Executive Summary

The National Comprehensive Soil Survey (NCSS) Project was conceived by the managers of Boosting Agriculture and Food Security (BAFS) Project and the leadership of Agricultural Engineering Division, Ministry of Agriculture to build upon the outputs of the Land Resources Survey of Sierra Leone at the reconnaissance level (UNDP/FAO, 1979), by providing an inventory of the soil resources at the semi detailed level to enhance the judicious utilization and management of the soil resources, and contribute to sustainable crop production, food security and protection of the environment.

The survey area covers Kono district, which is in the Eastern Region, and borders the Republic of Guinea to the northeast and southeast, Koinadugu district to the north and northwest, Tonkolili district to the west, Kenema district to the southwest and Kailahun district to the southeast. The district is comprised of 12 chiefdoms including Toli, Sandor, Lei, Gbense, Kamara, Mafindor, Gbane Kandor, Soa, Fiama, Tankoro, Nimikoro and Gorama Kono chiefdoms. Its capital and largest city is Koidu.

The climate is tropical with two distinct seasons: the rainy season (May to October) and dry season (November to April). The annual rainfall is high, ranging from 3000 mm in Toli and Mafindor chiefdoms in the northeast and northwest to 3680 mm in Gorama Kono, Nimiyama and Sandor chiefdoms in the southwest. Rainfall distribution is unimodal, with about 95 % of the total annual rainfall occurring in the months of July, August and September, but a peak in August.

The geology is dominated by granite migmatite complex of the Archean basement. Also associated with the geological formation is the deposition of the Tingi of the Granitic Massifs, Gori hills of the Supracrustal schist belts.

Following an initial literature review, remotely sensed and Geographic Information Systems (GIS) data were downloaded and consolidated into basemaps. Field surveys were conducted to establish the relationship between soil types and landscape units, based on the *catena* approach and Food and Agriculture Organization (FAO) Guidelines for soil description (FAO, 2006). Samples from representative soil profiles located along toposequences were analyzed at the Njala University Quality Control Laboratory (NUQCL) using standard soil analysis methods (ISRIC/FAO, 2002). Soil units were mapped using a GIS algorithm based on a Digital Elevation Model (DEM) and knowledge of soil-landscape relationship. Soils were evaluated for their suitability to support the optimal growth of 19 crops targeted by MAFS. These crops included rice, maize, cassava, sweet potato, groundnut, cowpea, onions, carrot, cabbage, tomato, Robusta coffee, Arabica coffee, cacao, oil palm, cashew, mango, pineapple, citrus and bananas using a rating system based on the Ojanuga modified FAO Guidelines for Land Evaluation (FAO, 1976; revised 2007).

The results of the survey, soil analyses and interpretations are presented in:

A district soil report setting out:

- The geographical context
- The survey methodology
- Soil profile descriptions and their physicochemical properties
- A district soil map at 1:500,000 (digital and hard copy versions)
- Soil capability classification and suitability ratings for each soil type on the soil map
- District statistics on arable land, land capability, soil suitability for major crops, soil fertility
- Challenges, opportunities, risks, and implications for agricultural development

The results of the survey show that three main soil associations exist in the district, namely, 1) Madina-Bandajuma soil association, which accounts for 905.6 km^2 (17.9%), 2) Segbwema-Baoma soil association, which accounts for 547.6 km^2 (10.3 %), and 3) Mokonde-Gbeika soil association, which accounts for 1942.1 km^2 (36.5 %). The Gbeika soils occupy the largest area (1172.4 km^2), followed by Mokonde (769.7 km^2), Bandajuma (597.1 km^2), Baoma (439.3 km^2), Madina (353.6 km^2) and Segbwema (108.3 km^2).

Arable land area covers 3440.3 km^2, which accounts for 64.6 % of the district land surface area, and the remaining area, 1884.6 km^2 (35.4 %) is non-arable. The land capability assessment reveals that soils of Baoma and Gbeika series, which account for about 1611.7 km^2 (28.2 %) of the total area belong to Class I. These have very few minor limitations relating to fertility, especially soil acidity. The soil of Segbwema and Bandajuma series, which account for 705.4 km^2 (13.2 %) belong to Class II. These soils are limited by one or more of factors such as poor soil structure and workability, and requirements for moderate conservation practices to prevent deterioration. The soils of Mokonde series, which account for 769.7 km^2 (14.5 %) belong to Class III and those of Madina series, which cover 353.6 km^2 (6.6 %) belong to Class IV. The Class III soils have moderate limitations for agricultural land use due to slope and erosion, while those of Class IV have somehow moderate to severe limitations of slope and erosion, and therefore have limited use for agriculture but alternatively, can be used for agri-horticulture and silvipasture systems.

Soil suitability analysis indicates that Gbeika soils are highly suitable (S1), and Baoma and Mokonde soils are moderately suitable (S2) for rainfed upland rice. For major food crops, Segbwema, Baoma, Mokonde, and Gbeika soils are highly suitable (S1) for cassava, sweet potato and groundnut; and Madina, Bandajuma, Segbwema, Baoma, Mokonde, and Gbeika soils are moderately suitable (S2) for cassava, maize, sweet potato, groundnut and cowpea. For tree crops, Baoma, Mokonde, and Gbeika soils are highly suitable (S1) for cocoa, cashew and oil palm; and Madina, Bandajuma, Segbwema, Baoma, Mokonde, and Gbeika soils are moderately suitable (S2) for cocoa, Arabica coffee and cashew. For fruit crops, Segbwema, Baoma, Mokonde, and Gbeika soils are highly suitable for pineapple and banana, and Madina, Bandajuma, Baoma, and Mokonde soils are moderately suitable (S2) for mango, citrus and banana. For vegetables, Gbeika soils are highly suitable for tomato, while Madina, Bandajuma, Segbwema, Baoma, Mokonde, and Gbeika soils are moderately suitable (S2) for onion, tomato, cabbage and carrot.

Priorities for soil management in the district should mainly target increasing and maintaining soil fertility through liming of those soils which are of high acidity, correct application of fertilizers and organic materials based on soil tests and also location-specific soil conservation practices, especially for soils located on hills and steep slopes. The investment strategy should include the conduct of trials on farmers' fields on benchmark sites and scaling up of proven agronomic and cost-effective climate smart agriculture technologies. Terrace level practices and land cover management involving growing of cover crops, agroforestry and holistic watershed development and management should be promoted in erosion-prone areas such as hills and steep slopes.

1 Overview of soil surveys and land evaluation in Sierra Leone and project context

1.1 Brief history

The history of soil surveys in Sierra Leone dates to British Colonial Times. Ojanuga (2008) reported that soil maps (without report) produced prior to 1928, were available at the time of his work in the Forestry Department of the Ministry of Agriculture, Forestry and Food Security. The European Union funded Boosting Agriculture and Food Security Project commissioned a stocktaking to serve as input for the integration of information from previous soil surveys into a unified soil information framework. The report (Rhodes, 2020) briefly presented information obtained from national and regional surveys conducted between 1951 and 2019, for which information was available, at scales ranging from reconnaissance to detailed. The United Nations Development Program (UNDP) and the Food and Agriculture Organization (FAO) of the United Nations sponsored or conducted the most nationally spread surveys. A few district level surveys covering large areas of land were also conducted by FAO and Njala University in the northern, southern, and eastern regions. The private sector has also funded several detailed soil surveys in various parts of the country.

Key information in the stock taking report were summarized in terms of geographic coordinates, size of area surveyed, scale, basis of grouping soil units, mapping units, classification system and land appraisal for crop production. Landform, gravel content and drainage were the most frequent basis for grouping land/soil units. Land suitability ranged from those with no or moderate to slight limitation for a given crop to lands having limitations so severe as to preclude any possibilities for a successful sustained use for a given crop.

Three major soil descriptions and surveys that have greatly influenced national development plans, research and extension work in soils are Odell et al. (1974), UNDP/FAO (1979), and Ojanuga (2008). Following up on the delineation of 16 soil provinces based on physiography, parent material and drainage by Dijkerman (1969), Odell *et al*. (1974) reported on the properties of soils in specific areas in 5 out of 6 soil provinces. Detailed soil profile descriptions and physical and chemical and mineralogical data were presented for 44 soil profiles representing 34 soil series. A detailed soil map of the Njala Area and Soil Association maps of the Torma Bum, Makeni, and Kenema areas were produced. The soils were classified in progressively decreasing order of importance as Ultisols, Inceptisols, Oxisols, Entisols, and Spodosols in the USDA system. Many of the Ultisols and Inceptisols have oxic properties. In the FAO/UNESCO system, they were classified as Nitosols, Cambisols, Ferralsols and Gleysols.

For soil fertility management, they grouped the soils into three main classes, namely, (i) well drained and aerated soils that occur on uplands, colluvial footslopes and terraces; (ii) poorly drained soils without excess sulphur along the major streams, in the bolilands and inland valley swamps and along the coast and (iii) tidal swamp soils high in sulphur. They also provided brief guidelines on the adaptation and management of these soils with a focus on rice, maize, and plantation crops.

UNDP/FAO (1979) conducted a reconnaissance survey of land resources in Sierra Leone and produced a soil map of Sierra Leone at a scale of 1:2,000,000 based on the FAO/UNESCO soil map legend. The map shows 12 soil associations based mainly on quantity and type of gravel in the upland soils and the degree of hydromorphism in the valley bottom soils. Because of the generalized nature of the survey and the resulting small-scale mapping, the legend units were broad. A major output of the project was a Land System map at a scale of 1:500,000. A Land System is an area of land with recurring pattern of landforms, climate, vegetation, and soils.

The UNDP/FAO 1979 reconnaissance survey of land resources in Sierra Leone describes the typical range in soil characteristics found under 44 landscape units, defined as “land systems”, named after a typical location in the country, and grouped under 12 sub-regions and 4 main regions (Figure 1 and Table 1).

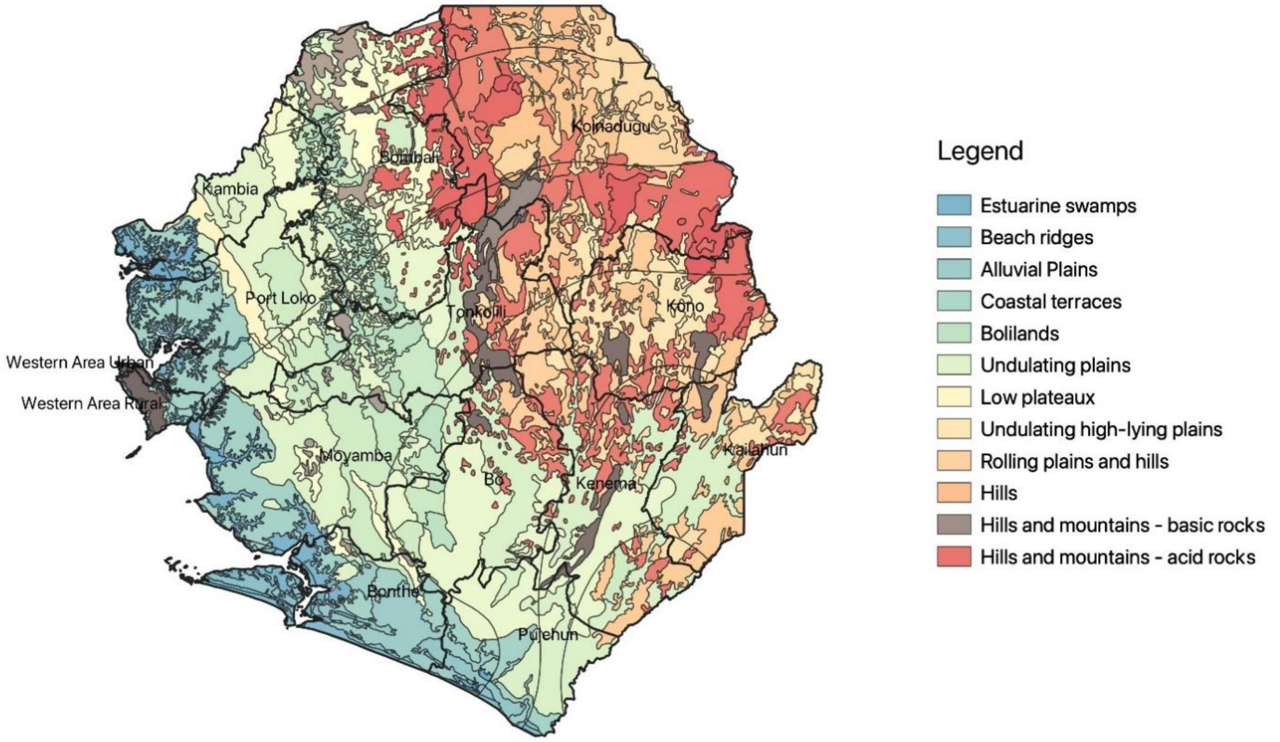

Figure 1. *Land systems map of Sierra Leone (Adapted from UNDP/FAO, 1979)*

Table 1. *Land regions, sub regions and systems of Sierra Leone presented and described in the 1979 Reconnaissance Survey of Sierra Leone (Adapted from UNDP/FAO, 1979)*

Regions	Sub-regions	Land Systems
Coastal Plains	Estuarine swamps	Scarcies, Tasso
	Beach ridges	Turner, Sherbro, Bonthe
	Alluvial plains	Torma Bum
	Coastal terraces	Newton, Hastings
Interior plains	Bolilands	Mabole, Senehun, Rokel
	Undulating plains	Njama, Lunsar, Laia, Blama, Moyamba, Yonibana, Bo, Wari, Borompo, Makundo, Kawakwie, Kamabai
	Low plateaux	Port Loko
Plateaux	Undulating high-lying plateaux	Musaia, Wadu, Koidu, Kailahun, Kombile, Kamaron
	Rolling plains and hills	Bendugu, Sandaru
	Hills	Kabala, Haffia
Hills and Mountains	On basic and ultra-basic rocks	Saionia, Kasewe, Sula, Kangari, Regent
	On acid rocks	Quantamba, Kulufaga, Saiama, Tonkolilini, Loma

The range of soil characteristics found within the 1979 land systems map can be very wide; ranging from well drained shallow soils on hill tops to poorly drained deep soils in the valleys contained within the mapping unit. The goal of the UNDP/FAO (1979) report was to serve as guide for more detailed surveys for investment in commercial agriculture. While the government is promoting these kinds of surveys, it also recognizes the need for paying attention to small holder farmers at the district level. The 44 Land Systems delineated by UNDP/FAO (1979) formed the basis for carrying out the field work of the National Comprehensive Soil Survey (NCSS).

To aid land use planning for optimizing agricultural production, Ojanuga (2008) carried out detailed soil surveys of select areas in 3 districts of Sierra Leone, namely, Falaba within the Moyamba District (Moyamba Land System), Magbafti within the Koya Rural District (Newton Land System) and Rolako within the Bombali District (Bo Land System). He produced soil maps, soil suitability ratings for arable crops, agroforestry & forestry for the Falaba area and identified land management units based mainly on position on the toposequence in each of these areas. One of the recommendations made was that Sierra Leone should embark on semi-detailed land resources surveys, including soil, water, biological materials, and climate.

Kono district has attracted quite a good number of soil surveys at the detailed levels mainly targeting tree crop such as cocoa, coffee and oil palm. Soil surveys conducted by Sivarajasingham (1968) and Stark (1968) are evidences of earlier soil surveys undertaken in the district. The four major landscapes identified in the mapped areas were steep slopes and hills, upland erosion surfaces, and colluvial footslopes and terraces Madina, Bandajuma, Segbwema, Baoma, Mokonde and Gbeika series. The semi-detailed soil survey work of Veldkamp (1980), Sutton et al (1980) and Odel et al (1980) further revealed similar soil types and characteristics.

1.2 Project context

1.2.1 Country background

Sierra Leone is in the humid region of West Africa, with a land area of 72,300 km^2, and a population of 7,541,641 at a growth rate of around 2 percent (STATSL, 2022). Based on the human development index (HDI) published in 2016, Sierra Leone was ranked 183rd out of 195 countries (2021/22 UNDP Human Development Report). The Sierra Leone Multi Cluster Survey of 2017 reported 64.8 percent multidimensionally poor people taking into consideration, health, education, living standards, housing, and energy. The Sierra Leone 2018 Integrated Household Survey found 56.8 percent of the people to be monetary poor and 12.9 percent extremely monetary poor. Agriculture is the backbone of the economy and therefore, its development is of strategic importance. However, smallholder farmers exhibit limited agricultural productivity, which makes their dominance in staple crop production mainly for subsistence with rarely any surpluses for sale.

Sierra Leone's current economic and social situation has been shaped by four events in the last three decades: the civil war (1991-2002), the Ebola Virus Disease (EVD) (2014-2015), and more recently the COVID 19 pandemic of 2020 and the Russia-Ukraine war of 2022. The civil war and social unrest years caused a severe economic decline that virtually destroyed the physical and social infrastructure of the country, leading to widespread poverty and over 50,000 human deaths with 1 million both internally and externally displaced. The EVD outbreak that occurred in 2014 worsened the country's development indicators, killing about 3,461 people (WHO, 2015) and further bringing down the whole economy. The Russia-Ukraine war has resulted in sharp rises in price of imported commodities and the downgrading by the IMF of the 2022 growth projection from 3.4 percent in April to 2.4 percent in October 2022.

1.2.2 Government policies and plans, Sierra Leone soils, and the NCSS

The Government of Sierra Leone’s Medium-Term National Development Plan 2019-2023 states that improving the productivity and commercialization of the agriculture sector and the protection of the environment is of high priority. The Ministry of Agriculture and Food Security (MAFS) has a National Agricultural Transformation (NAT) Plan 2019-2023, emphasizing management of the natural resources, site-specific management for fertilizer applications involving soil analysis, increased production, and productivity of the priority crops (rice and other cereals, cocoa, coffee, cashew, oil palm, vegetables, legumes, roots and tubers, and spices). The more recent policy orientation of MAFS-NAT 2023 brought out a strategic intervention of relevance to the NCSS, that is, ‘Data systems for evidence-based policy making: with output of countrywide agricultural land use zoning and area specific soil surveys carried out using Information Communication Technology (ICT) and innovative data tools leading to an updated map of the soils of Sierra Leone’. The development of the agriculture sector from the current level of low production and productivity of food and cash crops and the management of the soil resources, in transition from a system of bush fallow rotation in the uplands (associated with deforestation and release of greenhouse gases into the atmosphere) to diversified sustainable commercial farming would therefore contribute to the expressed vision and plans of government.

Increasing anthropogenic interference and climate change impacts are causing unprecedented soil degradation affecting the capacity of the soil resources in Sierra Leone to carry-out their functions sustainably. Additionally, soil characteristics and properties are key inputs for assessing erosion, land use suitability and hazard susceptibility analysis, particularly with respect to land use potential, which ultimately provide data to guide long and short-term development and investment decisions.

It is well known that soils of Sierra Leone are highly weathered low activity-clay soils (LACS); they are quite acidic and macro and micronutrient levels in the soils are generally low. There are however gaps in information on their properties and related natural resources because all national soil surveys in the past were done at the reconnaissance level (Dijkerman, 1969; UNDP/FAO, 1979). Given the dynamic nature of soils compounded by climate change, these resources are bound to have undergone pedogenic changes over the past 40 years. These studies did not map the spatial variability of soil fertility and evaluate the status of micronutrients. In the light of all these issues, there is an urgent need for an updated and comprehensive national soil survey for Sierra Leone and the drafting of a strategy for guiding sustainable soil management.

The European Union (EU) being a key supporter of the agriculture and food security sector of Sierra Leone has provided funding for the Boosting Agriculture and Food Security (BAFS) Programme in Sierra Leone. The programme is implemented through MAFS and covers the fifteen agricultural districts in the country. BAFS is the follow-up to the recently completed Agriculture for Development (A4D) programme, funded under the 10th European Development Fund.

Among its many supports to agricultural projects in MAFS, BAFS provided funding to the Agricultural Engineering Division (AED) to conduct a national comprehensive soil survey at the semi-detail level, four times the scale larger than that of the UNDP/FAO 1979 survey. This soil survey consists of a set of specific sub-activities that include (i) provision of material support for specialized laboratories at Njala University and the Sierra Leone Agricultural Research Institute (SLARI), in the form of procurement of specialized laboratory equipment and chemicals; (ii) field morphological description of representative soil profiles along toposequences; (iii) collection and analysis of soil samples; (iv) staff training and logistical support for the AED-MAFS. These set of activities would result in improved access to data, generation of comprehensive soil and land use maps, and soil fertility and land suitability information.

1.2.3 Overall and specific objectives of NCSS project

The overall objective is to conduct a national comprehensive soil survey and generate information for the judicious utilization and management of the soil resources aimed at sustainable crop production in Sierra Leone: The specific objectives are to:

(i) update maps of the agro-climatic/vegetation regions and rice agro ecological zones (ii) establish and map soil fertility management zones; (iii) identify, characterize and map soil types at the semi detailed level and determine land suitability for major crops; (iv) identify, characterize and map major soil types in the lowland rice growing agro-ecologies at the detailed level; (v) strengthen the capacity of staff of the Agricultural Engineering Division of MAFS to undertake soil surveys, interpret soil survey reports and make recommendations on land use and management; (v) enhance the capacity of the NU and SLARI laboratories for producing reliable data for making soil management recommendations; (vi) enhance the capacity of NU and SLARI for remote sensing/GIS work, and (vii) develop a framework for a national strategy on soil management. The expected impact of the project is a contribution to food security improvement, poverty reduction and minimization of environmental degradation in Sierra Leone.

1.2.4 Target groups and final beneficiaries of NCSS

According to the service contract between the National Authorizing Office (NAO) and Njala University, the target groups of the NCSS are Njala University, SLARI, the AED and policy makers of MAFS. Njala University is the leading university in Sierra Leone for agriculture and related environmental sciences. Its mandate is research, teaching, and extension. It has a School of Agriculture and Food Sciences (SAFS) in which the Department of Soil Science is located, a School of Environmental Sciences and a School of Natural Resources Management among other related Schools.

SLARI is responsible for conducting, on behalf of MAFS, agricultural research on crops and livestock through its seven research centers. One of its centers, the Njala Agricultural Research Centre (NARC) is based on the Campus of Njala University. There is close collaboration between NU and SLARI, in research, teaching, and extension.

The AED of MAFS took over some of the functions of the defunct Land and Water Development Division (LWDD) of MAFS. Among other activities, LWDD was involved in the development of swamps and other lowlands for intensified cropping in the rainy and dry seasons.

The final beneficiaries are farmers, traders, consumers, and the nation at large. Most of the population of Sierra Leone are involved in agriculture, predominantly small-scale rainfed subsistence farming. There are also a few large-scale commercial farming enterprises. The traders consist of itinerants, wholesalers, retailers of food crops and exporters of produce of cash crops. The consumers are in rural and urban areas; while the former produce part of their own food, the latter purchase food produced by the former. In the context of a rapidly increasing urban population, rural food production must keep pace with urbanization to avoid a food crisis in the country.

2 How to use this report

This section explains to readers how the soil survey report of the Kono District has been structured with a brief description of the information that can be found in each section (Table 2). The report represents one of a range of NCSS outputs and it is intended specifically for agricultural policy makers, extension officers, university research and teaching staff, research staff of SLARI, farmers, the private sector who seek information about the physical and chemical characteristics of soils at district level.

Table 2. *Soil survey report structure and general guidelines for use of district soil maps and reports*

Sections	Description
Executive summary	Provides an overview of the main soil forming factors, soil types, crop suitability, main limitations and how they can be overcome.
Section 1	Gives a brief history of soil surveys and the project context.
Section 2	Provides a general structure of the soil survey report and the information contained therein.
Section 3	Provides details about the main soil forming factors in the district, i.e., climate, geology, landscape, vegetation, land use and socioeconomics, along with their maps where appropriate.
Section 4	Describes the methods used to conduct the soil survey, study the soil profile pits, determine land capability and evaluation of soil suitability. The outcomes of the latter three activities are provided in the form of maps (soil maps, land capability maps and soil suitability maps for crop targeted by MAFS.
Section 5	Provides detailed information for each soil type identified on the soil map. This includes: (i) How soil types relate to the landscape – this allows users to identify possible ranges in soil characteristics across the landscape of interest including likely inclusions of neighboring soil types. (ii) How soil types correlate with international soil classifications, which allows comparisons with soils elsewhere. (iii) Typical soil surface features, such as stoniness, slope, vegetation, and land use. (iv) Typical (ranges of) physical soil characteristics, such as soil texture, drainage, soil depth, risk of flooding, gravel content. (v) Typical (ranges of) chemical soil characteristics, of topsoil and subsoil, such as soil organic carbon, available phosphorous, soil pH, Al saturation, cation exchange capacity (CEC), base saturation, exchangeable cations (Ca, Mg, K), and micronutrients (Fe, Cu, Zn).
Section 6	Provides detailed information for each soil mapping unit about: (i) the land capability evaluation of Bonthe District into arable and non-arable land and the main land degradation risks and how they can be overcome. (ii) the soil suitability evaluation and the main soil limitations attached to each soil type and how these can be overcome.
Section 7	Provides general information on soil fertility management, land degradation risks and the development of a national strategy for integrated soil fertility management.
Section 8	Provides detail information on soil fertility management strategies for the different soil types for sustainable use.

3 Geographical context

3.1 Location

Kono District is located on Longitude -10.475°W to -11.389°W and Latitude 8.311°N to 9.086°N in the Eastern region of Sierra Leone. It is bordered by the Republic of Guinea to the northeast and southeast, Koinadugu district to the north and northwest, Tonkolili district to the west, Kenema district to the southwest and Kailahun district to the southeast. The district has a geographical area of about 5,5304.5 km^2 and is comprised of 12 chiefdoms including Toli, Sandor, Lei, Gbense, Kamara, Mafindor, Gbane Kandor, Soa, Fiama, Tankoro, Nimikoro and Gorama Kono chiefdoms (Figure 2). Its capital and largest city is Koidu. The district accounts for 7.1% of the country's population, amounting to 506,100 (STATSL, 2017), and is predominantly belonging to the Kono ethnic group. The district is very rural, and most of its inhabitants are settled in small villages usually with fewer than 200 heads. The district is recognized as having the highest quantities of mineral deposits especially diamond but ironically, it's one of the poorest districts in Sierra Leone, and also one of those hardest hits by the long civil war (1991-2002), which was deeply rooted in poverty, injustice, corruption and socio-political marginalization. The economy of the district is largely based on agriculture and mining.

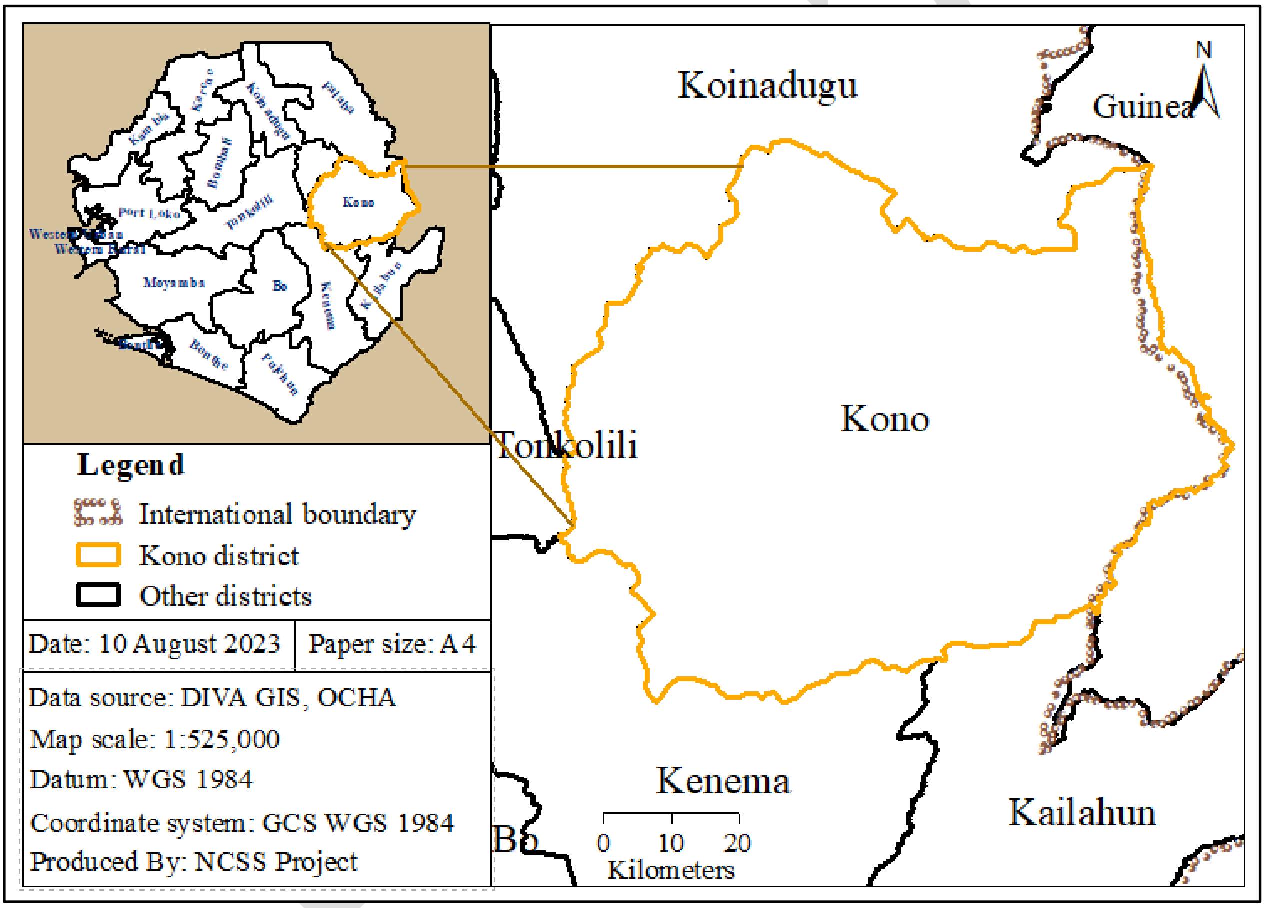

Figure 2. *Location map of Kono District*

3.2 Climate

The climate is tropical with two distinct seasons: the rainy season (May to October) and dry season (November to April). The annual rainfall is high, ranging from 3000 mm in Toli and Mafindor chiefdoms in the northeast and northwest to 3680 mm in Gorama Kono, Nimiyama and Sandor chiefdoms in the southwest (Amara *et al*., 2020) (Figure 3). Rainfall distribution is unimodal, with about 95 % of the total annual rainfall occurring in the months of July, August and September, but a peak in August. Rainfall distribution is unimodal, with about 95 % of the total annual rainfall occurring in the months of July, August and September, but a peak in August. Air humidity is generally high, ranging between 95–100 % during the rainy season, but may drop to as low as 20 % during the Harmattan. The average monthly temperature ranges from around 31.21°C to 32.13°C during the year but may rise to a maximum of 36°C especially in March (Figure 4). The number of sunshine hours per day varies from 6 to 8 in the dry season, and from 2 to 4 during the rainy season. The agro-climatic zone (ACZ) and agro-ecological zone (AEZ) maps of the district are shown in Figures 5 and 6, and this is further depicted in Tables 3 and 4.

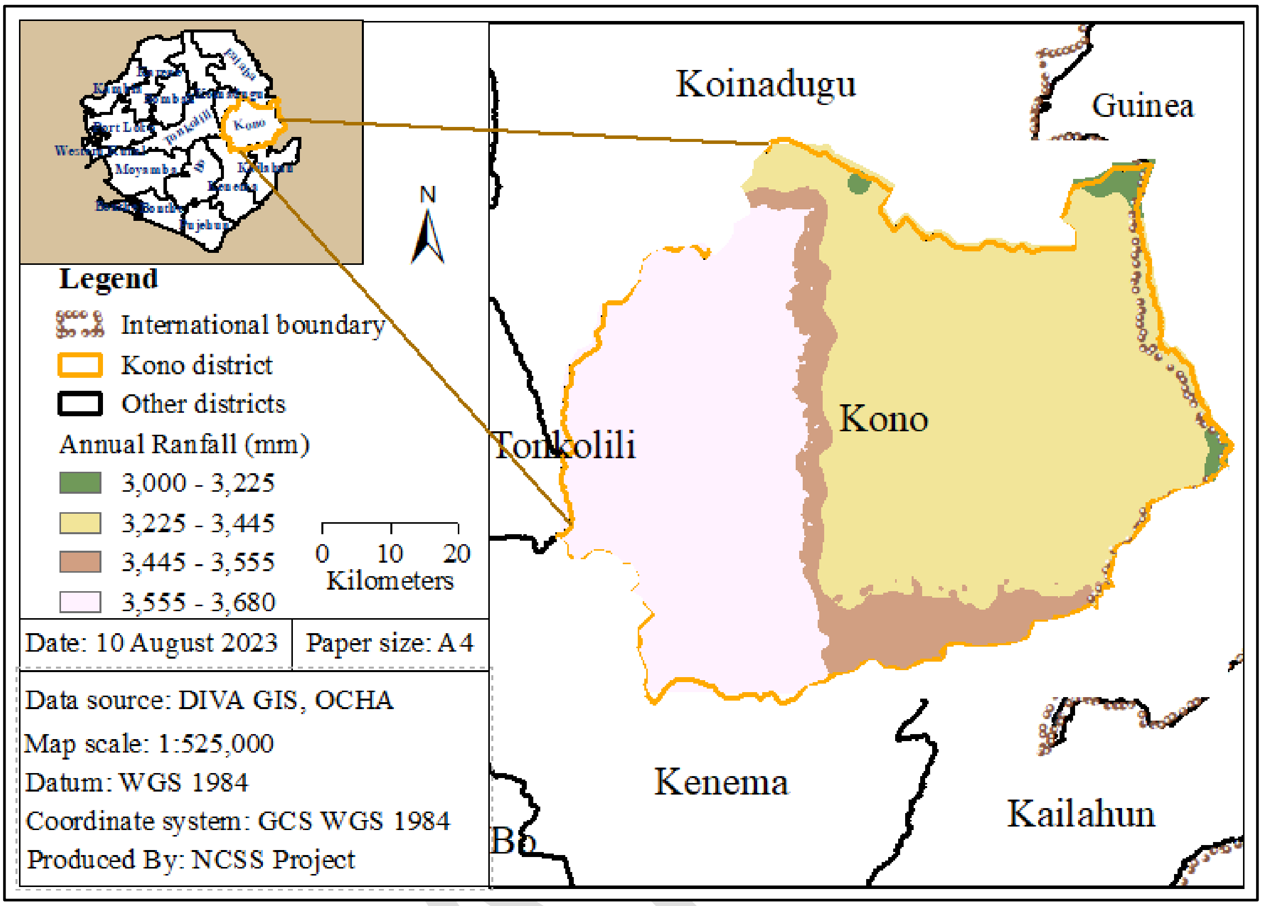

Figure 3. *Annual Rainfall distribution in Kono District (2021)*

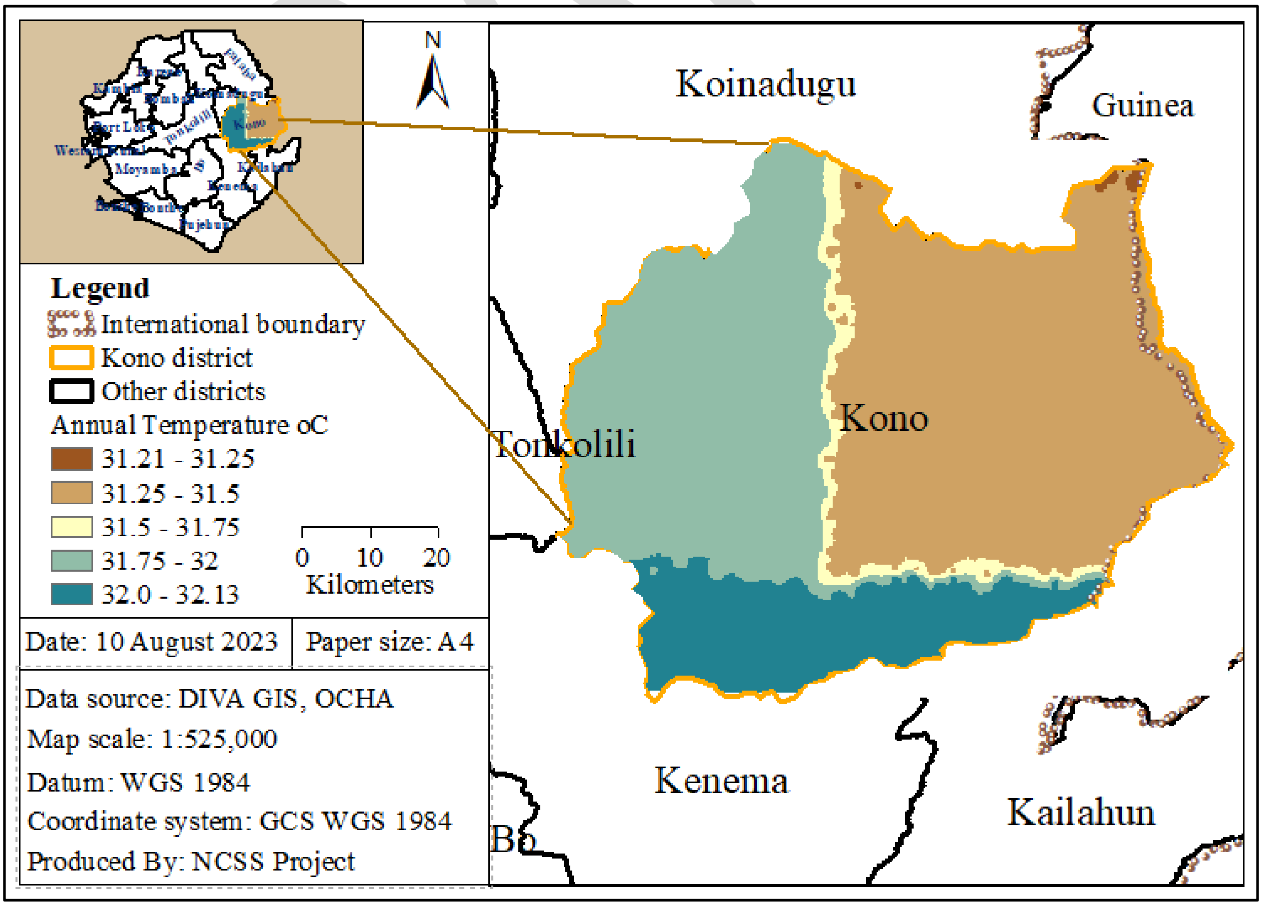

Figure 4. *Annual Temperature distribution in Kono District (2021)*

Table 3. *Characteristics of the agro-climatic regions of Sierra Leone (Adapted from UNDP/FAO 1979; MAFFS/MFMR 2004)*

Regions	Area (km2)	Dominant landform	Altitude (m)	Average temperature (°C)	Average annual rainfall (mm)	Average length of growing period (days)	Dominant vegetation
Coastal Plains	11,016	Estuarine swamps, alluvial plains, beach ridges and coastal terraces	<150	27.9	3000	260 ±10	Mangrove swamps and grassland
Savannah woodland	27,993	Drainage depressions, undulating plains, low plateau and hills	150-300	28.2	2280	255 ±10	Lophira, savannah woodland, mixed tree savannah, upland grassland and forest regrowth
Rainforest/ savannah	20,712	Plateaus with undulating high-lying plains, low plateaus and hills	150-300	28.5	2730	270-300	Savannah woodland, montane grassland and forest regrowth
Rainforest	12,579	Plateaus with undulating high-lying plains, rolling plains and hills	300-600	28.6	2660	314 ±9	Forest and forest regrowth
Hills and Mountains	14,725	Highly dissected hill ridges	>600	-	-	-	Montane grassland and upland grassland

Table 4. *Characteristics of the agro-ecological zones of Sierra Leone (Adapted from Verheye 1997)*

Zones	Location of representative meteorological station	Length of growing period (days)	Start of growing period	Rainfall (mm)	Length of humid period (days)	Length of dry season (days)
A	Daru	>300	Third decade of February	2500-3000	>240	<70
B	Bonthe	230-270	First decade of March	>3000	230-270	100-120
C	Newton	230-270	First decade of April	>3000	230-270	100-120
D	Bo	270-300	First decade of March	2750-3000	270-300	70-100
E	Yengema	270-300	Second decade of March	2500-2750	230	70-100
F	Kabala	230-270	First decade of April	2000-2500	<210	100-120
G	Makeni	230-270	First decade of April	2750-3000	220	100-120
H	Port Loko	<230	First decade of April	2500-2750	<200	>120
I	Musaia	<230	First decade of April	<2000	<210	>120

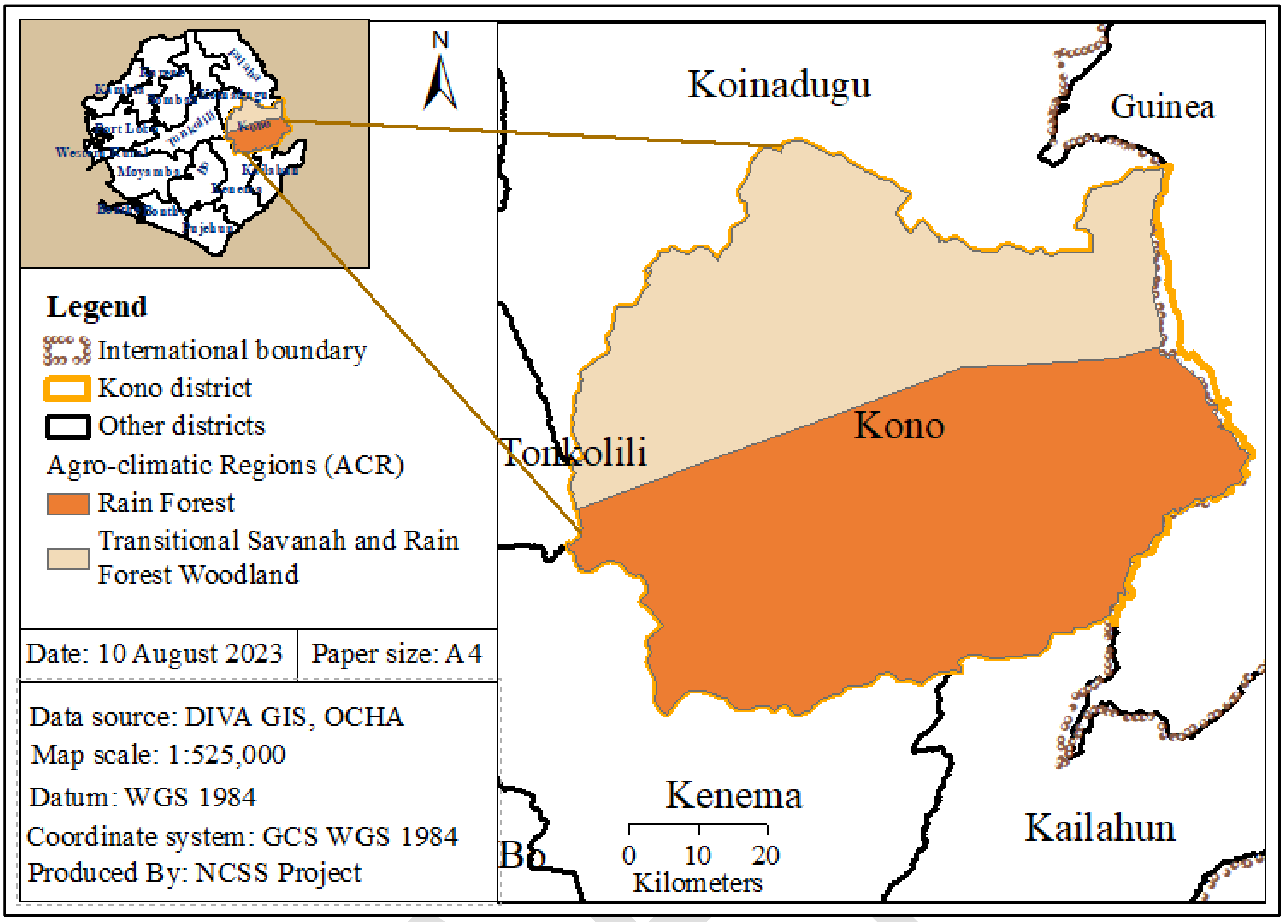

Figure 5. *Agro-climatic regions of Kono District (Adapted from UNDP/FAO, 1979)*

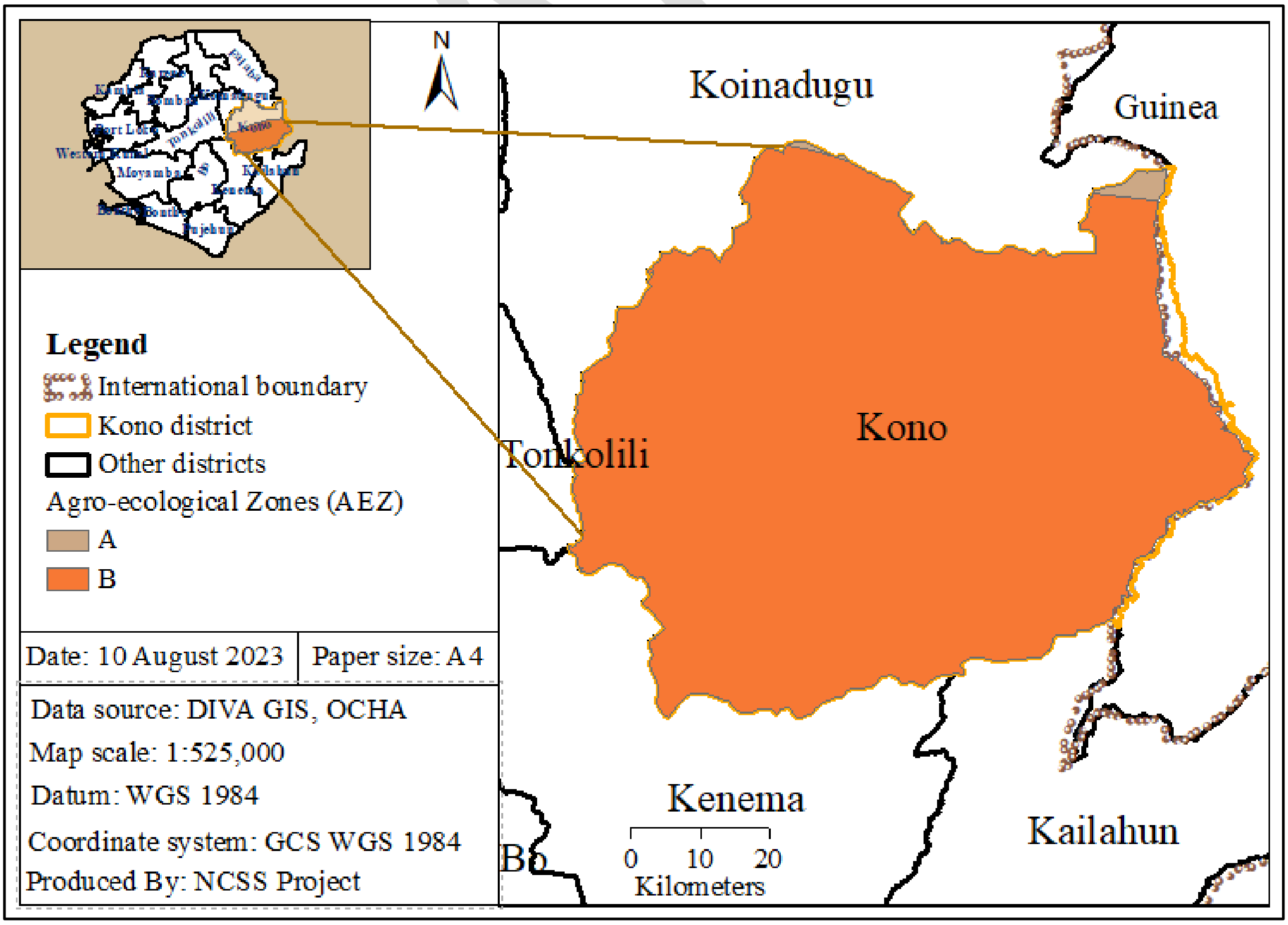

Figure 6. *Agro-ecological zones of Kono District (Adapted from Verheye, 1987)*

3.3 Geology

The geology is dominated by granite migmatite complex of the Archean basement. Also associated with the geological formation is the deposition of the Tingi of the Granitic Massifs, Gori hills of the Supracrustal schist belts. Further details on the geology of the district are given in Table 5 and Figure 7.

Table 5. *Geology of Kono District (Adapted from UNDP/FAO, 1979)*

Geology	Area (km^2)
Kambui Group (Lower)	9.8
Kambui Group (Upper)	91.5
Leonean Granite	5049.5
Liberian Granite	254.6

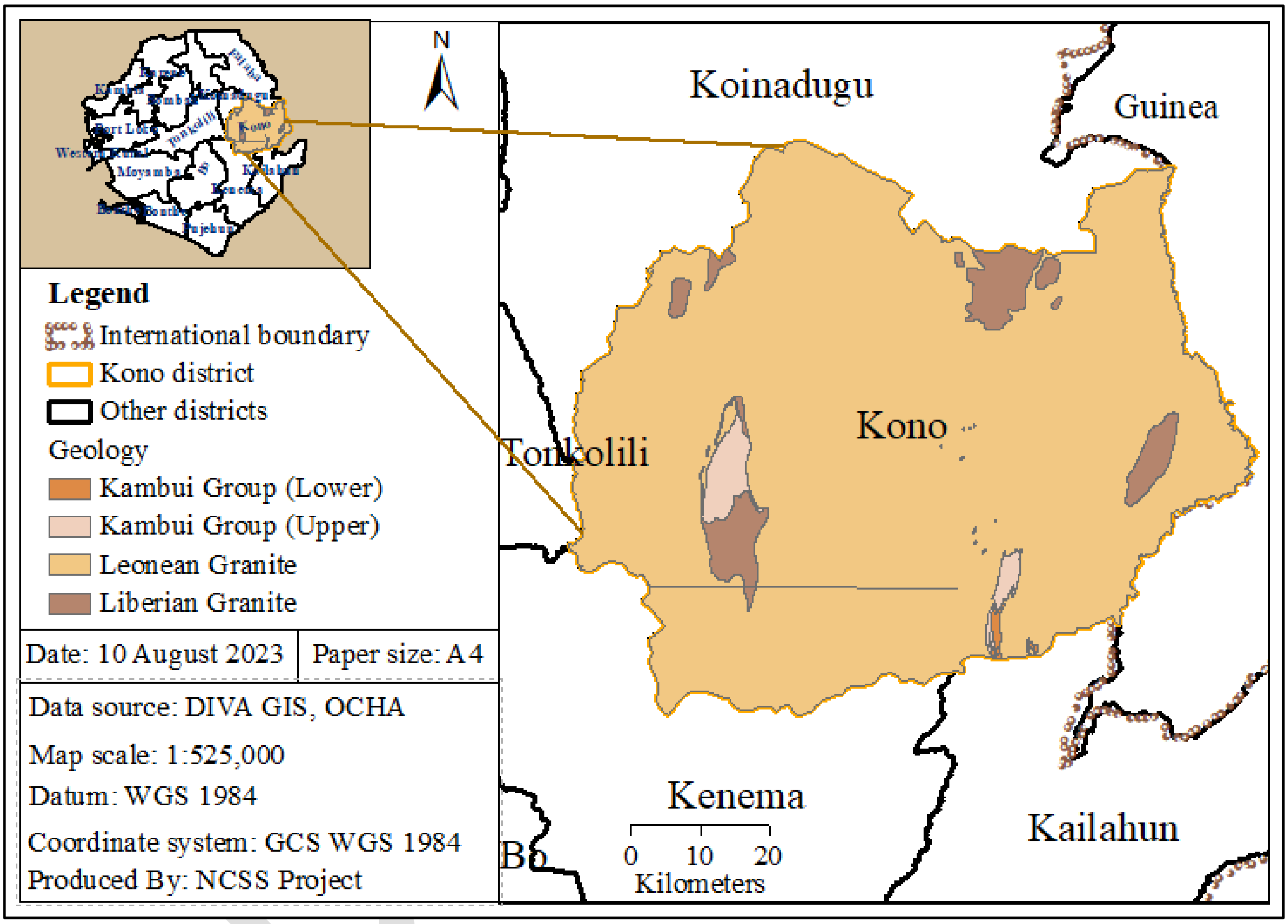

Figure 7. *Geology of Kono District (Adapted from UNDP/FAO, 1979)*

3.4 Land systems

The district is comprised of 10 land systems (Figure 8). A land system is defined as an area, or group of area, throughout which there is a recurring pattern of topography, soils and vegetation (Chriatian and Stewart, 1953). The most extensive of the district are beaches, alluvial plains, coastal terraces and undulating plains. The beaches vary in age and are somehow elongated adjacent to the coastal plains, which causes the deflection of Mano, Moa and Wanjei river. The alluvial plains are grasslands that lie up to 15 m above sea level and much of the area is flooded during the rainy season when the rivers overflow their banks. The coastal terraces are formed on Bullom sediments and lying at elevations between 2 and 40 m. The relatively unconsolidated nature of the sediments has led to an extremely intricate pattern of dissection by minor streams, especially along the seaward margin of the terraces. The undulating plains are formed on a complex of granitic rooks. Typically, slopes are very gentle, the density of narrow swamps increases and very few isolated hills may be seen in the area. Footslope terraces are common. The characteristics of the various land systems are given in Table 6.

Table 6. Characteristics of land systems of Kono District (Adapted from UNDP/FAO, 1979)

Land region	Subregion	Land system	Name	Code	Area (km^2)
Coastal Plains	Beach ridges	Coastal beach ridges	Koidu	3	1417.6
		Inland beach ridges	Kulufaga	4	679.2
		Degraded beach ridges	Sandaru	5	1137.1
	Alluvial Plains	Coastal floodplains	Kangari	6	343.3
	Coastal terraces	Dissected terraces	Kailahun	7	241.2
Plateaux	Undulating high-lying plateaux	Dissected plains with isolated small hills and common terraces	Blama	15	2.8
		Intricately dissected hills with isolated small hills	Wadu	18	616.8
	Rolling plateaux and hills	Variably dissected association of plains and rocky hills	Loma	32	262.7
Hills and Mountains	On basic and ultra-basic rocks	Dissected escarpment and hill ranges	Saiama	38	690.2
Plateaux	Undulating high-lying plains	Complex of plains and terraces associated with major rivers and their tributaries		Musaia	0.3

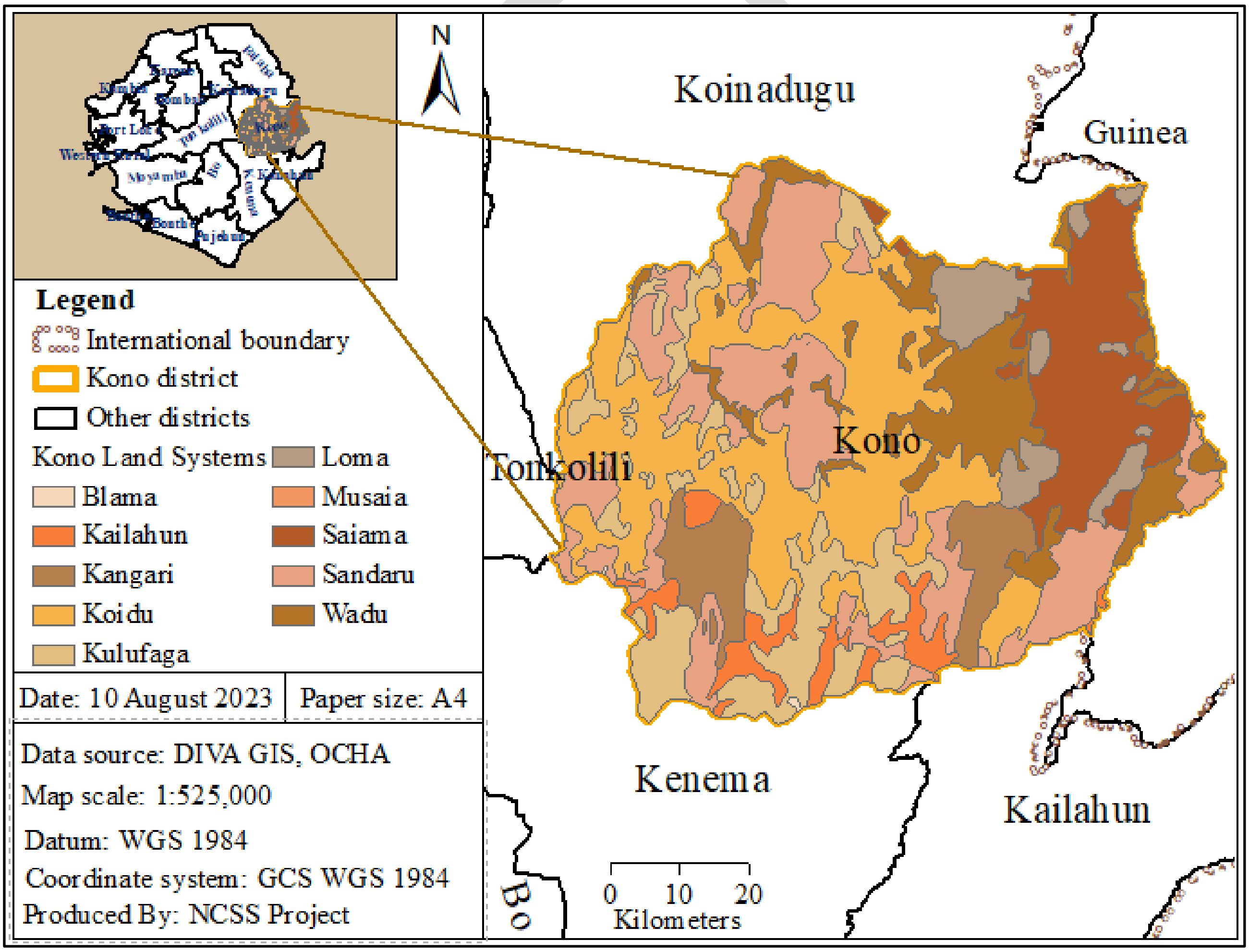

Figure 8. *Land systems of Kono District (Adapted from UNDP/FAO, 1979)*

3.5 Hydrology

The major rivers in the district include Mano, Moa and Wanjei (Figure 9), and these form a network of convergence in the southwest and southeast with their head flowing tributaries from northeast and northwestern peripherals. The Mano. Moa and Sewa rivers contribute the major portion to the district's hydrology. Major streams include mahoi, Yambase, Seye, Waiko, Luye, Wemago, Moawa, Poteye, Kondi, Gogpoh, Malei, Woloye, Senge, Maje, Mawusei, Makung, Yandeye, etc.

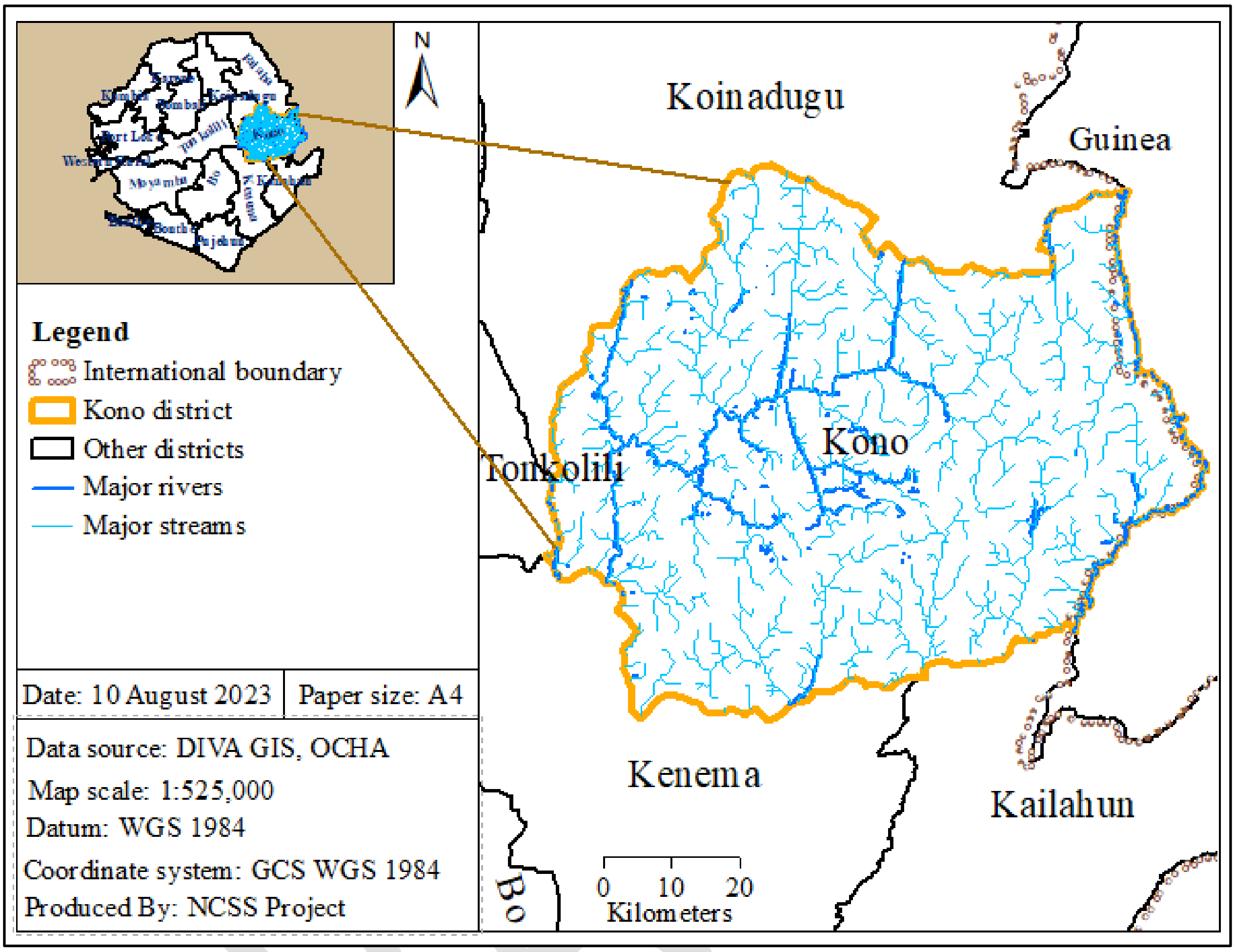

Figure 9. *Hydrology of Kono District (Source: Authors' data analysis)*

3.6 Main soil associations

The soils of Kono district generally vary depending on the agroecology in which they are found but share similar characteristics as those found in Moyamba and Bonthe. The upland soils are generally poor, lateritic and prone to heavy leaching while soils of the lowlands especially the inland valley swamps (IVSs) are more fertile and provide the optimum area in terms of water management and environmental sustainability for agricultural production. Generally, the soils can be grouped into five (5) representative soil types, which include 1) gravel soils, 2) gravel-free over gravel soils, 3) river terrace soils, 4) gravel-free soils and 5) colluvial hydromorphic. These soils occur in five main associations (Table 7 and Figure 10).

Table 7*. Main soil types and associations of Kono district (Adapted from UNDP/FAO, 1979)*

No.	Land region	Area (km^2)
1	Gravelly ferralitic soils over weathered granitic basement or colluvial gravel on southern interior and plateau plains	1720.0
2	Gravelly nodular ferralitic soils over weathered granitic basement on southern interior and plateau plains	617.8
3	Stony and gravelly ferralitic soils over weathered granitic basement or colluvial gravel on low to moderate relief hills	841.9
4	Stony and gravelly ferralitic soils with shallow soils on moderate to high relief hills formed from predominantly acid rocks	1568.7
5	Very gravelly ferralitic soils with shallow soils on moderate to high relief hills formed from basic and ultrabasic rocks	353,4
6	Shallow soils on plateau mountains and lateritic hills and terraces	307.5

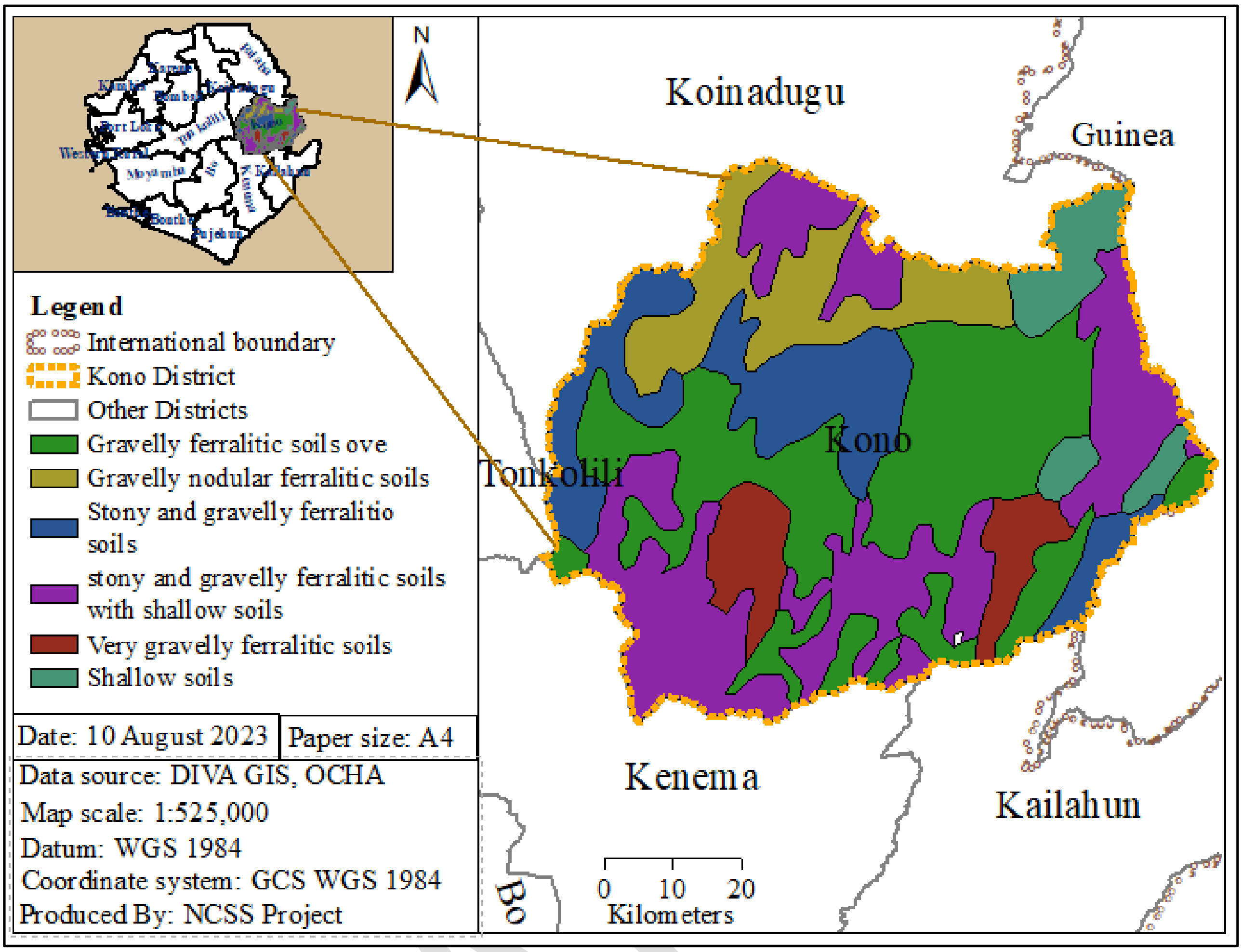

Figure 10. *Main soil associations of Kono District (Adapted from UNDP/FAO, 1979)*

3.7 Vegetation and land use

Eight major vegetation types have been identified in the district (FAO, 2007), among which are closed high forest, secondary forest, forest regrowth, mixed tree savana, montane grassland, upland crops, upland grassland, and rock outcrop (Table 8 and Figure 11). The forest regrowth vegetation is derived from the shifting cultivation pattern of farming that is common in the country. The secondary forest is an elongated generally narrow strip of dense secondary forest cover with widths that vary from place to place along the banks of major streams and rivers. The savannah grassland vegetation mainly comprises of Pennisetum purpurenum (the tall grass species commonly referred to as elephant grass).

Table 8. *Vegetation and land use types of Kono District (Adapted from FAO, 2007)*

Land region	**Area (km^2)**
Closed high forest	631
Secondary forest	425
Forest regrowth	2643
Mixed tree savanna	441
Montane grassland	6
Rock outcrop	55
Upland crops	264
Upland grassland	923

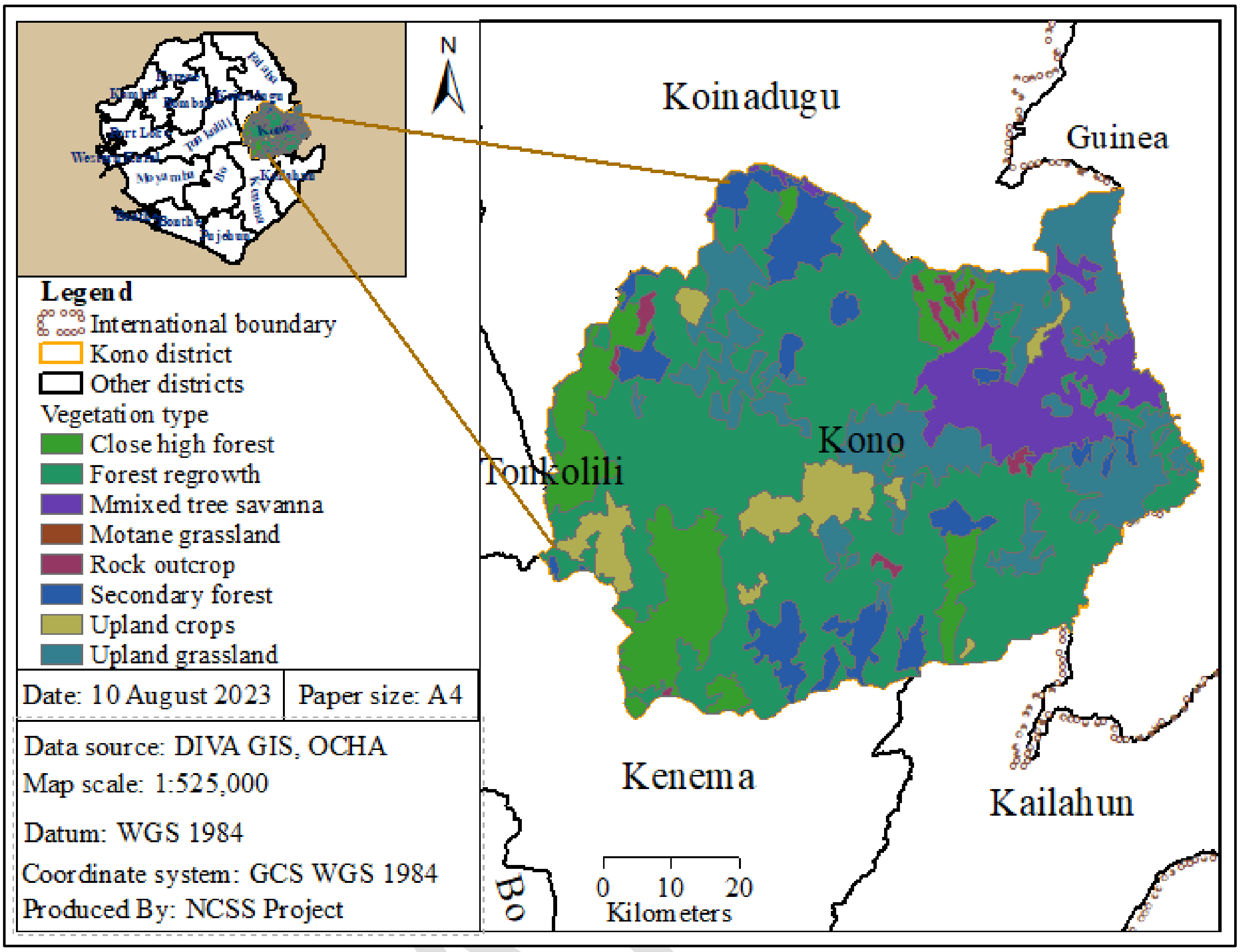

Figure 11. *Vegetation and land use of Kono District (Adapted from FAO, 2007)*

3.8 Socio-economy

The livelihoods are mining and trade, with some portion of the district including the Gorama Kono largely dependent on food and cash crop cultivation. Diamond and gold mining are the most popular livelihoods of a majority of the population. Rice and cassava are the major food crops grown, consumed and traded. Private sector cultivation of tree crops including cocoa, oil palm, and cashew also provide a major employment opportunity in the district especially in Gorama Kono chiefdoms. Both upland and lowland rice are cultivated. These commodities are a primary source of income for most households – either through sales or through employment as farm labor. Plantain and banana are also widely grown but to a lesser extent than rice and cassava, and these play a greater role in the socioeconomic growth of the district.

3.9 Environmental hazards

The district is prone to landslides, flooding, drought, epidemics, tropical storm, thunder & lightning (Mattai, 2017). The frequency of these natural hazards ranges from very rarely (for coastal erosion, storm surge and sea level rise) to rarely (for landslides, drought and epidemics), sometimes (for flooding and tropical storms) and frequently (for thunder and lightning) while the magnitude rages from trivial (for coastal erosion, storm surge and sea level rise) to small (for landslides and thunder & lightening), moderate (for flooding and tropical storms), and very large (for drought and epidemics).

4 Soil survey methodology

4.1 The planning phase of the survey

Prior to the commencement of field work, a soil survey methodology workshop was organized to ensure harmonization of soil survey techniques among the three teams working in different districts. During the same period, all existing soil data of Kenema District were harmonized into a unified framework to allow correlation of previously surveyed and mapped soils with the current soil survey exercise.

The 1979 land system map of Sierra Leone (UNDP/FAO, 1979) was digitized into district maps by the Soil Database and Information System (SDIS) unit of the NCSS project and prepared in both hard copy and .tiff GIS format for use as base maps in planning and conducting the district soil survey. The AED staff of the MAFS district offices led the process of setting the transect lines on the hard copy of the land system map on which the survey team will traverse, using the free (not grid) survey methodology. The MAFS district staff who had computers were encouraged to download the free Google Pro GIS application and were trained on how to overlay the district land system map in .tiff GIS format on their google maps.

4.2 How the survey was conducted

Once the survey team fully understood the survey terrain on google map, including the various locations, communities, landforms, and rivers along/across which the transect line will cross, the coordinates of these geographical locations and the transect points to be examined for digging profile pits and/or auger borings were inputted into the GPS handset. The "Go To" command of the GPS was then activated to guide the navigation of the survey team to the point/place of interest on the transect line.

Two transect lines (Figure 12) were drawn (as close to main motor ways as possible, guided by the experience of the terrain by the local MAFS staff) from west to east of the district map through as many land systems as possible to ensure the systematic observation of the various soils on the landscape elements (summit, shoulder, backslope and toeslope) within each land system polygon. If these soils repeat themselves in the same sequence on the landscape elements for the same land system, irrespective of the district the land system is located, they are identified as a soil association and labelled as a mapping unit. One unique sequence of soil associations constitutes a mapping unit and named by the soils individuals that make up the association. For example, map unit A constitutes X soil series, Y soil series and Z soil series is called the x, y, z soil association.

4.3 Soil profile excavation and soil sample collection

Representative soil profile pits of dimension 2m x 1.2m x 1.5m, were excavated at each landscape position within a land system for detailed morphological description using the FAO (2006) guidelines for soil description (Figure 13). These guidelines for soil description were transformed into a digital format from which a KoboCollect app version was developed and used for field data entry.

Soil samples were collected from each horizon and analysed for physicochemical properties at the Njala University and SLARI soil laboratories following the ISRIC/FAO (2002). To enhance the quality of the results, a 0.1 % number of samples was sent to the IITA Analytical Services Laboratory (ASLab) for validation analysis. The field and laboratory data were used to determine the suitability rating to produce crops selected by MAFS for each identified soil type using the FAO framework for land evaluation (FAO, 1976; FAO, 2007).

4.4 Benchmark soils

High-resolution soil monolith photos taken of a pedon (representative soil profile of a soil type) at the location/district where it was first described in a toposequence within a land system, served as a Benchmark soil for comparing, classifying, naming and discussing any other soils with similar morphology. The concept of benchmark soils speeded up the free survey as it limited the number of profile pits dug for the same soil types. Instead, soil augers were used to make quick excavation to confirm or deny the presence of the same or new soil type and establish the boundary between soil types. The use of benchmark soils also eliminated the confusion of given different names to soils of the same morphology as has been the practice in Sierra Leone when independent surveys were undertaken by soil surveyors in different districts. For example, the Njala series carries the same morphology and landscape position as the Makeni series. For the NCSS project, most of the benchmark soils were first describe in the Moyamba district. Where, soils of the same morphology exist in other districts, they were represented by one benchmark soil photo, but their chemical and morphological properties were recorded, and averages and ranges noted.

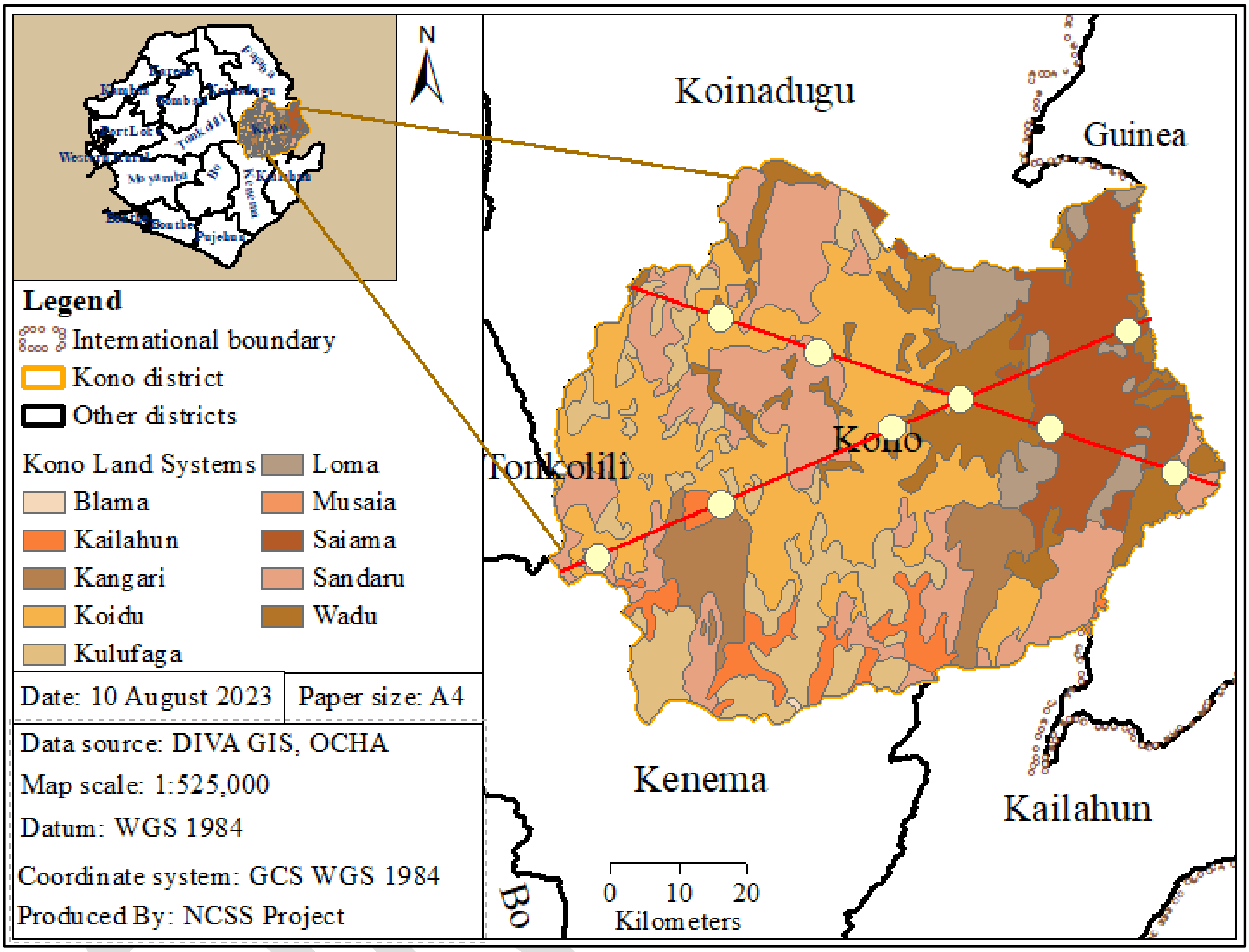

Figure 12. *Transect lines running through soil profile locations in preparation for a free-soil survey (adapted from Brady and Weil, 2008)*

District: Kono; **Chiefdom**: Gorama Kono; **Village**: Kangama; **GPS location**: 8.36259°/11.05808°; **Elevation**: 242m; **Physiography**: On acid rock; La**ndform/facet**: Side slope; **Parent Material**: Weathered Residium; **Landscape position**: Back slope; **Slope**: 3.3%; **Vegetation**: Plantation forestry with deciduous and semi-deciduous trees and shrubs; **Erosion class and intensity**:e2, slight; **Drainage and permeability:** Well drained and rapid; **Landuse**: Plantation forestry; **Major crops grown**: Cocoa, Coffee, Avogadro, banana.

Land System: Kailahun

Classification : USDA Taxonomy: Typic Paleaquult **FAO-UNESCO:** Dystric Nitosol

Mapping Unit: KAI008

Horizon (cm)	Morphological Description
Ah (0 – 60)	Red (10R 5/8 dry and 10R 4/8 moist); sandy loam; moderate, fine, crumbly; slightly hard (dry), friable (moist); non-sticky and non-plastic; plenty very fine, fine, and medium pores; plenty very fine, fine, medium, and few coarse roots; presence of termites, millipedes, ants and other insects; clear and wavy boundary to horizon below.
Bt1 (60 – 165)	Light red (10R 6/8 dry) to red (10R 5/8 moist); silty clay; moderate, fine, crumbly and sub-angular blocky; slightly hard (dry), firm (moist); slightly sticky and slightly plastic; plenty very fine, fine, and medium pores; plenty very fine, fine, medium, very few coarse roots; presence of earthworms and few burrows, termites, ants and other insects; clear and wavy boundary to horizon below.
Bt2 (165 – 192)	Reddish yellow (5YR6/8 dry and 5Y6/6 moist); sandy clay; strong, fine, crumbly and sub-angular blocky; hard (dry), firm (moist); non-sticky and non-plastic; very few very fine, fine, medium pores; plenty very fine, fine, medium roots; presence of termites, ants and other insects; clear and smooth boundary to horizon below.
Cr (192 – 300+)	Reddish yellow (5Y6/8 dry) and yellowish red (5Y7/6 moist); sandy clay; moderate, coarse, crumbly; slightly hard (dry), friable (moist); non-sticky and non-plastic; plenty fine, medium, few coarse pores; very few very fine and few fine, medium roots; horizon dominated by freshly decomposed rock materials; presence of termites, ants and other insects.

Figure 13*. A benchmark soil, first described in Kangama, Gorama Kono Chiefdom, Kono District to compare and represent all pedons described as the Baoma series that carry a similar morphology.*

Soil samples were collected from each horizon of a soil profile and analysed for physicochemical properties at the Njala University and SLARI soil laboratories following the ISRIC/FAO (2002). To enhance the quality of the results, a 0.1 % number of samples was sent to the IITA Analytical Services Laboratory (ASLab) for validation analysis. The field and laboratory data were used to determine the suitability rating to produce crops selected by MAFS for each identified soil type using the FAO framework for land evaluation (FAO, 1976; FAO, 2007).

4.5 Land capability evaluation

Land capability evaluation of the soil associations identified in Kono District was conducted according to the procedure and guidelines provided in the Agriculture Handbook No. 210 (Klingbiel and Montgomery, 1961). This provided the basis for separating arable lands from non-arable lands for the purpose of planning agricultural land use in the district. Appropriate soil conservation measures for the sustainable use of the soils were also indicated.

Land capability codified tables: Land capability classes were colour coded as recommended by Klingbiel and Montgomery (1961) as follows:

i. Light green - Land capability class 1
ii. Yellow - - Land capability class II
iii. Red - - Land capability class III
iv. Blue - - Land capability class IV
v. Dark-green - Land capability class V
vi. Orange - - Land capability class VI
vii. Brown - - Land capability class VII
viii. Purple - - Land capability Class VIII

Land capability classes 1- IV were classified as arable and land capability classes V-VII as non-arable.

4.6 Soil suitability evaluation

Soil suitability evaluation was conducted for 19 priority crops identified by MAFS for Sierra Leone. The crops included (1) Rice under 4 methods of production (Rainfed upland rice, Rainfed bunded rice, Natural flooded rice and Irrigated rice), (2) Other food crops (Cassava, Maize, Sweet potato, Ground nut and Cowpea), (3) Vegetables (Onion, Cabbage, Tomato and Carrot), (4) Tree crops (Cacao, Arabica coffee, Robusta coffee, Cashew, Oil palm), and (5) Fruit trees (Mango, Citrus, Pineapple and Banana). The optimal growth conditions for these crops were taken from Land Evaluation Part 3 (Sys et al., 1993). Using the 1976 FAO parametric method of land suitability evaluation, the landscape, climatic and soil properties collected in the field for each soil was matched against the internationally recognised optimal growth requirements of the target crops (Sys *et al*. 1993).

To expedite the matching process, a soil suitability algorithm was developed according to the FAO (1976) protocol to determine the Land Productivity Index (LPI) required for grouping the soils into suitability classes in decreasing order of crop productivity and constraints of S1> S2 >S3> N1 >N2. The limitations of the soils to the production of specific crops are coded as follows: f = fertility (pH, cation exchange capacity (CEC), Base saturation), s = soil physical characteristics (texture, bulk density), t = topographic (slope), w = wetness (drainage, flooding) and n = salinity / alkalinity).

The allocation of equal percentage weightings (100%) to the performance of the climatic, landscape and soil qualities in meeting a crop requirement as required by the FAO (1976) Land evaluation method, to the tropical soils resulted in the soils being mainly classified in the N1 and N2 classes on account of the zero (0) rating allotted to the poor performing chemical properties, particularly pH and CEC (Ojanuga, 2008). To avoid this problem with the FAO (1976) Land evaluation protocol for Sierra Leone soils, the Ojanuga recommendation of allocating a weighting of 80% to climatic and landscape and 20% to the chemical properties was found to produce more realistic LPIs for evaluating soil suitability. A soil suitability algorithm was therefore programmed to reflect the Ojanuga recommended weightings. Except for this modification in weightings, the parametric method prescribed by FAO in determining LPIs for the classification of soil suitability remained unchanged. The suitability classes were set according to Table 9.

Table 9. *Keys for defining soil suitability classes and limitations (FAO 1976)*

Suitability class	Aggregate stability class	Soil limitations
S1 = Highly suitable	S1 = 75-100	f = fertility
S2 = Moderately suitable	S2 – 74-50	S = soil physical characteristics
S3 = Marginally suitable	S3 = 49-25	T = topography (slope)
N1 = Currently not suitable	N1 = 24-15	W = wetness (drainage)
N2 = Permanently not suitable	N2 = 14-0	N = salinity/alkalinity

Soil suitability codified tables: Soil suitability classes were colour coded as recommended by AbdelRahman et al (2016) as follows:

i. green - S1 soil suitability
ii. grey - S2 soil suitability
iii. brown - S3 soil suitability
iv. saffron - N1soil suitability
v. yellow - N2 soil suitability

4.7 Production of maps

4.7.1 Soil maps

Soil maps were produced at a 1:500,000 scale using GIS algorithms trained by the relationship between soil and landscape attributes, which were established during the field survey phase. The ArcGIS and QGIS were used to develop the soil maps, using soil association as mapping units. The area extent of each soil associations was calculated in the GIS environment.

4.7.2 Land capability maps

Land capability mapping was done to classify the land units in accordance to their fitness for specific kinds of land uses on the basis of their suitability and non-suitability for cultivation. The maps were produced at a 1:500,000 scale using GIS algorithms trained by the relationship of five physical factors such as lithology (characteristics of parent materials), edaphology (kind of soil and its influence on land use), topography (shape and feature of land), gradient (slope of the land) and biotic (vegetation/ land use/ land cover). The base map of the district was prepared using the topographic map and digital elevation model (DEM) of the district. This was used to delineate the areas having different category of general elevation and slopes. The slope map together with the analyzed soil properties were used to identify the soil types. Based on the criteria of land capability classification explained above, classes were assigned to the delineated areas using standard colours specific to the classes as mentioned above in section 4.5.

4.7.3 Soil suitability maps

The production of soil suitability maps required the separation of the soil individuals (whose unique land and soil data are used to determine how well it meets the requirement of a crop for optimal growth/yield) relative to the other soil individuals in the association/toposequence. This was achieved by overlaying the soil association polygon on an ALOS/PARSAL Digital Elevation Model (DEM) of the district (having a spatial resolution of 12.5m) and clipping them together using the extraction-by-mask technique in the Spatial Analyst toolbox. The clipped soil association raster was classified according to the elevation ranges each soil individual occupied in the toposequence within a land system. Soils at the summit and shoulder were put into the highest elevation class, followed by soils on the back slopes and lowest, soils at the foot slope. The soil association raster files were converted to polygons and assigned the soil suitability codified colours of the different suitability classes as per section 4.6.

4.8 Data storage

All data generated including field data, laboratory data and interpretive maps were stored in the national Soil Database and Information System (SDIS) office for easy query and retrieval by end users through a web-based soil information system.

4.9 Limitations of the methodology

Soil individual boundaries in the soil maps were estimated using the following remote sensing technique: the soil association polygon was overlain on a Digital Elevation Map (DEM) of the district (having a spatial resolution of 12.5m) and clipped together (or extraction by mask). The clipped raster soil association polygons were classified according to the elevation ranges each soil individual occupy in the toposequence within a land system. Soils at the summit and shoulder were put into the highest elevation class, followed by soils on the back slopes and lowest, soils at the foot slope. The raster soil association files were converted to shape files and assigned the colours as indicated in the colour codified table in section 4.3.

5 Description and Classification of Soils of Kono District

5.1 Description of Soils of Kono District

5.1.1 Soils located on sloping terrains

Map unit 1: Madina-Bandajuma soil association

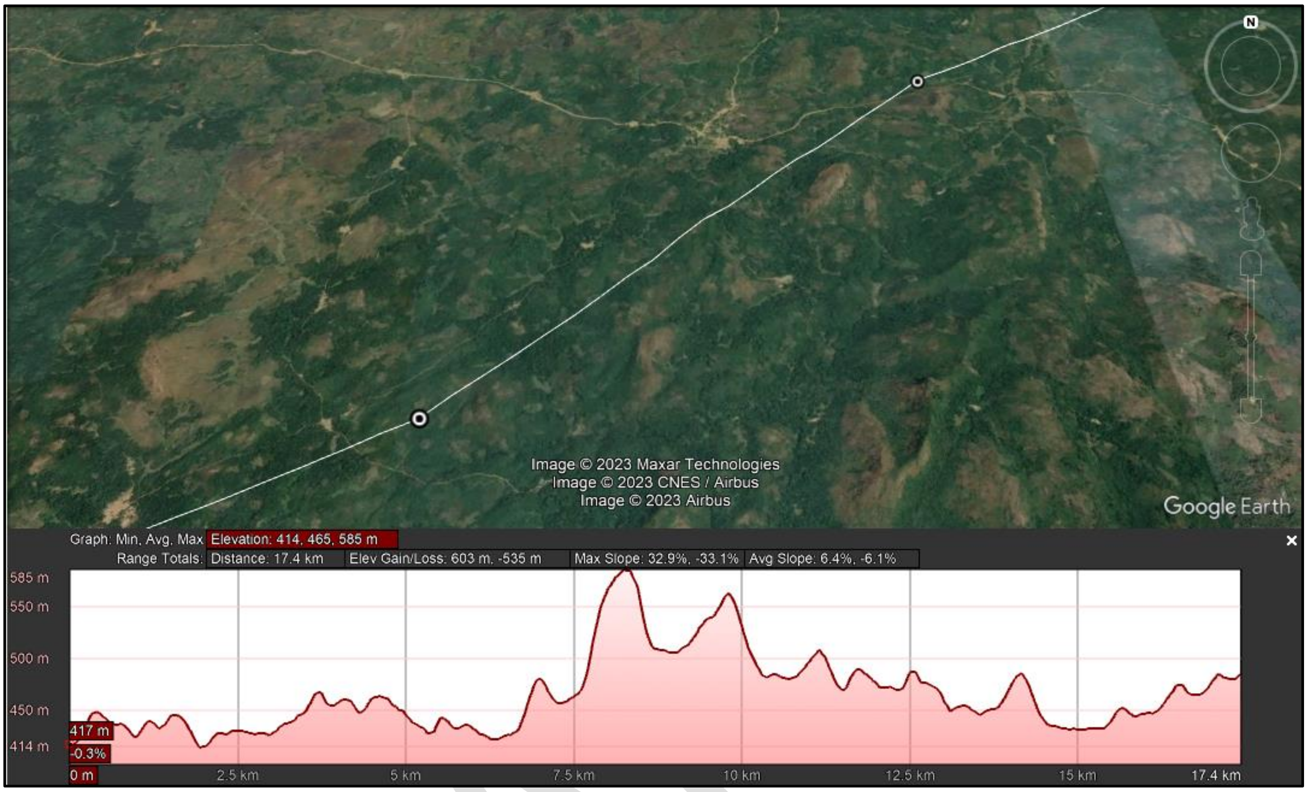

Photo 1. *Typical position of Madina and Bandajuma soil association in Kono District*

5.1.1.1 Madina series

Madina soils occur on sloping terrains and are developed on fine-grained granodiorite that is low in quartz and high in ferromagnesium minerals and feldspars. In these soils, the textures are typically sandy clay loam in the A and C horizons and clay loam in the B horizon. The Red (2.5YR5/8 dry) and dark red (2.5YR3/6 moist) colours of the A1 horizon qualifies as an ochric epipedon. Subsoil colors are typically Red (2.5YR5/8 dry and 2.5YR4/8 moist). Madina soils are well drained and are never waterlogged at the surface.

Chemically, Moa soils are very low in plant nutrients (Table 10). The organic carbon content is high in topsoil horizon and moderate in subsoil horizon. The available phosphorus (Bray P1) is low in both topsoil and subsoil horizons. The pH is high in both topsoil and subsoil horizons. Effective Cation Exchange Capacity (ECEC) (sum of exchangeable cations) cmol kg^{-1}) is low in both topsoil and subsoil horizons. The exchangeable Ca is low in both topsoil and subsoil horizons, exchangeable Mg is moderate in both topsoil and subsoil horizons, exchangeable K is moderate in both topsoil and subsoil horizons and exchangeable Na is low in both topsoil and subsoil horizons. Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio is low in both topsoil and subsoil horizons. The DTPA extractable Fe (cmol kg^{-1}) is low in both topsoil and subsoil horizons, DTPA extractable Co (cmol kg^{-1}) is moderate in topsoil horizon and low in subsoil horizon, while the DTPA extractable Zn (cmol kg^{-1}) is moderate in both topsoil horizon and subsoil horizons.

As revealed by the analytical results, the availability of nutrients to plants may be altered by the high soil pH. It is obvious that with such pH levels, the availability of the major plant nutrients such as nitrogen, phosphorous, potassium, sulfur, calcium, magnesium and also the trace element molybdenum may be reduced and become insufficient during cultivation.

According to Rhodes (1979), phosphorus levels in many agricultural soils of Sierra Leone are far below what is required for optimal production, and with most soils Pujehun district having pH levels that are below pH 5.5, this may further reduce uptake of phosphorus and other nutrients. Liming to raise the pH of acidic soil will increase the availability of these nutrients. In addition, availability of iron, manganese, copper, zinc and aluminium are increased in acidic soils. In Sierra Leone, toxic levels of aluminium and iron has been a topical issue for increasing crop production and productivity. Manganese toxicity is a potential issue for crop production in these acidic soils. However, if appropriate soil management considerations are taken, the concentrations of these exchangeable cations and micronutrients may be prevented from reaching toxic levels.

Because of the sloping nature of the landscape, runoff is rapid and erosion is a serious hazard. Permeability is rapid.

A detailed description and analytical data for a representative profile of the *Madina series*, KON001, are given in Appendices 1a and 1b.

Table 10. *Key land, morphological and chemical properties of Madina series*

Soil series name	Madina	
International soil name	Ferralic Cambisol	
Slope range	8.2 %	
Soil surface stoniness	NA	
Typical position in the landscape	*See Photo 1*	
Texture of the topsoil (0 – 20cm)	Sandy loam	
Texture of the subsoil (at 50cm)	Sandy clay loam	
Drainage	Well drained	
Colour of the topsoil:	Red (2.5YR5/8 dry) and dark red (2.5YR3/6 moist)	
Colour of the subsoil	Red (2.5YR5/8 dry and 2.5YR4/8 moist)	
Soil depth	Deep (>165 cm)	
Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	4.05	2.4
Available phosphorous (Bray P1 (mg kg^{-1})	4.05	4.1
Acidity (pH in 1:1 soil to water ratio)	4.3	4.3
Effective Cation Exchange Capacity (ECEC) (sum of exchangeable cations) cmol kg^{-1})	5.2	3.9
Exchangeable Calcium (cmol kg^{-1} soil)	1.8	1.1
Exchangeable Magnesium (cmol kg^{-1} soil)	1.3	1.2
Exchangeable Potassium (cmol kg^{-1}soil)	0.3	0.2
Exchangeable Sodium (cmol+ kg^{-1} soil)	0.3	0.2
Exchangeable Acidity (cmol+ kg^{-1} soil)	1.5	1.1
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	24	21.5
DTPA extractable Iron (cmol kg^{-1})	15.0	12.5
DTPA extractable Copper (cmol kg^{-1})	1.7	1.4
DTPA extractable Zinc	4.5	3.9

NOTE:

Effective cation exchange capacity (ECEC) is calculated as the sum of exchangeable bases plus exchange Al and H determined under the natural pH of the soil. In general, ECEC values higher than 4 cmol kg^{-1} indicate sufficient cation exchange capacity to prevent serious leaching losses of bases; base saturation calculated on the basis of buffered extractants underestimate the base status of acid soils (Sanchez, 1976).

5.1.1.2 Bandajuma series

The soils of the Bandajuma series usually occur on very gently slopes of the uplands, with slopes commonly ranging from 1 to 2 percent. The develop from gravelly colluvium boulders over clayey residuum from siltstone, sandstone, or shale.

In these soils, the textures are typically gravelly sandy loam in the A and C horizons and gravelly sandy clay in the B horizon. The upper layers of these soils are dominated by detrital hardened plinthite gravel. The strong brown (7.5YR 8/8 dry and 7.5YR 5/6 moist) colours of the A1 horizon qualifies as an ochric epipedon. Subsoil colors are typically reddish yellow (7.5YR 6/8 dry and 7.5YR 6/6 moist). Bandajuma soils are well drained and are never waterlogged at the surface.

Chemically, Bandajuma soils are very low in plant nutrients (Table 11). The organic carbon content is moderate in both topsoil and subsoil horizons. The available phosphorus (Bray P1) is low in both topsoil and subsoil horizons. The pH is moderate in both topsoil and subsoil horizons. Effective cation exchange capacity (ECEC) (sum of exchangeable cations) cmol kg^{-1}) is low in both topsoil and subsoil horizons. The exchangeable Ca is low in both topsoil and subsoil horizons, exchangeable Mg is moderate in both topsoil and subsoil horizons, exchangeable K is moderate in both topsoil and subsoil horizons and exchangeable Na is low in both topsoil and subsoil horizons. Electrical conductivity (salinity) ($\mu S\ cm^{-1}$) in 1: 5 soil to water ratio is low in both topsoil and subsoil horizons. The DTPA extractable Fe (cmol kg^{-1}) is low in both topsoil and subsoil horizons, DTPA extractable Co and Zn (cmol kg^{-1}) are moderate in topsoil horizon and low in subsoil horizons.

As revealed by the analytical results, the availability of nutrients to plants may be altered by the high soil pH. It is obvious that with such pH levels, the availability of the major plant nutrients such as nitrogen, phosphorous, potassium, sulfur, calcium, magnesium and also the trace element molybdenum may be reduced and become insufficient during cultivation.

According to Rhodes (1979), phosphorus levels in many agricultural soils of Sierra Leone are far below what is required for optimal production, and with most soils Pujehun district having pH levels that are below pH 5.5, this may further reduce uptake of phosphorus and other nutrients. Liming to raise the pH of acidic soil will increase the availability of these nutrients. In addition, availability of iron, manganese, copper, zinc and aluminium are increased in acidic soils. In Sierra Leone, toxic levels of aluminium and iron has been a topical issue for increasing crop production and productivity. Manganese toxicity is a potential issue for crop production in these acidic soils. However, if appropriate soil management considerations are taken, the concentrations of these exchangeable cations and micronutrients may be prevented from reaching toxic levels.

Because of the very gently sloping nature of the landscape, runoff is low and erosion is potential is low. Permeability is rapid.

A detailed description and analytical data for a representative profile, KON002, of the *Bandajuma series* are given in Appendices 2a and 2b.

__Table 11.__ Key land, morphological and chemical properties of Bandajuma series

Soil series name	Bandajuma	
International soil name	Dystric Nitosol	
Slope range	1.7 %	
Soil surface stoniness	Soil surface is partially covered with patches of fine and medium gravels	
Typical position in the landscape	*See Plate 1*	
Texture of the topsoil (0 – 20cm)	Gravelly sandy loam	
Texture of the subsoil (at 50cm)	Gravelly sandy clay	
Drainage	Well drained to moderately rapid	
Colour of the topsoil:	Strong brown (7.5YR 8/8 dry and 7.5YR 5/6 moist)	
Colour of the subsoil	Reddish yellow (7.5YR 6/8 dry and 7.5YR 6/6 moist)	
Soil depth	Deep (>160 cm)	
Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	1.5	1.1
Available phosphorous (Bray P1 (mg kg^{-1})	7.8	6.5
Acidity (pH in 1:1 soil to water ratio)	5.3	5.4
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	3.8	5.0
Exchangeable Calcium (cmol kg^{-1} soil)	1.2	1.1
Exchangeable Magnesium (cmol kg^{-1} soil)	1.6	1.6
Exchangeable Potassium (cmol kg^{-1}soil)	0.3	0.2
Exchangeable Sodium (cmol+ kg^{-1} soil)	0.2	0.2
Exchangeable Acidity (cmol+ kg^{-1} soil)	0.5	1.9
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	28.0	26.5
DTPA extractable Iron (cmol kg^{-1})	20.6	16.5
DTPA extractable Copper (cmol kg^{-1})	2.3	1.8
DTPA extractable Zinc (cmol kg^{-1})	6.4	5.1

NOTE:

Effective cation exchange capacity (ECEC) is calculated as the sum of exchangeable bases plus exchange Al and H determined under the natural pH of the soil. In general, ECEC values higher than 4 cmol kg^{-1} indicate sufficient cation exchange capacity to prevent serious leaching losses of bases; base saturation calculated on the basis of buffered extractants underestimate the base status of acid soils (Sanchez, 1976).

5.1.2 Soils on dissected uplands of high weathered materials

These are soils found on gentle to very gentle slopes, which contain weathering bedrock pieces in their subsoil or even solid bedrock. They are usually, fairly fertile, especially if the bedrock contains some weatherable minerals. They are not very suitable for upland cultivation, because the erosion danger is great. They can best be put into forest or used for tree crops such as coffee, cocoa, or oil palm.

Map unit 2: Segbwema-Baoma soil association

The ***Segbwema-Baoma*** soil association are a group of soils formed from alluvial parent materials on dissected uplands of high weathered materials.

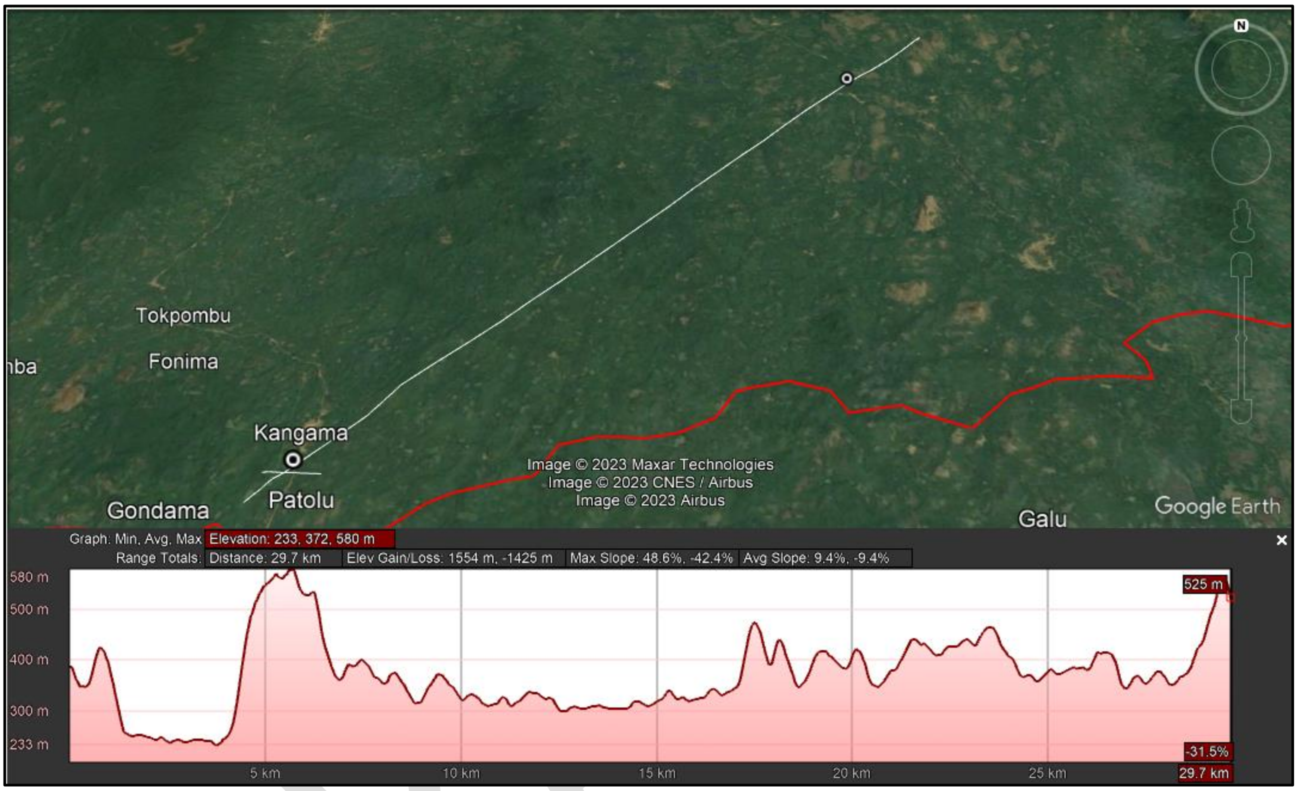

Photo 2. *Typical position of Madina and Bandajuma soil association in Kono District*

5.1.2.1 Segbwema series

Segbwema soils occur on gentle slopes, typically with gradients somehow greater than those of Baoma soils. Segbwema soils are formed from fine-grained granodiorite, which is low in quartz and high in ferromagnesium minerals and feldspars. In these soils, the textures are typically sandy clay loam in the A and C horizons and clay loam in the B horizon. Some detrital hardened plinthite gravel may be present in the upper layers though in most areas, the soil may be devoid of any ironstone gravels but rather replaced with a gravel-free layer of about 50–100 cm. In some areas, pieces of rock fragments and mica flakes are visible, with bedrock occurring at a depth of about 120 cm. Textures are loam to clay loam in the topsoil and clay loam in the subsoil. The topsoil of the A_1 horizon is red (2.5YR 4/8 dry and 2.5YR 4/6 moist), which qualifies as an ochric epipedon. The subsoil colors are typically red (2.5YR 5/8 dry and 2.5YR 6/8 moist). Segbwema soils are well drained and are never waterlogged at the surface.

Chemically, Segbwema soils are very low in plant nutrients (Table 12). The organic carbon content is moderate in topsoil horizon and moderate in subsoil horizon. The available phosphorus (Bray P1) is moderate in both topsoil and subsoil horizons. The pH is moderate in both topsoil and subsoil horizons. Effective cation exchange capacity (ECEC) (sum of exchangeable cations) cmol kg^{-1}) is low in both topsoil and subsoil horizons. The exchangeable Ca and Mg are low in both topsoil and subsoil horizons, exchangeable K is moderate in both topsoil and subsoil horizons, while exchangeable Na is low in both topsoil and subsoil horizons. Electrical conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio is low in both topsoil and subsoil horizons. The DTPA extractable Fe (cmol kg^{-1}) is low in both topsoil and subsoil horizons, DTPA extractable Co (cmol kg^{-1}) is moderate in topsoil horizon and low in subsoil horizon, while the DTPA extractable Zn (cmol kg^{-1}) is high in both topsoil horizon and subsoil horizons.

As revealed by the analytical results, the availability of nutrients to plants may be altered by the high soil pH. It is obvious that with such pH levels, the availability of the major plant nutrients such as nitrogen, phosphorous, potassium, sulfur, calcium, magnesium and also the trace element molybdenum may be reduced and become insufficient during cultivation.

According to Rhodes (1979), phosphorus levels in many agricultural soils of Sierra Leone are far below what is required for optimal production, and with most soils Pujehun district having pH levels that are below pH 5.5, this may further reduce uptake of phosphorus and other nutrients. Liming to raise the pH of acidic soil will increase the availability of these nutrients. In addition, availability of iron, manganese, copper, zinc and aluminium are increased in acidic soils. In Sierra Leone, toxic levels of aluminium and iron has been a topical issue for increasing crop production and productivity. Manganese toxicity is a potential issue for crop production in these acidic soils. However, if appropriate soil management considerations are taken, the concentrations of these exchangeable cations and micronutrients may be prevented from reaching toxic levels.

Because of the gently sloping nature of the landscape, runoff is somehow moderate and erosion is a moderate except in cases where the vegetation cover is tampered with. Permeability is rapid.

A detailed description and analytical data for a representative profile, KON003, of the *Segbwema series* is given in Appendix 3a and 3b.

Table 12. *Key land, morphological and chemical properties of Segbwema series*

Soil series name	Segbwema
International soil name	Ferralic Cambisol
Slope range	4.3 %
Soil surface stoniness	NA
Typical position in the landscape	*See Photo 2*
Texture of the topsoil (0 – 20cm)	Sandy loam
Texture of the subsoil (at 50cm)	Sandy clay
Drainage	Well drained
Colour of the topsoil:	Red (2.5YR 4/8 dry and 2.5YR 4/6 moist)
Colour of the subsoil	Red (2.5YR 5/8 dry and 2.5YR 6/8 moist)
Soil depth	Very deep (>170 cm)

Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	1.6	1.2
Available phosphorous (Bray P1 (mg kg^{-1})	17.7	10.9
Acidity (pH in 1:1 soil to water ratio)	5.0	5.2
Effective Cation Exchange Capacity (sum of cations) cmol kg^{-1})	4.5	4.8
Exchangeable Calcium (cmol kg^{-1} soil)	1.8	1.6
Exchangeable Magnesium (cmol kg^{-1} soil)	0.8	0.7
Exchangeable Potassium (cmol kg^{-1}soil)	0.4	0.3
Exchangeable Sodium (cmol kg^{-1} soil)	0.2	0.2
Exchangeable Acidity (cmol+ kg^{-1} soil)	1.4	2.0
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	4.5	4.8
DTPA extractable Iron (cmol kg^{-1})	23.5	19.4
DTPA extractable Copper (cmol kg^{-1})	2.6	2.1
DTPA extractable Zinc (cmol kg^{-1})	7.3	6.0

NOTE:

Effective cation exchange capacity (ECEC) is calculated as the sum of exchangeable bases plus exchange Al and H determined under the natural pH of the soil. In general, ECEC values higher than 4 cmol kg^{-1} indicate sufficient cation exchange capacity to prevent serious leaching losses of bases; base saturation calculated on the basis of buffered extractants underestimate the base status of acid soils (Sanchez, 1976).

5.1.2.2 Baoma series

Soils of *Baoma series* have 25-60 cm of gravel free colluvial or residual material over a gravelly subsoil. The soils are deep and gravel-free throughout the profile.

The textures are sandy loam in the topsoil A1 or A_P horizon but sandy clay in the subsoil. The topsoil colours are usually Red (10R 5/8 dry and 10R 4/8 moist), which qualifies it for an umbric horizon, while subsoil colours are light red (10R 6/8 dry) to red (10R 5/8 moist. The surface horizon is thick, which qualifies for an umbric horizon. The soils well drained and are never waterlogged.

Chemically, Baoma soils are very low in plant nutrients (Table 13). The organic carbon content is moderate in topsoil horizon and low in subsoil horizon. The available phosphorus (Bray P1) is low in both topsoil and subsoil horizons. The pH is moderate in both topsoil and subsoil horizons. Effective cation exchange capacity (ECEC) (sum of exchangeable cations) cmol kg^{-1}) is low in both topsoil and subsoil horizons. The exchangeable Ca is low in both topsoil and subsoil horizons, exchangeable Mg is moderate in both topsoil and subsoil horizons, exchangeable K is high in topsoil horizon and moderate in subsoil horizons, while exchangeable Na is low in both topsoil and subsoil horizons. Electrical conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio is low in both topsoil and subsoil horizons. The DTPA extractable Fe and Co (cmol kg^{-1}) are low in both topsoil and subsoil horizons, while the DTPA extractable Zn (cmol kg^{-1}) is moderate in topsoil horizon and low in subsoil horizon.

As revealed by the analytical results, the availability of nutrients to plants may be altered by the high soil pH. It is obvious that with such pH levels, the availability of the major plant nutrients such as nitrogen, phosphorous, potassium, sulfur, calcium, magnesium and also the trace element molybdenum may be reduced and become insufficient during cultivation.

According to Rhodes (1979), phosphorus levels in many agricultural soils of Sierra Leone are far below what is required for optimal production, and with most soils Pujehun district having pH levels that are below pH 5.5, this may further reduce uptake of phosphorus and other nutrients. Liming to raise the pH of acidic soil will increase the availability of these nutrients. In addition, availability of iron, manganese, copper, zinc and aluminium are increased in acidic soils. In Sierra Leone, toxic levels of aluminium and iron has been a topical issue for increasing crop production and productivity. Manganese toxicity is a potential issue for crop production in these acidic soils. However, if appropriate soil management considerations are taken, the concentrations of these exchangeable cations and micronutrients may be prevented from reaching toxic levels.

Because of the very gently sloping nature of the landscape, runoff is moderate and erosion is slight. Permeability is rapid. These soils are commonly found on A and B slopes, and erosion hazard is generally slight to moderate.

A detailed description and analytical result of a representative profile, KON004, of *Baoma series* are given in Appendices 4a and 4b.

Table 13. *Key land, morphological and chemical properties of Baoma series*

Soil series name	Baoma
International soil name	Orthic Ferralsol
Slope range	8-10 %
Soil surface stoniness	NA
Typical position in the landscape	*See Plate 2*
Texture of the topsoil (0 – 20cm)	Sandy loam
Texture of the subsoil (at 50cm)	Sandy clay
Drainage	Well drained and rapid
Colour of the topsoil:	Red (10R 5/8 dry and 10R 4/8 moist)
Colour of the subsoil	Light red (10R 6/8 dry) to red (10R 5/8 moist
Soil depth	Very deep (>300 cm)

Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	1.0	0.8
Available phosphorous (Bray P1 (mg kg-^{1})	6.5	4.7
Acidity (pH in 1:1 soil to water ratio)	5.0	5.3
Effective Cation Exchange Capacity (sum of cations) cmol kg^{-1})	6.7	5.4
Exchangeable Calcium (cmol kg^{-1} soil)	1.7	1.3
Exchangeable Magnesium (cmol kg^{-1} soil)	2.0	1.5
Exchangeable Potassium (cmol kg^{-1}soil)	0.4	0.2
Exchangeable Sodium (cmol kg^{-1} soil)	0.2	0.2
Exchangeable Acidity (cmol+ kg^{-1} soil)	2.4	2.3
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	47.0	33.0
DTPA extractable Iron (cmol kg^{-1})	3.1	9.1
DTPA extractable Copper (cmol kg^{-1})	0.3	1.0
DTPA extractable Zinc (cmol kg^{-1})	1.0	2.8

NOTE:

Effective cation exchange capacity (ECEC) is calculated as the sum of exchangeable bases plus exchange Al and H determined under the natural pH of the soil. In general, ECEC values higher than 4 cmol kg^{-1} indicate sufficient cation exchange capacity to prevent serious leaching losses of bases; base saturation calculated on the basis of buffered extractants underestimate the base status of acid soils (Sanchez, 1976).

5.1.3 Soils located on colluvial footslopes and terraces

On the colluvial footslopes of the area, soils such as Mokonde and Gbeika occur. Downslope from the upland, the upper gravel-free layer becomes progressively thicker. On the upland footslopes and highest terrace are the Mokonde soils, which have 20-60 cm of gravel-free material over a gravelly subsoil. At lower elevations are Gbeika soils, which have 40-120 cm of gravel-free material over a gravelly lower subsoil.

Map unit 3: Mokonde-Gbeika soil association

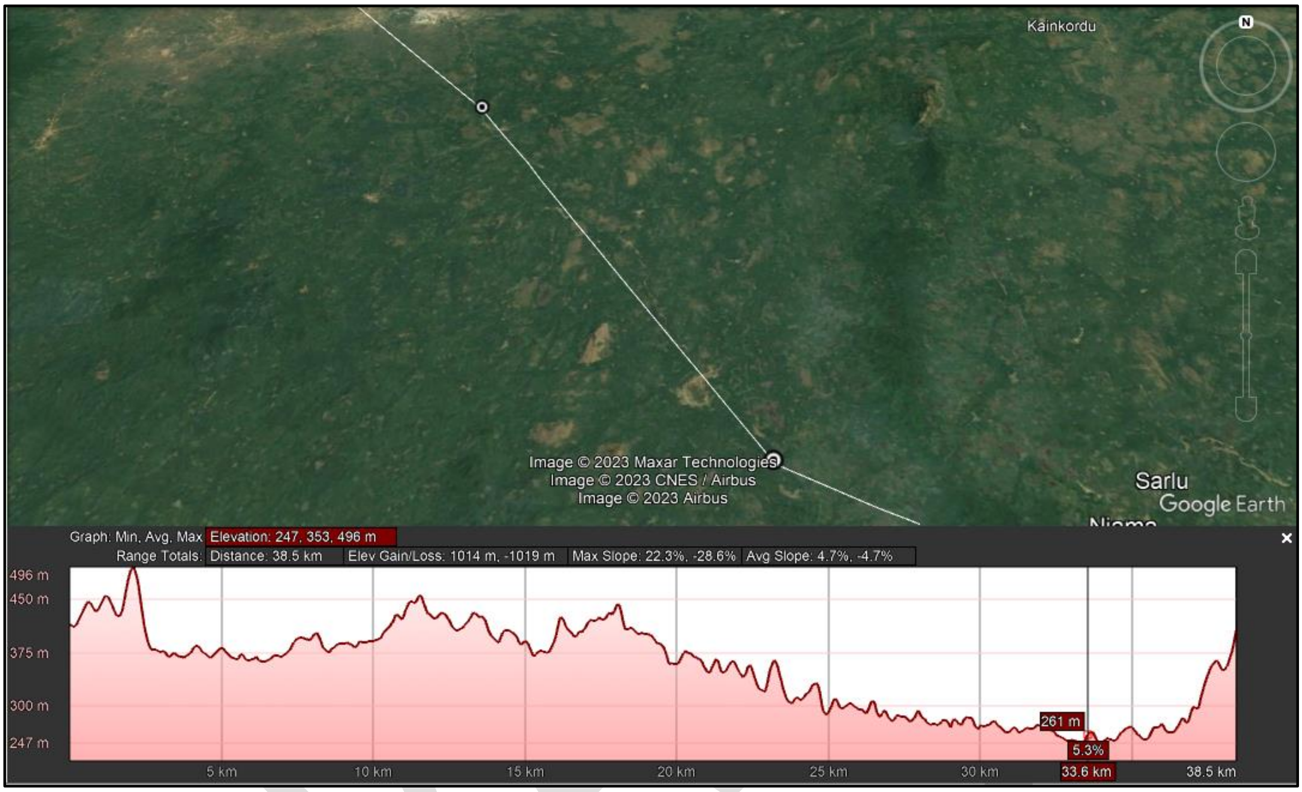

Photo 3. *Typical position of Madina and Bandajuma soil association in Kono District*

5.1.3.1 Mokonde series

Soils of the Mokonde series occur on concave colluvial footslopes of 2-5% slopes. The parent material is a gravel-free colluvium, overlying gravelly colluvium, over gravelly residual material, over weathered bedrock. The thickness of the gravel-free colluvium is usually 20 to 60 cm. The underlying subsoil layer is usually dominated by 35-50 % colluvial plinthite glaebules that are rounded, hard and dense, and dusky red to reddish black. The residual plinthite glaebules, formed in situ, are more irregular and relatively more porous and softer.

The topsoil textures are sandy loam, while the subsoil textures are clay loam to sandy clay loam. These soils have an ochric epipedon and a thin A1 horizon that is less than 25 cm thick. The topsoil colours are reddish brown (2.5YR 5/4 dry and 2.5YR 4/4 moist), and subsoil colours is light red (2.5YR 5/6 dry and 2.5YR 4/6 moist). In some cases where moisture remains high for most parts of the year, the subsoil may look yellowish-grey (2.5Y 7/6), which after being indurated for long periods normally results in the formation of prominent reddish (2.5YR 4/8) mottles. The soils are moderately well drained and are seldom waterlogged.

Chemically, Mokonde soils are very low in plant nutrients (Table 14). The organic carbon content is moderate in both topsoil and subsoil horizons. The available phosphorus (Bray P1) is high in topsoil horizons and moderate in subsoil horizons. The pH is moderate in both topsoil and subsoil horizons. Effective cation exchange capacity (ECEC) (sum of exchangeable cations) cmol kg^{-1}) is low in both topsoil and subsoil horizons. The exchangeable Ca is low in both topsoil and subsoil horizons, exchangeable Mg is moderate in topsoil horizons and low in subsoil horizons, exchangeable Kand Na are low in both topsoil and subsoil horizons. Electrical conductivity (salinity) ($\mu S\ cm^{-1}$) in 1: 5 soil to water ratio is low in both topsoil and subsoil horizons. The DTPA extractable Fe ($cmol\ kg^{-1}$) is low in both topsoil and subsoil horizons, while DTPA extractable Co and Zn ($cmol\ kg^{-1}$) are moderate in both topsoil horizon and subsoil horizons.

As revealed by the analytical results, the availability of nutrients to plants may be altered by the high soil pH. It is obvious that with such pH levels, the availability of the major plant nutrients such as nitrogen, phosphorous, potassium, sulfur, calcium, magnesium and also the trace element molybdenum may be reduced and become insufficient during cultivation.

According to Rhodes (1979), phosphorus levels in many agricultural soils of Sierra Leone are far below what is required for optimal production, and with most soils Pujehun district having pH levels that are below pH 5.5, this may further reduce uptake of phosphorus and other nutrients. Liming to raise the pH of acidic soil will increase the availability of these nutrients. In addition, availability of iron, manganese, copper, zinc and aluminium are increased in acidic soils. In Sierra Leone, toxic levels of aluminium and iron has been a topical issue for increasing crop production and productivity. Manganese toxicity is a potential issue for crop production in these acidic soils. However, if appropriate soil management considerations are taken, the concentrations of these exchangeable cations and micronutrients may be prevented from reaching toxic levels.

Because of the level to nearly level slopes, runoff is low and erosion is slight. Permeability is rapid.

A detail description and analytical data for a representative profile of the *Mokonde series*, KON005, is given in Appendices 5a and 5b.

Table 14. *Key land, morphological and chemical properties of Mokonde series*

Soil series name	Mokonde
International soil name	Haplic plinthosol
Slope range	3.1%
Soil surface stoniness	NA
Typical position in the landscape	*See Photo 3*
Texture of the topsoil (0 – 20cm)	Sandy loam
Texture of the subsoil (at 50cm)	Sandy clay
Drainage	Well drained
Colour of the topsoil:	Reddish brown (2.5YR 5/4 dry and 2.5YR 4/4 moist)
Colour of the subsoil	Light red (2.5YR 5/6 dry and 2.5YR 4/6 moist)
Soil depth	Deep (>140 cm)

Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	3.0	2.9
Available phosphorous (Bray P1 (mg kg^{-1})	21.4	13.9
Acidity (pH in 1:1 soil to water ratio)	5.0	5.1
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	6.5	7.2
Exchangeable Calcium (cmol kg^{-1} soil)	1.9	1.7
Exchangeable Magnesium (cmol kg^{-1} soil)	1.3	0.9
Exchangeable Potassium (cmol kg^{-1}soil)	0.2	0.1
Exchangeable Sodium (cmol+ kg^{-1} soil)	0.2	0.2
Exchangeable Acidity (cmol+ kg^{-1} soil)	3.0	4.2
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	71.0	52.5
DTPA extractable Iron (cmol kg^{-1})	16.2	15.3
DTPA extractable Copper (cmol kg^{-1})	1.8	1.7
DTPA extractable Zinc (cmol kg^{-1})	5.0	4.7

NOTE:

Effective cation exchange capacity (ECEC) is calculated as the sum of exchangeable bases plus exchange Al and H determined under the natural pH of the soil. In general, ECEC values higher than 4 cmol kg^{-1} indicate sufficient cation exchange capacity to prevent serious leaching losses of bases; base saturation calculated on the basis of buffered extractants underestimate the base status of acid soils (Sanchez, 1976).

5.1.3.2 Gbeika series

Gbeika soils are formed from gravel-free colluvium over gravelly subsoil that is usually high in weathered rock fragment. The textures are usually sandy loam in the surface A1 horizon, and sandy clay loam or sandy clay in the subsoil. The topsoil colours are light reddish brown (5YR 6/4 dry) and reddish brown (5YR 5/4 moist), whereas the subsoil colours are reddish yellow (5YR 6/6 dry) and yellowish red (5YR5/6 moist). The thickness and colour of the surface horizon qualify these soils for the umbric epipedon. These soils are well drained and never waterlogged.

Chemically, Gbeika soils are very low in plant nutrients (Table 15). The organic carbon content is moderate in topsoil and subsoil horizons. The available phosphorus (Bray P1) is high in both topsoil and subsoil horizons. The pH is moderate in both topsoil and subsoil horizons. Effective cation exchange capacity (ECEC) (sum of exchangeable cations) cmol kg^{-1}) is low in both topsoil and subsoil horizons. The exchangeable Ca is low in both topsoil and subsoil horizons, exchangeable Mg is moderate in both topsoil and subsoil horizons, exchangeable K and Na are low in both topsoil and subsoil horizons. Electrical conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio is low in both topsoil and subsoil horizons. The DTPA extractable Fe (cmol kg^{-1}) is low in both topsoil and subsoil horizons, DTPA extractable Co (cmol kg^{-1}) is high in both topsoil and subsoil horizons, while the DTPA extractable Zn (cmol kg^{-1}) is low in both topsoil horizon and subsoil horizons.

As revealed by the analytical results, the availability of nutrients to plants may be altered by the high soil pH. It is obvious that with such pH levels, the availability of the major plant nutrients such as nitrogen, phosphorous, potassium, sulfur, calcium, magnesium and also the trace element molybdenum may be reduced and become insufficient during cultivation.

According to Rhodes (1979), phosphorus levels in many agricultural soils of Sierra Leone are far below what is required for optimal production, and with most soils Pujehun district having pH levels that are below pH 5.5, this may further reduce uptake of phosphorus and other nutrients. Liming to raise the pH of acidic soil will increase the availability of these nutrients. In addition, availability of iron, manganese, copper, zinc and aluminium are increased in acidic soils. In Sierra Leone, toxic levels of aluminium and iron has been a topical issue for increasing crop production and productivity. Manganese toxicity is a potential issue for crop production in these acidic soils. However, if appropriate soil management considerations are taken, the concentrations of these exchangeable cations and micronutrients may be prevented from reaching toxic levels.

Because of the flat nature of the landscape, runoff is less and erosion is slight. Permeability is rapid.

A detailed description and analytical result of a representative profile of *Gbeika series,* KON006, is given in Appendices 6a and 6b.

Table 15. Key land, morphological and chemical properties of Gbeika series

Soil series name	Gbeika
International soil name	Dystric Nitosol
Slope range	3%
Soil surface stoniness	NA
Typical position in the landscape	*See Plate 3*
Texture of the topsoil (0 – 20cm)	Sandy loam
Texture of the subsoil (at 50cm)	Sandy clay loam
Drainage	Well drained
Colour of the topsoil:	Light reddish brown (5YR 6/4 dry) and reddish brown (5YR 5/4 moist)
Colour of the subsoil	Reddish yellow (5YR 6/6 dry) and yellowish red (5YR5/6 moist)
Soil depth	Deep (>120 cm)

Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	1.5	1.3
Available phosphorous (Bray P1 (mg kg^{-1})	21.4	20.1
Acidity (pH in 1:1 soil to water ratio)	4.9	5.1
Effective Cation Exchange Capacity (sum of cations) cmol kg^{-1})	6.4	5.4
Exchangeable Calcium (cmol kg^{-1} soil)	2.2	1.8
Exchangeable Magnesium (cmol kg^{-1} soil)	1.2	1.2
Exchangeable Potassium (cmol kg^{-1}soil)	0.1	0.1
Exchangeable Sodium (cmol+ kg^{-1} soil)	0.2	0.2
Exchangeable Acidity (cmol+ kg^{-1} soil)	2.6	2.1
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	56.0	47.5
DTPA extractable Iron (cmol kg^{-1})	17.9	15.4
DTPA extractable Zinc (cmol kg^{-1})	5.6	4.8
DTPA extractable Copper (cmol kg^{-1})	2.0	1.7

5.2 Soil Classification of Kono District

Following the field survey activities, the soils of Kono District were classified and mapped on the basis of their representative characteristics, as presented in Table 16. Based on the results show below, it can be noted that soils of the Gbeika series occupy the largest area (1172.4 km^2). This is followed by Mokonde (769.7 km^2), Bandajuma (597.1 km^2), Baoma (439.3 km^2), Madina (353.6 km^2) in decreasing order of area of coverage. The least is soils of the Segbwema series (108.3 km^2).

Table 16. *Correlation between the FAO WRB and USDA Soil Taxonomy systems of classification*

Map unit (soil series)	FAO World Reference Base Classification System (FAO World Reference Base (FAO, 2022)		USDA Soil Taxonomy Classification System (Keys to Soil Taxonomy 2022)				Area (km^2)
	Level 1	**Level 2**	**Order**	**Suborder**	**Great group**	**Sub group**	
Madina	Ferrasol	Ferralic Cambisol	Inceptisol	Tropept	Dystropept	Udoxic dystropept	353.6
Bandajuma	Nitosol	Dystric Nitosol	Inceptisol	Tropept	Dystropept	Plpnthic dystropept	597.1
Segbwema	Ferralsol	Ferralic Cambisol	Inceptisol	Tropept	Dystropept	Udoxic dystropept	108.3
Baoma	Ferrasol	Orthic Ferralsol	Oxisol	Orthox	Haplorthox	Typic haplorthox	439.3
Mokonde	Plinthosol	Haplic plinthosol	Ultisol	Udult	Paleudult	Plinthic Paleudult	769.7
Gbeika	Nitosol	Dystric Nitosol	Ultisol	udult	Paleudult	Typic paleudult	1172.4

5.3 Soil map of Kono District

The soils of Kono District as indicated in Table 16, were mapped on the basis of their representative characteristics, as presented in Figure 14.

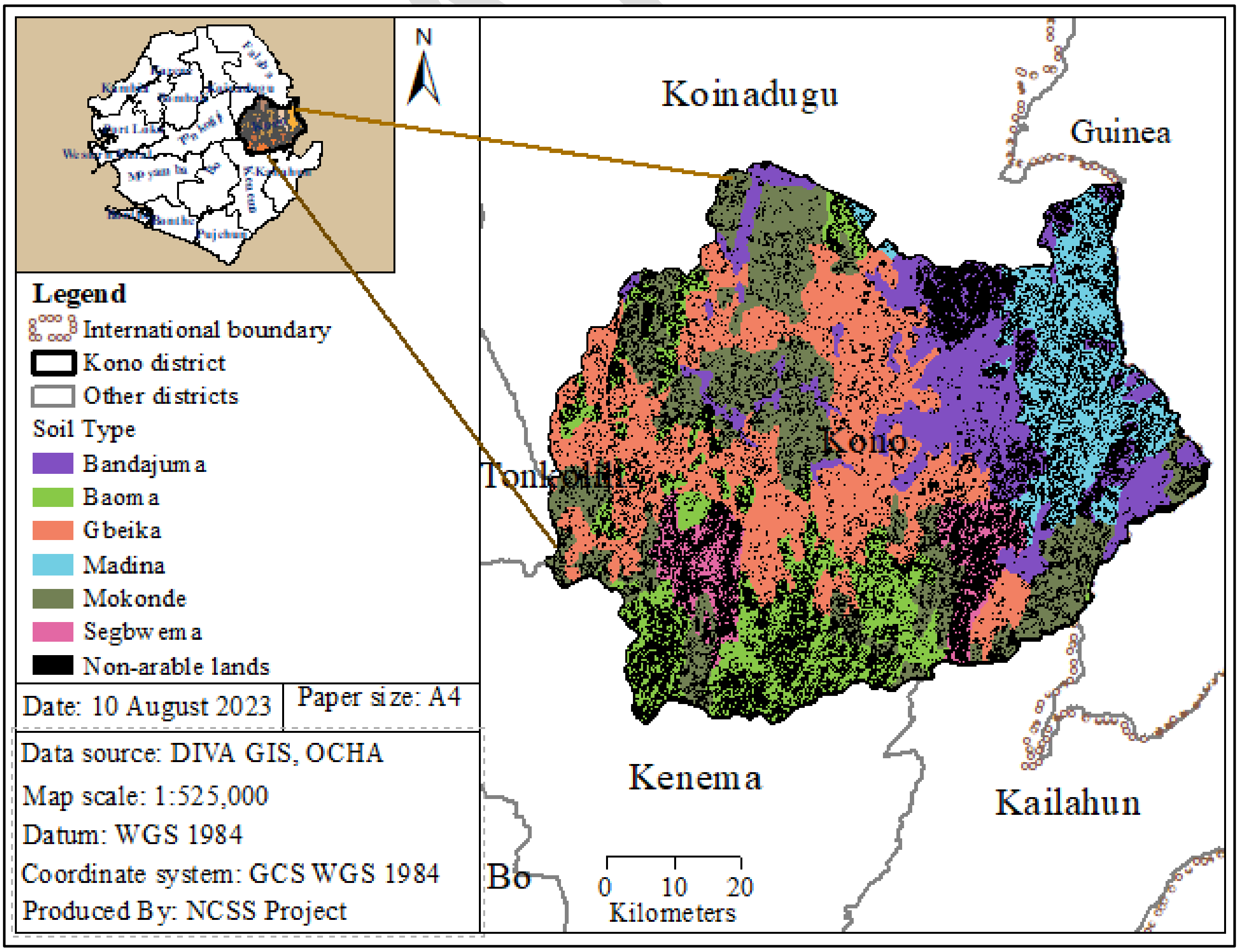

Figure 14. *Soil association map of Kono District*

6 Opportunities, challenges and agricultural development potential

This chapter deals with the interpretive aspect of the soil survey after the systematic identification, description, classification and mapping of soils in the Kono District.

The soils in Kono District were interpreted for their general potential for agricultural use by firstly classifying them into arable (Class 1-IV) and non-arable (Class V-VIII) classes, with clear statements on the risk of environmental hazard that each soil association bears when subjected to agricultural use.

Among the soil associations classed as arable, a soil suitability evaluation was conducted to determine their relative fitness for meeting the optimal requirement of the MAFS target crops and the agronomic/engineering constraints that have to be resolved by appropriate agronomic /engineering strategies to ensure their sustainable production and productivity. The soil associations with the highest suitability ratings (S1 and S2) for growing the MAFS target crops are recommended for agricultural investment.

To ensure that the premium agricultural soils in the district are used in a sustainable and environmentally friendly manner, proven soil management strategies that have been researched and tested over time in Sierra Leone, are recommended for the attention of farmers and the Government.

6.1 Land capability and implications for agricultural development

The goal of allocating various land capabilities to a land area with varied characteristics is to achieve complete soil conservation. Complete soil conservation implies perfect soil health and zero soil erosion on a sustained basis. This objective is consistent with that of the NCSS project.

The soils identified in Kono District have been systematically grouped into land capability classes according to those properties that determine their ability to produce crops on a virtually sustainable basis. There are many properties that may limit the use of soils in Kono District, some are minor and some are major limitations that should be addressed to enhance the sustainable use of these soils.

On the basis of those capability limitations, the soils have been broadly grouped into two major groups, known as (1) arable (or cultivable) and (2) non-arable (or non-cultivable). The arable (or cultivable) lands are those areas within the district that are either highly, moderately or marginally suitable for agriculture. These arable (or cultivable) lands are differentiated into Class I, II, II, IV lands based on four major limitations, including climate (climatic extremities and aberrant weather), soils (water holding capacity and fertility), water (excess water or drainage problems), and erosion (water erosion or wind erosion). Each of the above factors plays a significant role in soil behaviour and management. The non-arable (or non-cultivable) lands are those areas within the district that are not capable of supporting cultivation of crops but can be put to some other uses. Such lands also belong to four classes, namely, Class V, VI, VII, and VIII. These lands are used for growing grasses, forestry and supporting wildlife. Depending on the nature and properties of soils, they may be suitable for one or other uses. The land capability of the various land units is presented in Figure 15.

6.1.1 Arable and non-arable lands in Kono district

In order to evaluate the capability of land in Kono district, soil-site characteristics of the fifteen-soil series (Section 5.1.1.1 – 5.1.3.3) were matched with the criteria for land capability classification. The result of land capability evaluation of soils of Kono district, as presented in Table 17, indicates that 64.6 % of the land area is arable and 35.4 % is non-arable. Arable soils include Madina, Bandajuma, Segbwema, Baoma, Mokonde, and Gbeika soils. These soils are of high agricultural priority and therefore, a high premium should be put on them for the sake of sustainable agricultural development in Sierra Leone.

a. ***Class I lands:*** These are nearly level very good cultivable lands with few minor limitations that require normal soil and crop management practices. They are usually deep and somewhat well drained, and can be used for intense cultivation. They include soils of Baoma and Gbeika series, which account for about 1611.7 km^2 (30.3%) of the total area (Table 18). These soils are nearly level with slopes generally within 0-1 %. The soils are deep, fertile, easily workable and are not subjected to damaging overflows. There are hardly any restrictions or limitations for their use, except for minor limitations, such as fertility. Apart from this single limitation, these lands are very good lands which can be safely cultivated by using any farming method to grow any crop, even intensively also.

b. ***Class II lands:*** Soils in this class are referred to as good cultivable lands, which have slight to moderate limitations that restrict their use (Ghadekar and Pawar, 2009). These soils have gentle slopes, moderate erosion hazard, and are capable of sustaining less intensive cropping systems but have few other limitations that may require moderate conservation practices to prevent their deterioration. They include soils of the Segbwema and Bandajuma series. These soils are limited by one or more of factors such as: (a) moderate limitations which reduce choice of crop, (b) less than ideal soil structure and workability, (c) somewhat restricted drainage, and (d) require moderate conservation practices to prevent deterioration. The management practices that may be required for these soils include peripheral bunding, construction of retaining walls to divert flood water, etc. The result shows that 769.6 km^2 (14.5 %) is occupied by land capability class II lands as shown in Table 19. These soils are moderate to rapidly permeable and moderate to imperfectively well-drained with slight limitations of drainage, flooding, etc.

c. ***Class III lands:*** Soils in this class are referred to as moderately good cultivable lands, which have severe limitations that restrict their use. These soils are limited by one or more of factors such as: (a) severe limitations which reduce the choice of crops, (b) moderately steep slope (5 to 10 %), (c) high erosion hazards, (d) very slow water permeability, (e) shallow depth and restricted root zone, (f) low water holding capacity, (g) low fertility, (h) moderate alkalinity and salinity and (i) unstable structure. They include soils of Mokonde series. These soils are moderate to rapidly permeable and moderately well- to well-drained with moderate limitations of slope, erosion, depth, coarse fragments, profile development, organic carbon and base saturation. For this reason, these soils may require special conservation practices to raise field crops and special management practices are required in addition to the management practices required in Class II lands. According to the results, 705.3 km^2 (13.2 %) of the district is occupied by land capability class III lands as shown in Table 19. A sustainable alternate land use options for these lands could be agri-horticulture, growing of cassava, selected legumes (such as groundnut, cowpeas) and grasses. For the Scarcies series, these soils may need special soil management considerations due to their nature and ecology. Alternative uses such as wild life, recreation etc. should be considered.

d. ***Class IV lands:*** These lands are marginally suitable for cultivation of normal crops as they have very severe limitations on the choice of crops. The soils with this landscape are sandy all over the profile and have low water holding capacity especially during the dry season. They include soils of the Madina series, which cover 353.6 km^2 (6.6 %) of the district (Table 18). These soils have limited use for agriculture but alternatively, can be used for agri-horticulture and silvipasture systems. However, careful management is needed to raise fruit crops such as coconuts. Alternative uses such as wild life, sand mining, recreation etc. should be considered.

e. ***Non-arable:*** These are demarcated as steep slopes and hills, rock outcrops, settlements, roads and water bodies. They account for 1884.3 km^2 (35.4 %) of the district.

Table 17. *Area covered by soil associations/types in Kono district.*

Land capability group	**Soil-physiography**	**Soil association**	**Soil series**	**Area**	
				km^2	**%**
Arable	Soils located in sloping terrains	Madina-Bandajuma	Madina, Bandajuma	950.6	17.9
	Soils on dissected uplands of high weathered materials	Segbwema-Baoma	Segbwema, Baoma	547.6	10.3
	Soils on colluvial footslopes and terraces	Mokonde-Gbeika	Mokonde, Gbeika	1942.1	36.5
Non-arable	Steep slopes and hills, rock outcrops, settlements, roads and water bodies			1884.3	35.4

The challenges for use of these soils are also outlined in *Table 18* to guide users towards ensuring the sustainable production and productivity of these soils. Land that is not arable may be left for wildlife or protected with afforestation.

Table 18. *Land capability indices of soils and their implications for agricultural use in the Kono District*

Soil association	**Soil individuals**	**Capability group**	**Capability class**	**Capability subclass/ Risk of hazards**
Madina-Bandajuma	Madina	Arable	III	Marginally suitable for cultivation but have severe limitations which reduce the choice of crops such as moderately steep slope (5 to 10 %), high gravel content, high erosion hazards, low water holding capacity, low fertility, and unstable structure.
	Bandajuma	Arable	II	Moderately suitable for cultivation of arable crops but have few limitations, mainly relating to fertility (f).
Segbwema-Baoma	Segbwema	Arable	II	
	Baoma	Arable	I	Highly suitable for cultivation of rice, vegetables and groundnut but may have few moderate limitations of fertility.
Mokonde-Gbeika	Mokonde	Arable	IV	Marginally suited for fruit crops like coconut (limited by high sand and low moisture capacity)
	Gbeika	Arable	I	Highly suitable for cultivation of rice, vegetables and groundnut but may have few moderate limitations of fertility.

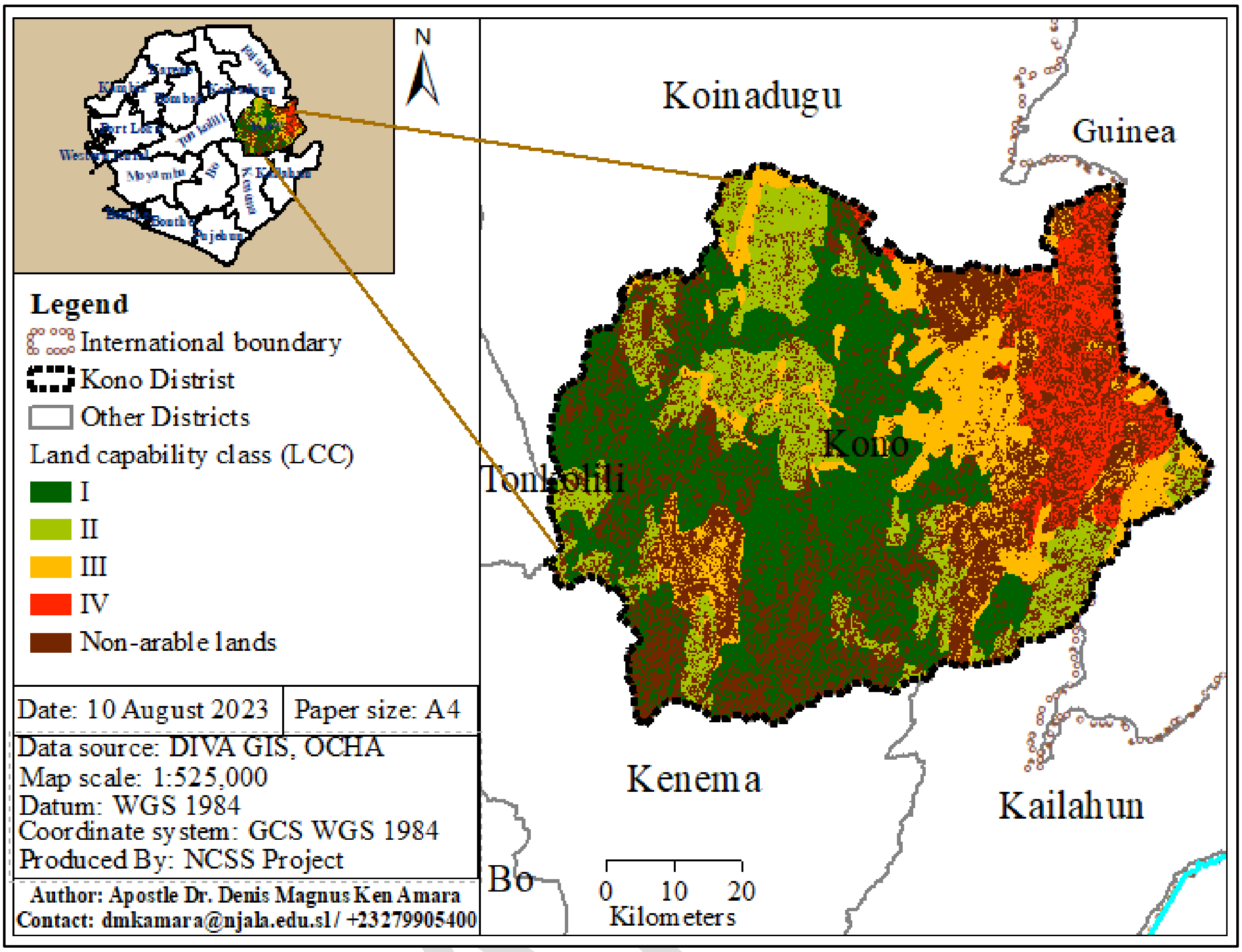

Figure 15. *Land capability map of Kono District*

6.2 Soil Suitability and implications for agricultural development

Soil suitability is used to evaluate the best combination of climatic, landscape and soil factors that can meet the optimal growth requirements of specific crops or land utilization type (LUT) along with information on the major constraints that may limit their use and recommendations on how to manage them in a sustainable and ecofriendly manner. This objective is in line with the National Comprehensive Project (NCSS), which sought to update the 40-year Sierra Leone soil survey data to serve as a scientific basis inform agricultural land use planning involving the selection of soils that are most suitable for the optimal production of (1) food crops (2) vegetables (3) tree crops and (4) fruit trees, as the country intensifies its agricultural drive towards boosting national economy and food self-sufficiency.

Suitability classes, produce Land Productivity (LPI) which are grouped into suitability classes in decreasing order of crop productivity and constraints of S1> S2 >S3> N1 >N2. The limitations of the soils to the production of specific crops are coded as f = fertility (pH, CEC, Base saturation), s = soil physical characteristics (texture, bulk density), t = topographic (slope), w = wetness (drainage, flooding), and n= salinity/ alkalinity.

The findings of the land suitability evaluation of soils in Kono district is discussed below:

6.2.1 Suitability evaluation for rice cultivation

Rice is the main staple food for Sierra Leone and is grown by almost 80% of farmers (STATSL, 2017). Out of the six soil individuals (i.e., soil series) that are arable in the district, soils of the Gbeika series ranked the highest; being highly suitable (S1), followed by soils of Baoma and Mokonde series, which are moderately suitable (S2) in their capacity to satisfy the optimal growth requirements and yield of rice under rainfed upland rice cultivation out of four cultivation schemes under low input level of management. Madina, Bandajuma and Segbwema soils ranked marginally suitable (S3) for rainfed upland rice cultivation. Overall, the results (Tables 19, 20, 21) show that soils on colluvial footslopes and terraces are highly suitable (Gbeika series) to moderately suitable (Mokonde series) rainfed upland rice cultivation.

The availability of water (low water holding capacity), high gravel content, and in some cases extreme limitations of depth and slope were identified as the main limiting factor for these soils.

6.2.1.1 Soils located on sloping terrains

According to the results presented in Table 19, soils located on sloping terrains are generally not suitable for rice cultivation, especially rainfed bunded, natural flooded and irrigated rice production systems due to several limitations, mainly related to topography (i.e., slope) and soil physical conditions (i.e., texture, stoniness, etc.). These soils are only marginally suitable (S3) for rainfed upland rice cultivation, with limitations ranging from slope to soil texture.

Table 19. *Suitability of the Madina-Bandajuma soil association for rice cultivation under four farming systems*

Soil association/series	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Madina	Rainfed Upland rice			■			fs
	Rainfed bunded rice					■	ts
	Natural flooded rice					■	ts
	Irrigated rice					■	ts
Bandajuma	Rainfed Upland rice			■			fs
	Rainfed bunded rice					■	ts
	Natural flooded rice					■	ts
	Irrigated rice					■	ts

s=soil physical characteristics (texture), t = topography (slope)

6.2.1.2 Soils located on dissected uplands of high weathered materials

According to the results presented in Table 20, soils on dissected uplands of high weathered materials are generally moderately suitable (S2) (Baoma series) to marginally suitable (S3) (Segbwema series) for rainfed upland rice cultivation, and not suitable for all the other rice cultivation systems.

Table 20. *Suitability of the Segbwema-Baoma soil association for rice cultivation under four farming systems*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Segbwema	Rainfed Upland rice			■			stf
	Rainfed bunded rice					■	tf
	Natural flooded rice					■	tf
	Irrigated rice					■	tf
Baoma	Rainfed Upland rice		■				stf
	Rainfed bunded rice					■	tf
	Natural flooded rice					■	tf
	Irrigated rice					■	tf

f= fertility (pH, CEC, Base saturation), s=soil physical characteristics (texture, bulk density), t = topography (slope)

6.2.1.3 Soils located on colluvial footslopes and terraces

According to the results presented in Table 21, the suitability of soils on colluvial footslopes and terraces for rice cultivation generally ranges from highly suitable (S1) for Gbeika to moderately suitable (S2) for Mokonde. They are not suitable (S3) for the other rice cultivation systems.

Table 21. *Suitability of Mokonde-Gbeika soil association for rice cultivation under four farming systems*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Mokonde	Rainfed Upland rice		■				sf
	Rainfed bunded rice					■	tf
	Natural flooded rice					■	tf
	Irrigated rice					■	tf
Gbeika	Rainfed Upland rice	■					f
	Rainfed bunded rice					■	tf
	Natural flooded rice					■	tf
	Irrigated rice					■	tf

f= fertility (pH, CEC, Base saturation), s=soil physical characteristics (texture, bulk density), t = topography (slope)

6.2.2 Suitability evaluation for cultivation of other food crops

According to STATSL (2017), cassava, maize, sweet potation, groundnut, and cowpea have also attracted the attention of farmers as major livelihood crops in Sierra Leone. The result of soil suitability evaluation conducted for the cultivation of other food crops including cassava, maize, sweet potato, groundnut, and cowpea reveals that all the seven of the nine-soil series that has been classified as arable are also suitable for the growing of these crops (Tables 22, 23 and 24). The suitability of these soil individuals ranges from moderately suitable (S2) to marginally (S3).

6.2.2.1 Soils located on sloping terrains

A consideration of soil suitability evaluation for soils on steep slopes and hills was done in order to assess their potential for sustainable cultivation of major field crops such as cassava, maize, sweet potato, groundnut, and cowpea. This was based on the fact that though these terrains seem not to be well-suited for growing of major field crops due to limitations such as steep slopes, gravelly soils, somehow shallow depth, and the antecedent soil degradation when these areas are brought under intense cultivation, but at the time of field survey, vast portions of these erosion-prone areas were under agricultural land use; farmers reported that these areas are their only source of livelihood. From our investigation, we observed that the two major soil individuals of these landscape, i.e., the Madina and Bandajuma soils, are moderately suitable (S2) for cassava, groundnut and sweet potato, and marginally suitable (S3) for maize and cowpea (Table 22), with limitations ranging slope, fertility and soil physical characteristics such as pH, CEC and base saturation.

Table 22. *Suitability of the Madina-Bandajuma soil association for cultivation of other food crops*

Soil association/series	**MAFS target crops**	**Suitability class**					**Limitations for management**
		S1	**S2**	**S3**	**N1**	**N2**	
Madina	Cassava		■				tf
	Maize			■			stf
	Sweet potato		■				sf
	Groundnut		■				tf
	Cowpea			■			stf
Bandajuma	Cassava		■				tf
	Maize			■			stf
	Sweet potato		■				sf
	Groundnut		■				tf
	Cowpea			■			stf

f= fertility (pH, CEC, Base saturation), s=soil physical characteristics (texture, bulk density), t = topography (slope)

6.2.2.2 Soils located on uplands of highly weathered materials

A consideration of soil suitability evaluation for upland soils of high weathered materials was done in order to assess their potential for sustainable cultivation of major field crops such as cassava, maize, sweet potato, groundnut, and cowpea. This was based on the fact that during at the time of field survey, vast portion of these erosion-prone areas were under agricultural land use, as the farmers claimed that this was their only source of livelihood. From our investigation, these soils are highly suitable (S1) for cassava, moderately suitable (S2) for sweet potato and groundnut, and marginally suitable (S3) for maize and cowpea (Table 23). Major limitations for use of these soil include moderate to strong slope, some amount of gravels in root zone layer, and fertility problems.

Table 23. *Suitability of the Segbwema-Baoma soil association for cultivation of other food crops*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Segbwema	Cassava						f
	Maize						stf
	Sweet potato						sf
	Groundnut						sf
	Cowpea						stf
Baoma	Cassava						f
	Maize						stf
	Sweet potato						sf
	Groundnut						sf
	Cowpea						stf

f= fertility (pH, CEC, Base saturation), s=soil physical characteristics (texture, bulk density), t = topography (slope)

6.2.2.3 Soils located on colluvial footslopes and terraces

The suitability evaluation of soils on colluvial footslopes and upper terraces reveals that soils of Mokonde and Gbonjeima series are highly suitable (S1) for cassava, sweet potato and groundnut, and moderately suitable (S2) for maize and cowpea (Table 24). These soils show great potential for supporting the growth of short duration varieties of cassava, maize, sweet potato, groundnut, and cowpeas. However, great attention should be paid to contingency crop planning for aberrant weather conditions that are likely to affect the growth and yield performance of these crops.

Table 24. *Suitability of Mokonde-Gbeika soil association for cultivation of other food crops*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Mokonde	Cassava						f
	Maize						sf
	Sweet potato						f
	Groundnut						f
	Cowpea						sf
Gbeika	Cassava						f
	Maize						sf
	Sweet potato						f
	Groundnut						f
	Cowpea						sf

f= fertility (pH, CEC, Base saturation), s=soil physical characteristics (texture, bulk density)

6.2.3 Suitability evaluation for cultivation of vegetable crops

Vegetables provide very important dietary requirements in human nutrition and their role in promoting good growth cannot be underestimated. According to STATSL (2017), about 26% of the country's farming population are into vegetable cultivation. In Kono district, the same 2015 census report reveals that 2,597 households, which account for 0.2% of country's farming population are engaged in vegetable cultivation, accounting for 3,604 hectares (0.1%) of the land under cultivation and yield of 194,618 kg. Hence, soil suitability evaluation would be of immense relevance for improving the productivity of the vegetable subsector. Based on the results (Table 25, 26 and 27), the suitability of soils for vegetable cultivation ranges from moderately suitable (S2) to currently not-suitable(N1). The details are presented below:

6.2.3.1 Soils located on sloping terrains

Soil suitability evaluation for soils on steep slopes and hills in Kono district shows that the arable soils of Madina and Bandajuma series are moderately suitable (S2) for tomato, marginally suitable (S3) for cabbage and currently not-suitable (N1) for onion and carrot due to moderate to extreme limitations of shallow depth and slope, and moisture availability (Table 25). However, with suitable soil conservation management practices, the currently not-suitable soils can be upgraded to marginally suitable (S3) soils.

Table 25. *Suitability of the Madina-Bandajuma soil association for cultivation vegetable crops*

Soil association/series	MAFS target crops	Suitability class S1	S2	S3	N1	N2	Limitations for management
Madina	Onion				X		stf
	Tomato		X				st
	Cabbage			X			st
	Carrot				X		stf
Bandajuma	Onion				X		stf
	Tomato		X				st
	Cabbage			X			st
	Carrot				X		stf

s=soil physical characteristics (texture, bulk density), t = topography (slope)

6.3.3.2 Soils located on uplands of highly weathered materials

Soil suitability evaluation for upland soils of highly weathered materials in Kono district shows that Momenga and Njala soils are only moderately suitable (S2) for tomato and carrot, marginally suitable (S3) for carrot and cabbage, and currently not-suitable (N1) for onion due to extreme limitations of shallow depth and slope, and moisture availability (Table 26). However, with suitable soil conservation management practices, the currently not-suitable soils can be upgraded to marginally suitable (S3) soils.

Table 26. *Suitability of the Segbwema-Baoma soil association for cultivation of vegetable crops*

Soil association	MAFS target crops	Suitability class S1	S2	S3	N1	N2	Limitations for management
Segbwema	Onion				X		t
	Tomato		X				st
	Cabbage			X			st
	Carrot			X			t
Baoma	Onion				X		t
	Tomato		X				st
	Cabbage		X				st
	Carrot			X			t

s=soil physical characteristics (texture, bulk density), t = topography (slope)

6.3.3.3 Soils located on colluvial footslopes and terraces

The suitability of soils on colluvial footslopes and terraces, i.e., soils of Mokonde and Gbeika series ranges from highly suitable (S1) for tomato (Gbeika series), moderately suitable (S2) for onion, tomato and carrot, to marginally suitable (S3) for cabbage (Table 27). This is due to major limitations ranging from imperfect to poor drainage, danger of flash floods, and waterlogging, which are major challenges for growing onion and cabbage on sustainable basis. However, growing these crops during the dry season while making use of residual soil moisture would alternatively help to manage and/or reduce shortages in the district.

Table 27. *Suitability of the Mokonde-Gbeika soil association for cultivation of vegetable crops*

Soil association	MAFS target crops	Suitability class S1	S2	S3	N1	N2	Limitations for management
Mokonde	Onion		X				f
	Tomato		X				f
	Cabbage			X			sf
	Carrot		X				f
Gbeika	Onion		X				f
	Tomato	X					f
	Cabbage			X			sf
	Carrot		X				f

f= fertility (pH, CEC, Base saturation), s=soil physical characteristics (texture, bulk density)

6.3.4 Suitability evaluation for cultivation of tree crops

The tree crop subsector contributes to a major portion of agricultural exports in Sierra Leone. According to STATSL (2017), the main export crops are cocoa, coffee, cola nut and oil palm. In Kono district, the 2015 census report reveals that out of a total of 33,320 agricultural households engaged in tree crop cultivation, 13,872 (i.e., 6.8%) are engaged in cocoa cultivation, 16,685 (i.e., 8.2 %) are engaged in coffee cultivation 2,175 (i.e., 1.1%) are engaged in oil palm cultivation, 505 (i.e., 0.2) are engaged in citrus cultivation, 83 (i.e., 0.1%) are engaged in cashew cultivation. In terms of area under cultivation per tree crop, out of a total area of 320,988 hectares under tree crop, cocoa accounts for 43,231 ha, coffee accounts for 61,651 ha, oil palm accounts for 5,688 ha, citrus accounts for 947 ha and cashew accounts for 608 ha. This is an indication of how important is the tree crop subsector in the national economy development. Based on the results (Table 28, 29 and 30), the suitability of soils for tree crop cultivation ranges from highly suitable (S1) to permanently not-suitable (N2). The details are presented below:

6.3.4.1 *Soils located on sloping terrains*

The suitability of Madina and Bandajuma soils, located on steep slopes and hills, ranges from moderately suitable (S2) for cocoa, arabica coffee and robusta coffee, to marginally suitable (S3) for cashew and oil palm (Table 28). Major limitations are associated with steep slopes, shallow depth, coarse texture due to gravel and fertility, which can be overcome by suitable soil conservation management practices.

Table 28. *Suitability of the Madina-Bandajuma soil association for cultivation tree crops*

Soil association/series	**MAFS target crops**	**Suitability class**					**Limitations for management**
		S1	**S2**	**S3**	**N1**	**N2**	
Madina	Cocoa		■				f
	Arabica coffee		■				f
	Robusta coffee		■				f
	Cashew			■			tf
	Oil palm			■			tf
Bandajuma	Cocoa		■				f
	Arabica coffee		■				f
	Robusta coffee		■				f
	Cashew			■			tf
	Oil palm			■			tf

f= fertility (pH, CEC, Base saturation), t = topography (slope)

6.3.4.2 Soils located on uplands of high weathered materials

The suitability of Segbwema and Baoma soils, located on dissected uplands of high weathered materials, ranges from highly suitable (S1) for cocoa and oil palm (Baoma series) to moderately suitable (S2) for cashew, to marginally suitable (S3) for arabica coffee, robusta coffee and oil palm (Table 29). Major limitations are associated with coarse texture due to high gravel content and fertility, which can be overcome by suitable soil conservation and management practices.

Table 29. *Suitability of Segbwema-Baoma soil association for cultivation of tree crops*

Soil association	**MAFS target crops**	**Suitability class**					**Limitations for management**
		S1	**S2**	**S3**	**N1**	**N2**	
Segbwema	Cocoa		■				f
	Arabica coffee			■			tf
	Robusta coffee			■			tf
	Cashew		■				f
	Oil palm			■			tf
Baoma	Cocoa	■					f
	Arabica coffee			■			tf
	Robusta coffee			■			tf
	Cashew		■				f
	Oil palm	■					tf

f= fertility (pH, CEC, Base saturation), t = topography (slope)

6.3.4.3 Soils located on colluvial footslopes and terraces

The suitability of soils located on colluvial footslopes and terraces, which include Mokonde and Gbeika series, indicates that the soils are highly suitable (S1) for cocoa, cashew and oil palm, and moderately suitable (S2) for arabica coffee and robusta coffee (Table 30). Despite this suitability, there might be few limitations of minor concern that are associated with fertility, which can be overcome by suitable soil conservation management practices.

Table 30. *Suitability of Mokonde-Gbeika soil association for cultivation of tree crops*

Soil association	**MAFS target crops**	**Suitability class**					**Limitations for management**
		S1	**S2**	**S3**	**N1**	**N2**	
Mokonde	Cocoa	■					f
	Arabica coffee		■				f
	Robusta coffee		■				f
	Cashew	■					f
	Oil palm	■					f
Gbeika	Cocoa	■					f
	Arabica coffee		■				f
	Robusta coffee		■				f
	Cashew	■					f
	Oil palm	■					f

f= fertility (pH, CEC, Base saturation)

6.3.5 Suitability evaluation for cultivation of fruit crops

Fruit crops such as mango, citrus, banana and pineapple are often referred to as the breakeven crops for the hunger season in most rural communities in Sierra Leone, especially during the period of June to August, when there is an off-peak moment in the availability of rice, the staple food. These crops also contribute to a major portion of agricultural trade, especially for women in Sierra Leone. This is an indication of how important are these crops in substituting for the staple food. Based on the results (Table 31, 32 and 33), the suitability of soils for fruit crop cultivation ranges from moderately suitable (S2) to permanently not-suitable (N2). The details are presented below:

6.3.5.1 Soils located on sloping terrains

The suitability of arable soils of Madina and Bandajuma series located on steep slopes and hills for fruit crops, ranges from moderately suitable (S2) for banana, marginally suitable (S3) for citrus, pineapple and banana, to currently not-suitable (S3) for mango (Table 31). This is due to major limitations ranging from steep slopes, coarse texture, stoniness, and moisture availability, which are major challenges for growing these crops on sustainable basis under such environmental conditions.

Table 31. *Suitability of the Madina-Bandajuma soil association for cultivation fruit crops*

Soil association/series	**MAFS target crops**	**Suitability class**					**Limitations for management**
		S1	**S2**	**S3**	**N1**	**N2**	
Madina	Mango				■		sf
	Citrus			■			sf
	Pineapple			■			f
	Banana		■				f
Bandajuma	Mango				■		sf
	Citrus			■			sf
	Pineapple			■			f
	Banana		■				f

f= fertility (pH, CEC, Base saturation), s=soil physical characteristics (texture, bulk density), t = topography (slope)

6.3.5.2 Soils located on uplands of high weathered materials

The suitability of Segbwema and Baoma soils ranges from moderately suitable (S2) for pineapple and banana, to marginally suitable (S3) for mango and citrus (for Baoma series) and marginally suitable

(S3) for Segbwema series (Table 32). This marginal suitability for soil of the Segbwema series is due to major limitations ranging from moderate to strong slopes, coarse texture, stoniness, and moisture availability, which are major challenges for growing these crops on sustainable basis under such environmental conditions.

Table 32. *Suitability of the Momenga-Njala soil association for cultivation of fruit crops*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Segbwema	Mango						sf
	Citrus						sf
	Pineapple						f
	Banana						f
Baoma	Mango						sf
	Citrus						sf
	Pineapple						f
	Banana						f

f= fertility (pH, CEC, Base saturation), s=soil physical characteristics (texture, bulk density)

6.3.5.3 Soils located on colluvial footslopes and terraces

The suitability of Mokonde and Gbeika soils shows that these soils are highly suitable (S1) for pineapple and banana to moderately suitable (S2) for mango and citrus (Table 33). This is due to major limitations of moisture availability and fertility to some extent, which are major challenges for growing these crops on sustainable basis under such environmental conditions.

Table 33. *Suitability of the Mokonde-Gbonjeima soil association for cultivation of fruit crops*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Mokonde	Mango						f
	Citrus						f
	Pineapple						f
	Banana						f
Gbeika	Mango						f
	Citrus						f
	Pineapple						f
	Banana						f

f= fertility (pH, CEC, Base saturation)

7 Soil Fertility Management

The soil tests reported in section 4 indicated low soil fertility status of many soils. It is not surprising therefore that the soil suitability evaluation found that the status of soil fertility is a key factor determining the suitability rating of a soil type for a given crop. Soil fertility management is therefore given special attention in this subsection. The capacity of soils to hold on to nutrient cations (cation exchange capacity), prior to crop uptake and soil acidity (which influences the availability to crops of nutrients in the soil) were often the limiting fertility factors. Soils of Sierra Leone are inherently of low fertility compared to soils of the temperate zone, a consequence of the factors of soil formation. They seem fertile when under bush fallow of several years. On clearing the bush and subjecting the soils to cultivation, their fertility declines due to soil nutrient mining (crop removal not replenished), soil erosion, nutrient leaching, method of land clearing and subsequent tillage. This sub-section of the report deals mainly with locally available technologies for overcoming the soil fertility problems outlined for the mapping units in section 4 of the report. Agronomic evidence for managing soil fertility based on soil tests, leaf analysis and field trials is not available for many of the districts and soils and so the presentation cuts across districts, but mention is made of specific locations when that kind of information is available.

Most of the problems associated with land use in Kono district are synonymous to those that have already been mentioned by earlier researchers (e.g., Stobbs, 1963; van Vuure and Miedema, 1973; Odell et al., 1974; UNDP/FAO, 1979, Amara and Momoh, 2014, Amara et al., 2013 and 2021). While farmers continue to modify farming systems and approaches, problems continue to pose major constraint to sustainability in agricultural production.

Several technologies for managing soil fertility are available in West Africa (Jalloh et al., 2011). They include liming, fertilization, seed priming and micro-fertilization, green manuring, composting, agroforestry, night corralling of livestock, small stock manure production and integrated soil fertility management. Technologies available in Sierra Leone for which there is within-country research-based evidence, that can be exploited as opportunities for overcoming the problem of low soil fertility, especially on the fields of small holder farmers, are outlined here for the groups of soils identified by Odell et al. (1974).

In the discussion of soil fertility management options for soils of Kono district, we observed that soils of Kono district share similar characteristics as those of Kenema and Kailahun districts since most of the soil associations and individuals are repeating. Hence, the soil fertility management options remain the same as those discussed for soils of Kenema and Kailahun districts except otherwise where slight modifications in soil properties probably due to land use were observed.

7.1 Well drained and aerobic soils (i.e. soils located on sloping terrains, dissected uplands of high weathered materials such as soils of the Madina, Bandajuma, Segbwem and Baoma series)

The well drained and moderately well drained soils on the uplands, and colluvial footslopes and terraces are of low fertility, in terms of pH, plant available nutrients, moisture availability, and storage capacity for nutrient cations. These soils are usually under serious threats of degradation and if this process is allowed to continue, it would create tremendous problems of run-off and soil erosion resulting in further deterioration of such areas, silting up of major reservoirs and floods. It is therefore extremely important to halt this process. The following management practices can be prioritized to improve the status of these soils:

7.1.1 Control of soil acidity

Control of soil acidity accompanied by increased yields of maize and groundnut by liming has been achieved with commercial calcium carbonate (NARC, 2009; NARC, 2010; Rhodes *et al*., 2020), ground oyster shells (Alpha, 1991a) and basic slag (Kamara and Funnah, 1981). Application of organic materials in the form of biomass from Gliricidia sepium (Robert *et al*., 2013) and Biochar made from rice straw (Kamara *et al*., 2015) also raised soil pH and maize and rice biomass. But Gliricidia was less effective than lime. Most of the evidence were obtained from station research conducted on station at Njala, on the Njala soil series and Rokupr. Liming with dolomitic lime (calcium and magnesium carbonate) would be desirable because of the low content of exchangeable magnesium in these acid soils. Residual values of liming on these very acidic soils need careful investigation to best exploit the value of liming.

7.1.2 Fertilizer use

Fertilizers, mainly NPK compound + urea tested by the FAO Fertilizer Programme of 1961-1986, the Sierra Leone Rice Project, based in Rice Research Station, Rokupr, Kambia district, in the 1970's and the Adaptive Crop Research and Extension Project based in Njala University College in the 1980's and implemented on farmers' fields in the Njala, Kenema, Makeni, Rokupr and Kabala zones raised yields of rice and other food crops. A major problem with the 60 kg N + 40 kg P_2O_5 + 40 kg K_2O ha-1 recommendation developed by RARC for rice, applied as 15:15: 15 compounds plus urea in Sierra Leone, is that in this country it is used as a blanket application. The same applies to the fertilizer recommendations developed by NARC, RARC and Njala University for other crops. Recommendations based on soil analysis (Conteh, 2017), especially when calibrated with crop response to fertilizers in the field (Odell *et al*., 1974) is the right way to go for efficient use of fertilizers and protection of the environment. This would permit choice from a range of compound and straight fertilizers for appropriate sites. The approach would however require capacity strengthening in the form of complementing automated wet analysis with very rapid dry laboratory analysis and implementing trials and demonstrations on carefully chosen and characterized sites, making use of NCSS data. Improving fertilizer use efficiency also requires planting on time, accessing quality fertilizer products, correct methods of fertilizers application, use of good quality seeds of high yielding adapted crop varieties and crop protection (Rhodes, 2012).

Concerning the micronutrients, crop deficiencies of boron, copper, molybdenum and zinc occur in soils of Sierra Leone (Sillaanpa, 1982). Application of molybdenum (Haque and Bundu, 1980; Rhodes and Nangju, 1979; Rhodes and Kpaka, 1982) and zinc (RARC, 2012) increased yields of rice and cowpea. The micronutrients in the last three studies were applied as seed coating or seeds primed with nutrient solutions. The trials were on station at Njala and Rokupr. The findings indicate that there is a potential for increasing crop yields in some areas of Sierra Leone by fertilization with micronutrient carriers in one form or the other. Micronutrient containing fertilizers are however not currently available to smallholder farmers in the country. It should be noted also that an additional benefit of organic materials is that they can be sources of micronutrients. For manganese and iron, the issue is more of toxicity. Iron toxicity to rice occurs in inland valley swamps and can be mitigated by good agronomic practices including use of tolerant varieties, liming, early planting, balanced fertilization recycling of crop residues, and water control. On farm trials and demonstrations are required.

7.1.3 Organic materials with or without fertilizers

Less attention has been given to the evaluation of organic materials as plant nutrient sources which because of their low nutrient content must be applied in heavy doses (tons compared to kilograms per hectare). An agroforestry alley cropping system of maize with Gliricidia sepium at an upland site at Senehun, Kamajei, Moyamba district resulted in significant yield increase of the crop (Karim *et al*., 1993); alley cropping has however not been adopted by farmers in Sierra Leone. Application of biomass of Cassia siamea, Gliricidia sepium, Gmelina arborea and compost in combination with NPK reduced the amount of fertilizers required to attain about the same yield of maize on the Njala soil series (Alpha, 1991b). Use of biomass of leguminous trees -Albizia zygia, Senna siamea and Gliricidia sepium with and without fertilization also resulted in improved rice yields at the Upland Samu site of the Rokupr Agricultural Research Centre (RARC, 2008). In both of these studies the amount of NPK + urea required was reduced when applied in combination with organic materials. This use of biomass from growing trees to amend soils is a promising agroforestry system for smallholders referred to as 'cut and carry'. The findings of these trials are of interest in the light of the escalating price of imported fertilizers. With the availability of adapted fast growing N fixing trees that can grow to heights of 2 to 4m producing 7 to 42 t ha- 1 biomass (MAFFS/MFMR, 2007), improving soil fertility with biomass in combination with fertilizers is an opportunity worth exploitation.

Apart from biomass from trees, there are other organic materials which have shown promise. A reduction in the amount of fertilizers needed when applied in combination with palm kernel cake was shown at the Samu upland site (RARC,2011). A residual effect of palm kernel cake (by-product in the processing of palm kernels for oil) applied in the first year on rice yield in the second year of cropping at the Samu upland site was reported (RARC, 2012). Application of biochar has been shown to increase available P, exchangeable cations and cation exchange capacity of a Njala soil series that led to significant increase of rice biomass (Kamara *et al*., 2015). Other researchers (Lahai *et al*., 2014; Feika *et al*., 2018; Margai *et al*., 2021) have reported crop yield increases on the Njala soil series from application of various types of organic materials. In general, annual additions of organic materials to soils or crop residue recycling can over time lead to increase in humus (the colloidal fraction of soil organic matter) and is therefore an opportunity for increasing cation exchange capacity and therefore soil suitability ratings.

7.1.4 Integrated soil fertility management (ISFM)

Njala University, through the Department of Soil Science and the Department of Forestry, participated in a regional capacity building project on Integrated Soil Fertility Management (ISFM) (FED/2013/320-275) (Kamara and Mattia, 2018). The Project was designed to enhance ISFM capacity aimed at promoting practical knowledge and practices of ISFM and encouraging participation and adoption of ISFM by local farmers.

The Project conducted a situation analysis to understand the local knowledge and capacities on ISFM existing in each country. The survey revealed that there existed some local knowledge on integrated soil management but there was inadequate capacity on ISFM in terms of understanding the basic principles and practices of ISFM and lack of trained (ISFM) manpower to provide technical advisory services to farmers and government.

The project trained 33 local smallholder farmers, 2 staffs from large-scale commercial agricultural industries, 53 staff and 52 students of Higher Education Institutions and research institute on the concepts and practices of ISFM and how to implement ISFM on-farm. ISFM "represents a means to overcome the dilemma of poor soil fertility with poor fertilizer access and the lack of knowledge about how to use them, by offering farmers better returns on investment in fertilizers through combination with indigenous agro-minerals and available organic resources" (Sanginga and Woomer, 2009). These conditions appear to be relevant for Kono district. and the rest of the country. The use of organic materials in combination with fertilizers as mentioned in earlier paragraphs constitute elements of ISFM.

7.1.5 Agroforestry and cover cropping

Agroforestry makes maximum use of the land by growing of both trees and agricultural/horticultural crops on the same piece of land, designed to provide multiple products (tree and other crop). Agroforestry also helps return nutrients to the soil such as nitrogen and at the same time protect, conserve, diversify and sustain important economic, environmental, social and natural resources. Agroforestry provides essential products and services that can help relieve the pressure on the natural forest domain. The system also provide food, fodder, fruit, construction materials, medicine, honey etc. Among the several techniques available in the subregion, cocoa agroforestry in the south-east, boundary planting, woodlot, and fruit orchard systems in the north, has all been proven to be soil and water conserving, nutrient replenishing, and economically sustainable in Sierra Leone (Björkemar, 2014).

7.2 Moderately and imperfectly drained soils (i.e. soils located on colluvial footslopes and terraces such as soils of the Mokonde and Gbeika series)

7.2.1 Fertilizer Use

These soils occur along the major streams, in bolilands and inland valley swamps. Rice response in inland valley swamps and bolilands to fertilizers especially N, P, and K have been reported for several years by the Sierra Leone Rice Project, the Adaptive Crop Research and Extension Project, Rice Research Station, and Rokupr Agricultural Research Centre. More recently, balanced application of

40 kg N + 40 kg P_2O_5 + 40 kg K_2O ha^{-1} based on rice response to fertilizers in the Kambia district was recommended (MAFFS/JICA, 2014). Deficiencies of zinc and sulphur were also found in some sites. The report stressed the need for adoption of improved crop cultural practices prior to the use of fertilizers.

These poorly drained soils are characterized by the development of a redox profile; and beneath the oxidized surface zone there exists an anaerobic zone. In this situation, management of nitrogen fertilizers for good uptake by rice and minimization of loss to the atmosphere (contribution to global warming) is critical. Positive response of rice to urea placed at the 20cm depth in non-acid mangrove soils of Rokupr was reported several years ago (Agyen-Sampong, 1981). The International Fertilizer Development Center has recently developed a Urea Super Granule Injector for efficiently placing urea fertilizer in the reduced zone where it is stable (IFDC, 2017). On farm trials and demonstrations in inland valley swamps and associated swamps with soils of different texture will be required to ascertain where it works best.

7.2.2 Organic Materials

Positive effects of the addition of biomass from N fixing trees on the fertility related properties of an acid hydromorphic soil have been shown (Baggie *et al*, 2000). Also, palm kernel cake was shown to increase yield of rice in an inland valley swamp at Rokupr (Johnson *et al*., 2011). However, compared to upland soils, there is less evidence on the use of organic materials as nutrient carriers.

7.3 Economics of fertilizer and organic materials use

The potential for fertilizer or organic material or lime use under commercial production is linked to the yield increases as well as the monetary returns to investments. Economic analysis done in the 1970s of response to 22.4 kg N + 22.4 kg P_2O_5 ha^{-1} fertilization of several annual crops grown in uplands and lowlands showed high value/cost ratios exceeding 2.0 in the FAO Fertilizer Programme (Zschernitz, 1973). Value/cost ratios from use of 40 kg N + 40 kg P_2O_5 + 40 kg K_2O ha^{-1} in the 1980s were lower but did not drop to below 2.0.(Mahapatra and Jalloh, 1979). The 1970s and 1980s were years when fertilizers were subsidized by government of Sierra Leone. The issue of subsidizing fertilizers is controversial. MAFS is currently promoting a voucher scheme, in cooperation with the private sector, to get fertilizers directly to farmers. However, recent data on the economics of fertilizer, organic materials and lime use is limited. Trials are required with new high yielding varieties, on-farm, in which economic analysis of crop response should be performed. The sensitivity analysis of rice response to fertilizers done by MAFFS/ JICA (2014) is a good start.

7.4 District fertilizer needs

Knowledge of the ranges and levels of key plant essential nutrients documented in section 4 for mapping units in each district in conjunction with information on the soil fertility mapping, expected acreages for cropping and target crop yields could be used to roughly estimate fertilizer or other nutrient carrier needs on a district basis. This is appropriate for the scales at which the soil survey was conducted.

7.5 Land Degradation Risks and Soil Conservations

As mentioned earlier, soil loss by erosion especially in the uplands contributes to the decline of soil fertility over time. Estimated soil loss by erosion and nutrient loss in Sierra Leone and their implications are of concern. Thus, Biot *et al*. (1989) predicted significant decline in maize and cowpea yields in the long term for Makeni as a consequence of soil erosion. Sessay and Stocking (1992) estimated soil loss ranging from 4.85 to 15.45 t ha^{-1} y^{-1} in the Makoni catchment of Makeni. Crasswell *et al*. (2004) estimated annual nutrient loss of 48 Kg N + P_2O_5 + K_2O ha^{-1} for Sierra Leone. Amara and Oladele (2014) calculated the soil erodibility (K-factor) values of soils in the Njala area to predict soil loss. They reported that Mokoli silty clay soils has the highest soil erodibility (K-factor) value of 0.57 ton/acre/ha and Momenga gravely clay, the lowest value of 0.26 ton/acre/ha, which indicates that Mokoli silty clay soils are highly vulnerable to erosion than the Momenga gravelly clay soils. Kamara (2023) reported cumulative soil loss on the Njala sloping of 7.49 t ha^{-1} and loss of nutrients from fertilized soils of 34.63 kg N ha^{-1}, 6.95 kg P ha^{-1}, 40.67 kg K ha^{-1} in three cropping phases/seasons.

Control of erosion by agronomic practices such as planting fast growing N-fixing trees in slopy areas from which biomass can be obtained for amending cropped plots and mulching/ridging on the Njala sloping have potentials. Sawyerr *et al*. (2019) reported that Arch ridging plus mulching gave high net seasonal returns for sweet potato production over 5 cropping seasons. Promising technologies for the control of soil erosion by inexpensive ways are worthy of testing and demonstrating to farmers on their fields.

7.6 Potential areas for investments

The purpose of a scientific agricultural soil suitability evaluation is to guide planners, and investors as to where the most productive lands (S1 and S2) exist for potential investment. The agricultural constraints and how they can be managed by farmers when the S2 soils are put into use are also indicated. Details of their management have been discussed in section 5.3 to guide the agronomic areas management if the soil should be focused to ensure its sustainable use and prevent environmental degradation. Table 34 summarizes the highly suitable (S1) and moderately suitable (S2) classes of soils recommended for agricultural investment in Kono district.

7.7 Development of a National Soil Management Strategy

The NCSS has been successful in updating the 40-year-old reconnaissance soil survey data (UNDP/FAO, 1979) used for planning Sierra Leone’s agricultural development. Scientific data on the land use, soil associations, soil fertility (including acidity) levels, land capability and soil suitability and their limitations can now be used to inform future agricultural planning in the country. Policy makers in the public and private sectors are now empowered to make evidence-based decisions on soil management and crop production potential areas, at the semi-detailed level, for investment in the production of the MAFS target crops. The staff of the Agricultural Engineering Division of MAFS are now equipped with technical skills and scientific information that will guide the effective management of the soil and related resources, thereby contributing well to the goals of MAFS in increasing agricultural production and productivity in an environmentally sound and sustainable way.

It is recommended that MAFS’s policy takes into consideration the evidence that soils with the highest potential for returns to investment in the Pujehun district are:

1. Set up a MAFS divisional/NU departmental/SLARI programme and other stakeholder Steering Committee to agree on aims and approaches and coordinate the process of strategy development, including public aware ness campaigns to incentivize public participation
2. Review the available data and information needs and agree on the core questions for research and stakeholder consultations. These consultations will include focus group discussions in all the 16 districts of Sierra Leone and key informant interviews. Elaborate a detailed “terms of reference’ for the process and assign departmental/divisional/programme responsibilities.
3. Use the soil data and associated maps produced by the NCSS and carry out additional research and consult with all relevant stakeholders to provide inputs.
4. Formulate the strategy, including vision, and mission statements, aims, guiding principles, action plans and institutional arrangements for implementation.
5. Conduct multi-stakeholder workshops to finalize the strategy and secure the buy-in of all relevant stakeholders including the national government
6. Translate the strategy into action plans and budgets and assign institutional roles and responsibilities for implementation.
7. MAFS hasn’t got a soil department within its organogram. Currently, AED superintend over soil in the ministry. While AED has demonstrated the technical capacity to address soil issues related to irrigation planning and management, however, the technical capacity to address major soil issues related to soil quality, soil productivity and soil fertility, as well as the management and conservation of these fragile resources is limited. We are recommending the establishment of a “Soil Department” to serve as the entering point for Feed Salone

Programme. There is need for a detailed soil survey of the entire country but most needfully and urgently in all of the target districts of the Feed Salone Programme. The established soil department in the ministry would help to facilitate the needed soil surveys that would inform MAFS's planning and decision if the "Feed Salone Programme" is to succeed.

Table 34. *Soils with high suitability (S1 and S2) for agricultural investment areas in rice, other food crops, tree crops, fruit trees and vegetables.*

Agricultural investment areas	**Crop type**	**Soil suitability class/ Soil individual**		**Limitations for management**
		Highly suitable (S1)	**Moderately suitable (S2)**	
Rice production	Rainfed upland rice	Gbeika	Baoma, Mokonde	f(pH, CEC), s(texture)
	Rainfed bunded rice	NONE	NONE	t(slope), w(drainage)
	Natural flooded rice			f(pH, CEC), s(texture), w(drainage)
	Irrigated rice			
Other food crop production	Cassava	Segbwema, Baoma, Mokonde, Gbeika	Madina, Bandajuma	f(pH, CEC), s(texture)
	Maize	NONE	Mokonde, Gbeika	f(pH, CEC), s(texture)
	Sweet potato	Mokonde, Gbeika	Madina, Bandajuma, Segbwema, Baoma	f(pH, CEC), s(texture)
	Groundnut	Mokonde, Gbeika	Madina, Bandajuma, Segbwema, Baoma	f(pH, CEC), s(texture)
	Cowpea	NONE	Mokonde, Gbeika, Madina, Bandajuma, Segbwema	f(pH, CEC), t(slope)
Tree crop production	Cacao	Mokonde, Gbeika	Madina, Bandajuma, Mokonde, Gbeika	f(pH, CEC)
	Arabica coffee	NONE	Madina, Bandajuma, Mokonde, Gbeika	f(pH, CEC)
	Robusta coffee		NONE	
	Cashew	Mokonde, Gbeika	Segbwema, Baoma	f(pH, CEC)
	Oil palm	Baoma, Mokonde, Gbeika	NONE	f(pH, CEC)
Fruit crop production	Mango	NONE	Baoma, Mokonde, Gbeika	
	Citrus		Baoma, Mokonde, Gbeika	
	Pineapple	Segbwema, Baoma, Mokonde, Gbeika	NONE	f(pH, CEC)
	Banana	Segbwema, Baoma, Mokonde, Gbeika	Madina, Bandajuma	f(pH, CEC), t(slope)
Vegetable production	Onion	NONE	Mokonde,	f(pH, CEC), s(structure)
	Tomato	Gbeika	Madina, Bandajuma, Segbwema, Baoma, Mokonde	f(pH, CEC), t(slope)
	Cabbage	NONE	Baoma	f(pH, CEC), s(texture)
	Carrot		Mokonde, Gbeika	f(pH, CEC), s(structure)

f= fertility (pH, CEC, Base saturation), w= wetness (drainage, flooding)

8 Conclusions and Recommendations

The NCSS has been successful in updating the 40-year-old reconnaissance soil survey data (UNDP/FAO, 1979) used for planning Sierra Leone's agricultural development. Scientific data on the land use, soil associations, soil fertility (including acidity) levels, land capability and soil suitability and their limitations for the district of Kono can now be used to inform future agricultural planning in the country. Policy makers in the public and private sectors are now empowered to make evidence-based decisions on soil management and crop production potential areas, at the semi-detailed level, for investment in the production of the MAFS target crops. The staff of the Agricultural Engineering Division of MAFS (MAFS-AED) is now equipped with scientific information that will guide the effective management of the soil and related resources, thereby contributing well to the goals of MAFS in increasing agricultural production and productivity in an environmentally sound and sustainable way.

It is recommended that MAFS's policy take into consideration the evidence that soils with the highest potential for returns to investment in the Kono district are:

i. Gbeika soils of high suitability (S1), and Baoma and Mokonde soils of moderate suitability (S2) for rainfed upland rice;
ii. Segbwema, Baoma, Mokonde, and Gbeika soils of high suitability (S1) for cassava, sweet potato and groundnut; and Madina, Bandajuma, Segbwema, Baoma, Mokonde, and Gbeika soils of moderate suitability (S2) for cassava, maize, sweet potato, groundnut and cowpea;
iii. Baoma, Mokonde, and Gbeika soils of high suitability (S1) for cocoa, cashew, and oil palm; and Madina, Bandajuma, Segbwema, Baoma, Mokonde, and Gbeika soils of moderate suitability (S2) for cocoa, Arabica coffee and cashew;
iv. Segbwema, Baoma, Mokonde, and Gbeika soils of pineapple and banana, and Madina, Bandajuma, Baoma, and Mokonde of moderate suitability (S2) for mango, citrus and banana; and
v. Gbeika soils of high suitability for tomato, and Madina, Bandajuma, Segbwema, Baoma, Mokonde, and Gbeika soils of moderate suitability (S2) for onion, tomato, cabbage and carrot.
vi. MAFS hasn't got a soil department within its organogram. Currently, AED superintend over soil in the ministry. While AED has demonstrated the technical capacity to address soil issues related to irrigation planning and management, however, the technical capacity to address major soil issues related to soil quality, soil productivity and soil fertility, as well as the management and conservation of these fragile resources is limited. We are recommending the establishment of a "Soil Department" to serve as the entering point for Feed Salone Programme. There is need for a detailed soil survey of the entire country but most needfully and urgently in all of the target districts of the Feed Salone Programme. The established soil department in the ministry would help to facilitate the needed soil surveys that would inform MAFS's planning and decision if the "Feed Salone Programme" is to succeed.

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Appendices

__1a.__ Soil profile description of profile pit No. KON001; Madina series

District: Kono; **Chiefdom**: Fiama; **Village**: Bekoh; **GPS location**: 8.63536°/10.79826 °; **Elevation**: 453m; **Physiography**: Undulating plain; La**ndform/facet**: Interfluve crest; Parent **Material**: Weathered Residium; **Landscape position**: Summit/crest; **Slope**: 8.2%; **Vegetation**: Savanna grassland with tress sparsely occupying some areas; **Erosion class and intensity**: e2, slight; **Drainage and permeability:** Well drained and rapid; **Landuse**: Tree cropping; **Major crops grown**: Cocoa, coffee, and banana.

Land System: Koidu

Classification : USDA Taxonomy: Plinthic Paleudult **FAO-UNESCO:** Haplic plinthosol

Mapping Unit: KON001 Gravel-free soil	**Horizon (cm)**	**Morphological Description**
	Ah (0 – 43)	Red (2.5YR5/8 dry) and dark red (2.5YR3/6 moist); sandy loam; moderate, fine, crumbly; slightly hard (dry), friable (moist); not sticky and not plastic; plenty very fine, fine, medium, coarse pores; plenty very fine, fine, few medium roots; presence of open boreholes, termites, millipedes, ants and other insects; clear and wavy boundary to horizon below.
	Bt1 (43 – 140)	Red (2.5YR5/8 dry and 2.5YR4/8 moist); sandy clay loam; moderate, fine, crumbly; slightly hard (dry), friable (moist); slightly sticky and slightly plastic; plenty very fine, fine, medium, very few coarse pores; plenty very fine, fine, few medium roots; presence of termites, ants and other insects; clear and wavy boundary to horizon below.
	Bt2 (140 – 165+)	Light red (2.5YR 6/8 dry) and red (2.5YR5/8 moist); sandy clay; moderate, fine, crumbly and sub-angular blocky; slightly hard (dry), friable (moist); slightly sticky and slightly plastic; few very fine, fine and plenty medium, and coarse pores; common very fine, plenty fine, and few medium roots; presence of termites, ants and other insects; clear and wavy boundary to horizon above.

***1b.** Analytical laboratory data of profile pit No. KON001; Madina series*

Horizon (cm)	**Unit**	**0-43**	**43-140**	**140-165**
Sand	%	64.96	46.96	46.96
Silt	%	10.00	22.00	8.00
Clay	%	25.04	31.04	45.04
Organic Carbon	%	4.05	0.83	0.70
Bray P1	mg/kg soil	4.05	4.05	2.81
pH 1:1 soil : water ratio		5.60	5.90	5.90
pH 1:1 M KCl ratio		4.30	4.30	4.40
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	5.22	2.59	3.12
Exchangeable calcium	mg/kg soil	1.79	0.35	0.42
Exchangeable magnesium	mg/kg soil	1.33	1.14	0.91
Exchangeable potassium	mg/kg soil	0.32	0.12	0.06
Exchangeable sodium	mg/kg soil	0.24	0.23	0.04
Exchangeable acidity	cmol/kg soil	1.54	0.75	1.69
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	24.00	19.00	17.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	15.02	9.99	4.54
DTPA extractable copper (mg kg^{-1})	mg/kg soil	1.66	1.10	0.50
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	4.69	3.12	1.41

2a. Soil profile description of profile pit No. KON002; Bandajuma series

District: Kono; **Chiefdom**: Fiama; **Village**: Bandaseidu; **GPS location**: 8.58464°/10.65314°; **Elevation**: 328m; **Physiography**: Undulating plain; La**ndform/facet**: Interfluve side slope; Parent **Material**: Weathered Residium; **Landscape position**: Foot slope; **Slope**: 1.7%; **Vegetation**: Shrubs; **Erosion class and intensity**: e2, slight; **Drainage and permeability:** Well drained and rapid; **Landuse**: Agriculture/fallow land; **Major crops grown**: Rice.

Land System: Blama
Classification : USDA Taxonomy: Typic haplorthox **FAO-UNESCO:** Orthic Ferralsol

Mapping Unit: KON002
(Gravel over gravel-free)

Horizon (cm)	Morphological Description
Ahe (0 – 20)	Strong brown (7.5YR 8/8 dry and 7.5YR 5/6 moist); sandy loam; moderate, fine, crumbly; slightly hard (dry), friable (moist); non-sticky and non-plastic; common very fine, fine and medium pores; common very fine, plenty fine, few medium, few coarse and very few vey coarse roots; presence of earthworms, termites, millipedes, ants and other insects; clear and smooth boundary to horizon below.
Bh (20 – 66)	Reddish yellow (7.5YR 6/8 dry and 7.5YR 6/6 moist); sandy clay; moderate, medium, crumbly and sub-angular blocky; hard (dry), firm (moist); slightly sticky and slightly plastic; common very fine, fine and medium pores; common very fine, plenty fine and few medium roots; presence of termites, ants and other insects; clear and irregular boundary to horizon below.
Bt (66 – 107)	Reddish yellow (7.5YR 7/8 dry and 7.5YR 6/8 moist); sandy clay; strong, fine, angular and sub-angular blocky; hard (dry), firm (moist); slightly sticky and slightly plastic; common very fine, fine, medium and very few coarse pores; common very fine, plenty fine, and medium roots; presence of earthworms, termites, ants and other insects; gradual and smooth boundary to horizon below.
Cg (107 – 160+)	Reddish yellow (7.5YR 8/6 dry and 7.5YR 7/8 moist); sandy clay; strong, massive, angular and sub-angular blocky; hard (dry), firm (moist); slightly sticky and slightly plastic; common very fine, fine and medium, and few coarse pores; common very fine, few fine and medium roots; presence of earthworms, termites, ants and other insects; presence of abundant soft mottles (2.5YR4/8 – red/moist); clear and smooth boundary to horizon below.

2b. Analytical laboratory data of profile pit No. KON002; Bandajuma series

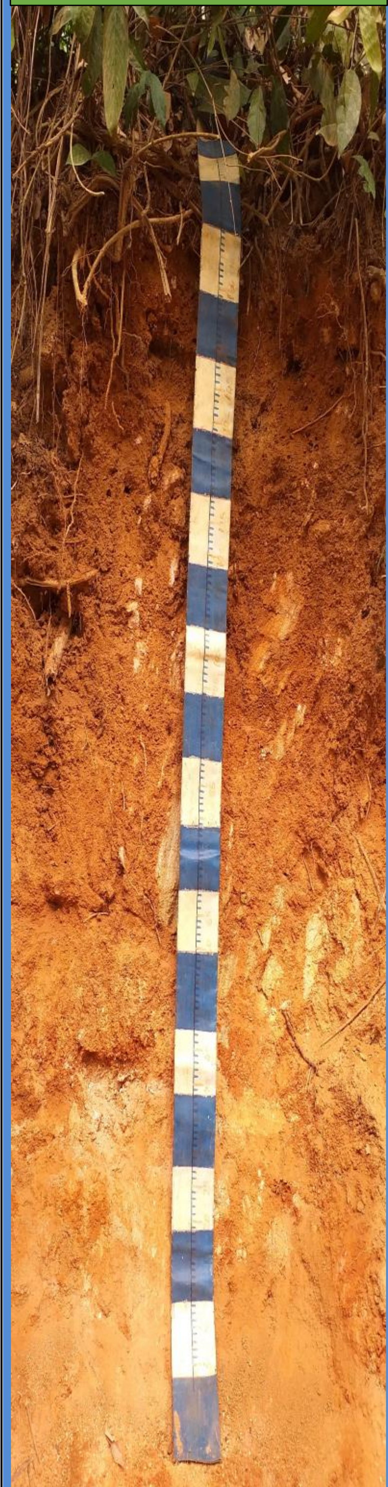
Horizon (cm)	**Unit**	**0-20**	**20-66**	**66-107**	**107-160**
Sand	%	72.96	74.96	62.96	62.96
Silt	%	12.00	10.00	10.00	12.00
Clay	%	15.04	15.04	27.04	25.04
Organic Carbon	%	1.53	0.62	0.25	0.12
Bray P1	mg/kg soil	7.76	5.28	2.81	4.05
pH 1:1 soil : water ratio		5.30	5.40	5.70	5.90
pH 1:1 M KCl ratio		4.20	4.20	4.40	4.50
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	3.82	6.22	2.14	2.41
Exchangeable calcium	mg/kg soil	1.19	1.02	0.57	0.28
Exchangeable magnesium	mg/kg soil	1.62	1.51	0.66	0.58
Exchangeable potassium	mg/kg soil	0.34	0.1	0.08	0.05
Exchangeable sodium	mg/kg soil	0.22	0.21	0.04	0.04
Exchangeable acidity	%	0.45	3.38	0.79	1.46
Electrical conductivity(salinity) in 1:5 soil water ratio	μS/cm	28.00	25.00	21.00	17.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	20.62	12.29	3.10	1.10
DTPA extractable copper (mg kg^{-1})	mg/kg soil	2.28	1.36	0.34	0.12
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	6.44	3.83	0.96	0.34

3a. *Soil profile description of profile pit No. KON003; Segbwema series*

District: Kono; **Chiefdom**: Gbane; **Village**: Papuima; **GPS location**: 8.51396°/10.90759°; **Elevation**: 379m; **Physiography**: Undulating plain; La**ndform/facet**: Dissected plain; Parent **Material**: Weathered Residium; Landscape **position**: crest; **Slope**: 4.3%; **Vegetation**: Semi-deciduous trees and shrubs; **Erosion class and intensity**: e2, Severe; **Drainage and permeability:** Well drained and rapid; **Landuse**: Tree crop plantation; **Major crops grown**: Coffee.

Land System: Kulufaga
Classification : USDA Taxonomy: Plinthic dystropept **FAO-UNESCO:** Dystric Nitosol

Mapping Unit: KON003
Gravel-free soil



Horizon (cm)	Morphological Description
Ae (0 – 40)	Red (2.5YR 4/8 dry and 2.5YR 4/6 moist); sandy loam; moderate, coarse, crumbly; slightly hard (dry), friable (moist); non-sticky and non-plastic; common very fine, fine, medium, and coarse pores; common very fine, plenty fine, few medium, very few coarse roots; presence of earthworms, termites, millipedes, ants and other insects; clear and smooth boundary to horizon below.
Bv1 (40 – 117)	Red (2.5YR 5/8 dry and 2.5YR 6/8 moist); gravelly sandy clay; moderate, coarse, crumbly; slightly hard (dry), friable (moist); non-sticky and non-plastic; few very fine, fine and common medium, and few coarse pores; common very fine, plenty fine, few medium, coarse and very coarse roots; presence of termites, ants and other insects; diffuse and irregular boundary to horizon below.
Bv2 (117 – 170+)	Light red (2.5YR 6/8 dry and 2.5YR 6/6 moist); gravelly sandy clay; strong, coarse, angular blocky; slightly hard (dry), friable (moist); slightly sticky and slightly plastic; common very fine, fine and medium, and few coarse pores; common very fine, plenty fine, and few medium roots; presence of earthworms, termites, ants and other insects; gradual and irregular boundary to horizon below.

3b. Analytical laboratory data of profile pit No. KON003; Segbwema series

Horizon (cm)	**Unit**	**0-40**	**40-117**	**117-170**
Sand	%	72.96	68.96	76.96
Silt	%	12.00	12.00	8.00
Clay	%	15.04	19.04	15.04
Organic Carbon	%	1.61	0.83	0.33
Bray P1	mg/kg soil	17.66	4.05	5.28
pH 1:1 soil : water ratio		5.00	5.40	5.50
pH 1:1 M KCl ratio		4.20	4.20	4.20
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	4.54	4.99	3.62
Exchangeable calcium	mg/kg soil	1.75	1.50	1.50
Exchangeable magnesium	mg/kg soil	0.82	0.63	1.21
Exchangeable potassium	mg/kg soil	0.36	0.18	0.16
Exchangeable sodium	mg/kg soil	0.18	0.17	0.15
Exchangeable acidity	cmol/kg soil	1.43	2.51	0.60
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	41.00	30.00	25.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	23.52	15.19	6.00
DTPA extractable copper (mg kg^{-1})	mg/kg soil	2.61	1.68	0.66
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	7.34	4.71	1.83

4a. Soil profile description of profile pit No. KON004; Baoma series

District: Kono; **Chiefdom**: Gorama Kono; **Village**: Kangama; **GPS location**: 8.36259°/11.05808°; **Elevation**: 242m; **Physiography**: On acid rock; La**ndform/facet**: Side slope; **Parent Material**: Weathered Residium; **Landscape position**: Back slope; **Slope**: 3.3%; **Vegetation**: Plantation forestry with deciduous and semi-deciduous trees and shrubs; **Erosion class and intensity**:e2, slight; **Drainage and permeability:** Well drained and rapid; **Landuse**: Plantation forestry; **Major crops grown**: Cocoa, Coffee, Avogadro, banana.

Land System: Kailahun

Classification : USDA Taxonomy: Typic Paleaquult **FAO-UNESCO:** Dystric Nitosol

Mapping Unit: KON004 (Gravel-free soil)	**Horizon (cm)**	**Morphological Description**
	Ah (0 – 60)	Red (10R 5/8 dry and 10R 4/8 moist); sandy loam; moderate, fine, crumbly; slightly hard (dry), friable (moist); non-sticky and non-plastic; plenty very fine, fine, and medium pores; plenty very fine, fine, medium, and few coarse roots; presence of termites, millipedes, ants and other insects; clear and wavy boundary to horizon below.
	Bt1 (60 – 165)	Light red (10R 6/8 dry) to red (10R 5/8 moist); silty clay; moderate, fine, crumbly and sub-angular blocky; slightly hard (dry), firm (moist); slightly sticky and slightly plastic; plenty very fine, fine, and medium pores; plenty very fine, fine, medium, very few coarse roots; presence of earthworms and few burrows, termites, ants and other insects; clear and wavy boundary to horizon below.
	Bt2 (165 – 192)	Reddish yellow (5YR6/8 dry and 5Y6/6 moist); sandy clay; strong, fine, crumbly and sub-angular blocky; hard (dry), firm (moist); non-sticky and non-plastic; very few very fine, fine, medium pores; plenty very fine, fine, medium roots; presence of termites, ants and other insects; clear and smooth boundary to horizon below.
	Cr (192 – 300+)	Reddish yellow (5Y6/8 dry) and yellowish red (5Y7/6 moist); sandy clay; moderate, coarse, crumbly; slightly hard (dry), friable (moist); non-sticky and non-plastic; plenty fine, medium, few coarse pores; very few very fine and few fine, medium roots; horizon dominated by freshly decomposed rock materials; presence of termites, ants and other insects.

4b. Analytical laboratory data of profile pit No. KON004; Baoma series

Horizon (cm)	Unit	0-60	60-165	165-192	192-300
Sand	%	64.96	58.96	74.96	76.29
Silt	%	8.00	12.00	8.00	9.33
Clay	%	27.04	29.04	17.04	14.37
Organic Carbon	%	0.99	0.70	0.74	0.56
Bray P1	mg/kg soil	6.52	2.81	1.57	1.30
pH 1:1 soil : water ratio		5.00	5.60	5.80	5.27
pH 1:1 M KCl ratio		4.00	4.30	4.40	4.63
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	6.66	4.21	3.06	2.36
Exchangeable calcium	mg/kg soil	1.69	0.81	0.62	1.03
Exchangeable magnesium	mg/kg soil	1.95	0.95	0.84	0.14
Exchangeable potassium	mg/kg soil	0.35	0.05	0.02	0.02
Exchangeable sodium	mg/kg soil	0.23	0.22	0.04	0.03
Exchangeable acidity	cmol/kg soil	2.44	2.18	1.54	1.15
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	47.00	19.00	17.00	14.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	3.10	15.02	9.99	16.26
DTPA extractable copper (mg kg^{-1})	mg/kg soil	0.34	1.66	1.10	1.79
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	0.96	4.69	3.12	2.08

5a. Soil profile description of profile pit No. KON005; Mokonde series

District: Kono; **Chiefdom**: Gbane; **Village**: Koriguma; **GPS location**: 8.40834°/10.84312°; **Elevation**: 250m; **Physiography**: Undulating plain; La**ndform/facet**: Dissected plain/ Interfluve crest; Parent **Material**: Weathered Residium; **Landscape position**: Back slope; **Slope**: 3.1%; **Vegetation**: Semi-deciduous dwarf shrubs; **Erosion class and intensity**: e2, moderate; **Drainage and permeability:** Well drained and rapid; **Landuse**: Tree crop plantation; **Major crops grown**: Cocoa, coffee and oil palm.

Land System: Kailahun

Classification : USDA Taxonomy: Udoxic dystropept **FAO-UNESCO:** Ferralic Cambisol

Mapping Unit: KON005 (Gravel-free over gravel soil)

Horizon (cm)	Morphological Description
Ap (0 – 26)	Reddish brown (2.5YR 5/4 dry and 2.5YR 4/4 moist); sandy loam; moderate, fine, crumbly; slightly hard (dry), friable (moist); not sticky and not plastic; plenty very fine, fine, medium pores; plenty very fine and fine, roots; presence of termites, millipedes, ants and other insects; clear and smooth boundary to horizon below.
Bt1 (26 – 68)	Light red (2.5YR 5/6 dry and 2.5YR 4/6 moist); sandy clay; moderate, fine, angular and sub-angular blocky; slightly hard (dry), friable (moist); sticky and plastic; plenty very fine, fine and very few medium pores; plenty very fine and fine roots; presence of few open boreholes, termites, ants and other insects; clear and gradual boundary to horizon below.
Bt2 (68 – 140+)	Light red (2.5YR 5/8 dry and 2.5YR 4/8 moist); sandy clay; moderate, fine, angular and sub-angular blocky; slightly hard (dry), firm (moist); sticky and plastic; plenty very fine and fine pores; common very fine and fine roots; presence of open boreholes, termites, ants and other insects; clear and wavy boundary to horizon below.

5b. Analytical laboratory data of profile pit No. KON005; Mokonde series

Horizon (cm)	Unit	0-26	26-68	68-140+
Sand	%	74.96	66.96	70.96
Silt	%	8.00	8.00	8.00
Clay	%	17.04	25.04	21.04
Organic Carbon	%	3.02	2.81	0.62
Bray P1	mg/kg soil	21.37	6.52	4.05
pH 1:1 soil : water ratio		5.00	5.20	5.50
pH 1:1 M KCl ratio		4.20	4.20	4.30
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	6.47	7.86	5.90
Exchangeable calcium	mg/kg soil	1.86	1.54	1.64
Exchangeable magnesium	mg/kg soil	1.26	0.56	0.6
Exchangeable potassium	mg/kg soil	0.17	0.12	0.11
Exchangeable sodium	mg/kg soil	0.18	0.16	0.17
Exchangeable acidity	cmol/kg soil	3.00	5.48	3.38
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	71.00	34.00	28.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	16.19	14.32	9.16
DTPA extractable copper (mg kg^{-1})	mg/kg soil	1.79	1.58	1.01
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	5.03	4.43	2.85

6a. Soil profile description of profile pit No. KON006; Gbeika series

District: Kono; **Chiefdom**: Tankoro; **Village**: Woama; **GPS location**: 8.55873°/10.93678°; **Elevation**: 391m; **Physiography**: Undulating plain; La**ndform/facet**: Dissected plain/ Interfluve side slope; **Parent Material**: Weathered Residium; **Landscape position**: Back slope; **Slope**: 3%; **Vegetation**: Grassland dominated by elephant grass; **Erosion class and intensity**:e1, slight; **Drainage and permeability:** Well drained and rapid; **Landuse**: Fallow shifting cultivation with newly planted oil palms; **Major crops grown**: Rice and oil palm.

Land System: Koidu

Classification : USDA Taxonomy: Udoxic dystropept **FAO-UNESCO:** Ferralic Cambisol

Mapping Unit: KON006 (Gravel-free soil)

Horizon (cm)	Morphological Description
Ap (0 – 30)	Light reddish brown (5YR 6/4 dry) and reddish brown (5YR 5/4 moist); sandy loam; moderate, fine, crumbly; slightly hard (dry), friable (moist); not sticky and not plastic; plenty very fine, fine, medium pores; plenty very fine, fine, very few coarse roots; presence of open boreholes, termites, millipedes, ants and other insects; clear and smooth boundary to horizon below.
Bt1 (30 – 55)	Reddish yellow (5YR 6/6 dry) and yellowish red (5YR5/6 moist); sandy clay loam; moderate, fine, crumbly and sub-angular blocky; slightly hard (dry), friable (moist); not sticky and not plastic; plenty very fine, fine and medium pores; common very fine and few fine roots; presence of open boreholes, termites, ants and other insects; clear and gradual boundary to horizon below.
Bt2 (55 – 76)	Pink (5YR7/4 dry) and reddish yellow (5YR 6/6 moist); sandy clay; moderate, fine, crumbly and sub-angular blocky; slightly hard (dry), friable (moist); slightly sticky and slightly plastic; plenty very fine, fine and medium pores; common very fine and few fine roots; presence of few open boreholes, termites, ants and other insects; clear and wavy boundary to horizon below.
Cr (90 – 120+)	Pink (5YR 7/4 dry and 5YR 7/3 moist); sandy clay; moderate, fine, crumbly and sub-angular blocky; slightly hard (dry), friable (moist); slightly sticky and slightly plastic; plenty very fine, fine and medium pores; common very fine and few fine roots; presence of few open boreholes, termites, ants and other insects; clear and wavy boundary to horizon below.

6b. Analytical laboratory data of profile pit No. KON006; Gbeika series

Horizon (cm)	Unit	0-30	30-55	55-76	76-120
Sand	%	70.96	70.96	64.96	70.96
Silt	%	12.00	12.00	10.00	10.00
Clay	%	17.04	17.04	25.04	19.04
Organic Carbon	%	1.53	1.12	0.37	0.29
Bray P1	mg/kg soil	21.37	18.9	5.28	2.81
pH 1:1 soil : water ratio		4.90	5.30	5.30	5.50
pH 1:1 M KCl ratio		4.00	4.2.00	4.20	4.30
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	6.35	4.50	4.91	4.23
Exchangeable calcium	mg/kg soil	2.19	1.50	1.39	1.39
Exchangeable magnesium	mg/kg soil	1.24	1.12	0.64	0.56
Exchangeable potassium	mg/kg soil	0.11	0.06	0.05	0.02
Exchangeable sodium	mg/kg soil	0.18	0.17	0.17	0.16
Exchangeable acidity	%	2.63	1.65	2.66	2.10
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	56.00	39.00	31.00	27.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	17.92	12.89	7.43	8.15
DTPA extractable copper (mg kg^{-1})	mg/kg soil	1.98	1.42	0.82	0.90
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	5.59	3.99	2.31	2.54