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 Pujehun district, which is in the Southern Region, and borders the Atlantic Ocean in the southwest, the Republic of Liberia to the southeast, Kenema district to the northeast, Bo district to the north and Bonthe district to the west. The district comprises 14 chiefdoms including Barri, Gallines, Kabonde, Kpaka, Kpanga, Kpanga Krim, Makpele, Malen, Mano Sakrim, Pejeh, Perri, Soro Gbema, Sowa, and Yakemu Kpukumu Krim chiefdoms. Its capital and largest city is Pujehun.

The climate is tropical with two distinct seasons: rainy season (May to October) and dry season (November to April). Rainfall is highest in the coastal areas, with annual rainfall ranging from 2899 mm in Malen, Sowa and Peje, and parts of Barri and Kabonde chiefdoms in the northeast to 4429 mm in Kpaka and Soro Gbema 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 the Kasila group and granite migmatite complex of the Archean basement, belonging to the Kenema-Man Archaean domain of the West African craton. Also associated with the geological formation is the deposition of Tertiary to Recent Bullom Group deposits, which occupy a belt along the coastal areas of the district including Kpaka, Mano Sakrim, Soro Gbema and Yakemoh Kukumu Krim chiefdoms. These deposits rest uncomformably on the Kasila Group and comprised of nearly horizontal beds of marine, estuarine and fluvial gravels, sands and clays of sedimentary origin.

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; 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 Mokonde-Bonjema soil association, which are soils found on colluvial footslopes and terraces occupy the largest area (1692.7 km^2). This is followed by Scarcies-Turner soil association (1205.8 km^2), Momenga-Njala soil association (655.0 km^2), and Newton-Gbesebu-Torma Bum soil association (137.3 km^2).

The arable land area comprises soils on uplands of high weathered materials, which accounts for 655.0 km^2 (17.5 %), soils on colluvial footslopes and terraces, which accounts for 1692.7 km^2 (45.3 %), riverain soils which accounts for 137.3 km^2 (3.7 %), and floodplain soils which account for 1205.8 km^2 (32.3 %) respectively. Four land capability classes were identified and mapped, ranging from soils suited for cultivation with moderate limitations or risks of damage from floods to soils that are moderately steep, and having severe limitations that restrict their use to grazing and forestry. Class I lands include soils of the Newton series. These soils have few limitations for cultivation, mainly soil fertility issues. Class II lands, which are soils suited for cultivation but having moderate risks of damage from flooding, include soils of the Torma Bum, Gbesebu and Bonjema series. Class III lands include soils of the Scarcies, Momenga, Mokonde and Njala series; and class VI lands are those of the Scarcies series.

Soil suitability analysis indicates that Newton, Gbesebu, Torma Bum, Scarcies soils are of highly suitable (S1) for Rainfed upland and natural flooded rice, while Mokonde, Gbonjeima, Newton, Gbesebu, Torma Bum and Scarcies are moderately suitable (S2) for rainfed upland rice and irrigated rice. For food crops, Momenga, Njala, Mokonde, Gbonjeima, Newton and Gbesebu soils are highly suitable (S1) to moderately suitable (S2) for cassava, sweet potato and groundnut, maize and cowpea. For tree crops, Momenga, Njala, Mokonde, Gbonjeima, Newton, Gbesebu and Turner soils are moderately suitable (S2) for cocoa, Arabica and Robusta Coffee, cashew and oil palm. For fruit crops, Mokonde, Gbonjeima, Newton, Gbesebu soils are highly suitable (S1) for pineapple and banana, while Momenga, Njala, Mokonde, Gbonjeima, Newton, Gbesebu, Torma Bum, Scarcies and Turner soils are moderately suitable (S2) for mango, citrus, pineapple and banana. For vegetables, Mokonde, Gbonjeima, Newton, Gbesebu, Torma Bum 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 soil conservation. The investment strategy should include the conduct of trials on farmers' fields on benchmark sites and scaling up of proven agronomic and cost-effective 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. Drainage to allow the cultivation of more upland crops on the extensive fluvial flood plains is worthy of investigation.

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).

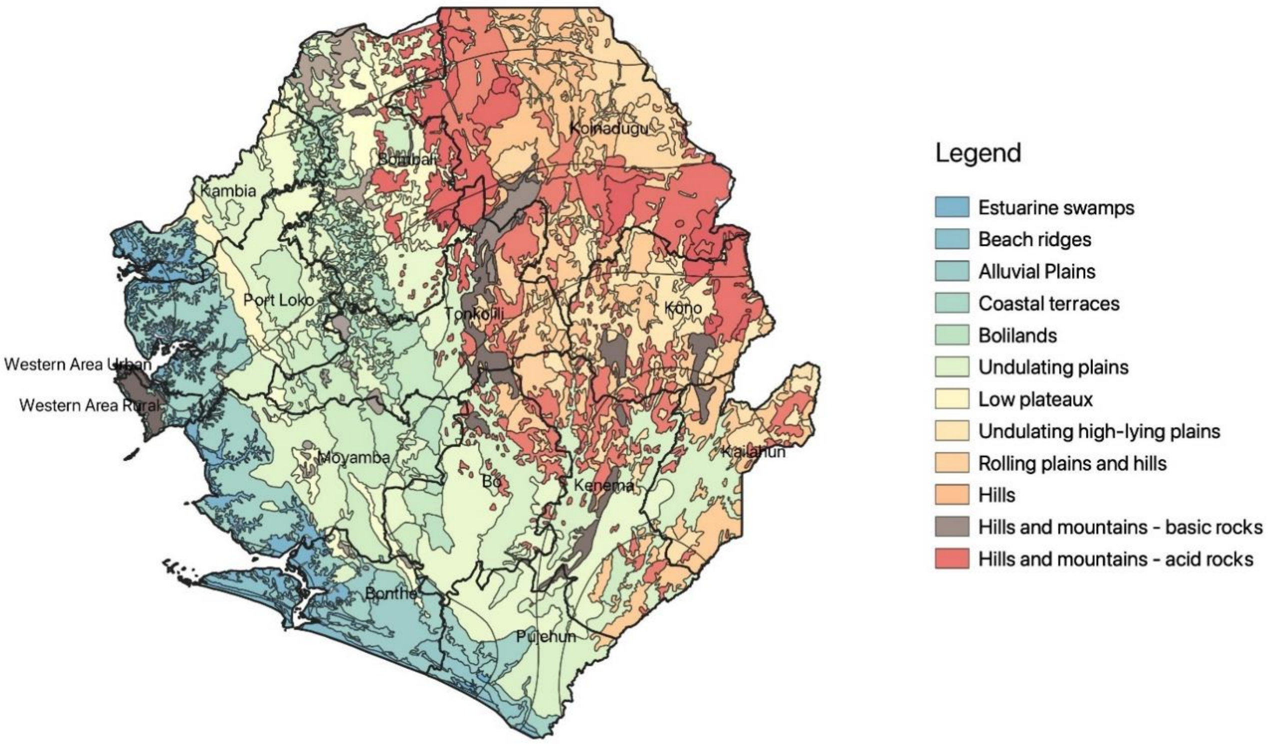

***Figure 1**. Land systems map of Sierra Leone (UNDP/FAO, 1979)*

***Table 1.** Land regions, sub regions and systems of Sierra Leone presented and described in the 1979 Reconnaissance Survey of Sierra Leone*

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 – spanning from well drained shallow soils on hill tops down 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.

Pujehun 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 hills, upland erosion surfaces, colluvial footslopes and upper terraces and swamps, and alluvial floodplains from which 9 major soil series occurred including Momenga, Njala, Mokonde, Gbonjeima, Newton, Gbesebu, Torma Bum, Scarcies, and Turner series. The semi-detailed soil survey work of Veldkamp (1980), Sutton et al (1980) and Odel et al (1980); and recent detailed soil survey by Amara et al (2011, 2013) 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 km2, 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 Policy and Plans, Sierra Leone Soils, and the National Comprehensive Soil Survey

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 and Westerveld, 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

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 Pujehun 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

Pujehun District is located on Longitude -11.138°W to -11.964°W and Latitude 6.915°N - 7.678°N in the Southern Province of Sierra Leone. It is bordered by the Atlantic Ocean in the southwest, the Republic of Liberia to the southeast, Kenema district to the northeast, Bo district to the north and Bonthe district to the west. The town of Pujehun is the capital of the district. The district has a geographical area of about 4,105 km2 and is comprised of 14 chiefdoms including Barri, Gallines, Kabonde, Kpaka, Kpanga, Kpanga Krim, Makpele, Malen, Mano Sakrim, Pejeh, Perri, Soro Gbema, Sowa, Yakemu Kpukumu Krim (Figure 2). The district accounts for 4.8% of the country's population, amounting to 346,461 (STATSL, 2017), is predominantly Muslim mainly belonging to the Mende ethnic group. The district is very rural, and most of its inhabitants are settled in small villages usually with fewer than 200 heads. It is recognized as one of the poorest regions 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. Despite the well adapted terrain features for arable crop production with 79.3% of the population engaged in agriculture as the main livelihood (STATSL, 2013), the district has about 54% of poverty rate (World Bank and STATSL, 2013) and 80% prevalence of food insecurity (WFP, 2015).

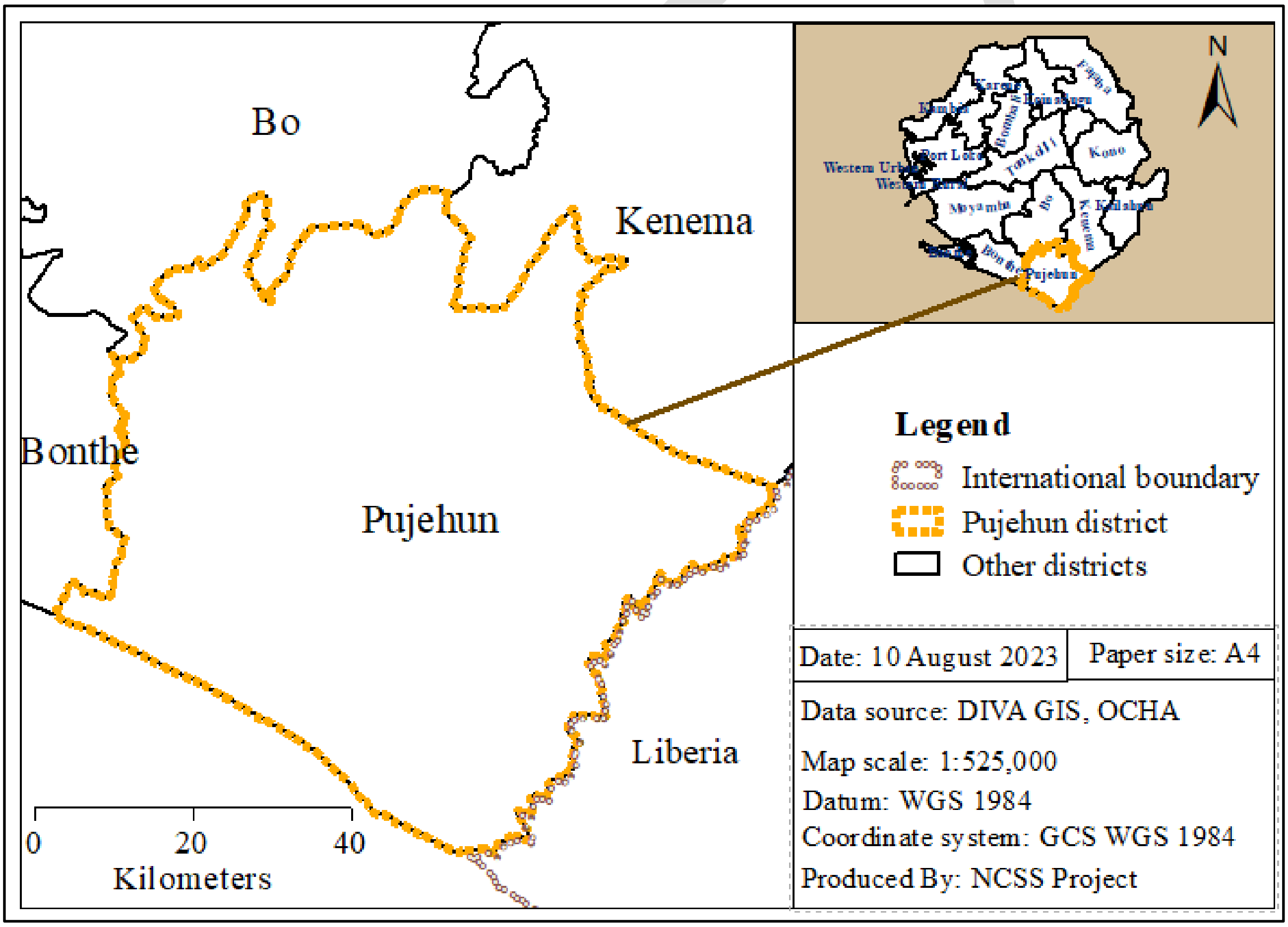

Figure 2. *Location map of Pujehun District*

3.2 Climate

The climate is tropical with two distinct seasons: rainy season (May to October) and dry season (November to April). Rainfall is highest in the coastal areas, with annual rainfall ranging from 2899 mm in Pejeh, Sowa, parts of Barri and Malen chiefdoms in the northeast and northwest to 4429 mm in Kpaka and Soro Gbema chiefdoms (Amara *et al*., 2020) (Figure 3). Rainfall distribution is unimodal, with about 95 % of the total annual rainfall occuring 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 22°C to 28°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 region (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.

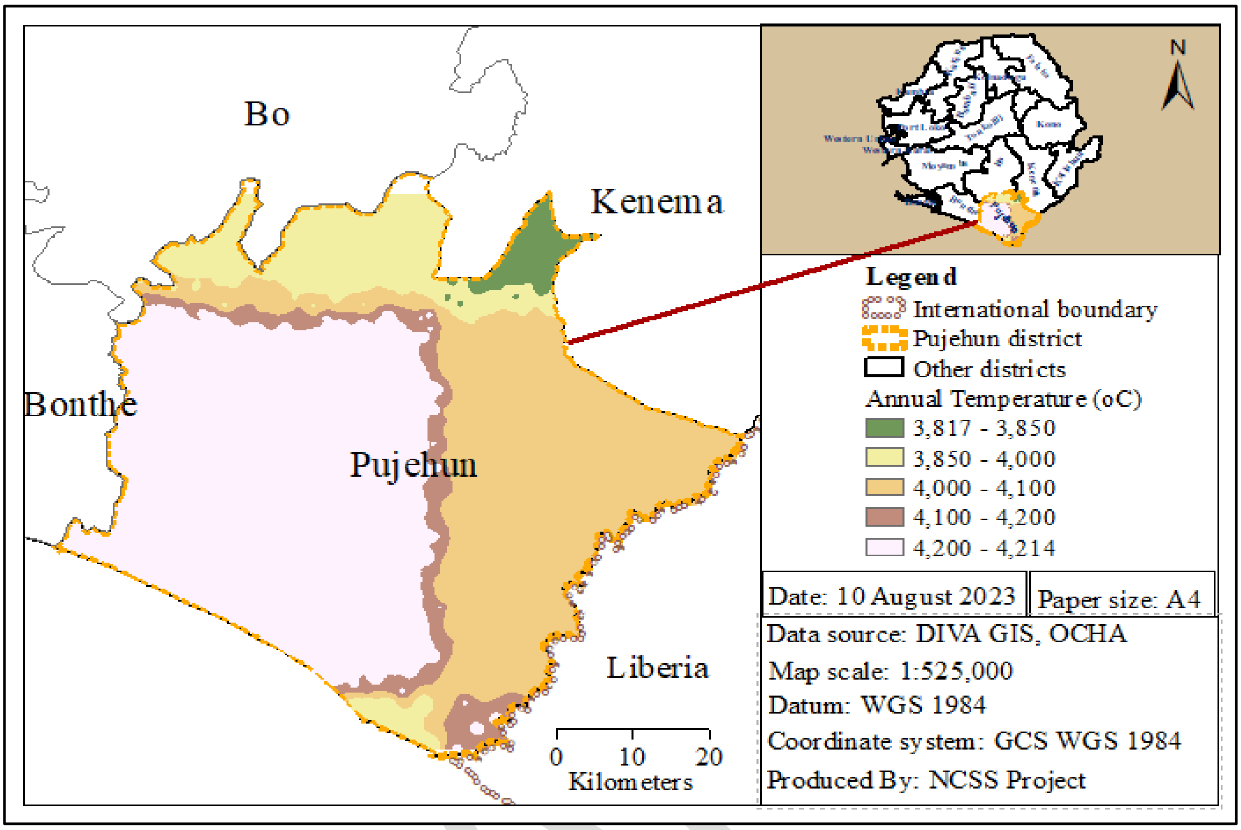

Figure 3. *Annual Rainfall distribution in Pujehun District (2021)*

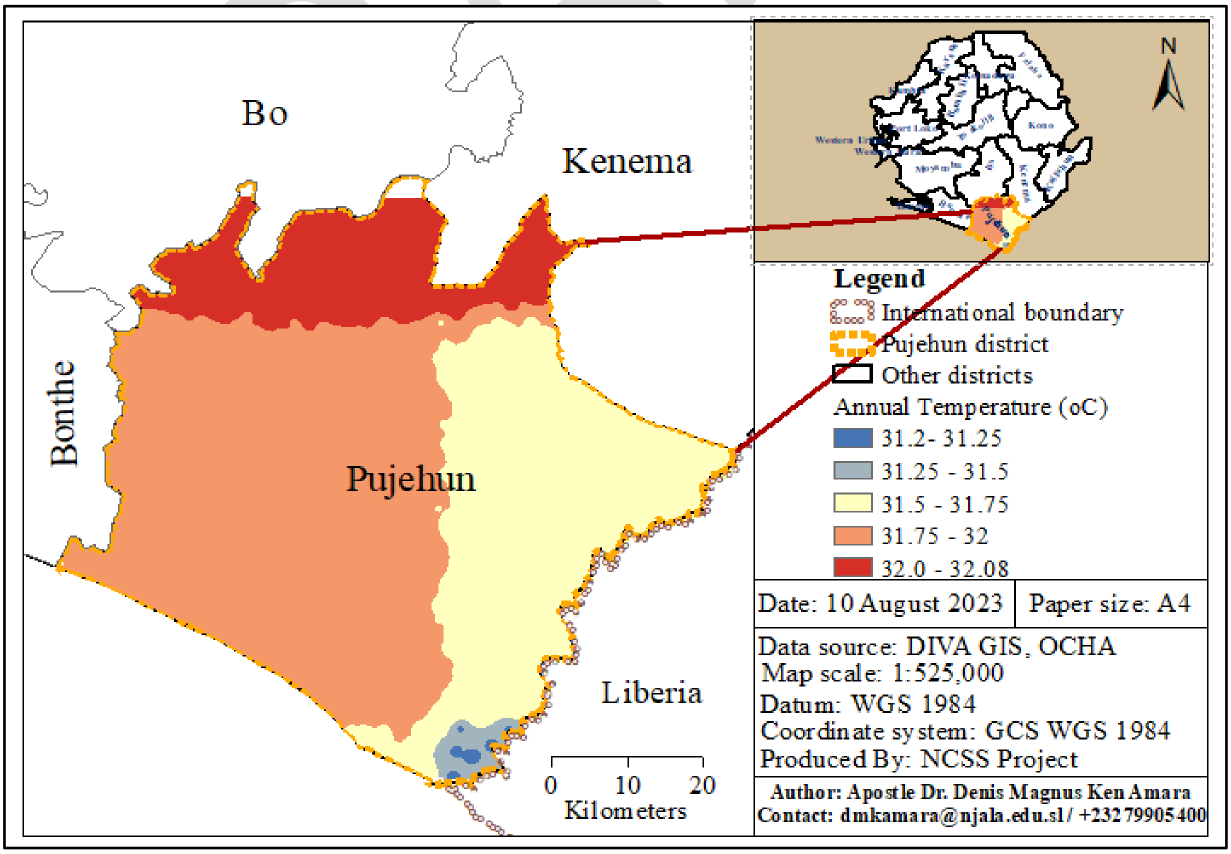

Figure 4. *Annual Temperature distribution in Pujehun District (2021)*

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

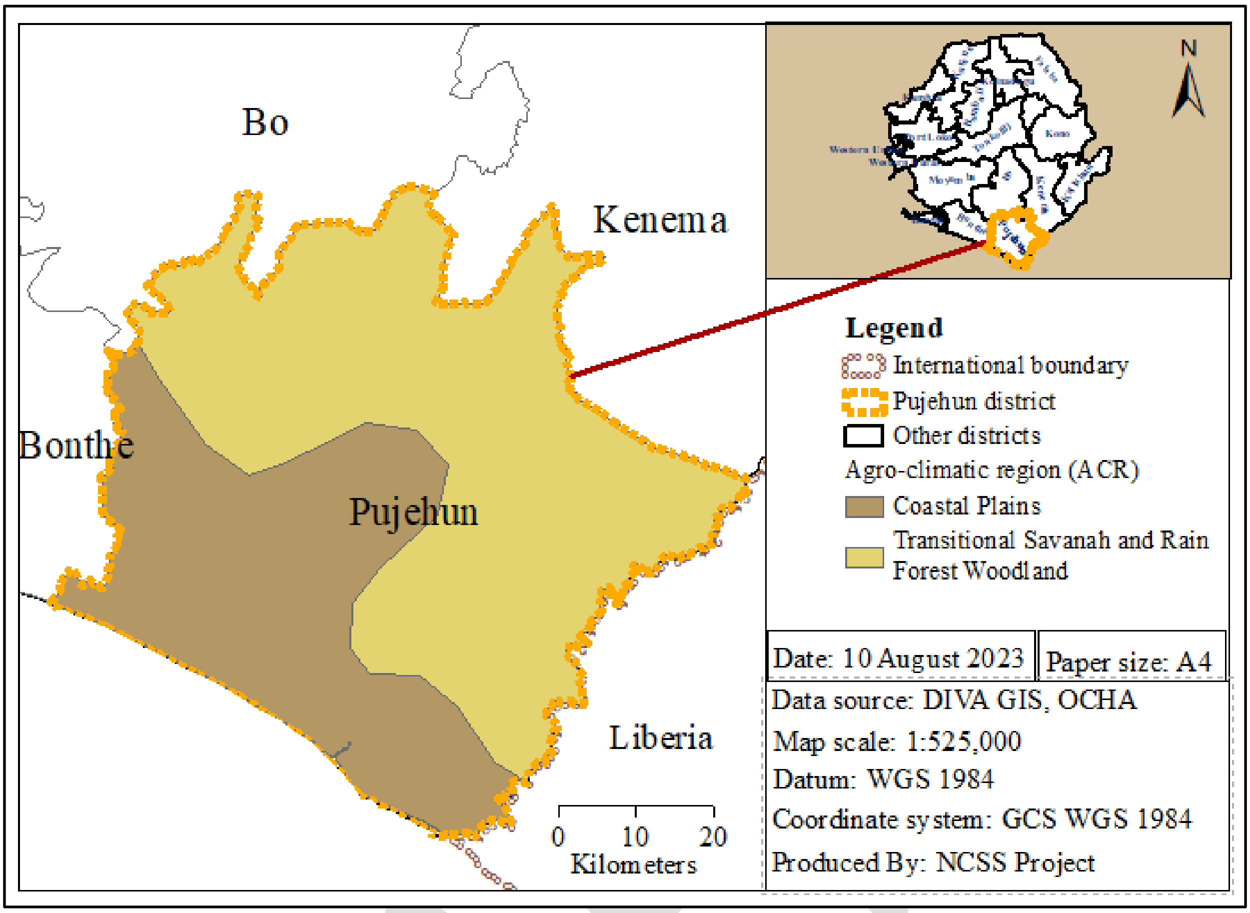

Figure 5. *Agro-climatic regions of Pujehun District (Adapted from UNDP/FAO 1979)*

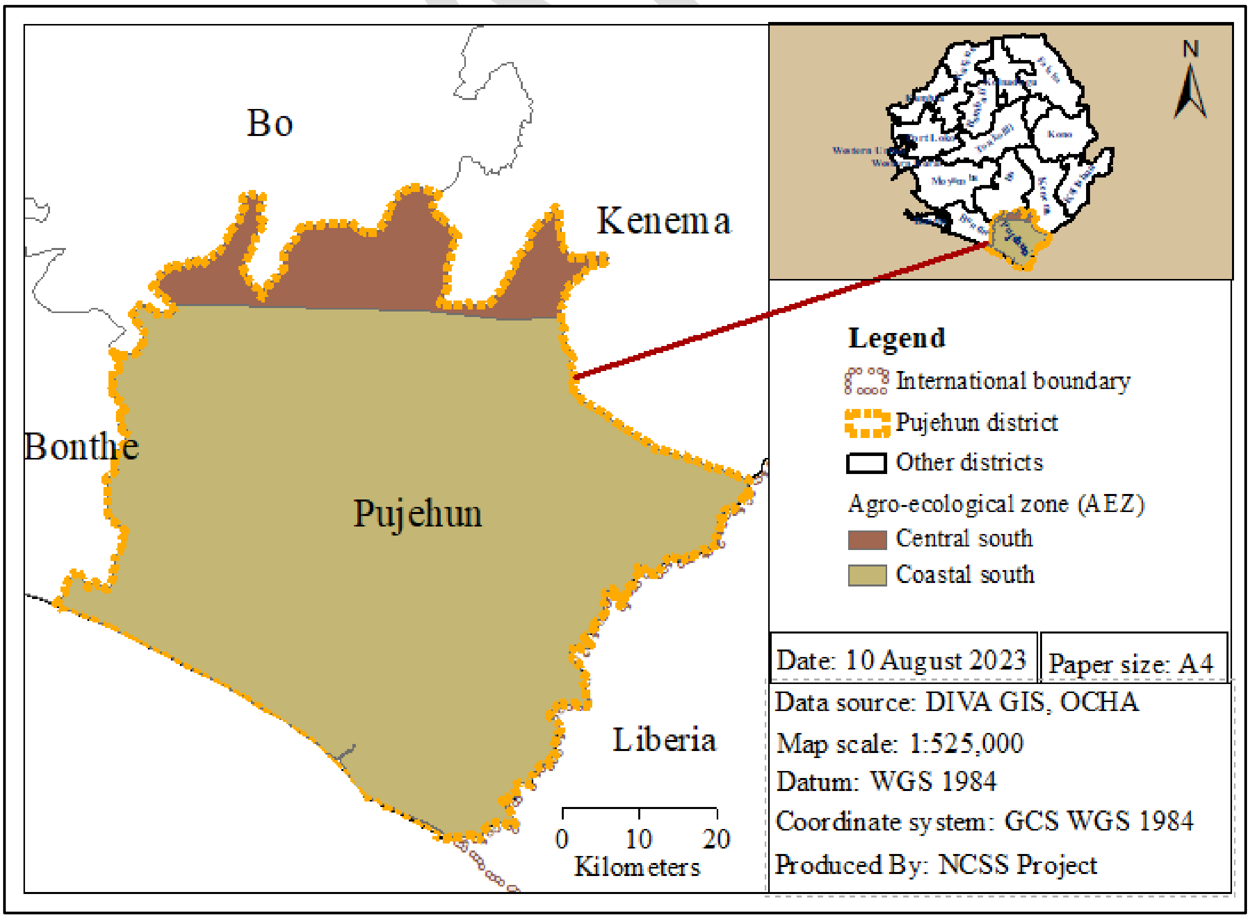

Figure 6. *Agro-ecological zones of Pujehun District (Adapted from Verheye 1997)*

3.3 Geology

The bedrock geology of the district is dominated by the Kasila group and granite migmatite complex of the Archean basement, belonging to the Pujehun-Man Archaean domain of the West African craton (Rollinson, 2016). Within this basement, a number of distinct supracrustal belts including the Kambui hills and Mano-Moa granulites have been mapped. In addition, tertiary to recent Bullom deposits showing traces of post-Archean activities is well documented. The Kasila Group consists of a series of high grade basic granulites and metamorphic beltbelts with rocks, flanked by amphibolites, which developed into a zone of extreme sheer deformation to form the southwest margin of the Archean basement complex. It comprises a highgrade series of granulites, consisting of garnet, hypersthene and hornblende gneisses, quartzites and associated migmatites. The granite complex comprises of a series of iron and magnesium-rich rocks that have been metamorphosed to the amphibolite facies known as the Sula Group, over a quartz-rich basement of granitic composition. The grade of metamorphism in the basement tends to increase towards the Sula Group boundary, thus giving rise to local occurrences of the Mano-Moa granulites. Also associated with the geological formation is the deposition of Tertiary to Recent Bullom Group deposits, which occupy a belt along the coastal areas of the district including Kpaka, Mano Sakrim, Soro Gbema and Yakemoh Kukumu Krim chiefdoms. These deposits rest uncomformably on the Kasila Group and comprised of nearly horizontal beds of marine, estuarine and fluvial gravels, sands and clays of sedimentary origin. Further details on the geology of the district are given in Table 5.

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

Geology	Area (km^2)
Unknown mineral	25.8
Branded iron formation	2.9
Dolerite dykes	4.7
Kamboi group (Lower)	24.6
Kamboi group (Upper)	0.6
Leonean Anorthosite and Metagabbro	2.4
Leonean granite	3957.3
Leonean Migmatites and hybrid rocks	18.0
Marampa group (Lower)	4.6

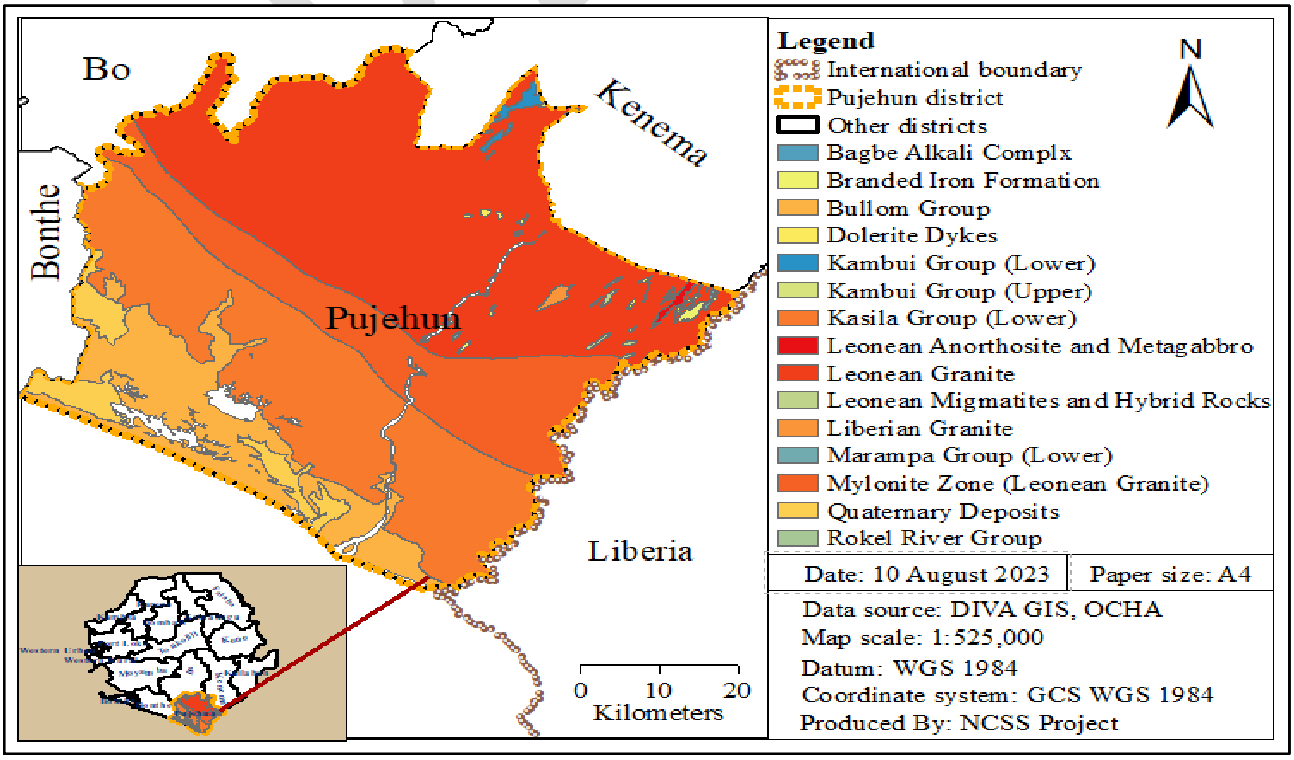

Figure 7. *Geology of Pujehun district (Adapted from UNDP/FAO 1979)*

3.4 Land systems

The district is comprised of 11 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 (Christian 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 lie 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 Pujehun District (Adapted from UNDP/FAO 1979)*

Land region	Subregion	Land system	Name	Code	Area (km^2)
Coastal Plains	Beach ridges	Coastal beach ridges	Turner	3	66.42
		Inland beach ridges	Sherbro	4	70.82
		Degraded beach ridges	Bonthe	5	222.7
	Alluvial Plains	Coastal floodplains	Torma Bum	6	295.9
	Coastal terraces	Dissected terraces	Newton	7	687.1
Plateaux	Undulating high-lying plateaux	Dissected plains with isolated small hills and common terraces	Blama	15	1486.0
		Intricately dissected hills with isolated small hills	Bo	18	1235.0
	Rolling plateaux and hills	Variably dissected association of plains and rocky hills	Sandaru	32	47.85
Hills and Mountains	On basic and ultra-basic rocks	Dissected escarpment and hill ranges	Kangari	38	30.85

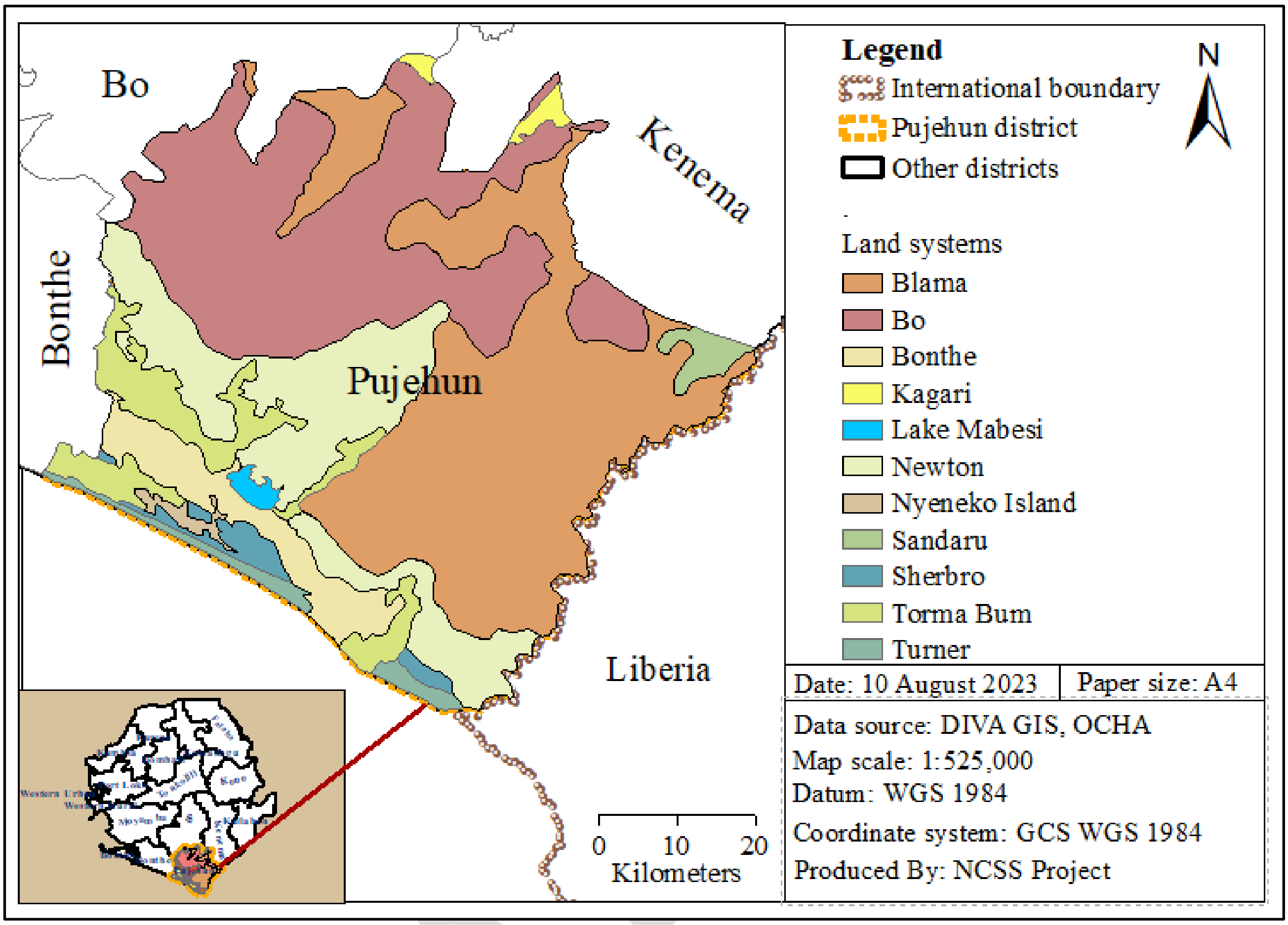

Figure 8. *Land systems of Pujehun district*

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.

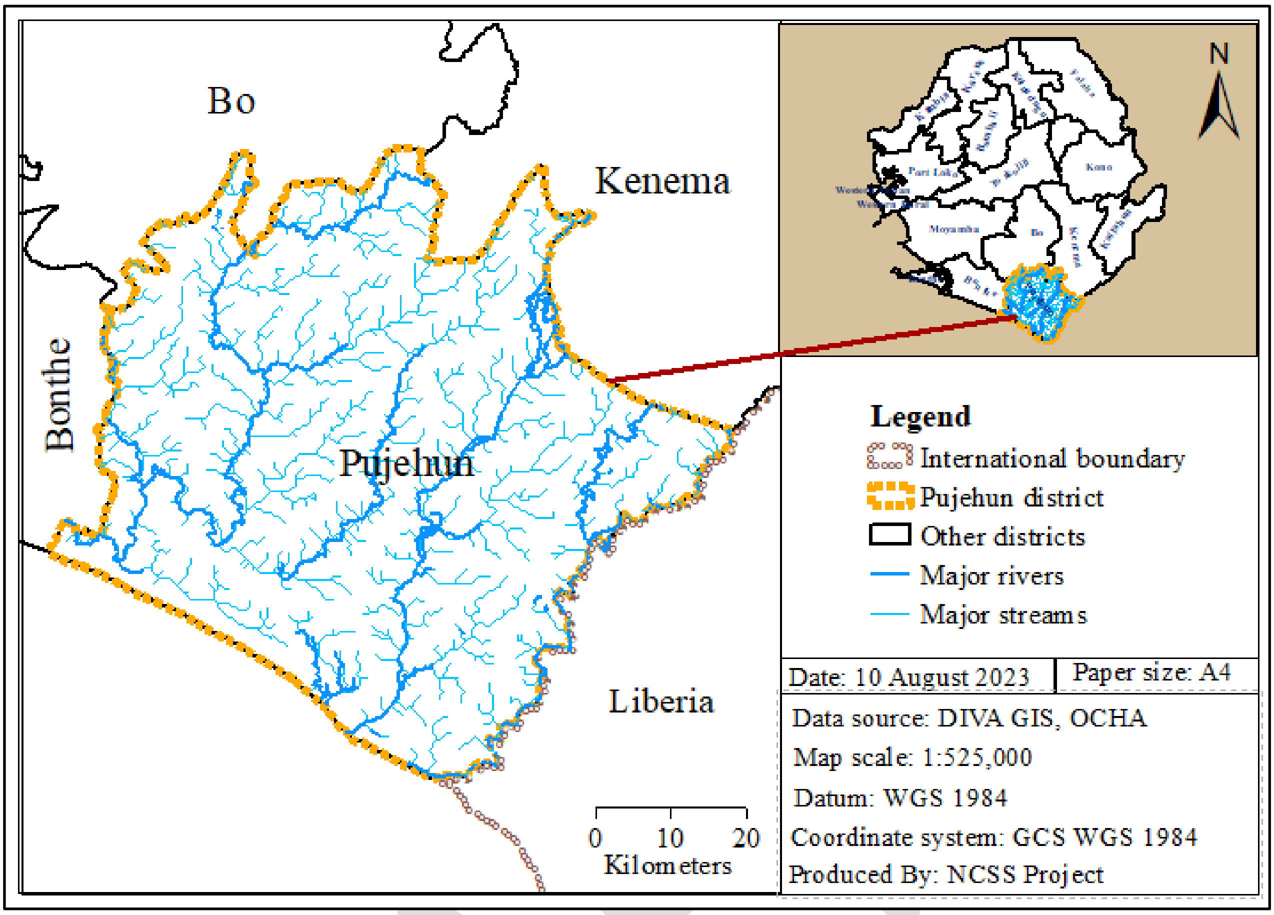

Figure 9. *Hydrology of Pujehun District*

3.6 Main soil associations

The soils of Pujehun 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 (Figure 11), 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 twelve main associations (Figure 9 and Table 8), namely, 1) weakly developed muds and hydromorphic clays along coastal river; 2) undeveloped to weakly developed sands on coastal beach plains; 3) hydromorphic clays and gravel free ferralitic soils on coastal floodplains; 4) gravel free ferralitic soils on coastal terraces; 5) gravelly ferralitic and plinthic hydromorphic soils on inland terraces, depressions and floodplains; 6) very gravelly ferralitic soils over colluvial gravel on western interior plains; 7) gravelly ferralitic soils over weathered granitic basement or colluvial gravel on southern interior and plateau plains; 8) gravelly nodular ferralitic soils over weathered granitic basement on northern interior and plateau plains; 9) stony and gravelly ferralitic soils over weathered granitic basement or colluvial gravel on low to moderate relief hills; 10) stony and gravelly ferralitic soils with shallow soils on moderate to high relief hills formed from predominantly acid rocks; 11) very gravelly ferralitic soils with shallow soils on moderate hills formed from basic and ultrabasic rocks; and 12) Shallow soils on plateau mountains and lateritic hills and terraces (Table 7 and Figure 10).

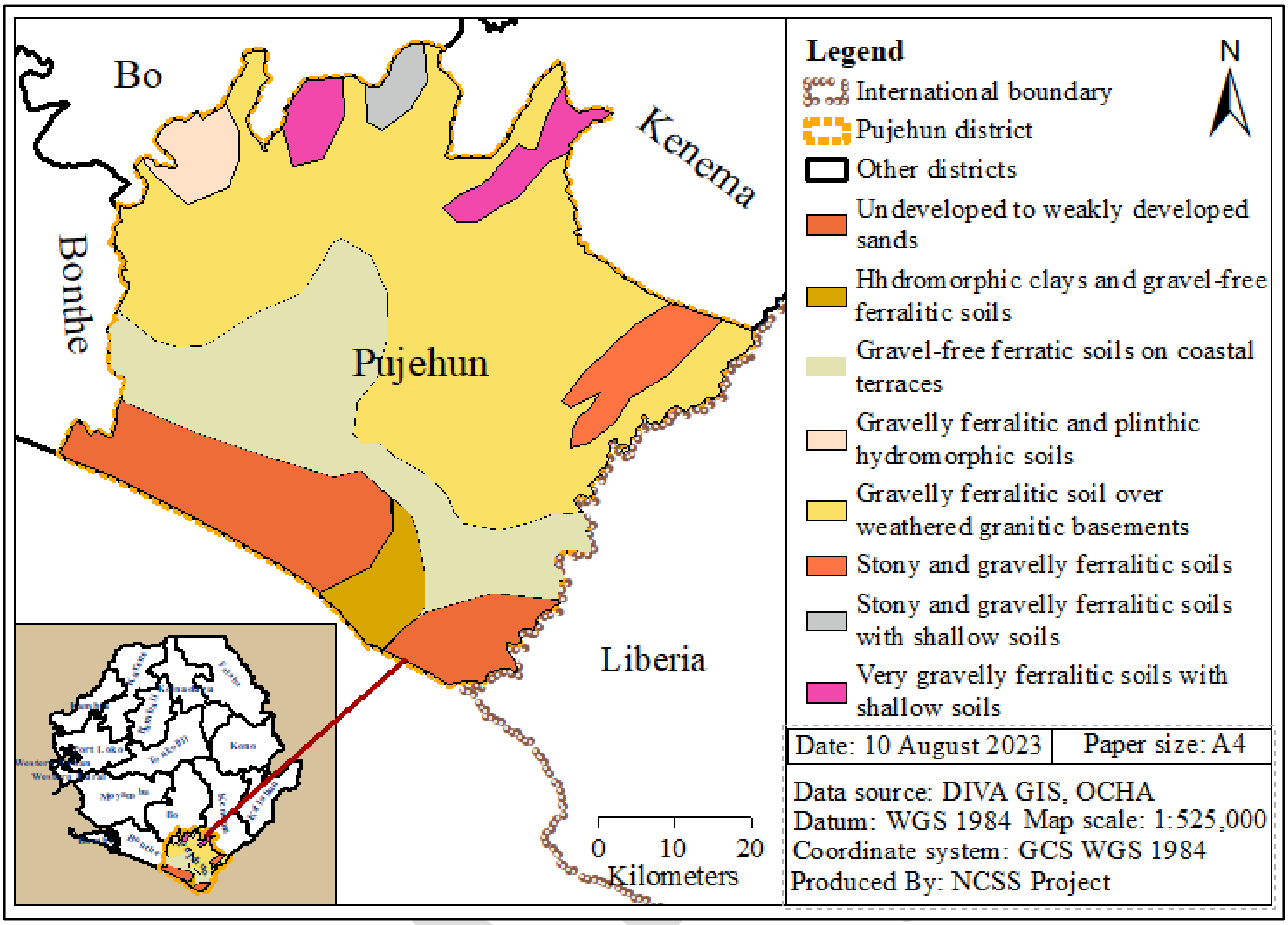

Figure 10. *Main soil associations of Pujehun district (Adapted from UNDP/FAO 1979)*

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

Land region	Area (km^2)
Undeveloped to weakly developed sands on coastal beach plains	623.99
Hydromorphic clays and gravel free ferralitic soils on coastal floodplains	128.58
Gravel free ferralitic soils on coastal terraces	856.42
Gravelly ferralitic and plinthic hydromorphic soils on inland terraces, depressions and floodplains	96.54
Gravelly ferralitic soils over weathered granitic basement or colluvial gravel on southern interior and plateau plains	2119.1
Stony and gravelly ferralitic soils over weathered granitic basement or colluvial gravel on low to moderate relief hills	148.39
Stony and gravelly ferralitic soils with shallow soils on moderate to high relief hills formed from predominantly acid rocks	52.22
Very gravelly ferralitic soils with shallow soils on moderate to high relief hills formed from basic and ultrabasic rocks	159.79

3.7 Vegetation and land use

Fourteen major vegetation types have been identified in the district (FAO, 2007), among which are closed high forest, secondary forest, forest regrowth, coastal tree savana, rubber plantation, mangrove swamp forest, upland crops, coastal woodland, fringing swamp forest, oil palm plantation, raffia swamp forest, swamp and riverain grassland, swamp cultivation and upland grassland. 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). The hydromorphic vegetation comprises of a variety of vegetation species specific to inland valley swamps (IVSs) that have been left to fallow (Table 8 and Figure 11).

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

Land region	Area (km^2)
Closed high forest	167
Secondary forest	195
Forest regrowth	3012
Coastal tree savannah	110
Rubber plantation	11
Mangrove swamp forest	36
Upland crops	5
Coastal woodland	219
Fringing swamp forest	86
Oil palm plantation	4
Swamp and riverain grassland	214
Swamp cultivation	41
Upland grassland	20
Water	50

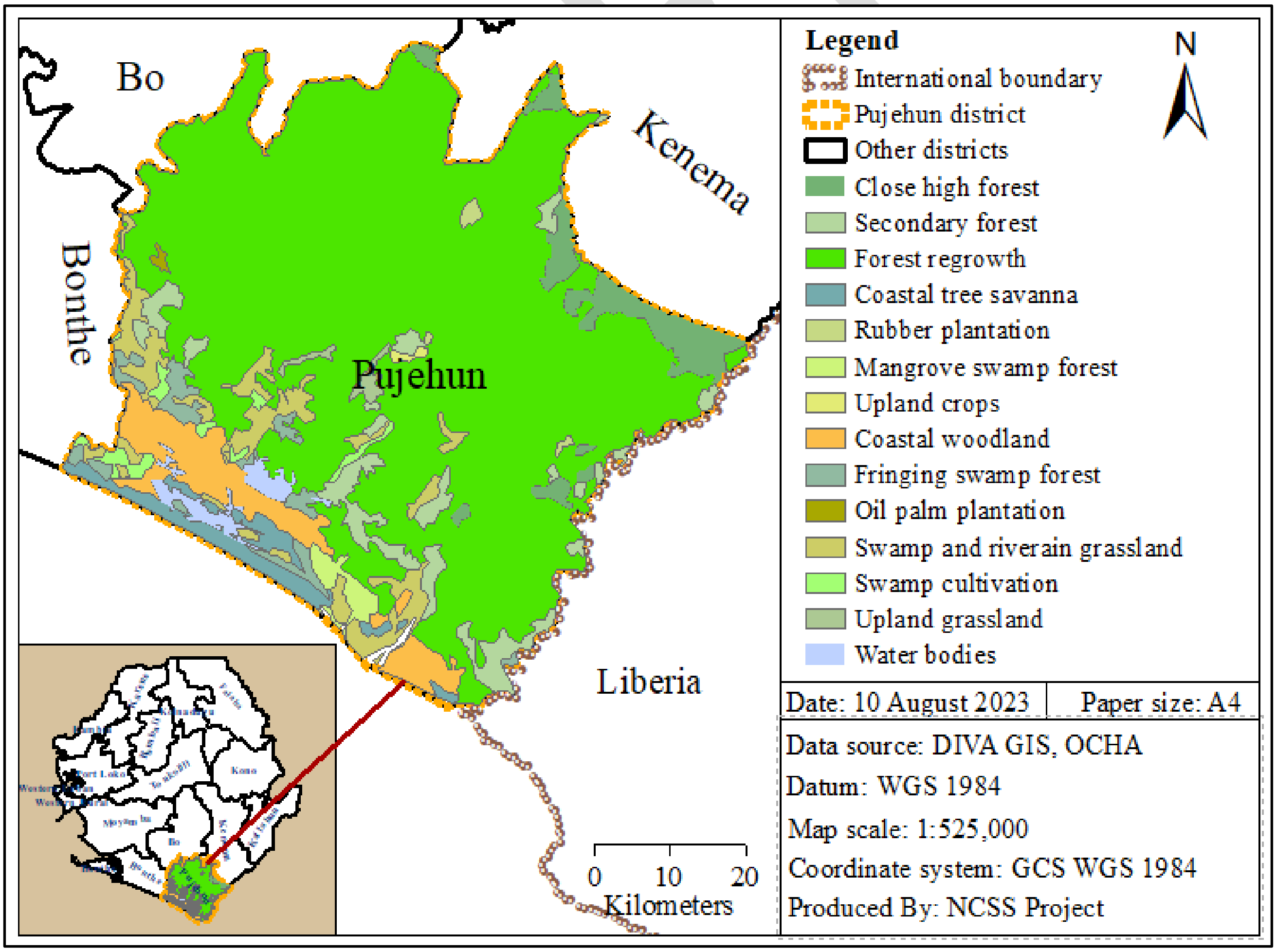

Figure 11. *Vegetation and land use of Pujehun district (FAO, 2007)*

3.8 Socio-economy

The livelihoods are largely dependent on food and cash crop cultivation, and artisanal fishing, a majority of households own person boats that they normally use for fishing along the major rivers and the Atlantic Ocean. Rice and cassava are the major food crops grown, consumed and traded. Private sector cultivation of cocoa, coffee and oil palm has over the years provided a major employment opportunity in the district especially in Barri, Kpanga, Malen and Soro Gbeima chiefdoms. Around the coastal areas, commercial fishing companies are dominant. 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. Mostly wealthier households own plantations while middle and poorer households are employed to maintain and harvest the trees. Plantain, banana, coconut 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. Diamond and gold mining on a localized level is also becoming popular, especially along the river terraces.

3.9 Environmental hazards

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

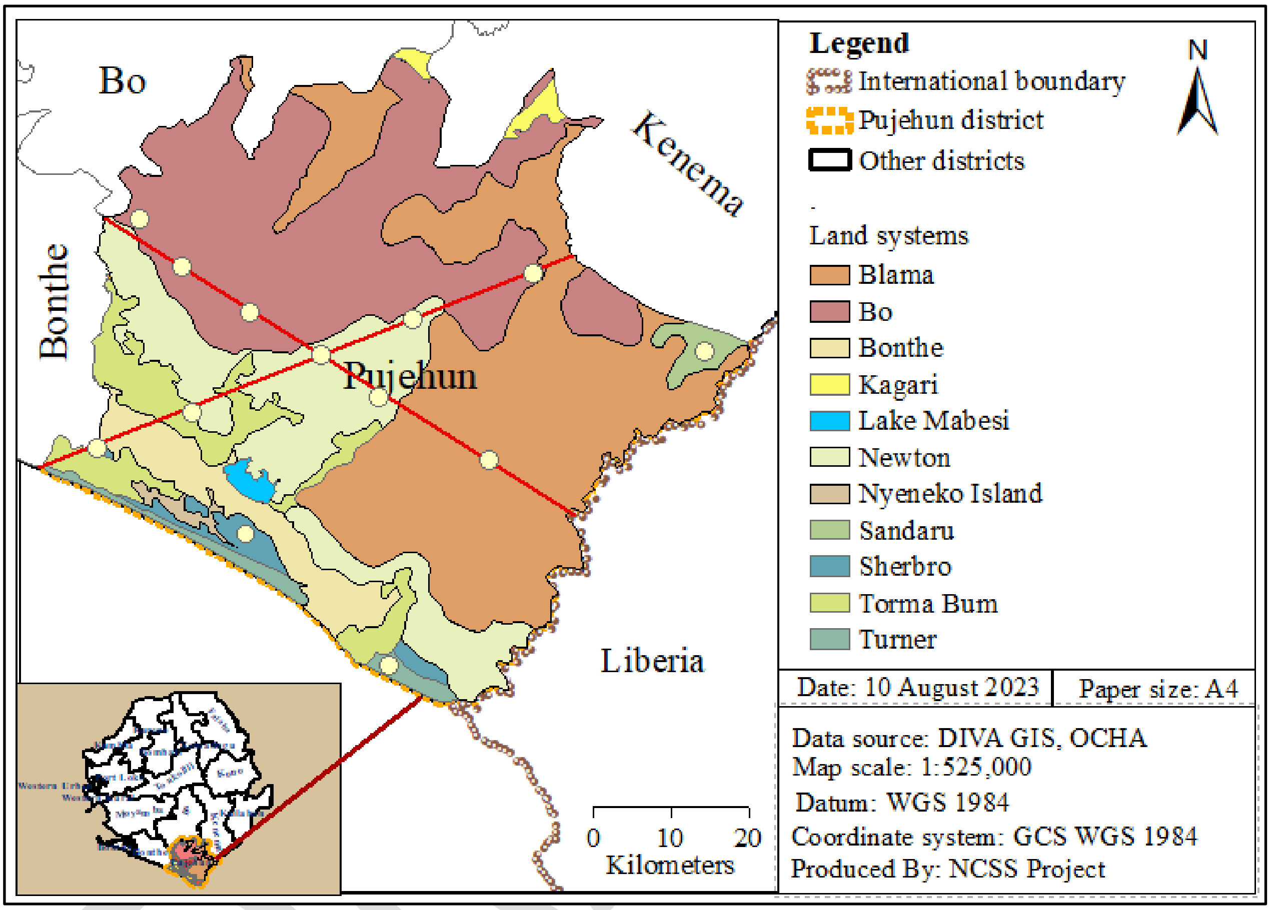

Figure 2 *Transect lines running through soil profile locations in preparation for a free-soil survey (adapted from Brady and Weil, 2008)*

District: Pujehun; **Chiefdom**: Soro Gbema; **Village**: Gornor; **GPS location**: 7.19601°/11.36385°; **Elevation**: 39m; **Physiography**: On acid rocks; **Landform/facet**: Interfluve side slope; **Parent Material**: Weathered Residium; **Landscape position**: Back slope; **Slope**: 2.4 %; **Vegetation**: Bush regrowth; **Erosion class and intensity**: e2, moderate; **Drainage and permeability**: Well drained and rapid; **Landuse**: Fallow shifting cultivation; **Major crops grown**: Cassava. **Other salient feature**: Profile contains partially weathered fragments of sandstone rocks that are at intermediate stage of weathering and being exposed as a result of road construction.

Mapping Unit: PUJ001
Gravel-free over gravel soil

Horizon (cm)	Morphological Description
A (0 – 40)	Brown (10YR 4/3 dry) and dark brown (10Y/R3/3 moist); sandy loam; moderate, fine crumbly and angular blocky; hard (dry), firm (moist); non sticky and non-plastic; plenty fine and medium pores; plenty very fine, fine and medium, few coarse roots; presence of termites, ants and other insects; clear and wavy boundary to horizon below.
E (40 – 100)	Brownish yellow (10YR 6/6 dry) and yellowish brown (10Y/R5/6 moist); sandy clay; moderate, coarse, crumbly; hard (dry), firm (moist); non-sticky and non-plastic; plenty fine, medium and coarse pores; few very fine, fine and medium roots; presence of termites, ants and other insects; presence of high amount of gravel and stones; clear and wavy boundary to horizon below.
Bt2 (100 – 138)	Brownish yellow (10YR 6/8 dry) and yellowish brown (10Y/R5/8 moist); sandy clay; moderate, medium, angular and sub-angular blocky; slightly hard (dry), friable (moist); non-sticky and non-plastic; few fine and plenty medium, and coarse pores; few very fine, fine, and very few medium roots; presence of termites, ants and other insects; presence of freshly weathered sandstones being converted into subsoil; clear and broken boundary to horizon below.
Bt3 (138 – 200+)	Brownish yellow (10YR 6/8 dry) and yellowish brown (10Y/R5/8 moist); sandy clay; strong, medium, angular and sub-angular blocky; slightly hard (dry), firm (moist); non-sticky and non-plastic; plenty fine, medium, and coarse pores; few very fine, fine, and very few medium roots; presence of termites, ants and other insects; presence of freshly weathered sandstones still in the process of forming subsoils, with traces of weathered rocks (pink colouration); clear and broken boundary to horizon below.

Figure 13. *A benchmark soil, first described in Gornor, Soro Gbema Chiefdom, Pujehun District to compare and represent all pedons described as the Momenga 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 Pujehun District were conducted according to the procedure and guidelines provided in Agriculture Handbook No. 210 (Klingbiel and Montgomery, 1961). This provided the basis for separating arable 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 (Adapted from 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 4.6.

5 Description and classification of soils of Pujehun District

5.1 Description of soils of Pujehun District

5.1.1 *Soils on uplands of highly weathered materials*

Map Unit 5: Momenga-Njala soil association

The *Momenga-Njala soil association* in Pujehun district comprises of upland soils located on highly weathered material, usually containing 35-75% hardened plinthite gravels. The fine earth fraction (< 2.0 mm) is usually sandy clay loam or sandy clay. These soils are low in available water-holding capacity and plant nutrients. Mainly, these soils are used for shifting cultivation, with upland rice and cassava as the main crops.

5.1.1.1 Momenga series

Photo 1. *Typical position of Momenga soil series in Pujehun District*

The soils of the Momenga series are formed colluvium parent material, usually overlying gravelly residual material, over weathered bedrock (saprolite), usually within a depth of 120 cm. In some cases, hard bedrock may also be present. The colluvial plinthite graveles are rounded, hard, and dense and weigh about 50 % by volume. The residual plinthite gravels, which form in situ, are more irregular, relatively porous, and soft. Quartz veins may occur in the residual material. Quartz gravels may be present in the whole profile, being rounded in the topsoil and more angular in the subsoil. A gravel-free surface layer from gravelly sandy loam to gravelly clay in the upper few cwntimeters and gravelly clay in the subsoil. The silt content of the subsoil often increases because of the presence of weathered bedrock pieces.

The topsoil A_1 horizon is only few centimeters thick, which qualifies it to be classed as ochric epipedon. The topsoil colours range from Brown (10YR 4/3 dry) to dark brown (10YR 3/3 moist). The colours of the subsoil vary from brownish yellow (10YR 6/6 dry) and yellowish brown (10YR 5/6 moist), with red and brown to white (saprolite) mottles.

Momenga soils are chemically poor, with a low nutrient content (Table 10). 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 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, Mg, K and 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 and Cu (cmol kg^{-1}) are low in both topsoil and subsoil horizons, while the DTPA extractable Zn (cmol kg^{-1}) is low in topsoil horizon and high 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.

A detailed description and analytical result of a representative profile, PUJ001, of the *Momenga series*, is given in Appendices 1a and 1b.

Table 10. Key land, morphological and chemical properties of Momenga series		
Soil series name	Momenga	
International soil name	Ferralic Nitrosol	
Slope range	1.3 %	
Soil surface stoniness	Soil surface is partially covered with patches of dried grasses but immediate areas show evidence of fine gravels occurring in patches on the surface	
Typical position in the landscape	*See Photo 1*	
Texture of the topsoil (0 – 20cm)	Gravelly sandy loam	
Texture of the subsoil (at 50cm)	Gravelly sandy clay loam	
Drainage	Moderately well drained to moderately rapid	
Colour of the topsoil:	Gray (2.5Y5/1 dry) and dark gray (2.5Y4/1 moist)	
Colour of the subsoil	Light brownish brown (2.5Y6/2 dry) and grayish brown (2.5Y5/2 moist)	
Soil depth	Deep (>170 cm)	
Nature of obstruction	NA	
Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	3.48	2.68
Available phosphorous (Bray P1 (mg kg-^{1})	8.2	3.20
Acidity (pH in 1:1 soil to water ratio)	5.5	5.43
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	3.76	2.85
Exchangeable Calcium (cmol kg^{-1} soil)	0.97	0.90
Exchangeable Magnesium (cmol kg^{-1} soil)	1.05	0.75
Exchangeable Potassium (cmol kg^{-1}soil)	0.15	0.10
Exchangeable Sodium (cmol+ kg^{-1} soil)	0.58	0.31
Exchangeable Acidity (cmol+ kg^{-1} soil)	1.01	0.79
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	26	15
DTPA extractable Iron (mg kg $^{-1}$)	3.22	7.57
DTPA extractable Copper (mg kg $^{-1}$)	0.4	0.67
DTPA extractable Zinc (mg kg $^{-1}$)	12.51	8.52

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 Njala series

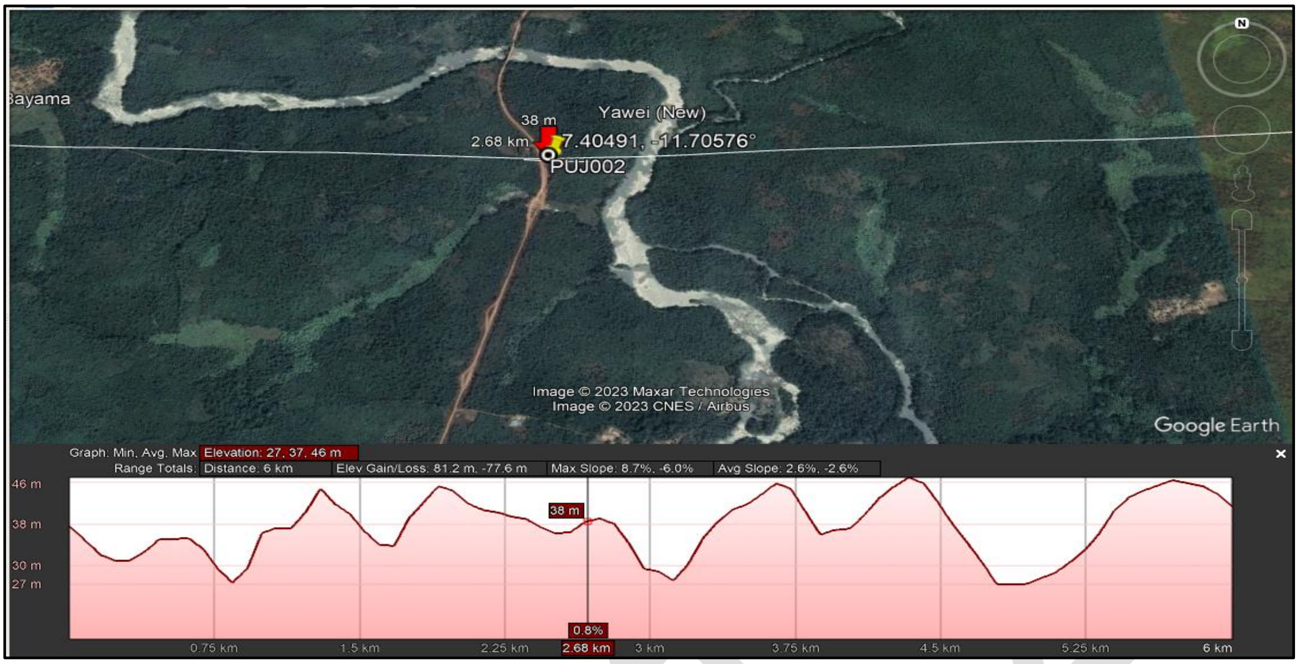

Photo 2. *Typical position of Njala soil series in Pujehun District*

Soils of the *Njala series* occur on nearly level ridgetops on gentle slopes (1-3%) and moderate slopes (3-15%) downward toward the drainageways. The parent material is a gravelly colluvium overlying gravelly residual material over weathered bedrock, which occurs at a depth of 100cm and above. The colluvial plinthite gravels are rounded, hard and dense, and dusky red to reddish black. The gravel content of the colluvial surface layer may weigh between 30 and 65% by volume but the thickness of the layer may variy from 50-150 cm. The residual plinthite gravels are more irregular, relatively more porous and soft, and are formed in situ. Colors are brighter red (10R 4/6). The gravel content varies with depth from 25-40% by volume. Quartz veins may be present in the residual material. Quartz gravels may be present in the whole profile, being relatively rounded in the colluvial layers and relatively angular in the residual layers.

A thin gravel-free surface layer of 5-25 cm may either be present or absent, with its thickness often depending on the topography. Textures are usually gravelly sandy clay loam in the surface soil and gravelly clay loam to gravelly clay in the subsoil. Topsoil colors are gray (10YR 6/1 dry and 10YR 6/5 moist). Subsoil colors are usually gray (10YR 6/1 dry) and light brownish gray (10YR 6/2 moist). Red mottles may or may not be present. The soils are well to moderately well drained.

Njala soils are very low in plant nutrients (Table 11). 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 and Mg are low in both topsoil and subsoil horizons, exchangeable K is high 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 and Cu (cmol kg^{-1}) are low in both topsoil and subsoil horizons, while the DTPA extractable Zn (cmol kg^{-1}) is high in topsoil horizon and moderate 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.

A detailed descriptions and analytical result of a representative profile, PUJ002, of the *Njala series* are given in Appendices 2a and 2b.

***Table 11.** Key land, morphological and chemical properties of Njala sloping series*

Soil series name	Njala sloping	
International soil name	Dystric Nitosol	
Slope range	0.8 %	
Soil surface stoniness	Soil surface is partially covered with patches of dried grasses but immediate areas show evidence of fine gravels occurring in patches on the surface	
Typical position in the landscape	*See Photo 2*	
Texture of the topsoil (0 – 20cm)	Gravelly sandy loam	
Texture of the subsoil (at 50cm)	Gravelly sandy clay loam	
Drainage	Well drained to rapid	
Colour of the topsoil:	Dark grayish brown (10YR4/2 dry) and very dark grayish brown (10YR3/2 moist)	
Colour of the subsoil	Yellowish brown (10YR 5/4 dry) and dark yellowish brown (10YR4/4 moist)	
Soil depth	Deep (>150 cm)	
Nature of obstruction	NA	
Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	1.71	1.67
Available phosphorous (Bray P1 (mg kg^{-1})	4.72	2.00
Acidity (pH in 1:1 soil to water ratio)	4.5	4.0
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	1.73	2.14
Exchangeable Calcium (cmol kg^{-1} soil)	0.55	0.47
Exchangeable Magnesium (cmol kg^{-1} soil)	0.29	0.36
Exchangeable Potassium (cmol kg^{-1}soil)	0.05	0.02
Exchangeable Sodium (cmol+ kg^{-1} soil)	0.46	0.42
Exchangeable Acidity (cmol+ kg^{-1} soil)	0.38	0.86
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	13	6
DTPA extractable Iron (cmol kg^{-1})	7.33	6.26
DTPA extractable Copper (cmol kg^{-1})	0	0.17
DTPA extractable Zinc (cmol kg^{-1})	1.04	1.50

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 colluvial footslopes and terraces

On the colluvial footslopes and terraces, soils such as Mokonde and Bonjema 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 Bonjema soils, which have 40-120 cm of gravel-free material over a gravelly lower subsoil.

Map unit 3: Mokonde-Bonjema soil association

5.1.2.1 Mokonde series

Photo 3. *Typical position of Mokonde soil series in Pujehun District*

Soils of the Mokonde series occur on concave colluvial footslopes of 2-8 % slopes and the upper river tributary terraces. 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 gravelly clay loam to gravelly 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 dark grey (10YR4/1 dry) and very dark grey (10YR3/1 moist), and subsoil colours is greyish brown (10YR5/2 dry) and dark greyish brown (10Y/R4/2 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.

Mokonde soils are very low in plant nutrients (Table 12). 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 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 and Ma are low in both topsoil and subsoil horizons, exchangeable K is moderate in topsoil and low 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, Cu and Zn (cmol kg^{-1}) are low in both topsoil 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.

A detailed description and analytical result of a representative profile, PUJ003, of the *Mokonde series* is given in Appendices 3a and 3b.

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

Soil series name	Mokonde	
International soil name	Haplic plinthosol	
Slope range	1.0 %	
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)	Very gravelly sandy clay	
Drainage	Well drained to rapid	
Colour of the topsoil:	Dark brown (10YR 3/3 dry) to very dark brown (10YR 4/3-4/4)	
Colour of the subsoil	Yellowish brown (10YR 5/6 dry) to yellow (10YR 7/6)	
Soil depth	Deep (>150 cm)	
Nature of obstruction	Paralithic lateritic layer	
Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	3.21	2.46
Available phosphorous (Bray P1 (mg kg^{-1})	14.91	11.36
Acidity (pH in 1:1 soil to water ratio)	4.1	4.2
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	3.63	2.42
Exchangeable Calcium (cmol kg^{-1} soil)	0.5	0.48
Exchangeable Magnesium (cmol kg^{-1} soil)	1.03	0.83
Exchangeable Potassium (cmol kg^{-1}soil)	0.13	0.07
Exchangeable Sodium (cmol+ kg^{-1} soil)	0.39	0.26
Exchangeable Acidity (cmol+ kg^{-1} soil)	1.58	0.79
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	22	18
DTPA extractable Iron (cmol kg^{-1})	6.64	6.41
DTPA extractable Copper (cmol kg^{-1})	0.79	0.64
DTPA extractable Zinc (cmol kg^{-1})	12.22	9.53

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 Bonjema series

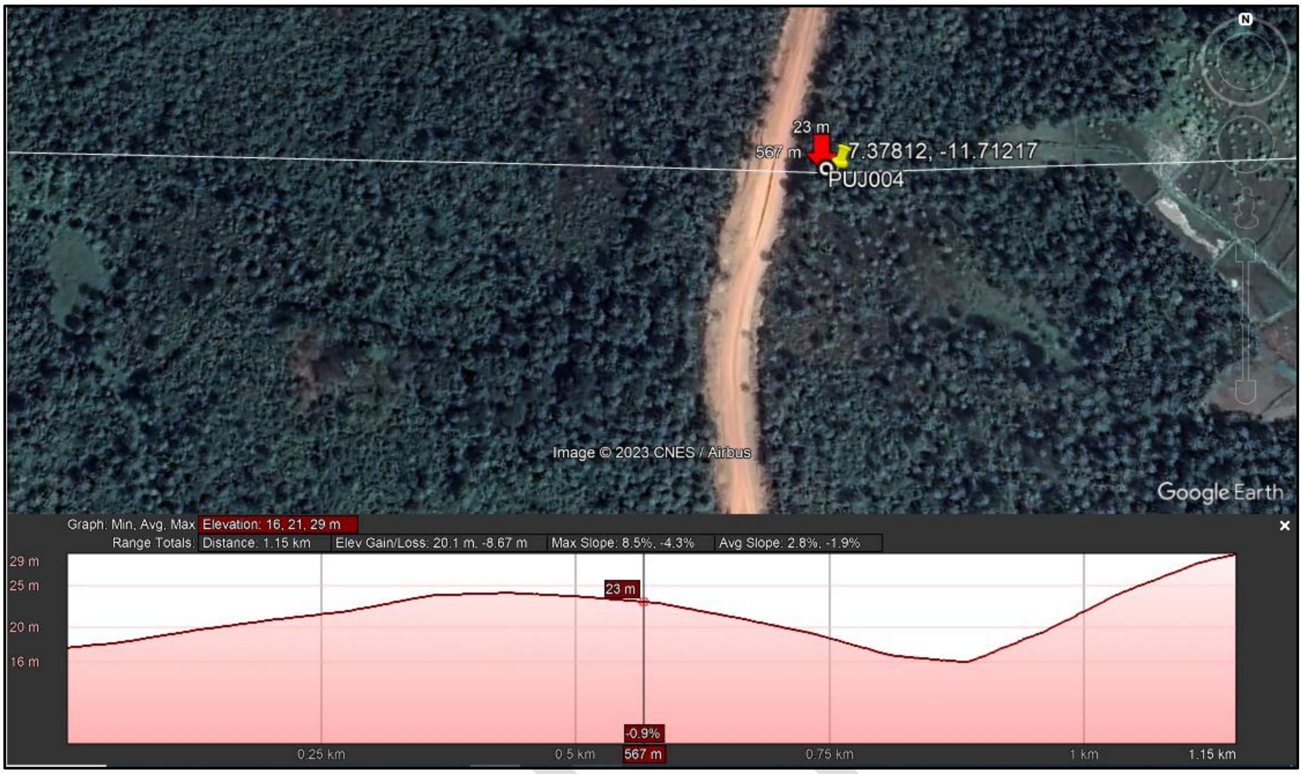

Photo 4. *Typical position of Bonjema soil series in Pujehun District*

These are soil mostly occurring on the concave colluvial footslopes that have slopes ranging from 2-5 % and upper terraces of the Moa River and its tributaries. The parent material is gravel-free colluvium or alluvium, over gravelly colluvium, over residual weathered material from the bedrock. The thickness of the gravel-free upper layer often varies from 50-120 cm. However, their gravelly colluvial layer is thinner than their counterpart soils and often has a characteristic stone line of 25 cm thickness. They have plinthite glaebules that are rounded, hard and dense, with gravel content ranging from 25-65 % by volume. In these soils, the residual materials are soft, often irregular, and tend to have more porous glaebules decrease with depth.

The topsoil textures are sandy loam to loam but as the depth gradually increases, these textures become sandy clay loam in the upper subsoil and gravelly clay loam in the lower subsoil. These soils have an ochric epipedon and a thin A1 horizon, whose thickness is often less than 25 cm. The topsoil colours are very brown (10YR4/3 dry) and very dark brown (10Y/R3/3 moist), while the subsoils are yellowish brown (10YR5/4 dry) and dark yellowish brown (10Y/R4/4 moist). Prominent red mottles (2.5YR 4/8) are usually present at depths of 50 cm or more. Bonjema soils are moderately well to imperfectly drained, and can be waterlogged at the surface and even submerged for a few weeks.

Chemically, Bonjema soils are very low in plant nutrients (Table 13). 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 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, Mg, 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 and Cu (cmol kg^{-1}) is low in both topsoil and subsoil horizons, 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.

A detailed description and analytical data for a representative profile of the *Bonjema series*, PUJ004, are given in Appendices 4a and 4b.

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

Soil series name	Bonjema	
International soil name	Dystric Nitosol	
Slope range	0.9 %	
Soil surface stoniness	NA	
Typical position in the landscape	*See Photo 4*	
Texture of the topsoil (0 – 20cm)	Sandy loam	
Texture of the subsoil (at 50cm)	Sandy clay loam	
Drainage	Well drained to rapid	
Colour of the topsoil:	Very dark grayish brown (10YR 3/2 dry) and yellowish brown (10YR 3/3-4/3 moist)	
Colour of the subsoil	Yellowish brown (10YR 5/6 dry) and light brownish gray (10YR 6/2 moist)	
Soil depth	Deep (>150 cm)	
Nature of obstruction	NA	
Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	5.73	3.42
Available phosphorous (Bray P1 (mg kg^{-1})	8.65	6.09
Acidity (pH in 1:1 soil to water ratio)	4.7	4.9
Effective Cation Exchange Capacity (sum of cations) cmol kg^{-1})	7.14	5.01
Exchangeable Calcium (cmol kg^{-1} soil)	1.23	1.11
Exchangeable Magnesium (cmol kg^{-1} soil)	3.17	1.97
Exchangeable Potassium (cmol kg^{-1}soil)	0.16	0.11
Exchangeable Sodium (cmol+ kg^{-1} soil)	0.52	0.34
Exchangeable Acidity (cmol+ kg^{-1} soil)	2.06	1.48
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	36	26
DTPA extractable Iron (cmol kg^{-1})	9.75	8.20
DTPA extractable Copper (cmol kg^{-1})	1.22	0.74
DTPA extractable Zinc (cmol kg^{-1})	40.86	24.83

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 Riverain soils

5.1.3.1 Newton series

Photo 5. *Typical position of Newton soil series in Pujehun District*

The Newton series are found on the coastal alluvial uplands that are associated with inland valley swamps. The upland soils are cultivated to rice, sweet potato, cassava, and maize. The textures are usually gravelly sandy loam in the surface A1 horizon, and gravelly sandy clay loam or gravelly sandy clay in the subsoil. The gravel content increases with depth. The topsoil colours are grey (10YR5/1 dry) and dark grey (10YR4/1 moist), whereas the subsoil colours are usually dark greyish brown (10YR4/2 dry) and very dark greyish brown (10YR3/2 moist). The thickness and colour of the surface horizon qualify these soils for the umbric epipedon. These soils are well drained and never waterlogged.

Newton soils are very low in plant nutrients (Table 14). The organic carbon content is high in topsoil horizon and low 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, Mg, 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, Co and Zn (cmol kg^{-1}) are low in both topsoil 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.

A detailed description and analytical result of a representative profile, PUJ005, of the *Newton series*, are given in Appendices 5a and 5b.

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

Soil series name	Newton	
International soil name	Dystric Cambisol	
Slope range	3.9 %	
Soil surface stoniness	NA	
Typical position in the landscape	*See Photo 5*	
Texture of the topsoil (0 – 20cm)	Sandy loam	
Texture of the subsoil (at 50cm)	Sandy clay loam	
Drainage	Well drained to rapid	
Colour of the topsoil:	Dark grayish brown (10YR4/2 dry) and very dark grayish brown (10YR3/2 moist)	
Colour of the subsoil	Yellowish brown (10YR 5/6 dry) and light brownish gray (10YR 6/2 moist)	
Soil depth	Deep (>160 cm)	
Nature of obstruction	NA	
Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	10.97	2.57
Available phosphorous (Bray P1 (mg kg^{-1})	4.3	10.26
Acidity (pH in 1:1 soil to water ratio)	3.8	4.5
Effective Cation Exchange Capacity (sum of cations) cmol kg^{-1})	3.66	3.24
Exchangeable Calcium (cmol kg^{-1} soil)	0.59	0.82
Exchangeable Magnesium (cmol kg^{-1} soil)	0.39	0.65
Exchangeable Potassium (cmol kg^{-1}soil)	0.14	0.11
Exchangeable Sodium (cmol+ kg^{-1} soil)	0.51	0.44
Exchangeable Acidity (cmol+ kg^{-1} soil)	2.03	1.23
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	21	25
DTPA extractable Iron (cmol kg^{-1})	7.84	7.67
DTPA extractable Copper (cmol kg^{-1})	0.97	0.93
DTPA extractable Zinc (cmol kg^{-1})	3.74	7.21

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 Gbesebu series

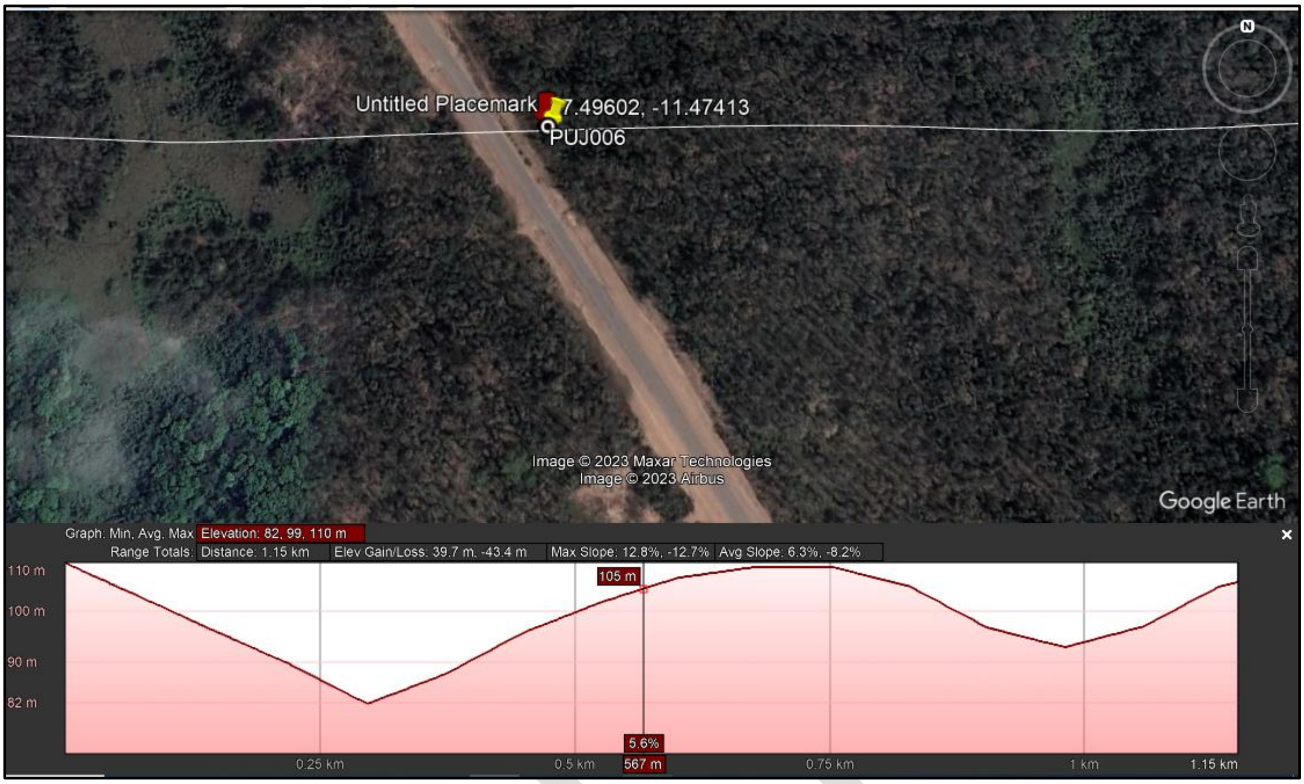

Photo 6. *Typical position of Gbesebu soil series in Pujehun District*

The Gbesebu series are the second most extensive soil on the alluvial flood plains in Pujehun district. They cover a land area of 551km^2. They develop on natural levees of the Moa, Sewa and Wanjei rivers and are therefore located at a higher elevation that the Torma Bum soil. They are moderately well drained and aerated soils and not subject to erosion.

The Gbesebu soils have good physical properties and are cultivated easily. The texture of the top 0-20 cm arable layer behaves like clay loam but particle size analysis in the laboratory puts it at sandy loam. The texture in the subsoil by the feel method was determined to clay but laboratory particle size analysis puts it at sandy clay loam. There appears to be an increase of clay with depth, suggesting a high potential to store water which deep rooted crops may access. The colour of the topsoil is gray (10YR5/1dry) and dark gray (10YR4/1 moist) and sub soils are pale brown (10YR6/3 dry) and brown (10YR5/3 moist). The soils are deep (>100cm).

Gbesebu soils are very low in plant nutrients (Table 15). The organic carbon content is high in topsoil horizon and low in subsoil horizon. The available phosphorus (Bray P1) is low in both topsoil and subsoil horizons. The pH is high in topsoil horizon and low in subsoil horizon. 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 high 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 and Cu (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 high 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.

A detailed description and analytical data for a representative profile of the *Gbesebu series*, PUJ006, are given in Appendices 6a and 6b.

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

Soil series name	Gbesebu	
International soil name	Umbric Fluvisol	
Slope range	6.1 %	
Soil surface stoniness	NA	
Typical position in the landscape	*See Photo 6*	
Texture of the topsoil (0 – 20cm)	Sandy loam	
Texture of the subsoil (at 50cm)	Silty clay	
Drainage	Moderately well drained	
Colour of the topsoil:	Light gray (2.5Y7/1dry) and gray (2.5Y6/1 moist)	
Colour of the subsoil	Light gray (2.5Y7/2 dry) and light brownish gray (2.5Y6/2 moist)	
Soil depth	Deep (>170 cm)	
Nature of obstruction	None	
Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	2.94	2.80
Available phosphorous (Bray P1 (mg kg^{-1})	30.01	16.90
Acidity (pH in 1:1 soil to water ratio)	4.3	4.3
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	1.38	0.54
Exchangeable Calcium (cmol kg^{-1} soil)	0.49	0.48
Exchangeable Magnesium (cmol kg^{-1} soil)	0.08	0.31
Exchangeable Potassium (cmol kg^{-1}soil)	0.05	0.05
Exchangeable Sodium (cmol+ kg^{-1} soil)	0.38	0.42
Exchangeable Acidity (cmol+ kg^{-1} soil)	0.38	0.54
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	20	23
DTPA extractable Iron (cmol kg^{-1})	6.47	6.30
DTPA extractable Copper (cmol kg^{-1})	0.79	0.76
DTPA extractable Zinc (cmol kg^{-1})	0.49	3.21

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).

5.1.3.3 Torma Bum series

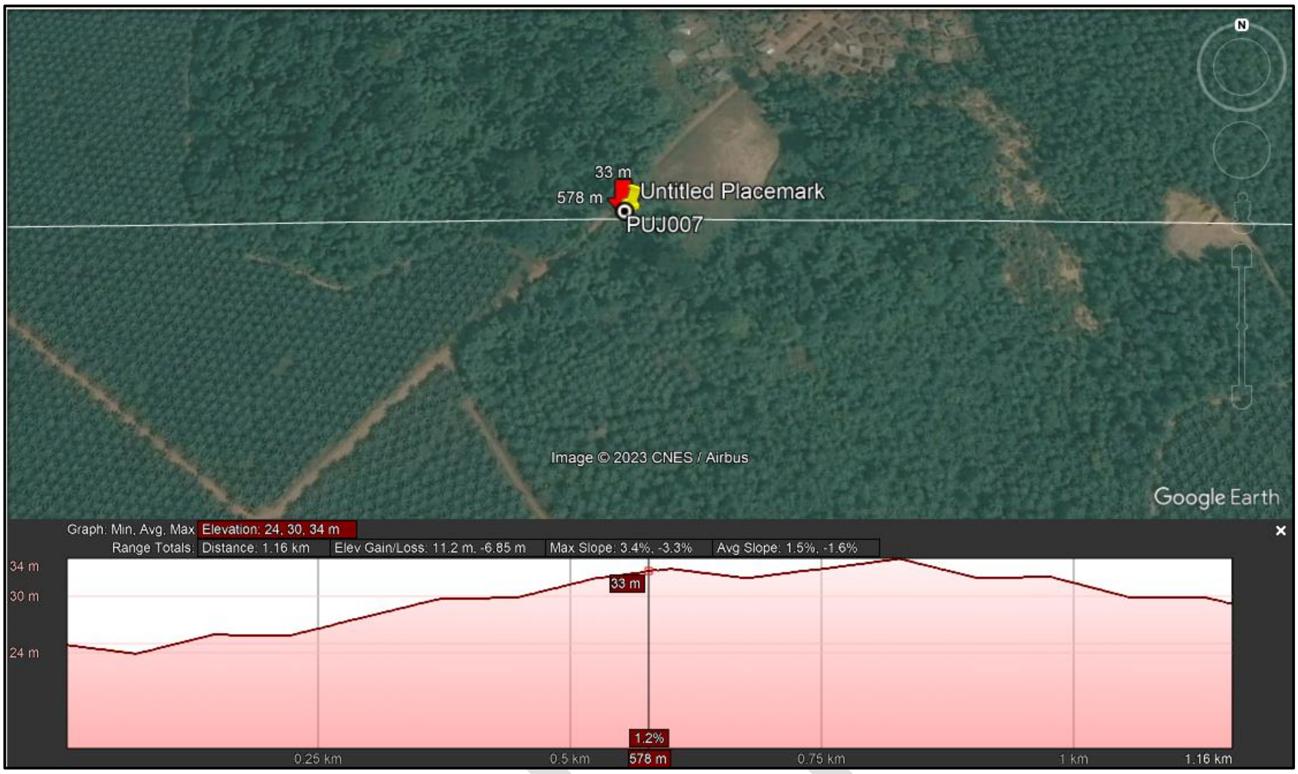

Photo 7. *Typical position of Torma Bum soil series in Pujehun District*

The Torma Bum series are soils on alluvial floodplains formed along the Taia, Sewa and Wanjei rivers. They are Taxonomically classified as Entisols whose central concept is that of soils that have little or evidence of pedogenic horizons. They show a lot of stratification, indicating the seasonal deposition of river sediments and the burying of old dark colored surface horizons. For this reason, they are classified at the suborder level as Fluvents. The Torma Bum soils occupies an area of 849.85 $Km^{2,}$ the most extensive in the Bonthe district. They are not prone to erosion but some phases of the soil at lower elevations of the basin may have problems of flooding and water logging.

They have good physical properties and are cultivated easily. The texture of the top 0-20 cm arable layer is clay loam by field determination but sandy clay loam by laboratory particle size analysis. The subsoil (20-50cm) is also a sandy clay texture by laboratory determination. The colour of the top and sub soils are mainly brown and the soil is deep (>100cm) with no root restrictive layer or pan.

Chemically, the Torma Bum series is Sierra Leone's most fertile alluvial soil for rice production as revealed by the analytical data (Table 16). 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 and Mg are low in both topsoil and subsoil horizons, exchangeable K is high 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 and Cu (cmol kg^{-1}) are low in both topsoil and subsoil horizons, while the DTPA extractable Zn (cmol kg^{-1}) is high in both topsoil horizon and subsoil horizons.

The soil is classified as an Umbric Fluvisol due to its AC horizon, alluvial parent material and high organic carbon content of its epipedon. The high nutrient status, moderate acidity and huge network of dams and lakes, perennial rivers put the Torma Bum soils as one of Sierra Leone's prime soils that holds a potential for solving the nations' food security challenges. Irrigation water can be available for dry season crop production ranging from rice to vegetable production as long as the soils are sustainably managed.

A detailed description and analytical data for a representative profile of the *Torma Bum series*, PUJ007, are given in Appendices 7a and 7b.

Table 16. *Key land, morphological and chemical properties of Torma Bum series*

Soil series name	Torma Bum	
International soil name	Umbric Fluvisol	
Slope range	1.2 %	
Soil surface stoniness	NA	
Typical position in the landscape	*See Photo 7*	
Texture of the topsoil (0 – 20cm)	Sandy loam	
Texture of the subsoil (at 50cm)	Sandy clay	
Drainage	Moderately well drained	
Colour of the topsoil:	Dark grey (7.5YR 4/1 dry) and very dark grey (7.5Y/R3/1 moist)	
Colour of the subsoil	Light reddish brown (2.5YR 6/4 dry) and reddish brown (2.5Y/R5/4 moist)	
Soil depth	Deep (>160 cm)	
Nature of obstruction	None	
Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	2.8	1.21
Available phosphorous (Bray P1 (mg kg^{-1})	9.72	7.49
Acidity (pH in 1:1 soil to water ratio)	4.5	4.7
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	3.43	2.35
Exchangeable Calcium (cmol kg^{-1} soil)	1.04	0.85
Exchangeable Magnesium (cmol kg^{-1} soil)	0.41	0.34
Exchangeable Potassium (cmol kg^{-1}soil)	0.08	0.05
Exchangeable Sodium (cmol+ kg^{-1} soil)	0.55	0.48
Exchangeable Acidity (cmol+ kg^{-1} soil)	1.35	0.63
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	23	10
DTPA extractable Iron (cmol kg^{-1})	4.08	1.61
DTPA extractable Copper (cmol kg^{-1})	0	0.00
DTPA extractable Zinc (cmol kg^{-1})	8.86	4.30

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).

5.1.4 Floodplain soils

5.1.4.1 Scarcies series

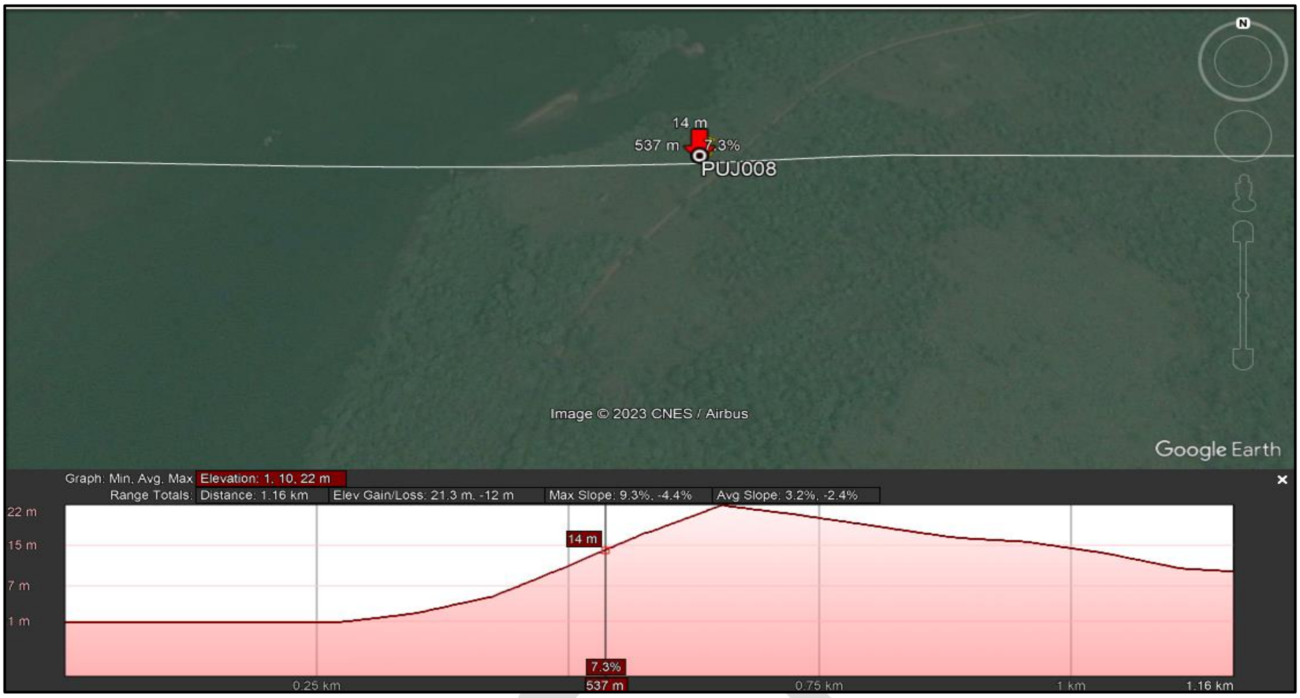

Photo 8. *Typical position of Scarcies soil series in Pujehun District*

The Scarcies series is found in tidal flats extending from the edges of the Sulima, Mano Kpendeh and Mano Salija communities into the network of channels of Creeks where the Moa River meets the Atlantic Ocean. It is generally structureless (massive) with a depth of at least 40cm deep. The parent material is alluvial silt, clay or sand that is periodically deposited by the tidal flow. It is poorly drained and periodically flooded with brackish water that comes with the tidal flow. The vegetation on this soil type is a remnant of medium sedge grass that is frequently cleared for rice cultivation. The textures of the topsoil horizon are brown (10YR 4/3 dry) and dark brown (10Y/R3/3 moist) and the those of subsoil horizons are dark yellowish brown (10YR 4/4 dry) and dark yellowish brown (10Y/R3/4 moist).

Chemically, soils of the Scarcies series seem to be limited in nutrient status (Table 17). The organic carbon content is moderate 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 and Mg are low in both topsoil and subsoil horizons, exchangeable K is high 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 Cu (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.

The soils are inundated for most times in the year and must be impoldered to control drainage and manage pH.

A detailed description and analytical result of a representative profile, PUJ008, of the *Scarcies series* are given in Appendices 8a and 8b.

Table 17. *Key land, morphological and chemical properties of Scarcies series*

Soil series name	Scarcies	
International soil name	Thionic Fluvisol	
Slope range	7.3%	
Soil surface stoniness	NA	
Typical position in the landscape	*See Photo 8*	
Texture of the topsoil (0 – 20cm)	Loam	
Texture of the subsoil (at 50cm)	Clay loam	
Drainage	Imperfectly drained	
Colour of the topsoil:	Dark grey (7.5YR 4/1 dry) and very dark grey (7.5Y/R3/1 moist)	
Colour of the subsoil	Dark yellowish brown (10YR 4/4 dry) and dark yellowish brown (10Y/R3/4 moist)	
Soil depth	Deep (>175 cm)	
Nature of obstruction	None	
Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	1.44	1.37
Available phosphorous (Bray P1 (mg kg^{-1})	10.26	9.01
Acidity (pH in 1:1 soil to water ratio)	6.3	6.07
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	3.58	2.52
Exchangeable Calcium (cmol kg^{-1} soil)	2.15	1.45
Exchangeable Magnesium (cmol kg^{-1} soil)	0.73	0.50
Exchangeable Potassium (cmol kg^{-1}soil)	0.09	0.08
Exchangeable Sodium (cmol+ kg^{-1} soil)	0.42	0.33
Exchangeable Acidity (cmol+ kg^{-1} soil)	0.19	0.16
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	21	12
DTPA extractable Iron (cmol kg^{-1})	18.99	9.62
DTPA extractable Copper (cmol kg^{-1})	0	0.00
DTPA extractable Zinc (cmol kg^{-1})	1.62	4.15

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).

5.1.4.2 Turner series

Photo 9. *Typical position of Turner soil series in Pujehun District*

This complex consists of soils of the beach ridges (young, inland, and degraded soils and their closely associated swales (shallow marshy channels with gently sloping sides) and mud flats. Along the beach ridges, the soils are very sandy, showing little or no horizon development. It is classified as an Albic Arenosol. The soils of the sandy beach ridges are widely used for coconut, cashew, and oil palm cultivation. The topsoil colours are brown (10YR4/3 dry) and dark brown (10YR3/3 moist), while the subsoil colours are dark yellowish brown (10YR4/4 dry and 10YR3/4 moist). The soil depth is at least 130 cm deep, moderately drained, sandy topsoil and a loamy sand subsoil.

The soils of Turner series seem to be limited in one or more chemical properties, which may challenge the production of most arable crops (Table 18). 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 and Mg is low in both topsoil and subsoil horizons, exchangeable K is moderate in topsoil horizon and low in subsoil horizon, 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 Cu (cmol kg^{-1}) are low in both topsoil and subsoil horizons, while the DTPA extractable Zn (cmol kg^{-1}) is high in topsoil horizon and moderate in subsoil horizon.

The low exchangeable cation status is an indication that the soil is highly leached and may need large quantities of soil amendments for it to support plant growth especially rice. Its sandy texture may cause low water storage for crops during the dry season. Its location near coastal flood plains may militate against the production of other food and tree crops that require aerobic conditions for their root growth during incidences of flooding. These characteristics pose a serious challenge to their management for crop production.

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.

A detailed description and analytical data for a representative profile, PUJ009, of the *Turner series* are given in Appendices 9a and 9b.

Table 18. *Key land, morphological and chemical properties of Turner series*

Soil series name	Turner	
International soil name	Albic Arenosol	
Slope range	0.7 %	
Soil surface stoniness	NA	
Typical position in the landscape	*See Photo 9*	
Texture of the topsoil (0 – 20cm)	Loam	
Texture of the subsoil (at 50cm)	Clay loam	
Drainage	Imperfectly drained	
Colour of the topsoil:	Brown (10YR4/3 dry) and dark brown (10YR3/3 moist)	
Colour of the subsoil	Yellowish brown (10YR5/6 dry) and dark yellowish brown (10YR4/6 moist)	
Soil depth	Deep (>175 cm)	
Nature of obstruction	None	
Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	1.98	1.42
Available phosphorous (Bray P1 (mg kg^{-1})	1.59	3.37
Acidity (pH in 1:1 soil to water ratio)	4.9	5.07
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	3.87	3.03
Exchangeable Calcium (cmol kg^{-1} soil)	0.83	0.92
Exchangeable Magnesium (cmol kg^{-1} soil)	1.09	0.66
Exchangeable Potassium (cmol kg^{-1}soil)	0.08	0.06
Exchangeable Sodium (cmol+ kg^{-1} soil)	0.52	0.53
Exchangeable Acidity (cmol+ kg^{-1} soil)	1.35	0.86
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	13	8
DTPA extractable Iron (cmol kg^{-1})	1.34	2.54
DTPA extractable Copper (cmol kg^{-1})	0.16	0.31
DTPA extractable Zinc (cmol kg^{-1})	13.09	7.30

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).

5.2 Soil Classification

Following the field survey activities, the soils of Pujehun District were classified and mapped on the basis of their representative characteristics, as presented in Table 19. Based on the results show below, it can be noted that soils of the Mokonde series occupy the largest area (1049.7 km^2). This is followed by Newton (661.2 km^2), Njala (523.2 km^2), Bonjema (551.2 km^2), Momenga (443.9 km^2), Torma Bum (286.9 km^2), Gbesebu (217.5 km^2) and Scarcies (70.4 km^2) in decreasing order of area of coverage. The least is soils of the Turner series (55.8 km^2).

Table 19. *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**	
Momenga	Leptosol	Ferallic Nitrosol	Inceptisol	Tropept	Dystropept	Plinthic Dystropept	443.9
Njala	Leptosol	Dystric Nitosol	Ultisol	Humult	Palehumult	Orthoxic Palehumult	523.2
Mokonde	Plinthosol	Haplic Plinthosol	Ultisol	Udult	Paleudult	Plinthic Paleudult	1049.7
Bonjema	Leptosol	Dystric Nitosol	Ultisol	Udult	Paleudult	Plinthic Paleudult	551.2
Newton	Cambisol	Dystric Cambisol	Inceptisol	Udept	Humudept	Psammentic Humudepts	661.2
Gbesebu	Fluvisol	Umbric Fluvisol	Entisol	Aquent	Fluvaquent	Aeric Fluvaquent	217.5
Torma Bum	Fluvisol	Umbric Fluvisol	Entisol	Aquent	Humaquent	Cummulic Humaquent	286.9
Scarcies	Fluvisols	Thionic Fluvisols	Entisol	Aquent	Sulfaquent	Fluventic Sulfaquent	70.4
Turner	Arenosol	Albic Arenosol	Inceptisol	Aquent	Psammaquent	Aeric Pssamaquent	55.8

5.3 Soil map of Pujehun District

The soils of Pujehun District as indicated in Table 19, were mapped on the basis of their representative characteristics, as presented in Figure 14.

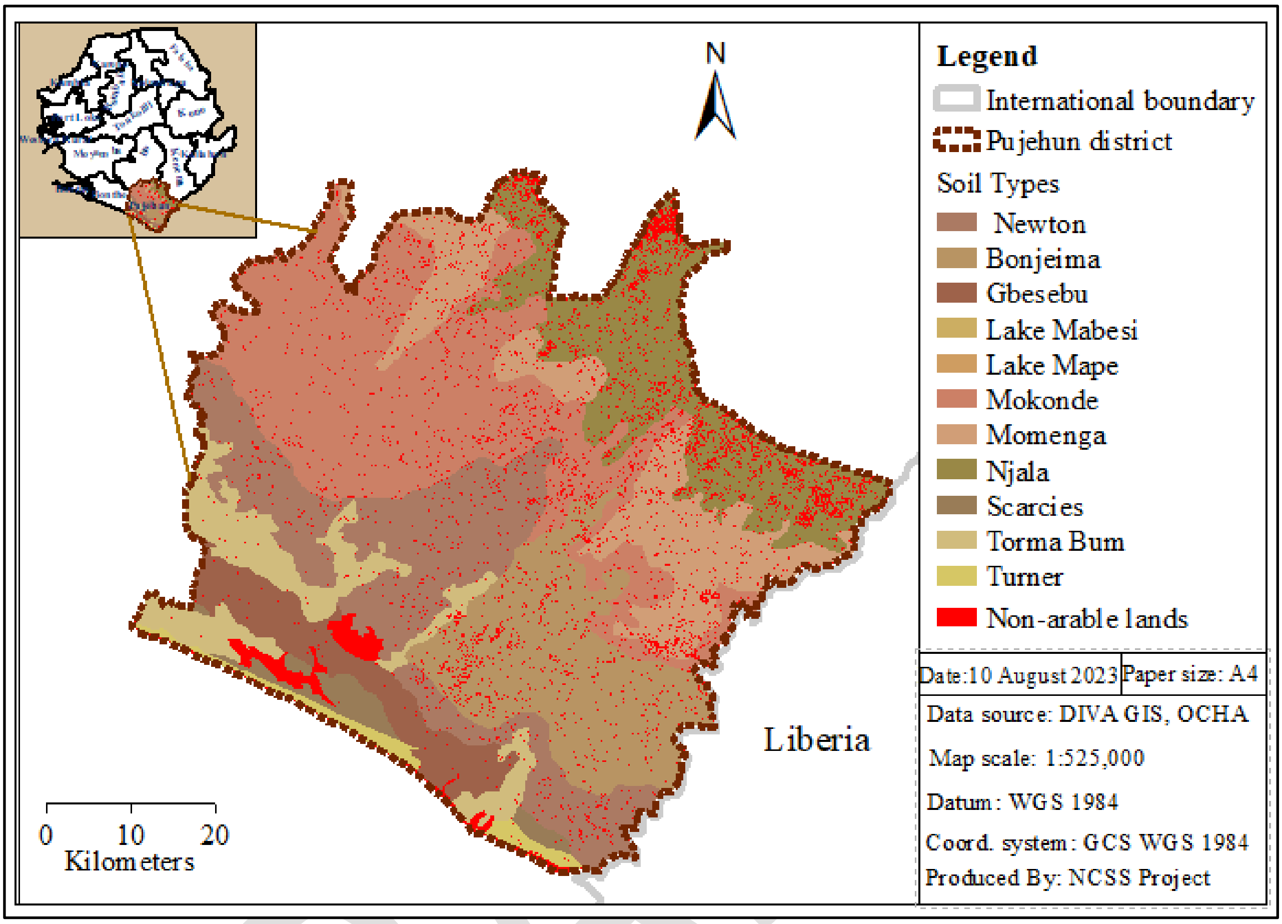

Figure 14. *Soil association map of Pujehun district*

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 Pujehun District.

The soils in Pujehun 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's 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 Pujehun 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 Pujehun 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 Pujehun District

In order to evaluate the capability of land in Pujehun district, soil-site characteristics of the nine-soil series (Section 3.7.1 – 3.7.5) were matched with the criteria for land capability classification. The result of land capability evaluation of soils of Pujehun District, as presented in Table 20 and Figure 15, indicates that 3859.7 km^2 (92 %) of the land area is arable and 334.8 km^2 (8 %) is non-arable. Arable soils include Momenga, Njala, Mokonde, Gbonjeima, Newton, Gbesebu, Torma Bum, Scarcies and Turner 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 the Newton series, which account for about 661.6 km^2 (15.8 %) of the total area. 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 Gbonjeima, Gbesebu and Torma Bum 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 1055.5 km^2 (25.2 %) is occupied by land capability class II lands. 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 Momenga, Mokonde, Njala and Scarcies 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, 2087.1 km^2 (49.8 %) of the district is occupied by land capability class III lands. 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 Turner series, which cover 55.8.4 km^2 (1.3 %) of the district. 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 334.8 km^2 (8 %) of the district.

Table 20. *Area covered by soil associations/types in Pujehun District.*

Land capability group	Soil-physiography	Soil association	Soil series	Area	
				km^2	%
Arable	Soils on uplands of high weathered materials	Momenga-Njala	Momenga, Njala	967.1	23.1
	Soils on colluvial foot slopes and terraces	Mokonde-Gbonjeima	Mokonde, Gbonjeima	1600.8	38.2
	Riverain soils	Newton-Gbesebu-Torma Bum	Newton, Gbesebu, Torma Bum	1165.6	27.8
	Floodplain soils	Scarcies-Turner	Scarcies, Turner	126.2	3.0
Non-arable	Steep slopes and hills, rock outcrops, settlements, roads and water bodies			334.8	8.0

The potential risk of degradation when these arable soils are put under agricultural use are also outlined in *Table 21* 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 21. *Land capability indices of soils and their implications for agricultural use in the Pujehun district*

Soil association	Soil individuals	Capability group	Capability class	Capability subclass/ Risk of hazards
Momenga-Njala	Momenga	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.
	Njala	Arable	III	
Mokonde-Gbonjeima	Mokonde	Arable	III	Highly suitable for cultivation of arable crops but have few limitations, mainly related with gravel in subsoil, shallow gravel-free layer, etc.
	Gbonjeima	Arable	II	Moderately suitable for cultivation of arable crops but have few limitations, mainly relating to fertility (f).
Newton-Gbesebu-Torma Bum	Newton	Arable	I	Highly suitable for cultivation of rice, vegetables and groundnut but may have few moderate limitations of fertility.
	Gbesebu	Arable	II	Moderately suited for cultivation of rice and vegetables but may have moderate risk of damage from flooding (w)
	Torma Bum	Arable	II	
Scarcies-Turner	Scarcies	Arable	III	Somewhat extremely wet soil (w) and not suited for cultivations, grazing or forestry. Suited for wildlife, watershed, or recreation.
	Turner	Arable	IV	Marginally suited for fruit crops like coconut (limited by high sand and low moisture capacity)

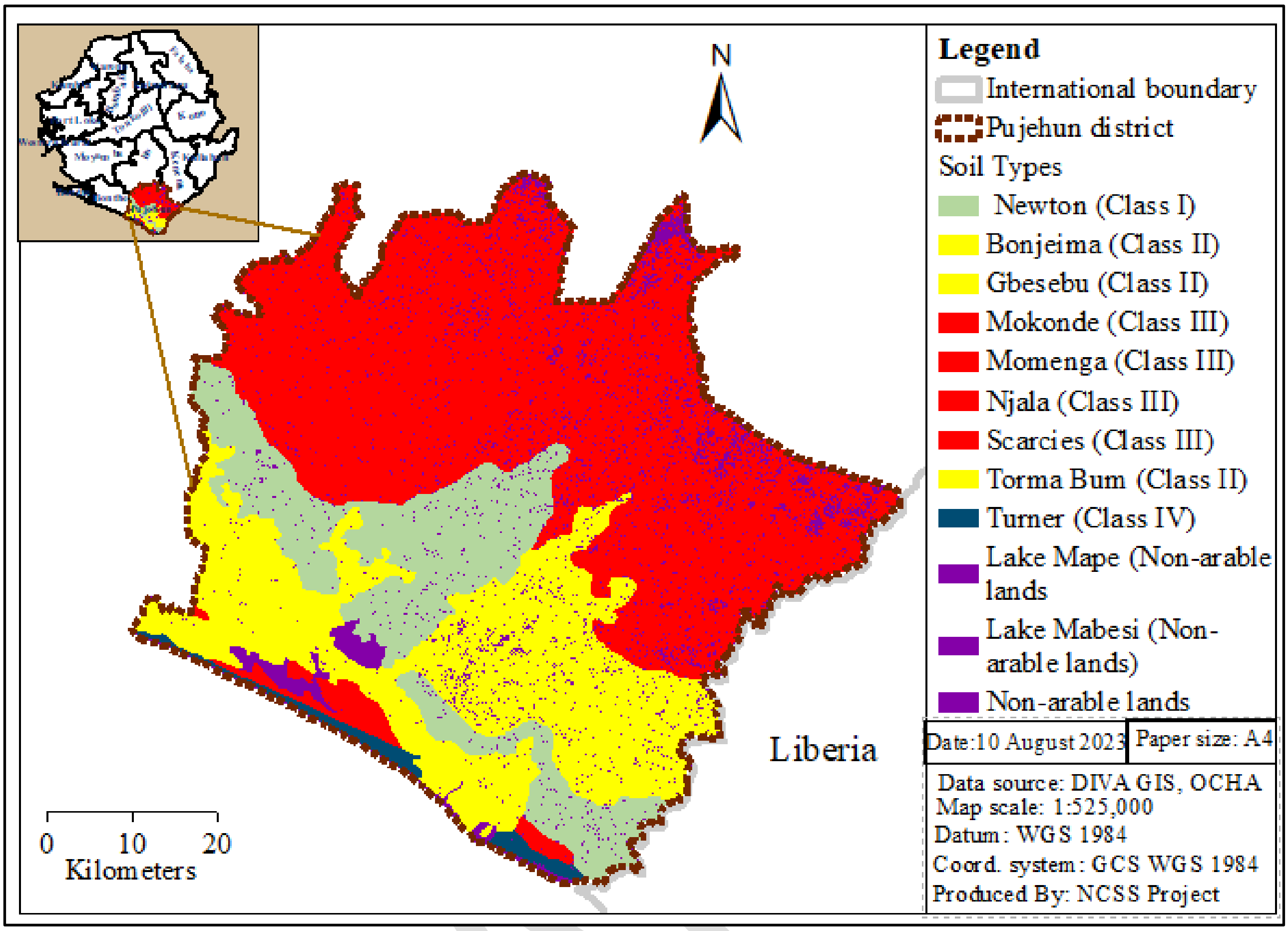

Figure 15. *Land capability of soils in Pujehun District*

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 Pujehun 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 nine soil individuals (i.e., soil series) that are arable in the district, Newton, Gbesebu and Torma Bum series ranked the highest; being moderately suitable (S2) in their capacity to satisfy the optimal growth requirements and yield of rice in two (rainfed upland rice and naturally flooded rice cultivation systems) out of four cultivation schemes under low input level of management. This is followed by Gbonjeima and Mokonde series for moderate suitability (S2) for rainfed upland rice cultivation. The other soil individuals ranked either marginally suitable (S3) or not suitable for rainfed upland rice and irrigated rice cultivation.

Overall, the results (Tables 22, 23, 24 and 25) show that soils on uplands of high weathered materials are moderately to marginally suitable for 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 on uplands of high weathered materials

According to the results presented in Table 22, soils on uplands of high weathered materials are generally marginal to not suitable for rice cultivation. Only a portion of these soils are marginally suitable (S3) for rainfed upland rice cultivation and the rest is not suitable for rainfed bunded, natural flooded and irrigated rice cultivation due to limitations of topography and moisture availability.

Table 22. *Suitability of the Momenga-Njala soil association for rice cultivation under four farming systems*

Soil association	**MAFS target crops**	**Suitability class**					**Limitations for management**
		S1	**S2**	**S3**	**N1**	**N2**	
Momenga	Rainfed Upland rice						sf
	Rainfed bunded rice						t
	Natural flooded rice						t
	Irrigated rice						t
Njala	Rainfed Upland rice						sf
	Rainfed bunded rice						ts
	Natural flooded rice						ts
	Irrigated rice						ts

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

6.2.1.2 Soils on colluvial footslopes and terraces

According to the results presented in Table 23, the suitability of soils on colluvial footslopes and terraces for rice cultivation generally ranges from moderate (S2) for Gbonjeima to marginal (S3) for Mokonde. They are only marginally suitable (S3) for rainfed upland rice cultivation.

Table 23. *Suitability of Mokonde-Gbonjeima 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
Gbonjeima	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)

6.2.1.3 Riverain soils

According to the results presented in Table 24, the suitability of riverain soils of Pujehun district for rice cultivation varies from highly suitable to marginally suitable. The Newton soils are the most suitable soils in the district. This is followed by the Gbesebu and Torma Bum soils. are moderately suitable (S2) for rainfed upland rice cultivation and some (Tisso soils) are marginally suitable (S3) for natural flooded rice cultivation.

Table 24. *Suitability of Newton-Gbesebu-Torma Bum soil association for rice cultivation under four farming systems*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Newton	Rainfed Upland rice	■					f
	Rainfed bunded rice			■			sf
	Natural flooded rice		■				sf
	Irrigated rice		■				sf
Gbesebu	Rainfed Upland rice	■					f
	Rainfed bunded rice			■			sf
	Natural flooded rice		■				sf
	Irrigated rice		■				sf
Torma Bum	Rainfed Upland rice	■					f
	Rainfed bunded rice			■			sf
	Natural flooded rice		■				sf
	Irrigated rice		■				sf

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

6.2.1.4 Floodplain soils

According to the results presented in Table 25, the suitability of floodplain soils under the four rice cultivation systems ranges from highly suitable (S1) for natural flooded rice to moderately suitable (S2) and currently not suitable (N1) due to somewhat extremely wet soil (w) condition and their unsuitability for cultivation of major food crops, grazing and forestry. They area however suitable for tourism, wildlife, watershed, recreation and fruit crops such as coconut.

Table 25. *Suitability of Scarcies-Turner soil association for rice cultivation under four farming systems*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Scarcies	Rainfed Upland rice				■		fw
	Rainfed bunded rice				■		fw
	Natural flooded rice	■					fw
	Irrigated rice		■				fw
Turner	Rainfed Upland rice				■		fw
	Rainfed bunded rice				■		sfw
	Natural flooded rice				■		sfw
	Irrigated rice				■		sfw

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

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 26, 27, 28 and 29). The suitability of these soil individuals ranges from moderately suitable (S2) to marginally (S3).

6.2.2.1 Soils 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 moderately suitable (S2) for cassava and groundnut, and marginally suitable (S3) for maize, sweet potato, and cowpea (Table 26). Major limitations for use of these soil include moderate to strong slope, some amount of gravels in root zone layer, and fertility problems.

Table 26. *Suitability of the Momenga-Njala soil association for cultivation of other food crops*

Soil association	**MAFS target crops**	**Suitability class**					**Limitations for management**
		S1	**S2**	**S3**	**N1**	**N2**	
Momenga	Cassava	■					f
	Maize			■			stf
	Sweet potato		■				sf
	Groundnut		■				sf
	Cowpea			■			stf
Njala	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)

6.2.2.2 Soils 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 27). 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 27. *Suitability of Mokonde-Gbonjeima 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
Gbonjeima	Cassava	■					f
	Maize		■				sf
	Sweet potato	■					f
	Groundnut	■					f
	Cowpea		■				sf

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

6.2.2.3 Riverain soils

Riverain soils have proven sustainable for short duration varieties of major field crops such as cassava, maize, sweet potato, groundnut, and cowpea in some African countries like Nigeria, Ghana, and Kenya, especially during aberrant weather conditions of short-term dry spells and delayed onset of rainy season. Our evaluation of such soils in Pujehun district has revealed that these soils are highly suitable (S1) to marginally suitable (S3) for maize and sweet potato, and marginally suitable for cassava, groundnut, and cowpea (Table 28).

Table 28. *Suitability of the Newton-Gbonjeima-Torma Bum soil association for cultivation of other food crops*

Soil association	**MAFS target crops**	**Suitability class**					**Limitations for management**
		S1	**S2**	**S3**	**N1**	**N2**	
Newton	Cassava	■					f
	Maize		■				sf
	Sweet potato	■					f
	Groundnut	■					f
	Cowpea		■				sf
Gbesebu	Cassava	■					f
	Maize		■				sf
	Sweet potato		■				sf
	Groundnut	■					f
	Cowpea			■			sfw
Torma Bum	Cassava			■			sfw
	Maize			■			fw
	Sweet potato			■			fw
	Groundnut		■				sf
	Cowpea			■			sfw

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

6.2.2.4 Floodplain soils

The result stated in Table 29 shows that only a very small portion of soils located on floodplains are marginally suitable (S3) for maize, sweet potato and groundnut, and the rest is not suitable. The potential of these soil individuals for supporting optimum growth of these crops is related to their imperfectly drained nature and the high proportion of sand in their structure, which is a major requirement for root and tuber, and leguminous crops.

Table 29. *Suitability of Scarcies-Turner soil association for cultivation of other food crops*

Soil association	**MAFS target crops**	**Suitability class**					**Limitations for management**
		S1	**S2**	**S3**	**N1**	**N2**	
Scarcies	Cassava				■		sw
	Maize			■			sf
	Sweet potato			■			sf
	Groundnut			■			sf
	Cowpea				■		sw
Turner	Cassava				■		sw
	Maize				■		sw
	Sweet potato				■		sw
	Groundnut				■		sw
	Cowpea				■		sw

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 Pujehun district, the same 2015 census report reveals that 2,317 households, which account for 0.2% of country's farming population are engaged in vegetable cultivation, accounting for 5,673 hectares (0.2%) of the land under cultivation and yield of 325,374 kg. Hence, soil suitability evaluation would be of immense relevance for improving the productivity of the vegetable subsector. Based on the results (Table 30, 31, 32 and 33), 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 on uplands of highly weathered materials

Soil suitability evaluation for upland soils of highly weathered materials in Pujehun district shows that Momenga and Njala soils are only marginally suitable (S3) for tomato and currently not-suitable (N1) for onion, cabbage and carrot due to extreme limitations of shallow depth and slope, and moisture availability (Table 30). However, with suitable soil conservation management practices, the currently not-suitable soils can be upgraded to marginally suitable (S3) soils.

Table 30. *Suitability of the Momenga-Njala soil association for cultivation of vegetable crops*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Momenga	Onion				■		t
	Tomato			■			st
	Cabbage			■			st
	Carrot				■		t
Njala	Onion				■		t
	Tomato			■			st
	Cabbage			■			st
	Carrot				■		t

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

6.2.3.2 Soils on colluvial footslopes and upper terraces

The suitability of soils on colluvial footslopes and terraces, i.e., soils of Mokonde and Gbonjeima series ranges from moderately suitable (S2) for onion, tomato and carrot, to marginally suitable (S3) for cabbage (Table 31). 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 31. *Suitability of the Mokonde-Gbonjeima soil association for cultivation of vegetable crops*

Soil association	MAF target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Mokonde	Onion		■				f
	Tomato		■				f
	Cabbage			■			sf
	Carrot		■				f
Gbonjeima	Onion		■				f
	Tomato		■				f
	Cabbage			■			sf
	Carrot		■				f

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

6.2.3.3 Riverain soils

Riverain soils of Pujehun district are moderately suitable (S2) for tomato to marginally suitable (S3) for onion, cabbage and carrot (Table 32). Major limitations are associated with waterlogging, flooding, and fertility, which can be overcome by suitable soil conservation management practices.

Table 32. Suitability of the Newton-Gbesebu-Torma Bum soil association for cultivation of vegetable crops

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Newton	Onion		■				fw
	Tomato		■				f
	Cabbage		■				fw
	Carrot		■				fw
Gbesebu	Onion			■			fw
	Tomato		■				f
	Cabbage			■			fw
	Carrot			■			fw
Torma Bum	Onion			■			fw
	Tomato		■				f
	Cabbage		■				fw
	Carrot			■			fw

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

6.2.3.4 Floodplain soils

The results show that soils of Scarcies and Turner, located on floodplains, are marginally suitable (S2) to not suitable (N1) for vegetables such as onion, tomato, cabbage and carrot. Major limitations are associated with high sand content (Table 33).

Table 33. Suitability of Scarcies-Turner soil association for cultivation of vegetable crops

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Scarcies	Onion			■			sf
	Tomato			■			f
	Cabbage			■			f
	Carrot			■			sf
Turner	Onion				■		sf
	Tomato				■		f
	Cabbage				■		f
	Carrot				■		sf

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

6.2.4 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 Pujehun district, the 2015 census report reveals that out of a total of 8,176 agricultural households engaged in tree crop cultivation, 867 (i.e., 0.4%) are engaged in cocoa cultivation, 957 (i.e., 0.5%) are engaged in coffee cultivation, 6,201 (i.e., 3.0%) are engaged in oil palm cultivation, 135 (i.e., 0.1) are engaged in citrus cultivation, 16 are engaged in cashew cultivation. In terms of area under cultivation per tree crop, out of a total area of 200,489 hectares under tree crop, cocoa accounts for 3,533 ha, coffee accounts for 3,489 ha, oil palm accounts for 31,038 ha, citrus accounts for 362 ha and cashew accounts for 135 ha. This is an indication of how important is the tree crop subsector in the national economy development. Based on the results (Table 34, 35, 36 and 37), the suitability of soils for tree crop cultivation ranges from moderately suitable (S2) to permanently not-suitable (N2). The details are presented below:

6.2.4.1 Soils on uplands of high weathered materials

The suitability of Momenga and Njala soils, located on dissected uplands of high weathered materials, ranges from moderately suitable (S2) for cocoa and cashew, to marginally suitable (S3) for arabica coffee, robusta coffee and oil palm (Table 34). 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 34. *Suitability of Momenga-Njala soil association for cultivation of tree crops*

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

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

6.2.4.2 Soils on colluvial footslopes and terraces

The suitability of soils located on colluvial footslopes and terraces, which include Mokonde and Gbonjeima series, indicates that soils are moderately suitable (S2) for cocoa, arabica coffee, robusta coffee, cashew and oil palm (Table 35). 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 35. *Suitability of Mokonde-Gbonjeima 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
Gbonjeima	Cocoa						f
	Arabica coffee						f
	Robusta coffee						f
	Cashew						f
	Oil palm						f

f= fertility (pH, CEC, Base saturation)

6.2.4.5 Riverain soils

The suitability of riverain soils of Newton, Gbesebu and Torma Bum series, ranges from marginally suitable (S3) to permanently not-suitable (N2). for arabica coffee, robusta coffee and cashew (Table 36). This is due to major limitations ranging from imperfect to poor drainage, danger of flash floods, and waterlogging, which are major challenges for growing arabica coffee, robusta coffee and cashew on sustainable basis.

Table 36. *Suitability of Newton, Gbesebu and Torma Bum soil association for cultivation of tree crops*

Soil association	**MAFS target crops**	**Suitability class**					**Limitations for management**
		S1	**S2**	**S3**	**N1**	**N2**	
Newton	Cocoa		■				fw
	Arabica coffee		■				fw
	Robusta coffee		■				fw
	Cashew		■				fw
	Oil palm		■				fw
Gbesebu	Cocoa		■				fw
	Arabica coffee		■				fw
	Robusta coffee		■				fw
	Cashew		■				fw
	Oil palm		■				fw
Torma Bum	Cocoa				■		fw
	Arabica coffee					■	tfw
	Robusta coffee					■	tfw
	Cashew			■			tfw
	Oil palm				■		fw

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

6.2.4.4 Floodplain soils

The suitability of floodplain soils of the Scarcies and Turner series for tree crops is very poor. For Turner soils, the suitability ranges from moderately suitable (S2) for cashew to marginally suitable (S3) for arabica coffee and oil palm cocoa to currently not suitable (N1) and permanently not suitable (N2) for cocoa and robusta coffee, respectively (Table 37). Scarcies soils are permanently not suitable for tree crop cultivation. Major limitations are associated with high sand content, flooding, poor soil structure and fertility.

Table 37. *Suitability of Scarcies-Turner soil association for cultivation of tree crops*

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

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

6.2.5 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 38, 39, 40 and 41), the suitability of soils for fruit crop cultivation ranges from moderately suitable (S2) to permanently not-suitable (N2). The details are presented below:

6.2.5.1 Soils on uplands of high weathered materials

The suitability of Momenga and Njala soils ranges from moderately suitable (S2) for pineapple and banana, to marginally suitable (S3) for mango and citrus (Table 38). This 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 38. *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	
Momenga	Mango			■			sf
	Citrus			■			sf
	Pineapple		■				f
	Banana		■				f
Njala	Mango			■			sf
	Citrus			■			sf
	Pineapple		■				f
	Banana		■				f

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

6.2.5.2 Soils on colluvial footslopes and terraces

The suitability of Mokonde and Gbonjeima soils shows that these soils are highly suitable (S1) for pineapple and banana to moderately suitable (S2) for mango and citrus (Table 39). 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 39. *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
Gbonjeima	Mango		■				f
	Citrus		■				f
	Pineapple	■					f
	Banana	■					f

f= fertility (pH, CEC, Base saturation)

6.2.5.3 Riverain soils

The suitability of Newton, Gbesebu and Torma Bum soils is variable. For Newton and Gbesebu soils, suitability varies from highly suitable (S1) for pineapple and banana to moderately suitable (S2) for mango, and marginal suitable (S3) for citrus. For Torma Bum soils, suitability ranges from moderately suitable (S2) for banana to marginally suitable (S3) for pineapple, and somewhat permanently not-suitable for citrus and mango (Table 40). This is due to major limitations of high moisture and fertility to some extent, which could pose major challenges for growing these crops on sustainable basis under such environmental conditions.

Table 40. *Suitability of Newton, Gbesebu and Torma Bum soil association for cultivation of fruit crops*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	**S2**	**S3**	**N1**	**N2**	
Newton	Mango		■				fw
	Citrus			■			fw
	Pineapple	■					tfw
	Banana	■					f
Gbesebu	Mango		■				fw
	Citrus			■			fw
	Pineapple	■					tfw
	Banana	■					f
Torma Bum	Mango					■	fw
	Citrus					■	fw
	Pineapple			■			tfw
	Banana		■				fw

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

6.2.5.4 Floodplain soils

The suitability of floodplain soils of the Scarcies and Turner series for fruit crops such as mango, citrus, pineapple and banana are somehow very poor (Table 41). For Turner soils, the suitability ranges from moderately suitable (S2) for pineapple and banana to marginally suitable (S3) for mango and citrus. For Scarcies soils, Suitability varies from moderately suitable (S2) to marginally suitable (S3) for pineapple, and currently not suitable (N1) for mango and citrus cultivation. Major limitations are associated with high sand content, flooding, poor soil structure and fertility.

Table 41. *Suitability of Scarcies-Turner soil association for cultivation of fruit crops*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	**S2**	**S3**	**N1**	**N2**	
Scarcies	Mango				■		sft
	Citrus				■		sft
	Pineapple			■			f
	Banana		■				f
Turner	Mango			■			sf
	Citrus			■			sf
	Pineapple		■				f
	Banana		■				f

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

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 Pujehun 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). 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 Pujehun district, we observed that some of the soils of Pujehun district share similar characteristics as those of Kenema, Kailahun, and Kono districts since most of the soil associations and individuals are repeating. Hence, the soil fertility management options remain the same as for those discussed for soils of Kenema, Kailahun, and Kono 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 uplands of high weathered materials, and colluvial footslopes and terraces such as soils of the Momenga, Njala, Mokonde, and Gbonjeima 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 Pujehun 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 Poorly drained Non-Acid Sulphate soils (i.e. riverain soils such as soils of the Newton, Gbesebu, and Torma Bum 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 Tidal swamp soils high in Sulphur (i.e. soils located in flood plains such as soil of the Scarcies and Turner series)

The soils occur in coastal areas under Rhizophora racemose mangrove vegetation. They are better in nutrient status than the soils previously mentioned in this section because nutrients are replenished from the water that comes in from the sea; they however accumulate salt in the dry season (Odell et al., 1974). These soils are referred to as potential acid sulphate soils (the sulphur is in the reduced form FeS_2), when the soil is under water and acid sulphate soils when the sulphur has been oxidized to sulphuric acid, if drainage and exposure to the atmosphere of the sulphide containing horizon occurs. These soils in coastal areas benefit from nutrients coming in from the sea but accumulate salts in the dry season. Soils in the mangrove swamp areas of Rokupr were cultivated for years giving good rice yields without fertilization. Management to prevent the development of very high acidity is to keep the soil covered with sea water, knowing that the rains will wash out the salt prior to transplanting rice seedlings in the next season. Impoldering and completely leaching out the acidity is another option which is expensive and takes years to achieve. Use of liming materials is indicated for the acid sulphate soils and soil tests should be used to determine the need for fertilization. Management of urea is the same as outlined for poorly drained non-acid sulphate soils.

7.4 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.

7.5 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.

7.6 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.

7.7 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 42 summarizes the highly suitable (S1) and moderately suitable (S2) classes of soils recommended for agricultural investment in Pujehun district.

7.8 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 42. *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	Newton, Gbesebu, Torma Bum,	Mokonde, Gbonjeima	f (pH, CEC), s (texture)
	Rainfed bunded rice			t (slope)
	Natural flooded rice	Scarcies	Newton, Gbesebu, Torma Bum, Scarcies	t (slope)
	Irrigated rice			f (pH, w)
Other food crop production	Cassava	Momenga, Njala, Mokonde, Gbonjeima, Newton, Gbesebu,		f(pH, CEC), s (texture)
	Maize		Mokonde, Gbonjeima, Newton, Gbesebu	f (pH, CEC), s (texture)
	Sweet potato	Mokonde, Gbonjeima, Newton, Gbesebu	Momenga, Njala, Gbesebu, Torma Bum	f (pH, CEC), s (texture), w (drainage)
	Groundnut			f (pH, CEC), s (texture)
	Cowpea		Mokonde, Gbonjeima, Newton, Gbesebu,	f (pH, CEC)
Tree crop production	Cacao		Momenga, Njala, Mokonde, Newton, Gbesebu	f (pH, CEC)
	Arabica coffee		Mokonde, Newton, Gbesebu	f (pH, CEC), s (texture)
	Robusta coffee			
	Cashew		Momenga, Njala, Mokonde, Newton, Gbesebu, Turner	f (pH, CEC), s (texture)
	Oil palm		Mokonde, Newton, Gbesebu	f (pH, CEC)
Fruit crop production	Mango		Mokonde, Gbonjeima, Newton, Gbesebu	
	Citrus		Mokonde, Gbonjeima	
	Pine apple	Mokonde, Gbonjeima, Newton, Gbesebu	Momenga, Njala, Turner	f (pH, CEC), s (texture)
	Banana		Momenga, Njala, Torma Bum, Scarcies, Turner	f (pH, CEC)
Vegetable production	Onion		Mokonde, Gbonjeima, Newton, Gbesebu, Torma Bum,	f (pH, CEC)
	Tomato			f (pH, CEC)
	Cabbage		Newton, Torma Bum	f (pH, CEC), s (texture)
	Carrot		Mokonde, Gbonjeima, Newton,	f (pH, CEC)

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 Bonthe 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 Pujehun district are:

i. Newton, Gbesebu, Torma Bum and Scarcies soils of high suitability (S1) for Rainfed upland rice and natural flooded rice;
ii. Mokonde, Gbonjeima, Newton, Gbesebu, Torma Bum and Scarcies of moderate suitability (S2) for rainfed upland rice and irrigated rice.
iii. Momenga, Njala, Mokonde, Gbonjeima, Newton and Gbesebu soils of high suitability (S1) for cassava, sweet potato and groundnut.
iv. Momenga, Njala, Mokonde, Gbonjeima, Newton, Gbesebu and Torma Bum soils of moderate suitability (S2) for maize, sweet potato, groundnut and cowpea.
v. Momenga, Njala, Mokonde, Gbonjeima, Newton, Gbesebu and Turner soils of moderate suitability (S2) for tree crops such as cocoa, arabica and Robusta Coffee, cashew and oil palm
vi. Mokonde, Gbonjeima, Newton, Gbesebu soils of high suitability (S1) for pineapple and banana.
vii. Momenga, Njala, Mokonde, Gbonjeima, Newton, Gbesebu, Torma Bum, Scarcies, Turner soils of moderate suitability (S2) for moderate suitability for mango, citrus, pineapple and banana
viii. Mokonde, Gbonjeima, Newton, Gbesebu, Torma Bum soils of moderate suitability (S2) for onion, tomato, cabbage and carrot.

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***1a.** Soil profile description of profile pit No. PUJ001; Momenga series*

District: Pujehun; **Chiefdom**: Soro Gbema; **Village**: Gornor; **GPS location**: 7.19601°/11.36385°; **Elevation**: 39m; **Physiography**: On acid rocks; La**ndform/facet**: Interfluve side slope; **Parent Material**: Weathered Residium; **Landscape position**: Back slope; **Slope**: 1.3 %; **Vegetation**: Bush regrowth; **Erosion class and intensity**: e2, moderate; **Drainage and permeability:** Well drained and rapid; **Landuse**: Fallow shifting cultivation; **Major crops grown**: Cassava. **Other salient feature:** Profile contains partially weathered fragments of sandstone rocks that are at intermediate stage of weathering and being exposed as a result of road construction.

Land System: Blama; **Classification (USDA Taxonomy):** Ferralic Nitrosol; **FAO-UNESCO:** Plinthic dystropept

Mapping Unit: PUJ001
(Gravel-free over gravel soil)

Horizon (cm)	Morphological Description
A (0 – 40)	Brown (10YR 4/3 dry) and dark brown (10YR 3/3 moist); sandy loam; moderate, fine crumbly and angular blocky; hard (dry), firm (moist); non-sticky and non-plastic; plenty fine and medium pores; plenty very fine, fine and medium, few coarse roots; presence of termites, ants and other insects; clear and wavy boundary to horizon below.
E (40 – 100)	Brownish yellow (10YR 6/6 dry) and yellowish brown (10YR 5/6 moist); sandy clay; moderate, coarse, crumbly; hard (dry), firm (moist); non-sticky and non-plastic; plenty fine, medium and coarse pores; few very fine, fine and medium roots; presence of termites, ants and other insects; presence of high amount of gravel and stones; clear and wavy boundary to horizon below.
Bt2 (100 – 138)	Brownish yellow (10YR 6/8 dry) and yellowish brown (10YR 5/8 moist); sandy clay; moderate, medium, angular and sub-angular blocky; slightly hard (dry), friable (moist); non-sticky and non-plastic; few fine and plenty medium, and coarse pores; few very fine, fine, and very few medium roots; presence of termites, ants and other insects; presence of freshly weathered sandstones being converted into subsoil; clear and broken boundary to horizon below
Bt3 (138 – 200+)	Brownish yellow (10YR 6/8 dry) and yellowish brown (10YR 5/8 moist); sandy clay; strong, medium, angular and sub-angular blocky; slightly hard (dry), firm (moist); non-sticky and non-plastic; plenty fine, medium, and coarse pores; few very fine, fine, and very few medium roots; presence of termites, ants and other insects; presence of freshly weathered sandstones still in the process of forming subsoils, with traces of weathered rocks (pink colouration); clear and broken boundary to horizon below.

1b. Analytical laboratory data of profile pit No. PUJ001; Momenga series

Horizon (cm)	**Unit**	**0-40**	**40-100**	**100-138**	**138-200+**
Sand	%	70.80	64.80	60.80	65.50
Silt	%	8.72	6.70	6.70	7.40
Clay	%	20.48	28.5	32.5	27.1
Organic Carbon	%	3.48	2.8	1.77	2.68
Bray P1	mg/kg soil	8.20	1.23	0.16	3.20
pH 1:1 soil : water ratio		5.50	5.40	5.40	5.43
pH 1:1 M KCl ratio		4.10	4.20	4.10	4.13
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	3.76	2.64	2.14	2.85
Exchangeable calcium	mg/kg soil	0.97	0.88	0.84	0.90
Exchangeable magnesium	mg/kg soil	1.05	0.72	0.49	0.75
Exchangeable potassium	mg/kg soil	0.15	0.1	0.04	0.10
Exchangeable sodium	mg/kg soil	0.58	0.19	0.17	0.31
Exchangeable acidity	cmol/kg soil	1.01	0.75	0.60	0.79
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	26.00	11.00	8.00	15.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	3.22	9.75	9.75	7.57
DTPA extractable copper (mg kg^{-1})	mg/kg soil	0.40	1.21	0.40	0.67
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	12.51	8.08	4.96	8.52

__2a.__ Soil profile description of profile pit No. PUJ002; Njala series

District: Pujehun; **Chiefdom**: Kpanga Krim; **Village**: Yawei; **GPS location**: 7.40491°/11.70576°; **Elevation**: 41m; **Physiography**: On basic and ultra-basic rocks; La**ndform/facet**: Interfluve side slope; Parent **Material**: Weathered Residium; **Landscape position**: Foot slope; **Slope**: 0.8 %; **Vegetation**: Oil palm; **Erosion class and intensity**: e1, slight; **Drainage and permeability:** Well drained and rapid; **Landuse**: Tree cropping; **Crops grown**: Oil palm.

Land System: Bo; **Classification (USDA Taxonomy):** Dystric Nitrosol; **FAO-UNESCO:** Orthoxic Palehumult

Mapping Unit: PUJ002
Gravel-free over gravel soil

Horizon (cm)	Morphological Description
A (0 – 9)	Gray (10YR 6/1 dry and 10YR 6/5 moist); gravelly sandy clay loam; moderate, fine, crumbly; loose (dry), soft (moist); non-sticky and non-plastic; plenty very fine, fine and coarse pores; plenty very fine, fine and medium roots; presence of termites, ants and other insects; clear and wavy boundary to horizon below.
E (9 – 57)	Gray (10YR 6/1 dry) and light brownish gray (10YR 6/2 moist); gravelly sandy loam; moderate, coarse, crumbly; loose (dry), friable (moist); non-sticky and non-plastic; plenty medium, coarse and very coarse pores; common very fine and fine, very few medium roots; presence of termites, ants and other insects; gradual and irregular boundary to horizon below.
Bt2 (57 – 101)	Gray (10YR 5/1 dry) and grayish brown (10YR 5/2 moist); very gravelly sandy clay; moderate, coarse, crumbly; slightly hard (dry), friable (moist); non-sticky and non-plastic; plenty medium, coarse and very coarse pores; few very fine and fine roots; presence of termites, ants and other insects; clear and wavy boundary to horizon below.
Bt2 (101 – 160+)	Brown (10YR 5/3 dry) and brown (10YR 4/3 moist); gravelly sandy clay; moderate, coarse, crumbly; slightly hard (dry), firm (moist); slightly sticky and slightly plastic; plenty fine, medium and coarse pores; very few very fine and fine roots; clear and wavy boundary to horizon below.

2b. Analytical laboratory data of profile pit No. PUJ002; Njala series

Horizon (cm)	Unit	0-9	9-57	57-101	101-160+
Sand	%	88.80	90.80	88.80	84.80
Silt	%	0.72	0.72	0.72	4.72
Clay	%	10.48	8.48	10.48	10.48
Organic carbon	%	1.71	0.68	0.27	4.51
Bray P1	mg/kg soil	4.72	2.84	1.94	0.43
pH 1:1 soil : water ratio		4.50	4.90	4.90	2.70
pH 1:1 M KCl ratio		4.00	4.20	4.20	2.50
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	1.73	1.38	1.21	3.33
Exchangeable calcium	mg/kg soil	0.55	0.45	0.43	0.42
Exchangeable magnesium	mg/kg soil	0.29	0.23	0.27	0.74
Exchangeable potassium	mg/kg soil	0.05	0.03	0.02	0.01
Exchangeable sodium	mg/kg soil	0.46	0.48	0.41	0.43
Exchangeable acidity	cmol/kg soil	0.38	0.19	0.08	1.73
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	13.00	8.00	8.00	1.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	7.33	5.96	5.78	5.61
DTPA extractable copper (mg kg^{-1})	mg/kg soil	0.00	0.00	0.02	0.06
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	1.04	2.20	1.14	0.75

3a. Soil profile description of profile pit No. PUJ003; Mokonde series

District: Pujehun; **Chiefdom**: Malen, **Village**: Hinai; **GPS location**: 7.41722°/11.85240°; **Elevation**: 29m; **Physiography**: Undulating plain; La**ndform/facet**: Dissected plain; Parent **Material**: Weathered Residium; **Landscape position**: Foot slope; **Slope**: 1.0 %; **Vegetation**: Shrubs; **Erosion class and intensity**: e1, slight; **Drainage and permeability:** Well drained and rapid; **Landuse**: Fallow shifting cultivation; **Crops grown**: Oil palm.

Land System: Newton; **Classification (USDA Taxonomy):** Haplic plinthosol; **FAO-UNESCO:** Plinthic paleudult

Mapping Unit: PUJ003
(Gravel-free over gravel soil)

Horizon (cm)	Morphological Description
A (0 – 19)	Dark grey (10YR4/1 dry) and very dark grey (10YR3/1 moist); sandy loam; moderate, fine, crumbly and angular blocky; slightly hard (dry), firm (moist); non-sticky and non-plastic; plenty very fine, fine and medium pores; plenty very fine, fine, medium roots; presence of earthworms, termites, ants and other insects; clear and wavy boundary to horizon below.
E (19 – 37)	Greyish brown (10YR5/2 dry) and dark greyish brown (10Y/R4/2 moist); clay loam; strong, fine, angular and sub-angular blocky; very hard (dry), firm (moist); slightly sticky and slightly plastic; plenty very fine and fine pores; plenty very fine and fine roots; presence of earthworms, ants and other insects; presence of open boreholes and pressure faces; clear and irregular boundary to horizon below.
Bt2 (37 – 160+)	Light yellowish brown (2.5Y6/4 dry) and light olive brown (2.5Y5/4 moist); gravelly sandy clay; moderate, coarse, crumbly; loose (dry), very friable (moist); slightly sticky and slightly plastic; plenty fine, medium and coarse pores; common very fine and few fine roots; presence of earthworms, ants and other insects; high content of coarse and very coarse gravels; clear and wavy boundary to horizon below.

3b. Analytical laboratory data of profile pit No. PUJ003; Mokonde series

Horizon (cm)	**Unit**	**0-19**	**19-37**	**37-160+**
Sand	%	80.80	80.80	88.80
Silt	%	6.72	4.72	2.72
Clay	%	12.48	14.48	8.48
Organic Carbon	%	3.21	2.25	1.91
Bray P1	mg/kg soil	14.91	13.74	5.43
pH 1:1 soil : water ratio		4.10	4.10	4.40
pH 1:1 M KCl ratio		3.80	3.80	3.90
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	3.63	2.20	1.45
Exchangeable calcium	mg/kg soil	0.50	0.47	0.47
Exchangeable magnesium	mg/kg soil	1.03	0.79	0.67
Exchangeable potassium	mg/kg soil	0.13	0.04	0.03
Exchangeable sodium	mg/kg soil	0.39	0.22	0.17
Exchangeable acidity	cmol/kg soil	1.58	0.68	0.11
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	22.00	18.00	13.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	6.64	6.30	6.30
DTPA extractable copper (mg kg^{-1})	mg/kg soil	0.79	0.39	0.75
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	12.22	8.97	7.40

4a. *Soil profile description of profile pit NoPUJ004; Bonjema series*

District: Pujehun; **Chiefdom**: Kpanga Krim; **Village**: Kpanga; **GPS location**: 7.37812°/11.71217°; **Elevation**: 23m; **Physiography**: Interior plain; **Landform/facet**: Interfluve crest; **Parent Material**: Weathered Residium; **Landscape position**: Foot slope; **Slope**: 0.9 %; **Vegetation**: Bush regrowth; **Erosion class and intensity**: e1, slight; **Drainage and permeability**: Well drained and moderately rapid; **Landuse**: Fallow shifting cultivation; **Crops grown**: Upland rice, sorghum, groundnut, and cassava.

Land System: Bo; **Classification (USDA Taxonomy):** Dystric Nitrosol; **FAO-UNESCO:** Plinthic Paleudult

Mapping Unit: PUJ020/ 04
Gravel-free over gravel soil

Horizon (cm)	Morphological Description
A (0 – 27)	Brown (10YR4/3 dry) and very dark brown (10Y/R3/3 moist), sandy loam; strong, fine, angular and sub-angular blocky; hard (dry), firm (moist); non-sticky and non-plastic; plenty very fine and fine pores; plenty very fine and fine, few medium roots; presence of earthworms, termites, ants and other insects; gradual and irregular boundary to horizon below.
E (27 – 69)	Yellowish brown (10YR5/4 dry) and dark yellowish brown (10Y/R4/4 moist); sandy clay; strong, fine, angular and sub-angular blocky; hard (dry), firm (moist); slightly sticky and slightly plastic; plenty very fine and fine pores; common very fine and fine roots; presence of earthworms, termites, ants and other insects; clear and smooth boundary to horizon below.
Bv1 (69 – 145+)	Brownish yellow (10YR6/6 dry) and yellowish brown (10YR5/6 moist); gravelly sandy clay; strong, coarse, crumbly and angular to sub-angular blocky; hard (dry), firm (moist); slightly sticky and slightly plastic; few fine and plenty fine, medium and coarse pores; few very fine and medium roots; presence of termites, ants and other insects; horizon interspersed with intermediately weathered ironstones showing evidence of weathering and the effects of recurrent oxidation and reduction; clear and wavy boundary to horizon below.

4b. Analytical laboratory data of profile pit No. PUJ004; Bonjema series

Horizon (cm)	**Unit**	**0-27**	**27-69**	**69-145+**
Sand	%	66.80	60.80	78.80
Silt	%	8.72	8.72	6.72
Clay	%	24.48	30.48	14.48
Organic Carbon	%	5.73	3.18	1.34
Bray P1	mg/kg soil	8.65	4.45	5.16
pH 1:1 soil : water ratio		4.70	4.70	5.30
pH 1:1 M KCl ratio		4.10	4.10	4.20
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	7.14	5.02	2.85
Exchangeable calcium	mg/kg soil	1.23	0.98	1.11
Exchangeable magnesium	mg/kg soil	3.17	2.00	0.75
Exchangeable potassium	mg/kg soil	0.16	0.1	0.08
Exchangeable sodium	mg/kg soil	0.52	0.33	0.16
Exchangeable acidity	cmol/kg soil	2.06	1.61	0.75
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	36.00	35.00	8.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	9.75	9.75	5.11
DTPA extractable copper (mg kg^{-1})	mg/kg soil	1.22	0.41	0.59
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	40.86	25.16	8.48

5a. Soil profile description of profile pit No. PUJ005; Newton series

District: Pujehun; **Chiefdom**: Yakemoh Kpukumu Krim; **Village**: Mano Gbonjeima; **GPS location**: 7.15313°/11.75344°; **Elevation**: 13m; **Physiography**: On basic and ultra-basic rocks; La**ndform/facet**: Interfluve side slope; Parent **Material**: Weathered Residium; Landscape **position**: Back slope; **Slope**: 3.9 %; **Vegetation**: Forest regrowth; **Erosion class and intensity**: e1, slight; **Drainage and permeability:** Well drained and rapid; **Landuse**: Forest; **Crops grown**: Natural fruit trees.

Land System: Bonthe; **Classification (USDA Taxonomy):** Dystric Cambisol; **FAO-UNESCO:** Psammentic Humudepts

Mapping Unit: PUJ005
(Gravel-free soil)

Horizon (cm)	Morphological Description
A (0 – 27)	Grey (10YR5/1 dry) and dark grey (10YR4/1 moist); loamy sand; weak, fine, granular; loose (dry), loose (moist); non-sticky and non-plastic; plenty very fine, fine and medium pores; plenty very fine and fine roots; presence of termites, ants and other insects; clear and wavy boundary to horizon below.
E (27 – 52)	Dark greyish brown (10YR4/2 dry) and very dark greyish brown (10YR3/2 moist); sandy loam; weak, fine, crumbly; loose (dry), loose (moist); non-sticky and non-plastic; plenty very fine and fine pores; common very fine and fine, very few medium roots; presence of open boreholes, ants and other insects; clear and wavy boundary to horizon below.
Bt2 (52 – 96)	Brown (7.5YR4/3dry) and dark brown (10YR3/3 moist); sand; weak, fine, granular; loose (dry), loose (moist); non-sticky and non-plastic; plenty very fine, fine and medium pores; few very fine and fine roots; presence of termites, ants and other insects; gradual and irregular boundary to horizon below.
Bt2 (96 – 160+)	Strong brown (7.5YR5/6 dry) and strong brown (10YR4/6 moist); sand; weak, fine, granular; loose (dry), loose (moist); non-sticky and non-plastic; plenty very fine and fine pores; very few very fine and fine roots; clear and irregular boundary to horizon below.

5b. Analytical laboratory data of profile pit No. PUJ005; Newton series

Horizon (cm)	Unit	0-27	27-52	52-96	96-160+
Sand	%	68.80	54.80	60.80	61.50
Silt	%	10.72	12.72	4.72	9.4
Clay	%	20.48	32.48	34.48	29.10
Organic Carbon	%	3.55	2.32	1.84	2.57
Bray P1	mg/kg soil	10.97	8.20	11.60	10.30
pH 1:1 soil : water ratio		4.30	4.50	4.60	4.50
pH 1:1 M KCl ratio		3.80	3.90	3.90	3.87
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	3.66	2.94	3.13	3.24
Exchangeable calcium	mg/kg soil	0.59	0.74	1.13	0.82
Exchangeable magnesium	mg/kg soil	0.39	0.71	0.86	0.65
Exchangeable potassium	mg/kg soil	0.14	0.10	0.08	0.11
Exchangeable sodium	mg/kg soil	0.51	0.53	0.27	0.44
Exchangeable acidity	cmol/kg soil	2.03	0.86	0.79	1.23
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	21.00	14.00	40.00	25.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	7.84	9.90	5.28	7.67
DTPA extractable copper (mg kg^{-1})	mg/kg soil	0.97	1.19	0.63	0.93
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	3.74	7.98	9.90	7.21

6a. Soil profile description of profile pit No. PUJ006; Gbesebu series

District: Pujehun; **Chiefdom**: Barri; **Village**: Potoru; **GPS location**: 7.49602°/11.47413°; **Elevation**: 106m; **Physiography**: Interior plain; La**ndform/facet**: Interfluve side slope; Parent **Material**: Weathered Residium; **Landscape position**: Back slope; **Slope**: 6.1 %; **Vegetation**: Forest regrowth; **Erosion class and intensity**: e3, severe; **Drainage and permeability:** Well drained and rapid; **Landuse**: Fallow shifting cultivation; **Major crops grown**: Rice, cassava, sesame, sour-sour.

Land System: Blama; **Classification (USDA Taxonomy):** Umbric Fluvisol; **FAO-UNESCO:** Aeric fluvaquent

Mapping Unit: KAI006 Gravel-free over gravel soil

Horizon (cm)	Morphological Description
Ap (0 – 33)	Gray (10YR5/1dry) and dark gray (10YR4/1 moist); clay loam; moderate, fine, crumbly; slightly hard (dry), friable (moist); not sticky and not plastic; plenty very fine and fine pores; plenty very fine and fine roots; presence of termites, millipedes, ants and other insects; clear and wavy boundary to horizon below.
Bt (33 – 68)	Pale brown (10YR6/3 dry) and brown (10YR5/3 moist); very gravelly sandy clay; strong, coarse, crumbly; slightly hard (dry), friable (moist); slightly sticky and slightly plastic; few fine and plenty medium and coarse pores; few very fine and fine roots; presence of termites, ants and other insects; clear and wavy boundary to horizon below.
Cr (68 – 151+)	Brownish yellow (10YR6/6 dry) and dark yellowish brown (10YR4/6 moist); gravelly sandy clay; strong, coarse, crumbly; slightly hard (dry), friable (moist); slightly sticky and slightly plastic; very few fine and plenty medium and coarse pores; very few very fine and fine roots; presence of soft plinthite having red colour 7.5YR5/8 moist (covering about 50% of soil mass), termites, ants and other insects; clear and wavy boundary to horizon above.

6b. *Analytical laboratory data of profile pit No. PUJ006; Gbesebu series*

Horizon (cm)	**Unit**	**0-33**	**33-68**	**68-151+**
Sand	%	84.80	80.80	86.80
Silt	%	2.72	6.72	2.72
Clay	%	12.48	12.48	10.48
Organic Carbon	%	2.94	3.69	1.77
Bray P1	mg/kg soil	30.01	15	5.7
pH 1:1 soil : water ratio		4.30	4.20	4.40
pH 1:1 M KCl ratio		3.90	3.70	3.90
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	1.38	2.20	1.79
Exchangeable calcium	mg/kg soil	0.49	0.49	0.45
Exchangeable magnesium	mg/kg soil	0.08	0.08	0.76
Exchangeable potassium	mg/kg soil	0.05	0.07	0.02
Exchangeable sodium	mg/kg soil	0.38	0.43	0.45
Exchangeable acidity	cmol/kg soil	0.38	1.13	0.11
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	20.00	38.00	12.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	6.47	6.47	5.96
DTPA extractable copper (mg kg^{-1})	mg/kg soil	0.79	0.79	0.71
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	0.49	0.49	8.65

7a. Soil profile description of profile pit No. PUJ007; Torma Bum series

District: Pujehun; **Chiefdom**: Malen; **Village**: Hinai; **GPS location**: 7.40547°/11.85786°; **Elevation**: 32m; **Physiography**: Flood plain; La**ndform/facet**: Dissected plain/ Interfluve Toe slope; **Parent Material**: Weathered Residium; **Landscape position**: Foot slope; **Slope**: 1.2 %; **Vegetation**: Grassland; **Erosion class and intensity**: e1, slight; **Drainage and permeability:** Well drained and rapid; **Landuse**: Fallow shifting cultivation; **Major crops grown**: Rice and groundnut.

Land System: Newton; **Classification (USDA Taxonomy):** Umbric Fluvisol; **FAO-UNESCO:** Cummulic Humaquent

Mapping Unit: KAI007 Gravel-free over gravel soil

Horizon (cm)	Morphological Description
Ap (0 – 11)	Reddish gray (5YR5/2 dry) and dark reddish gray (5YR4/2 moist); loamy sand; moderate, fine, crumbly and sub-angular blocky; hard (dry), firm (moist); slightly sticky and slightly plastic; plenty very fine, fine, and medium pores; plenty very fine, fine, few medium roots; presence of termites, millipedes, ants and other insects; clear and smooth boundary to horizon below.
Btv1 (11 – 31)	Reddish brown (5YR5/4 dry) and reddish brown (5YR4/4 moist); sandy clay; moderate, medium, crumbly; hard (dry), firm (moist); slightly sticky and slightly plastic; plenty very fine, fine, medium and coarse pores; plenty very fine, fine, few medium roots; presence of soft plinthite having red colour 7.5YR5/8 moist (covering about 20-25% of soil mass), earthworms, termites, ants and other insects; clear and wavy boundary.
Btv2 (31 – 67)	Reddish brown (5YR5/6 dry) and reddish brown (5YR4/6 moist); sandy clay; strong, medium, crumbly and sub-angular blocky; hard (dry), firm (moist); sticky and plastic; plenty very fine, fine, medium, and few coarse pores; plenty very fine and fine, few medium roots; presence of soft plinthite having red colour 7.5YR5/8 moist (covering about 30-40% of soil mass), termites, ants and other insects; clear and wavy boundary to horizon above.
Bt2 (67 – 117)	Yellowish red (5YR6/8 dry) and yellowish red (5YR5/8 moist); sandy clay; strong, fine, angular and sub-angular blocky; hard (dry), firm (moist); sticky and plastic; plenty very fine, fine, medium pores; plenty very fine and fine, few medium roots; presence of weathered plinthite having red colour 7.5YR5/8 moist (covering about 50% of soil mass), termites, ants and other insects; clear and wavy boundary to horizon above.
Cssg (117 – 156+)	Yellowish red (5YR5/8 dry) and yellowish red (5YR5/6 moist); sandy clay; strong, fine, angular and sub-angular blocky; very hard (dry), firm (moist); sticky and plastic; plenty very fine, fine, medium pores; few very fine and fine, very few medium roots; presence of weathered plinthite having red colour 7.5YR5/8 moist (covering about 50% of soil mass), termites, ants and other insects; clear and wavy boundary to horizon above.

7b. Analytical laboratory data of profile pit No. PUJ007; Torma Bum series

Horizon (cm)	**Unit**	**0-11**	**11-31**	**31-67**	**67-117**	**117-156+**
Sand	%	70.96	64.96	62.8	86.96	90.8
Silt	%	15.28	15.28	14.72	0.56	0.72
Clay	%	13.76	19.76	22.48	12.48	8.48
Organic Carbon	%	2.80	1.91	0.61	0.07	0.68
Bray P1	mg/kg soil	9.72	1.86	3.46	19.38	3.02
pH 1:1 soil : water ratio		4.50	4.70	4.60	4.90	5.00
pH 1:1 M KCl ratio		3.80	3.80	3.90	3.90	4.10
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	3.43	2.83	2.25	1.70	1.53
Exchangeable calcium	mg/kg soil	1.04	0.91	0.79	0.77	0.75
Exchangeable magnesium	mg/kg soil	0.41	0.33	0.4	0.31	0.25
Exchangeable potassium	mg/kg soil	0.08	0.05	0.05	0.02	0.04
Exchangeable sodium	mg/kg soil	0.55	0.49	0.41	0.49	0.45
Exchangeable acidity	cmol/kg soil	1.35	1.05	0.60	0.11	0.04
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	23.00	9.00	6.00	5.00	6.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	4.08	2.36	0.82	0.48	0.31
DTPA extractable copper (mg kg^{-1})	mg/kg soil	0.00	0.00	0.00	0.00	0.00
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	8.86	3.26	4.51	2.39	2.48

8a. Soil profile description of profile pit No. PUJ008; Scarcies series

District: Pujehun; **Chiefdom**: Soro Gbema **Village**: Folu; **GPS location**: 6.98876°/11.56759°; **Elevation**: 19m; **Physiography**: Interior plain; La**ndform/facet**: Dissected plain; **Parent Material**: Weathered Residium; **Landscape position**: Back slope; **Slope**: 7.3 %; **Vegetation**: Semi-deciduous dwarf shrubs; **Erosion class and intensity**: Nil; **Drainage and permeability:** Well drained and rapid; **Landuse**: Fallow shifting cultivation; **Crops grown**: Cassava.

Land System: Torma Bum; **Classification (USDA Taxonomy):** Thionic Fluvisol; **FAO-UNESCO:** Fluventic Sulfaquent

Mapping Unit: PUJ010/ 08 Gravel-free soil	Horizon (cm)	Morphological Description
	A (0 – 69)	Brown (10YR 4/3 dry) and dark brown (10Y/R3/3 moist); loamy sand; moderate, fine, granular to crumbly; loose (dry), very friable (moist); non-sticky and non-plastic; many fine and medium pores; many very fine and fine, few medium roots; presence of termites, millipedes, ants and other insects; and open boreholes; gradual and irregular boundary to horizon below.
	Bv1 (69 – 150)	Dark yellowish brown (10YR 4/4 dry) and dark yellowish brown (10Y/R3/4 moist); sandy loam; moderate, fine, granular to crumbly; loose (dry), friable (moist); non-sticky and non-plastic; plenty very fine, fine and medium pores; few very fine and fine, few medium roots; presence of termites, ants and other insects; clear and smooth boundary to horizon below.
	Bt2 (150 – 175+)	Dark yellowish yellow (10YR 4/6 dry) and dark yellowish brown (10Y/R3/6 moist); sand; weak, fine, granular; loose (dry), friable (moist); non-sticky and non-plastic; plenty fine and medium pores; very few very fine and fine roots; presence ants and other insects; clear and smooth boundary to horizon below.

8b. Analytical laboratory data of profile pit No. PUJ008; Scarcies series

Horizon (cm)	Unit	0-69	33-150	60-175+
Sand	%	88.96	86.96	88.96
Silt	%	3.28	3.28	1.28
Clay	%	7.76	9.76	9.76
Organic Carbon	%	1.44	1.71	0.96
Bray P1	mg/kg soil	10.26	2.03	14.73
pH 1:1 soil : water ratio		6.30	60	5.90
pH 1:1 M KCl ratio		3.90	3.70	3.90
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	3.58	2.29	1.69
Exchangeable calcium	mg/kg soil	2.15	1.10	1.10
Exchangeable magnesium	mg/kg soil	0.73	0.41	0.35
Exchangeable potassium	mg/kg soil	0.09	0.11	0.04
Exchangeable sodium	mg/kg soil	0.42	0.44	0.12
Exchangeable acidity	cmol/kg soil	0.19	0.22	0.08
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	21.00	9.00	7.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	18.99	4.94	4.94
DTPA extractable copper (mg kg^{-1})	mg/kg soil	0.00	0.00	0.00
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	1.62	8.84	2.00

__9a.__ Soil profile description of profile pit No. PUJ009; Turner series

District: Pujehun; **Chiefdom**: Yakemoh Kpukumu Krim; **Village**: Boma; **GPS location**: 7.17014°/11.75784°; **Elevation**: -20m; **Physiography**: On basic and ultra-basic rocks; La**ndform/facet**: Interfluve side slope; Parent **Material**: Weathered Residium; **Landscape position**: Foot slope; **Slope**: 0.7 %; **Vegetation**: Gallery Forest; **Erosion class and intensity**: e1, slight; **Drainage and permeability:** Well drained and rapid; **Landuse**: Uncultivated; **Crops grown**: None.

Land System: Bonthe; **Classification (USDA Taxonomy):** Albic Arenosol; **FAO-UNESCO:** Aeric Psammaquent

Mapping Unit: PUJ023/ 09
Gravel-free soil

Horizon (cm)	Morphological Description
A (0 – 30)	Brown (10YR4/3 dry) and dark brown (10YR3/3 moist); loamy sand; weak, fine, granular; loose (dry), loose (moist); non-sticky and non-plastic; plenty very fine and fine pores; plenty very fine, fine, few medium and coarse roots; presence of open boreholes, termites, ants and other insects; clear and straight boundary to horizon below.
E (30 – 57)	Dark yellowish brown (10YR4/4 dry) and dark yellowish brown (10YR3/4 moist); sand; weak, fine, granular; loose (dry), loose (moist); non-sticky and non-plastic; plenty very fine and fine pores; few very fine and fine, very few medium roots; presence of open boreholes, ants and other insects; gradual and irregular boundary to horizon below.
Bt2 (57 – 136)	Yellowish brown (10YR5/6 dry) and dark yellowish brown (10YR4/6 moist); sand; weak, fine, granular; loose (dry), loose (moist); non-sticky and non-plastic; plenty very fine and fine pores; few very fine roots; presence of open boreholes, termites, ants and other insects; clear and wavy boundary to horizon below.
Bt2 (136 – 160+)	Brownish yellow (10YR6/6 dry) and yellowish brown (10YR5/6 moist); sand; weak, fine, granular; loose (dry), loose (moist); non-sticky and non-plastic; plenty very fine and fine pores; clear and irregular boundary to horizon below.

9b. *Analytical laboratory data of profile pit No. PUJ009; Turner series*

Horizon (cm)	**Unit**	**0-30**	**30-57**	**57-136**	**136-160+**
Sand	%	80.80	82.80	82.80	82.13
Silt	%	4.72	2.72	0.72	2.72
Clay	%	14.48	14.48	16.48	15.15
Organic Carbon	%	1.98	1.56	0.71	1.42
Bray P1	mg/kg soil	1.59	3.55	4.98	3.37
pH 1:1 soil : water ratio		4.90	5.10	5.20	5.07
pH 1:1 M KCl ratio		3.90	4.10	3.90	3.97
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	3.87	2.87	2.36	3.03
Exchangeable calcium	mg/kg soil	0.83	1.11	0.82	0.92
Exchangeable magnesium	mg/kg soil	1.09	0.45	0.45	0.66
Exchangeable potassium	mg/kg soil	0.08	0.04	0.05	0.06
Exchangeable sodium	mg/kg soil	0.52	0.52	0.55	0.53
Exchangeable acidity	cmol/kg soil	1.35	0.75	0.49	0.86
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	13.00	6.00	6.00	8.33
DTPA extractable iron (mg kg^{-1})	mg/kg soil	1.34	5.11	1.17	2.54
DTPA extractable copper (mg kg^{-1})	mg/kg soil	0.16	0.63	0.14	0.31
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	13.09	4.41	4.41	7.30