crops	Variety	Germination rate (%)	Flowering (Days)	Height at flowering (cm)	Grain wt/plant	Plant dry weight
Juba	Sorghum	ICSV-700	80	120	137.2	16.5	12.5
	Sorghum	ICSR-93034	75	120	147	18.2	15.5
	Peal Millet	IP-13150	70	63	110	5.3	3.2
	Barley	CM-72	86	64	123	4.5	2.3
	Cowpea	11114A	75	60	35	8.5	6.3
Kapoeta	Barley	58/1A	86	64	123	4.5	2.8
	Sesbania	ILRI-1198	85	60	66	5.1	3.2
	Sesbania	ILRI-9643	83	62	52	5.5	3.2
Aweil	Cowpea	TVU-9716	80	70	108	6.5	4.3
	Sesbania	ILRI-9643	85	60	66	5.1	3.2
	Sesbania	ILRI-1198	83	62	52	5.5	3.2
Bor	Cowpea	TVU-9716	65	63	52	6.5	4.5
	Sesbania	ILRI-9643	85	60	60	10.5	8.3
	Sesbania	ILRI-1198	80	60	51	8.7	5.3
Renk	Sorghum	ICSR-93034	80	120	163	22.5	18.5
	Peal Millet	IP-13586	85	60	110	5.5	3.2
	Peal Millet	IP-13150	88	62	105	3.5	3.3

Different crops are grown for seed multiplication in South Sudan

5.5 Managing irrigation at trial sites

Two water sources (i.e., river Nile and groundwater) were used for field demonstrations and trials. Water from the Nile is pumped to irrigate the demonstration and seed multiplication plots at the riverbank in Rajaf East. In contrast, the electric motor was used to extract groundwater to a storage tank located at the center of the field in the Kapuri farmers' training center. Realizing that without a continued supply of irrigation water, field trials and field demonstration of successful varieties will not be possible, the RAMSAP project supplied a water pump to the farmer in the Rajaf-East site to extract water from the Nile River irrigation. In Kapuri, the farmer's training center has a well-established water pump system, but it was out of service due to some technical breakdown. Therefore, the RAMSAP project did the maintenance, and now it is used to irrigate the cropped fields. In both locations, farmers were extremely happy for this assistance because now they can irrigate project fields and their fields where they have grown other local forages and cereals.

As mentioned earlier, access to irrigation water and its distribution within the field to increase water use efficiency and crop productivity is one of the biggest challenges for the smallholder farmers in South Sudan. Farmers usually do not have enough cash and technical skills to install irrigation systems in their fields. Therefore, a low-cost drip system was designed and installed at the Juba field site under this project. This system can be operated using groundwater and surface water from the river. Instead of traditional costly rubber pipes, this drip system has been designed using locally made PVC pipes of different sizes. These pipes are cheap and durable and cannot be damaged by rodents (Figure 49). The system can effectively work for 10 years if properly maintained.

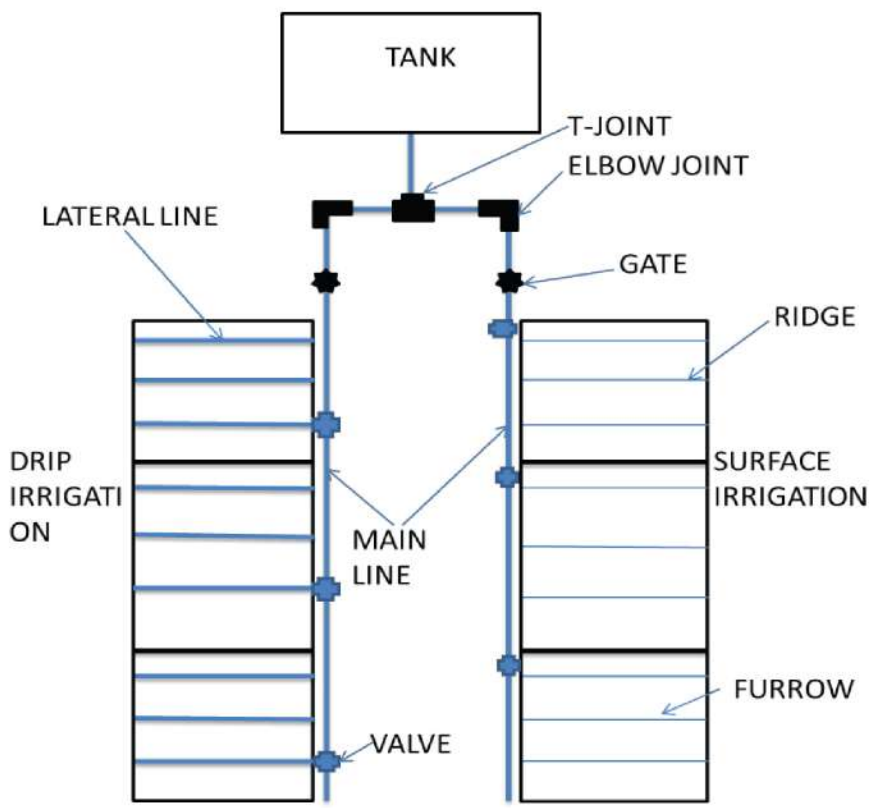


Figure 49. Layout of the installed irrigation system at Juba

This system can be re-adjusted to different crops grown in each season. The system has got great acceptance by farmers due to its low cost and ease of operation and maintenance. A groundwater well (6m deep) was also installed to ensure sustained irrigation water supply to crops. Irrigation water was pumped from the nearby rivers at the other four sites. Therefore, no groundwater wells were planned.

Before the commencement of field activities, farmers were trained on using and maintaining the water pump for irrigation purposes. The irrigation water supply is crucial in South Sudan, especially dry season. Most farmers rely on small plots along the river Nile to produce vegetables for domestic and commercial purposes. Farmers highly appreciated the introduction of ICBA salt-affected crop varieties. These farmers consider them very good for increasing their production and farm incomes.

The farmers from nearby villages also came to see the crops grown by ICBA seed, and they asked for seed as well. Therefore, the seeds will be distributed to these farmers after the crop harvest as part of our scaling-up activities. It was proposed and agreed that each farmer who will get seed from ICBA will further distribute it to at least five farmers to multiply the benefits for the rural community. This model will enhance cooperation among farming communities. Through this initiative, farmers will also learn from their experiences about managing soil and water resources to increase their productivity.

This project has enabled Linkages' development between local seed companies and MoA through meetings, farm/field visits, and telephone calls. Consequently, seed companies are also multiplying cowpea seed. The Gumbo Glow seed companies visited the field sites and promised to start setting up demos on their fields by the first season of 2020, and after that, they can take over the multiplication of seeds. The seed companies also showed interest in ICBA materials which were still under evaluation.

Eleven genotypes were selected for field demonstration and seed multiplication purposes (Table 37). The demonstration fields were established according to the ICBA recommended protocol whereby each crop variety was planted in 10*10m plots. For seed multiplication, farmers were provided with all inputs such as fertilizer, seed, pesticides, and other necessary information about the crop's sowing and care. Farmers were also trained to harvest the crops, separate the seed, and keep it healthy for scaling up. During the crop growth period, the field staff of the DRT visited field sites to monitor the progress and guide farmers.

Table 37. Genotypes multiplied in South Sudan for scaling up

S/N	Crop	Variety	Origin
1	Cowpea	ILRI 12713	ICBA
2	Cowpea	ILRI 9331	ICBA
3	Cowpea	AGRAC01	South Sudan
4	Sorghum	ICSV700	ICBA
5	Sorghum	ICSR93034	ICBA
6	Sorghum	Gadam	South Sudan
7	Grass	Sesbania 1198	ICBA
8	Grass	Chloris gayana	ICBA
9	Peal Millet	IP 13586	ICBA
10	Peal Millet	IP 13150	ICBA
11	Peal Millet	Local	South Sudan

5.6 Conclusions and recommendations

The rising global demand for food has challenged scientists to look for alternate crops, especially for the marginal areas where agricultural production is inefficient due to unfavorable climatic conditions, low soil fertility, and lack of good quality irrigation water. In many of the Middle East and African countries, scientists experiment with different crops tolerant to salinity and use much less water than other crops. Against this backdrop, this study was designed to assess the feasibility of genotypes of different crops for the dry and saline soil under controlled and field conditions. The seed germination and crop yields were adversely affected by the rising salinity. The salinity impedes seed germination either without loss of viability at higher salinities and/or by inducing stress to seeds. The effects of five soil salinity levels on the agronomic and nutritional quality parameters were evaluated on different food and fodder crops under other agro-climatic conditions in Ethiopia and South Sudan. The main findings for each crop are briefly discussed below:

The tested barley genotypes showed significant differences in grain yield, dry biomass yield, and spike length. However, differences in days to 50% emergency, days to 50% maturity, number of tillers per plant, and plant height were non-significant. The CM-72 genotype performed superior in grain yield compared to CM-58/1A. However, the highest dry biomass yield was recorded in CM-58/1A. Both genotypes performed better in relatively less saline and wet regions.
Sorghum genotypes showed significant differences in all parameters except panicle length at high salt stress. Among the sorghum genotypes, Melkam was superior in terms of grain yield than ICSR-93034 and ICSV-700 genotypes. However, ICSR-93034 and ICSV-700 genotypes produced higher dry matter yields than the local Melkam genotype. This made these genotypes highly attractive for animal feeds. Farmers prefer these two varieties because they have reasonable grain yields and significantly higher biomass.

Under field conditions, the IP-13150 genotype produced higher grain and dry biomass yields than the IP-19586 genotype. The highest dry biomass yield was recorded in IP-13150, which is very important for animal feeds. The field data shows that pearl millet varieties produce more than 1.0 tha-1 grain yield and around 10 tha-1 dry biomass yields under highly saline field conditions. These are very encouraging results for the highly saline areas of Ethiopia. This shows that these two ICBA introduced varieties (IP-13150 and IP-19586) can successfully be grown to improve the productivity of saline lands.

The cowpea genotypes showed significant differences in all growth parameters under field conditions. The ILRI-9643 genotype performs superior in grain and biomass yields than the other two tested genotypes (ILRI-9334; ILRI-12713). The grain and dry biomass yield of ILRI-9643 was higher than the two different genotypes. This shows that this cowpea genotype is more suitable for high lands with relatively lower temperatures and higher rainfall. Therefore, it would be wise to recommend these varieties for this area.

The three Rhoades grass (Chloris gayana) genotypes (ILRI-6633; ILRI-7384 and CV-massaba) for dry and hot conditions of Ethiopia were evaluated. The highest germination rate, lowest germination time, maximum plant height, and the number of tillers per plant were observed in ILRI-6633 compared to ILRI-7384 and CV-massaba. Root length was more affected than the shoot length at all salinity levels for all genotypes. Increasing soil salinity negatively affected the shoot and dry root matter of three Chloris gayana genotypes. The reduction in dry shoot matter was more noticeable at the higher salinity levels (15-20 dSm-1).

There are considerable differences in various plant growth parameters with the increasing salinity on five quinoa genotypes. The most limiting factor for decreased plant growth was the reduction in photosynthesis expressed in chlorophyll production. We suggest that plant breeding should focus on developing new genotypes that can withstand salinity and have high antioxidant activity in the future. In this study, the performance of ICBA-Q3 was superior, followed by ICBA-Q4 and ICBA-Q5. However, further optimization of these genotypes is recommended to enhance their productivity.

The agronomic and nutritional composition of three L. purpureus genotypes (ILRI-6529T, ILRI-184T, local cultivar) showed a declining trend with the growing salt stress. The results of this study indicate that the ILRI-6529T and ILRI-184T genotypes performed superior compared to the local cultivar in terms of all agronomic and nutritional parameters at all salinity levels. Therefore, these two genotypes can be grown in salt-affected areas to increase the productivity of the livestock sector.

The agronomic and nutritional composition of two Sesbania sesban genotypes (ILRI-1198, ILRI-1178) and local cultivar) showed a declining trend with the growing salt stress. Both genotypes gave the highest maximum shoot and root length compared to local genotypes. Shoot length was less affected than root length for all genotypes and salinity levels. The shoot and dry root matter were affected more under high soil salinity conditions. The chlorophyll content (SPAD value) showed a falling trend at 15-20 dSm-1. The CP and IvDMD contents were higher for ILRI-1198 and ILRI-1178 than local genotypes. IvDMD content and metabolizable energy content were also negatively affected by increasing salinity.

In South Sudan, ICBA genotypes also recorded higher seed weight, low severities for common diseases, and more stability throughout the vegetative and maturity stages than the local varieties used as checks. It is worth mentioning that South Sudan has preferences for cereals and legumes; therefore, the crops that resemble the farmers' choice may be significant in promoting adoption. The wide range of growth habits among ICBA varieties has enabled the crops to grow under different agro-ecological environments of South Sudan. Farmers favored these varieties because their early maturing uniqueness allows them to get good cash returns. Thus, farmers should cultivate ICBA seeds as a business rather than for subsistence use.

At the same time, seed multiplication of the selected genotypes was done for scaling up in the designated areas. These activities were carried out along the River Nile and where the water source was available. Two locations such as Rajaf-East and Kapuri, were selected around Juba. In the Rajaf-East area, field activities were conducted on farmer fields by selecting active farmers. In Kapur, field demonstrations were carried out in the Farmers' Training Center. Farmers were provided all inputs, i.e., the entire operation cost (Land preparation, sowing, weeding, irrigation, pesticides in case of any infection, technical supervision, and harvest). Farmers were responsible for field operations.

06 SCALING UP OF RECOMMENDED TECHNOLOGIES

6.1 Challenges for wide-scale adoption of recommended technologies

Scaling up best practices for broader adoption and institutionalization faces technological, socio-economical, and institutional problems. Challenges driven by the absence of small-scale irrigation infrastructures, incorrect perceptions, and lack of awareness and knowledge of farmers and extension advisors are also equally important. Despite these challenges, many opportunities could harness scaling up efforts such as the existing institutional arrangements (specifically, the presence of extension advisors at kebele level in research stations nearby), the growing demand for high-value agricultural products from the ever-increasing middle-class population, and the increase of innovative young farmers in the community. These kinds of scaling, institutionalization, and wide-scale adoption challenges are discussed in this section concerning the best practices of the RAMSAP project. For each identified challenge, possible solutions and existing opportunities are highlighted.

6.1.1 Limited awareness among farmers and extension workers

Socio-economic baseline survey in the target areas of Ethiopia and South Sudan revealed that limited awareness and information about the causes of salinity among farming communities result in a limited ability to take appropriate measures to mitigate salinity. The report also indicates that the frontline extension workers, who are the primary source of agricultural information, should be trained in the basic skills and knowledge about salinity. This suggests that increasing awareness and capacity among farmers and extension workers is of utmost importance for preventive measures against the worsening soil salinity and sodicity conditions. In addition, the lack of trained human resources to manage irrigated agriculture was among the significant problems in irrigated commercial farms. Irrigation water is primarily controlled by untrained irrigation crew who have no concept of proper water application regarding amount and frequency based on crop and leaching requirements. As a result, poor water management and lack of adequate drainage facilities have contributed significantly to the groundwater build-up in a short period.

The limited awareness among farmers, extension workers, and irrigation agronomists points to the need to provide capacity-building training on salinity management options to extension workers and farmers alike. Farmer awareness creation can be achieved by employing local FM radios to send critical messages related to saline soil management. In this regard, the traditional means of information exchange (the dagu system) can disseminate information on saline soil management. Organizing on-job training for the extension workers requires skill transfer and exchange visits. Short-term training of relevant practitioners at all levels, including experience sharing study tours in the field of irrigation water management and irrigation agronomy, would be necessary. The extension workers are graduates of the Agricultural colleges, but the training lacks practical field attachments to irrigation sites. This calls for institutional capacity and strengthening of agricultural education and training effectiveness, including curriculum revision to include practical training on irrigation water management.

Further, the lack of on-job training and other field level incentives (e.g., transport such as motorbikes) to stay in their position and perform as expected is often weak. This needs to be addressed by the policymakers at MoA. The envisaged plan was to assign a team of extension workers composed of an expert in natural resource management, livestock/veterinary, crop agronomy, and cooperative development experts at Farming Training Centers (FTC). The Development Agents (Das) team in Ethiopia is expected to support farmers in knowledge and information transfer and demonstrate modern production practices.

6.1.2 Lack of good quality seed

The supply of good quality fodder seed is a significant scaling challenge to disseminate the salt-tolerant crop and fodder species and varieties. The promising salt-tolerant fodder grasses (Rhoades grass, Sudan grass), legumes (alfalfa), and food crops (barley, quinoa, and brush sorghum) have already been identified and screened by the RAMSAP project. Most of these species are heavy seeders to ensure germination under fallow with no or light cultivation and produce enough hard seed to persist in the cropping system. Many indigenous forages grow in the dry regions of Ethiopia, which can be used as feed. This germplasm can be evaluated, and promising species identified for incorporation into livestock production systems. However, no public institution is mandated with fodder seed multiplication in Ethiopia and South Sudan. The seed enterprise in these countries is engaged with the multiplication and distribution of the seed for staple cereals (maize, wheat, barley, sorghum).

With increasing degradation of the pasture and a critical shortage of livestock feed, there is an increasing trend of developing backyard fodder reserves among pastoralist communities. This offers opportunities for forage seed multiplication. The experience of innovative and model farmers who have already started backyard fodder production can be used for forage seed production with some level of training and technical assistance. The newly launched LLRP and NGOs/development partners can assist in purchasing seed from producer farmer groups for distribution to other farmers. Farm saved seeds have already been collected from the farmers who participated in the RAMSAP project.

6.1.3 Policy misperceptions towards pastoral lowlands

The (agro-) pastoral communities inhabit the arid and semi-arid lowlands. In these areas, the salt-affected soil naturally occurs due to geochemical processes and inappropriate water management when irrigated agriculture is practiced. However, a fundamental misunderstanding of the pastoral mode of production seems to exist in land use and land management under pastoral production systems. Due to the pastoral land use system based on seasonal mobility, pastoralists cannot administer and implement tax revenue collection. Hence, there has been a limited effort to mainstream pastoral land management in the national policies and programs. Because pastoralists move over a large area searching for pasture and water for their animals, policymakers believe that pastoral lands have no potential for agricultural production unless irrigated and are considered unproductive and left for ranches and national parks.

This policy misperception can be removed by opening a dialogue with policymakers to improve their understanding of the problem and its future implications. This can be achieved by organizing high-level policy excursions to field sites, meetings, and workshops to open dialogue. The production and distribution of policy briefs and technical papers based on in-depth thematic studies and establish thematic platforms such as research-extension platforms saline soils at regional and national levels.

6.1.4 Lack of inter-institutional collaboration

Several government institutions are involved in managing salt-affected soils and irrigation water quality. Usually, their roles overlap, and they do not talk to each other and make independent policies. Therefore, there is a need to Establish a solid inter-institutional collaboration mechanism. Coordination and concerted actions are needed to enhance collaborations, experience exchange, and avoid duplicated efforts in rehabilitating salt-affected soils. The involvement of experts from regional and federal extension departments in preparing best practices creates a sense of ownership of the best practices. It paves the way for their incorporation in the national/regional extension packages.

6.2 Recommendations to address the gaps and challenges

There is an increasing realization of rehabilitating the existing salt-affected soils and preventing their further spread in the newly developed irrigated areas. Several technologies are readily available for the reclamation of saline and sodic soils. However, soil salinity problems in Ethiopia are complex, and straightforward solutions do not exist. The approaches need to be multidimensional and consider the biophysical and socio-economic conditions of the target area and the livelihood aspects of the associated communities.

The guiding principles in planning the strategies should include (1) following a people-centered approach that deals with people, their sensitivities, resources, and livelihoods and that has a closer alignment with national/regional development plans through the bottom-up planning and demand-driven extension process; (2) adopting an integrated approach involving agro-economic (on-farm soil and water management options) and socio-economic (institutions/services, input/output prices, market linkage, farmers' knowledge, and perceptions) considerations; (3) integrating a local capacity building for farmers, extension workers/advisors; and (4) linking with policy – demonstrate evidence to formulate realistic and favorable policies for management of land and water in the irrigated areas; and (5) creating awareness on the extent and impacts of the problem among policymakers.

The following recommendations can be made for policymakers, extension workers, and farmers to rehabilitate salt-affected soils and halt further expansion of secondary salinization and sodification:

6.2.1 Promote Biosaline agriculture

Under the prevailing economic conditions and low levels of technological development in Ethiopia and South Sudan, bioremediation is an economical and practical approach to use unproductive lands to grow food crops and fodder grasses/legumes on saline/sodic marginal soils. The Biosaline approach is advantageous because it increases economic benefits and solves the problems of saline effluent disposal. It can also effectively assist in lowering the groundwater table (via bio-pump) to reduce waterlogging and consequent salinity in irrigated areas (fodder trees/shrubs serve as biological pumps).

Forage production on saline soils can help increase the livestock productivity constrained by feed shortage in the drylands. Many prime grazing and water points are being converted into irrigation farms (state or private) and, in some cases, for ranching. Introducing salt-tolerant and high-yielding fodder grasses and legumes is of paramount importance for the backyard forage production schemes and the integration of forage legumes into cereal production systems.

Engineering solutions to waterlogging and soil salinization in irrigated agriculture are expensive for a low-income country like Ethiopia and technically complex. Such options often cause water pollution and environmental degradation when drained water containing high soluble salts and sodium mixes with irrigation water. Therefore, bio-drainage can be a viable option to control the rising groundwater table above critical depth for crop growth. Exploring the possibility of bio-drainage for waterlogged saline lands through the plantation of salt-tolerant trees (e.g., sesbania sesban) can reduce the volume and cost of drainage.

In this regard, the demonstrated evidence of the ICBA-RAMSAP project has generated scalable experiences and best practices as outlined earlier. These tested practices in target areas should be scaled out to more expansive areas where salt-affected soils are prevalent. To fully exploit the full potential of halophytic and other salt-tolerant plant species, there is a need to increase the performance of plant species used to manage salt-affected soils.

6.2.2 Improve drainage and leaching systems

In all field-based reclamation activities, a balance between irrigation, leaching, and drainage must be kept to prevent irrigated lands from excessive waterlogging and salinity problems. In large-scale irrigated farms, adequate drainage systems should be critical for rehabilitation activities. Therefore, it is essential to make a comprehensive cost/benefit analysis associated with constructing drainage facilities or repairing and functionalizing the existing damaged infrastructures developed by the state farms. This is crucially important in the context of the renewed interest to expand irrigated wheat production in the semi-arid areas to ensure food security. FAO guidelines for rehabilitation drainage systems should be applied to these systems. Timing of leaching (intermittent, regular, etc.) should precede the critical growth stages at which stress should be prevented. The periodic leaching is considered more effective than continuous leaching. Since salt is more damaging to seedlings, applying leaching water is more effective during pre-plant irrigation to reduce salt in the seed zone and salinity through the soil profile.

6.2.3 Improve on-farm water management

Irrigation inefficiency is the single most important cause of waterlogging and soil salinity. Water application above crop and leaching requirements contributes significantly to waterlogging, groundwater build-up, and soil salinization. Hence, it is crucially important to avoid flooding/basin method of irrigation and adopt efficient irrigation methods (requirement, frequency) based on crop requirement. Sprinkler irrigation allows control of the amount and distribution of water. To this effect, it is essential to develop manuals, bulletins, and flyers as guides for better water management practices.

6.3 Strategies for scaling up

The ICBA-RAMSAP project has tested the importance of biosaline agriculture as a remedial measure for soil salinization in Ethiopia and South Sudan. This approach integrating crop and forage-livestock production systems is hugely important for the pastoral/agro-pastoral communities that inhabit the salt-affected areas. When combined with appropriate on-farm soil and water management practices (e.g., normal leaching/flashing), the approach forms an effective strategy to alleviate soil salinity. In this regard, the demonstrated evidence of the ICBA-RAMSAP project has generated a substantial amount of data and information on selected salt-tolerant crops and fodder species of economic importance.

The project has introduced more than 25 genotypes of different food and fodder crops and shrubs that produce excellent biomass yield under high soil salinity levels where no output is expected from cultivating other field crops. What remains to be done is to activate the extension service for scaling up these genotypes to all salt-affected areas with some level of adaptation and validation. The scalable experiences gained and best practices validated need to be scaled out to more areas where saline soils are prevalent.

Serious attempts should be made to generalize the local level results for wider scale dissemination through the extension systems. Since identification, documentation, and scaling up of best practices are vital components of the extension strategies, ample opportunities exist. Still, efforts need to be made to document, characterize, and scale up the ICBA-RAMSAP experiences with farmers. This chapter aims to provide policy guidelines for successful scaling and broader uptake of the best practices following a brief theoretical discussion on the conceptual issues of scaling up/out.

6.3.1 Theoretical building blocks of scaling

Scaling generally refers to bringing more quality benefits for more people over a wider geographic area more quickly, more equitably, and sustainably. Simply, the term scaling is used to refer to the adoption, adaptation, uptake, and use of innovations and agricultural best practices across a broader range of actors and or geographical areas. Scaling involves horizontal (scaling out) and vertical (scaling-up) elements. Horizontal scaling (scaling out) refers to increased adoption of agricultural innovation, expanding the geographical area of innovation beyond the original intervention area covering more people and communities. Vertical scaling (scaling-up) refers to the institutionalization of a piloted approach within the government system involving the participation of stakeholders and decision-making at a higher level. However, it is an entirely separate concept of scaling up and out because they are interactive processes (Figure 50). Some spontaneous or organic scaling up process occurs when local stakeholders integrate the best practice on their initiatives while a project is doing scaling out activities in a particular target area.

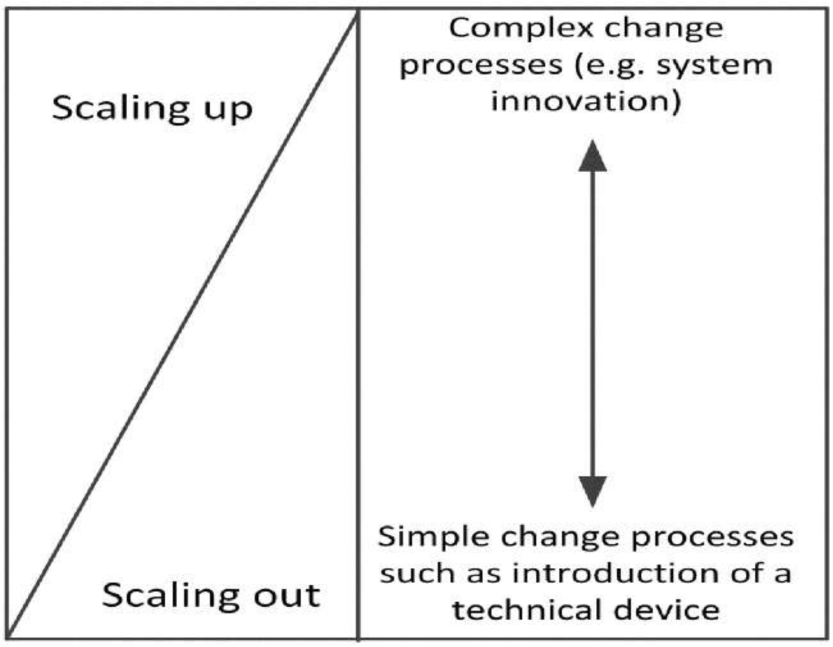


Figure 50. The interactive process of scaling up and scaling out

Scalability and complexity are also different in scaling out from scaling up. Whereas scaling out involves replicating the same prototype, scaling up requires adapting and applying innovations to different contexts involving many actors and institutions. Scaling up means system transition, and it relates directly to the scale 'levels' - from crop field level to farming system and from local to regional/national policy level. In other words, vertical scaling means crossing scale levels, while scaling out (horizontal scaling) means increased adoption within the particular scale level. There has been a recent surge of interest in scaling, specifically natural resource management and agricultural research. Achieving impact at scale has been one of the most significant challenges in agricultural development. Many decades of agricultural research that developed technologies to increase agricultural productivity have failed actually to do so. In countries where smallholder farmers pre-dominantly practice agriculture, uptake of these technologies has been poor. There are various reasons for this, such as the agro-ecological conditions in which the farmer operates not being conducive for the uptake of a specific technology or the institutional setting, not supporting innovations.

Scaling up cannot be implemented in a business as a usual mindset; it demands new ways of organizing things, an innovative institutional setup, communication and knowledge generation, and a platform for sharing. Scaling is designed to stimulate a broader scale change to the target clients and the government policy, operational modalities, and institutional setup and structure. Smallholders' agriculture is dynamic and subject to change as much as capital-intensive agriculture. While change is happening all the time, it can be slow or fast, deliberate or spontaneous, negative or positive. Empirical studies show that change will be positive, immediate, and more beneficial through planning and intentional action. This calls for understanding the drivers of change and harnessing these powerful in uences. The drivers of change are enormous. They can be internal or external; they can also push or pull changes. Most often, changes happen as the result of a multitude of factors.

6.3.2 Understand the drivers and inhibitors of adoption

Identifying the drivers and pathways to promote more extensive adoption of agricultural technologies is a crucial step in the scaling process. Better understanding is needed of the factors that in uence the adoption and diffusion of technology and the inhibitors of technology adoption at various levels of aggregation (field, farm, community, etc.). Experience suggests that successful adoption and uptake of technologies depends on a favorable con uence of technological aspects, economic conditions (household resource endowment, labor supply), institutional (access to credit, market), and policy (right to land and water, pricing) factors.

Understanding the link between drivers of technology adoption or a best practice is essential (Figure 49). For instance, climate change forces smallholder farmers to adapt alternate cropping patterns, mix livestock types, and start early or late. Hence, scaling up must understand the drivers or inhibitors of adaptation to change by adopting best practices and scaling up the same for the best outcome. The drivers of adoption may include technology supply, institutional support (market, extension advice, credit), population, policy, etc., which can be called push factors. The access to credit, household income, livestock ownership, farm size, level of education of household head, and membership to a primary cooperative are among the significant drivers of adopting the extension package delivered to farmers. Among the adoption inhibitors were the high cost of inputs (fertilizer, seed, etc.), labor demand (e.g., for row planting), low-profit margins, and unavailability of good quality seeds.

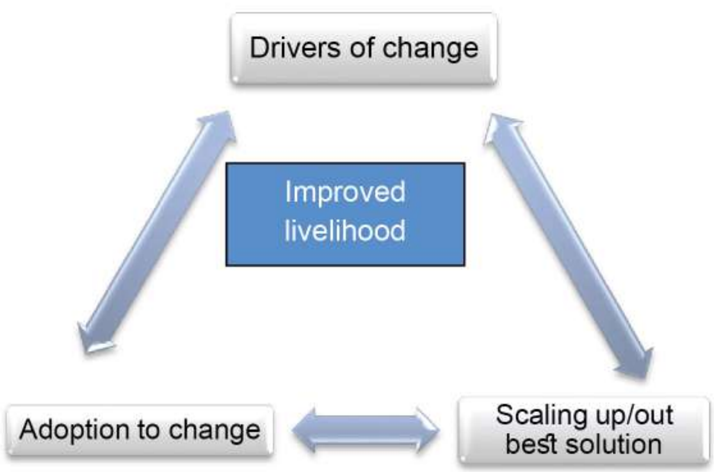


Figure 51. Linking drivers of change, adoption, and scaling up (Kommen et al., 2013)

6.3.3 Define recommendation domains and development pathways

Recommendation domains are defined as a group of farmers whose circumstances are similar enough that the same recommendation can be given. Recommendation domains may be defined by agro-ecological and/or socio-economic (human) circumstances. As long as there is heterogeneity among farmer groups depending on their socio-economic characteristics, farm characteristics, and wealth, then uptake of innovations and recommendations for scaling out will rely on the specific target group. Similarities in the biophysical environment such as agro-ecology, soil types, climate, topography, and socio-economic conditions (e.g., market access, extension service, livestock ownership) are essential for scaling innovations and best practices from sites of testing/piloting to areas of scaling for more comprehensive implementation. Differences in agroecology affect the production potential, while differences in socio-economic circumstances affect farmers' ability to exploit the area's agricultural potential.

To give appropriate recommendations about innovations and agricultural best practices, we have to look into the composition of the farmers within the experimental areas, farmers' views about the 'innovations', and the socio-ecological niches for a particular innovation. From this analysis, a best-fit strategy might be deduced. In general, blanket recommendations of technologies and innovations do not work; matching innovations to target groups can increase the successful uptake. Targeting can be done at various scales – from field to farm to the community to regional scale. Recommendations based on farm typologies (model vs. non-model farmers) can be a step between understanding the drivers for adopting innovations and horizontal scaling up or scaling out. This could be an essential step leading to the success or failure of a particular innovation, as a single technology will never be suitable for all farmers for a variety of reasons.

6.3.4 Evaluate promising best practices for different recommendation domains

As implied in the best practice definition above, a best practice is best for a given set of biophysical (soil conditions, agro-ecology, land use, etc.) and socio-economic (market, labor supply, etc.) conditions. Using Participatory Rapid Assessment (PRA) tools, testing and validating promising technologies involving researchers, extension workers, and farmers should be conducted. The effectiveness of current practices should be evaluated against set indicators as a pre-condition for scaling up/out of best practices. The validation/verification process provides evidence to determine under which biophysical and socio-economic circumstances a method functions as expected. Therefore, the nationally harvested best practices are required to pass through the validation process by the research system and development partners.

Regarding the biosaline approach of remediation of salt-affected soils, we assume that the ICBA-RAMSAP project has already implemented this step with the national and woreda stakeholders, including EIAR and the woreda office of agricultural extension. Through a bottom-up planning process, RAMSAP tested and validated several promising salt-tolerant fodder species such as Chloris gayana, Coloured Guinea (Panicum coloratum), and crops (barley, quinoa, sorghum) in target sites. We now know the conditions in which these best practices can be scaled out/up, reaching more farmers and geographical areas.

6.3.5 Preparation of best practices manuals and their inclusion in the extension package

Developing a technological package consisting of best practices should be the essential first step outlining the conditions for successful implementation and ensuring its wide-scale adoption in different recommendation domains. Best practice manuals should be prepared for each of the components. The package should be based on field-tested best practices and demonstrated evidence under farmers' conditions, such as the biosaline technologies tested by the ICBA-RAMSAP project in target areas.

Institutionalizing the best practices into the national and regional extension package and woreda development plan is an example of vertical scaling of innovation. The continuous engagement with policymakers at different levels – woreda, zone, region, and national – made it possible to incorporate some of the validated best practices into the government plans and strategies. The extension directorate has now formulated new extension packages for model farmers to grow maize, wheat, potato, soybean, faba bean, malt barley, and garlic.

6.3.6 Prepare simplified extension training materials in local languages

There are often language barriers for extension advisors, subject matter specialists (SMSs), and DAs to understand the best practice manual and innovation guidelines written in English due to their limited knowledge of technical/agronomical jargon. For this reason, it is necessary to translate best practice manuals into local languages. In addition, appropriate media of communication and language must be selected for the training sessions and best-fit practice briefing workshops. Furthermore, we learned that linear transfer of technologies does not always work, as seen with maize and malt barley in the southern region. Different materials targeting different groups should be considered.

6.3.7 Capacity development of extension workers and farmers

Diagnostic studies done under the RAMSAP project in the target areas have shown that lack of awareness and knowledge about the saline/sodic soils among the local communities and the managers, supervisors, and the irrigation crew of the irrigated farms has failed to implement the available solutions. Due to the lack of farmer skills in irrigation water management, salinity problems worsen. For instance, due to poor land leveling and use of flooding irrigation, water use efficiency is only about 35% in many areas. Uneven water distribution due to poor land leveling produces low and high infiltration rates, making low and high salinity patches within the same field. Therefore, comprehensive training of extension staff and farmers will be required to implement best practices and technologies available to rehabilitate saline/sodic soils.

Therefore, extension officers, development agents, and farmers should be fully trained in all aspects of crop tolerance and production (soil, water, climate, and crop management) under saline conditions. The training should include field assessment of saline/sodic soils and reclamation methodologies, including drainage, crop production technologies, and management. The training of trainers (TOTs) may be given to the woreda SMSs who then train the field staff at the FTCs. Different training modules and facilitators' guidelines and manuals should be prepared appropriately for each training group. The idea is that stakeholders can prepare training guidelines and simplified extension messages on different aspects of soil salinity and irrigation water quality management. The key informant interviews show that the farmers have limited experience in mixing ratios, irrigation amounts, frequencies, and cultural practices (e.g., land leveling, minimum tillage, crop residue mulching, etc.) that help avoid salt accumulation in the root zone.

An effective means of skills training and capacity building for farmers are using the FTCs by encouraging information exchange and knowledge sharing among fellow farmers. This can be further enhanced by adopting the farmers' research and extension groups (FREGs) widely used in the AGP/CASCAPE projects. Although the FAO promotes the farmers' field schools (FFS), the FREG widely experiments in the Ethiopian agricultural research and extension system.

6.3.8 Awareness creation among policymakers

As indicated in the guiding principles of planning strategies, it is essential to link the field demonstrated evidence to policy at regional and national levels. Policymakers lack awareness of the extent, cause, and impact of salinization/sodification. This is evidenced in the lack of an elaborated institutional strategy and priorities specific to Ethiopia's rehabilitation of salt-affected soils. A fundamental policy misunderstanding regarding land management under pastoral production systems exists. High-level policy engagement and awareness creation on the problem of salt-affected soils is essential to encourage the formulation of realistic and favorable land and water management policies in the irrigated areas. This goal can be achieved by opening a dialogue with policymakers to improve their understanding of the problem and its future implications. The management options for salt-prone land and water resources built on the accumulated wisdom of relevant stakeholders will assist in adopting these crops by communities. Policy engagement by pastoral communities residing in the salt-affected soil has been weak partly due to a lack of field-based empirical evidence on the problem of salinization/sodification. Field investigation generates essential empirical evidence that would form the basis for engagement with policymakers to formulate favorable policies that would address land degradation from salt accumulation.

In this regard, the experiences and results obtained by the ICBA-RAMSAP project are essential to be shared with policymakers at regional and national levels. These results can be helpful to take a more proactive policy lobbying and advocacy work to address the general land degradation and salinization of irrigated lowland agriculture. Proper understanding of the ecology of the traditional pastoral production system and the complex customary arrangements for resource management is necessary to formulate appropriate land policies that can halt ever-increasing soil salinization.

6.3.9 Incentives for farmers and enabling environment for DAs

A conducive enabling environment is an essential factor in scaling. Without appropriate incentives, innovation would be hampered, and the process of scaling-up would not be successful. Scaling up operations needs to include incentives for the key actors, mainly farmers, and DAs. The scaling process and uptake by farmers consist of different elements such as building effective extension systems; policy reforms on input/output pricing; expanding access to credit and financing; accounting for social, cultural, and political realities on the ground; and building local cooperation and partnerships.

Due to limited economic benefit, farmers (agro-pastoralists) are less interested in adopting best practices. Access to institutional and financial support positively stimulates technology adoption by relaxing the liquidity constraint and boosting a household's risk-bearing ability. A proper study on market pull and production push should determine whether market demand for commodities is expected to rise, resulting in increased commodity prices. If this is the case, farmers are likely to invest in these practices. Cost/benefit analysis should understand how initial investments will lead to higher returns.

For scaling up the biosaline agriculture practices, it is essential to create market linkage for fodder-producing farmers to have economic benefits. As highlighted in earlier sections, there is a soaring market for hay in the beef and dairy sectors in major regional cities. Creating linkages between local communities, industry and traders is of utmost importance to exploit the full potential of the feed market. Local youth/agro-pastoral communities can go beyond backyard fodder production to hay production to supply booming beef and dairy farms. But first, it would be necessary to train them. Since field staff plays a vital role in farmers' technology dissemination and uptake, special training should be arranged. In addition, they should be facilitated with equipment, and resources to carry out their tasks more efficiently.

6.4 Seed distribution in Ethiopia

Crop plants differ in their ability to survive under saline conditions. Information on crops' relative tolerance to salinity is critical to plan cropping schedules. There are situations where farmers must live with salinity problems, e.g., areas with saline irrigation water. In areas where good quality water is available for irrigation, crops can be grown with reclamation efforts to make reclamation economical. Studies done under the RAMSAP project showed promising results in salinity tolerance, biomass yield, and ameliorative effects for different forage and legume crops.

Based on the agronomic and economic efficiency, about 25 genotypes of five different crops were selected for scaling up in other areas. These include Sorghum, Barley, Cowpea, lablab, and three forages (i.e., Rhoades grass, Panicum, and Cinchrus grasses). These recommended genotypes have shown superior performance in production potential, nutritious values, and increased economic returns under salt-affected conditions than the existing local crop varieties. For these reasons, farmers in the four regions (Afar, Amara, Oromia, and Tigray) have shown great interest in these crops and forage varieties. The seed multiplication units were established in different research stations and farmer fields. In the Werer research station, genotypes of three forage crops (Cowpea = 3; Lablab = 3; Rhoades grass = 3) and two food crops (Sorghum = 3; Barley = 2) were cultivated on 11 ha. These crops produced more than 15 tons of seed for different crops. About 500 grams of seed was given to each farmer for testing and further multiplication.

Interested farmers from selected woreda of different regions were chosen to work with the extension workers to scale up the recommended seed. Each farmer was given the seed required to cultivate a 100 m2 area. This area size was preferred because most farmers were smallholders, and they could not afford to allocate more land to test a new crop variety. From each of the six districts, 50 woredas were selected. From each woreda, about 100 farmers were selected. This way, we were able to reach 30,000 farmers.

Besides, seed multiplication units were established in different regions. Seed multiplication activities were also carried out on farmer fields, and more than 2.5 tons of seed were obtained from these fields. Most of this seed was kept by farmers for the next season, and the remaining was distributed to 100 neighboring farmers. Therefore, this seed was not used for distribution outside the project areas. Before the large-scale distribution of seeds, special training is organized for extension workers to apprise them about these crops' different agronomic and physiological parameters. They are educated about appropriate sowing and harvesting times, soil, and water quality requirements, fertilizer, pest management issues, and safe storage of the produced seed.

6.5 Seed distribution in South Sudan

The project's focus in South Sudan was to provide improved food and fodder crops to help develop the livestock sector and ensure food security during the dry period. Since more than 70% of the population consumes cereals as the primary food, we introduced cereals that can grow in dry and hot environments with less water. Many of these crops, such as Sorghum and Pearl Millet, could also be used as fodder. The field trials indicate that the fresh biomass production of these crops is much higher than the local varieties. Therefore, farmers showed great interest in these crops.

The salt-affected lands in South Sudan are in the White Nile irrigation schemes. These areas have hardly been utilized for agricultural production despite having great potential due to freshwater availability from the Nile. Therefore, bringing these degraded lands to acceptable production levels is essential for food security and social stability. The baseline survey conducted under the RAMSAP project in South Sudan shows that 23.5% of the seeds cultivated by the farmers are from their savings, NGOs supply 13.5%, 62.5% are purchased from the market, and 0.5% from government aids. Low crop yields were reported due to poor germination of the seeds. Poor seed germination was due to the following:

- Lack of productive varietal testing, introduction, and development research.
- Inadequate crop varietal maintenance.
- Absence of local seed, thus foundation seeds of certified and/or commercial seed production.
- Lack of well-planned seed production, i.e., multiplication of seed up to the quantities needed,
- Lack of seed conditioning. Farmers' traditional seed saving methods handled the quantities of seed produced in a seed program. These damages stored seed. Therefore, seed threshing, drying, cleaning, treating, packaging, and storage facilities are required.
- Lack of proper seed marketing and distribution. Seeds have value only to the extent they are distributed to farmers and planted. Marketing, therefore, involves the promotion of the seed produced so that farmers demand it.
- Lack of quality assurance and control. The quality of the seed is crucial. Therefore, a system is needed to assure and control the quality of the seed produced and marketed. Seed certification, seed testing, seed legislation are mechanisms for ensuring and maintaining grain quality.

In the RAMSAP project, we undertook some activities to overcome the challenges before starting the upscaling. The primary focus was training the field staff on the production, harvesting, and storage of seeds. The training was conducted in all the selected seed multiplication sites and implemented scaling up. In many areas, farmers also attended training and shared their opinion about the scaling-up program. These include the following.

1. Establishment of field trials for imported and local varieties of cereals and legumes crops
2. Management of seed multiplication sides
3. Training of field supervisors on crop diseases and management, crop harvesting, and post-harvesting techniques to reduce losses
4. Training on the marketing of agricultural products
5. Training on field crop data collection and management
6. Training on land preparation, establishing, and planting
7. Training on storage of farm products
8. Training on seed packaging and storage
9. Training on management of covid19 impact on agricultural productivity

Scaling up resilient non-traditional crops to selected farmer groups in the project area was meant to be part of seed security. This would enable the sustainable capacity for farmers to have enough seeds from the different crops at the right agriculture calendar timing in all the different levels such as family, community, agro-ecological zone, or food economy zone. Interaction with the farmer groups indicated that although there is a local seed market, a seed may also be acquired inside communities and other neighboring communities. The seed market has no certified seed of improved varieties. The market is affected by the free seed distribution by Non-Governmental Organizations (NGOs) and governmental institutions. Because most of those NGOs import the seeds from neighboring countries, there is a risk of mixing, poor storage, and transport. Therefore, the scaling-up is the best option to reach many potential farmer groups/ individual progressive commercial farmers.

As per RAMSAP project protocol, South Sudan should reach 20,000 farmers. The project activities were implemented in the country's ten most potential agricultural sites. At each of the ten RAMSAP project sites in South Sudan, ten villages were selected and from each town. Around 250 farmers were targeted for seed distribution (10*250*8 = 20,000). This way, we reached 20,000 farmers. Among others, crop variation was critically important for these locations. Therefore, we focused on six crops for each site for upscaling. The beneficiaries include farmers from the rural areas (Individuals and groups), government institutions (ministries, universities, and high schools), private agricultural companies, and Agricultural NGOs.

Subsistent farmers dominate South Sudan; thus, to reach out to 20,000 farmers, the ICBA team packaged the different seeds in small packs of 750g each. About 16 tons of seed was produced through seed multiplication activities, distributed to more than 21,000 farmers at various locations in South Sudan (Table 6). The packing materials were prepared by preparing envelopes and then placing printed labels showing seed type, variety, and quantity. After the seed packing activities, seeds were distributed to targeted locations through air plans and vehicles depending on the distance.

See packing in South Sudan

Various approaches were used to cover the targeted groups in South Sudan. These include seed multiplication fields, locally available or imported from ICBA. Other approaches include extension work, i.e., farmer field schools and organizing field days at the selected demonstration farms to train farmers in optimal production practices. The trainers were the technical members of the RAMSAP project, technicians from the MoA, and food security at the state level for direct monitoring and supervision. The collaboration with some local partners was also considered.

A comprehensive scaling strategy was developed in the second approach, targeting crop production and consumption across South Sudan. Due to variation in food types in different parts of the country, five crops (Sorghum, Barley, pearl millet, Quinoa, and cowpea) were distributed. All the activities in the upscaling program build a good understanding of seed's primitive and catalytic roles in crop agriculture, which is essential for formulating effective agricultural and rural development strategies. Farmers are now aware that seeds are required in relatively small quantities, multiplied rather than consumed in the production process, familiar to all cultivars. On the other hand, farmers are now aware that seed has two disadvantages often overlooked compared to other inputs. They are alive and must be maintained in a living condition to fulfill their propagative function, and the seed production must be planned well in advance. They should be used on time and should not be kept for long. Before the scaling up, the seed labeling, seed weighing and packaging, and seed chick list and allocation activities were performed. Several meetings were organized with the farmer representatives, government officials, and other concerned authorities to distribute seeds among potential selected farmers. These include

1. Meetings with Directors and field supervisors at state levels
2. Interview with farmers' representatives on the seed.
3. Seed distribution.
4. On-Farm training on/ each location:
5. Importance of seed selections, management, and proper field operations
6. Selection of appropriate locations for better water management
7. Encourage farmers to produce more food to overcome food shortages.
8. Prepared farmers' fields for seed upscaling.

Training workshop before seed distribution in South Sudan

Quality improved seeds from various varieties ranging from cereals (Sorghum, pearl millet), legumes (cowpea), and grasses (Chlorosis Guyana, Sesbania). Packaging envelopes weighing half a kilogram each were prepared with labels indicating the name of the variety, the seeds' weight, production season, agronomic practices (spacing, number of seeds, depth of planting, etc.). To avoid contamination, the different crop seeds were weighed, packed, and sealed in the envelopes.

See distribution at different locations in South Sudan

Table 38. Distribution of seed and number of beneficiary farmers in different locations.

Sites	Crops	Quantity (kg)	Farmers	Site	Crops	Quantity (kg)	Farmers
Juba	Sorghum	650	900	Yei	Sorghum	650	900
	Peal Millet	450	600		Peal Millet	450	600
	Maize	450	600		Maize	450	600
	Cowpea	450	600		Cowpea	450	600
	Total	2,000	2,700		Total	2,000	2,700
Torit	Sorghum	650	900	Renk	Sorghum	650	900
	Peal Millet	450	600		Peal Millet	450	600
	Maize	450	600		Maize	450	600
	Cowpea	450	600		Cowpea	450	600
	Total	2,000	2,700		Total	2,000	2,700
Kapoeta	Sorghum	650	900	Yambio	Sorghum	650	900
	Peal Millet	450	600		Peal Millet	450	600
	Maize	450	600		Maize	450	600
	Cowpea	450	600		Cowpea	450	600
	Total	2,000	2,700		Total	2,000	2,700
Aweil	Sorghum	650	900	Wau	Sorghum	650	900
	Peal Millet	450	600		Peal Millet	450	600
	Maize	450	600		Maize	450	600
	Cowpea	450	600		Cowpea	450	600
	Total	2,000	2,700		Total	2,000	2,700
	All Total	**8,000**	**10,800**			**8,000**	**10,800**

6.6 Farmers' responses on seed distribution

High-level support: A proper plan within the government system that links the national government with state authorities is essential to meet the need and determination within the decision-making levels. The ministry must establish a standard seed development policy to ensure stability in the seed development program. This policy must prioritize the agricultural sector's total development, not only for seed, research, and extension. In the absence of such high-level support to assure a sustainable supply of personnel, finance, and land, a seed program cannot develop beyond its current level.

Productive plant research program: The cornerstone of a practical plant breeding, introduction, and varietal testing program is a seed program/industry. Organizing a seed program on local or unimproved varieties can rarely be justified. Improved seed production and processing practices might result from sporadic yield increases, but it has a negative long-term effect. History has proved that farmers have worked out practical approaches for saving seeds of self-pollinated varieties over hundreds of years. Most farmers require only a small quantity of seed for their plantings. They always rely on one type of seed until a better variety is introduced at the farm level. Due to the absence of sustainable funding in South Sudan, these associated activities are unsuitable.

Cultivator demand: Introducing a new variety is the most challenging task to develop a seed program. Therefore in our ongoing seed distribution activity, we are creating awareness among the cultivators of ICBA imported and local varieties from various South Sudan locations to use high-yielding crop varieties. The outcomes of this field activity will be evaluated at the end of the season after getting farmers' feedback and perception.

Sound plan and organized effort: Planning and management are the most influential driving forces of the seed program. So far, RAMSAP-South Sudan has a well-developed strategy for seed upscaling. The Ministry of Agriculture and Food Security, in collaboration with ICBA, takes the lead in the ongoing program. Good coordination between the national and state ministries is needed to ensure proper monitoring and supervision of the distributing, planting, and seed management. We understand that there is no formula for seed program success because its biological characteristics impose limitations. Aside from these limitations, we managed to provide a plan and organization that will foster maximum effectiveness and efficiency and encourage farmers, private persons, and institutions to become contract seed producers and other private persons and institutions.

A crew of trained personnel: Three components must be considered for seed production activities. These include seed production, processing, and storage. As per RAMSAP scheduled activities, we are at the production level, and the other remaining activities are theoretically implemented through training and workshops. Therefore, we are working with the farmers to implement the practical exercises. For the implementation of these activities, trained staff is the prerequisite.

Under the RAMSAP project, the seed of alternative crops was distributed to smallholder farmers in Ethiopia and South Sudan. The seed was distributed to over 50,000 smallholder farmers and agro-pastorals and their households. This will indirectly benefit more than 250,000 people covering 100,000 ha, assuming an average household size of 5. The improved seed of alternate crops will reach many farmers through this strategy. The cultivation of this seed will help improve the productivity of salt-affected lands, improve farm incomes, and enhance the livelihood of smallholder farmers. Farmers have shown great satisfaction and interest in these seeds to rehabilitate their salt-affected soils.

07 GENDER DIFFERENTIALS IN THE SALT-AFFECTED AREAS OF ETHIOPIA

7.1 Socio-economic status of rural communities in Ethiopia

In Ethiopia, 80% of the population lives in rural areas. About 98% of the rural population depend on agriculture for their livelihood. Crop production and livestock are dominant sub-sectors within agriculture, accounting for more than 60% and 20% of the agricultural GDP, respectively. Ethiopian agriculture is characterized by subsistence farming that depends on rainfall and is highly vulnerable to shocks. As a result, the vast majority of the country's population is in extreme poverty and faces persistent food shortages. Therefore, increasing agricultural productivity is crucial for developing the agricultural sector, which many constraints challenge, including soil fertility.

The productivity of the agricultural production systems in the country is highly constrained by degraded soils and increasing incidences of drought due to climate change. Ethiopia suffers from acute poverty, especially in rural areas, despite relentless efforts over the last two decades. In 2018, the Global Food Security Index (GFSI) ranked Ethiopia as 100th among 113 countries with food affordability, availability, quality, and safety. Ethiopia has been declared a state with a 29% prevalence of undernourishment, 201 kcal/person/day of food deprivation intensity, low diet diversification performance, food consumption as a share of total household expenditures, and proportion of proportion population under the poverty line.

Poverty is still predominant, particularly in rural areas of Ethiopia. About a third of rural households face food shortages at least one month a year. This figure drops to 21% for a small town. In June to September, food insecurities get severe, and this seasonality is more prominent in rural than urban areas. This indicates that rural areas, with more than 95% of the population depending on farming, are more vulnerable to poverty. This situation is further exacerbated by unfavorable climate conditions and low soil fertility in many areas. A household's welfare is often measured by the consumption or spending they make. According to the World Bank estimates, the median consumption in the rural areas of Ethiopia increased only by 7% during 2011-16, whereas it increased by 32% in the urban areas. Similarly, the actual consumption levels in 2015/16 were approximately 43% higher in urban than in rural areas.

The low welfare index in smallholder farmers is attributed to the fact that agricultural production is mainly used to secure food for home consumption and generate cash to meet other needs such as clothing, farm inputs, and other expenditures. The average landholding in rural areas of Ethiopia is 1.38 ha per household, which shows the small and fragmented nature of farmland ownership. Though this figure varies across regions and gender, the small land size per household shows that special attention must be given to increase agricultural productivity in areas with low soil fertility either because of salinity or acidity. This emphasis is desirable because: (i) smallholder agriculture is the most important sub-sector of Ethiopia's economy; (ii) there remains a high prevalence of poverty among smallholder farming communities; and (iii) there is an enormous potential to improve crop and livestock productivity using proven, affordable and sustainable technologies.

Effective sustainable development policy needs to understand the differences in poverty levels between different geographic regions of Ethiopia. For instance, most rural regions of the country did not experience a rise in consumption during 2011-16. For instance, except for a few, consumption level in other country regions was not statistically different. On the contrary, overall consumption increased in urban areas except for Afar and Amhara (Table 39).

Table 39. Household consumption (regional median annual consumption per adult equivalent)

	Total			Urban			Rural		
Region	2011	2016	Change (%)	2011	2016	Change (%)	2011	2016	Change (%)
Tigray	9,308	10,749	15.5	13,786	15,665	13.6	8,604	9,705	12.8
Afar	9,031	8,503	-5.9	11,317	15,339	35.5	8,277	7,892	-4.7
Amhara	9,395	9,219	-1.9	10,289	16,095	56.4	9,301	8,758	-5.8
Oromia	9,748	10,993	12.8	10,758	14,090	31.0	9,615	10,894	13.3
Somali	9,197	10,195	10.9	11,052	12,143	9.9	8,868	10,128	14.2
Benishangul-Gumuz	9,671	10,641	10.0	11,640	14,659	25.9	9,506	9,971	4.9
SNNPR	9,278	9,972	7.5	10,308	14,089	36.7	9,169	9,692	5.7
Gambella	9,134	11,382	24.6	10,304	13,862	34.5	8,837	10,210	15.5
Harari	11,255	16,739	48.7	12,448	18,392	47.8	10,638	15,607	46.7
Addis Ababa	10,377	12,718	22.6	10,377	12,718	22.6	-	-	-
Dire Dawaa	9,610	12,203	27.0	9,540	15,876	66.4	9,733	11,280	15.9

Through the RAMSAP project, ICBA has addressed the issues of rural women empowerment who make essential contributions to agriculture and the country's rural economy. Rural women often manage complex household tasks and pursue multiple livelihood strategies, particularly when threatened by adverse environmental factors such as soil salinity and droughts. Thus, understanding practical undertakings and attitudes of both men and women for women engagement in farm labor, controlling the household finances, engaging in leadership roles are critical inputs for policy decisions regarding women empowerment.

7.2 Theory of change

The theory of change assumed in this project is that rural farmers in salt-affected areas, including women, increase farm productivities. By strengthening rural women's access to resources for agricultural activities, entrepreneurial inputs, and coping mechanisms at the household levels, interventions can achieve inclusive growth by also harnessing women's contribution to and benefit from the economic growth anticipated in line with national, regional, and local level policies and plans. The theory of change for the project identifies three areas where change needs to happen for progress to be made on gender equality and women's empowerment. For gender equality to happen: (1) changes need to take place at the individual level, where individual capabilities must change; (2) changes must happen within institutions (changes in standards, norms, and practices) so that they promote gender equality and ensure equitable service provision; and (3) changes are required at the community level, where norms, attitudes, and practices that often undermine gender equality must be challenged.

The project adopted a multi-sectoral and comprehensive approach at three levels that reinforce and support each other by maintaining horizontal linkages using various entry points at the implementation level. The intervention should build individual skills and provide inputs for rural women to manage and expand their smallholding farms to increase their farm productivity. Developing such skills/capacities and support is assumed to affect changes at the individual level. For example, individual women improve livelihoods, food security, nutrition, and capacity to engage with formal institutions to access more benefits and influence in decision-making processes at household and broader levels (Diagram 1).

Diagram 1. A schematic illustration of impact way for RAMSAP project

Strategic impacts	Project outcomes	Project Outputs	Intervention Domains
Increased food security	Enhanced assessment of salt-affected lands in the irrigated areas and the capacity for identifying and managing most vulnerable farming communities	Most vulnerable irrigated salt-affected areas are identified in both countries	Soil salinity impacts
Improved nutrition and health	Improved and sustained farm productivity, stability in crop yields, increased farm returns of salt-affected farming communities, improved nutritional status and health of rural communities especially women and children	Alternative and modified and resilient crop and forage production are identified, tested (based on crop diversification, better livestock integration, forage processing and marketing etc)	Alternate crop and forage production systems
Reduction in rural poverty		Successful production system packages are disseminated and adapted by farmers	Socio-economic evaluation and policy constraints
More resilient environment	Inclusion of rehabilitation and management of salt-affected lands in the national policy and development agenda	Farmers including women, extension workers and project staff are trained and their skills enhanced	Capacity building
	Policy recommendations and guidelines are adopted by governments for change in policy and agricultural plans.	Seminars/workshops to create awareness among policy makers and managers are organized	Knowledge management and dissemination

7.3 Food insecurity and health issues in target areas

The study showed that decreased crop yields and increased cost of production due to salinity had caused food insecurity for the households because many could not afford higher production costs. Increased production costs imply that poor farmers cannot hire an additional labor force for their farmland. In contrast, decreased production implies that the amount of food available for farmers' household consumption decreases. Non-availability of adequate food for the household both in quantity and in its nutritional value and lack of access to safe drinking water creates health issues for the rural communities. The study showed many inter-related health issues observed in the population because of salinity. Farmers in Werer and Showa Robit districts showed similar concerns about health issues. The farmers mentioned several health problems due to soil salinity. These include skin problems, early birth of children, and poor energy levels due to low calory intake. These problems can further increase if no action is taken to address this issue.

Mohammed, a farmer aged 45, from Fantalle reports that:

"There is a water pump near our home, which was installed for the community for drinking water. When we drink that water, it tastes like salt; people who drink the water gradually start to feel sick. Slowly the saltwater affects their bones, especially backbones. So, when you walk around this town, you will see many people have hunched backs. They literally cannot walk straight. This is the effect of the drinking water we have in this area. Most of our land has stopped giving us yield; the salinity prevents our grain from maturing."

Contrary to Werer and Showa Robit districts, respondents of Raya-Alamata district reported clear evidence of salinity-induced health issues. More precisely, in the Raya-Alamata district, the effect of soil salinity on food insecurity is reported because of a continuous decrease in productivity from year to year. The majority of farmers in this area indicated that the farmland that utilizes irrigation water had experienced significant changes in production (94.2%). This has resulted in decreased food availability and loss of household income, leading to the migration of the younger generation out of the area. Furthermore, poor groundwater quality has affected people's health in the field by giving them skin disease and other related dermatological issues.

A male farmer from Raya-Alamata district *reported that:*

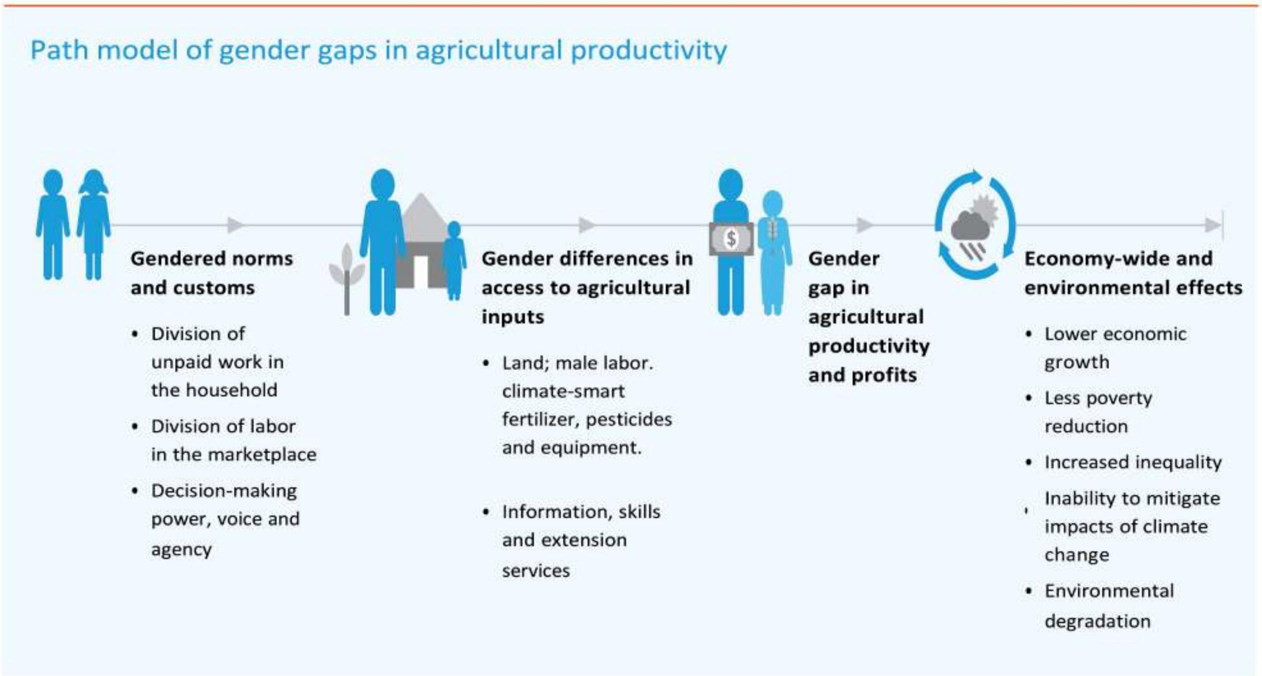
"Previously we used to work standing in the irrigation water the whole day without any problem. But now, if we stand in the water for an hour, our skin becomes itchy, so it seems the water is not good for our skins. Thus this irrigation water has become a threat not only to the crop but also for our human health".

Farmers in this district have also reported that unknown worms were found in their bodies even though they ensure they do not use the irrigation water for drinking purposes. Farmers also reported that the irrigation water is salty and contains other elements harmful to the inhabitants' health. Hence, in Raya-Alamata, irrigation water has a visible effect on human health.

7.4 Women's perspective on soil salinity problems

The knowledge of women perspectives on environmental and agricultural issues is essential for two reasons: (1) women in the developing countries are considered as the good custodians of the environment; (2) the existence of gender gap in agriculture is identified, a significant reason for overall low agricultural productivity in sub-Saharan African (SSA) countries. For instance, the UNDP-UNEP-PEI report has shown a significant gender gap in agricultural productivity across SSA countries, with an estimated 11% in Ethiopia. The gender gaps in agricultural productivity range from 8% in Kenya to more than 30% in Nigeria.

The determinants of gender gaps in agricultural productivity are women's low access to agricultural land, lack of cash income, and women's tendency to plant food that serves immediate family needs rather than to plant high-value crops. In Ethiopia, unequal access to male family labor accounts for about 45% of the agricultural productivity gap. The path model of gender gaps in agricultural productivity that affect the country's economy and environment is shown below.



Removing the gender gap in agriculture via increasing women's access to agricultural inputs and improving returns has economic benefits and reduction in poverty. It is estimated that, in Ethiopia, closing the gender gap can increase crop production by 1.4% that can add US$ 221 million in agricultural GDP (Figure 52). This strengthens the notion that women can play a vital role in sustaining the land, building resilience, ensuring food security, and improving the agricultural value chain, including availability and access to food.

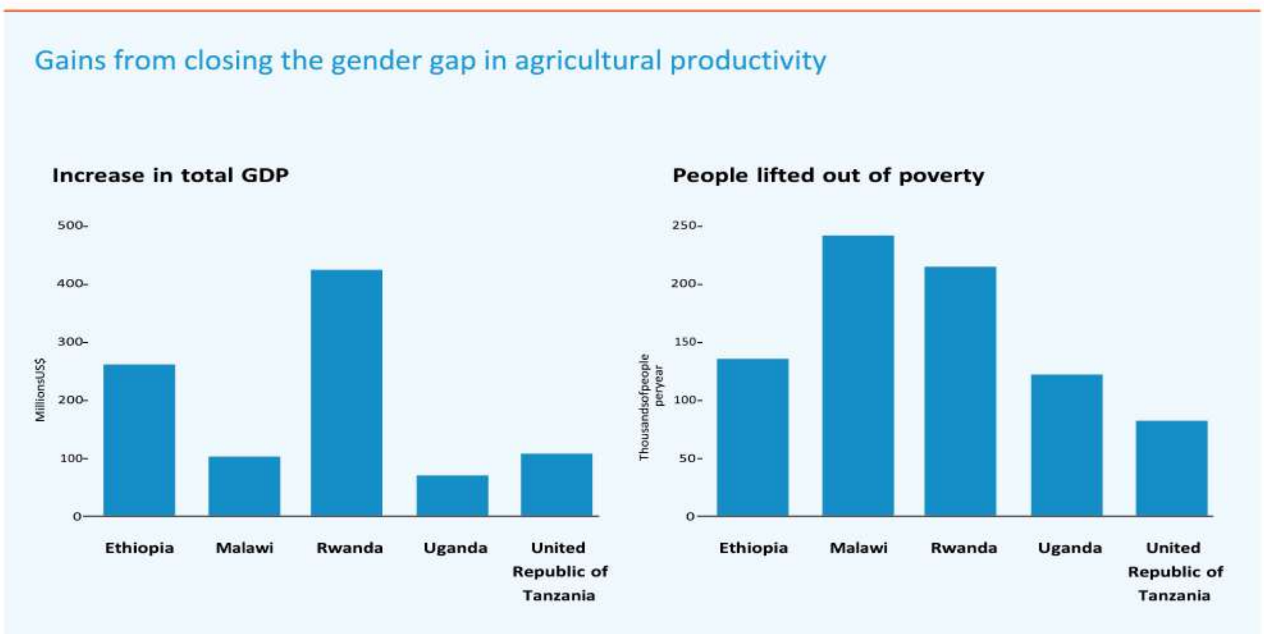


Figure 52. Gains from closing the gender gap in agricultural productivity.

The above discussion shows that including women's perspectives will enable an in-depth understanding of the problem. Involving women in solving the low productivity of soil via removing the gender gap in agricultural productivity will increase agricultural productivity and decrease rural poverty. During this study, special interviews and focus group discussions were organized with the women of the target areas to get their perspective on salinity and other related agricultural issues and get their feedback on possible solutions to overcome these challenges.

In line with other respondents, the women in the study areas also stressed the effect of salinity with reduced crop yields. They increased production costs, often not affordable for poor farmers, resulting in poor crop yields or abandoning their lands to relatively wealthy farmers who could afford the increased production costs. Women respondents also showed that only a tiny portion of their land is being used, intensifying the increased poverty in their communities. The household must hire many laborers and utilize additional fertilizers to perform agricultural activities, often not affordable to women or poor farmers. In the same way, women farmers have reported that most of their land has been rendered useless either because of the soil salinity or the flooding that changed their land into a salty lake.

Momina Musa, a female farmer aged 30, reports that:

"Soil salinity affected both our crop yield and our families' health, especially that of women and children. Women suffer from various health problems, mainly due to poor drinking water quality, making them feel excessive tiredness and dizziness. We find it very hard to get the energy to rise for work in the morning. This is because of the heat in this area which is intensified by salinity. We go to health stations frequently, but all the medicine they give us seems not working. Amazingly it seems all the women have the same health problem. So, we are less productive as human beings, although our work requires more energy. Even our children find it very hard to find the strength to rise and play like happy children. This salinity is decreasing our productivity and destroying our grains, damaging our health and the health of our children. Dizziness and joint pain have become a continuous challenge for us. Physically we are weak, and our bones are affected. Even our children do not look healthy. They remain sick and tired all the time. Therefore, we face enormous family and community problems because of the soil salinity".

Fatuma Ali (Werer Area), age 27, also reported that:

"The soil salinity has significantly decreased productivity in this area. Most of the soils in the area are covered with salt. The appearance of white salts on the soil surface becomes more prominent after rainfall events. Hence, after the rainfall, our whole village is covered with salt, and we avoid going out to work on the farmland. Due to this situation, we do not always have sufficient food to feed our family and animals. This causes weakness in our bodies, and we become more vulnerable to diseases. Children are more affected by this situation. As a result, our work efficiency is compromised, and farm production suffers. Children are reluctant to go to school because they feel active and energetic to bear long school hours. Due to poor feeding, our animals are also underweight. Therefore, we want the government and/or other international organizations to do the needful to solve soil salinity problems in our areas before it is too late.

7.5 Women in agriculture in the target areas

In rural areas of Ethiopia, mainly where the livelihood of the population includes pastoralism, most of the household work, including putting food on the table for the family, falls on the shoulders of the women. Under these circumstances, women are more vulnerable to salinity-induced health problems because they are subjected to more work pressure than men. The women have also reported the prevalence of such pressure on them. However, they are committed to being part of farm activities to improve the productivity of their degraded lands.

> *Rukiha Adam (Fantalle Area), age 38, reported that:*
>
> *"If I get help in making my land free of salinity, I will spend more time in farming and changing my life as well as the life of my children. Currently, both plots of my land are located at different sites, and they are badly salinized due to flooding from Lake Basaka. We know how to do farming well, but we cannot work because our land is now rendered useless as it is changing into small lakes than farmland."*

It is not always the case that women are considered contributors to improving agricultural productivity in Ethiopia. For instance, gender gaps in agricultural productivity in Ethiopia are about 11%, which is lower than in many neighboring countries. Figure 15 shows that there is still a great potential to improve agricultural productivity in Ethiopia by increasing the contribution of women in agriculture. This should include better access to agricultural land and credit facilities to buy agricultural inputs, assistance in reclaiming salt-affected lands, and access to local and regional markets.

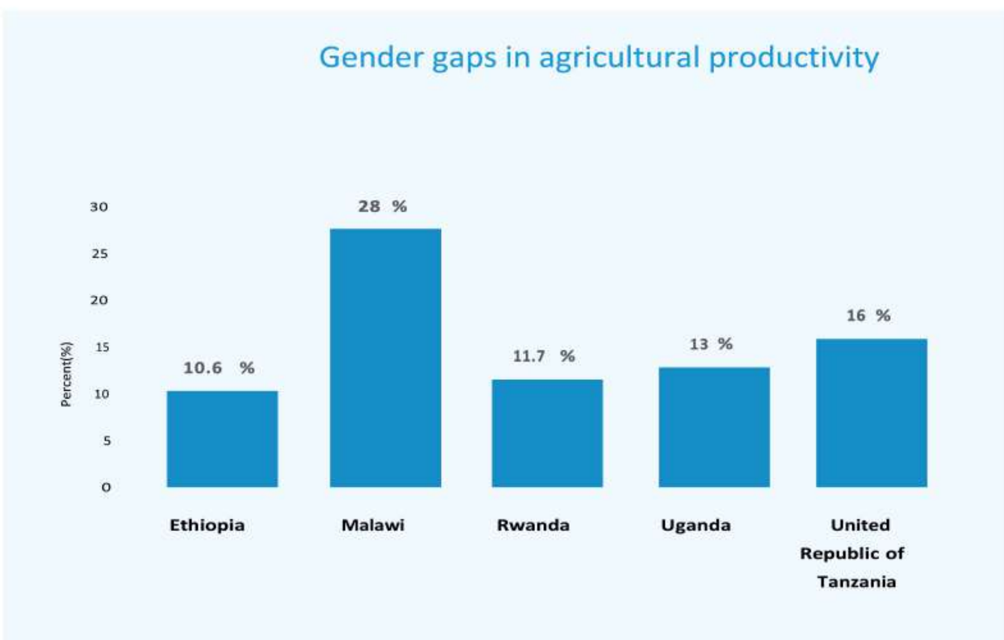


Figure 53. Gender gaps in agricultural productivity in selected SSA countries.

A practical assessment was done to understand women's problems and challenges for engaging them in agricultural activities. This enables us to directly assess the prospects of women's empowerment in agriculture in the project's target areas. In the Fantalle and Werer area, women participate in farming, while in Showa Robit and Raya-Alamata, women's participation in agriculture is limited even if they are household heads.

Fatuma Ahmed (Fantalle area), a woman farmer aged 40, reported that:

"Women are active participants in farming in this area. They will be on the field most of the time, helping and ensuring that food is prepared for the family at home. In the meantime, women are engaged in many household activities. Thus interventions such as providing access to salt-tolerant seeds to the household can positively affect the lives of the women."

In the Werer area, women are also actively involved in farming. Therefore, interventions by the RAMSAP project are of great value for women farmers.

Fatuma Ali (Werer Area), aged 27, reported:

"As a woman, we are interested in getting access to salt-tolerant seeds, especially those we can use for fodder because getting access to seed will help us increase the farm productivity. Thus, we are hopeful that the project will help us fight soil salinity and low productivity.

Since women are not involved in farming in Showa Robit and Raya-Alamata districts, these areas can be considered areas with possible challenges in women empowerment. It would be interesting to study why women are not interested in farming and what can be interested in farming. For instance, in the Raya Alamata district, it was found that women do not engage in farming even though they own farmlands. In cases where there is no husband to do the farming, women prefer to hire male helpers to do the farm work for them. In the same way, in Showa Robit district, it was reported that women do not engage in farming but spend most of their time taking care of the household chores. Engaging women in farming can help in decreasing production costs and increasing on-farm incomes to reduce poverty. However, this requires good motivation and incentives for women to view their social norms.

7.6 Attitudinal analysis of respondents on women empowerment

One of the factors contributing to the high gender gap in agricultural productivity between men and women is the existing social norms in the communities. It is often the case in rural areas of Ethiopia where women are expected to spend most of their time on domestic work. These norms reduce the amount of available time women can spend working on their farms. Moreover, these social norms also restrict women from participating in socio-economic, political matters that concern them.

The results show that societies' attitude towards women's empowerment is not as favorable as it should be. To examine this issue, we have made a general attitudinal analysis of all respondents based on four different women empowerment-related variables. The mean scores of all respondents on each variable are shown in Table 40. The results show that even though Fantalle and Werer areas perform better in engaging women in agriculture, the attitudinal score of whether women's role should be mainly household activities than outdoor work is lower than Showa Robit and Raya-Alamata districts. Therefore, to ensure that women directly benefit from the project, systematic discrimination against them should be considered rather than mere attitudinal analysis. This will help design the means and policies to engage women in the scaling-up processes for direct benefit and economic empowerment in the target areas. The aggregate attitudinal analysis in all regions is above average, as the Likert scale was coded from 1 to 5. This attitudinal analysis indicates that in all areas, respondents have a positive attitude in engaging women in farming and empowering them financially, socially, and politically.

	Fantalle	Werer	Showa Robit	Raya Alamata
I believe women role should be mainly household activities than outdoor work	2.267 (1.486)	2.867 (1.846)	4.333 (0.816)	4.063 (1.692)
I believe women should be empowered in financial terms equal with men	4.600 (0.632)	4.267 (1.438)	3.333 (1.862)	4.938 (0.250)
I believe women should be empowered in social participation on equal basis with men	4.533 (0.915)	4.400 (1.121)	3.500 (1.643)	4.563 (1.209)
I believe women should be empowered in political participation on equal basis with men	4.600 (0.507)	4.143 (1.292)	3.167 (1.722)	4.750 (0.775)
Overall attitudinal analysis at district level	4 (0.55)	3.9 (0.85)	4.6 (0.99)	4.9 (0.60)

(Mean coefficients; SD in parentheses)

7.7 Summary of findings

The soil salinity in Ethiopia causes land productivity loss, resulting in reduced farm incomes, food shortage, and increased poverty. Consequently, rural unemployment has increased, adding miseries to the life of people of salt-affected areas. Many have opted to work as daily laborers to win their daily bread rather than regular farmers. This has resulted in unprecedented migration of the family members to nearby urban areas exacerbating prevalent problems of urban unemployment. Most rural populations do not have clean drinking water, causing huge health problems for communities, particularly women and children. The inhabitants are gradually starting to feel sick. Backbone problems are most common. Therefore, many people have hunched backs, and they literally cannot walk straight.

Women are aware of salinity problems and their impacts on their lives. They are mainly concerned with increasing production costs, reduced yields, farm incomes, and health problems. The overall impact of this situation is increased food insecurity and household poverty. Women in Fantalle and Werer areas take part in farming, while in Showa Robit and Raya-Alamata districts, they prefer to focus on household chores due to socio-cultural norms. In the rural areas, mainly where the livelihood of the population includes pastoralism, most of the household work falls on the shoulders of the women. This makes them more vulnerable to salinity-induced health problems as they took more work pressure than men. This reduces their capacity to contribute to agriculture, although engaging women can decrease production costs.

Women's involvement in agriculture largely depends on the societies' attitude towards women empowerment, which is not always as favorable as it should be. The attitudinal analysis done under this study reveals that respondents have a positive attitude towards engaging women in farming and empowering them financially, socially, and politically in all regions. However, gender gaps in agricultural productivity in Ethiopia are still 11%, which is much lower than in many neighboring countries. It is estimated that, in Ethiopia, closing the gender gap can increase crop production by 1.4% that can add US$ 221 million in agricultural GDP. This shows a great potential to improve agricultural productivity in Ethiopia by increasing the contribution of women in agriculture. However, this should include better access to agricultural land and credit facilities to buy agricultural inputs, assistance in reclaiming their salt-affected lands, and better access to local and regional markets to sell their produce at competitive prices.

08 PROJECT MEETINGS, CAPACITY BUILDING, AND KNOWLEDGE SHARING

8.1 Project meetings and workshops

Project inception workshop

The project inception workshop was organized in Addis Ababa from March 23-24, 2016. The workshop was inaugurated by the Advisor of the State Minister of Agriculture and Natural Resources (MoANR), Government of Ethiopia. The workshop was attended by 45 participants, including representatives of MoANR-Ethiopia, the Ministry of Agriculture of South Sudan, researchers from local and international organizations, and ICBA scientists. During this two-day meeting, different aspects of the project implementation were discussed, an action plan was agreed upon, and the tasks of the first year of the project work plan were finalized. The roles and responsibilities of different partners and collaborating organizations were identified. The socio-cultural, organizational, and political issues in Ethiopia and South Sudan were discussed to implement the project activities smoothly. Based on these discussions, ICBA finalized the work plan, and project agreements with all partners were signed along with budget details. Following the agreements, funds were transferred to kick-off project activities in both countries.

Participants of the project inception workshop, Addis Ababa, Ethiopia

Following the project inception workshop, the first technical committee meeting was held in Addis Ababa on March 25, 2016, to finalize a detailed work plan for each project partner. The second technical committee meeting was organized in Addis Ababa on November 22, 2016, to review the project progress and plan for the next cropping season. The two-day meeting was attended by all local partners in Ethiopia and South Sudan and the ICBA team. This meeting was also attended by senior scientists of the agriculture ministry and other international organizations such as ILRI and ICRAF. The project's progress was satisfactory as the baseline survey was started, and the first field trials were established in Ethiopia and South Sudan.

Before the second technical committee meeting, a steering committee meeting was organized. The meeting was attended by the Minister of Agriculture of Ethiopia and the senior government officials of Ethiopia and South Sudan. The meeting reviewed the work plan to develop a consensus on project activities and financial matters of the project. This steering committee emphasized making the project activities part of the Ethiopian Institute for Agricultural Research (EIAR) annual research program. This was a good step because it can help local scientists benefit from the research being done under this project. The members from South Sudan also promised to include it in their annual program of the ministry for mutual benefit.

ICBA team with the Minister of Agriculture after the steering committee meeting in Ethiopia

During 2017, two technical committee meetings were organized to review the project progress in both countries and the work plan for the following year. Both meetings were organized in Addis Ababa, Ethiopia, as the security situation did not allow travel to South Sudan. These meetings were attended by EIAR staff, Ministry staff, researchers from national centers involved in the project, and members of the project team from South Sudan. The government representatives from both countries were appreciative of the progress. They commended the ICBA efforts to provide seeds of salt-tolerant food and fodder crops to improve the productivity of salt-affected and less fertile soils.

Technical committee meeting in Addis Ababa, Ethiopia

In February 2018, a second project steering committee (SC) meeting was organized in ICBA-HQ in Dubai. The meeting was attended by the State Minister of Agriculture of Ethiopia, H.E. Dr. Kaba Urgesa. The ICBA-DG, Dr. Ismahane Elouafi, briefed the SC members about the project's progress. The committee members showed great satisfaction with the project's progress and suggested further steps. The Minister thanked IFAD and ICBA for their efforts to support the Ethiopian government in combating soil salinization problems in Ethiopia. The Directorate of Research and Rural Development of South Sudan also expressed his appreciation for including South Sudan in this project. He mentioned that this is the first project where large-scale research and training activities are being carried out. He promised his full support for the project.

Members of the Steering Committee of the RAMSAP project at ICBA-HQ, Dubai

In 2018, two technical committee meetings were also organized in Addis Ababa, Ethiopia, to discuss the project's progress in both countries and agree on activities for the following year. The meetings were attended by EIAR staff, Ministry staff, researchers from national centers involved in the project, and members of the project team from South Sudan. The participants of the Ministry appreciated the progress made by this project. They emphasized the need for seed distribution among farmers of the salt-affected areas for use and further multiplication.

One brainstorming session and two consultative meetings with different stakeholders (Ministry of agriculture staffs, NGos, farmers union representatives, seed companies) and policymakers were also organized in Juba, South Sudan. The main objective of these consultations was to solicit political and administrative support for scaling up project activities in the target areas. Senior professors from Juba University, Upper Nile University, and Dr. John Garang University were invited to these meetings as special guests to formulate a scaling-up strategy.



ICBA team also held meetings with the local IFAD representative in Ethiopia to discuss the linkage between the RAMSAP and the IFAD-funded small-scale irrigation (SSI) project. Based on these meetings, the ICBA project team established two demonstration sites in the SSI project area in the Tigray region. The farmers of the SSI project area were provided with the seeds of high-yielding food and fodder crop varieties to get the maximum benefit of the available irrigation water.

The project developed an exchange program of scientists from Ethiopia and South Sudan. In 2018, five scientists from Ethiopia and three scientists from South Sudan visited ICBA-HQ in Dubai to work with the project team and learn from ICBA's experiences in managing salt-affected soils. The ICBA project officer from Ethiopia visited South Sudan to train the local project team in soil and crop management techniques.

In 2019, two project technical committee meetings were organized in Ethiopia. All concerned people attended the meetings, including Ethiopian State Minister of Agriculture, H.E. Dr. Kaba Urgessa. The technical committee showed complete satisfaction with the project's progress in both countries and gave helpful suggestions for further improving the project's performance. The committee members also extended full support for implementing activities in both countries and the upcoming events planned under this project. The third steering committee meeting was held in Ethiopia to review the project's progress and approved the scaling-up strategy for seed distribution to the smallholder farmers in the salt-affected areas.

In April 2019, a stakeholder workshop was also organized in Addis Ababa to share the project outcomes with the larger scientific community, donors, NGOs, and the relevant ministries. The workshop was inaugurated by State Minister H.E. Dr. Kaba Urgesa and attended by more than 50 participants from both countries. The workshop was organized with the collaboration of the Ministry of Agriculture.

During 2020-21, no physical meetings were organized due to the COVID-19 pandemic and following travel restrictions. Therefore consultations were done virtually. However, local training and farmer field days were organized wherever possible. The scaling-up work was also severely affected due to this situation.

8.2 Technical trainings

During this project, several technical trainings for farmers and extension workers were organized at the project locations in Ethiopia and South Sudan. Farmers were briefed about different aspects of the rehabilitation and management of salt-affected soils. Farmers and extension workers took a keen interest in these trainings and field activities. The trainings were given by the ICBA staff, prominent scientists from the partner countries, and the staff of local and international partners. These trainings cover various topics, including soil and water analysis, crop management, irrigation, water management, scaling up strategies, seed multiplication, and production. These trainings were organized at two levels. The first training was for soil, water, and irrigation technicians from different partner organizations. These were technical trainings. The second type of training was for the field staff related to their duties in the project's field activities. The details of technical trainings organized in Ethiopia and South Sudan are given in Table 41.

Table 41. Details of trainings organized during the project

No.	Title of training	Time	No. of participants		
			Male	Female	Total
Trainings organized in Ethiopia					
1	Land degradation and management in Africa	2016	45	15	60
2	Data collection for the socioeconomic baseline survey	2016	35	15	50
3	Options for the management of salt-affected soils	2017	45	10	55
4	Strategies for the reclamation of salt-affected soils	2017	45	20	65
5	Agronomic practices for salt-tolerant sorghum	2018	40	15	55
6	Management of salt-affected lands in the lowlands of Ethiopia	2018	35	15	50
7	Crop management for salt-affected lands	2019	35	15	50
8	Development of extension materials for farmers and extension workers	2019	45	22	67
9	Seed multiplication and production	2020	55	23	78
10	Management of sodic soils	2020	40	10	50
11	Developing scaling up strategy	2021	50	12	62
12	On-farm irrigation water management techniques	2021	35	23	58
	Total		**505**	**195**	**700**
Trainings organized in South Sudan					
1	Data collection for the socioeconomic baseline survey	2016	50	20	70
2	Soil and water sample collection and analysis	2016	50	20	70
3	Operation and maintenance of drip irrigation systems	2017	50	30	80
4	Crop management to improve productivity	2017	60	15	75
5	Soil and water management techniques	2018	50	30	80
6	Seed multiplication and production	2019	60	20	80
7	Agronomic practices for newly introduced crops	2019	80	20	100
8	Scaling up strategies	2020	50	30	80
9	Seed storage, packing, and distribution	2020	50	40	90
10	Soil and water management for improved productivity	2021	60	15	75
	Total		**560**	**240**	**800**
	Grand Total		**1065**	**435**	**1500**

In 2017, special training was organized in Ethiopia with the International Livestock Research Institute (ILRI), with the Ministry of Agriculture of Ethiopia, the Ethiopian Institute of Agricultural Research (EIAR). The participants belong to research and extension organizations of both countries. This training focused on selecting appropriate crops and grasses suitable for salt-affected soils and different soil and water management practices for their sustainable growth and improved yields. The training was followed by a field trip to the research station of ILRI in DeberZiet, where trainees were exposed to different salt-tolerant species of legumes, grasses, and forages and the establishment of field trials for their testing and screening. Participants also visited other facilities of the ILRI research station, which included a plant testing laboratory, nursery growing arrangements, and seed storage and processing units.

Participants of the training visiting ILRI research station in Deberziet

During 2018, several trainings on water, soil, and crop management were organized in South Sudan. These trainings focused on crop irrigation requirements, soil and water analysis, soil management techniques, and plantation techniques of different salt-affected genotypes. During the training, field visits were also organized to make them aware of field problems and constraints of different crops and how to fix them. The participants were also involved in collecting soil samples in the field. The participants took a keen interest and considered this training very useful for advancing their professional obligations.

Participants of the training on soil sampling techniques

During 2019, a training was related to “seed multiplication, production, and storage.” This training was organized before the start of the scaling-up activities. The State Minister for Agriculture, H.E. Dr. Kaba Urgessa, attended the closing session and distributed certificates to the participants. He also thanked ICBA for organizing this vital training in Ethiopia.

Participants of the training course on "seed multiplication and production" with H.E. Dr. Kaba Urgessa, the state minister for Agriculture, Government of Ethiopia

8.3 Farmer field days

Farmer field days were organized regularly in both countries to introduce new crops such as Barley, cowpea, Pearl Millet, Quinoa, and sorghum. Farmers from neighboring villages were invited to witness the progress of forage grasses and legume crops. The grasses used for field demonstration include Cynchrus grass, Sesbania, and Panicum. The legume crops were Sorghum and Cowpea. Participants were briefed about all aspects of forage and legume production in salt-affected areas. Farmers were delighted to see the tremendous growth of grasses and legumes and requested seeds of these grasses and legume crops.

Model farmers were selected and involved in all field activities. Farmers of the neighboring villages also came to visit these demonstrations. Farmers were particularly interested in the Panicum and Sesabania grasses because of their high biomass production. The cooperating farmers were trained in sowing, weeding, and irrigation practices. During these events, farmers' perception and preference among demonstrated crops and respective genotypes were also evaluated. Farmers reveal that they face feed and food shortages and show interest in adopting these practices, mainly forage crops. Farmer's field days showed that the economical use of marginally productive soil resources through the cultivation of salt-tolerant food and forage crops as an alternative to existing salt-sensitive crops could help a great deal in optimizing land use. By promoting integrating crop-forage-livestock production systems, poverty in rural areas can be reduced. Most participants positively perceived the role and advantage of the salt-tolerant crop varieties provided by ICBA to increase the marginal lands' productivity.

Field demonstrations of the selected forage grasses in Ethiopia

In South Sudan, field days were also organized to educate farmers on new crop varieties and the irrigation pump installed by the project. This was important because in the off-season majority of the farmers rely on small plots along the river Nile to produce vegetables for domestic and commercial purposes. Farmers highly appreciated the training and new ICBA varieties tolerant to drought and soil salinity.

Farmers during the field days in South Sudan

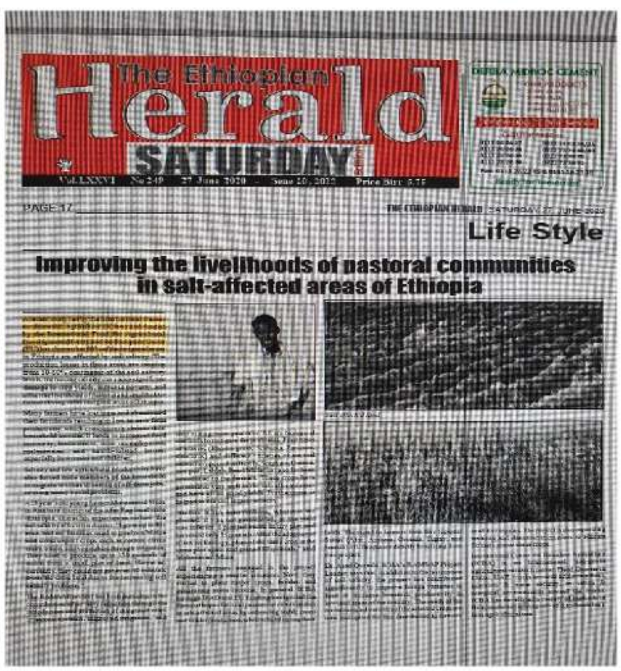
During the field days, farmers were convinced that ICBA recommended genotypes have shown superior performance than the existing local crop varieties in production potential, nutritious values, and increased economic returns under salt-affected conditions. Farmers showed great interest in these crops and forage varieties and demanded seeds for these food and forage crops. Therefore, seed multiplication units were established in different regions and farmer fields. The produced seed was distributed free of cost to the interested farmers. Farmers were also trained to create awareness among farmers on "how to grow these seeds successfully on salt-affected soils and to use brackish water for improved crop production."

8.4 Knowledge sharing and media coverage

The RAMSAP project introduced more than twenty salt-tolerant Quinoa, Sorghum, Lablab, Sesbania, and Cowpea genotypes. These genotypes were evaluated for their yield performances under different soil salinity conditions. The promising varieties were recommended for adoption and production under salt-affected areas of the country (for more details, please refer to Project Report # 7). However, producers in Ethiopia usually do not know the suitable varieties for their fields, which results in lower yields. Lack of production technique, training, and information systems are significant constraints for low adoption. Therefore, the introduction of improved varieties should be accompanied by practical training of farmers or agro-pastorals and extension agents. In addition to trainings, workshops, and farmer field days, manuals for the farmers and extension workers were prepared. The manuals were prepared in English and local Amahari languages. Therefore, these manuals are prepared to educate farmers on appropriate agronomic practices for growing Quinoa, Sorghum, Lablab, Sesbania, and Cowpea crops in salt-affected areas. In addition, the manual will help agro-pastorals and extension workers in the salt-affected areas of Ethiopia.

The main events and achievements of the project were shared on ICBA-managed social media regularly. The project team also participated in conferences, workshops, and seminars to present the project outcomes to the more extensive scientific and research communities. The project team in South Sudan managed to deliver speeches on local FM radio to broadcast project-related messages. The project achievements were also highlighted in internationally reputed newspapers to reach a wider audience.


The Ethiopian Herald
SATURDAY
Fast Forward
Rehabilitating salt-affected lands to improve livelihood


The Ethiopian Herald
SATURDAY
Life Style
Improving the livelihoods of pastoral communities in salt-affected areas of Ethiopia

8.5 Project-end workshops

The project-end workshops were organized in Ethiopia and South Sudan to share the project achievements with different stakeholders including, researchers, academia, NGOs, donors, and farmers. In Ethiopia, the Minister of Natural Resources Management inaugurated this 2-days workshop. Detailed presentations were given in this workshop to elaborate on the work performed, and the accomplishments gained. The participants lauded the project's contributions to the rehabilitation and management of salt-affected soils in Ethiopia. The results of the following studies were discussed during the workshop.

- Baseline socio-economic survey at the household ad regional level
- Extent and characterization of salt-affected soils in Ethiopia
- Irrigation and on-farm water management strategies for salinity control
- Field evaluation of salt-tolerant food and forage crops
- Scaling up of the recommended technologies and seed distribution
- Role of women in the management of salt-affected lands and agriculture

The minister emphasized that seed distribution of salt-tolerant food and forage crops should be continued after the project's termination. For this purpose, he suggested that MoA should work closely with ICBA. The ongoing World Bank-funded Lowland Livelihood Resilience Project (LLRP) in Ethiopia should consider adopting these technologies and reach out to farmers of the agro-pastoral areas. The workshop participants were also provided with the different technical reports prepared under this project.


H.E. Dr. Eyasu Elias, the Minister for Natural Resources, speaking at the project-end workshop



Participants of the project-end workshop of the RAMSAP project in Ethiopia

The workshop in South Sudan was organized in Juba and was attended by more than 40 participants from different research, academia, and government agencies. The workshop was inaugurated by Prof. Mathew Gordon Udo, Under-Secretary of the Ministery of Agriculture. Detailed presentations were given in this workshop to highlight the accomplishments of the RAMSAP project in South Sudan. The participants lauded the work done by this project to improve crop productivity of salt-affected and low-productive lands. They particularly appreciated the project's training program for irrigation and extension workers and farmers to improve on-farm water use efficiency and crop yields. The distribution of seeds for salt-tolerant food and forage crops to the interested farmers was also happily welcomed by the farmers.

The following topics were discussed during this workshop.

1. Baseline socio-economic survey (agricultural challenges and opportunities
2. Characterization of soil and water using remote sensing approach
3. Field evaluation of salt-tolerant food and forage crops.
4. Irrigation and on-farm water management strategies to improve the water use efficiency
5. Scaling up of the recommended technologies and seed distribution
6. Capacity building and knowledge sharing activities
7. Recommendations for providing incentives to farmers to improve agricultural productivity

The participants emphasized that the seed distribution of salt-tolerant food and forage crops should be continued after the project's termination. The government should also support affordable access to agricultural machinery and other inputs to improve agricultural productivity. The Director-General emphasized that the recommendations of this project be included in the annual work plans of the concerned organizations for adoption and further research. He assured farmers that government would take serious note of these recommendations and try to help them as much as possible. The workshop participants were also provided with the different technical reports prepared under this project.

8.6 Publications

In addition to the workshops, trainings, and media coverage, several papers/book chapters were published in internationally reputed journals to share the scientific outcome of the project to the larger scientific community. The journal papers/book chapters published under this project are listed below:

1. Qureshi, A.S., Shoaib, I., 2016. Improving agricultural productivity by promoting low-cost irrigation technologies in Sub-Saharan Africa. Glo. Adv. Res. J. Agric. Sci. July 2016 Vol: 5(7): 283-292 (ISSN: 2315-5094). Available online http://garj.org/garjas/home

2. Qureshi, A.S., 2017. Sustainable use of marginal lands to increase food security in the United Arab Emirates. Journal of Experimental Biology and Agricultural Science, Vol. 5(Spl-1- SAFSAW). DOI: http://dx.-doi.org/10.18006/2017.5(Spl-1-SAFSAW).S41.S49.

3. Gelaw, AM., Qureshi, A.S., 2017. Tef (Eragrostis tef): a potential food crop for the marginal lands of Ethiopia. In Book: Emerging Research in Alternative Crops under Marginal Environment (edited book). Springer International Publishing.

4. Qureshi, A.S., Adballah, A.J., Tombe, L.A., 2018. Farmers' perceptions, practices and proposals for improving agricultural productivity in South Sudan. African Journal of Agricultural Research. Vol. 13(44): 2542-2550. DOI: 10.5897/AJAR2018.13525.

5. Qureshi, A.S., Ertebo, T., Mehansiwala, M., 2018. Prospects of alternative cropping systems for salt-affected soils in Ethiopia. Journal of Soil Science and Environmental Management, Vol. 9(7):98-107. DOI: 10.5897/JSSEM2018.0686.

6. Ashenafi, W.D., Qureshi, A.S., Bethelo, N., 2019. Evaluating the effect of different salinity levels on the agronomic and quality parameters on selected Rhodes grass (Chloris gayana) genotypes. Appl. Sci. 2019, 9, 143; doi:10.3390/app9010143 www.mdpi.com/journal/appl.

7. Qureshi, A.S. and A.W. Daba, 2020. Evaluating growth and yield parameters of five quinoa (Chenopodium quinoa W.) genotypes under different salt stress conditions. Journal of Agricultural Sciences, Vol. 12 (3): 128-140. doi:10.5539/jas.v12n3p128.

8. Qureshi, A.S. and A.W. Daba, 2020. Differential analysis of five quinoa (Chenopodium quinoa W.) genotypes under different salt stresses in a controlled environment. American-Eurasian Journal of Sustainable Agriculture. Vol. 14 (1): 14-21. DOI: 10.22587/aejsa.2020.14.1.2.

9. Ashenafi, W. D., Qureshi, A. S. and Senbeta, B. M., 2020. Evaluation of some Sesbania genotypes for their salt tolerance, biomass yield, nutrient composition, and soil ameliorative response. Asian Journal of Plant Science, 19, pp. 300-312. doi: 10.3923/ajps.2020.300.312.

10. Qureshi, A.S., Ashenafi, W.D., 2019. Evaluating the Impact of Different Salt Stress on Growth and Nutritional Parameters of three Lablab-bean (Lablab purpureus) Genotypes. Intl. J. Agric. Biol., 22: 921–926. DOI: 10.17957/IJAB/15.1149.

11. Aweke, M.G., and Qureshi, A.S., 2020. Tef (Eragrostis tef): A Superfood Grain from Ethiopia with Great Potential as an Alternative Crop for Marginal Environments. In: Hirich, A., Choukr-Allah, R. & Ragab, R. (eds.) Emerging Research in Alternative Crops under Marginal Environment. Springer. doi: 10.1007/978-3-319-90472-6.

12. Getinet, B. W., Daba, A.W., and Qureshi, A.S., 2020. Effects of Salinity on Producers' Livelihoods and Socio-economic Conditions; The Case of Afar Region, Northeastern Ethiopia. J. Sus. Agric. Sci. Vol. 46, No. 3. pp. 35 – 46. DOI: 10.21608/jsas.2020.23444.1200.

13. Ashenafi, W. D., Qureshi, A. S., Senbeta, B. M., 2020. Evaluation of some Sesbania genotypes for their salt tolerance, biomass yield, nutrient composition, and soil ameliorative response. Asian Journal of Plant Science, 19, pp. 300-312. doi: 10.3923/ajps.2020.300.312.

14. Daba, A.W., Nisaren, B.N., Qureshi, A.S., Haile, M., Banje, T.B., 2021. Assessment of Salt Affected Soil and Irrigation Water Quality in Amibara and Dubti irrigated Areas, Afar Regional states of Ethiopia/American-Eurasian Journal of Sustainable Agriculture. 15(1): 1-14.DOI: 10.22587/aejsa.2021.15.1.1.

15. Hopmans, J.W., Qureshi, A.S., Kisekka, I., Munns, R., Grattan, S.R., Rengasamy, P., Ben-Gal, A., Assouline, S., Javauxh, M., Minhas, P.S., Raatsj, P.A.C. Skaggs, T.H., Wang, G., Jong van Lier, Q.D., Jiaol, H., Lavado, R.S., Lazarovitch, N., Li, B., Taleisnik, E., 2021. Critical knowledge gaps and research priorities in global soil salinity. Advance in Agronomy, https://doi.org/10.1016/bs.agron.2021.03.001.

16. Qureshi, A.S., A.W. Daba, 202. Review of soil salinity and sodicity challenges to crop production in Ethiopia and its management strategies. Land 2021, www.mdpi.com/journal/land.

BRIEF ABOUT THE RAMSAP PROJECT

Background

Increasing salinity remains a challenge to the sustainability of irrigated agriculture in Ethiopia and South Sudan as it reduces natural biodiversity and farm and livestock productivity. The agricultural sector in Ethiopia supports 85% of the workforce. About 85% of the population living in rural areas is directly dependent on agriculture. Seven million smallholder farmers produce more than 95% of the total agricultural outputs, including food crops, cereals, oilseeds, and pulses. Cotton and sugar are grown in state-owned large-scale enterprises. Ethiopia also has enormous livestock resources, including cattle, sheep, goats, and camels. Despite high biodiversity and distinctive ecosystems, food shortages are widespread, and since 1970 there have been severe famines almost once per decade.

Land degradation is considered one of the major causes of low and, in many places, declining agricultural productivity and continuing food insecurity, and rural poverty in Ethiopia. Ethiopia stands first in Africa in salt-affected soils due to human-induced and natural causes. About 11 million ha (Mha) land in Ethiopia is exposed to salinity and sodicity. About 8 Mha have both salinity and sodicity problems, whereas the rest 3 Mha have alkalinity problems. About 9% of the population lives in salt-affected areas. The saline areas in Ethiopia are in the Awash River basin, and the situation is expected to exacerbate due to climate change-induced factors. There is an urgent need for salt-affected soils to be restored to their production potential to produce enough food for the rising population.

In South Sudan, agriculture accounts for 36% of the non-oil GDP, with 80% of the population living in rural areas largely dependent on subsistence farming and 75% of the households consuming cereals as a prominent part of their daily diet. Despite abundant water supplies, only 5% of 30 Mha arable land is cultivated. Crop yields are low, which negatively affects the incomes and livelihood of poor farmers. Significant barriers are lack of agricultural inputs such as seed and fertilizer, poor advisory services, and inefficient irrigation management. Although South Sudan has the highest livestock per capita globally, with 23 million cattle heads, sheep, and goats, there is little use for improved seed or livestock breeds. There is a need to introduce improved forage varieties resistant to common diseases for increased livestock productivity. The salt-affected lands in South Sudan are in the White Nile irrigation schemes. These areas have not been utilized for agricultural production despite freshwater from the Nile. Therefore, bringing degraded lands to production is essential for food security and social stability.

With a 3% average population growth in these countries, future food security and the livelihood source for a considerable portion of the population remains a challenge to the governments. Increasing the productivity of existing salt-affected lands and protecting newly developed areas from the spread of salinity is therefore of paramount importance. The smallholder farmers in both countries can increase their agricultural productivity and farm incomes if their technical and financial capacity is enhanced. They need guidance on the improved irrigation and salinity management strategies and access to modified salinity-tolerant seeds for crops and forages.

The areas of low to moderate salinity levels can be restored by improving irrigation and crop management practices. However, in areas where increased salinity levels have restricted the growth of regular field crops, the Biosaline Approach could be a potential solution. This approach is based on adaptable technology packages of salt-tolerant fodders and halophytes integrated with livestock and appropriate management systems. These integrated crop-forage-livestock feeding systems can increase the resilience of smallholder farmers who are mainly dependent on the livestock sector.

This project will devise a strategy to improve the productivity of saline soils to an economically feasible level and minimize future salinity development in these areas. The project will draw on past work's successful experiences to identify the most productive alternative crop and forage production systems and devise a strategy for scaling up these production packages to improve the livelihood of rural communities, especially women in the target areas of both countries. Through enhanced crop yields and reduced land degradation, the project will improve farmers' resilience, thereby reducing migration to cities and health problems due to stress on families suffering from the impact of salinity on their livelihoods.

Project Goals and Objectives

The project's overall goal is to attain higher agricultural productivity, food security, and income for smallholder farmers, agropastoral/pastoral communities through rehabilitation and sustainable management of irrigated salt-affected farming areas of Ethiopia and South Sudan. The main objective of this project is to introduce and promote appropriate technologies and practices for rehabilitation and management of salt-affected lands in Ethiopia and South Sudan and draw lessons for scaling up.

The Target Group

The project will directly target 5,000 smallholder farmers in selected areas in Ethiopia and South Sudan who face high food insecurity due to their high dependency on marginal water and land resources. The indirect beneficiaries will be about 50,000 farmers (40,000 farmers in Ethiopia and 10,000 farmers in South Sudan) dependent on forage production in both countries with an estimated total area of about 200,000 ha (150,000 ha in Ethiopia and 50,000 in South Sudan). These targets will be achieved by producing and distributing tested crop and forage seeds, disseminating improved soil and water management practices, and training farmers and extension workers in the target areas.

The rehabilitation of degraded lands will improve the livelihood of 9% of the population of Ethiopia which lives in salt-affected areas. In South Sudan, where 7% of 30 Mha of land is being cultivated, rehabilitation and management strategies developed under this project will open a window of opportunity for thousands of rural farmers to improve the productivity of their degraded lands and increase their farm incomes. The outcomes of this project will significantly benefit women as they will have better access to food and health facilities. The transformation of degraded lands into productive lands will also create direct and indirect job opportunities for the large young population. This will help reduce the migration trends of unemployed youth from rural areas to urban areas.

The project will target Ethiopian highlands (Tigray, Amhara, and Afar) and lowlands (Omara and Somali), which produce 87% of cattle and 5% of its sheep and goats; however, land degradation has reduced farm and livestock productivity of these areas resulting in rural poverty. The developed crop-livestock value chain system will benefit Ethiopia because this is the largest livestock producer in Africa.

The project will target the White Nile irrigation schemes (50,000 ha) in South Sudan. These soils have an immense potential due to the availability of freshwater from the White Nile River and its tributaries which run through 7 out of 10 states, providing ready access to an abundant water supply and river transport access for agriculture producers. However, these soils are not being cultivated for decades due to low soil fertility and the non-availability of good quality seeds for crops and forages. Currently, 18% of the land is not cultivated because of seed shortage, and 9% is due to low soil fertility. Increasing the productivity of these lands will be crucial to ensure food security for the smallholder farmers of the area.

Strategy, Approach, and Methodology

This project will adopt an integrated soil and water management approach to tackle the salinity problems in irrigated areas of both countries. The project strategy would be first to diagnose the issues and then develop long-term mitigation, management, and rehabilitation strategies at the farm and regional level relevant to the problem using proven and high-level international salinity science and management. Since rehabilitating saline soils through engineering or chemical amendments is an expensive and time-consuming process, this project will work on adaptive and mitigation methods to rehabilitate these soils.

This project will adopt a participatory approach to conduct field trials in different parts of both countries to test the suitability of local and imported crop and forage species to rehabilitate salt-affected soils. Adaptation trials will be conducted at the Farmers Training Centers (FTCs) and volunteer farmers' plots in collaboration with the national partners. These trials will also be used for demonstration purposes before scaling up. The project team will jointly implement the best management practices for salinity control at the farm level. Smallholder farmers (especially women and young farmers) will be trained to establish seed/gene banks at the community level. ICBA has successfully applied this approach in SSA.

The project will generate and disseminate sustainable integrated crop-livestock technology packages to diversify farmers' incomes by selling animal products and forages to local markets, thus making the production systems economically sustainable. However, salt-tolerant forage plants are variable in biomass production and nutritional value. The available salt-tolerant forages have not been selected or managed for improved livestock production. For this reason, they need to be tested locally for their (a) edible biomass production, (b) nutritional value (i.e., the response in animal production per unit of voluntary feeding intake), and (c) the use of micronutrients and nutraceutical properties.

The project will address gender equality and social issues as cross-cutting themes in each area. The project will include the most vulnerable groups of the society to ensure that the interventions benefit poor farmers and households. Since rural women play a crucial role in undertaking agricultural and livestock activities, enhancing their knowledge and capacity will be one of the main targets of this project.

Project Outcomes and Impacts

The immediate outcome will be the full implementation of new salt-affected management strategies within the pilot sites with related benefits to farming communities and land management organizations. The long-term effect will be new thinking and awareness about the new salinity management approaches and implementation of overall system reform. This, in turn, will lead to out-scaling of production packages beyond the project area through project partners, including key government organizations. The successful implementation of the above activities will increase the productivity of salt-affected lands, which will positively contribute to the country's economy and reduce rural poverty. The project's overall impact will be revitalized agriculture in Ethiopia and South Sudan.

Scaling up Pathways

The critical element of this project is to pilot innovative strategies and approaches for the rehabilitation and management of salt-affected soils and then "scale up' recommended technologies to reach up to a more significant number of rural poor. All activities of this project will be carried out with the involvement of local rural communities. Once convinced, these communities will act as the champions of change and critical drivers in the process of scaling up. For successful scaling up, policy support and institutional infrastructure are very crucial. Opportunities and constraints that may affect the scaling-up process will be critically evaluated during the pilot stage. For long-term sustainability, the overall impact of the alternative production systems on the lives of the rural poor, natural resources, and the environment will be reviewed.

Socio-Economic and Environmental Impacts

The project will develop modified approaches to improve water management for salinity control and demonstrate best soil management practices for different salt-tolerant crops and forages. Adopting alternative crop and forage production systems will reduce the area lost to salinity degradation, bring income to farmers, and improve the livelihood of poor rural communities, especially women. The transformation of salt-affected lands into productive lands will also contribute to poverty reduction by increasing fuelwood, construction materials, wild foods, and medicinal plants.

ABOUT THE INTERNATIONAL CENTER FOR BIOSALINE AGRICULTURE (ICBA)

ICBA is a not-for-profit, international center of excellence for research and development in marginal environments. It was established in 1999 through the visionary leadership of the Islamic Development Bank (IDB), the Organization of Petroleum Exporting Countries (OPEC) Fund, the Arab Fund for Economic and Social Development (AFESD), and the Government of United Arab Emirates. Through the Ministry of Climate Change and Environment and the Environment Agency – Abu Dhabi extended the agreement with IDB in 2010 and increased their financial support to the Center.

ICBA initially focused on salinity problems and using saline water for irrigated agriculture. Over the last 15 years, ICBA has evolved into a world-class modern research facility with a team of international scientists conducting applied research to improve the well-being of poor farmers in marginal environments. In 2013, the Center developed a new strategic direction addressing the closely linked income, water, nutrition, and food security challenges. The new Strategy takes innovation as a core principle and identifies five innovations that form the core research agenda: assessment of natural resources; climate change adaptation, crop productivity, and diversification; aquaculture and bioenergy, and policy analysis. ICBA is working on several technology developments, including conventional and non-conventional water (such as saline, treated wastewater, industrial water, and seawater); water and land management technologies, remote sensing, and modeling for climate change adaptation.

ICBA is a unique institute with a clear mandate and capacity to work on rehabilitating salt-affected lands. ICBA is the custodian of the world's largest collections of genetic resources of crops and forages suitable for salt-affected lands with a proven capacity of seed development and seed multiplication for a variety of environments. In addition, ICBA's long history of working in Africa with local partners makes it fully qualified and eligible to lead this project.

The International Center for Biosaline Agriculture (ICBA) is implementing a 4-year project on the "Rehabilitation and management of salt-affected soils to improve agricultural productivity (RAMSAP)" in Ethiopia and South Sudan. The project is funded by the International Fund for Agricultural Development (IFAD) and is being implemented with the technical support of the Ministry of Agriculture (MoA), Ehiopia and the Directorate of Research and Training (DRT), South Sudan. The project is of great importance for both countries as it directly targets resource-poor smallholder farmers, especially women and children, who face high food insecurity due to their dependence on marginal soils. The project is introducing innovative soil and water management practices and salt-tolerant genotypes of food and forage crops that have the potential to grow in marginal areas. In addition, scientists, extension workers and farmers are being trained to improve their capacity for the management of marginal resources. Through improved crop yields and reduction of loss of land to degradation, the project empowers farmers by increasing their resilience against the impact of salinity on their livelihoods.

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