Project Report 2

EXTENT, CHARACTERIZATION AND MANAGEMENT STRATEGIES FOR THE SALT-AFFECTED SOILS IN ETHIOPIA





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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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EXECUTIVE SUMMARY

Soil salinization is recognized as the most important problem in Ethiopia for reduced crop yields, low farm incomes and increased rural poverty. Ethiopia stands first in Africa in the extent of salt-affected soils with an estimated 11 million ha of land exposed to salinity, which corresponds to 9% of the total land mass and 13% of the irrigated area of the country. These soils are concentrated in the Rift Valley, Wabi Shebelle River Basin, the Denakil Plains and other lowlands and valleys of the country where 9% of the population lives. In addition to naturally occurring salts, mismanagement of land and water resources is usually held responsible for the development of saline and sodic soils. These include poor drainage facilities which gave rise to groundwater table, use of saline water for irrigation, and poor on-farm water management and cultural practices. In Ethiopian Rift valley agricultural system, main sources of salts are shallow groundwater tables, natural saline seeps and marine origin. Development of large irrigation schemes at middle and lower Awash Valley without appropriate drainage systems along with poor irrigation management practices have resulted in the gradual 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.

Salinity problems in Ethiopia have manifested to the extent that farmers are experiencing huge crop losses while many farms have gone out of production in the last two decades. It is believed that the continuation of current rrigation practices will further aggravate the existing soil salinity problems., Therefore mitigating existing soil salinity problems and preventing futher spread of salinity in the irrigated areas is of vital importance to ensure food security for the rising population. In Ethiopia, very limited information is available on the extent of soil salinity and its spatial distributions. This report is an attempt to gather all the available information and present it in the form that can be used to develop effective strategies for the rehabilitation and management of degraded soils in Ethiopia.

Due to lack of research and development efforts, the extent and causes of salt-affected soils are not fully known and its economic implication are not well understood. The institutional arrangements to monitor, evaluate, and take necessary actions for the rehabilitation and management of salt-affected lands are weak. There is no autonomous institute to look after the welfare of the national natural resources and keep up to-date data on the status of soil, water, forestry, etc. This makes it difficult to obtain tangible information on the extent of salt-affected soils, quality of irrigation water, available arable land, and to combat the resources degradation jointly, and secure food self-sufficiency. This clearly indicates the need for more concerted efforts to characterize salt-affected soils and develop technologies to reclaim and halt further expansion of soil salinity in the country.

Desalinization and desodication of salt-affected soils and prevention of secondary salinisation and sodication of potentially salt-affected soils can be done by adopting number of management measures. These may include introduction of proper drainage systems, practicing minimum tillage to avoid soil compaction, use good quality water for irrigation, ensure post and pre-plant leaching to evacuate salt from the root zone, adopting efficient on-farm water management practices to avoid over-irrigation and improve water use efficiency, selection of appropriate crops according to lands, and avoid mixing drained water with the river water for irrigation.

Adverse effects of salinity and sodicity can also be reduced using approved biological and agronomic reclamation practices. These include growing salt-tolerant crop species, using highly saline and sodic soils for the production of improved pasture under flood irrigation system temporarily, and those lands with courser texture, low soil salinity or sodicity for the production of food and industrial crops. Supply of adequate nutrients to soils is also essential for the amangemnt of saline soils. Initiating reclamation of saline and sodic soils through chemical amendments where calcium sources such as gypsum ($CaSO_4.2H_2O$) and promoting proper soil, water and crop management practices can also help a great deal in the management of salt-affected soils.

As a long-term strategy, there is a need for a continuous work on the development and dissemination of knowledge and technologies to farmers. We need to focus on the development of diagnostic based appropriate technologies to reclaim salt-affected soils and halt future expansion. In order to properly address the problem of salinity and sodicity, researchers have overwhelming responsibility to provide the required data and information to conserve and utilize soil and water, advise the government on issues related to national policy and strategy to develop agriculture and seek lasting solutions to emerging problems of Ethiopian agriculture.

In highly saline areas where growth of normal crops is not possible, biosaline agriculture is an economical and effective approach to use unproductive lands for growing different food and fodder crops. This approach, if prudently adapted, can help in improving livelihood of rural and pastoral communities of the salt-affected areas by enhancing feed and fodder production. Through proper identification of field crop and fodder species and varieties that can tolerate soil salinization and poor irrigation water quality, productivity of marginal lands can be maximized. In Ethiopia, this approach is of special importance due to the following reasons:

- Shortage of livestock feed is among the major reasons for low productivity gains from this sector. Forage production on saline soils can help in increasing the productivity of livestock sector especially for agro-pastoral communities in the moisture stress dry regions of Ethiopia.

- 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 table above critical depth for crop growth. Exploring the possibility of bio-drainage for waterlogged saline lands through the plantation of salt tolerant trees 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 growth of normal crops in these soils is not possible, planting halophytes can be a viable solution to produce food, fuel, fodder, fiber, essential oils, and medicine. At the same time, halophytes can help in restoration of saline soils through phytoremediation. By adopting these strategies, unused and marginal lands can be brought under cultivation to improve livelihood of poor rural communities.

01

BACKGROUND

Soil salinization is one of the major threats to sustainable agricultural production and food security in the arid and semi-arid regions of the world (Ventura and Sagi, 2013; Hasanuzzaman et al., 2014). Globally, over 900 million ha (Mha) of land is affected by the twin problems of salinity and sodicity (Wicke et al., 2011). Currently, 33% of the irrigated area (76 Mha) is affected by different levels of salinity and it is estimated that by 2050, more than 50% of the farms around the world will be salt-affected (Jamil et al., 2011; Kumar and Shrivastava, 2015). Saline soils occur in all environments of the world. They are found in cold (permafrost), temperate, subtropical, and tropical belts that are spreaded all the way from the sub-arctic to the equator, and in arid climates of the South, where evapotranspiration exceeds rainfall for most part of the year. Based on the FAO/UNESCO soil map of the world, about 60 Mha (24% of the total irrigated area) are affected by salinity, of which 38 Mha are located in five countries i.e. India (20 Mha), China (6 Mha), USA (5.0 Mha), Pakistan (4.5 Mha), and Soviet Union (2.5 Mha).

Table 1. Global distribution of salt-affected soils

Continent/region	Area (1,000 ha)		
	Saline	Sodic/Alkali	Total
North America	6191	9564	15755
Mexico and Central America	1965	-	1965
South America	69410	59573	129163
Africa	53492	26946	80438
South Asia	83312	1798	85110
North and Central Asia	91621	120065	211686
Southeast Asia	19983	-	19983
Australia	17359	339971	357330
Europe (Total)	50800	-	50800
Total	**343333 + Europe**	**558097 + Europe**	**952200**

In the arid and semi-arid parts of Africa, salinity and sodicity problems are affecting about 24% of the continent. These problems are common because rainfall is insufficient to leach salts and excess sodium ions out of the rhizosphere. Salt-affected soils are especially prevalent in northern Africa, South Africa, Botswana and in arid and semi-arid zones of tropical Africa (Senegal, Mauritania, Upper Volta, Chad, northern Cameron, Swaziland, Malawi, Kenya, Zambia, southern Angola and southern Mozambique) (Tully et al., 2015) (Table 2).

In addition to naturally occurring saline soils, mismanagement of land and water resources is usually held responsible for the development of human-induced saline and sodic soils. These include poor drainage facilities which gave rise to groundwater table, use of brackish groundwater for irrigation, intrusion of seawater in coastal areas, and poor on-farm water management and cultural practical. Rising groundwater tables due to lack of drainage provisions and use of poor quality irrigation water are major causes of soil salinization in most of the African and Asian countries. The reclamation of these soils by improving drainage infrastructure will remain a challenge for the governments due to political and economic reasons. Therefore adoption of adaptive and mitigation approaches to improve the productivity of these soils would be an attractive option in the short term.

Table 2. Distribution of salt-affected soils in the top 10 African countries (1,000 ha).

Countries	Saline	Sodic	Total
Algeria	3,201	129	3,150
Botswana	5,009	670	5,679
Chad	2,417	5,850	8,267
Egypt	7,360	-	7,360
Ethiopia	10,608	425	11,033
Kenya	4,410	448	4,858
Libya	2,457	-	2,457
Mali	2,770	-	2,770
Nigeria	665	5,837	6,502
Somalia	1,569	4,033	5602

Ethiopia stands first in Africa in the extent of salt-affected soils with over 11 Mha of land exposed to salinity (Kidane et al., 2006; Gedion 2009; Frew et al., 2012; Ashenafi and Bobe, 2016) (Table 2). This relates to 9% of the total landmass and 13% of the irrigated area of the country (Birhane, 2017). Most of the saline soils are concentrated in the plain lands of arid, semi-arid and desert regions of the llift valley system including Afar, the Somali lowlands, the Denakil plain and valley bottoms throughout the country (Heluf, 1995; Fantaw, 2007; Sileshi, 2016). Most of the export crops such as cotton, sugarcane, citrus fruits, and vegetables are being produced in the Rift valley. The expansion of large-scale irrigation schemes in the Rift valley in the absence of appropriate drainage systems has resulted in rapid expansion of salinity and sodicity problems leading to complete loss of land for crop cultivation in these areas. The growing occurrence of these soils is reducing natural biodiversity and farm and livestock productivity in the country.

Ethiopia is heavily dependent on agriculture sector for its overall economic growth and social sector development as it accounts for 40% of the GDP, 80% of the total employment and 70% of the export earnings (African Economic Outlook, 2015). The development of agriculture sector during the last decade has brought food self-sufficiency in the country with grain production reaching up to 27 million tons. This was the result of a strong commitment by the government, which allocated more than 15% of the total budget and introduced effective policies and programs for the development of agriculture sector (Yohannes et al., 2017).

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 and a large proportion of population continues to rely on food aid and safety net programs (Mekonen, 2007). Major causes of low agi·icultural productivity in these are declining soil fertility and increasing soil salinity, lack of improved crop varieties and lack of irrigation water. The depletion rate for the major plant nutrients is estimated to be 40, 6.6 and 33.2 kg ha-lyr-1 for N, P and k, respectively (Stoorvogel and Smaling, 1990). Other problems related to lower agricultural productivity are limited choice of crop varieties that are tolerant to soil salinity and water stress (Kidane, 1999). The yields of traditional major crops such as sorghum, tef, maize, finger millet and lowland pulses are generally low (Getachew, 1986).

Despite this alarming situation, attempts to resolve land degradation problems could not get due attention. With a 3% average population growth, future food security as well as the livelihood source for a considerable portion of the population remains a challenge to the governments. The soil salinity problems in Ethiopia stems from use of poor quality water coupled with the intensive use of soils for irrigation, poor on-farm water management practices and lack of adequate drainage facilities (Gebremeskel et al., 2018). Restoration of salt-affected lands into productive lands and protection of newly developed areas from the spread of salinity through improved irrigation and crop management is therefore of paramount importance. In the high salinity areas where growth of normal field crops is restricted, use of bioremediation methods including planting halophytic forages could bring these soils back into production.

In Ethiopian Rift valley agricultural system, main sources of salts are shallow groundwater tables, natural saline seeps and marine origin. Development of large irrigation schemes at middle and lower Awash Valley without the provision of appropriate drainage systems along with the poor irrigation management practices have caused 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 (Frew et al., 2012). If the current irrigation practices will continue in the salt-affected soils, salinity problems will further exacerbate in the future. Salinity problems in Ethiopia have manifested to the extent that farmers are experiencing huge crop losses while many farms have gone out of production over the last decade. Currently, soil salinity is recognized as the most important problem in the lowlands of the country resulting in reduced crop yields, low farm incomes and increased rural poverty (Gebremeskel et al., 2018). Among others, farmers' poor knowledge about the processes of salinity development and suitable coping strategies is considered as the major reason for rapidly increasing salinity problems.

Agricultural production in Ethiopia is predominantly rain-fed, it is extremely susceptible to changes in rainfall patterns and other adverse impacts of climate changes. Mitigating soil salinity to increase crop productivity of existing salt-affected soils and preventing futher spread of salinity is therefore of paramount importance for agricultural development in the country. In Ethiopia, very limited data and information is available on the extent of soil salinization and its spatial distributions. This report is an attempt to gather all the available information and present it in the form that can be used by researchers and policy makers to develop workable strategies for the rehabilitation and management of salt-affected soils in Ethiopia.

There is also a need to identify best adaptation and mitigation practices for salinity management, increasing farmer incomes and improve livelihood of poor rural communities. This is particularly important for Ethiopia considering their 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.

02

TYPES, CAUSES AND EXTENT OF SALT-AFFECTED SOILS

2.1 TYPES OF SALT-AFFECTED SOILS

Soil salinization is one of the major threats to sustainable agricultural production and food security in the arid and semi-arid regions of the world (Ventura and Sagi, 2013; Hasanuzzaman et al., 2014). Globally, over 900 million ha (Mha) of land is affected by the twin problems of salinity and sodicity (Wicke et al., 2011). Category Currently, 33% of the irrigated area (76 Mha) is affected by different levels of salinity and it is estimated that by 2050, more than 50% of the farms around the world will be salt-affected (Jamil et al., 2011; Kumar and Shrivastava, 2015). Saline soils occur in all environments of the world. They are found in cold (permafrost), temperate, subtropical, and tropical belts that are spreaded all the way from the sub-arctic to the equator, and in arid climates of the South, where evapotranspiration exceeds rainfall for most part of the year. Based on the FAO/UNESCO soil map of the world,about 60 Mha (24% of the total irrigated area) are affected by salinity, of which 38 Mha are located in five countries i.e. India (20 Mha), China (6 Mha), USA (5.0 Mha), Pakistan (4.5 Mha), and Soviet Union (2.5 Mha).

Table 3. Summary of classification of salt-affected soils

Category	Electrical conductivity of saturation extracts (ECe) ($dS\ m^{-1}$)	Exchangeable sodium percentage (ESP)	pH
Saline	≥ 4.0	< 15	<8.5
Saline-sodic	≥ 4.0	≥ 15	<8.5
Sodic	< 4.0	≥ 15	8.5-10
Non-saline non-sodic	< 4.0	< 15	≈ Neutral

2.1.1 Saline Soils

Salt-affected soils more commonly occur in irrigated areas, especially in arid and semiarid regions, where annualrainfall is insufficient to meet the evaporation needs of plants and leaching of salts. In humid areas, soluble salts are carried down through the soil profile by percolating rainwater and ultimately are transported to sea. In arid regions, salts tend to accumulate due to limited leaching. Saline soils contain excessive sodium chloride (NaCl) and sodium sulphate (Na2S04), or other neutral salts which inhibit the plant growth. They are characterized by an ECe of equal or greater than 4 $dS\ m^{-1}$, ESP ofless than 15 and pH value less than 8.5 (Table 3). Saline soils are recognized visually by the presence of white crusts of salts on the surface during dry weather formed through evaporation. Saline soils are generally flocculated, well-structured with permeability equal to or higher than that of normal soils. Chemically saline soils are composed of Cl^-, SO_4^{2-}, Na^+, Ca^{2+}, Mg^{2+} ions and small amounts of NO_3^-, HCO_3^-, and K^+, with soluble Na^+ seldom exceeding the sum of the other cations and thus not adsorbed on soil exchange complex to extent.

2.1.2 Saline-sodic soils

Saline-sodic soils contain soluble salts and exchangeable sodium (Na^+) in quantities that can be detrimental for the plant growth and soil structure. These soils are characterized by an ECe of equal or more than 4 $dS\ m^{-1}$, an ESP equal or greater than 15 and pH value usually below 8.5 (Table 3). Saline-sodic soils possess appearances and properties of both saline and sodic soils independently and are characterized by subsoils which are hard and impermeable to water. In a saline-sodic soil, the dispersing effect of exchangeable Na^+ may be fully counterbalanced by the coagulating effect of the soluble salts (electrolyte effect) present in excessive concentrations in the soil.

Unlike sodic soils, saline-sodic soils are well-structured and permeable. However, this is true for soils having high ECe (ECe > 10; ESP = 20). If ECe is low and ESP is high (ECe = 6; ESP > 25), saline-sodic soils will also behave like sodic soil. Therefore, removal of excessive soluble salts from saline-sodic soils by leaching changes their properties markedly and become similar to that of sodic soils. As a result, the soil becomes strongly alkaline (pH > 8.5), soil particles swell and disperse and translocate to subsoils where they are lodged in conducting pores and blocked them making the soil unfavourable for the movement of water and air, and for tillage.

2.1.3 Sodic soils

Sodic soils contain excessive quantities of exchangeable sodium (Na^+) destroying the soil structure with subsequent negative effects on plant growth. Sodic soils are generally low in salts but contain heavy amounts of sodium carbonate (Na_2CO_3), which causes clay particles in soils to disperse, or deflocculate, by ion exchange processes, resulting in the deterioration of soil structure. These soils have low air and water permeability and a pH of above 8.2. They are characterized by an ESP of equal or greater than 15 (SARP> 13 mmoles/1)0.5), an ECe less than 4 dS m^{-1} and a pH reading often above 8.5 or usually ranging between 8.5 and 10 (Table 3). Sodic soils consist mostly of the anions Cl^-, SO_4^{2-}, HCO_3 - and small amounts of CO_3^{2-}.

Sodic soils are typically poorly-structured, characterized by the presence of dispersed colloidal clays and organic matter in the topsoil. The surface horizons of sodic soils are exceptionally compact and cemented, and puddles of water on these soils are usually turbid, brownish black in color (Na-humus) and a shiny black crust of film of dry colloidal substance remains on the surface of the soil when dry. The presence of dispersed colloidal clays of smectites group of clay minerals and organic matter on the soil surface is attributed to swelling, physically damaging the soil structure leading to low permeability and drainage problems. This causes low infiltration rates, poor aeration and surface crusting, which make it difficult to till and difficulty for plant roots to penetrate through.

Irrigated sodic soils are impervious to water. Since clay soils are sensitive to Na, ESP values as low as 5-10 may reduce infiltration particularly with good quality water and swelling clays. Apart from irrigation systems where water supplies contain appreciable sodium, there is limited evidence to indicate that sodicity is increasing or decreasing in either severity or extent or both. Irrigation with waters containing appreciable quantities of potassium has a similar effect as sodium, causing clay dispersion and reduced permeability. The deleterious effect of potassium is estimated to be about one-third of that of sodium (Smith et al., 2014).

There are many responses in the region to contain the salinity threat such as: (1) direct leaching of salts, (2) planting salt tolerant varieties, (3) domestication of native wild halophytes for use in agro-pastoral systems, (4) phytoremediation (bioremediation), (5) chemical amelioration and (6) the use of organic amendments. In Iraq and Egypt, surface and subsurface drainage systems have been installed to control rising water tables and arrest soil salinity. Breeding of salt-tolerant crops are also recognized as response management in saline environment, though most work findings are based on controlled environment, those from real field are not too many.

2.2 CAUSES AND IMPACT OF SALINITY DEVELOPMENT ON IRRIGATED SOILS

The natural cause of soil salinity is the weathering process of the parent material of the soils and the underlying sodium-rich shale that is present in the bedrock below the soil sediments. During the weathering process, both physical and chemical, salts were released from rocks and minerals of the earth's crust. In arid regions, salts are brought in by streams draining into the basins. In sub-humid regions, dissolved sodium accumulates as exchangeable sodium in the B horizon, due to vertical or horizontal leaching. Salt-affected soils often occur on irrigated lands, especially in arid and semiarid regions, where amount of annual rainfall is significantly lower than the evaporation demand. In humid areas, soluble salts are carried down through the soil profile by percolating rainwater and ultimately are transported to sea.

Saline and sodic soils are influenced by climate, agricultural practices, irrigation methods and policies related to land management. Low annual precipitation and high temperatures have also contributed to the problems of salinity. In many regions of the country, consistent over-irrigation has rsulting in the rise of groundwater table leading to increased salinization and degradation of soils. From the very scattered information on the extent and characteristics of salt-affected soils, it can be estimated that salinity and sodicity is rapidly increasing, both in irrigated as in non-irrigated areas.

The soluble salts that occur in salt-affected soils consist mostly of various proportions of Na^+, Ca^{2+}, Mg^{2+}, Cl-, SO_4^{2-},HCO_3- and occasionally K^+, CO_3^{2-} and NO_3^- ions with minor quantities ofB, F and Li that are seldom of major importance because of their toxicity to plants. These ionic constituents of salt-affected soils are released and made soluble from rocks and weatherable minerals during the processes of geochemical and pedochemical weathering. Four main sources of the constituents of soil salinity and sodicity {Na^+, Ca^{2+}, Mg^{2+}, K^+ (common metals) and SO_4^{2-}, Cl^-, HCO_3^-, NO_3^- (common ligands)} are (a) mineral weathering (Na rich feldspars), (b) precipitation or rainfall, (c) fossil salts (marine or lacustrine deposits) and (d) collection of saline sediments in catchment areas. Salts may also be introduced in irrigation water, or as a result of fertilization

Increasing salinity in Ethiopia is decreasing agricultural production and increasing environmental problems. Number of factors are responsible for the development of salinity in different regions of Ethiopia. These include high temperatures, lack of good quality irrigation water, climate changes and poor land and water management practices. Major factors for salinity development in Ethiopia are summarized below.

Lack of good quality water for irrigation

Salt-affected lands in Ethiopia are mainly located in arid, semi-arid and lowland dry areas (60% of total land area of the country), where rainfall is neither sufficient nor reliable for sustainable crop production. In these areas, irrigation is necessary for stabilizing agricultural production and leaching excessive salts. In the absence of effective surface irrigation systems, availability of irrigation water in required quantities and the time when it is most needed remains a challenge. For this reason, farmers in many areas have developed flood-based farming systemso called as spate irrigation. Spate irrigation is beneficial in mountain catchment border lowlands, where farmers can make use of short duration floods. However, as water comes often either long before or late after the cropping season, crop productivity is severely affected. The success of spate irrigation depends on the availability of good infrastructure and cooperation of farmers. Based on the review of the spate irrigation systems in the Tigray region, Van Steenbergen et al. (2011) has listed the following problems with the spate irrigation.

- Upstream and downstream users do not share the flood flow equitably;
- Technical faults in developing local diversion canals generate changes in the river course;
- Improper secondary and tertiary canals leading to in-field scour and creation of gullies in the fields - which reduces available soil moisture.

The limited capacity of rainfed agriculture due to erratic nature of the rainfall has persuaded farmers to expand irrigated agriculture for sustainable crop production (Tesfaye and Fassil, 2011). In the arid lowlands of the country, conventional irrigation is limited due to the perennial nature of most rivers. Other forms of irrigation such as based on temporary flows and floods, have more potential but are not fully developed. Development of soil salinity in Kewet and Efratana Gidim areas is associated to the use of poor quality water for irrigation from dug wells during the dry season when freshwater availability from the river is not sufficient to meet irrigation demand. The quality of these wells is only marginally fit for irrigation (Yonas, 2005). In many other lowlands, there is a considerable groundwater potential. However it is challenging to exploit this water source for irrigation due to its existence at deeper depths, lack of drilling facilities and associated costs. In other lowlands, poor quality of groundwater restrict its use for agriculture.

Declining irrigation water quality

The hot and dry climates of saline areas require that the irrigation water does not contain soluble salts in amounts that are harmful to the plants or have an adverse effect on the soil properties. However, this is not the case in Ethiopia. Studies done to evaluate the impact of irrigation on soil salinity and crop production in Gergera Watershed, Atsbi-Wonberta, Tigray, Northern Ethiopia have shown the potential risk of soil sodification due to the use of poor quality surface water for irrigation and suggested the need for adopting alternative water and crop management practices for sustaining crop productivity in these areas (Yeshitela et al., 2012).

Soils of Central Rift valley are naturally sodic in the subsurface horizons and the use of marginal quality groundwater for irrigation has exacerbated the salinity problems. In North Shewa, the widely irrigated areas of the zone are the lowlands of Kewet and Efratana Gidim are also facing growing threats of soil salinity especially in small-scale irrigated farms (Tilaye & Mekonen, 2002). Development of soil salinity in this area is often associated to the use of poor quality water for irrigation from dug wells during the dry season when fresh water availability from the river is not sufficient to meet irrigation demand. The quality of these wells is only marginally fit for irrigation (Yonas, 2005). Deterioration of water quality along major river streams of the Awash River is also becoming an important ecological concern because water from this river is extensively used for more than 3000 hectares of farm land along the River Basin (EIAR Annual Report, 2015).

Poor land and water management practices

Waterlogging and salinity problems have aggravated due to poor drainage facilities and on-farm water management practices that has caused excessive seepage of irrigation water resulting in elevated groundwater levels. The combined effect of waterlogging, salinity and sodicity has emerged as the major constraint for crop production in Zeway Dugda around Lake Zeway, farms around Gerjele and Tumuga swampy area, irrigated farm areas of Abaya and Arbaminch, etc. Farmers in these areas have the tendency to over-irrigate their crops (whenever water is available), which results in excessive seepage and rising groundwater levels. Most of the farmers still use flooding and basin methods of irrigation on poory leveled fields, which results in un-even distribution of irrigation water and salts within the same field. Use of soil amendments, required amounts of fertilizers and other soil management techniques is limited due to technical and financial constraints. The development of salt-affected soils and the associated problems are most pronounced in arid and semi-arid regions. The insufficient water availability through rainfall (evapotranspiration exceeding precipitation) and other sources to leach down salts from the plant rooting zone favours the excessive accumulation of salt constituents in soils of arid and semi-arid regions.

Impact of salinity development on socio-economic and environmental conditions

Increasing salinity problems in the irrigated areas of arid and semi-arid lowlands are causing huge social (i.e. migration and diseases) and economic problems (i.e. reduction in crop production, declining farm incomes, poor living standards and increasing poverty) for the country. Farmers are increasingly abandoning their farms in irrigation schemes due to rising salinity problems. These problems are more serious in arid and semi-arid regions, where soil salinity strongly limits crop growth. Due to increasing soil salinity, per capita land availability has reduced to 0.2 ha in Ethiopia (Spielman et al., 2011). In many parts of the country, high salinity and sodicity levels from increasing groundwater levels are threatening the sustainability of irrigated agriculture (Kidane et al., 2003). Sardo (2005) has revealed that increase in groundwater levels due to excessive irrigation has caused salinity development in irrigated areas. In arid and semi-arid regions, accelerated capillary rise due to high evapotranspiration rates helps the buildup of salt in soil profiles. Increasing salinization is also preventing farmers to bring more area under cultivation in these arid and semi-arid regions. Since new agricultural land will be scarce, increasing food production for the rising population of the country will require bringing these salt-affected lands back to their production potential.

The accumulated soluble salts can adequately be leached out of the profile in humid environments. However, in arid environments where ET often exceeds rainfall, additional application of irrigation water is needed to leach down salts. Therefore, the process of secondary salinization and sodication of soils in arid and semi-arid climatic regions are the consequences of quite diverse and interacting factors of surface and ground waters, soil physical properties, climate, relief and geomorphology, biological activities and human interference. Continued irrigation practices without proper drainage can slowly accumulate salts in the soils. Therefore, good irrigation management is needed to leach down salts from thee soil profile. In irrigated fields, soluble salt concentration increases with the depth of soil profile. Under shallow groundwater conditions, salt concentration increases near the surface due to capillary rise of groundwater.

2.3 EXTENT OF SALT-AFFECTED SOILS IN ETHIOPIA

The soil classification method defined by FAO (1984e) is widely used to describe extent and nature of salt-affected soils in Ethiopia. According to this classification, soils in arid and semi-arid areas of Ethiopia (typically Regosols, Xerosols and Yeromosols) are less developed; tend to be stony and shallow saline (Solonchaks, Solonetz). The soils in the valley bottoms and flat plains are dominantly Vertisols, while in the undulating to gently rolling plateau, Luvisols, Nitosols and Acrisols soil types ai·e more common. The mountains and tarnished landscapes are known as Leptosols and the major alluvial plains are dominantly Fluvisols and Vertisols with saline and sodic phases.

The arid and semi-ai·id agro-ecologies which account for nearly 50% of the country's land area are regarded as marginal environments for crop production mainly due to soil and water salinity. Low levels of annual rainfall and high temperatures have resulted in excessive water evaporation rates, contributing to high concentrations of soluble salts in these lowland areas, (Sileshi et al., 2015). In Ethiopia, about 44 Mha (36% of the total land area) is potentially susceptible to salinity problems, of which 11 Mha have already been affected by different levels of salinity and mainly concentrated in the Rift valley (Hawando, 1995). The soils of the Melka Sedi-Amibara Plain of the Middle Awash Valley are highly saline with ECe ranging from 16-18 dS m^{-1}. Generally, Na^{+}, Ca^{2+}, Cl^{-}, and SO_4^{2-} are the dominant salts (mainly NaCl and CaS04) contributing to the higher salinity levels in the soils (Auge et al., 2018). Ethiopia ranked 7th in the world in terms of percentage of the total land area affected with salinity. This has resulted in the degradation of natural habitats, ecosystems and threatened the productivity of irrigated lands, which is producing more than 40% of the total food requirement of the country (Mohammed et al., 2015).

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 (Sileshi et al., 2016). In irrigated areas of arid and semi-arid regions, the ascending motion of capillary water is generally greater than the descending motion and it facilitates the buildup of salt in soil profiles due to high evapotranspiration rates. Due to poor drainage conditions in the Middle Awash Valley of the Rift Valley System, the large state-owned irrigated farms are also fast going out of production due to increasing soil salinity (Fantaw, 2007). 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 (Mesfin, 2001; Heluf and Mishra, 2005).

The original 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 (Heluf,1985;1987). These parent materials undergo severe disintegration and decomposition when exposed to the action of natural waters and carbonic acid forming large quantities of mobile silica, alumina and free bicarbonate and carbonateions of alkali and alkaline earth bases. However, the processes responsible for salinization and sodication of salt-affected soils in Ethiopia particularly those of the Awash River Basin ai·e rather more diverse and complicated (Heluf, 1985, 1987; 1995; Heluf and Mishra, 2005).

It is also estimated that the total area of land covered by salt-affected soils in the former Hararghe Administrative Region (eastern region) is 1,159,300 ha, that is about 12.9% of the arable land area in the Region (Girma and Fentaw 1996). 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. Similar a considerable area of land has been abandoned for cultivation due to the prevalence of salt-affected soils at the Middle Awash. Furthermore, about 39% of the Abaya State Farm (southern regional state) are salt-affected.

The Rift Valley Zones and South-Eastern (Somali) lowlands of the country are the most valuable agricultural lands as they offer a huge potential for multiple cropping. Most of the irrigated State Farms, where export crops i.e. cotton, sugarcane, citrus fruits, banana and vegetables are being grown, are also located in the Rift Valley Zone. However, due to the absence of effective drainage systems, a substantial proportion of the areas of this zone are being converted to saline and saline-sodic soils annually (Heluf and Mishra, 2005). They have shown a huge salt build up in the soils of 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 providing 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 1.

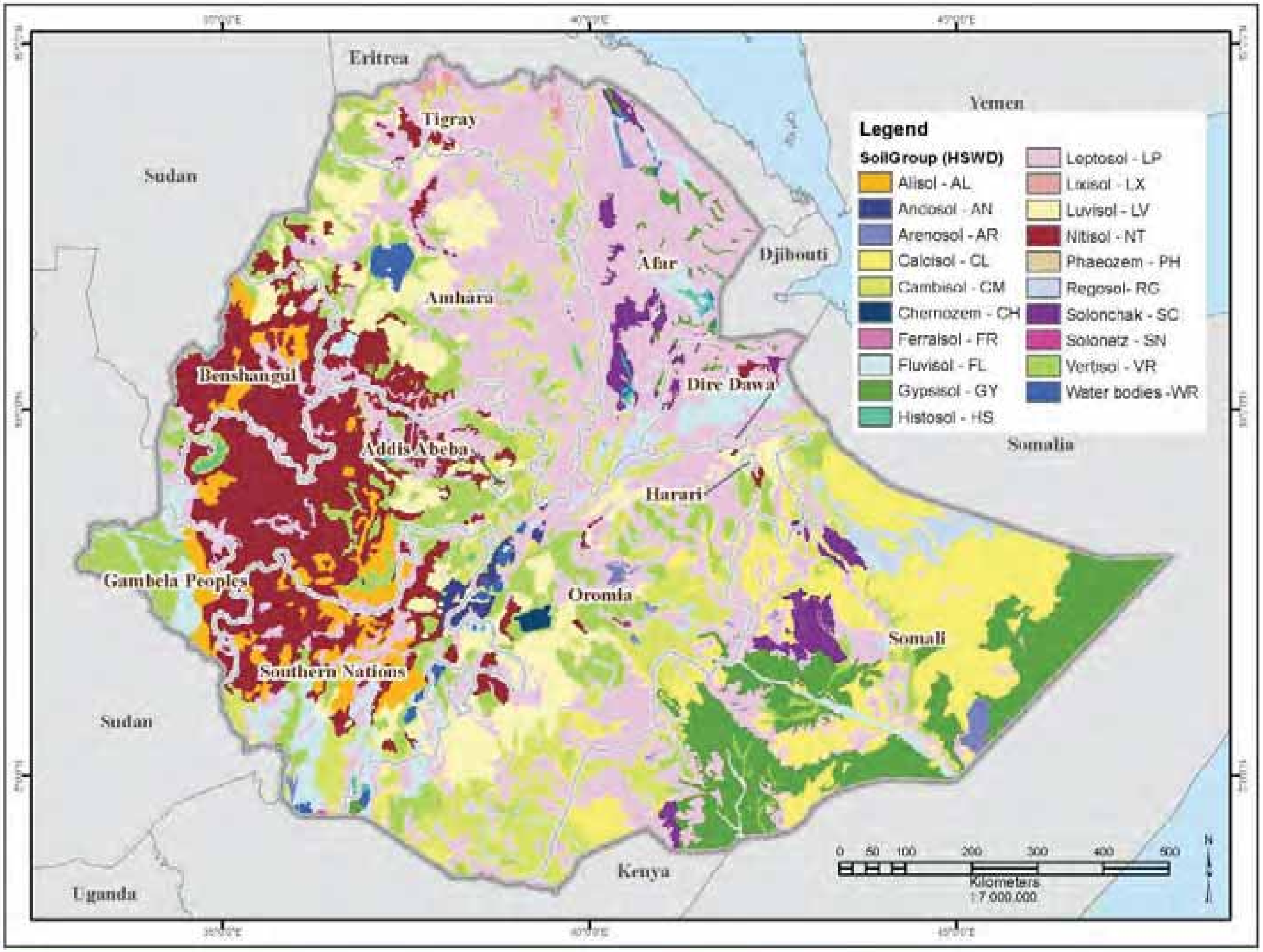

Figure 1. Soil groups in different regions of Ethiopia.

2.4 SPATIAL VARIABILI1Y OF SALINI1Y IN THE RAMSAP PROJECT AREAS

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 for soil characterization and development of surface salinity (0-30cm) maps for Afar, Oromia, Amhara and Tigray regions (Figure 2). 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. For the data management purposes, the spatial variation in (ECe) was categorized based on standard ratings. Universal Transverse Mercator (UTM), Zone 37N projection and Datum ofWGS_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 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.

Figure 2. Map of different administrative regions in Ethiopia

2.4.1 Chracterization of the Afar region

For the Afar region, a total of 16 Reference Soil Groups (RSGs) were identified covering 82% of the area as given in Table 4. 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 3.

Table 4. Area covered by different RSGs in the Afar region

No.	Soil Types	Area		No.	Soil Types	Area	
		Km²	%			Km²	%
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 levels of salinity (Table 5). Low and medium surface soil salinity classes cover 38% of the area and are found in the central and the southern part of the region. High and extremely saline surface salinity levels cover 20% of the region and spatially cover the north-eastern part of the region (Figure 4). The severity and spatial coverage of sub surface soil salinity is presumed to be higher than the upper 30 cm soil layer. Therefore, it is recommended to conduct deep soil profile salinity analysis for proper selection of salt-tolerant species for these regions.

Table 5. Distribution of surface (0-30 cm) soil salinity levels in the Afar region

Soil salinity Levels	Area	
	km²	%
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

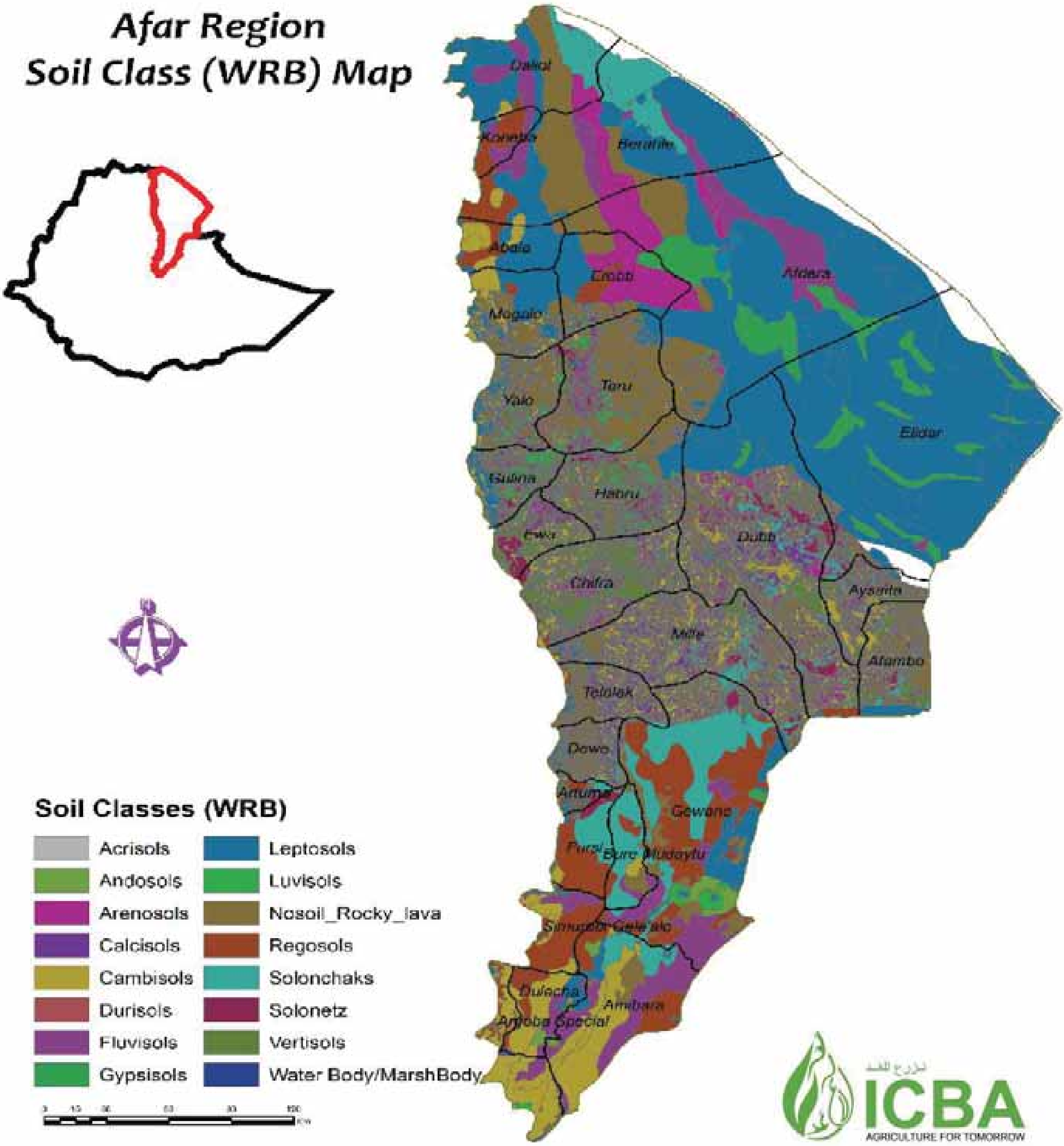

Figure 3. Dominant RSGs in the Afar region

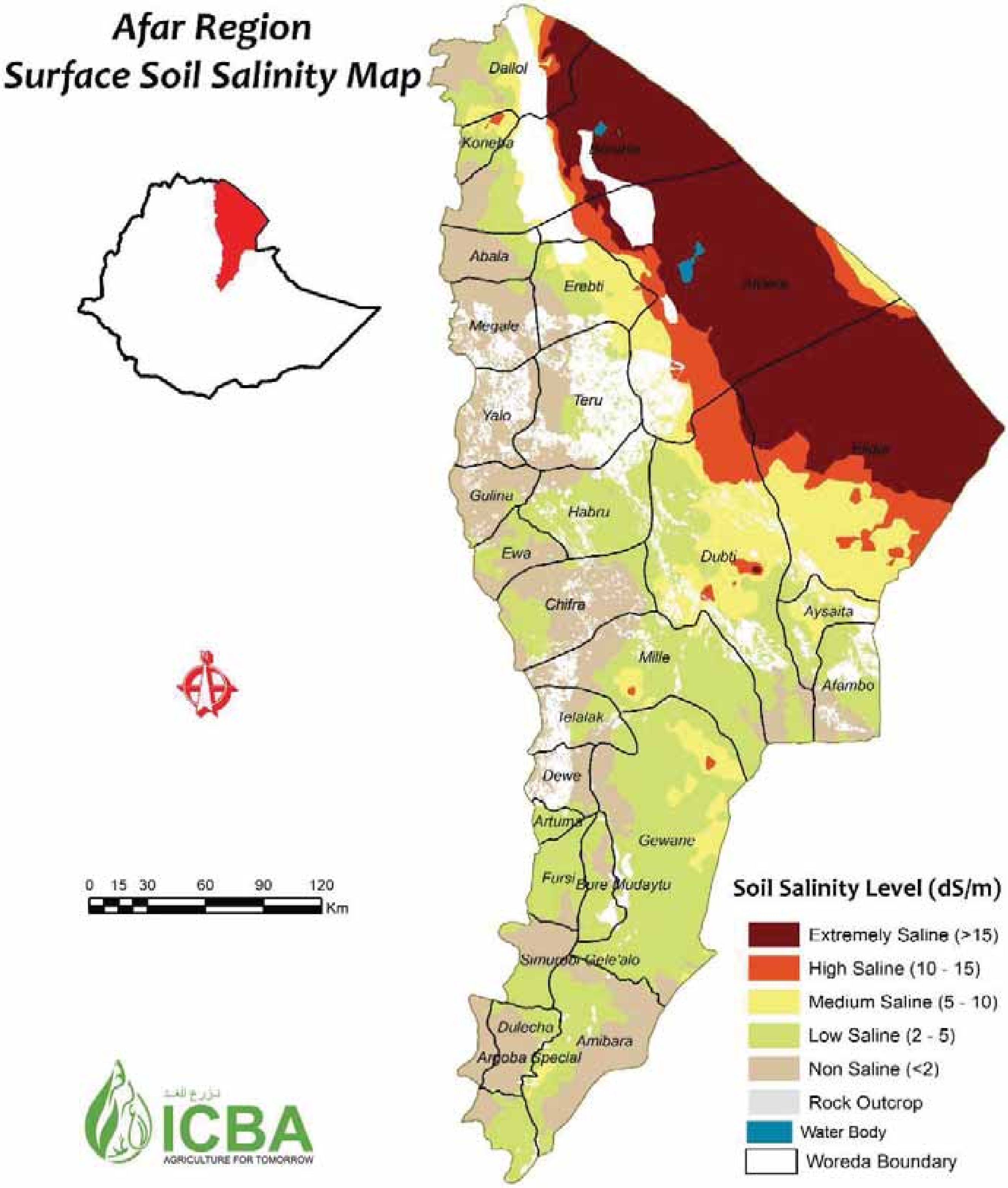

Figure 4. Surface salinity map of the Afar region

2.4.2 *Characterization of the Amhara region*

A total of 18 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 6. Leptosols (38.2%) being the dominant in the region following by vertisols, cambisols and luvisols.

Table 6. 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 south and south-eastern part of the region (Figure 5). Table 7 shows the surface salinity in the top 0-30 cm depth. Surface salinity map of the Amhara region is shown in Figure 6.

Table 7. 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

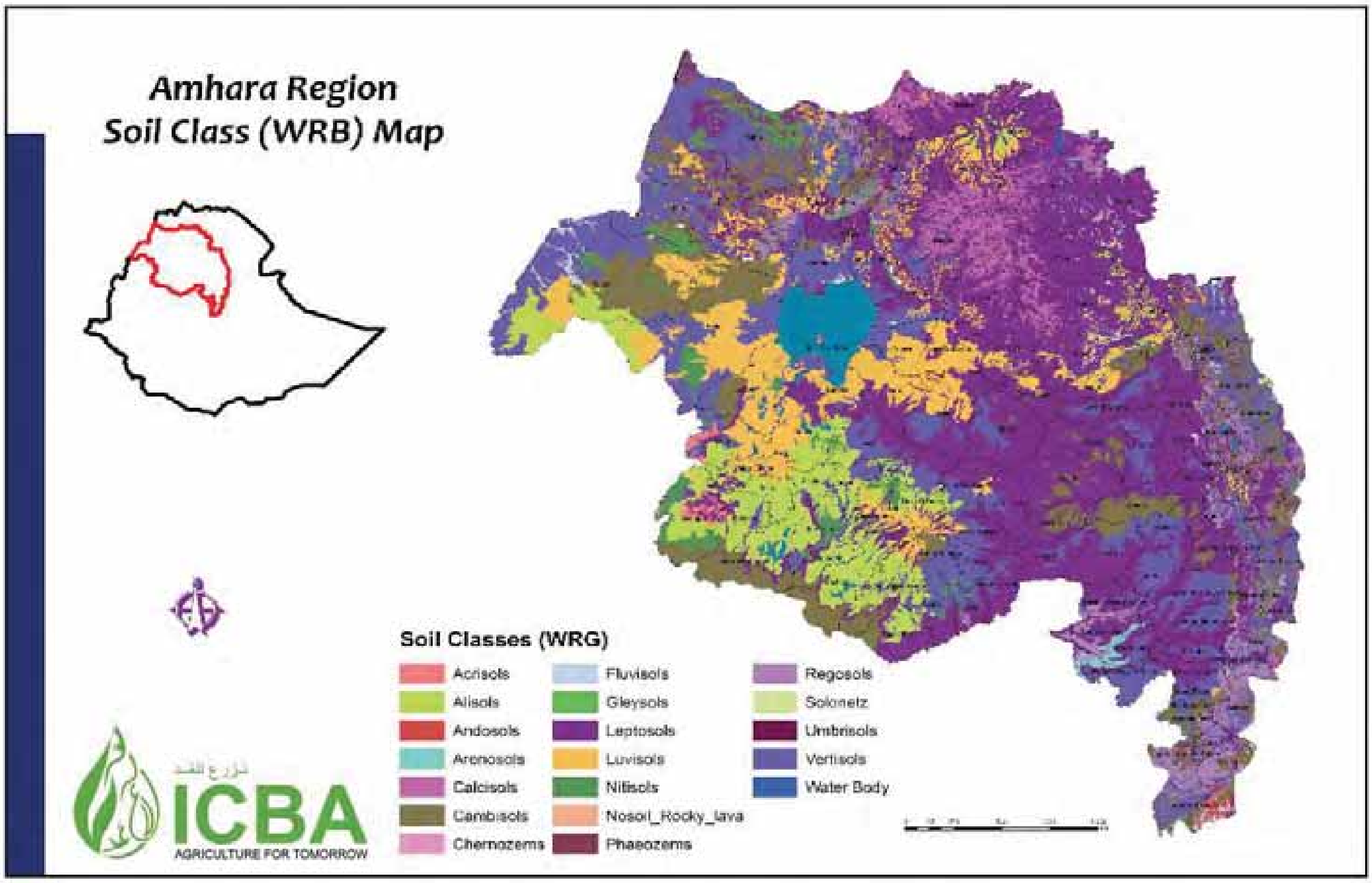

Figure 5. Dominant RSGs in the Amhara region

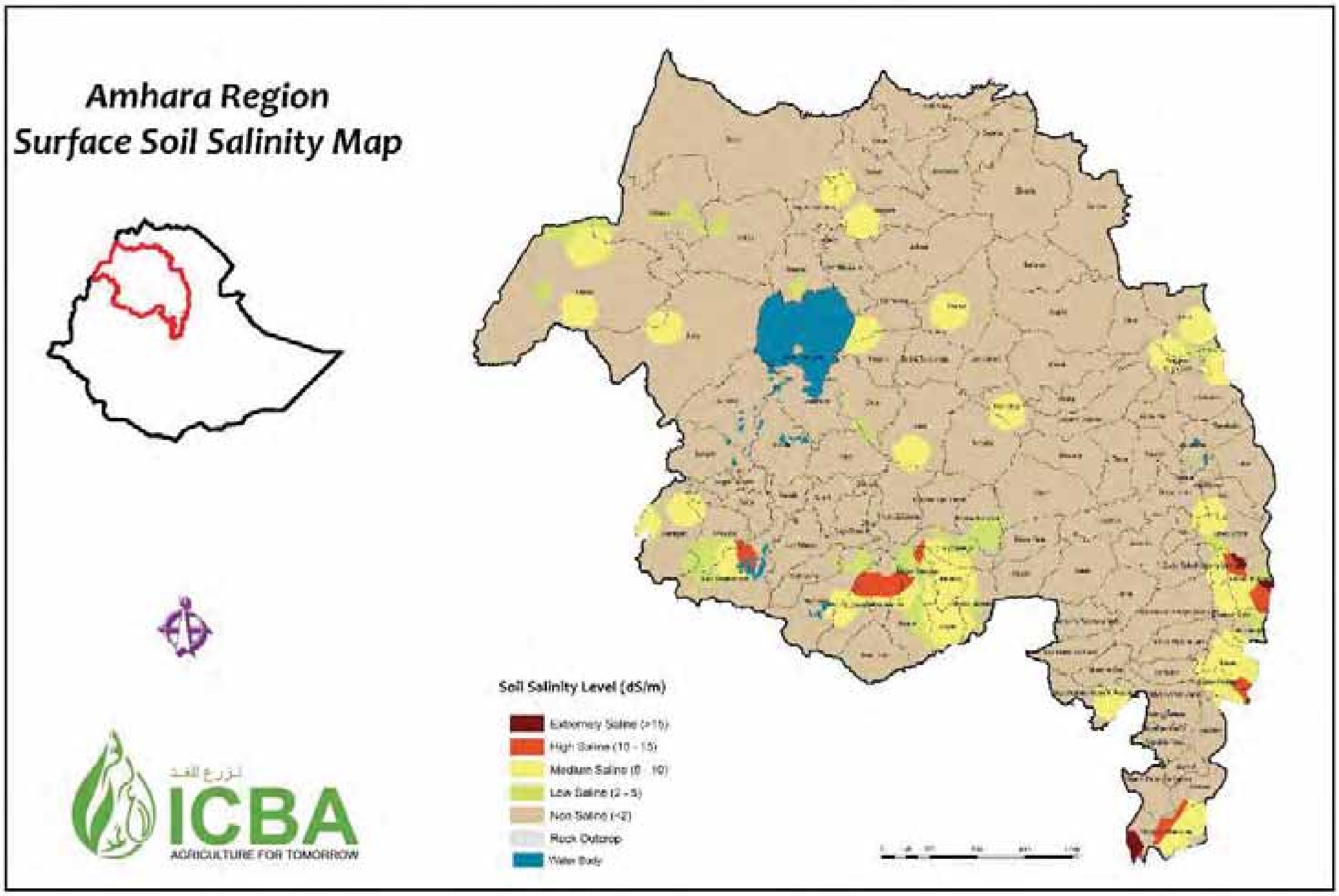

Figure 6. Surface salinity maps of the Amhara region

2.4.2 *Characterization of the Oromia region*

In the Oromia region, 14 Reference Soil Groups (RSG) have been identified covering about 96.55% of the area (Table 8; Figure 7). The soil surface salinity (0-30 cm) in the Mahara region ranges from none-saline (<2 dS m^{-1}) to extremely saline (>15 dS m^{-1}). It is estimated that 11.83% of the soils in the region are affected by salinity (Table 9). 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 extremely surface salinity soils cover only 0. 71 % and spatially cover south and south-eastern part of the region. Figure 8 shows surface soil salinity (0-80 cm depth) in the Oromia region.

Table 8. Area covered by each RGS in the Oromia region

Soil salinity levels	Area	
	km²	%
Non-saline/Waterbody/Rock out crop (<2 dS m⁻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

Table 9: Distribution of surface (0-30cm) soil salinity in the Oromia Region

No.	Soil Types	Area		No.	Soil Types	Area	
		Km²	%			Km²	%
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

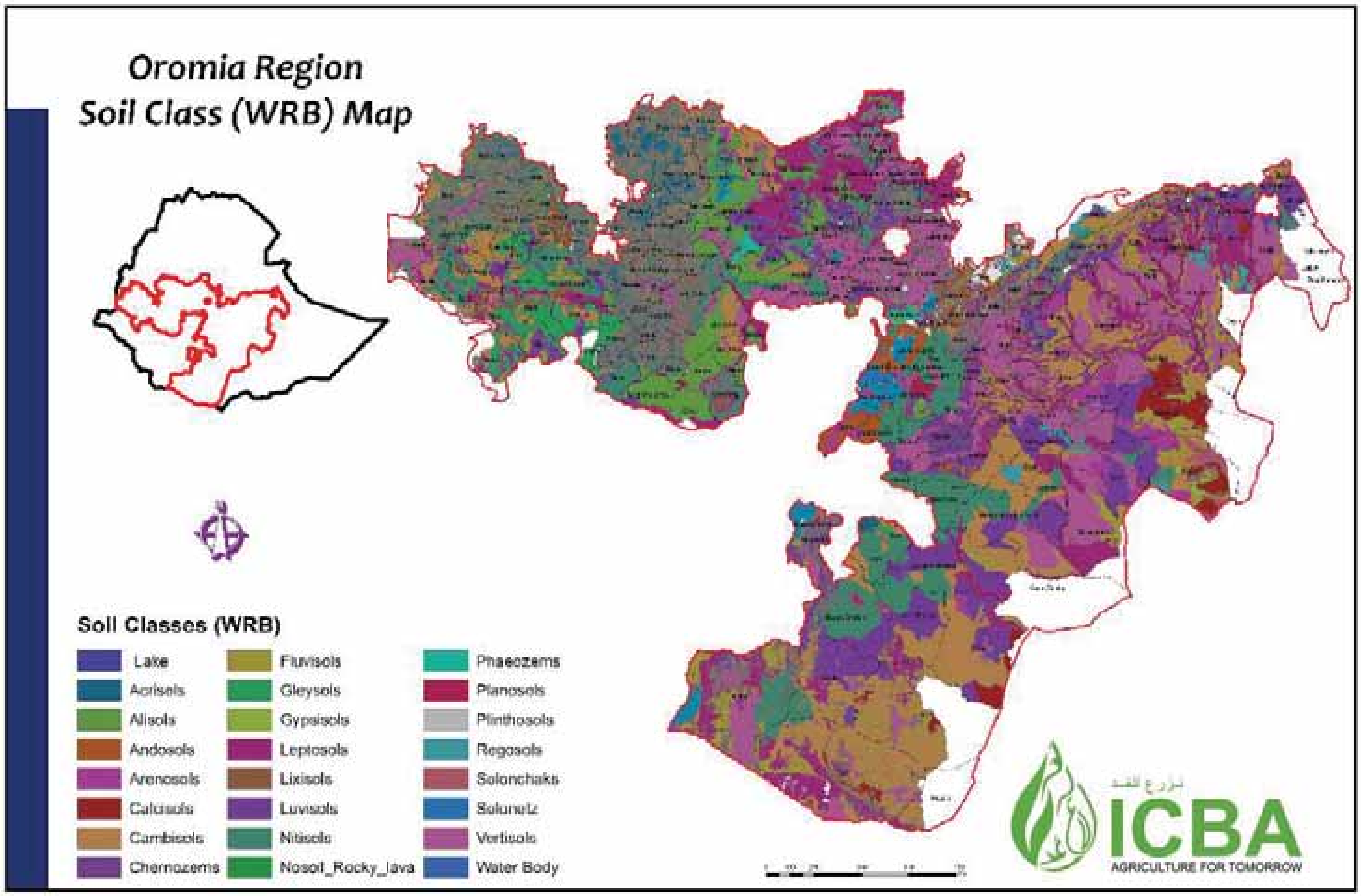

Figure 7. Soil group types in the Oromia region.

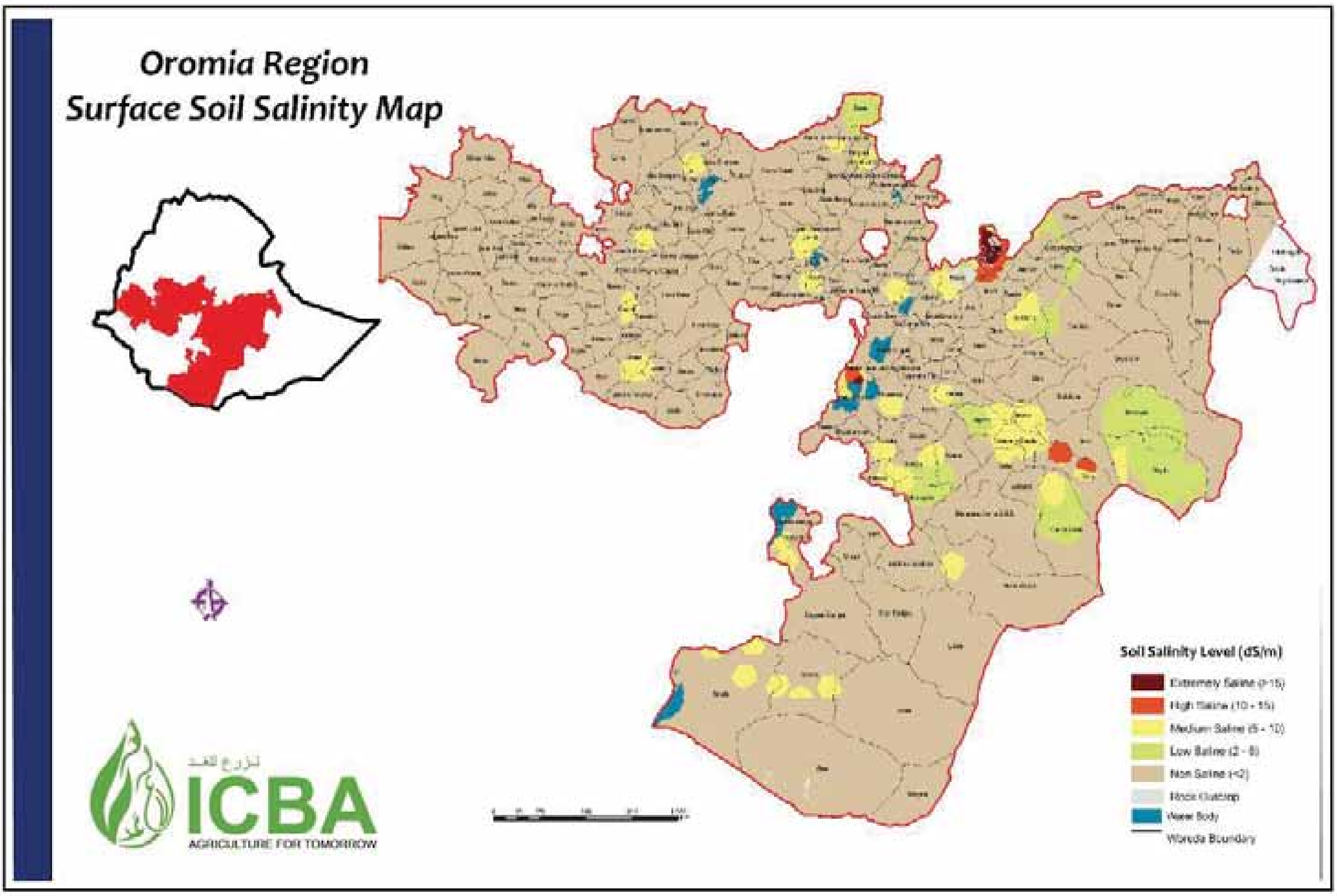

Figure 8. Surface soil salinity (0-30 cm) map of the Oromia region

2.4.4 *Characterization of the Tigray region*

A total of 11 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 10; Figure 9) The results of 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 71% soils of the region are medium saline (Table 11). These soils are located in the central, south, south west and eastern part of the region.

Table 10. 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

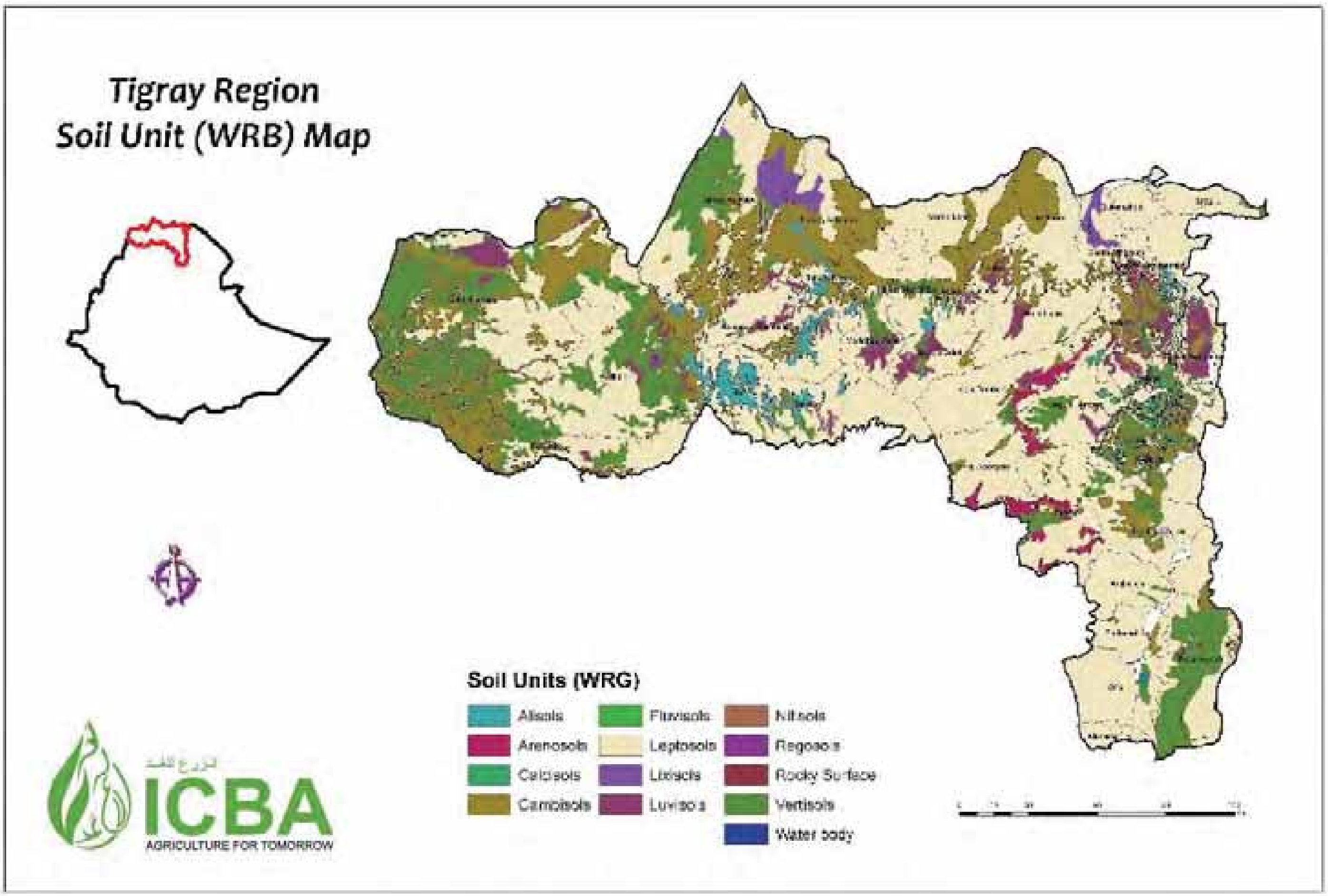

Figure 9. Soil groups types in the Tigray region.

Table 11. Distribution of suface (0-30) soil salinityin 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 10 shows the surface soil salinity classes (0-30 cm) in the Tigray region. The salinity of the deeper layers may be higher due to variation in soil properties. Therefore, it is suggested to do detailed sub surface salinity analysis before suggesting most-suited cropping systems for these areas.

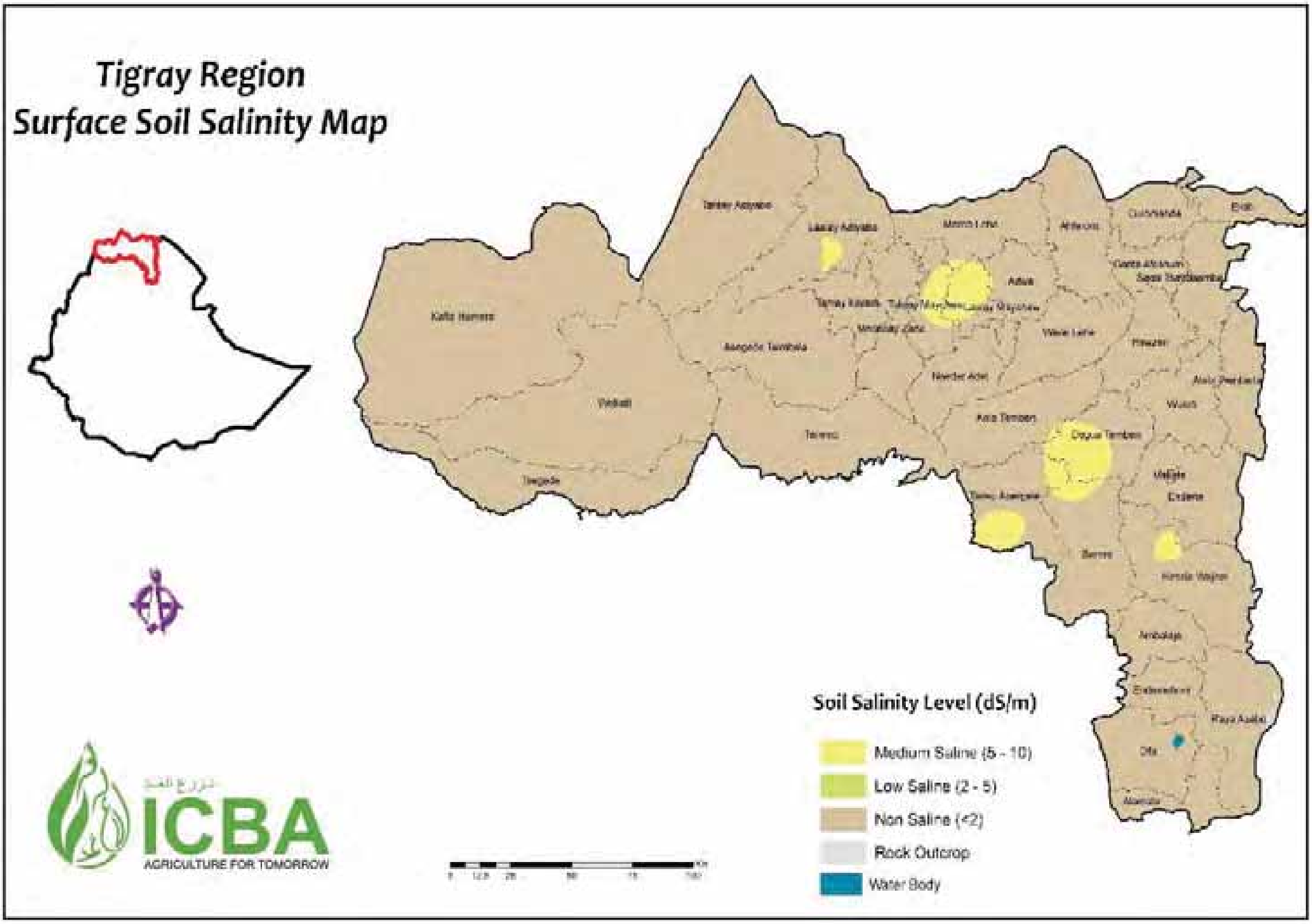

Figure 10. Surface soil salinity (0-30 cm) map of the Tigray region.

03

CHARACTERIZATION OF
SOILS IN THE RIFT VALLEY

3.1 SALT-AFFECTED SOILS OF THE MIDDLE AWASH RIVER BASIN

The laboratory analysis of the soil profiles from the MeTh-a Sedi-Amibara Plain of the Middle Awash Valley are presented in Tables 12. The data shows that the soils of the MeTh-a Sedi-Amibara Plain sampled on abandoned cotton field contains excessive soluble salts (ECe at 25°C ranging between 16.6-18.6 dS m^{-1}). Soluble Na^{+}, Ca^{2+}, Cl^{-}, and $SO4^{2-}$ were the dominant soluble salt constituents throughout the depth of the profile. Accordingly, chloride and sulphate salts of sodium and calcium (mainly NaCl and CaS04) were assumed to be the major soluble salts contributing to the very high salinity levels. The SAR values are extremely high, however, ESP values are moderate (6.21 at the surface) and varied from 4.2 to 7.0 within the soil profile.

Table 12. Chemical composition of soil profile samples taken from the abandoned cotton field (Pedon 1) of the Melka Sedi-Amibara Plain of the Middle Awash valley.

12a. Ionic composition of the saturation extracts of soils

Depth (cm)	pH	ECe (dS m^{-1})	Soluble cations (me l^{-1})				SAR (mmoles/l)$^{0.5}$	**Soluble anions (me l^{-1})**			
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}		CO_3	HCO_3	Cl	**SO_4**
0-25	7.2	18.57	59.38	3.70	208.14	15.39	37.06	Nil	1.10	165.8	**77.11**
25-50	7.2	17.79	55.54	3.29	197.6	14.43	36.43	Nil	1.00	160.2	**71.83**
50-70	7.2	17.46	53.14	3.70	197.5	14.10	37.05	Nil	1.00	157.0	**68.54**
70-90	7.2	17.24	51.55	3.37	120.0	13.72	22.91	Nil	1.40	147.0	**64.26**
90-120	7.2	16.57	47.31	3.13	132.5	10.26	26.38	Nil	1.00	132.4	**59.98**

12b. Ionic composition of the soil solid surface

Depth (cm)	Charge characterization			Exchangeable cations and CEC ($cmol_c$ kg^{-1})					ESP
	pH_{H2O}	pH_{KCl}	ΔpH	Ca	Mg	Na	K	CEC	
0-25	7.2	6.80	0.40	38.27	6.60	3.28	4.15	52.81	6.21
25-50	7.2	6.90	0.30	41.83	5.87	2.38	3.77	54.11	4.39
50-70	7.2	6.90	0.30	40.34	5.94	2.37	3.28	52.08	4.55
70-90	7.2	6.30	0.90	37.77	6.22	3.55	2.79	50.59	7.02
90-120	7.2	6.80	0.40	40.2	6.11	2.17	2.99	51.64	4.20

(Source: Heluf, 1985)

Table 13 present chemical composition of soil profile samples from the poor cotton field (Pedon 2) of Melka Sedi-Amibara Plain of the Middle Awash Valley. The salt composition was similar to that of Pedon 1.

Table 13. Chemical composition data of typical saline soil profile samples on poor cotton field (Pedon 2) of Melka Sedi-Amibara Plain of the Middle Awash Rift Valley

12a. Ionic composition of the saturation extracts of soils

Depth (cm)	pH	ECe (dS m^{-1})	Soluble cations (meq l^{-1})				Soluble anions (meq l^{-1})			
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}
0-20	7.20	16.68	103.79	3.29	54.37	14.36	Nil	1.20	119.40	55.69
20-40	7.18	17.88	95.21	4.28	65.46	10.26	Nil	0.90	126.20	55.69
40-64	7.20	18.23	63.62	4.11	73.68	10.77	Nil	1.10	133.30	59.98
64-88	7.23	18.57	41.48	4.93	130.75	1.28	Nil	1.10	133.30	59.98
88-97	7.45	18.30	28.14	2.30	84.38	0.64	Nil	0.80	113.00	51.41
97-140	7.38	19.79	33.83	4.44	202.27	1.41	Nil	0.90	139.8	85.68

13b. Ionic composition of the soil solid surface

Depth (cm)	pH	Exchangeable cations (cmol$_c$ kg^{-1})				Exch. acidity (cmol$_c$ kg^{-1})	CEC (cmol$_c$ kg^{-1})	PBS	ESP
		Ca	Mg	Na	K				
0-20	6.90	43.89	5.76	2.23	3.23	0.15	55.26	99.73	4.03
20-40	6.90	43.79	5.66	2.07	2.08	0.15	53.75	99.72	3.85
40-64	6.80	47.37	5.95	3.19	0.90	0.20	57.61	99.65	5.53
64-88	7.00	36.59	6.64	3.63	0.41	0.15	47.52	99.68	7.64
88-97	7.00	27.16	22.68	3.05	0.26	0.10	53.25	99.81	5.73
97-140	7.00	32.28	42.10	2.96	0.46	0.05	77.85	99.93	3.80

The results of the chemical characteristics of the soil profile samples taken from the uncultivated field of the Amibara irrigation project (AIP) in Melka Sedi-Amibara (Middle Awash Valley) are presented in Tables 14-16. The soil on the uncultivated land contained excessive concentrations of soluble salts (ECe ranging from 13-16 dS m^{-1}) as well as excessive concentrations of exchangeable sodium (ESP ranging from 7-32). The soluble Na^{+}, $S04^{2-}$ and Cl^{-} ions are present in large quantities. This shows that Na_2SO_4 (thenardite mirabilite) and NaCl (halite) are the major salts causing higher salinity levels in the soil profile. Based on the analytical results, the soil is classified as saline-sodic.

The high salinity and sodicity levels compounded with the poor drainage conditions have resulted in abandoning of vast area of productive lands. In the Middle Awash Valley of the Rift Valley System, over 2000 ha of the Melka Sedi-Amibar a State Farm that was cultivated for banana plantation from 1971-1986 (16 years) and from 1982-1992 (10 years) for cotton and other crops have gone out of cultivation due to the problems associated with soil salinity, sodicity and poor drainage. It is also apparent that the problem will continue expanding further to cause more lands to be abandoned for cultivation unless an integrated diagnostics based soil reclamation procedures (combination of physical, chemical, hydrological and biological) are adopted (Shahid et al., 2018b). Therefore, it is important to install appropriate drainage systems to evacuate excessive salt from the soil profile so that sustainability of irrigated agriculture can be maintained in these areas. In addition, crops that are tolerant to high soil and water salinity should be introduced to improve the agricultural productivity of these soils.

Table 14. Chemical composition of soil profile samples taken from the banana field (Pedon 3) of Melka Sedi-Amibara (Middle Awash Valley).

14a. Ionic composition of the saturation extracts of soils

Depth (cm)	pH	ECe (dS m^{-1})	Soluble cations (me l^{-1})				SAR (mmoles l^{-1})$^{0.5}$	**Soluble anions (meq l^{-1})**			
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}		CO_3^{2-}	HCO^{-}	Cl^{-}	SO_4^{2-}
0-23	7.6	2.22	1.55	1.50	6.92	1.67	5.70	Nil	1.20	6.20	8.57
23-46	7.5	3.36	2.89	1.73	6.83	1.28	4.49	Nil	1.20	5.00	12.85
46-66	7.5	3.34	2.79	2.06	6.00	1.28	3.85	Nil	0.90	3.40	17.14
66-86	7.5	3.11	2.56	2.53	6.05	1.15	3.79	Nil	0.90	0.98	11.78
86-106	7.7	1.33	1.65	1.23	6.52	0.51	5.44	Nil	1.10	3.40	4.57
106-146	7.7	1.22	1.80	1.64	6.09	0.51	4.64	Nil	2.40	2.40	6.43

14b. Ionic composition of the soil solid surface

Depth (cm)	Charge characterization			Exchangeable cations and CEC (cmol$_c$ kg^{-1})					ESP
	pH_{H2O}	pH_{KCl}	ΔpH	Ca	Mg	Na	K	CEC	
0-23	7.63	6.90	0.73	42.04	14.01	0.30	3.44	59.97	0.42
23-46	7.50	6.80	0.70	42.48	10.13	0.09	1.85	54.68	0.16
46-66	7.50	6.60	0.90	42.02	11.13	0.10	1.01	54.48	0.18
66-86	7.50	6.70	0.80	39.72	14.59	0.21	1.04	55.48	0.39
86-106	7.68	6.70	0.98	39.49	17.80	0.31	0.77	58.47	0.53
106-146	**7.65**	**6.60**	**1.05**	**38.15**	**22.74**	**0.27**	**0.99**	**62.30**	0.43

Table 15. Chemical composition data of a typical saline soil profile sampled on uncultivated land (Pedon 4) of Melka Sedi-Amibara (Middle Awash Valley)

15a. Ionic composition of the saturation extracts of soils

Depth (cm)	pH	ECe (dS m^{-1})	Soluble cations (meq l^{-1})				Soluble anions (meq l^{-1})			
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}
0-10	8.40	14.23	2.00	1.32	664.64	1.41	0.20	2.75	128.00	281.52
10-20	8.48	13.90	2.15	0.66	578.51	1.15	0.20	3.50	129.20	281.34
20-50	8.73	13.34	1.75	0.16	604.61	1.03	2.20	3.80	136.00	280.52
50-80	8.93	14.34	1.60	0.16	703.78	1.03	2.20	3.80	148.80	245.52
80-105	8.95	14.46	1.55	0.16	657.68	1.22	2.40	3.60	145.00	250.05
105-135	9.05	15.57	1.85	0.16	533.88	1.09	2.80	3.90	147.20	240.43
135-145	9.05	15.79	1.75	0.25	450.89	0.83	2.30	2.30	148.40	240.06
145-185	9.10	16.12	1.45	0.08	433.49	1.03	3.80	3.80	149.60	239.90

15b. Ionic composition of the soil solid surface

Depth (cm)	pH	Exch. cations (cmolc kg^{-1})				Exch. acidity (cmolc kg^{-1})	CEC (cmol$_c$ kg^{-1})	PBS	ESP
		Ca	Mg	Na	K				
0-10	7.70	24.49	8.81	19.45	0.90	0.05	53.66	99.91	36.25
10-20	7.60	16.89	6.62	11.55	0.82	0.05	35.93	99.86	32.14
20-50	8.10	7.22	6.67	13.06	1.56	0.05	28.56	99.82	45.73
50-80	8.50	7.48	6.83	43.50	1.77	0.10	59.68	99.83	72.81
80-105	8.50	7.10	7.03	32.81	2.06	0.10	49.10	99.80	66.82
105-135	8.50	9.57	7.83	32.74	2.89	0.10	53.13	99.81	61.62
135-145	8.60	9.45	7.55	23.11	2.50	0.20	42.71	99.77	54.11
145-185	8.60	8.88	7.34	39.34	0.96	0.20	56.61	99.65	69.30

(Source: Heluf, 1985)

Table 16. Chemical composition of soil profile samples from AIP's pilot drainage projec(tP edon 5) of Melka Sedi-Amibara Plain of the Middle Awash Rift Valley

16a. Ionic composition of the saturation extracts of soils												
Depth (cm)	pH	EC (dS m^{-1})	Soluble cations (me l^{-1})				SAR mmoles/l)$^{0.5}$	**Soluble anions (me l^{-1})**			
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}		CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}
0-22	7.2	16.24	2.10	4.63	62.64	4.49	34.15	Nil	0.90	19.50	68.50
22-50	7.6	17.65	1.85	3.37	84.38	1.28	52.23	Nil	1.40	26.40	70.52
50-63	7.9	17.79	1.55	3.29	94.21	1.15	60.56	Nil	1.20	27.60	72.06
63-103	7.9	18.24	1.85	6.91	241.91	1.92	115.56	Nil	1.00	29.00	183.10
103-160	7.6	20.73	2.00	8.06	304.48	2.05	135.76	Nil	1.30	44.00	228.52
160-180	7.7	18.90	1.55	0.74	118.31	1.15	110.57	Nil	2.00	64.00	102.82

16b. Ionic composition of the soil solid surface									
Depth (cm)	Charge characterization			Exchangeable cations and CEC (cmol$_c$ kg^{-1})					ESP
	pH_{H2O}	pH_{KCl}	ΔpH	Ca	Mg	Na	K	CEC	
0-22	7.20	6.90	0.30	36.50	15.22	3.48	3.51	58.81	5.92
22-50	7.60	6.90	0.70	32.68	18.53	7.75	2.58	61.55	12.29
50-63	7.90	7.10	0.80	30.48	17.00	9.44	1.82	58.84	16.04
63-103	7.90	7.00	0.90	27.18	19.98	8.65	1.45	57.46	15.05
103-160	7.60	7.00	0.60	25.42	18.39	9.55	1.85	55.41	17.23
160-180	**7.70**	**7.00**	**0.70**	**28.08**	**15.12**	**10.94**	**0.83**	**55.17**	19.83

The summary of the 5 pedons of the Melka Sedi-Amibara of the Middle Awash Valley is given in Table 17. This shows that soils are not only highly saline but also sodic in nature. This is the reason that reclamation of these soils need special treatment than just leaching of salts.

Table 17. Classification of soils based on relevant properties of the surface soils

Properties	Pedon 1	Pedon 2	Pedon 3	Pedon 4	Pedon 5
pH (H_2O)	7.20	7.20	7.63	8.40	7.20/12.29
ECe (dSm^{-1})	18.57	16.68	2.22	14.23	16.24
SAR(mmoles/l)$^{0.5}$	37.06	7.43	5.70	14.86	34.15
ESP	6.21	4.03	0.42	36.25	5.92
Classification	Saline slightly sodic	Saline-potentially sodic	Slightly saline	Saline-sodic	Saline- sodic

The analysis of chemical characteristics of the soil samples from 0-30 and 30-60 cm depth (Table 16) and profiles (Table 17) of the research fields of the Melka Werer research Center also showed accumulation of high levels of soluble salts and low to moderate levels of exchangeable sodium. Accordingly, most of the fields are saline and slightly to moderately sodic. In most of the Farms, the ECe of the surface 0-30cm varied from 1.43-14.85 dSm^{-1} (Table 18) and the level of salt accumulation in this depth was higher than in the 30-60cm depths. The salinity and sodicity levels of the soil profiles studied in the Melka Werer Farms also showed similar trends with that of the surface soils represented by the profiles. However, the extent of sodicity (ESP) appears to be higher in the soil profiles than in the surface soils (Table 19). Although levels of salinity and sodicity increased with depth in some profiles while both showed a decreasing trend with increasing soil profile depth.

Table 18. Chemical properties of soil samples taken from the Werer Research Center (Middle Awash)

Field No.	Depth (cm)	ECe ($dS\ m^{-1}$)	pH	Soluble cations ($meq\ l^{-1}$)				Soluble anions ($meq\ l^{-1}$)				CEC and exch. cations ($cmolc\ kg^{-1}$)					ESP
				Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO_4	CEC	Na	K	Ca	Mg	
112	0-30	14.85	7.40	41.74	0.75	62.00	16.00	Trace	5.4	52.0	6.7	40.0	2.0	1.9	57.6	2.4	5.10
	30-60	6.49	7.80	19.57	0.76	32.00	2.00	Trace	1.8	30.0	5.3	31.6	2.1	1.8	50.4	7.2	6.52
113	0-30	1.98	8.10	7.74	0.86	4.00	2.00	Trace	3.6	32.0	4.6	36.7	1.1	3.6	51.2	4.8	3.08
	30-60	2.20	8.10	9.78	0.66	2.00	2.00	Trace	1.8	12.0	4.6	32.9	1.3	3.1	47.2	4.8	3.83
114	0-30	4.29	7.90	14.35	1.29	10.00	12.00	Trace	1.8	20.0	3.3	41.0	1.7	3.2	52.8	6.4	4.02
	30-60	3.30	8.00	13.48	0.80	6.00	8.00	Trace	1.8	20.0	4.0	40.5	1.7	3.0	47.2	9.6	4.07
115	0-30	4.51	7.90	13.00	1.64	12.00	8.00	Trace	5.4	30.0	3.3	42.5	1.1	4.9	56.8	6.4	2.66
	30-60	6.38	7.70	13.91	1.38	30.00	4.00	Trace	5.4	28.0	2.7	42.3	1.3	1.8	56.0	7.2	3.12
116	0-30	2.97	8.00	10.44	1.21	4.00	12.00	Trace	5.4	20.0	2.1	46.4	1.4	3.1	55.0	8.0	3.02
	30-60	4.29	7.90	12.17	1.11	12.00	14.00	Trace	3.6	32.0	1.7	52.6	2.2	2.4	58.0	6.0	4.09
117	0-30	4.95	7.90	12.91	1.37	18.00	12.00	Trace	7.2	38.0	3.3	48.2	1.8	2.5	48.0	9.0	3.69
	30-60	4.07	8.00	12.61	0.95	14.00	Nil	Trace	5.4	28.0	0.9	52.2	2.2	2.5	49.0	9.0	4.21
118	0-30	3.63	8.00	10.78	1.18	10.00	10.00	Trace	5.4	22.0	0.4	53.6	1.7	3.0	48.0	11.0	3.13
	30-60	2.86	8.00	9.56	0.82	4.00	14.00	Trace	5.4	22.0	0.9	85.6	2.6	1.6	51.7	10.0	3.04
119	0-30	1.43	8.40	4.26	0.70	4.00	4.00	Trace	7.2	20.0	2.7	67.3	1.9	2.0	50.0	6.7	2.82
	30-60	1.32	8.40	5.37	0.47	4.00	2.00	Trace	3.6	4.0	5.3	71.3	1.7	1.5	48.3	15.0	2.38
120	0-30	5.61	7.80	11.96	1.71	18.00	14.00	Trace	5.4	44.0	6.0	75.0	2.0	1.9	48.3	10.0	2.67
	30-60	4.51	7.90	12.09	1.09	14.00	8.00	Trace	5.4	32.0	3.3	64.6	2.8	1.5	50.0	8.3	4.33
121	0-30	5.50	7.70	13.48	1.34	24.00	4.00	Trace	21.6	36.1	1.8	72.6	3.3	1.8	51.7	11.7	4.55
	30-60	5.30	7.70	15.22	1.06	24.00	2.00	Trace	19.8	36.1	4.0	61.9	2.8	1.5	53.3	13.3	4.52
122	0-30	4.65	7.90	11.31	1.54	20.00	2.00	Trace	14.4	34.2	1.8	61.6	3.3	2.2	50.0	10.0	5.36
	30-60	3.79	8.00	10.87	1.18	20.00	4.00	Trace	9.0	28.5	6.0	59.9	2.9	3.1	51.7	33.3	4.84
123	0-30	6.92	7.80	14.14	1.97	28.00	4.00	Trace	25.2	26.6	0.9	55.9	3.4	3.8	51.7	13.3	6.08
	30-60	7.07	7.70	16.35	1.71	34.00	8.00	Trace	30.6	30.4	0.9	56.3	2.4	3.3	75.0	5.0	4.26
124	0-30	6.80	7.90	14.48	2.45	32.00	6.00	Trace	28.8	38.4	6.0	48.5	3.2	4.7	63.3	8.4	6.60
	30-60	7.65	7.90	20.66	2.32	34.00	14.00	Trace	23.4	49.4	1.3	48.8	3.5	3.8	70.0	10.0	7.17
125	0-30	13.16	7.60	23.92	4.30	66.00	18.00	Trace	48.6	77.9	0.9	50.0	3.2	4.7	66.7	15.0	6.40
	30-60	6.56	7.80	17.48	1.91	28.00	8.00	Trace	25.2	38.9	2.2	48.8	3.7	3.4	66.7	10.0	7.58
126	0-30	12.83	7.60	29.14	4.32	48.00	34.00	Trace	37.8	83.6	2.2	47.5	3.8	3.4	71.7	8.3	8.00
	30-60	9.50	7.70	25.01	2.13	40.00	30.00	Trace	34.2	57.0	1.8	50.0	2.3	2.4	43.8	7.5	4.64
127	0-30	4.35	7.90	13.83	1.74	20.00	22.00	Trace	19.8	20.9	3.4	59.5	1.1	2.9	43.8	6.3	1.82
	30-60	4.92	7.90	14.13	1.57	28.00	12.00	Trace	24.3	10.0	0.9	61.1	1.0	2.7	45.0	6.3	1.64
128	0-30	6.98	7.90	16.79	2.04	26.00	18.00	Trace	30.6	28.5	1.3	53.6	0.9	2.6	42.5	7.5	1.70
	30-60	5.40	7.90	14.87	1.43	26.00	18.00	Trace	28.8	20.9	7.4	47.1	1.1	1.7	47.5	6.3	2.23

129	0-30	6.42	7.80	14.22	1.79	36.00	6.00	Trace	27.9	36.1	1.3	62.5	0.9	2.5	38.8	10.0	1.47
	30-60	6.55	7.90	19.88	1.23	34.00	16.00	Trace	24.3	39.9	0.9	55.0	1.1	2.0	42.5	8.8	2.04
130	0-30	14.53	7.60	20.01	2.25	34.00	58?	Trace	28.8	96.9	0.9	58.7	0.9	2.3	37.5	12.5	1.53
	30-60	11.12	7.60	19.75	1.65	44.00	18.00	Trace	32.4	74.1	0.9	48.7	1.0	1.9	38.8	16.3	2.06
222	0-30	4.21	7.80	10.31	1.35	16.20	1.80	Trace	3.6	35.3	3.3	52.0	1.7	2.4	51.0	8.0	3.21
	30-60	**2.93**	**7.90**	**10.35**	**0.92**	**10.80**	**3.60**	**Trace**	**0.9**	**23.5**	**4.4**	**52.0**	**2.3**	**2.4**	**50.0**	**14.0**	4.46

(Source: Wondimagegne Chekol 2001; Unpublished)

Table 19. Soil chemical properties of soil samples taken from the Werer Research Center (profile samples).

Field No.	Depth (cm)	ECe (dS m^{-1})	pH	Soluble cations (meq l^{-1})				Soluble anions (meq l-1)				CEC & exch. cations (cmolc kg^{-1})					ESP
				Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO_4	CEC	Na	K	Ca	Mg	
105/6	0-19	1.20	8.10	6.53	0.46	2.00	2.00	Trace	1.9	7.6	1.9	37.0	3.4	2.0	30.5	3.0	9.19
	19-37	2.04	8.00	9.57	0.56	6.00	2.00	Trace	0.9	15.2	0.4	38.0	3.4	1.8	31.5	2.5	8.82
P1	37-55	2.87	7.80	13.92	0.41	12.00	2.00	Trace	1.8	19.0	0.4	34.0	3.0	0.8	31.5	2.0	8.91
	55-70	2.45	7.90	13.44	0.18	8.00	2.00	Trace	3.6	15.2	0.8	39.0	3.5	1.0	31.0	6.5	8.85
	70-80	2.80	7.80	14.79	0.33	8.00	6.00	Trace	3.6	17.1	1.1	44.0	3.3	0.6	31.5	5.5	7.52
	80-95	3.62	7.80	16.31	0.36	12.00	6.00	Trace	7.2	20.9	0.8	42.5	3.4	0.8	33.0	2.0	8.00
	95-115	4.88	7.50	18.97	0.23	22.00	4.00	Trace	10.8	22.8	4.0	40.5	3.8	0.9	30.0	5.0	9.48
	115-130	5.61	7.50	27.67	0.33	26.00	2.00	Trace	9.9	34.2	1.9	49.0	4.4	1.0	34.0	2.0	8.88
	130-168	6.93	7.50	27.36	0.44	26.00	14.00	Trace	16.2	36.1	1.1	55.0	4.6	1.2	29.5	2.0	8.35
	168-200	8.57	7.40	26.54	0.49	40.00	14.00	Trace	11.7	53.2	1.9	56.0	4.6	1.4	29.0	1.0	8.14
111/2	0-17	13.02	7.00	20.57	1.59	56.00	16.00	Trace	9.0	98.8	0.8	40.0	4.3	1.8	32.5	1.5	10.68
	17-33	13.01	7.10	18.44	1.48	58.00	22.00	Trace	8.1	100.7	0.4	38.0	3.8	1.7	31.0	2.5	10.08
	33-50	9.57	7.00	18.23	0.61	40.00	14.00	Trace	3.6	79.8	1.3	44.0	3.3	1.0	32.5	3.5	7.52
P2	50-65	7.01	7.10	16.92	0.44	28.00	12.00	Trace	6.3	41.8	0.7	37.0	3.2	0.7	31.0	3.0	8.62
	65-83	6.83	7.30	18.57	0.44	26.00	14.00	Trace	5.4	55.1	0.8	51.5	4.1	1.3	29.5	4.0	7.88
	83-135	7.72	7.20	22.84	0.61	28.00	16.00	Trace	9.0	49.4	4.4	37.0	3.7	1.0	32.5	5.0	10.00
	135-157	7.03	7.30	20.66	0.54	28.00	8.00	Trace	5.4	47.5	1.1	53.0	6.5	1.5	60.0	5.0	12.34
	157-200	6.73	7.50	20.92	0.54	26.00	8.00	Trace	8.1	45.6	1.1	52.0	5.9	1.4	51.0	4.0	11.40
129/30	0-26	12.03	7.00	19.01	1.54	54.00	12.00	Trace	7.2	104.5	0.8	49.0	6.5	2.7	57.0	3.0	13.35
	26-44	17.48	7.10	30.88	1.00	82.00	18.00	Trace	7.2	148.2	1.3	50.5	5.6	1.5	58.0	3.5	11.09
	44-64	15.58	7.10	36.54	0.49	54.00	26.00	Trace	7.2	134.9	0.4	44.5	6.7	0.7	71.5	6.5	15.03
P3	64-88	14.26	7.20	33.71	0.97	52.00	24.00	Trace	8.1	119.7	0.4	50.5	7.8	0.9	61.0	5.5	15.37
	88-110	13.32	7.30	42.41	0.54	38.00	22.00	Trace	11.7	110.2	4.8	52.5	8.1	1.2	55.5	5.0	15.35
	110-135	10.87	7.20	39.59	0.51	40.00	20.00	Trace	8.1	83.6	1.3	52.5	8.5	1.3	56.5	9.5	16.23
	135-158	10.08	7.50	40.24	0.54	40.00	18.00	Trace	7.2	76.0	0.9	42.5	8.7	1.3	57.5	5.5	20.40
	158-200	10.73	7.50	43.93	0.55	50.00	10.00	Trace	9.0	78.0	2.0	51.0	9.0	1.4	62.5	5.0	17.61
202/3	0-10	0.62	8.40	4.24	0.22	1.00	0.60	Trace	1.0	4.0	0.7	40.5	4.6	2.2	52.5	3.3	11.31
	10-25	0.56	8.40	3.48	0.15	1.00	0.80	Trace	1.0	2.0	2.0	46.5	5.4	1.8	49.5	3.5	11.66
P4	25-45	0.42	8.50	2.96	0.09	0.80	0.20	Trace	0.2	2.0	2.0	49.0	5.3	1.7	53.0	2.5	10.86
	45-70	0.46	8.50	3.35	0.13	0.60	0.20	Trace	0.2	2.0	2.4	44.5	4.9	1.6	55.0	2.0	10.94
	70-95	0.40	8.30	2.91	0.15	0.60	0.20	Trace	0.1	2.0	2.0	52.5	5.3	1.8	51.0	5.0	10.13
	95-23	0.49	8.30	3.37	0.13	0.80	0.20	Trace	0.5	4.0	0.3	53.0	5.0	1.7	50.0	2.0	9.47
	123-150	0.48	8.30	3.13	0.33	0.80	0.20	Trace	1.0	2.0	1.6	43.0	4.4	1.6	43.5	2.5	10.26
	150-200	0.44	8.30	2.86	0.18	0.80	0.20	Trace	0.4	1.6	2.4	45.5	4.6	1.7	55.0	2.0	10.02
211/2	0-20	0.60	8.40	2.70	0.32	2.00	0.80	Trace	0.6	2.0	3.3	47.0	5.3	2.4	48.0	3.5	11.32
	20-45	0.43	8.50	2.12	0.35	1.00	0.60	Trace	0.6	2.0	1.6	47.0	5.0	2.4	48.0	3.5	10.68

211/2	0-20	0.60	8.40	2.70	0.32	2.00	0.80	Trace	0.6	2.0	3.3	47.0	5.3	2.4	48.0	3.5	11.32
	20-45	0.43	8.50	2.12	0.35	1.00	0.60	Trace	0.6	2.0	1.6	47.0	5.0	2.4	48.0	3.5	10.68
P5	45-60	0.37	8.30	2.10	0.21	0.80	0.20	Trace	1.0	2.0	0.7	48.0	5.3	2.2	59.0	3.0	11.08
	60-100	0.49	8.20	2.17	0.18	1.40	0.60	Trace	0.8	2.0	2.0	40.0	4.4	1.5	66.0	8.5	11.03
	100-120	0.38	8.20	2.19	0.16	0.80	0.20	Trace	0.2	0.2	3.3	40.5	4.0	1.3	87.5	5.0	9.75
	120-138	0.44	8.30	2.78	0.09	1.00	0.40	Trace	0.5	2.8	1.0	43.0	4.4	1.4	80.0	3.0	10.26
	138-155	0.47	8.30	2.77	0.10	1.00	0.60	Trace	0.6	3.0	1.0	41.0	4.1	1.4	70.0	3.0	10.00
	155-180	0.48	8.30	2.78	0.13	1.00	0.40	Trace	0.2	1.2	3.3	53.0	4.6	1.7	56.0	4.0	8.60
230	0-25	0.73	8.20	3.22	0.23	3.00	0.60	Trace	0.5	3.0	3.8	52.5	5.3	2.2	55.0	2.5	10.13
P6	25-46	0.50	8.30	2.52	0.20	2.00	0.20	Trace	0.2	1.8	2.9	51.0	5.5	2.2	55.0	3.0	10.75
	46-78	0.40	8.40	2.58	0.07	1.00	0.20	Trace	0.0	0.2	3.8	52.0	4.6	1.6	51.0	2.0	8.77
	78-95	0.49	8.50	3.57	0.07	1.00	0.20	Trace	0.3	1.6	2.9	50.0	5.3	1.4	45.0	3.0	10.64
	95-160	0.67	8.40	4.46	0.12	1.60	0.40	Trace	0.1	3.2	3.3	51.0	6.2	1.7	51.5	3.5	12.24
	160-195	1.40	8.10	9.35	0.22	4.00	0.40	Trace	1.0	8.0	4.7	50.5	7.2	1.7	62.0	4.5	14.16

(Source: Wondimagegne Chekol, 2001; Unpublished)

3.2 SALT-AFFECTED SOILS OF THE LOWER AWASH VALLEY

Chemical characteristics of the soil of Tendaho Agricultural Development Enterprise farms at Dubti are presented in Tables 20-21. In most of the soil profiles, soluble salts (ECe) and exchangeable sodium percentage (ESP) is increasing with the soil depth. The studied soils indicates that this part of the Awash River basin falls under potentially saline and potentially sodic soils. The increasing salt concentration with depth suggests that irrigation water could one of the causes of the salinity and sodicity development in these soils.

Highly saline soil

Moderately saline and sodic soil

Low salinity and highly sodic soil

Highly sodic soil

Table 20. Chemical properties of soils of Lower Awash (Dubti development farm)

Depth (cm)	ECe (dS m⁻¹)	pH	Soluble cations (meq⁻¹)				Soluble anions (meq l⁻¹)				CEC and exch. cations (cmolc kg-1)					ESP
			Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO_4	CEC	Na	K	Ca	Mg	
0-37	1.01	8.5	5.48	0.10	4.00	Trace	Trace	2.0	4.8	1.7	37.0	1.9	0.3	12.0	28.0	5.19
37-61	5.75	8.1	29.65	1.80	16.00	2.00	Trace	6.0	17.6	1.2	35.0	1.9	0.1	10.0	34.0	5.40
61-78	9.15	7.9	34.54	0.86	28.00	22.00	Trace	12.0	36.8	1.2	45.0	2.1	0.2	12.0	24.0	4.60
78-103	5.05	8.1	22.58	0.68	12.00	8.00	Trace	6.0	19.2	1.2	35.0	1.6	0.1	12.0	10.0	4.46
103-150	2.81	8.1	11.83	0.32	8.00	4.00	Trace	4.0	16.0	1.2	40.0	1.6	0.2	12.0	18.0	3.98
0-30	0.47	8.	3.36	0.10	1.20	0.20	Trace	1.0	1.6	0.6	46.0	2.6	0.4	10.0	30.0	5.67
30-60	1.50	8.3	7.91	0.25	6.00	1.00	Trace	2.0	11.2	0.7	30.0	3.1	0.4	12.0	30.0	10.40
60-90	1.71	8.2	8.89	0.26	6.00	2.00	Trace	2.0	11.2	0.7	45.0	3.2	0.3	12.0	20.0	7.00
90-120	1.35	8.2	7.42	0.23	4.00	1.00	Trace	2.0	9.6	0.7	50.0	2.7	0.3	12.0	14.0	5.46
0-30	0.82	8.5	5.45	0.22	1.40	0.40	Trace	1.0	6.4	0.6	42.0	2.0	0.4	10.0	40.0	4.86
30-60	4.75	8.0	28.56	0.68	12.00	6.00	Trace	4.0	35.2	1.7	40.0	3.2	0.4	12.0	22.0	8.03
60-90	5.89	7.9	33.05	0.72	16.00	8.00	Trace	4.0	38.4	1.7	45.0	2.9	0.3	10.0	30.0	6.53
90-120	4.47	7.8	24.75	0.45	12.00	6.00	Trace	4.0	28.8	1.7	40.0	2.7	0.3	12.0	20.0	6.75
0-30	0.71	8.5	5.00	0.15	1.60	0.20	Trace	1.0	4.8	0.7	50.0	2.5	0.3	10.0	24.0	4.98
30-60	0.97	8.5	6.17	0.18	2.00	1.00	Trace	1.0	6.4	0.7	50.0	2.7	0.3	10.0	26.0	5.34
60-90	3.09	8.3	22.30	0.32	8.00	Trace	Trace	2.0	20.8	1.7	45.0	2.9	0.3	10.0	30.0	6.53
90-120	4.79	8.0	29.51	0.54	12.00	6.00	Trace	4.0	38.4	1.7	40.0	3.1	0.3	12.0	20.0	7.73
Field No. 4; Plot No. 1																
0-30	0.34	8.41	2.47	0.06	0.40	0.20	Trace	1.0	1.6	0.6	51.0	3.0	0.4	8.0	50.0	5.82
30-60	0.65	8.35	4.32	0.09	1.00	0.40	Trace	1.0	3.2	1.7	46.0	3.2	0.4	8.0	46.0	7.04
60-90	0.74	8.23	4.71	0.08	1.40	0.40	Trace	2.0	3.2	0.6	50.0	3.3	0.3	8.0	56.0	6.60
90-120	2.40	8.25	18.50	0.14	4.00	1.00	Trace	3.0	16.0	0.7	46.0	3.1	0.3	10.0	34.0	6.78
0-30	0.47	8.54	3.21	0.09	1.20	0.20	Trace	1.0	1.6	0.6	39.0	1.7	0.3	6.0	58.0	4.46
30-60	0.91	8.39	4.96	0.17	2.00	1.00	Trace	2.0	3.2	0.7	30.0	2.2	0.2	8.0	30.0	7.33
60-90	1.50	8.34	6.49	0.19	6.00	2.00	Trace	2.0	11.2	0.7	31.0	2.0	0.2	8.0	28.0	6.45
90-120	1.83	8.25	6.99	0.22	6.00	2.00	Trace	2.0	11.2	0.7	29.0	2.0	0.2	6.0	60.0	6.90
0-30	0.38	8.39	2.77	0.05	0.60	0.40	Trace	1.0	1.6	0.6	33.0	2.1	0.2	8.0	38.0	6.36
30-60	2.60	8.55	19.57	0.76	4.00	3.00	Trace	2.0	9.6	0.9	35.0	2.1	0.3	10.0	22.0	6.00
60-90	2.08	8.49	17.62	0.76	2.00	2.00	Trace	2.0	9.6	0.7	33.0	2.1	0.1	10.0	16.0	6.36
90-120	4.22	8.29	24.79	0.95	8.00	4.00	Trace	4.0	17.6	3.7	30.0	2.1	0.1	8.0	28.0	7.00

(Source: Wondimagegne Chekol, 2001; Unpublished)

Table 21a. Soil chemical properties of soils of Lower Awash (Dubti development farm)

Depth (cm)	ECe (dS m⁻¹)	PHe	Soluble cations (meq l⁻¹)				SAR	Soluble anions (meq l⁻¹)				CEC and exch. cations (cmolc kg⁻¹)					ESP
			Na	K	Ca	Mg		CO_3	HCO_3	Cl	SO_4	CEC	Na	K	Ca	Mg	
Field No. 5; Plot No. 1																	
0-30	1.0	8.6	4.5	0.2	2.0	Trace		Trace	2.0	6.4	0.9	32.0	2.1	0.3	10.0	20.0	**6.56**
30-60	2.6	8.5	20.2	1.0	4.0	2.0		Trace	2.0	9.6	1.0	40.0	3.7	0.5	10.0	44.0	**9.25**
60-90	2.0	8.4	15.7	0.6	2.0	1.0		Trace	2.0	8.0	0.7	36.0	2.4	0.2	12.0	28.0	**6.67**
90-120	2.1	8.3	14.4	0.6	4.0	2.0		Trace	2.0	9.6	0.7	35.0	2.2	0.1	12.0	18.0	**6.29**
Field No. 6; Plot No. 10																	
0-30	2.9	8.5	24.1	0.4	2.0	1.0		Trace	3.0	12.8	1.0	38.0	2.1	0.4	10.0	20.0	**5.53**
30-60	1.6	8.6	7.4	0.2	2.0	1.0		Trace	3.0	6.4	1.1	44.0	2.2	0.2	10.0	26.0	**5.00**
60-90	1.7	8.4	6.0	0.2	2.0	1.0		Trace	3.0	6.4	1.1	36.0	2.1	0.2	10.0	34.0	**5.83**
90-120	3.1	8.3	18.9	1.0	6.0	4.0		Trace	5.0	14.4	2.4	26.0	1.6	0.1	8.0	24.0	**6.15**
Field No. 8; Plot No. 1																	
0-30	5.0	8.2	30.7	0.8	8.0	2.0		Trace	5.0	14.4	3.3	40.0	2.4	0.3	8.0	34.0	**6.00**
30-60	1.8	8.5	6.6	0.3	4.0	2.0		Trace	3.0	6.4	1.1	34.0	2.4	0.3	10.0	24.0	**7.06**
60-90	7.9	8.3	51.6	1.3	24.0	14.0		Trace	8.0	27.2	4.2	35.0	2.8	0.2	8.0	38.0	**8.00**
90-120	6.2	8.3	35.9	0.8	14.0	10.0		Trace	6.0	24.0	3.7	35.0	2.6	0.1	8.0	30.0	**7.43**
Field No. 13 & 14; Plot No. 6																	
0-30	2.3	8.4	15.0	1.3	4.0	2.0		Trace	3.0	8.0	0.8	43.0	3.3	0.3	10.0	46.0	**7.67**
30-60	2.5	8.5	18.3	1.0	2.0	1.0		Trace	3.0	9.6	1.0	45.0	3.5	0.3	12.0	20.0	**7.78**
60-90	1.2	8.7	5.6	0.2	2.0	1.0		Trace	2.0	6.4	1.0	46.0	3.4	1.4	12.0	22.0	**7.39**
90-120	0.9	8.5	4.4	0.1	2.0	1.0		Trace	1.0	4.8	0.6	40.0	3.4	1.9	10.0	30.0	**8.50**
Field No. 14; Plot No. 5																	
0-30	2.1	8.7	13.1	0.8	2.0	1.0		Trace	3.0	8.0	0.7	40.0	1.7	2.0	10.0	36.0	**4.25**
30-60	2.4	8.7	14.4	0.6	2.0	1.0		Trace	3.0	9.6	1.0	50.0	4.3	1.6	12.0	14.0	**8.60**
60-90	3.5	8.1	28.1	1.1	2.0	1.0		Trace	5.0	14.4	2.4	40.0	4.2	1.7	12.0	20.0	**10.50**
90-120	5.4	8.1	26.1	0.8	16.0	4.0		Trace	7.0	20.8	3.7	40.0	3.9	1.4	10.0	36.0	**9.75**
Field No. 15; Plot No. 8																	
0-30	1.2	8.6	5.4	0.2	4.0	1.0		Trace	2.0	6.4	0.9	40.0	3.0	1.9	12.0	18.0	**7.50**
30-60	0.7	8.5	3.5	0.2	2.0	0.6		Trace	1.0	4.8	0.6	40.0	3.1	1.7	12.0	18.0	**7.75**
60-90	0.7	8.5	4.0	0.2	2.0	1.0		Trace	1.0	4.8	0.6	40.0	3.2	1.5	12.0	20.0	**8.00**
90-120	**1.5**	**8.7**	**7.0**	**0.3**	**2.0**	**1.0**		**Trace**	**2.0**	**6.4**	**1.0**	**40.0**	**3.2**	**1.4**	**8.0**	**50.0**	**8.00**

Field No. 17; Plot No. 6																	
0-30	0.8	8.7	4.2	0.2	2.0	0.6		Trace	1.0	4.8	0.6	40.0	3.2	1.8	10.0	26.0	**8.00**
30-60	1.0	8.7	5.0	0.2	2.0	1.0		Trace	1.0	4.8	0.6	40.0	3.5	1.7	12.0	20.0	**8.75**
60-90	0.7	8.6	3.7	0.2	2.0	1.0		Trace	1.0	4.8	0.6	40.0	3.5	1.5	10.0	30.0	**8.75**
90-120	4.6	8.2	32.6	1.0	8.0	4.0		Trace	4.0	9.6	3.5	40.0	3.6	1.3	12.0	16.0	**9.00**
Field No. 20; Plot No. 1																	
0-30	1.0	8.7	4.7	0.2	2.0	1.0		Trace	2.0	4.8	0.6	40.0	2.8	1.8	8.0	54.0	**7.00**
30-60	0.9	8.7	4.6	0.2	2.0	1.0		Trace	2.0	4.8	0.6	40.0	2.8	1.3	8.0	60.0	**7.00**
60-90	1.4	8.5	6.0	0.2	2.0	1.0		Trace	2.0	6.4	1.0	30.0	2.8	0.9	10.0	32.0	**9.33**
90-120	1.4	8.5	5.8	0.2	2.0	1.0		Trace	2.0	6.4	1.0	25.0	2.6	0.6	6.0	68.0	**10.40**
Field No. 23; Plot No. 1																	
0-30	1.8	8.7	6.9	0.3	2.0	1.0		Trace	3.0	6.4	1.0	31.0	2.1	1.5	8.0	60.0	**6.77**
30-60	4.0	8.4	28.7	1.5	6.4	4.0		Trace	4.0	16.0	3.0	30.0	2.0	0.9	6.0	80.0	**6.67**
60-90	8.7	8.2	47.6	0.8	12.0	4.0		Trace	9.0	25.6	4.2	36.0	4.1	1.0	8.0	80.0	**11.39**
90-120	12.2	8.1	53.5	2.3	30.0	14.0		Trace	12.0	36.8	3.7	38.0	4.2	1.0	6.0	80.0	**11.05**
Field No. 1; Plot No. 3B (Profile 1)																	
0-30	1.6	8.1	4.7	0.2	2.0	1.0		Trace	2.0	6.4	1.1	35.0	3.2	1.5	6.0	80.0	**9.14**
30-60	5.2	8.0	35.2	1.9	12.0	2.0		Trace	6.0	16.0	3.3	35.0	3.0	1.1	4.0	80.0	**8.57**
60-90	4.4	8.2	26.8	0.8	6.0	4.0		Trace	4.0	20.8	3.3	35.0	3.0	0.8	6.0	74.0	**8.57**
90-120	2.2	8.5	13.1	2.1	4.0	2.0		Trace	3.0	9.6	1.0	22.0	2.9	0.6	8.0	46.0	**13.18**
Field No.1; Plot No. 3B (Profile 2)																	
0-30	5.5	8.3	31.3	0.8	14.0	6.0		Trace	6.0	25.6	3.5	38.0	2.9	1.4	8.0	50.0	**7.63**
30-60	3.7	8.4	26.1	0.8	4.0	2.0		Trace	5.0	17.6	2.4	40.0	3.2	1.0	10.0	32.0	**8.00**
60-90	8.4	8.3	37.2	1.0	16.0	6.0		Trace	8.0	25.6	4.2	38.0	3.6	0.9	8.0	60.0	**9.47**
90-120	8.7	8.3	32.0	0.8	20.0	4.0		Trace	8.0	28.8	4.2	35.0	3.7	1.0	10.0	60.0	**10.57**
Field No. 1; Plot No. 7																	
0-30	1.4	8.7	5.7	0.3	2.0	1.0		Trace	2.0	6.4	0.9	34.0	3.5	2.0	8.0	60.0	**10.29**
30-60	1.3	8.6	5.7	0.2	2.0	1.0		Trace	2.0	6.4	0.8	38.0	3.6	1.8	10.0	40.0	**9.47**
60-90	1.9	8.6	4.6	0.2	4.0	2.0		Trace	3.0	8.0	1.0	35.0	2.4	1.4	8.0	40.0	**6.86**
90-120	**1.4**	**8.6**	**5.8**	**0.2**	**2.0**	**1.0**		**Trace**	**2.0**	**6.4**	**0.8**	**35.0**	**3.5**	**1.5**	**10.0**	**20.0**	**10.00**

(Source: Wondimagegne Chekol, 2001; Unpublished)

Table 21b. Changes in salt-affected area from 1972-2014 at Dubti/Tendaho State farm.

Salinity level	1972 Area (ha)	%	1994 Area (ha)	%	2014 Area (ha)	%	1972-1994 Area (ha)	%	1994-2014 Area (ha)	%	1972-2014 Area (ha)	%
Normal soil	3783	35	2930	27	2189	20	-652.5	-7.90	-741	-6.86	-1593	-14.76
Saline-Sodic	2178	20	2423	23	3154	30	+245.8	+2.27	+730	+6.77	+976	+9.04
Saline	4035	38	4138	38	2929	27	+203.2	+0.95	-1210	-11.2	-1106	-10.25
Sodic	797	7	1301	12	2521	23	+503.8	+4.67	+1220	+11.3	+1725	+15.97
Total	10,793	100	10,793	100	10,793	100	-	-	-	-	-	-

(Source: Sileshi Abbi , 2016)

According to satellite images of 2014, more than 80% of Dubti/Tendaho state farm is dominated by salt-affected soils (27.14% saline, 29.22% saline-sodic and 23.36% sodic). From the year 1972 to 2014, salt-affected soils (saline, saline-sodic, sodic) have increased at the expense of normal soils and they have increased by about three-folds, however the overall areal extent of saline soils has reduced. This could be due to the fact that most of the simple saline areas have now changed to severe salt-affected soils (i.e. saline-sodic and sodic soils) due to inappropriate irrigation practices and poor drainage (Sijali et al. 2003). Sileshi et al. (2015) has also revealed that soils which were initially not saline have turned saline and sodic due to hydrological disturbances caused by excessive irrigation and changes in land use. This is possible because in irrigated areas of arid and semi-arid regions, the ascending motion of capillary water is generally greater than the descending motion and it facilitates the buildup of salt in soil profiles due to the high evapotransporation rates (Fan et al. 2011). Due to this phenomenon, soil salinity areas found in shallow groundwater and poor-quality drainage water areas could increase five-folds compared to deep groundwater and well-drained soils (Kirda, 2003).

CHARACTERIZATION OF SOILS IN DIFFERENT REGIONS

04

4.1 MEKI-ZUWAI AREAS (OROMIA REGIONAL STATE)

Assessment of soils in irrigated lands of Meki Zuwai areas of the Oromia region shows that the soils are sodic in nature in the sub-surface horizons (Tables 22-25) (Mengistu, 2001). The ESP of the soil profile at the Ethio-Flora farm increased from 9.03 at 0-30cm to 19.6 at the depth of 166-200cm. Similarly, the levels of exchangeable sodium in the Zuwai State farm and the rainfed farmer's field at Meki Zuwai increased consistently and markedly with increasing soil depths. In the farmer fields, ESP increased from 3.13 at 0-30cm to 55.22 at the depth of 27-85cm. On the other hand, the ESP of the profile studied at the Zuwai State farm increased from 6.10 at 0-30cm to 92.8 at the depth of 144-200cm. However, the soils do not have excessive concentrations of soluble salts which makes them non-saline but potentially sodic. Nevertheless, the relative concentration of soluble salts increased with depth in the soil profiles at the Zuwai State farm and the farmers fields in the rainfed areas.

4.2 YELLEN - JEWEHA AREA (AMHARA REGION)

The results of the study of the spatial structures and mapping of top soil salinity of Yellen-Jeweha areas in Northern Shewa Zone of the Amhara region by Yonas (2005) indicated that the soils are dominantly sodic. The ESP of the soil profile in the waterlogged areas increased from 10.45 at 0-30cm to 35.25 at the depth of 60-90cm. The soil profiles representing the flood plains of the study area are non-saline but potentially sodic. However, the soils of Pedon 3 are saline at the subsoil and sodic throughout the profile.

Table 22. Chemical characteristics of Ethio-Flora private farm in Meki-Zuwai (Profile MZ-1-ETF)

Soluble chemical composition

Depth (cm)	pH	ECe (dS m^{-1})	Soluble cations (meq l^{-1})				SAR $(mmoles/l)^{0.5}$	Soluble anions (meq l^{-1})				**RSC (me l^{-1})**
			Na	K	Ca	Mg		SO_4	Cl	CO_3	HCO_3	
0-28	7.5	2.09	10.12	3.31	9.72	3.03	4.00	7.01	10.00	2.00	5.65	**-**
28-70	7.9	0.68	5.08	0.62	2.72	0.65	3.91	-	4.50	4.00	2.00	**2.63**
70-96	8.1	0.58	3.57	0.55	2.29	3.00	2.22	0.36	3.30	2.60	3.23	**0.54**
96-126	8.0	0.56	3.33	0.56	1.58	0.79	3.06	0.18	3.00	1.70	1.18	**0.51**
126-166	8.0	0.52	2.88	0.64	1.31	0.76	2.83	-	2.50	-	3.22	**1.15**
166-200	8.7	0.58	5.26	0.59	2.10	0.26	4.84	0.10	2.50	5.00	1.50	**4.14**

Exchangeable chemical composition

Depth (cm)		ΔpH	Exchangeable cations (cmolc kg-1)				CEC (cmolc kg^{-1})	**PBS**	**ESP**	**$CaCO_3$**
			Na	K	Ca	Mg				
0-28	7.1	0.4	2.80	6.16	26.85	4.91	31.00	131	9.03	9.30
28-70	7.0	0.9	2.19	4.66	28.29	3.67	29.60	131	7.40	11.70
70-96	7.0	1.1	2.75	5.20	16.92	3.17	26.00	108	10.58	19.65
96-126	7.0	1.0	3.00	5.86	16.82	5.83	29.20	108	10.27	19.65
126-166	7.0	1.0	3.16	5.77	24.70	8.41	29.60	142	10.68	14.35
166-200	7.1	1.6	6.69	7.36	17.66	2.25	34.20	99	19.56	18.90

(Source: Mesfin, 2001)

Table 23. Chemical characteristics of Zuwai State farm soil (Profile MZ-2-B26)

Soluble chemical composition

Depth (cm)	pH	ECe (dS m-1) at 25 °C	Soluble cations ($meq\ l^{-1}$)				SAR	Soluble anions ($meq\ l^{-1}$)				RSC ($meq\ l^{-1}$)
			Na	K	Ca	Mg		SO_4	Cl	CO_3	HCO_3	
0-28	8.0	0.49	2.37	0.74	4.50	0.45	1.51	0.16	2.37	2.39	4.11	**1.55**
28-84	9.6	0.80	11.80	0.20	1.71	0.31	11.74	0.26	2.51	5.00	5.43	**8.41**
84-144	9.5	0.99	10.05	0.53	3.82	1.47	6.18	0.73	2.51	5.60	6.40	**6.71**
144-200	9.7	1.46	14.15	0.53	0.89	0.85	15.17	0.55	3.64	9.57	2.50	**10.33**

Exchangeable chemical composition

Depth (cm)	pH	ΔpH	Exchangeable cations ($cmol_c\ kg^{-1}$)				CEC ($cmol_c\ kg^{-1}$)	PBS	ESP	$CaCO_3$
			Na	K	Ca	Mg				
0-28	6.7	1.3	0.79	2.96	12.43	2.00	13.80	132	6.10	2.65
28-84	7.8	1.8	12.17	1.96	6.64	1.25	14.80	149	82.23	9.20
84-144	7.9	1.6	8.46	2.91	4.49	0.67	11.80	140	71.69	5.45
144-200	8.3	1.4	18.75	4.56	3.14	0.67	20.20	134	92.82	6.15

Table 24. Chemical composition of Rain-fed cultivated farmers' field Meki-Zuwai (Profile MZ-4) (Source: Mesfin, 2001)

Soluble chemical composition

Depth (cm)	pH	ECe ($dS\ m^{-1}$)	Soluble cations ($meq\ l^{-1}$)				SAR	Soluble anions ($meq\ l^{-1}$)				RSC ($meq\ l^{-1}$)
			Na	K	Ca	Mg		SO_4	Cl	CO_3	HCO_3	
0-27	7.4	0.35	3.03	1.08	1.35	0.40	3.20	0.15	2.50	-	3.40	**1.65**
27-85	9.4	1.29	14.88	1.04	0.40	0.44	22.90	0.28	10.00	3.50	3.00	**5.66**
85-200	10.0	1.69	18.26	0.67	0.50	0.33	28.30	0.11	1.00	9.17	10.43	**18.77**

Exchangeable chemical composition

Depth (cm)	pH	ΔpH	Exchangeable cations ($cmol_c\ kg^{-1}$)				CEC	**PBS**	**ESP**	**$CaCO_3$**
			Na	K	Ca	Mg				
0-27	6.1	1.3	0.52	3.42	11.18	2.00	16.60	103	3.13	3.00
27-85	7.6	1.8	15.24	10.07	9.18	1.50	27.60	130	55.22	8.25
85-200	8.9	1.1	7.19	3.75	7.04	0.08	16.60	109	43.31	5.60

Table 25. Chemical characteristics of vertic waterlogged soils (Pedon 1) at Yellen-Jeweha (Amara region)

Soluble chemical composition

Depth (cm)	pH	ECe (dS m-1)	Soluble cations (meq l^{-1})				Soluble anions (meq l^{-1})			
			Na^+	K^+	Ca^{2+}	Mg^{2+}	$SO4^{2-}$	Cl^-	CO_3^{2-}	HCO_3^-
0-30	8.9	4.78	2.285	0.059	0.614	0.382	0.940	1.689	Nil	0.583
30-60	8.6	7.38	2.817	0.052	0.864	1.658	2.435	1.620	Nil	0.938
60-90	8.7	9.36	5.515	0.040	0.844	0.645	3.590	2.264	Nil	1.097
90 -120	8.8	7.14	3.650	0.034	0.756	0.395	2.320	1.817	Nil	0.698
> 150	8.8	1.11	0.925	0.024	0.059	0.024	Nil	0.588	Nil	0.419

Exchangeable chemical composition

Depth (cm)	pH	Exchangeable cations (cmolc kg^{-1})				CEC (cmolc kg^{-1})	**ESP**
		Na^+	K^+	Ca^{2+}	Mg^{2+}		
0-30	**8.5**	**5.62**	**4.04**	**33.12**	**4.76**	53.80	10.45
30-60	**8.5**	**19.20**	**2.73**	**27.42**	**3.83**	55.20	34.78
60-90	**8.7**	**22.49**	**1.70**	**29.75**	**4.96**	63.80	35.25
90 -120	**8.8**	**15.43**	**1.99**	**27.87**	**5.04**	55.48	27.81
> 150	**9.7**	**17.89**	**1.85**	**24.84**	**5.91**	59.36	30.14

(Source: Yonas, 2005)

Table 26. Chemical characteristics of flood plain soil (Pedon 2) at Yellen-Jeweha Areas

21a. Soluble chemical composition

Depth (cm)	pH	ECe ($dS\ m^{-1}$)	Soluble cations ($me\ l^{-1}$)				Soluble anions ($meq\ l^{-1}$)			
			Na^+	K^+	Ca^{2+}	Mg^{2+}	$SO4^{2-}$	Cl^-	CO_3^{2-}	HCO_3^-
0-30	8.7	0.66	0.260	0.014	0.077	0.027	Nil	0.137	Nil	0.242
30-60	9.0	0.76	0.252	0.030	0.081	0.030	0.222	0.092	Nil	0.089
60-90	9.0	0.77	0.231	0.038	0.095	0.014	0.280	0.053	Nil	0.060
90 -120	8.8	0.74	0.184	0.032	0.091	0.060	0.251	0.045	Nil	0.058
120-150	8.6	0.81	0.197	0.010	0.099	0.017	0.305	0.019	Nil	0.001

21b. Exchangeable chemical composition

Depth (cm)	pH	Exchangeable cations ($cmolc\ kg^{-1}$)				CEC ($cmolc\ kg^{-1}$)	**ESP**
0-30	9.2	2.61	3.63	23.27	3.60	41.00	6.37
30-60	9.1	2.83	6.30	19.13	4.27	37.80	7.49
60-90	9.2	2.97	7.15	21.02	4.55	38.60	7.69
90 -120	9.3	1.18	5.63	17.48	3.92	34.20	3.45
120-150	9.1	1.11	2.13	20.61	5.61	35.60	3.12

Table 27. Chemical characteristics of Pedon 3 at Yellen-Jeweha Areas (Amara Region) (Source: Yonas, 2005)

22a. Soluble chemical composition

Depth (cm)	pH	ECe (dS m^{-1})	Soluble cations (cmolc kg^{-1})				Soluble anions (cmolc kg^{-1})			
			Na^+	K^+	Ca^{2+}	Mg^{2+}	$SO4^{2-}$	Cl^-	CO_3^{2-}	HCO_3^-
0-30	9.2	0.51	0.329	0.010	0.086	0.043	Nil	0.212	Nil	0.250
30-60	9.3	0.77	0.648	0.008	0.059	0.035	0.180	0.243	Nil	0.327
60-90	9.2	1.49	2.453	0.008	0.057	0.036	0.967	0.749	Nil	0.800
90 -120	8.9	6.99	3.855	0.020	0.835	0.043	Nil	3.829	Nil	0.724
120-150	8.9	7.98	4.547	0.022	0.996	0.051	Nil	4.371	Nil	1.069

22b. Exchangeable chemical composition

Depth (cm)	pH	Exchangeable cations (cmolc kg^{-1})				CEC (cmolc kg^{-1})	ESP
0-30	9.8	5.53	2.95	33.14	8.77	60.00	9.22
30-60	9.6	11.45	1.93	33.62	6.80	64.36	17.79
60-90	9.5	14.38	1.68	36.17	7.20	66.36	21.67
90 -120	8.3	16.56	1.52	34.55	8.85	64.86	25.53
120-150	8.3	20.00	1.47	34.83	9.66	67.36	29.69

4.3 LOWER OMO VALLEY (SOUTHERN ADMINISTRATIVE REGION)

The soil characteristics of the Lower Omo River Basin are shown in Table 28 (FAO, 1984). Table 28 indicates relatively higher values of ESP (18) at the depths of 5-45cm and 45-75cm qualifying these soils as sodic. These soils are also potentially saline due to higher ECe values at the subsoil layers.

The pH of these soils varies from 7.4 to 8.5 within the soil profile. The ECe of these soils are low to moderately high ranging between 0.99 and 3.54 dS m^{-1}. Soluble sodium ranged from 3 to 20 meq l^{-1} followed by soluble Ca^{2+} ranging between 2 to 3 meq l^{-1} throughout the profile. Likewise soluble Cl- was the dominant (3.4 to 18.6 meq l^{-1}) anion followed by S042- (2.2-7.2 meq l^{-1}) throughout the profile (Table 28) indicating that NaCl and CaSO4 are the dominant soluble salts in these soils.

Table 28 shows that the soils of Ped on 1 and 2 are silty clay in nature up to a depth of 0-75cm and becomes pure clay afterwards. The overall salinity also increases three fold as we move from the surface to the deeper layers of the soil. Soil profile developed on alluvial deposits along with the poorly drained flood plains meet the requirements of saline-sodic soil. The pH of the saline-sodic soil is greater than those of the sodic soils especially at the 0-5cm soil depth and ranged between 8.1 and 8.9 within the profile. The ECe of saline-sodic soils is very high throughout the profile. It increased considerably and consistently with increasing depth from 12.3 dS m^{-1} at the surface (0-5cm) to 32.6 dS m^{-1} at depths 35cm from the surface. The ESP of these soils also varied and ranged between 55 and 84 indicating very high levels of salinity and sodicity (Table 28). In addition to the sodic soil, NaCl and CaS04 were found to be the dominant soluble salts. In the saline-sodic soils, highly saline white efflorescence are observed in the top 50cm of the soil profile (FAO, 1984).

Table 28. Physico-chemical characteristics of the soils of Lower OMO Valley

Depth (cm)	Texture	pH	ECe (dS m^{-1})	ESP	Soluble cations (meq l^{-1})				Soluble anions (meq l^{-1})		
					Na^+	Ca^{2+}	Mg^{2+}	K^+	Cl^-	SO_4^{2-}	CO_3^{2-}
Pedon 1: Sodic of Lower Omo River Valley											
0-5	Sicl	7.4	0.99	3.00	2.9	3.00	1.60	0.8	3.40	3.42	0.90
5-45	Sicl	8.2	2.25	18.0	15.3	1.95	1.02	0.3	14.8	2.24	0.98
45-75	Sicl	5.5	3.54	18.0	20.4	2.25	1.90	0.3	18.6	7.17	1.04
75+	Sicl	8.2	1.92	16.3	13.9	2.10	1.10	0.2	9.08	6.32	0.94
Pedon 2: Saline sodic of Lower OMO River Valley											
Depth (cm)	Texture	pH	ECe (dS m^{-1})	ESP	Soluble cations (meq l^{-1})				Soluble anions (meq l^{-1})		
					Na^+	Ca^{2+}	Mg^{2+}	K^+	Cl^-	SO_4^{2-}	CO_3^{2-}
0-5	Sicl	8.9	12.3	55	10.3	7.5	2.5	1.4	82.2	24.0	1.22
5-35	Sic	8.1	31.6	84	260	47	13.9	0.9	249	87.7	0.60
35+	C	8.1	32.6	55	250	64	21.0	1.1	310	48.0	0.36

(Source: FAO, 1984)

4.4 LOWER WABI SHEBELLE BASIN (SOMALI REGIONAL STATE)

The lower Somali Regional State (SNRS) is an area with little rainfall and as a result, there is limited soil development. Soils in these areas are reported to be calcareous, gypsiferous in certain areas, and in other cases they contain excessive amounts of soluble salts and excessive exchangeable sodium (Murphy, 1968). Some soils are good soils, which could be favorable for productive farming under good irrigation management practices. These soils include alluvial soils along the Wabi Shebelie River basin. Some of the problems of these soils are salinity, sodicity, swampy (waterlogging), wind and water erosion, lack of water and high contents of $CaCO_3$ (calcareous) and $CaSO_4$ (gypsiferous). In Warder areas from Ferfer up to the north side of the Wabi Shebelie Valley toward Sulsul, salt Cedar vegetation and some slick alkali spots occur indicating that these soils are salty and sodic.

The National Water Resources Commission (NWRC) of the Ethiopian Government had carried out a study on irrigation suitability and agricultural productivity potential of the soils of the Lower Wabi Shebelie Valley in 1973. Accordingly the soils of the lower SNRS were classified into two classes where the class-I consist of those soils that are very suitable for irrigation and covers a total land area of 265,000 ha and the class-II) soils are those that are not very suitable for irrigation and covers an area of 90,000 ha (NWRC, 1973). The data of selected soil profiles representing four major soil types suitable for irrigation development in the lower SNRS areas (Table 29) showed that all soils are potentially saline and the pH values are above 8.0 indicating the presence of high sodium.

Table 29. Chemical characteristcs of major soils in the lower Wabi Shebelie valley

Soil type	Depth (cm)	pH	$CaCO_3$ (%)	ECe ($dS\ m^{-1}$)	Organic carbon (%)	Total nitrogen (%)	Exchangeable cations ($cmolc\ kg^{-1}$)	
							Na	K
				Gode South				
A	0-15	7.2	26.7	1.6	0.48	0.048	0.15	1.50
	15-50	7.7	18.0	1.9	0.48	0.048	1.05	0.70
	70-80	8.0	23.0	3.2	0.50	0.036	1.20	0.75
	100-120	7.8	14.0	4.1	0.30	0.020	1.30	0.20
	180-200	7.9	14.0	4.8	0.10	0.010	1.38	0.20
				Kungo				
B	0-5	8.7	12.3	2.0	0.72	-	0.50	1.50
	5-20	8.6	16.4	2.0	0.50	-	0.30	0.90
	20-30	8.8	8.6	2.1	0.45	-	1.50	1.20
	30-60	8.5	13.1	2.5	0.45	-	2.30	1.00
	60-155	8.6	12.5	6.4	0.50	-	2.20	1.10
				Kelafo				
C	0-3	8.0	20.0	2.0	1.66	1.400	0.30	2.20
	3-25	8.1	25.2	2.0	0.94	0.700	0.75	1.10
	25-60	8.0	24.3	3.1	0.88	0.800	0.21	1.22
	60-110	8.0	28.9	3.1	0.82	0.700	0.42	1.30
	110-160	7.6	28.9	3.0	0.75	0.650	0.54	1.10
	160^+	7.6	30.4	3.1	0.69	0.560	1.40	1.07
				Mustahil				
D	0-2	7.4	18.2	2.0	9.30	0.950	0.60	1.90
	2-35	8.2	17.4	2.0	0.35	0.020	0.50	1.07
	35-80	8.0	17.8	3.0	0.60	0.050	0.95	1.00
	80-150	8.1	17.2	12.0	0.33	0.040	1.10	1.25

**ECe = Electric conductivity of saturated soil paste extract (Source: National Water Resources Commission, 1973)*

A series of vertisols occur in the Wabi Shebelie flood plain in the southern Ogaden, where the annual rainfall is less than 200mm. Sodicity is not a problem in these soils, however, salinity is often high at the lower depths of the soil profile. This can create problems for irrigated soils under the climate conditions of the southern. The ECe remains low at the surface and moderates to high at deeper depth (Table 30).

Table 30. Chemical properties of Chromic vertisols and Calcaric Gleysols of Lower Wabi-Shebele Valley (Somali region)

Soil depth (cm)	pH	ECe ($dS\ m^{-1}$)	$CaCO_3$ (%)	Soluble salt (%) of saturation extract	
				NaCl	$CaSO_4.2H_2O$
Profile 1: Chromic vertisols (saline phase)					
0-30	8.1	2.0	19	0.009	0.070
30-80	8.0	4.3	20	0.027	0.106
80+	7.9	7.4	19	0.092	0.170
Profile 2: Calcaric Gleysols (saline soil)					
0-15	7.9	3.9	14	0.400	15.100
15-50	8.0	3.2	17	0.700	10.300
50+	8.1	3.6	16	0.900	10.300

(Source: FAO, 1984)

The chloride (NaCl) and sulphate (mainly gypsum: CaSO4.2H2O) are the predominant groups of salts in these soils. Lower quantities of chloride content are present in the deeper depths of the profile ranging from 0.3-0.5g/1000g. Without drainage, toxicity effect due to the concentration of chloride may be observed under irrigation in horizons at a medium depth. Gypsum also increases with depth from 0.5-0.8g/1000g. The gypsum concentration indicates that saturation extract dissolves all the gypsum in soils. The highest gypsum solubility is 1.1g/1000ml.

Like the vertisols, a series of fluvisols also occur in the Wabi Shebele river basin in general and the Lower Wabi Shebele in particular. According to FAO (1984), fluvisols of the Ogaden region are almost all calcaric but can be saline or non-saline. Table 31 presents physical and chemical properties of three modal soil profiles representing the calcaric fluvisols (saline and non-saline phase) of the Lower Wabi-Shebele River Valley.

The presence of gypsum in the soils of the Ogaden (Somali region) as a whole and the Wabi Shebele basin in particular is due to the presence of main gypsum formation, i.e. a huge source of gypsum and the solubility of CaS04 in water in relation to CaC03. However, only small amounts of this gypsum reach the alluvial plain of the Wabi Shebele due to plain's topographic position in relation to the drainage system of the gypsum and depth of the ground water table on the upper terrace of this plain, from where these soil series are taken (FAO, 1984). ECe increases with the depth and its mean value below 90cm is 9.5 dSm^{-1}. The soluble salt content is still low. However, due to under-irrigation and absence of appropriate drainage sodium chloride may concentrate and have a toxic effect on plants (FAO, 1984).

Table 31. Chemical characteristics of Calcaric Fluvisols of Gode plain (Somali Region)

Soil depth (cm)	Textural class	ECe ($dS\ m^{-1}$)	Soluble salt (%) of saturation extract	
			NaCl	$CaSO_4.2H_2O$
Profile 1: Saline phase soil of Gode plain (1 km south of Gode bridge)				
0-20	Silt	0.8	0.0020	0.027
20-90	Clay	4.1	0.0025	0.120
90+	Clay	22.7	0.4600	0.344
Profile 2: Saline phase soil of Gode plain				
0-20	Clay	2.0	0.005	0.051
20-90	Clay	3.0	0.002	0.103
90+	Loam	4.1	0.023	0.120

(Source: FAO, 1984)

4.5. UPPER BORKENA AREA (AMHARA REGIONAL STATE)

The physical and chemical characteristics of the salt-affected soils of the Upper Borkena ai·ea were described by FAO (1984e). These soils have high exchangeable sodium with ESP ranging from 12-20 (Table 32). The source of high sodium is probably sodium rich groundwater, coming from a nearby spring. The soils are exceptionally to frequently flooded, depending on their topographic region. Table 32 shows that the sodic soils of the Borkena plain contain have excess concentration of sodium in their exchange complex. The pH is less than 8 throughout the profile indicating that the concentrations of CO_3^{2-} and $HCO3^-$ ions in the soil are low while the ECe of the soil is moderate.

Table 32. Physico-chemical characteristics of sodic soils in the Borkena plain

Soil depth (cm)	Texture	pH	ECe ($dS\ m^{-1}$)	ESP
Profile 1: Sodic soil in the Borkena plain				
0-20	Clay	7.8	2.1	12
20-40	Clay	7.9	2.1	15
40-80	Clay	7.8	0.7	20
Profile 2: Sodic phase soils in the Borkena plain				
0-15	Clay	6.5	-	5
15-40	Silty clay	7.4	-	11
40-60	Silty clay loam	8.0	-	22
60-90	Silty clay loam	8.0	-	15

4.6 HUMERA AND MEKELE AREA (TIGRAY REGION)

The Chromic Vertisol soils were characterized by FAO (1984) based on a soil profile developed on alluvium parent materials that are primarily of metavolcanic and volcanic origin at the alluvial plains of Humera (Table 33). The area is characterized under rainfed receiving an annual rainfall of about 500mm. The Vertisols represented by the data in Table 28a are moderately to strongly alkaline in reaction with pH value increasing consistently with depth from 8.4 at the surface (0-30cm) to 9.2 at 120-170cm depths. The exchangeable sodium and ESP also increased consistently with the depth from 1.0 to 8.1 cmolc kg^{-1} and are highly base saturated (85-94%) throughout the profile. The ECe of the surface soils is low (0.90 dSm^{-1}) and increased linearly with the depth to moderate (2.7 dSm^{-1}) at the depth of 120-170cm. This soil qualifies for potentially saline and potentially sodic particularly in the subsurface soil layers

FAO (1984e) characterized a saline phase of Haplic Xerosols on a soil developed on alluvium volcanic origin under a rainfall regime of less than 400mm per annum at the edge of the north-eastern escarpment, east of Mekelle town (Table 33). The ECe ranged from 30.2 dSm^{-1} at the surface (0-lOcm) to 45 dSm^{-1} at the depth of 10-60cm but contain very low exchangeable sodium and ESP levels. This soil, therefore, qualifies as severely saline. Results of questionnaire survey in relation to this assessment study also indicated that about 120 ha of salt-affected soils are known to occur in Southern Tigray (Adigodem, Mekelle), Eastern Tigray (Wukro) and Central Tigray (Axum) regions. Observations and available information also indicate that soils on a large area of recently initiated small-scale irrigation around small dams in different regions are showing signs of accumulation of soluble salts to the extent to qualify the criteria for saline and/or saline-sodic soils.

Table 33. Chemical properties of Humera and Mekelle areas (Tigray Region).

Depth (cm)	Textur e	pH	ECe ($dS\ m^{-1}$)	Exch Sodium (cmolc kg^{-1})	ESP	PBS
		Sodic Phase Soil at Humera Plain				
0-30	SiC	8.4	0.9	1.0	2	85
30-60	SiC	9.0	0.9	4.0	5	88
60-100	Clay	9.1	1.8	5.8	8	94
100-120	Clay	9.1	1.8	5.4	8	94
120-170	Clay	9.2	2.7	8.1	11	91
		Saline Soil at the edge of the NE Escarpment, East of Mekelle City				
0-10	Sil	7.7	30.3	0.0	0.0	100
10-60	Sil	7.7	45.1	0.0	0.0	68
60-75	SiCl	7.6	36.0	1.3	4.6	71
75-100	Cl	7.6	35.0	0.7	2.5	73

05

CHARACTERIZATION OF

IRRIGATION WATERS

The quality of water depends on a number of chemicals, physical and biological parameters. For many purposes, the presence of biological materials, such as animal and human wastes, bacteria, viruses or other micro-organisms constitute serious water quality degradation. The presence of even relatively minute amounts of toxic elements from municipal and industrial wastes can exert a marked effect on plant growth (Bresleret al., 1982). However, suitability of water for irrigation purposes is mostly affected by the extent of its contamination with inorganic ions (such as boron (B), lithium (Li), chloride (Cl), sodium (Na), fluoride (F), etc.). The relative concentrations of these ions characterize waters as saline, sodic and toxic in nature.

Richards (1954) of the United States Salinity Lab Staff (USSSL, 1954) published a widely used classification system of irrigation water using EC, SAR and RSC values (Table 29). Furthermore, the information given in Table 30 helps in interpreting salinity and sodicity hazards of irrigation water vis-a-vis the implications and practical significance in terms of possible use for irrigation purposes and the special considerations and management practices to be followed.

5.1 SALINITY HAZARD OF IRRIGATION WATERS

Salinity hazard refers to the extent of the concentration of total soluble salts in the irrigation water. The total soluble salt content of irrigation waters is measured as total dissolved salts (TDS) or electrical conductivity (EC). Soil salinity is an issue when water or reclaimed water or liquid wastes containing excessive dissolved salts are applied to soils. Continuous application of saline water for irrigation can transform a normal soil into a saline soil, making it useless for agricultural purpose. Appropriate management of saline soils involves proper drainage, leaching of soluble salts occasionally by applying excess water coupled with using judicious crop as well as the land selection may alleviate the problems of salinity (Bresler et al., 1982).

The TDS or EC values indicate the salinity hazard of the irrigation water. Measurement of TDS involves determination of any soluble salt, and/or solid phases which have not been filtered from the solution by taking a known volume of water, evaporating it to dryness (oven-dried), and weighing the solids which are left after complete removal of the water. Irrigation water salinity, as total dissolved salts (TDS), may also be determined by summing the concentration of the individual ions. The TDS is expressed as mg l^{-1} or parts per million (ppm) and is easily converted to other units such as EC and percent or kg salt. EC is expressed by mho which is the reciprocal of ohm, the standard (basic) unit of electrical resistance. A more convenient and commonly used expression of EC is dSm^{-1} or $mScm^{-1}$ or $\mu S\ cm^{-1}$. The relationship is (1 mmhos cm^{-1} = 1 dS m^{-1} = 1 mS cm^{-1} = 1000 $\mu S\ cm^{-1}$).

Table 34. Classification of irrigation waters based on salinity and sodicity hazards

Salinity hazard (EC)			Sodicity hazard (SAR)			Residual $NaCO_3$ (RSC)		
Salinity class	Salinity hazard	EC ($\mu S\ cm^{-1}$)	Sodicity class	Sodicity hazard	SAR mmoles/L)$^{0.5}$	RSC class	RSC	RSC meq l^{-1}
C1	Low	100-250	S1	Low	<10	1	Safe	< 1.25
C2	Medium	250-750	S2	Medium	10-18	2	Marginal	1.25-2.50
C3	High	750-2250	S3	High	18-26	3	Unsafe	> 2.50
C4	VH	>2250	S4	Very high	>26	-	-	-

(Source: Richards, 1954)

The electrical conductance of a solution or extract is directly proportional to its salt content. EC is temperature dependent wherein the value of measured EC for aqueous salt solutions increases on the average by 2.0 to 2.3% per unit increase in the temperature at which the measurement is carried out. EC is measured at 25oC as a standard and if EC is measured at temperatures below or above 25oC, they are corrected to 25oC. Generally, soils ai·e always more saline than the irrigation water applied to them, because of evaporation and transpiration. The more saline the irrigation water, the more water that must be moved through soil (leaching requirement) to prevent salt build up in the soil (Table 35).

Table 35. Use of different salinity (EC) and Sodicity (SAR) classes of irrigation waters.

1.	Classification based on salinity hazard	2.	Classification based on sodicity hazard
C1	Low salinity water can be used to irrigate S 1 most crops on most soils with little likelihood of salinity development. Some leaching is required under nonnal irrigation practices except in soils of extremely low permeability.	S1	Low sodium water ai·e suitable for irrigation on almost all soils with little danger for the development of harmful levels of sodicity. However, sodium sensitive crops such as stone fruit trees & avocado may accwnulate high sodium concentrations in the leaves.
C2	Medium salinity water can be used if a moderate amotmt of leaching occurs. Plants with moderate salt tolerance can be grown in most instances without special practices for salinity control.	S2	Medium sodium water may present sodic problem in fine textured soils under low leaching unless gypsum is present in the soil. This water is suitable for coarse soils or organic soils with good permeability.
C3	High salinity water, cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be needed. High salt-tolerant plants should be selected.	S3	Highly sodic waters are not good for irrigation without good drainage, leaching and addition of organic matte. Gypsiferous soils may be safe butchemical amendments may be required for gypsum free soils.
C4	Very high salinity water is not suitable for irrigation under normal conditions. Can be used in good permeable and well-drained soils. For these waters, high salt-tolerant crops should be selected.	S4	Very high sodium water is generally unsatisfactory for irrigation except at low and medium salinity levels, when the use of gypsum or some other amendment makes it possible to use such water.

(Source: FAO, 1984)

The increasing demand of water for domestic and industrial uses has put enormous pressure on agriculture sector to decrease its share of good quality water use. The hot and dry climates of saline areas require that the irrigation water does not contain soluble salts in amounts that are harmful to the plants or have an adverse effect on the soil properties. Studies done to evaluate the impact of irrigation on soil salinity and crop production in Gergera Watershed, Atsbi-Wonberta, Ti.gray, Northern Ethiopia have shown potential risk of soil sodification due to the use of surface water for irrigation and suggested the need for adopting alternative water and crop management practices for sustaining crop productivity in these ai·eas (Yeshitela et al., 2012).

Soils of Central Rift valley are naturally sodic in the subsurface horizons and the use of marginal quality groundwater for irrigation has exacerbated the salinity problems. In North Shewa, the widely irrigated areas of the zone are the lowlands of Kewet and Efratana Gidim are also facing growing threats of soil salinity especially in small-scale irrigated farms (Tilaye & Mekonen, 2002). Development of soil salinity in this area is often associated to the use of poor quality water for irrigation from dug wells during the dry season when fresh water availability from the river is not sufficient to meet irrigation demand (Yonas, 2005).

Deterioration of water quality along major river streams of the Awash River is also becoming an important ecological concern because water from this river is extensively used for more than 3000 hectares of farmland along the River Basin (EIAR Annual Report, 2015).

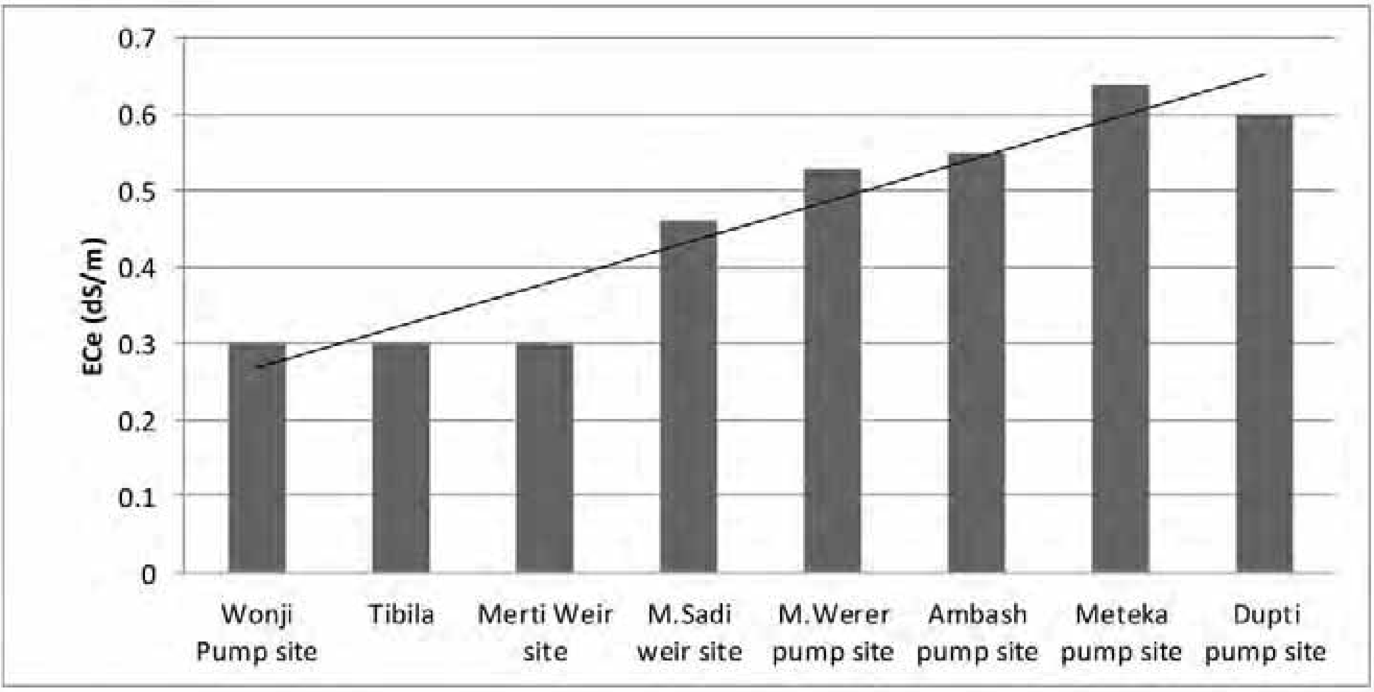

Figure 11. Trends in surface water quality along the Awash River (from upper to lower stream)

Figure 12 depicts spatial trend of Awash River water quality at different diversion weir and pump sites along the stream flow. The water quality is deteriorated as we move from upper to lower river streams due to increase in salt concentration over time. This means that the suitability of Awash River water for irrigation at down streams is continuously deteriorating, which may cause further soil degradation in future.

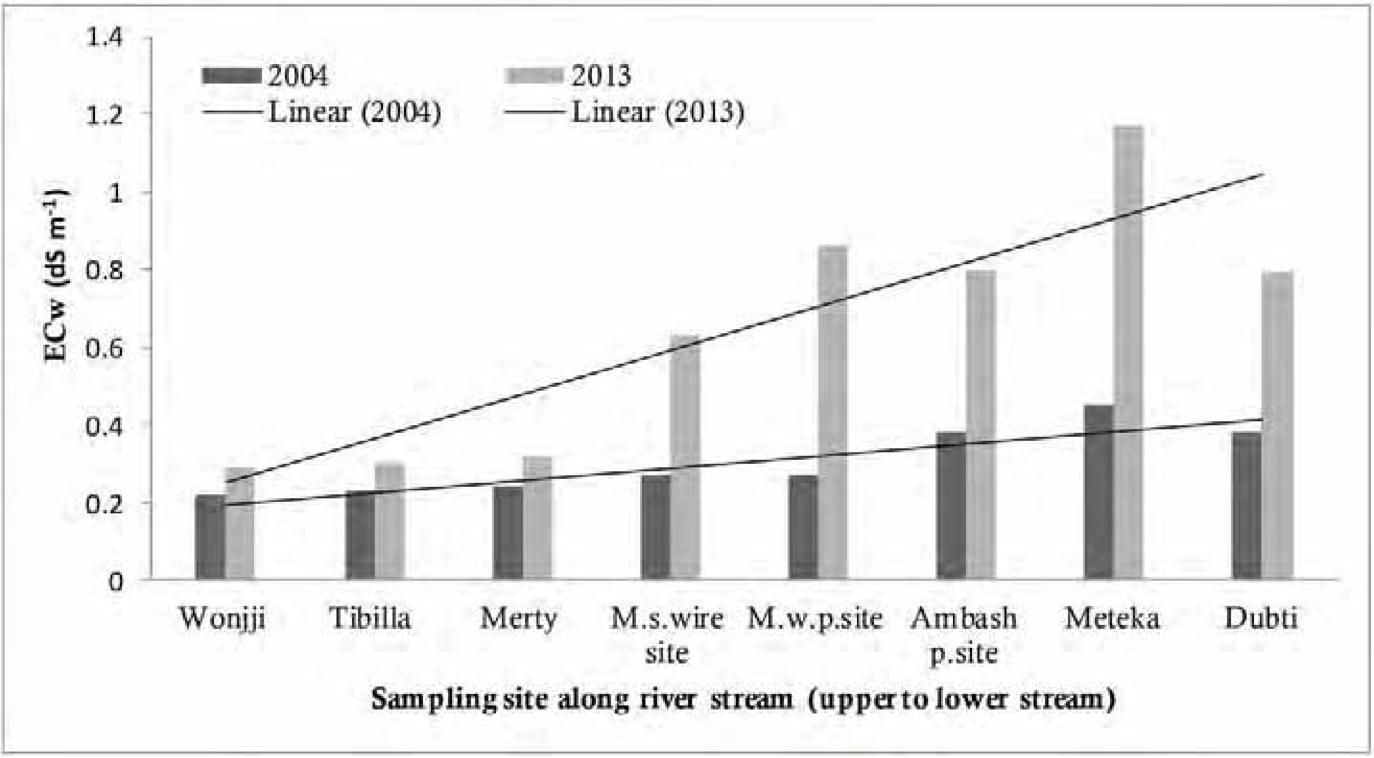

Figure 12. Changes in Awash River water quality from 2004 to 2013

Salinity levels of irrigation waters analyzed from three different locations in Ethiopia are shown in Tables 36-38. These include Awash River (Melka Sedi-Amibara), Lower Wabi Shebelle and Yellen-Jeweha areas. The Awash River water at the diversion weir and in the main canal at different distances was medium in salinity hazard, low in sodium hazard and marginal to unsafe in residual sodium carbonate content (RSC) (Table 36). On the other hand, the groundwater and drainage waters of the Melka Sedi-Amibara Plain were high in salinity, sodicity and residual sodium carbonate being not good for irrigation purposes. The Wabi Shebelle River Water both at the diversion weir and the main canal were medium in salinity and low in sodicity (Table 37). The flood water at Danlay village in the Lower Wabi Shebelle Basin proved to be extremely saline (EC = 2680-2780 μscm^{-1}) but low in sodicity hazard. Chemical composition of irrigation waters forms Lower Wabi Shebelle areas (Somali region) are good to moderate for irrigation purpose. Different levels of salinity, sodicity and sodicity hazards were observed in the irrigation waters (river, spring, well waters) from Yellen-Jeweha areas of North Shewa Zone (Table 38).

Table 36. Chemical composition of irrigation, underground and drainage waters from Melka Sedi-Amibara areas

Sampling site	pH	EC, (μS cm⁻¹)	Cations (meq l⁻¹)					Anions (meq l⁻¹)				
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SAR	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	RSC
Irrigation water samples												
Awash river at the diversion Weir	7.40	285	0.22	0.19	0.92	0.13	2.03	Nil	2.70	10.80	Nil	2.29
Main canal, 3km from the D.W.	7.50	325	0.25	0.22	0.93	0.15	1.92	Nil	3.10	14.00	1.07	2.63
Main canal 6km from the D.W.	7.10	340	0.28	0.20	0.97	0.16	1.98	Nil	3.40	20.20	2.54	2.92
Main canal 9km from the D.W.	7.40	368	0.29	0.20	0.99	0.18	2.00	Nil	3.50	22.20	4.28	3.01
Groundwater samples												
Ground water in pedon 2	7.00	12,200	22.83	81.61	313.78	0.90	43.42	Nil	8.30	519.80	51.41	-
Ground water in pedon 4	7:30	2,400	0.24	1.18	2.76	0.23	3.28	Nil	7.70	11.60	4.28	6.28
GW on AIP's Pilot or study site	8.00	10,000	0.28	1.40	88.44	0.54	37.37	2.60	11.90	72.60	42.84	12.85
Drainage water sample												
Main drain before joining the A.R.	7.50	895	0.24	0.40	66.35	0.26	117.29	Nil	3.80	51.60	19.28	3.16

(1000 ⊠S cm-1 = 1 mSc m-1 = 1dS m-1= 640 ppm = 0.064% =10 meq l-1 = 0.01N) (Source: Heluf, 1985)

Table 37. Chemical composition of irrigation waters from Lower Wabi Shebelle areas, Somali Region

Sampling site	pH	EC (μS cm⁻¹)	TDS (mg l⁻¹)	SAR	RSC (meq l⁻¹)	B (mg l⁻¹)
Shebelle R., WG	8.2	583	760	Low	Low	0.390
Shebelle R., WG	8.0	936	860	Low	Low	0.392
Shebelle R., WG	8.2	727	840	Low	Low	0.324
WG-Inside irrig. Canal	8.6	669	660	Low	Low	0.490
WG-Inside Irrig. Canal	8.5	657	680	Low	Low	0.496
WG-Inside Irrig. Canal	8.6	644	740	Low	Low	0.370
Gode River	8.2	683	600	Low	Low	0.536
Gode River	8.3	616	580	Low	Low	0.434
Gode River	8.2	902	960	Low	Low	0.454
Flood Water-Danlay Village	8.1	2780	3020	Low	Low	0.726
Flood Water-Danlay Village	7.9	2720	2320	Low	Low	0.720
Flood Water-Danlay Village	8.1	2680	2980	Low	Low	0.690

Table 38. Chemical characteristics of irrigation water from Jellen-Jeweha areas of North Shewa zone (Amara Region)

Site location	pH	ECe (dS m^{-1})	Soluble cations (meq l^{-1})				Soluble anions (meq l^{-1})				SAR (mmoles/L)$^{0.5}$	RSC (meq l^{-1})
			Na^+	K^+	Ca^{2+}	Mg^{2+}	$SO4^{2-}$	Cl^-	CO_3^{2-}	HCO_3^-		
Ambo spring	8.8	1.06	7.78	0.15	1.17	1.83	2.00	1.44	1.40	5.40	6.35	3.79
Shulashule	8.5	0.30	1.52	0.09	0.94	0.61	0.16	0.31	1.20	1.60	1.73	1.25
Bira Boy Minch	8.6	0.90	5.51	0.17	1.20	3.16	1.45	1.29	1.40	5.79	3.73	2.83
Tkure diversion	8.5	0.89	4.51	0.17	2.72	1.44	3.47	1.59	0.40	3.00	3.13	-0.76
Tkure water well	8.5	1.84	5.40	0.19	5.77	2.78	5.41	4.44	0.60	2.85	2.02	-10.90
Kuribri Monopol	8.6	0.22	0.84	0.10	0.87	0.40	0.11	0.27	0.50	1.55	1.05	0.78
Shiwshiwa school	8.6	0.62	3.99	0.16	1.34	0.57	1.94	0.87	0.80	2.00	4.08	0.89
Pit one	8.6	5.92	41.76	0.37	5.21	9.97	42.71	2.91	0.80	9.84	15.16	-4.54
Tikur Weha Wacho	8.6	0.50	2.47	0.14	1.24	1.17	0.48	0.48	0.60	3.80	2.25	2.00
Gashabekinde 1	8.6	0.70	3.37	0.13	2.41	0.96	2.63	1.08	0.50	2.80	2.60	-0.07
Gola at the head	8.6	0.27	0.98	0.17	0.96	0.39	0.39	0.31	0.50	1.60	1.20	0.75
Dabo Boy Filla	8.5	0.59	3.15	0.08	2.01	0.67	2.23	0.84	0.40	2.70	2.72	0.42
Gola at the Tail	8.7	0.73	5.21	0.10	1.21	0.63	2.71	1.06	0.30	2.95	5.45	1.42
Gashabekinde 2	8.7	0.68	4.25	0.10	0.86	1.30	2.22	0.76	0.50	3.55	4.08	1.88
Eddo Chekecheq	8.6	0.35	1.51	0.12	0.97	0.68	0.33	0.39	0.40	2.70	1.66	1.45
Sewer Wenze	8.6	0.96	6.19	0.17	1.89	1.00	3.35	1.38	0.40	3.05	5.15	0.56
Serar Canal outlet	8.5	0.25	1.19	0.08	0.94	0.46	0.16	0.35	0.40	1.90	1.42	0.89
Ergoye Minch	8.5	0.75	4.50	0.12	1.24	1.37	1.87	1.38	0.20	4.55	3.93	2.13

5.2 SODICITY HAZARD OF IRRIGATION WATERS

Sodium present in irrigation water displaces Ca and Mg from the soil. This creates a sodic soil with a dispersed physical condition. Sodicity hazard of irrigation water is determined by the relative concentrations of Na^+, Ca^{2+} and Mg^{2+} ions. The proportion of $HCO^{3-}+CO_3^{2-}$ relative to Ca^2++Mg^{2+} concentrations also determines the sodicity hazard of irrigation waters indirectly (Richards, 1954; Ahmed, 1965; Rhoades et al., 1973; Bresler et al., 1982; FAO, 1989). The relative proportion of Na+ to $Ca^{2+}+Mg^{2+}$ is known as sodium adsorption ratio (SAR) and is calculated as:

$$SAR = \frac{Na^+}{[(Ca^{2+} + Mg^{2+})/2]^{½}}$$

The ESP, ESR and SAR are related to sodicity hazard. The residual sodium carbonate (RSC) is a measure of HCO^{3-} and CO_3^{2-} concentrations and is computed from the difference of:

$$ESR = -0.01 + 0.015\ (SAR), \text{ and}$$

$$ESP = \frac{100\ ESR}{1 + ESR} = \frac{100\ (KG\ SAR)}{1 + (KG\ SAR)}$$

The relative proportion of $HCO^{3-}+ CO_3^{2-}$ to the contents of Ca^2+Mg^{2+} is the sum of the contents of these ions as: RSC= $[(HCO^{3-}+ CO_3^{2-}) - (Ca^2+Mg^{2+})]$, where concentrations are in meq 1^{-1}.

Sodicity hazard (SAR) is an important factor in determining the quality and suitability ofi rrigation water for use on different soil types and different crop species and varieties. The sodicity hazard of irrigation water is determined by its SAR and RSC content (Richards, 1954; FAO, 1989). Irrigation waters high in Na (SAR) produce soils with high Na both in the soil solution and the exchange site limiting its suitability for irrigation purpose. On the other hand, high exchangeable Na causes soil sodicity resulting in swelling and dispersion of soil colloidal particles which adversely affects soil productivity through its negative interference on soil structure, porosity, infiltration, permeability, aeration, crusting and tillage properties of the soil and root penetration. High soluble sodium in soils results in building the exchangeable sodium content of the soil through exchange reactions with other cations in the soil exchange complex.

The RSC of irrigation water also indicates the Na hazard as it indirectly increases the exchangeable sodium percentage (ESP) of the soil by increasing the SAR of soil solution through precipitation of Ca and Mg ions both in the soil and the irrigation water as insoluble compounds of carbonates and bicarbonates. Whether the source is high SAR or RSC, soil clays get saturated with Na and the soil becomes sodic. Colloidal clay and organic materials of sodic soils are dispersed as a result of increased thickness of the diffused double layer. The large diffused double layer created due to high exchangeable Na causes clays to swell and particles to disperse because they cannot get as close together. As a result of this dispersion and lack of flocculation, particles do not aggregate well and the soil profile is clogged forming impermeable layers. Apparently, there is a need to measure the amount of Na in irrigation water to predict the amount of Na that might end up in the soil solution and on the exchange sites of irrigated soils.

5.3 BORON TOXICITY HAZARD OF IRRIGATION WATER

Ions such as B, Li, Cl, Na, F and others may be present in irrigation waters in amounts toxic to plants grown on soils irrigated with such waters. As a result, the concentrations of boron or other specific elements are also usually considered important in the appraisal of irrigation water quality, not due to their relationships to salinity and/or sodicity but because these ions can be toxic to plants when their concentrations are higher than the optimum ranges for most crop plants (Richards, 1954; Bresler et al., 1982; FAO, 1989). Table 39 presents a classification system of irrigation water based on boron content for crops of deferring tolerance to boron toxicity. Toxicity can develop within a few irrigations or in one or more growing seasons depending upon the concentrations of the toxic ion in the irrigation water and the leaching fraction accomplished.

Table 39. Classification of irrigation waters based on boron concentration

Boron class	Boron hazard	Boron content (ppm) for different levels of crop tolerant		
		Sensitive plants	Semi-tolerant plants	Tolerant plants
1	Excellent	< 0.33	< 0.67	< 1.00
2	Good	0.33-0.67	0.67-1.33	1.00-2.00
3	Moderate	0.67-1.00	1.33-2.00	2.00-3.00
4	Poor	1.00-1.25	2.00-2.50	3.00-3.75
5	Unsuitable	> 1.25	> 2.50	> 3.75

Table 40. Permissible limits (ppm) for boron in saturation extract of soils

Class	Boron range (ppm)	Safety level for plants
1	< 0.7	Safe for most sensitive plants
2	0.7-1.5	Marginal for many crop plants
3	> 1.5	Unsafe for most tolerant plants

06

EFFECTS OF SALINITY AND SODICITY ON

SOIL PROPERTIES AND PLANTS

Saline soils adversely effect plant growth due to the presence of excessive concentrations of either soluble salts, or exchangeable sodium, or both. Plants in salt-affected soils of the arid regions grow in a fragile balance with theie environment since the contents of soluble salts and exchangeable sodium in these soils are sufficient enough to create harmful effects on plants. Under these circumstances, lack of proper management can lead to reduced crop production or in severe cases complete crop failure followed by a decline in land value and subsequently abandoned for agricultural use (FAO, 1989). When soluble salts occur in excess in a given soil, they limit the availability of water to plants by reducing osmotic or water potential of the soil. This effects the transpiration capacity of the roots of the plants to extract water from the soil. Moreover, soluble salts increase the concentration of certain ions that have characteristic toxic effects on plant metabolism.

The sodicity problem is of a more permanent nature than the salinity problem of the soil because exchangeable sodium remains in soil profile even after the salts are removed by leaching. In general, the adverse effects of excessive concentrations of soluble salts and exchangeable sodium on plant growth and soil properties can be summarized as follows: (U.S. Salinity Laboratory Staff, 1954).

- Excessive salt concentration in soils limits the ability of plants to extract water from the soil for their growth and development due to increased osmotic tension of the soil.
- Toxicity effects of certain specific ions such as boron, chlorine, fluorine, lithium, sodium, etc. on plant physiological processes.
- Nutritional disorders, that is, decreased or increased solubility and availabilities of essential nutrients caused by the presence of excessive accumulations of specific ions and/or salts such as Na^+, HCO^{3-}, CO_3^{2-}, SiO_3^{2-}, or NaCl and Na2S04.
- Alteration of soil physical properties resulting from the swelling and dispersion of clay particles, which finally results in inhibiting water infiltration and movement, air movement, root penetration and seedling emergence problems.
- Disturbance of the population, composition and activity of beneficial soil microorganisms either through the osmotic effects of soluble salts or toxicity of certain ions of such soils.

Table 41. Response of plants to soil salinity at different ranges of ECe.

ECe (dS m^{-1})	Plant response
0-2	Salinity effects mostly negligible
2-4	Yields of very sensitive crops (Beans, Carrot, Lemon, Orange, Avocado, Pineapple, Peach, Strawberry, Onion, Rose etc.) may be restricted
4-8	Yields of many crops restricted
8-16	Only tolerant crops (Wheat, Grapes, Sorghum, Oats, Mandarin, Soybean, Clover, Sudan grass, Wild rye, Safflower etc.) yield satisfactorily
> 16	Only a few very tolerant crops (Barley, Sugar beet, Bermuda grass, Alkali grass, Salt grass, Cotton, Wheat grass, etc.) yield satisfactorily

Salinity threshold is the maximum level of soil salinity that does not reduce the potential yield of a specific crop or it is the salinity (ECe) value at which crop yield start declining. The threshold values differ for different crops depening on their physiological characteristics. Attributed to the difference in the levels of tolerance to the effects of salinity, threshold salinity, yield reduction compared to no salinity and slope (S) is the %age of yield reduction per unit of ECe increase above threshold values. For instance, Hordeum vulgare (Barley) is very tolerant while Phaseolus vulgaris (Beans) are very sensitive to salinity. Differences in salt tolerance exist not only between crop species but also between different varieties of the same species.

In salty soils, roots of plants cannot absorb enough water. Thus, as the growth rates of their cells are limited, they have small leaves and closed stomata resulting in low CO2 fixation (i.e. reduced photosynthesis). However, often wilting is not seen because of adaptation through synthesis and accumulation of non-toxic, osmotic substances as sugars, amino acids, and amides (K+, Ca2+, NOS-) in the plant. This changes plants to C4 instead of C3 photosynthesiswith the consequence of a lower transport of NaCl via xylem into the shoot and reduced transpiration because of succulence. Toxicity is due to the uptake of many specific ions, often Na+ and/or Cl-, sometimes Mg2+ or others.

It is useful to classify plants as ***halophytes*** (tolerant of salinity) or asglycophytes (not salinity tolerant). In reality, even the ***glycophytes*** have some ability to tolerate salinity. Tolerance varies within crop species. The ability of plants to tolerate high salt concentrations is due in part to the ability to sequester those ions (example H_3BO_3, Cl^-). Also, most halophytes require Na for growth accounting in part for their Na tolerance (Bernstein, 1964). Pearson (1960) has described that plants also show marked differences in their tolerance to exchangeable sodium contents of soils(Table 42).

Table 42. Tolerance of various crops to (ESP) under non-saline conditions (Source: Pearson, 1960)

Tolerance to ESP	Crop plants	Growth (field) response
Extremely sensitive *(ESP = 2-10)*	Extremely sensitive (ESP = 2-10) Deciduous fruits, Nuts, Citrus *(Citrus spp.)*, Avocado *(Perseaamericana)*	Sodium toxicity symptoms even at low ESP values
Sensitive *(ESP = 10-20)*	Beans *(Phaseolus vulgaris)*	Stunted growth at low ESP although the physical condition of the soil may be good
Moderately tolerant *(ESP = 20-40)*	Clover *(Trifolium spp.)*, Oats *(Auena sativa)*, Tall fescue *(Festuca arundinacea)*, Rice *(Oryza sativa)*.	Stunted growth due to both nutritional factors and adverse soil conditions
Tolerant *(ESP = 40-60)*	Wheat *(Triticum aestivum)*, Cotton *(Gossypium hirsutum)*, Alfalfa *(Medicago sativa)*, Barley *(Hordeum vulgare)*, Tomatoes *(Lycopersicon esculentum)*, Beets *(Beta vulgaris)*	Stunted growth usually due to adverse physical condition of soil
Most tolerant *(ESP > 60)*	Crested and Fairway Wheat grass, Tall Wheatgrass *(Agropyron elongatum)*, Rhodes grass *(Chloris gayana)*	Stunted growth usually due to adverse physical conditions of soil

Crops tolerance to Boron: Plants also vary in their tolerance to the level of B in soils (Table 43). The range of tolerable boron concentration is indicated for each group: tolerant, semi-tolerant and sensitive. Tolerance decreases in descending order in each column (Wilcox, 1960).

Table 43. Crop tolerance limits for boron in saturation extracts of soil

Tolerant plants	Semi tolerant plants	Sensitive plants
4.0 ppm of Boron	*2.0 ppm of Boron*	*1.0 ppm of Boron*
Athel (*Tamarix aphylla*)	Sunflower (*Hellanthus annus)*	Plum *(Prunus domestica*)
Palm (*Phoenix conariensis*)	Potato *(Solanum tuberosum L.)*	Pea *(Pyrus communis)*
Date palm *(P. dactylifera)*	Cotton (*Gossypium hirsutum)*	Apple (*Malus sylvestris)*
Sugar beet *(Beta vulgaris*)	Tomato *(L. esculentum)*	Grape (*Vitis spp.)*
Alfalfa (*Medicago sativa)*	Radish (*Rapharus sativus L.)*	Cherry *(Prunus spp.)*
Broad bean *(Vicia faba L.)*	Field pea *(Pisum sativum)*	Peach (*Prunus persica)*
Onion (*Allium cepa L.)*	Barley *(Hordeum vulgare)*	Orange (*Citrus sinensis*)
Turnip (*Brassica rapa L.)*	Wheat (*Triticum aestivum*)	Avocado (*Persea americana)*
Cabbage *(Brassica oleracea)*	Corn *(Zea mays)*	Grapefruit *(Citrus P. macfafad)*
Lettuce *(Lactuca sativa L.)*	Sorghum *(Sorghum bicolor)*	Lemon *(Citrus lemon)*
Carrot *(Daucus carota L.)*	Oat *(Avena sativa)*	Apricot (*Prunns americana)*
	Pumpkin *(Cucurbita spp.)*	Navy bean (*Phaseolus vulgaris)*
	Pepper *(Caspsinum annum)*	
	Sweet Potato *(Ipomoea batatas)*	

Source: (Wilcox, 1960).

07

MANAGEMENT AND RECLAMATION OF SALT-AFFECTED SOILS

7.1 MANAGEMENT OF SALT-AFFECTED SOILS

The procedure of reclamation and management of salt-affected soils depends upon the type of the problem, its causes and other factors interfering or influencing its management and reclamation activities. Therefore prior to the initiation of reclaiming salt-affected soils, proper diagnostics of the problem must be made. The following information may be helpful in this regard:

- The type of the salt-affected soil (Saline, Saline-Sodic or Sodic)
- The cause of soil salinity/ sodicity
- The severity or the degree of salinity/sodicity
- The physical properties and mineralogical composition of the soil
- The hydraulic conductivity of the soil
- Calcium carbonate and gypsum contents
- The desired extent of leaching or removal of salts (permissible final ECe level) and the rate of replacement of exchangeable sodium (desired final ESP)
- Gypsum requirement of saline-sodic and sodic soils
- Crops to be grown (tolerance level and economic value, etc.)

7.2 RECLAMATION OF SALT-AFFECTED SOILS

This increasing soil salinity in Ethiopia has forced farmers to shift to salt-tolerant legume and forage crops instead of cultivating traditional cereal crops, which has consequences for the household food security. Reclamation of salt-affected soils requires satisfactory leaching with good quality water to remove excess salts from the root zone. Gupta and Abrol (1990) have indicated that the inhibiting factors to remove excess soluble salts include one or more of the following:

- Inadequate drainage because of the high water table and low soil hydraulic conductivity
- Inadequate supply of good-quality leaching water and also the cost of water.

Reclaiming sodic and saline-sodic soils is a recurring and a challenging problem. The reclamation procedure however, generally include:

- Improvement of infiltration and drainage
- Replacement of exchangeable Na by applying amendments, gypsum is commonly used.
- Removal of Na-salts which can become part of the soil solution after the leaching of excess soluble salts.
- Factors inhibiting reclamation of either sodic or saline-sodic soils are almost similar to that of reclamation of saline soils.

7.3 BIOREMEDIATION OF SALT-AFFECTED LANDS

The limited capacity of rainfed agriculture to sustain crop production due to erratic nature of the rainfall has persuaded farmers to look for alternative ways of improving the availability of food (Tesfaye and Fassil, 2011). Due to increasing soil salinity, per capita land availability has reduced to 0.2 ha in Ethiopia (Spielman et al., 2011). Abiotic stresses such as water scarcity, high temperatures, waterlogging, salinity, and increasing marginality of production systems are the major constraints to enhance productivity at the farm level, resulting in food and nutrition insecurity in arid and semi-arid regions of the country. Since new agricultural land will be scarce, increasing food production will require utilization of marginal land and water resources.

With a 3% average population growth, future food security as well as the livelihood source for a large proportion of the population will remain a challenge for the country (Ringheim et al., 2009). 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 Ethiopia have the potential to increase their agricultural productivity and farm incomes if they get proper guidance on the improved irrigation and salinity management strategies and access to modified salinity-tolerant seeds for crops and forages. Therefore, for millions of farm families in Ethiopia, access to improved knowledge and inputs will be a dividing line between poverty and prosperity.

Saline and sodic soils are marginally productive for commonly grown food crops. Therefore, for sustainable agricultural production, new agricultural practices and cropping systems should be adopted considering changing environmental conditions. One of the approaches for this purpose is to investigate and include in the cropping system plant species which can tolerate abiotic stresses. Moreover, the competition for fresh water resources will increase in future due to increasing demand from domestic and industrial sectors, leaving agriculture to use low-quality water with adverse effects on agricultural productivity as most of the commonly cultivated crops are salt-sensitive. In this scenario, diversification of production systems based on more salt and water tolerant crops could be an important strategy to sustain agricultural productivity and increase economic returns at the farm level. The potential alternative crops that can be used in salt-affected lands of Ethiopia are summarized below.

7.3.1 Salt tolerant field crops

Plants differ a great deal in their ability to survive and yield satisfactorily when grown in saline soils. Information on the relative tolerance of crops to a soil environment is of practical importance in planning cropping patterns for optimum returns. The areas of low to moderate salinity levels can be restored by adopting improved irrigation and crop management practices. However, in areas where increased salinity levels have impeded the growth of normal field crops, use of Biosaline Approach could be a potential solution. This approach is based on adaptable technology packages composed of salt-tolerant fodders and halophytes integrated with livestock and appropriate management systems (on-farm irrigation, soil fertility, etc.). These integrated crop and forage-livestock feeding systems have the capacity to increase resilience of small scale crop-livestock farms, particularly in Ethiopia where livelihood of smallholder farmers is largely dependent on the development of livestock sector.

Biological approach is one of the easiest approaches of reclamation and management of salt-affected soil; especially for small farmers who do not have the resources to implement costlier corrective measures. The judicious selection of salt-tolerant crops that can grow satisfactorily under moderately to highly saline or sodic soil conditions has merit in most cases.

Barley *(Hordeum vulgare L.)*, sorghum, wheat, mustru·d and oilseeds (safflower and sunflower) are among economically important crops with diverse genetic diversity for better adaptation under saline soil conditions. Barley is among cereal crops widely grown in high land areas of Ethiopia and currently it is about to expand to mid altitude areas as well. Even though barley, among commonly grown cereal crops, has been well described for its potential ability to tolerate stress induced by salinity, its introduction and potential use under marginal environment is not common in the country. For instance, farmers at Zeway Dugda area in Ethiopia used to grow barley instead of maize and other horticultural crops when the soil is getting more salinized.

Existence of genetic variation for salinity stress tolerance among different barley genotypes is well documented. The possibility of improvement of salinity tolerance in barley is in great demand due to its wider use potential as alternative crop under salt affected soils. Result from pot trials have shown the potential ability of some sunflower cultivars to high salinity stress level of 19 dS m^{-1} with 50 percent decrease in growth. Safflower is among important multi-purpose oilseed crops with great potential as source of edible oil and feed source. From field plot trials conducted over two seasons to evaluate salinity tolerance of among 52 genotypes using irrigation water of different qualities, it was found that safflower is moderately salt-tolerant and cultivation on salt-affected lands can prove beneficial to farmers (ICBA, 2014)

Prospects of improving salt tolerance in barley, wheat, sorghum and oilseed include, among others, the use of intra-specific variation and screen out resistant varieties that suits to saline areas. Ethiopia being a country of center of origin of barley and wide genetic diversity for sorghum and oilseed crops have great potential for the identification of genotypes among available gen pool and introduce the best-suited alternative salinity crops into the existing cropping system.

7.3.2 Salt tolerant legumes and forage grasses

Over the last two decades, considerable work has been done on the development of salt-tolerant crops and forages. These crops have the capacity to tolerate increasing salt concentration in the soils and uses much lower water to grow. These crops have successfully been grown in many parts of the world. Under high soil salinity conditions, planting salt-tolerant forage grasses and legume crops is more practical. Field and greenhouse studies have shown that Karnal grass *(Diplachne fusca)*, Rhodes grass *(Chloris gayana)*, Para grass *(Brachiaria mutica)* and Bermuda grass *(Cynodon dactylon)* are highly salt-tolerant and can successfully be grown in saline and sodic soils. Kamal grass grows extremely well in highly sodic soils (ESP = 80) even when no amendments are applied *(Deifel et al., 2006)*. In Pakistan, dry matter yields of 7.5 tons per hectare have been reported (Chang et al., 1994). In trials of the performance of a range of summer grasses on saline soils in Saudi Arabia, Rhodes grass yielded 8.9 tons of dry matter per hectare in 188 days; this was more than double the yield of any other tested species (Rozema, 2013).

Studies done by EIAR during 2011-14 have shown promising results in terms of salinity tolerance, biomass yield and ameliorative effects for four forage crop species i.e. *Cinchrus spp., Panicum antidotale, Sudan grass and Chloris gayana* and 3 legume species; *Desmodium triflorum, Sesbania sesban and Medicago sativa* (Alfalfa). *Salt stress levels under which Cinchrus spp, Panicum antidotale, Sudan grass and Chloris gayana* were subjected contained mean ECe values of 8.2, 10.4, 12.7 and 17.9 dSm^{-1}, respectively. The biomass yields obtained under saline soil conditions were closely comparable with that obtained under normal soil condition (EIAR annual report, 2016). Under saline stress condition *Chloris gayana* (Rhodes grass) gave the highest mean fresh biomass yield (127 tons/ha/yr.), closely followed by *Cinchrus species* (118 ton/ha/yr). Dry matter yield obtained under saline soil was also higher in *Chloris gayana* (36 tons/ha/yr) and Cinchrus species (37 tons/ha/yr) than both *Panicum antidotale* (30 tons/ha/yr) and *Sudan grass* (27 tons/ha/yr).

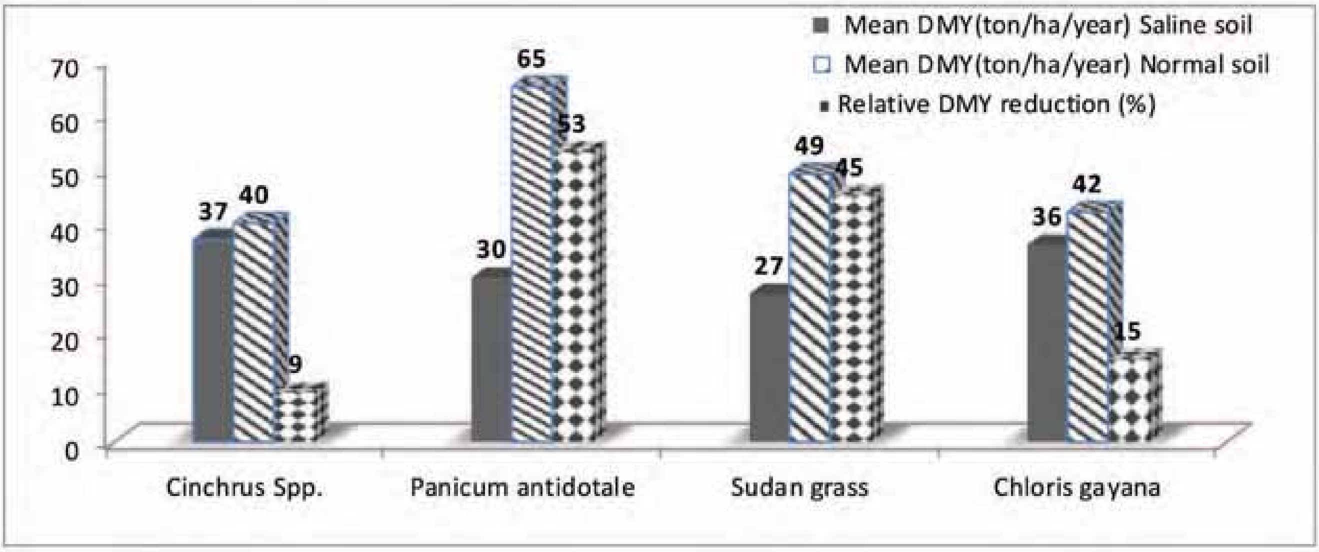

Figure 13. Dry matter yield for different grasses under saline and normal soil conditions

Under Ethiopian conditions, effect of salinity is less distinct in *Chloris gayana* and *Cinchrus* species as the dry matter yield reductions under saline conditions are 15% and 9%, respectively. However, dry matter yield reduction of *Panicum antidotale* and *Sudan grass* under saline conditions were 53% and 45%, respectively. Therefore, in highly salt-affected areas of Ethiopia, *Chloris gayana* and *Cinchrus* are the most suitable salt-tolerant forage crop compared to other grass species. These results confirm earlier findings of Deifel *et al.,* (2006) who indicated *Chloris gayana* as the most salt-tolerant forage grass. In the salt-affected lands of United Arab Emirates, high dry matter yields of Chloris gayana (Rhodes grass) have also been achieved by applying irrigation water up to 23 dS m^{-1} (ICBA, 2014).

The growth of these salt-affected grasses also results in remarkable improvement in soil quality. Soil salinity decreased markedly in all grass treatments from a mean ECe value of 12.3 to 3.7 dS m-1 in upper 0-30 cm soil layer. Rhodes grass *(Chloris gayana)* and *Panicum antidotale* have been reported as promising grasses for saline-sodic soils (Akhter *et al.,* 2003; Ashenafi et al., 2018). There was also an improvement in soil pH and bulk density resulting from growing of salt tolerant grass species. Thus, growing salt-tolerant grasses will not only provide much needed forage but also improve the soils resulting in increased absorption of rain water, reduced runoff and soil losses due to erosion.

Cultivation of salt-tolerant grasses also helps in restoring soil structure and permeability through penetration of their roots and increased solubility of native-soil $CaCO_3$, resulting in enhanced leaching of salts. In addition to buildup of biomass, their cultivation and growth can improve the water retention and infiltration characteristics of saline soils because of root penetration and root decay to loosen the otherwise compacted soil. The net result is enhanced leaching of salts to deeper layers and decreased salt concentration in the upper soil layers of the soil profile. This increases the potential of reclamation of salt-affected lands.

Among tested forage legume species *Susbania susban* has also shown excellent potential for salinity and moisture stress tolerance and remarkable biomass yield. Susbania, in addition to its tolerance to salinity, require less water to grow and have a wide range of uses such as feed and fire wood. This makes it promising candidate for legume forage production system and economic use of marginal quality soil and water resources. Alfalfa has also shown proved salinity tolerance with remarkable biomass yield. Alfalfa because of its salinity tolerance, high water use with deep-rooted system would be best alternative crop for the areas where salinity and canal seepage losses are a problem. Both forage and legume crops gave economically reasonable biomass yield indicating their ability to tolerate high level of soil salinity under which no yield is expected from cultivating other field crops.

7.3.3 Bio-drainage to control waterlogging

The recent emphasis on additional sources of energy has demanded that a sizeable fraction of available land resources be diverted to forestry. Due to increasing competition for good land to grow food crops, use of marginal lands for tree plantation is desirable. Plant species such as *Eucalyptus hybrid, Prosopis juliflora* and *Acacia nilotica can* successfully be grown on salt-affected soils by creating favorable conditions for seed germination. All major in-iga-tion schemes in Ethiopia face problems of waterlogging and soil salinity which can partly be tackled by planting trees. The excessive use of water by these trees can help control groundwater table rise to the critical depth, where it can harm the crop growth (Qureshi, 2016). However, this would require that the annual rate of discharge is equal or exceeds the rate of recharge to groundwater.

The tree plantation for bio-drainage is suitable where engineering approaches to control groundwater table are not feasible due to economic and technical reasons. The tree plantation also provides additional economic benefits for farmers. The bio-drainage is an eco-friendly and cost-effective technique for combating waterlogging and salinity problems compared to expensive conventional drainage systems (Qureshi, 2017). Howeve. to make it attractive for farmers, long-term objectives need to be combined with short term incentives.

In the desert areas of India, this technique has effectively been used for lowering groundwater table. The annual evapotranspiration from tree plantations (eucalyptus) with a density of 1900 trees/ha was estimated to be 3446mm (Dagar, 2009). The annual water use of eucalyptus forest is two times higher than most agricultural crops. Colder et al. (1994) have also found that fully developed plants like Eucalyptus camaldulensis, Acacia nilotica, and Prosopis cineraria, with a tree density of 1100 trees/ha or more can be expected to transpire water in a year equal to annual-Class A Pan evaporation.

7.3.4 Halophytes plantation for highly salt-affected lands

Increasing pressure on land and water resources in Ethiopia makes it necessary to make optimal use of available fresh water resources to expand agriculture in non-traditional areas where extreme soil and water conditions exist. Under extreme conditions of soil or water salinities where normal agricultural crops cannot be grown, dedicated halophyte plantations for forage production can be practiced. Halophyte plantation may help in rehabilitation of saline lands, landscaping, bioenergy generation, carbon dioxide sequestering and many other useful purposes (Sardo, 2005). The presence of halophytes has long been recognized, however much of the scientific work has been carried out during the last four decades, which has demonstrated unsuspected value of halophytes (Michalk *et al.*, 2013)

Because of their diversity, halophytes have been tested as vegetable, forage, and oilseed crops in agronomic field trials. The oilseed halophyte, *Salicornia bigelovii*, can produce up to 2 tons/ha of seed containing 28% oil and 31% protein, like soybean yield and seed quality (Girma *et al.*, 2007). Halophytic forage and seed products can replace conventional ingredients in animal feeding systems, with some restrictions on their use due to partially high salt content and anti-nutritional compounds present in some species (Khan and Duke, 2009).

The facultative halophytic species such as Quinoa, with a high protein content and unique amino acid composition can successfully be cultivated in saline lands. Quinoa (*Chenopodium quinoa* Willd.) is an edible seed species of the family Chenopodeaceae, which originates from the Andean region of South America, and has dietary importance due to its richness in proteins, fiber and fat, and gluten free qualities. Quinoa has substantial resistance to drought, frost and high soil salt content. In recent years, quinoa has received worldwide attention as a multi-purpose agro-industrial crop that can grow well in marginal environments characterized by poor soil and irrigation water quality (ICBA, 2014).

Timothy et al. (2015) suggests that selecting plants tolerant to salinity is an alternative strategy for a sustainable agriculture in salt-affected lands. Meanwhile, soil reclamation could be done through bioremediation method by planting halophytes which can absorb salts from the soil. The halophytes can be used as fodder. According to Khan and Duke (2001), the use of halophytic plants in pasture and fodder production on saline soils is the best economically feasible solution.

Studies conducted by ICBA (2014) have shown that high salinity tolerance ability of Atriplex makes it useful for use as feed source to improve soil salinity. Their findings also indicate that soil salinity was improved by 40% under Atriplex treatment for one-year experiment. ICBA has also successfully investigated the benefits of growing Atriplex for feed production in highly salt-affected areas and valued as a high-protein animal feed.

In Ethiopia, there is wide area of barren and abandoned marginal lands that are commonly believed useless. In Ethiopia, efforts are underway to collect and evaluate the potential of local halophytes for wide economic use in arid and semiarid regions in the light of the progressive shortage of fresh water resources and expanding soil salinization. Collection of halophytes made during 2016 from limited salt-affected farm area of Middle Awash in Ethiopia indicates widely distributed halophyte species.

08

STRATEGIES FOR THE REHABILITATION

OF SALT-AFFECTED SOILS

Saline soils have a high accumulation of soluble salts and low exchangeable sodium. Saline phase soils do not have significant salt accumulation in the crop rootzone but have a high accumulation of soluble salts below the root depth. Saline-sodic soils contain an excess accumulation of soluble salts and excessive exchange-able sodium in their solution phase and in exchange site, respectively. The pH value of these soils seldom exceeds 8.5. Sodic soils contain excessive exchangeable sodium (ESP >15) in their exchange complex and have pH value greater than 8.5.

In Ethiopia, vast areas of salt-affected soils are known to occur in the arid semi-arid low lands. Salt-affected soils cover a greater extent of land in the Ogaden lowlands (in Somali region), the northern part of the Rift Valley (the Awash River Basin), the Denakil plains and depressions, the central part of the Rift Valley (Zeway, Shala & Abaya lake) areas, the southern and extreme southern part of Rift Valley and the Omo River Basin (in Southern region). Also, small areas of saline soils are known to occur along many river basins such as the Blate and the Setit River basins in the southern and northwestern part of the country, respectively.

The majority of the soils in the drier parts of the country at present, are either saline or sodic and are at state of salt-affected or potentially salt-affected. The soils in the dry areas of the country are exposed to adverse process of secondary salinisation due to the establishment of irrigated farms without due consideration irrigation water quality, characteristics of the cultivated soil, depth of ground water and uncontrolled irrigation water application and poor drainage systems coupled with very limited management skills during the development of irrigated farms.

On salt-affected soils, crop yield is reduced to the extent that the land becomes abandoned for agricultural use. This can be attributed to the fact that the soluble salts and exchangeable sodium contents of the soils are high enough to produce harmful effects. That is reducing the osmotic or water potential of the soil and limiting the availability of water to plants. In addition, the soil physical properties such as hydraulic conductivity, infiltration, air circulation and root penetration is also affected. Also, the concentration of certain ions can be increased to such extent that the soils will develop toxic characteristic that might affect plant metabolism. In most cases, this situation can lead to forceful abandonment of lands which cannot be used for any agricultural purposes. However, such large farm lands of the country could be of great value if saline soils are reclaimed and controlled through proper management approaches.

Despite the presence of vast areas of salt-affected phases with the high possibility of expansion in the country, research and development endeavor to alleviate the problems of salinity have been bearing minimal in Ethiopia. Therefore, the extent of salt-affected soils is not exactly known, the causes are not investigated to the desired level and documented, economic implication of the problem is not brought to the policy makers to take timely and appropriate action, and there is no autonomous and full-fledged institution to make inventory of 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-afffected soils are either missing or not sufficient. As a result, farmers continue their efforts to manage these soils using indiginous methods but with a limited success.

Concerning the management of salt-affected soils and quality of irrigation water it appears that there is no organization and/or institution that monitors, evaluates, and grants permission or deny either the establishment of new irrigated farms or stops the expansion and/or discontinues the existence of those believed to cause permanent damage to the soil. Above all, the absence of autonomous institution to look after the welfare of the national natural resources and keep up to-date data on the status of soil, water, forestry, etc. made it difficult to obtain tangible information on the extent of salt-affected soils, quality of irrigation water, available arable land, and to combat the resources degradation jointly, and secure food self-sufficiency.

Currently, available information and data are not exhaustive and are based on preliminary studies and field observations which are in most cases 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 in the world are becoming a common practice to convince funding agencies including federal and regional governments. The development of strategies and plans to mitigate the problem of salinity and sodicity is based on information and data obtained from outside Ethiopia. This clearly indicates the urgent need to embark on sustained research endeavor to characterize salt-affected soils and quantify the extent of damage and develop technologies to reclaim and halt further expansion of soil salinity in the country.

8.1 SHORT-TERM STRATEGIES

In order to reclaim salt-affected soils, curtail future expansion and make sound and successful utilization of salt-affected phase and potentially salt-affected soils, any recommendations to be made must be based on the results of detailed studies, investigation and thorough analysis of the factors affecting salt built-up, their practical management including reclamation and intended utilization. Under the prevailing conditions of Ethiopia, the combination of two or more of the following methods may be practiced to control and/or minimizing salinity and sodicity, and to prevent or reduce the rate at which secondary salinisation and sodication processes of potentially salt-affected soils takes place. Nonetheless, it should be noted that the practice may not be always successful due to the very fact that the suggested practices are based on the results studies and investigations made elsewhere and experience other countries.

Desalinization and desodication of salt-affected soils and prevention of secondary salinisation and sodication of potentially salt-affected soils can be done through the following technical measures:

- Introducing proper land drainage to lower the level of mineralization near the surface groundwater through subsurface drainage or through deep channels and preventing water tables from rising to the surface. Controlling the quantity of irrigation water through a practical and economic way could be another alternative.

- Practice minimum tillage to avoid soil compaction, maintains good soil structure, improve surface and internal drainage and to facilitate deep leaching.

- Practice surface mulching; organic matter and crop residue management to reduce evaporation, develop desirable soil structures that will improve water movement and root penetration hence facilitate deep leaching and reduce salt accumulation.

- Avoiding 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, applying 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.
- 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 insure adequate surface and sub-surface drainage.
- Salt-affected soils must be surface mulched during the dry periods of the year in order 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 flooding of farm lands 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 desired depth which will be available to the crop at the time of need.
- Maintain enough water available in the root zone during critical crop growth stages.
- Select proper seeding and planting method and shape seedbeds properly to avoid salt accumulation in the rootzone of seeds and growing seedlings; establish optimum plant population to avoid competition among plants and to assure normal growth of crops. Eradicate weeds to avoid nutrient and water competition with the crops.
- Proper land selection, i.e., avoid cultivation of lands with a high water table and hardpans that will perch added water and impede drainage. If the land 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 uniform layer of salt-free soil on the surface after land levelling.
- Use lined canals or other salt-free conveyance or waterways at least 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 drainage system provided that it contains undesired salt levels and types…

Adverse effects of salinity and sodicity and the processes of salinisation and sodication of potentially salt-affected soils can be reduced using approved biological and agronomic reclamation practices and measures such as:

- Grow crops or crop species which 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.
- Grow salinity and sodicity tolerant crops, forages, legumes, etc. This practice will be more feasible and advisable in areas having soils with a high concentration of salt in the liquid phase due to continues salinization.

- Use high salinity or sodic fine soils for the production of improved pasture under flood irrigation system temporarily, and those lands with courser texture, low soil salinity or sodicity for the production of 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 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. Improving 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.
- Initiating 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 enforcing strong 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

8.2 LONG-TERM STRATEGIES

The influence of salinization and sodication process is manifested through the adverse effect on crop growth leading to reduced yield and abandonment of the land at the end. In addition to this, the physical and chemical properties of the soil will be 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 the agricultural productivity and food security for the country.

Being an agrarian country, research efforts should be given priority for providing lasting solutions to the problems of agricultural production, conservation and efficient utilization of the two vital natural resources; soil and water. Once the research and development actions are taken to boost agricultural production without upsetting the environment, then it can be claimed that the path for sustainable agricultural production, food security and national economic growth is reliable. The development of long-term policy framework for the rehabilitation and management of salt-affected soils in Ethiopia is urgently needed as the delays can have serious socio-economic and environmental implications.

Reclamation of salt-affected soils, halting the future expansion, proper management of soil and water requires a profound knowledge in the areas of natural resources conservation and optimum utilization. One of the most cardinal problems of soil reclamation and management in arid and semi-arid regions is the lack of locally amendable technologies. To develop a technology, an in-depth investigation is required to have quantitative and qualitative information on the dynamic nature of soil and water in relation to plant growth. 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 a must. Hence, research has a vital and pivotal role to play in generating science and technology that will change the lives and livelihoods of millions on the planet earth and in this regards Ethiopia cannot be exceptional.

Research endeavors, in the Ethiopian context and in relation to management of salt-affected soils, we should focus on the development of diagnostics based appropriate technologies to reclaim salt- affected soils and halt future expansion. In order to properly address the problem of salinity and sodicity, researchers have overwhelming responsibility to provide the required data and information to conserve and utilize soil and water, advise the government on issues related to national policy and strategy to develop agriculture and seek lasting solutions to emerging problems of Ethiopian agriculture. Hence, the following are recommended in the future research endeavor in relation to the management of saline and sodic soils.

- Observational and diagnostic studies must be made in salt-affectd areas.
- Investigations into physical, chemical, biological, environmental, economical, and other social factors affecting soil salinity to be made and their relationships must be established.
- Field and laboratory studies to be conducted to characterize salt-affected soils.
- Interpretation of field and laboratory findings in relation to the various environmental, hydro and agrotechnical, human or social factors responsible for the expansion of salt-affected soils must be made.
- Make estimates of damages to create awareness on the processes of salinity and sodicity among farmers and develop preparedness plans to combat salinity and sodicity.
- Distinguishing and classifying salt-affected soils into different types and classes based on the results obtained from field visit and laboratory studies.
- Mapping and properly locating salt-affected soils at zonal, regional, and national level through reconnaissance and a large-scale survey of both irrigated and dry land areas.
- Investigate the quality of the country's irrigation water and classification of the same based on their chemical characteristics related to salinity and sodicity.
- Study the deleterious 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 selection of salt and sodium tolerant crop, forage, grass and tree species, and test adaptation of ameliorating and tolerant crop, grass and tree species that will be used to reclaim and management salt-affected soils.
- Undertake research works to solve the theoretical and practical problems with regard to the degree of sodicity or sodicity; methods of reclamation; type, rate and quality of gypsum to be applied, method and depth of incorporating or mixing the amendments into the soil; quality and quantity of leaching water, and systems of water application and drainage during leaching after applications of amendments; the effective duration or reclamation measures and their economics in reclaiming saline-sodic and sodic soils.
- Develop and establish appropriate soil, water and crop management practices for all classes of salt-affected soils in the country.
- Formulate or prepare up-to-date soil and water salinity and sodicity maps indicating the methods to be practiced to combat salinity and sodicity or sodicity.
- Identify and characterize representative watersheds to develop proper water management and drainage plans.

- Revise and popularize readily available technologies and facilitate transfer of these techniques to the end users.
- Develop agricultural water management manuals, bulletins and flyers for use 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.

8.3 BIOREMEDIATION

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

This approach, if prudently adapted, can help in improving livelihood of rural and pastoral communities of the salt-affected areas by enhancing feed and fodder production. The above discussion reveals that there is an abundant unexplored and unexploited genetic variation that can be harnessed to improve the salt tolerance of field crops. Through proper identification of field crop and fodder species and varieties that can tolerate soil salinization and poor irrigation water quality, productivity of marginal lands can be maximized. In Ethiopia, this approach is of special importance due to the following reasons:

- Shortage of fodder is among major reasons for low productivity gains from the livestock sector. Forage production under saline soil conditions without competition with other farm land for field crops is important for Ethiopia for pastoral and agro-pastoral communities in the moisture stress dry regions. The above-mentioned alternative crops, in addition to their tolerance to salinity and ameliorative effect, require less input to produce. This makes them promising candidates for the diversification of production system and economic 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 growth of normal crops in these areas is restricted, plantation of halophytes can be a viable solution to produce food, fuel, fodder, fiber, essential oils, and medicine. At the same time, halophytes can also help in desalination and restoration of saline soils through phytoremediation. Through these strategies, unused marginal lands can be brought under cultivation to improve livelihood of rural communities.

Despite above advantages, bioremediation systems have certain shortcomings which can make their adoption restricted under certain circumstances. Selection of plant species for bioremediation depends on the environmental conditions for which they are planned. For agricultural crops, salt tolerance information based on Maas and Hoffman (1977) is most commonly used. For non-agricultural tree and bush species, reliable information is limited and more difficult to obtain. Marcar *et al.* (1995) provide detailed information on the use of 30 tree species for use on salt-affected land and less detailed summary descriptions for an additional 30 species. The efficiency of different plant species for the reclamation of saline-(sodic) soils is highly variable (Qadir and Oster, 2004). In general, species with higher biomass production and tolerance against ambient salinity are more efficient in soil reclamation. The reduction in sodicity levels through bioremediation treatment was found to be 52% compared to 62% through chemical treatments (gypsum) (Kuar et al., 2002). Furthermore, bioremediation works well on coarse to medium textured, moderately saline and saline sodic soils.

Production systems based on salt-tolerant grasses and forage crops using saline irrigation water 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 effluent can be minimized. Therefore for the success of bioremediation systems, selection of plants capable of producing adequate biomass is very vital. The bioremediation technology is economically beneficially when there is a market for the bioremediation crops for forage and/or for firewood (Barret, 2002). However, for the economic analysis of these technologies, one must also consider the value of rehabilitated lands in the long run.

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. Involvement of communities in 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, fuel wood, 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 (Heuperman and kapoor, 2002).

One of the major 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 where individual land holdings are very small, farmers have to make joint efforts for the success of bioremediation. Bioremediation is also less effective in removing salts from the root zone and do not allow controlled drainage. Therefore these systems need to be complimented with the conventional drainage system for removing salts from the root zone. Combining bioremediation with conventional drainage system could yield potential results in reclaiming salt-affected and water-logged soils.

09

DISCUSSION AND

FUTURE PROSPECTS

9.1 DEGRADATION OF THE RESOURCE BASE

Agricultural sector is the most important component of Ethiopian economy as it accounts for 50% of the GDP and 85% of the foreign exchange earnings. This sector supports 85% of the work force and about 85% of the population is directly dependent on the agriculture for their livelihood. About 90% of the population lives in rural areas. The total land area of Ethiopia is 123 Mha, of which 84.6 Mha is occupied by agricultural land (FAO, 2013). Out of 84.6 Mha of agricultural land, 13.7 Mha is cultivated, 62.1 Mha is pastureland and 8.8 Mha are forests. Most of the agricultural production is done in the Ethiopian Highlands, where 88% of the total population lives. The original fertile soils of the high and medium altitudes have been intensively cultivated for centuries and are now degraded in many parts. Currently, soil salinity has become the most important problem in irrigated soils of Tigray region and Awash River basin in Central and Eastern Ethiopia. The semi-arid and arid lowlands and valleys in Ethiopia have major problems of salinity and alkalinity.

The salinity problems in Ethiopia are the result of inadequate provision of drainage systems, poor water management and cultural practices and use of saline groundwater for irrigation. Currently, 11 Mha are affected by different types of salt-affected soils with average yield losses as high as 50 percent, causing billions of dollars annual loss to the national economy. Out of 11 Mha, 8 Mha have combined salinity and alkalinity problems and 3 Mha are dominantly alkaline. The problems of salinity and water logging are not just agricultural problems, but they do affect the country as a whole and ultimately the social fabric of Ethiopian society. Salt-prone land and water resources have very adverse social and economic effects on communities, causing poor living standards in affected areas and health problems for humans and animals. This situation has forced the local population to abandon their lands and migrate to other areas to earn their living.

Despite these huge challenges, no comprehensive database is available to evaluate the extent and characterization of salt-prone land and water resources. Furthermore, there are large differences in various studies conducted for the quantification of salt-prone land and water resources, which raise serious concerns about the reliability of data. The problems of salinity/ sodicity and water logging are spread over a range of landscapes, including irrigated lands, rainfed dryland farming areas and rangelands. The salt-affected soils in Ethiopia are present in the Rift Valley, Wabi Shebelle River Basin, the Denakil Plains and other lowlands and valleys of the country where 9% of the population lives. In addition to naturally occurring salty soils, mismanagement of land and water resources is largely held responsible for the development of saline and sodic soils.

In Rift valley agricultural system, salts are contributed through shallow groundwater tables, natural saline seeps and marine origin. Development of large irrigation schemes at middle and lower Awash Valley without appropriate drainage systems along with poor irrigation management practices have also resulted in the gradual rise of saline groundwater to the top soil. Due to high temperatures, water evaporates from the soil surface leaving the salts behind causing secondary salinization in many areas in Ethiopia.

Salinity problems in Ethiopia have manifested to the extent that farmers are experiencing huge crop losses while many farms have gone out of production in the last two decades. The development of irrigation in Ethiopia started in early 1960s and is historically concentrated in the Awash valley. Due to salinization of irrigated lands, in Middle Awash areas, more than 3000 ha of agricultural lands have been abandoned causing an estimated economic loss of 3.5 million US dollars per year. Investigation results in Malka Sadi in Awash Valley where irrigation has been practiced since 1972 showed that 40% of the farm areas had salinity and 17% sodicity problems. In these areas ground water is reported to have risen from 10m to only 2m by increasing at a rate of 60 cm per year. As a result, 72% of the area suffers from waterlogging. The incipient salinity and waterlogging conditions have affected the crop yields. Crop yield data from Awash Development Corporation (1978-82) shows that crop yields have reduced from 34% to 68%. Cotton yield has declined from 2.0 tha-1 to 0.83 tha-1. The area abandoned due to soil salinity ranges from 5% to 36% of the total landholdings.

Over the last decade, government has given special attention to the agriculture sector, which has brought food self-sufficiency in the country with grain production reaching up to 27 million tons. This was the result of a strong commitment by the government with the allocation of more than 15% of the total budget and introduction of effective policies and programs for the development of the agriculture sector. During the current growth and transformation plan, government is planning to develop additional irrigation area of 660,000 ha. While more emphasis is given on the development of irrigation infrastructure, the management and sustainable use of irrigation facilities also needs attention to prevent these areas from waterlogging and soil salinization problems. It is generally believed that with the continuation of expanding irrigation practices, soil salinity problems will be further aggravate if proper measures to avoid salinization are not taken. Therefore mitigating existing soil salinity problems and preventing futher spread of salinity in the irrigated areas is urgently needed to ensure food security for the rising population.

9.2 MANAGEMENT OF SALT-AFFECTED LANDS

Farmers in Ethiopia are continuing their efforts for the management of salt-prone land and water resources based on their indigenous knowledge which include physical, chemical and biological interventions. These include leaching practices to remove excess salts from the root zone, use of chemical amendments to reclaim sodic soils, application of higher rates of fertilizers and compost to mitigate salinity effects, growing of salt-tolerant plants, and use of improved genotypes of commonly grown field crops. These efforts have made some improvements in isolated places however little has been translated to a larger scale. This is mainly due to the fact that research conducted to advice farmers was confined to local field scale experiments. The results of these studies were therefore regarded as local solutions and could not get the attention of the larger farming community. Furthermore, no serious attempts were made to generalize the results of these studies for wide scale dissemination to the farming community through extension services. As a result, problems of soil degradation still persist in vast tracts of irrigated areas. Therefore, the farming communities should be involved in the planning and execution of amelioration and management of salt-prone land and water resources. This will increase their confidence and build capacity for wider adaptability. Without farmers' participation, true benefits of research could not be achieved.

The future projections also suggest that to produce more food and fiber for the rising population, an increased use of salt-prone water and land resources will be inevitable. Therefore, an assessment of the impact of such use on the environment and crop productivity have to be made through a holistic approach. The problems of soil salinity in Ethiopia are complex and a straight forward solution does not exist. The management of these resources need to be multi-dimensional and must consider biophysical and environmental conditions of the target area as well as livelihood aspects of the associated communities. The following priorities may be helpful in this regard:

1, Development of salinity awareness and preparedness programs, databases and maps of salinity hotspots and potential markets for the agricultural produce from salt-prone areas;

2, Use of innovative applications and advanced knowledge for salinity management;

3, Introduction of food and forage crops as well as halophytic plant species capable of growing and producing on salt-affected lands;

4, Improved management of saline drainage water in areas where these waters predominate and their disposal options are limited;

5, Community-based management of salt-prone land and water resources that would help in strengthening linkages among researchers, farm advisors, and farmers as well as minimize the chances of developing secondary salinization.

There is a strong need to establish network to monitor spatial and temporal changes in soil salinity and water quality in the country. Detailed investigations are needed to prepare an extensive database and soil salinity and water quality maps to select representative sites for in-depth analysis of land and water degradation issues. These sites should be established as pilot to demonstrate the sustainable methods of managing saline soils and waters. Latest approaches using GIS, remote sensing and satellite measurement techniques can help a great deal in spatio-temporal analysis of salt-prone land and water resources. These techniques are now widely used for this type of analysis and have proved to be accurate, less-expensive and effective in overcoming data limitation problems (Bastiaanssen and Ali. 2003).

9.3 MANAGEMENT OF DIFFERENT QUALITY IRRIGATION WATERS

Despite the shortage of water and lack of effective drainage facilities, there is a general tendency of over-irrigation in Ethiopian farmers, whereas the opposite should be accomplished. Due to poor land levelling and use of basin/-flooding methods of irrigation, water use efficiencies are around 35% (Kadigi et al., 2012). Un-even distribution of water due to poor leveling of fields produces patches of low and high infiltration rates, which in turn produce patches of low and high salinity within the same field. 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, adoption of water conservation strategies can save up to 25% of the irrigation water without compromising the crop yields (Qureshi and Bastiaanssen, 2001). Improved cultural practices such as precision land leveling, zero tillage and bed and furrow-bed methods of planting have shown water savings of up to 40% and reduced levels of salinity development (Qureshi et al., 2003; Ahmad et al., 2007). These resource conservation techniques are now widely used in arid and semi-arid areas for growing variety of 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 very limited economic benefits, farmers are not very interested to adopt these practices and prefer to leave their lands and look for off-farm income employment. Due to increasing dependence on irrigated agriculture, it is important to develop strategies to use different quality irrigation water for agriculture. Studies have shown the technical feasibility of using saline water and land for irrigated agricultural production in the mixed farming systems of West Asia and North Africa (WANA) region (ICBA, 2003; Koocheki and Moghaddam, 2004). With practical examples from Egypt, Syria and Tunisia, they have shown the efficacy of using saline and drainage water for conventional crops.

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 (Qureshi and Bastiaanssen, 2001). However, before deciding about options, it is very important to do economic and environmental analysis to evaluate trade-offs between risks and costs. In Ethiopia, like in many other areas, salinity management and drainage control measures are adopted when soil salinity and groundwater levels have reached alarming levels. However, for sustainable management of irrigated lands, drainage should be considered a complementary activity to irrigation. 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.

One of the major bottle-necks in persuading farmers to use saline water for agricultural production is the lack of proper guidelines for farmers on mixing ratios of different quality water, irrigation amounts and frequencies, and cultural practices that can be instrumental in avoiding salt accumulation in the root zone. Considerable amount of work has been done to develop strategies for conjunctive use of different quality waters for irrigation under different climatic and crop conditions (Rhoades 1990; Rhoades et al., 1992; Qadir and Oster 2004; Qureshi et al., 2004a; Qureshi et al., 2004b). However, these findings need to be refined and tested for local climatic, soil and crop conditions. Therefore, there is a need to develop plans for targeted research in this area. Farmers alone cannot tackle the huge task of rehabilitating degraded land and water resources. Therefore, government should take lead in preparing strategic plans to improve the quality of research and extension services leading to better solutions for the rehabilitatin of salt-affected soils.

9.4 CROP-BASED MANAGEMENT OF SALINE SOILS

Although crop-based management of salt-prone soils has been in practice for decades in the world including Ethiopia, there has been a renewed interest in this approach because in addition to soil amelioration there are economic incentives from the crops in terms of their market demand or farm level utilization (Qureshi, 2017). Additional benefits from crop-based interventions include improved nutrient availability and carbon storage in the post-plantation soil. Various field scale evaluations reveal such benefits through crop-based management of salt-prone soils (Barret, 2002; Qadir and Oster, 2004; Qureshi, 2017). A number of crops, forage shrubs and grasses, aromatic and medicinal species, and fruit tree and agroforestry systems have been found to be successful on a variety of salt-prone environments. This approach is also considered environment friendly because it does not include addition of any chemicals or other toxic amendments in the soil.

Crop diversification and production systems based on salt-tolerant plant species (biosaline agriculture) are likely to be the key of future agricultural and economic growth and social wealth in the salt-affected areas of Ethiopia. Therefore, there is a need to exploit full potential of Halophytic and other salt-tolerant plant species in Ethiopia. However, to increase the performance of plant species used for the management of salt-affected soils, involvement of local communities and stakeholders such as industry and traders is of utmost importance. In addition, markets for the products produced from salt-prone soils need to be established and strengthened to make it a profitable business for farmers. In addition to halophytes, different crop genotypes have been identified for salt-affected areas.

In Ethiopia where off-farm income generation activities are limited due to lack of industries, using abandoned soils for biomass production would be a viable option. Many tree species capable of growth and production in highly saline conditions are now available and are being used in Australia, Pakistan, India and other Central Asian and Arabian countries (Qureshi, 2017). ICBA together with the national partners has also successfully tested the growth of a large number of halophytic species in Uzbekistan and Kazakhastan and found them extremely benefcial to individuals and communities for eradicating household poverty. These studies have shown that although global land degradation trends are still a major concern, improvements in the life of communities is possible through these localized resource conservation strategies.

In Ethiopia livestock obtain feed from three different sources, i.e. grazing and browsing on natural pastures; crop residues and agro-industrial by-products; and cultivated pasture and forage-crop species. The feed shortages are common causing undernutrition and malnutrition and constraining animal production in the country. Nutritional stress causes low growth rates, poor fertility and high mortality, which is compounded by diseases. About 85% of feed intake is used to meet the animals' maintenance requirements and only 15% is utilized for production. The area of improved pastures and fodder crops is insignificant and natural pastures are overgrazed causing invasion of inferior species. In Ethiopia, about 40% of the land is occupied by pasturelands and another 22% is severely degraded. These lands have become too saline for crops and represent an opportunity for the growth of salt-tolerant fodder plants to complement livestock production systems. Although research on cultivated pasture and forage-crop species in Ethiopia was initiated in the late 1960s, cultivated pastures and forage crops, with the exception of alfalfa and Rhodes grass, have not been used on large areas outside government stations, state farms and farmer's demonstration plots. The growth of alfalfa and Rhodes grass is usually discouraged due to high water intake.

Through the RAMSAP project, ICBA has introduced more than 20 genotypes of different food and forage crops that are suitable for salt-affected lands of Ethiopia. These genotypes have been tested under local conditions to evaluate their response to different salinity levels. Based on the results of these tests, different crops have been recommended for different regions. There is a need to activate the existing extension services for scaling up these genotypes to all salt-affected areas of the country. This goal can be achieved by opening a dialogue with farming communities and policy makers 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 the adoption of these crops by communities. Such participatory approaches create a sense of ownership among the farmers.

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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 as well as farm and livestock productivity. The agriculture sector in Ethiopia supports 85% of the work force. About 85% of the population living in rural areas is directly dependent on agriculture for their livelihood. There are 7 million smallholder farmers, which produces more than 95% of the total agricultural outputs including food crops, cereals, oil seed and pulses. Cotton and sugar are produced on state-owned large-scale enterprises. Ethiopia also has large livestock resources including cattle, sheep, goats and camels. Despite this high biodiversity and distinctive ecosystems, Ethiopia is known as a country of famine. Where food shortages are widespread and there have been severe famine 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. Today, Ethiopia stands first in Africa in the extent of area of salt-affected soils due to human-induced and natural causes. Current estimates suggest that about 11 million ha (Mha) land in Ethiopia is exposed to salinity and sodicity, out of which 8 Mha have combined salinity and alkalinity problems whereas the rest 3 Mha have alkalinity problems. About 9% of the population lives in the salt-affected areas. The saline areas in Ethiopia are in the Tigray region, and Awash River basin and the situation is expected to exacerbate in the future due to climate change induced factors. For sustainable development and to produce enough food for the rising population, there is an urgent need that salt-affected soils are restored to their production potential.

In South Sudan, agriculture account 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 the main part of their daily diet. Despite abundant water supplies, only 5% of the total 30 million ha arable land is cultivated. Crop yields are low, which negatively affects incomes and livelihood of poor farmers. Lack of agricultural inputs such as seed and fertilizer, poor advisory services and inefficient irrigation management are considered as the major barriers. Although South Sudan has the highest livestock per capita in the world, with 23 million head of cattle, sheep, and goats, there is little use of improved varieties of seed or breeds of livestock. For increasing livestock productivity, there is a need to introduce improved forage varieties that are resistant to common diseases. 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 fresh water availability from the Nile. Therefore, bringing back these degraded lands into acceptable production levels is essential to ensure food security and social stability.

With a 3 percent annual average population growth in these countries, future food security, as well as 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 have the potential to 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. Therefore, for millions of farm families in these countries, access to improved knowledge and inputs will be a dividing line between poverty and well-being.

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 normal field crops, use of Biosaline Approach could be a potential solution. This approach is based on adaptable technology packages composed of salt-tolerant fodders and halophytes integrated with livestock and appropriate management systems. These integrated crop and forage-livestock feeding systems have the capacity to increase resilience of small scale crop-livestock farms, particularly in Ethiopia and South Sudan where the livelihood of smallholder farmers is largely dependent on the development of livestock sector.

This project will devise a strategy to improve the productivity of saline soils to an economically feasible level and to minimize future salinity development in these areas. The project will draw on the successful experiences of past work to identify most productive alternative crop and forage production systems, test them for local conditions and devise a strategy for scaling up these production packages to improve livelihood of rural communities especially women in the target areas of both countries. Through improved crop yields and reduced loss of land to degradation, the project will improve the resilience of farmers thereby reducing both 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 overall goal of the project 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 is to introduce, test and promote appropriate technologies and practices for rehabilitation and management of salt-affected lands and draw lessons for scaling up.

PROJECT GOALS AND OBJECTIVES

The project will directly target 5,000 smallholder farmers in selected areas in Ethiopia and South Sudan who are facing 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 farmer in Ethiopia and 10,000 farmers in South Sudan) that are 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 through the production and distribution of tested crop and forage seeds, dissemination of improved soil and water management practices, training of farmers and extension workers in the target areas.

The Biosaline approach was developed by ICBA, in partnership with NARS of at least eight African countries and support of international donors including IFAD, OFID and IDB.

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 only 7% of 30 million ha 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 especially benefit women as they will have better access to food and health facilities. Transformation of degraded lands into productive lands will also create direct and indirect job opportunities for the large segment of young population. This will help in reducing the migration trends of unemployed youth from rural areas to urban areas.

The project will target Ethiopian highlands (Tigray, Amhara and Afar) and lowlands (Oromia and Somali) which produce 87% of Ethiopia's cattle and 5% of its sheep and goats, however, land degradation has reduced farm and livestock productivity of these areas resulting in extreme 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 (about 50,000 ha area) in the South Sudan. These soils have a large potential due to availability of fresh water from 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 non-availability of good quality seeds for crops and forages. It is estimated that about 18% of the land is not cultivated due to a shortage of seed and another 9% due to low soil fertility. Increasing 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 to first diagnose the issues and then to 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 the rehabilitation of saline soils through engineering (drainage systems) or chemical amendments is an expensive and time-consuming process, this project will work on adaptive and mitigation approaches for the rehabilitation of salt-affected 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 for the rehabilitation of 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.

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The project will generate and disseminate sustainable integrated crop-livestock technology packages to diversify incomes of farmers through the sale of 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 nutritive 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 (kg/ha/year); (b) nutritive value of edible biomass (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 most vulnerable groups of the society, to ensure that the interventions benefit very poor men and women farmers and households. Since rural women play a key role in undertaking agricultural and livestock activities, enhancing their knowledge and capacity will be one of the main targets of this project.

STRATEGY, APPROACH AND METHODOLOGY

The immediate outcome will be the implementation of new salt-affected management strategies within the pilot sites with related benefits to farming communities and land management organizations. The longer-term outcome will be new thinking and awareness of the gains possible from new salinity management approaches and both support and implementation of overall system reform. This, in turn, will lead to out-scaling of alternative 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 contribute positively to the country's economy and reducing rural poverty. The overall impact of the project will be revitalized agriculture in Ethiopia and South Sudan.

SCALING UP PATHWAYS

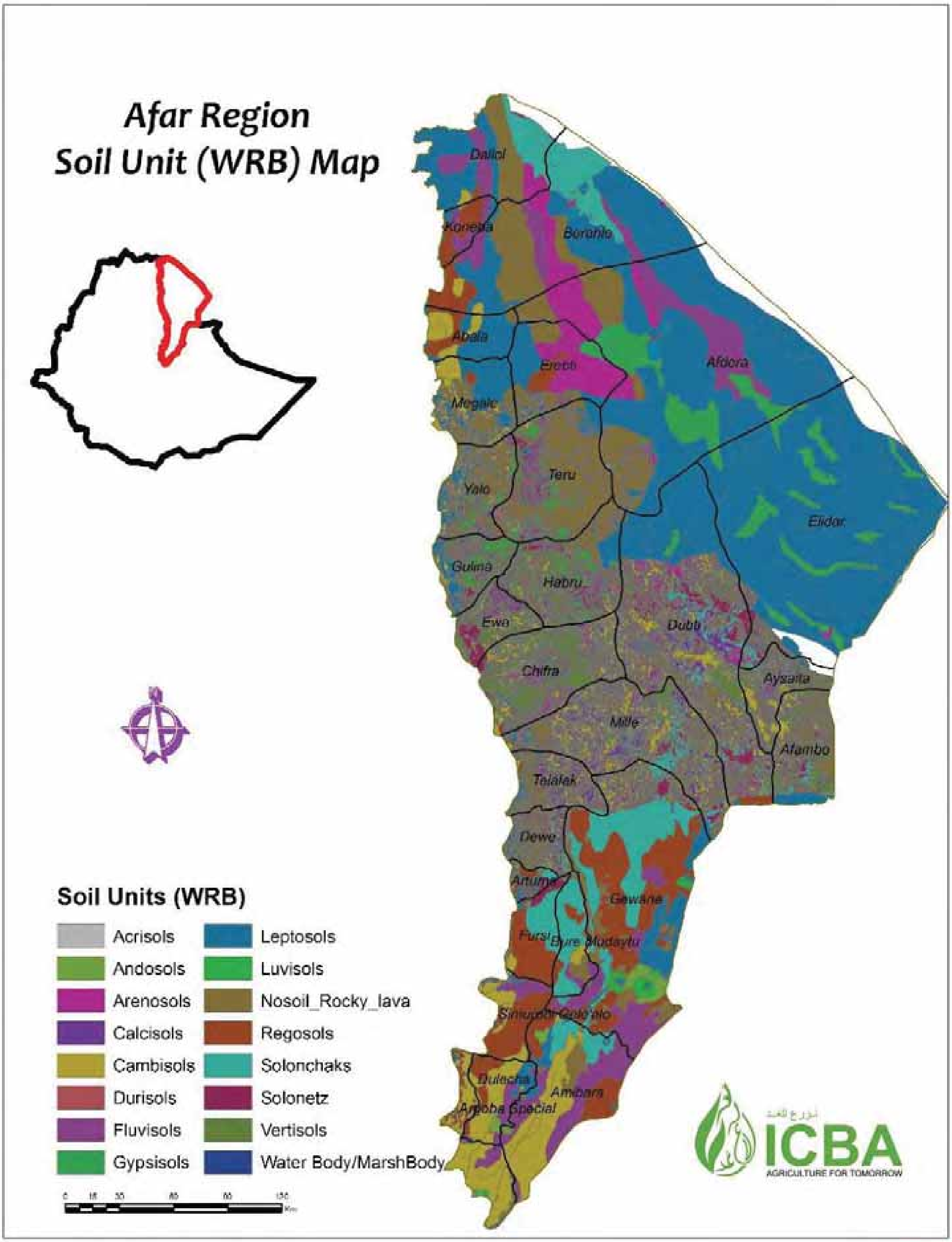
The key element of this project is to pilot test innovative strategies and approaches for the rehabilitation and management of salt-affected soils and then "scale up' recommended technologies to reach up to a greater number of rural poor. All activities of this project will be carried out with the involvement of 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. During the pilot stage, opportunities and constraints that may affect the scaling up process will be critically evaluated. For long-term sustainability, the overall impact of the alternative production systems on the lives of the rural poor, natural resources and environment will also be reviewed.

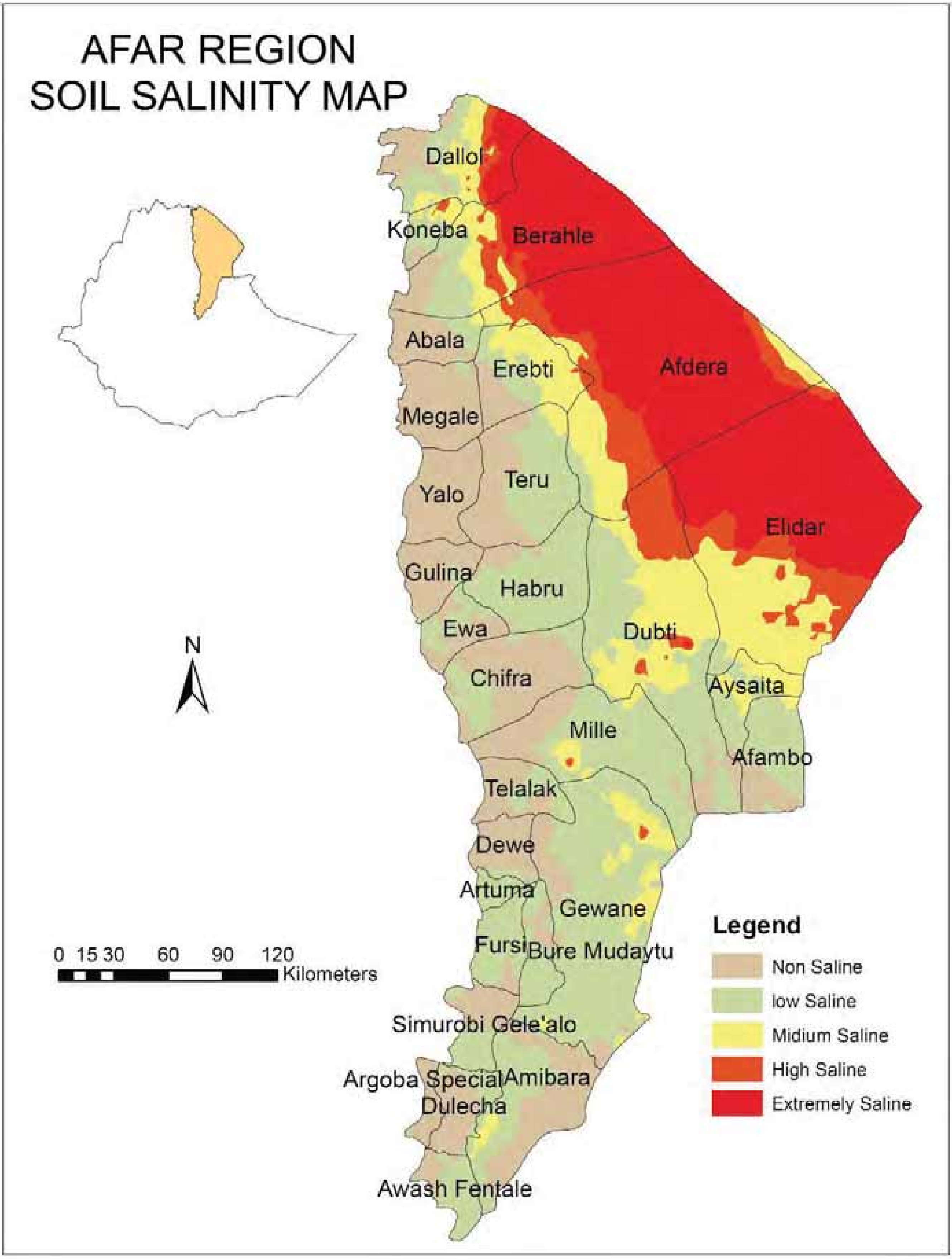
SOCIO-ECONOMIC AND ENVIRONMENTAL IMPACTS

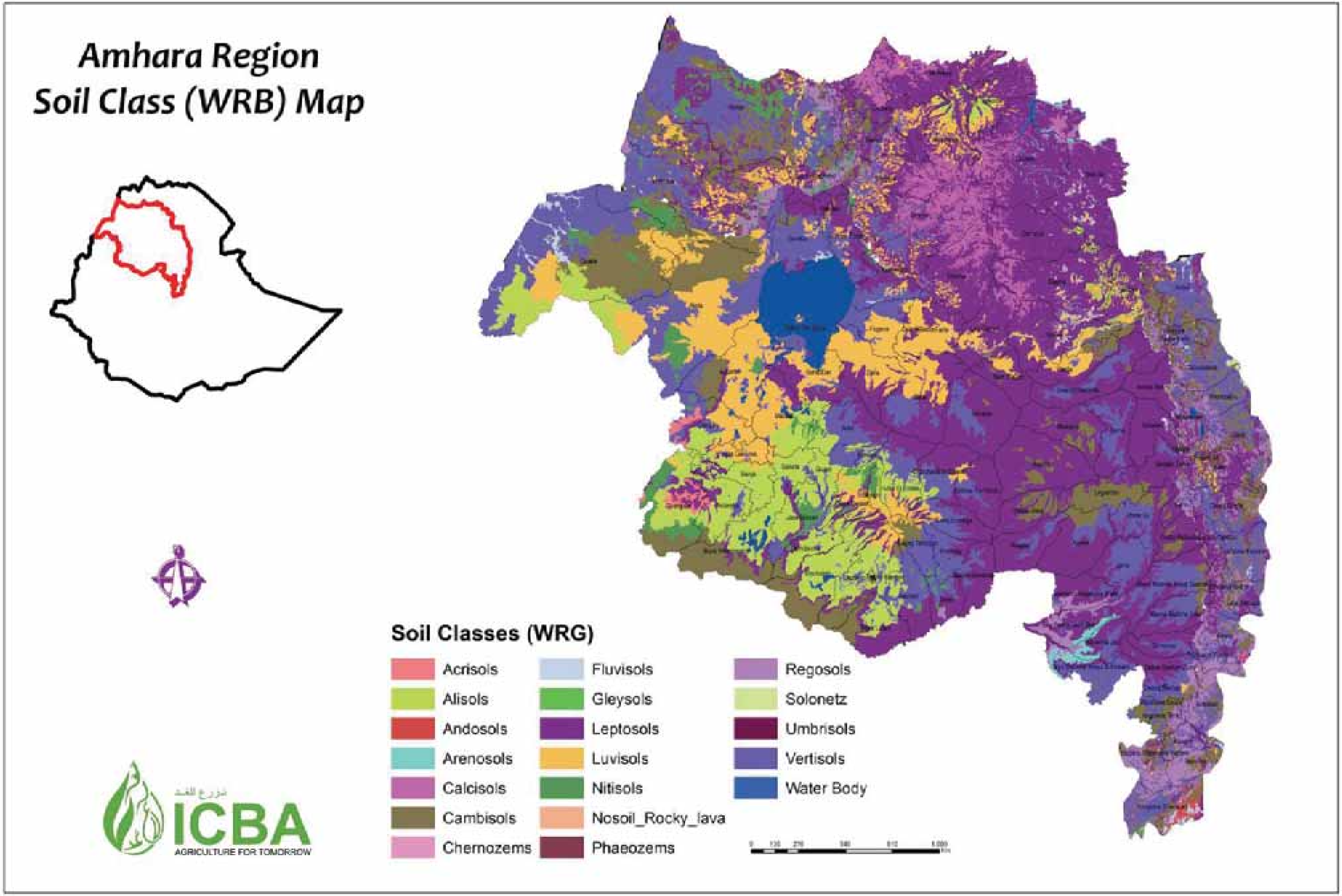
The project will develop modified approaches to improve water management for salinity control and demonstrate best soil management practices for different salt tolerant crops and forages. Adoption of alternative crop and forage production systems will reduce the area lost to salinity, bring income to farmers and improve the livelihood of poor rural communities especially women. Transformation of salt-affected lands into productive lands will also contribute to poverty reduction.

SOIL TYPES AND SURFACE SALINITY MAPS OF FOUR REGIONS

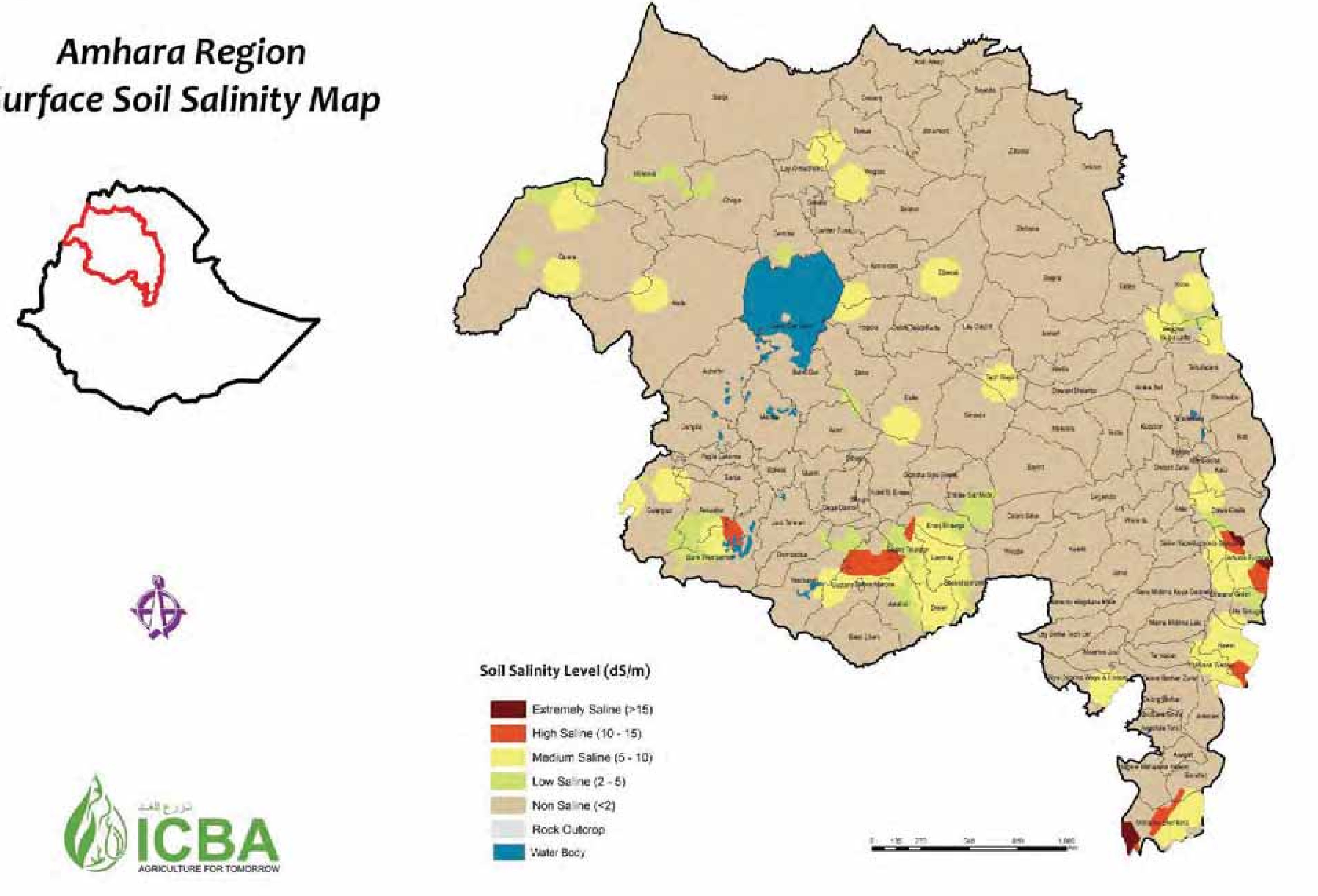
APPENDIX - 2



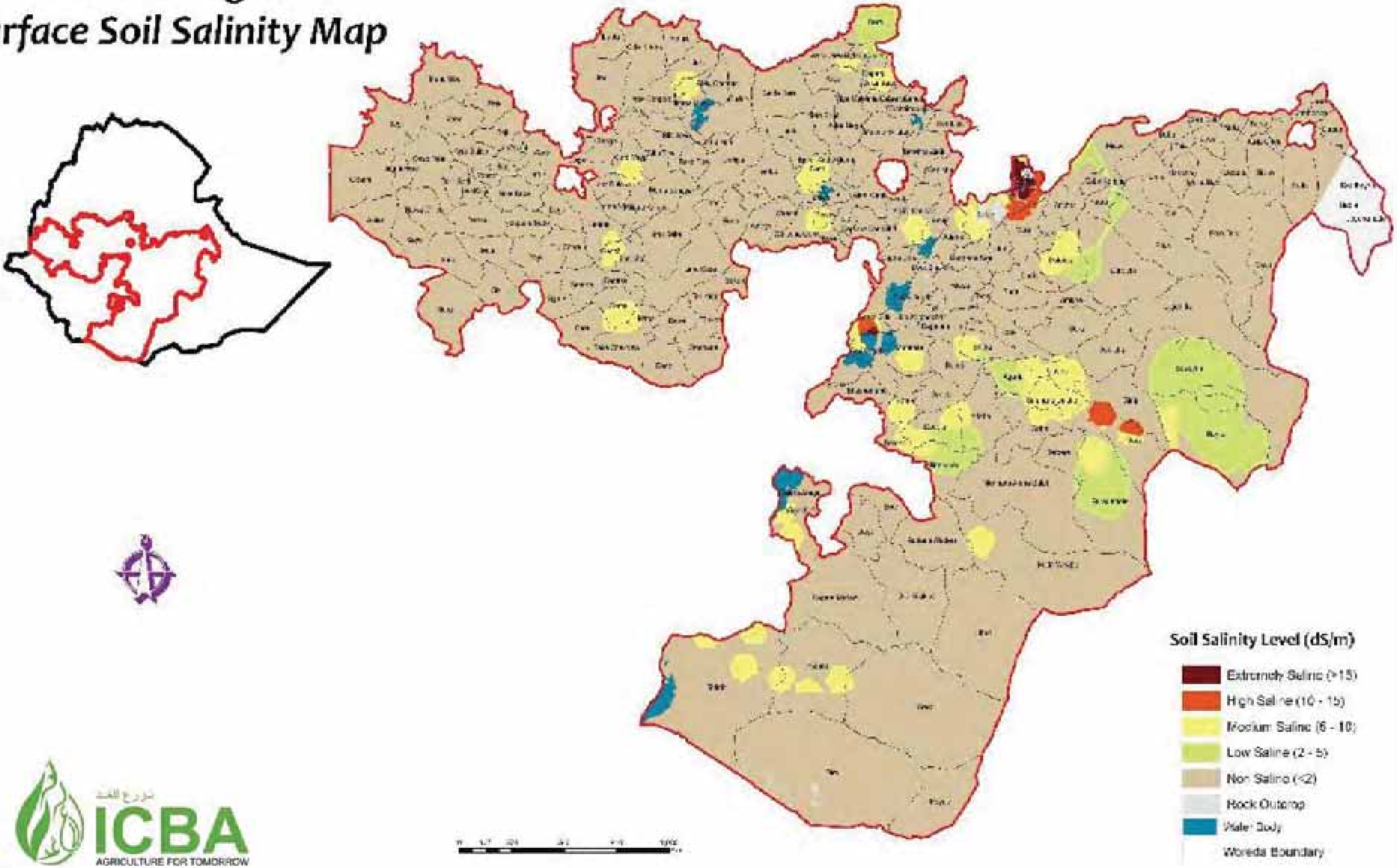

AFAR REGION
SOIL SALINITY MAP
Dallol
Koneba
Berahle
Abala
Erebti
Afdera
Megale
Teru
Yalo
Elidar
Gulina
Habru
Ewa
Dubti
N
Chifra
Aysaita
Mille
Afambo
Telalak
Dewe
Artuma
Gewane
Fursi
Bure Mudaytu
0 15 30 60 90 120
Kilometers
Simurobi Gele'alo
Argoba Special
Amibara
Dulecha
Awash Fentale
Legend
Non Saline
low Saline
Midium Saline
High Saline
Extremely Saline


Amhara Region
Soil Class (WRB) Map
Soil Classes (WRG)
Acrisols
Alisols
Andosols
Arenosols
Calcisols
Cambisols
Chernozems
Fluvisols
Gleysols
Leptosols
Luvisols
Nitisols
Nosoil_Rocky_lava
Phaeozems
Regosols
Solonetz
Umbrisols
Vertisols
Water Body
ICBA
AGRICULTURE FOR TOMORROW

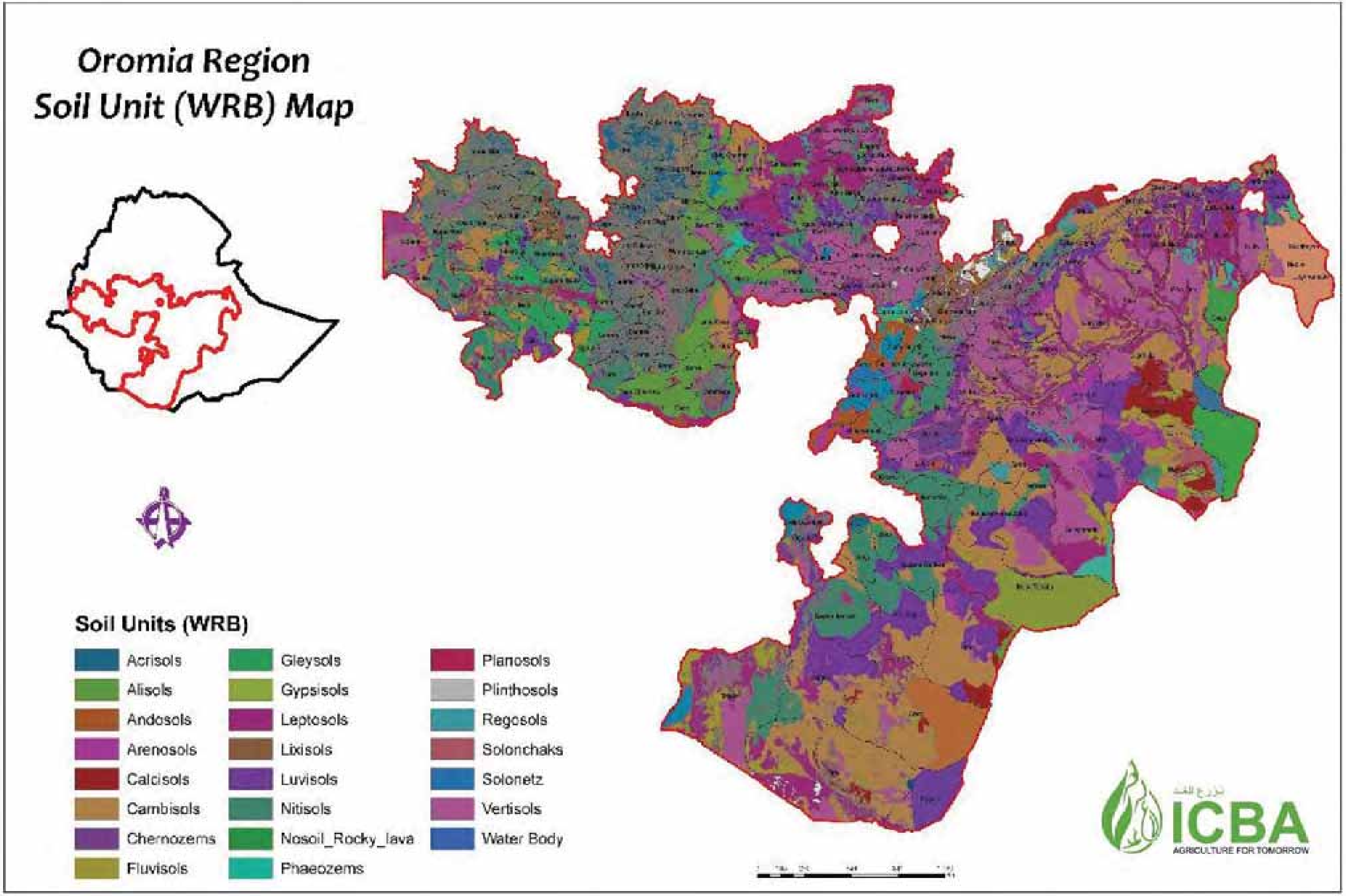
Amhara Region
Surface Soil Salinity Map



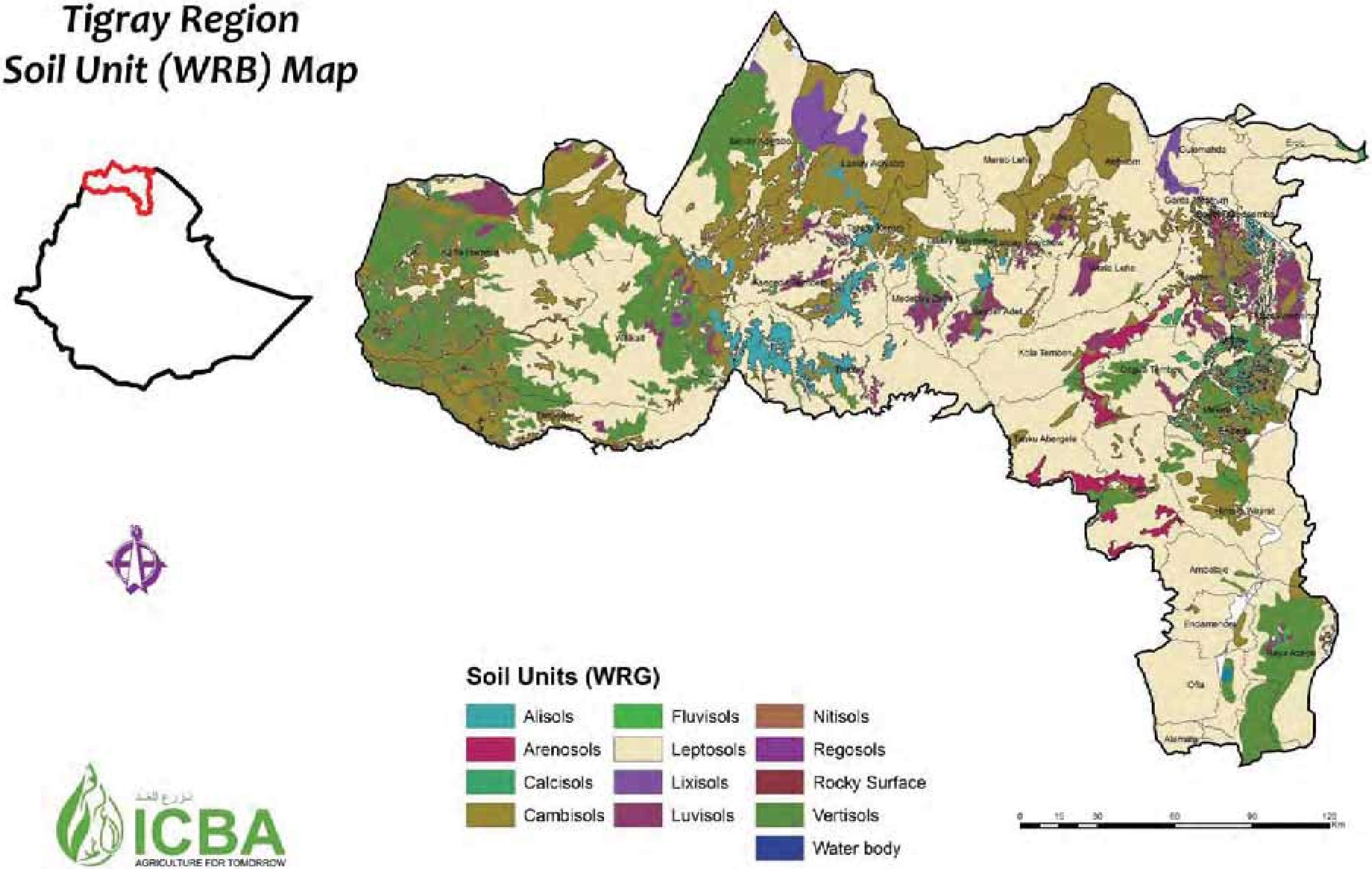
Oromia Region
Surface Soil Salinity Map



ICBA
AGRICULTURE FOR TOMORROW


Oromia Region
Soil Unit (WRB) Map
Soil Units (WRB)
Acrisols
Alisols
Andosols
Arenosols
Calcisols
Cambisols
Chernozems
Fluvisols
Gleysols
Gypsisols
Leptosols
Lixisols
Luvisols
Nitisols
Nosoil_Rocky_lava
Phaeozems
Planosols
Plinthosols
Regosols
Solonchaks
Solonetz
Vertisols
Water Body
ICBA
AGRICULTURE FOR TOMORROW

Tigray Region
Soil Unit (WRB) Map



ABOUT 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. The host country, 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 originally focused on the problems of salinity 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 challenges of income, water, nutrition, and food security. 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 a number of technology developments including the use of 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 the rehabilitation of salt-affected lands. ICBA is 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 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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