Consultancy for Sustainable Agriculture

Final Report

Land and Soil Suitability Assessment of the Agricultural Development Zone within the Opara Forest Reserve, Oyo state

Project:	Land and soil survey for the suitability assessment of the Gambari and Opara forest reserve areas, Oyo State, Nigeria
Project code:	PJ 002947 (IITA)
Client:	Oyo State Government
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Cover photo: Samuel Mesele, Picture taken at sampling point J4 (GPS coordinates: 8.4729181, 2.9841187)

Preamble and Acknowledgements

The Oyo State Government contacted IITA for assistance in two projects. One was on the development of a policy framework for the agricultural development of the Oyo State and the second was for the development of Agribusiness parks in the (Oni)Gambari Forest Reserve area and the Opara Forest Reserve area. Several meetings were held which resulted in the establishment of two working groups and ultimately in two contracts awarded to IITA for the implementation of the studies; one for the policy framework document and the other for the land and soil survey to assess the suitability and identify the most suitable areas for the establishment of agribusinesses in these areas.

Notification of approval of the proposal was received by letter from the Permanent Secretary, dated June 11, 2018. The first tranche of the payment was received on October 10th, 2018, which meant that field activities could start. The letter of agreement was signed only on 31st in January 2019, and thereafter also additional funds were released, in different instalments.

We gratefully acknowledge Oyo Sate Government and the Governor of Oyo State for commissioning IITA for conducting this feasibility study for the establishment of agribusiness parks aiming to identify the most suitable area for the establishment of such park and focusing on the land and soil suitability aspects. A working group was established to prepare the content of the assignment and to report back to on the progress of the work and on the results. We acknowledge the contributions of the following persons from Oyo State Government that were part of that working group:

- Prince Oyewole Oyewumi, Honourable Commissioner of Agriculture, OYS
- Professor O. Adekunle, special Advisor (Agriculture)
- Mr Atilola Víctor Adewale, Permanent Secretary
- Mrs F. Akande, Programme Manager & CE OYSADEP
- Mrs Ganiat O. Olawore, Special Adviser, Agric OYSAI
- Mr Oyeranmi Rasheed I., Director Planning Research & Statistics

IITA representatives in the WG on Agribusiness Park development:

- Mr Frederick Schreurs, CEO of the Business Incubation Platform
- Dr Godwin Atser
- Mr Oluwadare Odusanya
- Dr Jeroen Huising

To assist in the field survey, we acquired the assistance of IAR&T (for the Gambari and Opara field surveys) and of FUNAAB (for the Opara field survey) besides our own team that we had in the field. The IAR&T teams was headed by".

- Dr Ande Funmi (Mrs.)

- Prof. Gabriel Oluwatosin
- Dr Kayode S. Are

The team of FUNAAB was headed by:

- Dr Godwin Ajiboye
- Dr James Adigun
- Mr Jamiu Aderolu

The following persons from IITA participated in this study, in their various capacities:

- Augustine Ekeke, GIS unit, field survey and sample collection
- Basil Akwarandu, GIS unit, field survey and sample collection
- Tunrayo Alabi, head GIS unit
- Sarah Chiejile, GIS unit, mapping and digitizing
- Joseph Uponi, Analytical Services Lab
- Philip Igboba, Analytical Services Lab
- Samuel Mesele, BIP/AgriServe, field survey, data quality control and report writing
- Jeroen Huising, BIP/AgriServe, project leader and coordinator

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Acronyms

ADZ	Agricultural Development Zone
AoI	Area of Interest
CEC	Cation Exchange Capacity
ECEC	Effective Cation Exchange Capacity
ESA	European Space Agency
ESRI	Environmental Systems Research Institute
FUNAAB	Federal University of Agriculture, Abeokuta
IAR&T	Institute of Agricultural Research & Training
IITA	International Institute of Tropical Agriculture
LULC	Land use and land cover
LU	Land unit
NPK	Nitrogen, Phosphorus and Potassium
NS	Not suitable
ODK	Open Data Kit (https://opendatakit.org)
OFR	Opara Forest Reserve
OYSG	Oyo State Government
SI	Suitability index
SOC	Soil Organic Carbon
SOP	Standard Operating Protocol
SRTM	Shuttle Radar Topographic Mission
SQI	Soil quality index
SV	Suitability value
TSQI	Total soil quality index
USGS	United States Geological Survey

INTRODUCTION

Oyo State Government (OYSG) wants to promote agricultural development in Oyo state in part through the establishment of agribusiness parks by which it aims to attract private investments in fully mechanized and modern agriculture. Oyo state intends to and has allocated land for this purpose. One such location is the Onigambari Forest Reserve that is located approximately 20 to 30 km to the south of Ibadan. The other location is within the northern part of the Opara Forest Reserve which is located in the north-western part of Oyo state, bordering Benin republic. From the Gambari Forest Reserve an area of around 6000 ha has been allocated for agricultural development, to be referred to as the Agricultural Development Zone (ADZ). The survey of the Gambari ADZ has been conducted, the findings have been presented and discussed and the final report has been submitted.

This report presents the findings of the survey of the Opara Forest Reserve–ADZ. The original assignment was to conduct a survey of the complete northern part of the OFR of which the perimeter data was provided and that measures around 150,000 ha. From this a 20,000 ha was to be identified being the most suitable for business park development and which would then be characterized in more detail, if needed.

It is only after presenting the results for the Gambari ADZ that we learned that OYSG had already allocated specific parts of the land to prospective investors and that the assignment for the land and soil suitability assessment should subsequently concentrate on this part of the land. We subsequently made an effort to acquire the information on the exact location of the proposed ADZ, and which proved to be an area of 56100 ha approximately. We do not have the information on which basis specifically this part of the land was allocated for this purpose. The assignment remained the same, namely, to conduct the land and soil suitability assessment for this area to identify the suitability of the land for the various crop types and type of agricultural enterprise that uses modern farming techniques. The approach we use is the same we use for this kind of assignment, with adjustment made to the sampling design, considering the large size of the area. The approach is explained in the section on the methodology.

Two preliminary field visits were made to Opara Forest Reserve prior to any work and before any agreement had been signed to get a better impression of the opportunities and challenges this area may present, and to get a better understanding of the requirements for the land and soil survey. For this purpose, we made video recordings using a drone and we took some soil samples for analyses in the lab. The report of this orientation visits has been submitted and videos that were recorded can be made available if required. The observation was that a considerable part of the area is likely to be in use for arable cropping and that a number of settlements have been established in the area. There seem to be extended areas of flat to gently sloping topography, but possible limitations might be expected related to the soil depth and texture of the soil. This report thus presents the overall findings of the land and soil suitability assessment of Opara Agricultural Development Zone.

METHODS and DATA SOURCES

Approach

IITA was asked to make an assessment of the suitability of the land and soils for commercial farming. The suitability assessment took into account the following aspects that are considered important in making investment decisions, whether by government or by private entities:

- Accessibility of the terrain
- Topography: slope and relief
- Water resources and availability of water
- Land use and land cover to identify available land and possible implications for land clearing
- Soil properties and site characteristics

We define general requirements that we consider are relevant to modern and mechanised farming identify and describe constraint in relation to these requirements. For the accessibility that means the terrain needs to be accessible for smaller trucks at least. For the topography it means that the land needs to be flat to gently undulating at the most to allow for mechanized operations and slopes need to be straight and not converging and that the soils surface should not be uneven (no micro-relief). Water needs to be available for irrigation purposes. We look at the current land use and land cover to identify potentially cultivatable land and to identify the requirements for land clearing.

For the soil we consider the following criteria:

- Stoniness at soil surface and in the soil profile in relation to possibility for mechanised field operation
- Soil depth (effective), in relation to possible rooting depth restrictions
- Soil drainage in relation to possible drainage restriction and water logging risk related to soil aeration
- Soil texture and physical properties in relation to water holding capacity, infiltration, workability and soil degradation
- Soil fertility in relation to possible nutrient limitations for crop production, including soil reaction, Cation Exchange Capacity (CEC) and other properties that may be of influence on crop production

We generate map layers for the following themes, based on which the evaluation is done:

- Road network (access roads, tracks)
- Drainage network, rivers and streams
- Topography: elevation, slope and contour
- Land use and land cover
- Rock outcrop
- Built-up area and settlements

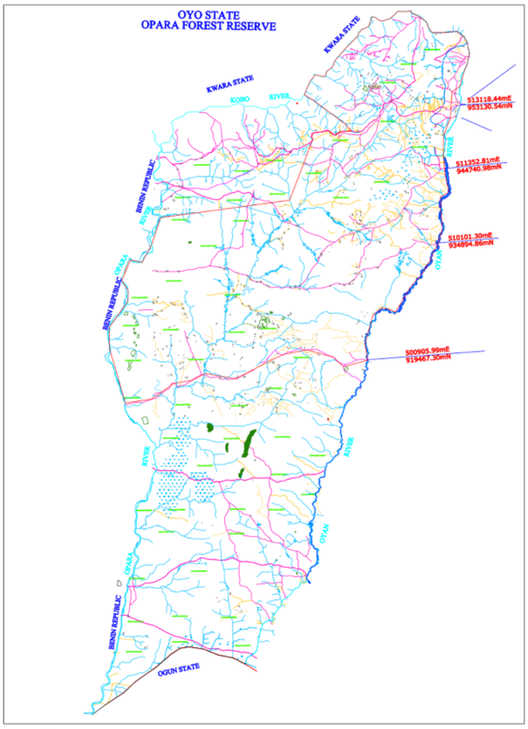
Mapping of these different features is done using satellite imagery. We purchased commercially available most recent high-resolution imagery of the area publicly available imagery of various dates. Recent imagery is used for mapping of the features mentioned above by image interpretation and on-screen digitizing, and these are verified in the field.

Elevation is mapped using existing STRM data.

In the field, observations are made on land use and land cover, terrain and soil characteristics. The data collected can be used for ground truthing for the image interpretation and for the validation of data and maps generated.

Study area and sampling design

Map 1 depicts the area, delineated in red that was originally indicated as the area to be surveyed. It covers the whole northern part of the Opara FR, apart from a small corner in the Northwest. This data was provided by OYSG, Forestry Department, which was digitized using AUTOCAD and that we converted to TIFF format. The area measures about 1500 km^2



Map 1 Opara Forest Reserve with in red the area to be surveyed originally

Map 2 Reduced survey area together with the sections allocated to prospective investors with their names

Later we received information of the area considerably reduced in size and of which the different sections have been allocated to the various prospective investors. Map 2 shows that area, together with the different sections. This area measures approximately 561 km^2. We were informed to concentrate our efforts on this area. We refer to this area as the Area of Interest (AoI)

Considering the size of the area we opted for a sampling frame approach, rather than using a fixed grid sampling design. The latter would result in a much larger distance to cover if we were to reach all the points, and it would reduce the efficiency of the survey considerably taking the poor accessibility into consideration. The area frame sampling approach clusters the points of observation into sampling frames that are randomly selected. The sampling frame also allows us to look at spatial patterns within the frame that might be characteristics for particular land uses. Together the sampling frames are supposed to give a representative sample of the whole are under investigation, for which the sampling frames together should cover 6% of the total area. We have opted for a size of the sampling frame of 1 km2, which results in 30 sampling frames to be selected. For each sampling frame six observation points are selected through random allocation, which results in 180 observation in total. This gives us a point density that is normally required for semi-detailed surveys for large projects and regional surveys (scale 1:50000). At this scale the land and soil units will generally be of complex nature; that is, consist of associations of soil series and land uses. This is not detailed enough to give a comprehensive and detailed assessment of the soil and land capabilities of each of the sections allocated as farmland for the various investors. For each allotment/section a detailed survey would be required to determine the suitability for the specific crops of interest. This is needed to provide a site-specific fertilizer recommendation.

Soil sampling and laboratory analysis

The sample and data collection are done following standard operating procedures and for the data recording we use standard forms that are implemented in *ODK-Collect* for the use of the forms on an electronic device. The data is automatically uploaded to the ODK-server once there is internet connection.

At each point of observation soil samples are taken from the topsoil (0-20cm) and subsoil (20 -50 cm) for analyses in the lab. We measure gravel content, soil depth, soil colour, soil texture, soil carbon, total nitrogen, pH 1:2.5, available phosphorus, exchangeable cations (k, Ca, Mg and Na), and micronutrient contents (Zn, Cu, Mn and Fe) which are important soil quality parameters.

We analysed about 10% of the total soil samples by using standard wet chemistry methodologies, while all the soil samples are subjected to dry chemistry methodology using spectral analysis by Mid- infrared spectroscopy (MIR). From this, we predict the important soil quality parameters.

Activities

Activities have been carried out in the chronological order as indicated in the table below. This include the general of activities for both the Gambari and Opara Agricultural Development zones.

Table 1. Chronology of activities for both Opara and Gambari land and soil suitability assessment

Timelines	Activities
January – June 2018	Reconnaissance field visit to both Opara and Gambari Agric zone
September & October 2018	Preparations: getting information of the boundaries of both areas, ordering satellite imagery, developing SOPs for field survey and ODK form for data recording, create the sampling design, negotiations with IAR&T for assisting with the field work, training and organizing the field work.

31 Oct 2018 – 1 Nov 2018	Field visit to provide training and instruction on field survey procedures
23 Nov 2018 – 17 Jan 2019	Field survey and sample collection by IAR&T and IITA-GIS teams
15 – 16 January 2019	Field visit for monitoring data collection and getting better idea of the condition of the terrain
28 Jan 2019 – 26 Mar 2019	Sample preparation and soil analysis
February – March 2019	Image interpretation and mapping
8 April 2019	Presentation of semi-final report of land and soil suitability of Gambari Agricultural Zone
May 2019	Preparation and logistic arrangements for the field survey and soil sample collection at Opara Agricultural zone
11 June – 6 July 2019	Field survey and soil sample collection at Opara agricultural zone by five field teams
8 – 26 July 2019	Soil sample registration and sample preparation for chemical and spectral analyses
23 – 25 July 2019	Opara field visit by the project leader to get general overview of the terrain
15 August 2019	Submission of the Gambari soil suitability final report and interim report of Opara soil survey to the Governor of Oyo state
29 July – 4 September 2019	Chemical and spectral analyses of soil samples in the laboratory
5 – 20 September 2019	Data quality control and data analyses, Image interpretation and mapping
16 September – 4 October 2019	Report writing
7 – 11 October 2019	Submission of report to the Ministry of Agriculture, Oyo state

Data sources

Table 2 Data sources used for this study

SN	Type of data	Data source	Spatial resolution	Usage
1	LANDSAT ETM 7	USGS Earth Explorer (https://earthexplorer.usgs.gov/)	30 m	Land use classification (1990 & 2000)
2	SENTINEL 2	The Copernicus Open Access Hub (https://scihub.copernicus.eu/dhus/)	10, 20 m	Land use classification (2019)
3	WorldVIEW 2	Digital Globe (https://www.digitalglobe.com/)	0.4m, 1.6m	Creation of drainage

				network, road network, Rock outcrop
4	NASA Shuttle Radar Topography Mission (SRTM)	USGS Earth Explorer (https://earthexplorer.usgs.gov/)	30m	Creation of Contour, slope & land unit map

RESULTS

Location and access

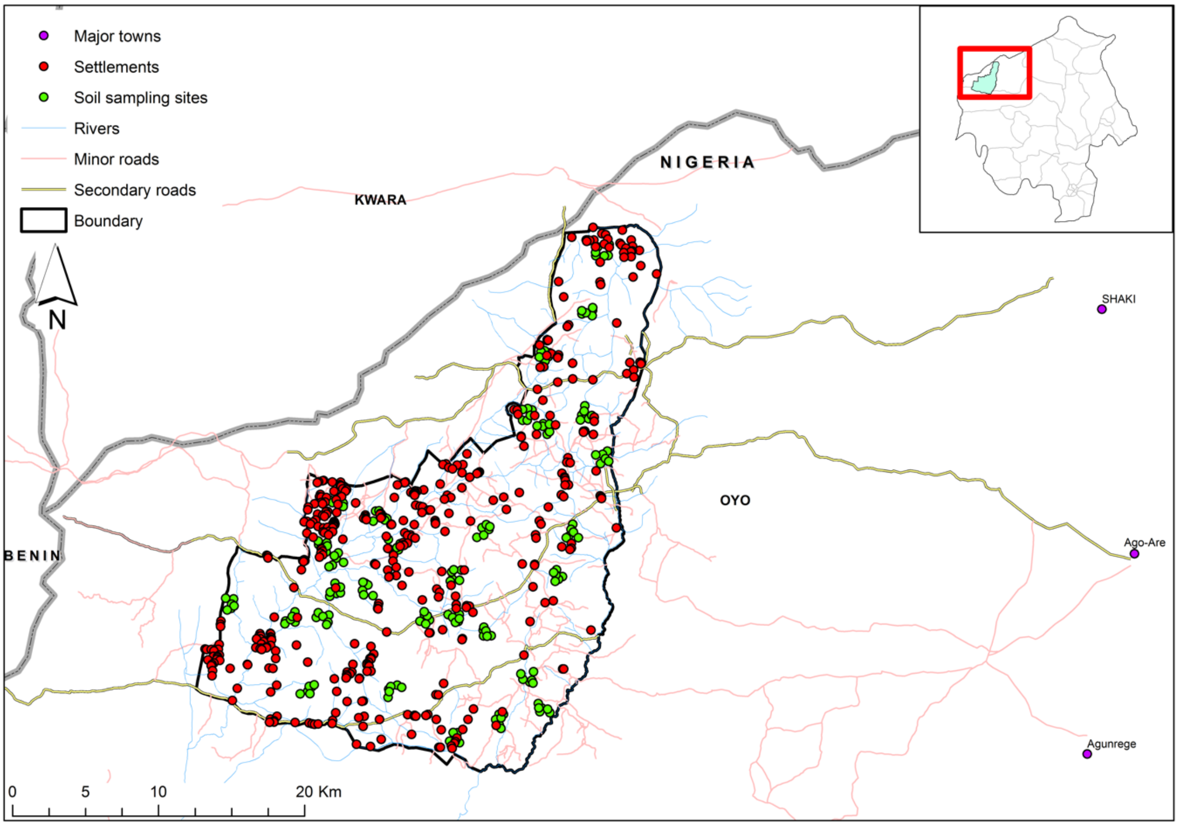
The AoI is located within the higher ranges of the Opara Forest Reserve. The Opara forest reserve is an extensive area of land covering about 250,000 hectares. It borders with the Benin republic in the west and with Kwara state in the north. The part of the OFR that is allocated for agriculture, and that is being referred to as the Opara Agricultural Development Zone (OADZ) covers an area of about 56100 hectares and is located in the north-eastern part of the OFR. The area can be reached by road from Ago-Are at a distance of about 51 km. This road gives access to the mid and southern section of the AoI. There is another road that connects Shaki to Garage, the village at the Benin border and that cuts through the smaller northern section of the AoI. Both roads are classified as secondary roads. Both are 'through roads' that connect to the Benin border, the northern road being the main route to the border. There is heavy traffic on both roads. Both roads are unpaved and are in very poor condition because of the heavy trucks that pass here. These secondary roads cross a number of streams (within the AoI as well as outside on the way to Ago-Are) and for which no further provisions have been made to cross (or where they have, they have broken down). The streams are shallow and can be crossed but nevertheless forms severe obstacles for normal traffic. Otherwise, the minor roads and feeder roads are in relatively good condition, especially in the central and southern parts where we find the sandier soils. In the northern part and north-western part where we may find more clay in the soil the roads are more easily affected and there may be parts that are difficult to pass. There is a relatively dense network of minor roads and tracks through which most parts of the area are fairly good accessible.

The access roads and the road network within the AoI need to be improved, but there do not seems to be major or specific obstacles that would prevent this.

Aleniboro is the only larger settlement/village located in the centre of the AoI at 8.4755 decimal degrees north and 3.0109 decimal degrees east (See Picture 1). It has a school and there is a newly built clinic to be commissioned shortly. The village was established some 20 years ago and has reached a considerable number of inhabitants in this time. There are numerous small settlements (generally individual families) in the AoI shown as red circles in Map 3. There is a clear concentration of the settlements in the mid-western part of the AoI.

It is also from the west that people started encroaching into this some 30 years ago. Maybe 5% of the area was used for cultivation at this time and another 16% of the land, predominantly in the upper part of the southwestern section, was used as range land. A large proportion of the land area (62%) was still under tree cover at this time. Ten years later, at about 20 years ago, about 14% of the land was used for arable cropping (and the area had extended from the western part into the central mid part of the land) and another 20% was used as range land (predominantly the southwestern part) by the Fulani herdsmen.

In January 2019, we find that people have occupied different parts of the land and the distribution of cropland has become widespread in the area, though most concentrated around the northern, western and south-western sections of the AoI. The central and mid-eastern sections seem less populated. We find that the cultivated land is directly correlated with the location of the settlements in the area.



Map 1 Location of the AoI within Oyo state and access roads. Red dots are the smaller settlements and green dots are the points of observation for this study

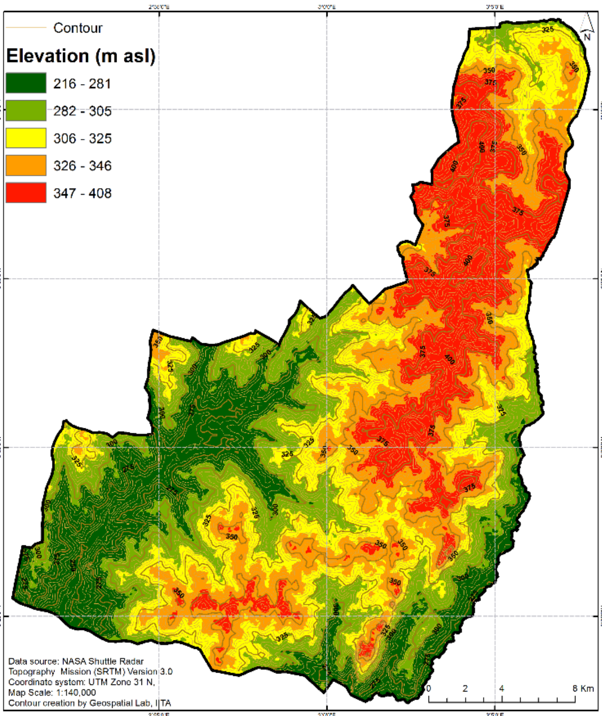
The landform we find is typical of the landform derived from the basement rock complex, which consist of hard crystalline and metamorphic rocks (granite and gneisses). In the AoI we do not find the large rock outcrops which otherwise is so typical of this type of landscape. It results on a very gently to gently undulating landscape with relatively low relief intensity. The soils in this landscape have developed in-situ. The soils are generally of light texture, and the soil depth generally depends on the amount of topsoil that has been removed in the past, as result of soil erosion which depends on the land cover and slope.

Picture 1 Some of the Aleniboro villagers and the IITA team in the village square of Aleniboro and picture of the main road

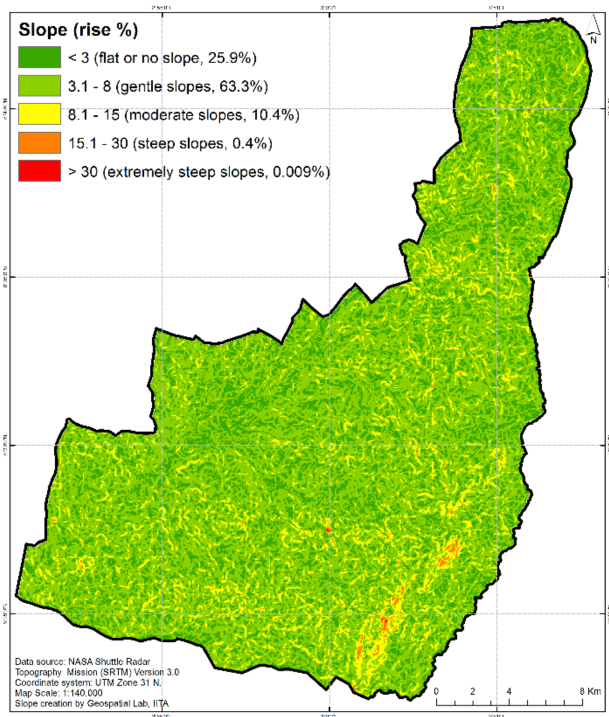
Topography and elevation

The AoI is located at the highest parts of the Opara Forest Reserve, the highest parts are actually located within the AoI (northern section). There are two gradients that determine the terrain and landform. One gradient is the general trend of the land is sloping down in a South-South-West direction. The higher elevation areas extend down through the centre of the AoI to the SSW. The other gradient is determined by the main drainage systems that also run from a NNE to SSW direction (Map 7). One of the main drainage systems runs along the east side of the AoI, the other originates from within the AoI and drains towards the SSW and is located in the western section of the AoI. The second gradient is therefore general in a NEE or SWW direction. The drainage density is low, which is expected from a landscape derived from the basement rock complex, with very well drained sandy soils.

The resulting landscape is gently undulating with a low relief intensity. The lowest elevation is around 216 masl and the highest elevation is around 408 masl (see Map 4). The slope classes are 'flat to almost flat' and 'gently sloping', with moderately steeps slopes occurring occasionally and steep slopes only at specific locations (see Map 5). With this drainage pattern the slopes are generally diverging though not very strongly. The terrain is fairly level in most parts. The slope has a slight concave form and can be considered fairly straight over moderate distance.



Map 2 Map of elevation and contour lines of the AoI



Map 5 Map of slope classes of the AoI

Based on the elevation profiles we can get information about the distribution of the slopes classes and how this may differ for the different section of the terrain. Below the elevation profiles for the southern, mid and northern section of the AoI are presented. In the direction of the transects, we expect the highest gradients and therefore the maximum slopes.

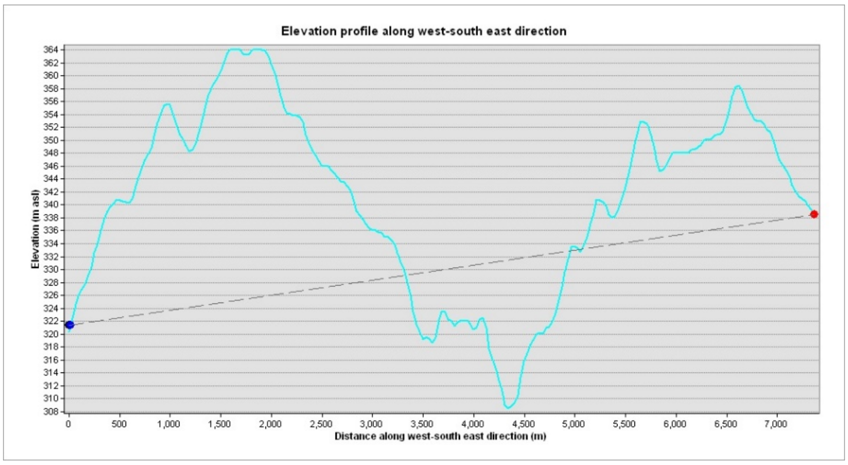
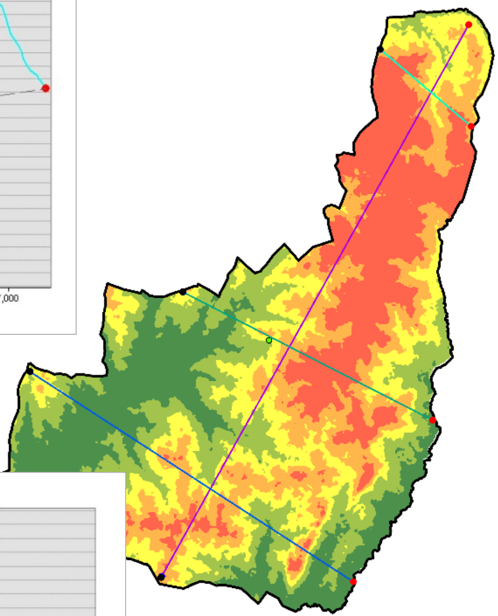
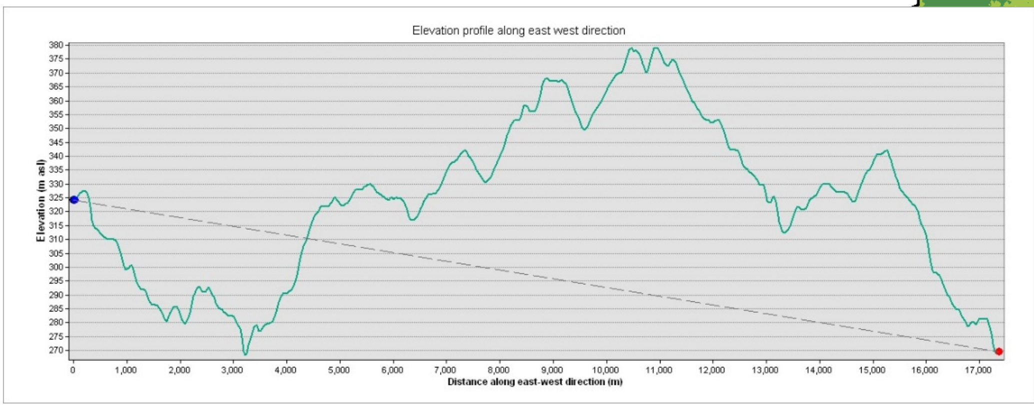


Figure 1 Elevation profile of the northern section of the AoI





Map 6 Map of the AoI with locations of the transects for the elevation profiles

Figure 2 Elevation profile of the mid-section of the AoI

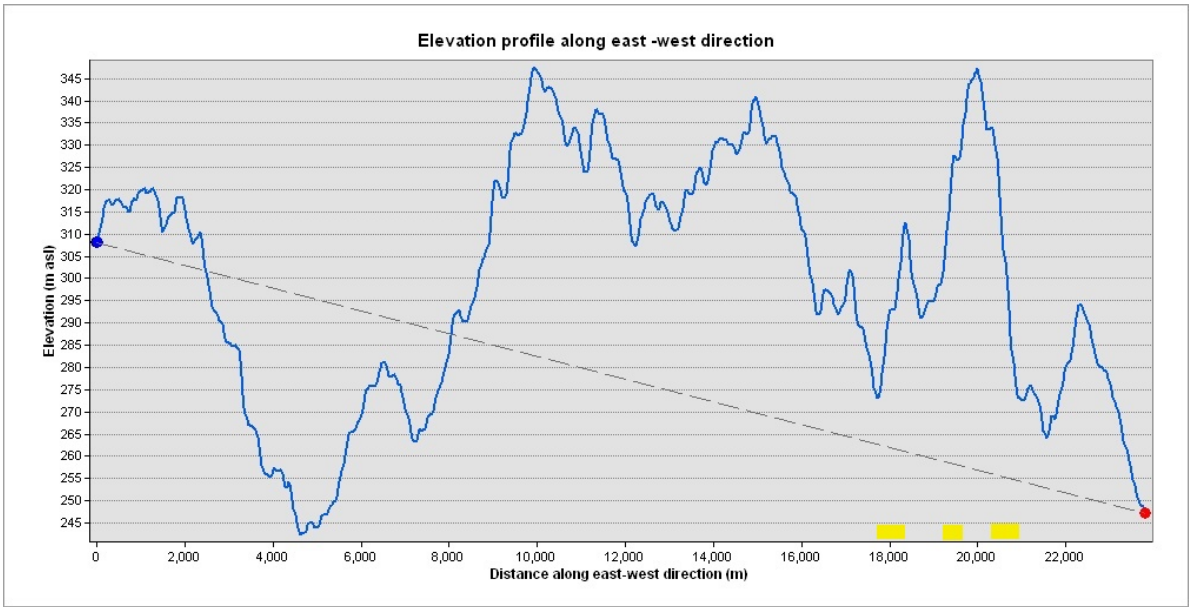


Figure 3 Elevation profile of the southern section of the AoI. Yellow bars indicate the location where moderately steep slopes are found

For the southern section of the terrain (the blue elevation profile) we find 'flat to almost flat' slopes for 44% of the total length of the transect (Table 3). We see that the average slope length is 209m, indicating we have rather large swaths of land that is flat to almost flat. The higher percentage of flat to almost flat land is associated with the main drainage system of the western part. Especially in the first 5 km west of the stream and in the first 3km of the transect east of the stream we find most of the flat terrain. The moderately steep slopes are all in the eastern part of the transect.

In the middle section (the 'green' transect) we see the percentage of 'flat to almost flat' land decreasing, and the percentage of gently sloping land increasing. This is because the lesser impact of the main drainage system on the landscape and topography. We get a pattern that is typical of the upland area. The average slope length for the 'flat to almost flat' slope class also decreases. For the gently sloping land the average slope length remains the same.

The transect in the northern section is relative short and covers the higher situated areas (the broad ridge). There is less influence of the major drainage systems on the topography. The share of the flat to almost flat land increases again and the average slope length as well. About half of the slopes fall in the category of 'gently sloping' and the slope length further increases for this category. Also, the average slope percentage for this slope class tends to reduce, moving more towards the 'very gently sloping'. The impression you get form this area is one of a very gently undulating terrain, with wide views and an open landscape.

Table 3: Distribution of the various slope classes within the three transects in the lower, middle and upper section of the RoI

	Flat to almost flat		Gently sloping		Moderately steep	
	Percent of total transect	Avr. slope length (m)	Percent of total transect	Avr. slope length	Percent of total transect	Avr slope length
Blue elevation profile	44%	209	47%	201	9%	161
Green elev. profile	40%	155	54%	198	4%	90
Cyan elev. profile	46%	181	51%	210	0.4%	NA
NNE-SSW transect	45%	206	49%	184	4.1%	145

We have included in the overview the statistics for the SSW-NNE transect (Table 3). It portrays the same picture. We find a relative high percentage of the flat to almost flat slopes in the first 6 to 7 kilometres in the of the southern section, where the flat terrain is alternated with very gently sloping land, resulting in a very gently undulating landscape. The same is true for the last 6 km of this transect in the northern section, where again we find a very gently undulating landscape, as we already concluded.

Flat to almost flat terrain does not pose any restriction to the large-scale mechanised operations depending on the size of the patches of land. Gently sloping terrain also does not pose major problems, but soil conservations measures need to be considered, like ploughing along contour lines. The convergence of slopes will start to play a role, as well as the length of the slope. From this perspective the northern section, the mid southern section and the south-western section seem to be optimum.

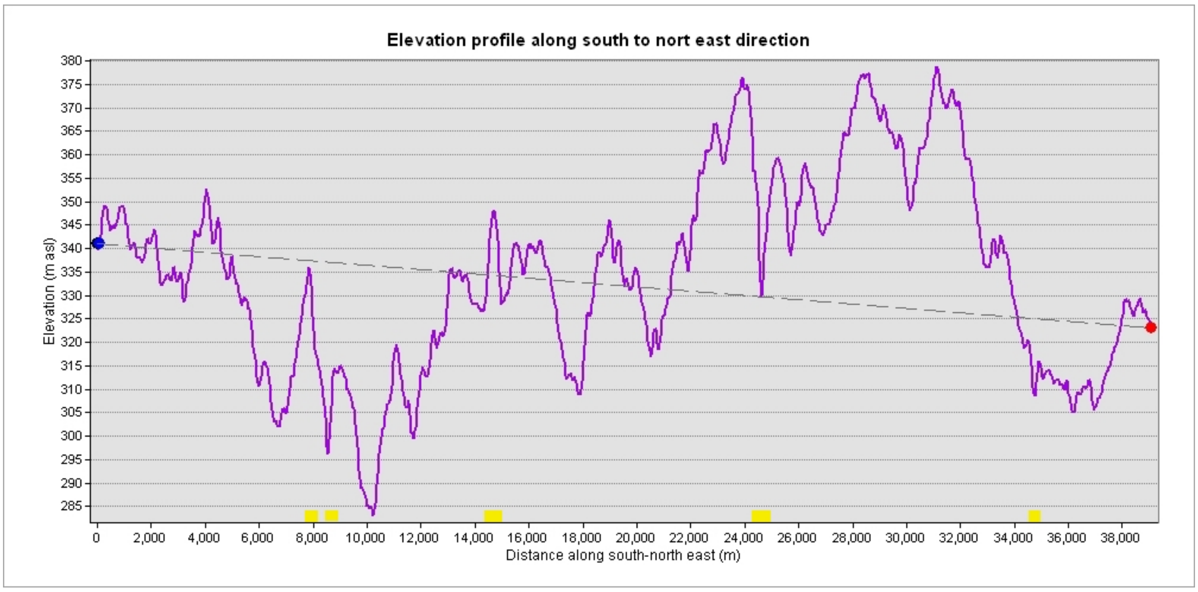
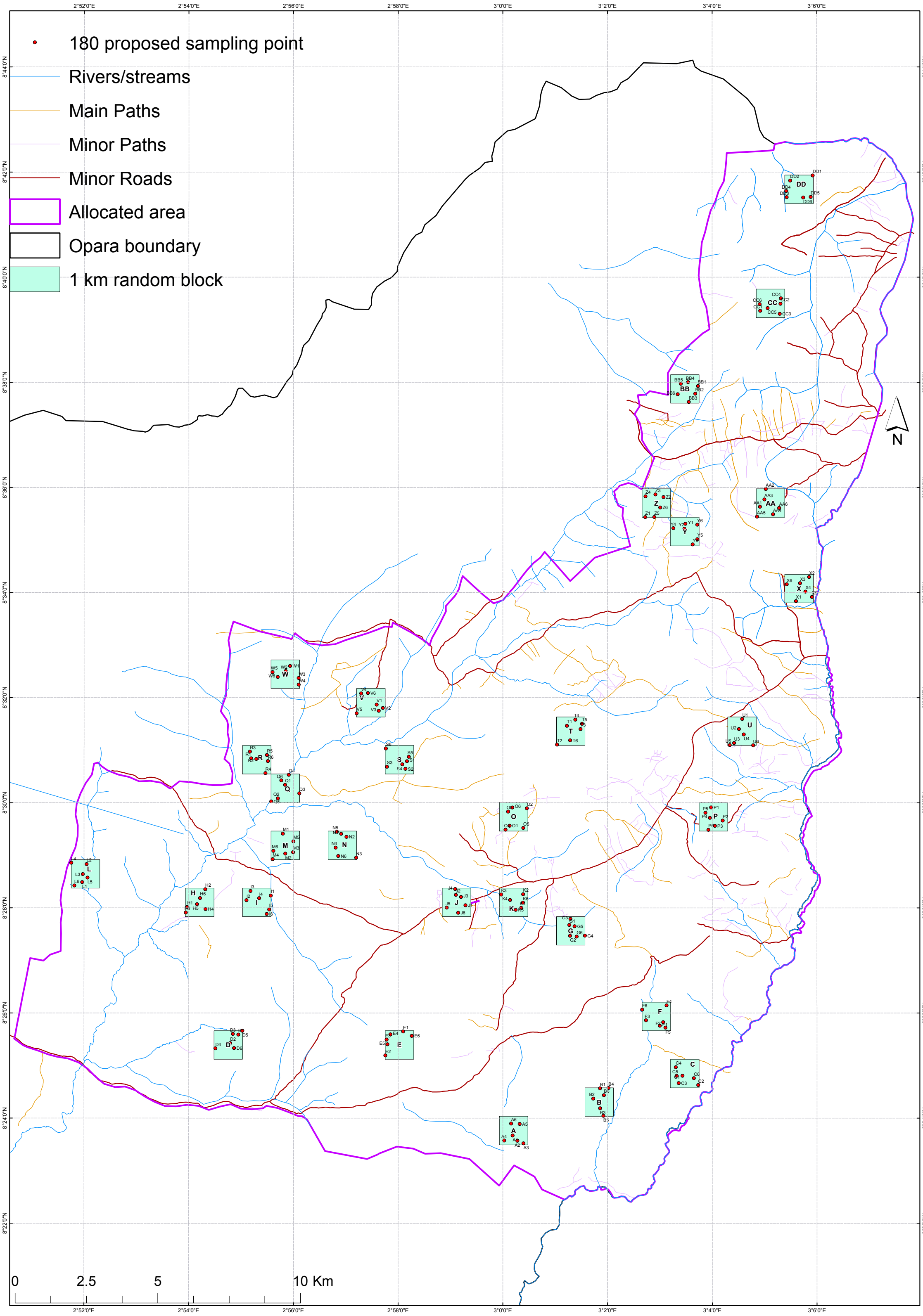


Figure 1 Elevation profile along south to north east direction.

Water resources and drainage network

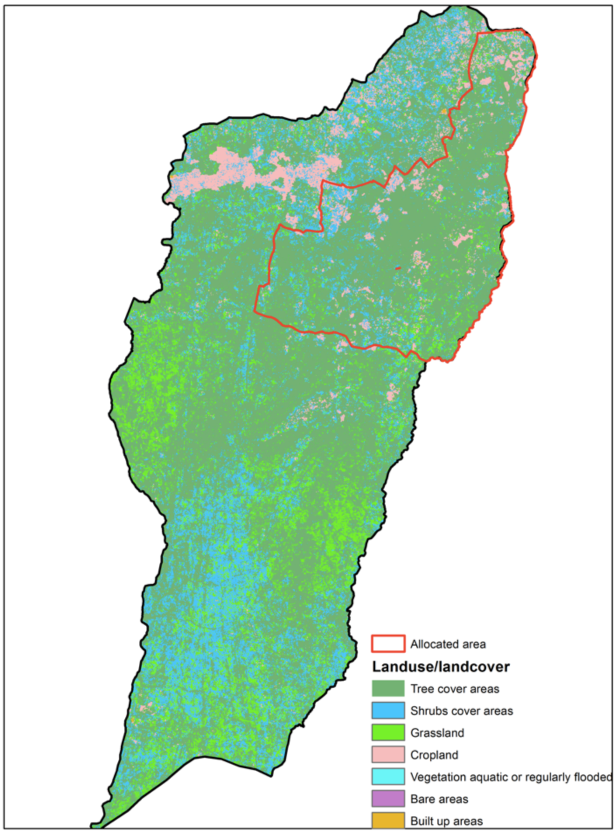
The drainage divide runs from the neck in the northern section to the south, with a curve to the southwest to cut across the southern border of the AoI midway (Map 7). The section north of the secondary road from Shaki is draining towards the north. The drainage pattern is dendritic. The rivers and streams have not deeply incised, and the drainage density is also relatively low. The main and larger drainage system is the one located in the western section of the AoI. The other stream runs along the eastern border of the AoI, but it is a much smaller system. This means the drainage density in the central body especially, is rather low. We will find only seasonal small streams in this area and this means that there is little water available. There is no surface water within in central part of the AoI, or in the northern section. Ground water in not likely to be a major source of water for irrigation or other, giving the type of soil and geology of the area. Alternative sources of water need to be found if needed for irrigation.



Map 7: Map showing the river and drainage networks

Land use and land cover

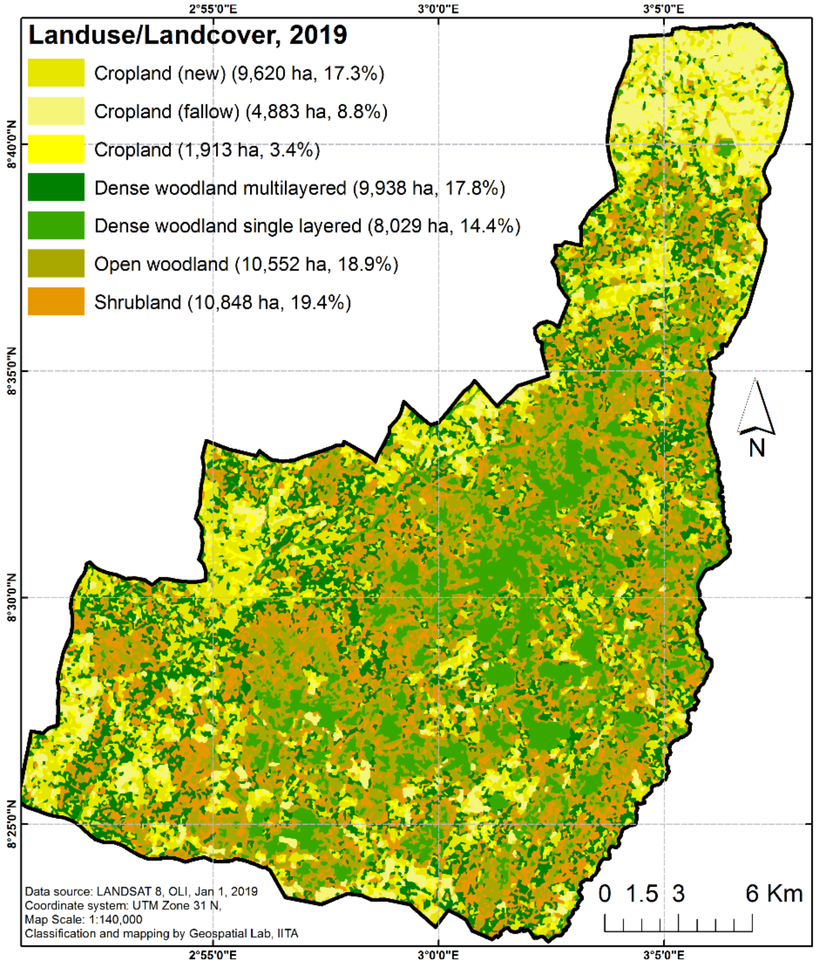
The Land Cover map of 2016 for the AoI (Map 8; source: ESA, Centre of Earth Observation) shows the area to be classified as 'tree cover areas' mainly. The map suggests that there are some isolated spots of cropland, whereas larger parts of the area are actually cropped and have been cropped in the past. Even though the area of tree cover is quite substantial, there is very little left of the original woody savannah vegetation



Map 8 Land cover map of Opara FR (2016, 20m resolution; source: ESA/ESRIN)

From our field observations we find that 17% is cropland. This correspond remarkably well with the results from the land use and land cover classification (Map 8), that also indicates 17% of the land being classified as cropland. In 26% of the observation in the field the land use is classified as 'idle', which means the land has been left idle after it has been cultivated. The land cover may vary from 100% herbaceous cover to regrowth with woody species (shrub and trees) of 2 to 4 years old, which results in a sort of thicket, and which would technically be classified as 'shrub cover' or 'tree cover'. In about 50% of the observations the land use is classified as 'woodland', which, again, tallies well with the results of the LULC classification. These are generally areas with secondary regrowth with a high density of trees that are often not taller that 10 to 12 meters in most cases. These woodlots are either dominated by *Anogeissus leiocarpus,* which is indicative of former cultivated land, or by *Vitellaria paradoxa* (shea tree), which is likewise an indication of land being cultivated previously. Often clear signs of former cultivation of the land are observed (remnants of ridges or mounds) and from the height and diameter of the stem of the woody vegetation one can conclude that this was more than 10 years ago. This particular type of land cover is classified as 'Dense woodland single layered' (which refers to dense woody vegetation (closed canopy) with a single structural layer of woody vegetation). From our observations in the field it seems that there are very few areas of original forest or savanna woodland left.

The spatial distribution of the LULC classes is shown in Map 9, the result of the land use and land cover classification making use of the most recent satellite imagery and using the field observations for ground truthing. The map shows that the extreme northern part of the AoI is completely cultivated. The other area that is largely cultivated is the western corridor associated with the main the drainage system in the western part of the AoI, especially the area to the west of the river. And then we see the upland area in the southern region of the AoI with a relatively high percentage of cropland area. These are also the areas where most of the settlements have concentrated. The central core of the AoI shows the lowest percentage of cropland, with most of the cropland concentrated around Aleniboro, which is the main settlement in the area.

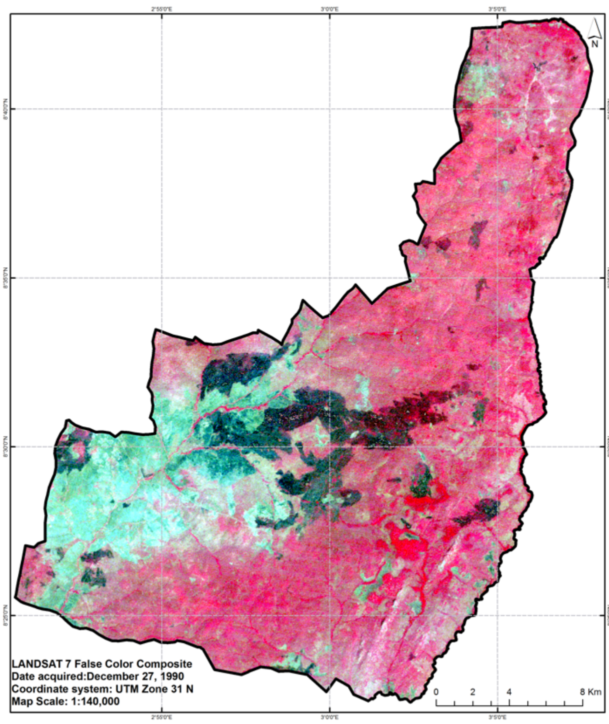


Map 9 2019 Land use and land cover classification of the Opara Agricultural Development Zone

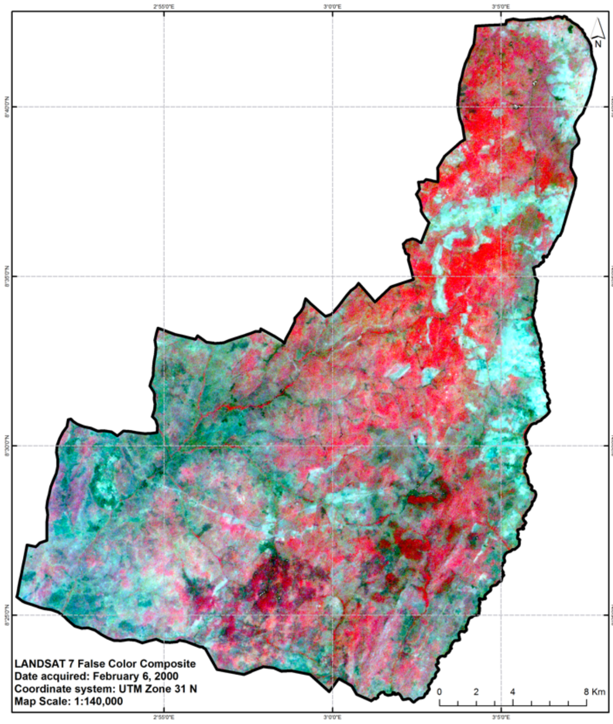
If we look at historical imagery, we can see how the colonization of the AoI has taken place. Maps 10 and 11 show the false colour composites of Landsat 7 imagery of 1990 and 2000 respectively, in which vegetation shows up in red. We see that the AoI was colonized from the south-west and is associated with the main drainage system in the area. The availability of water obviously played an important role. We also see larger areas reaching into the core of the area that have been burned to clear the land.

In the image of 2000, we see that larger parts along the eastern border of the AoI were cleared, as if a new front line was opened. Very clear is the area being opened up along the through road (the road from Shaki) in the northern section of the AoI. We see further expansion of the cultivated area in the western section and we see the southern region being opened up. Many of these areas were in 2019 again covered under woody vegetation.

There seem to be a few densely vegetated areas that have been spared, and it would be good to find out what these relate to. Also, we see, when comparing with the LULC map of 2019, that there are few areas where we will find pristine vegetation still. It might be useful to consider how these areas could be preserved.



Map 10: False colour composite of the 1990 Landsat 7 satellite imagery



Map 11: False colour composite of the Landsat 7 imagery February 6, 2000 (vegetation shows up in red)

The crops grown in the field at the time the survey was conducted were maize, yam, cowpea and soybean. Very little cassava was observed. This may indicate that the soils are relatively fertile. We find a patchy distribution of the cropland, especially in the central region. The cropland seems typically associated with the location of settlements, and the bigger the settlement/village the larger the area that is being cultivated.

Below are a few pictures to illustrate the different types of land use and land cover. The current woody vegetation will pose little problems for clearing of the land, which should be done with the chain rather than using bulldozers or other in order to protect the soil. Based on the current land use and land cover information we can make an estimate of the effort required for land clearing for each specific piece of land.

Picture 2 Maize field close to a small settlement with a minor road illustrating the general good conditions of the roads and tracks (loc. 8°24'32.2"N, 2°58'51.9")

Picture 3 Soybean field in the southern section of the AoI (loc. 8°27'45.5"N, 2°59'24.8"E)

Picture 4 Open woodland vegetation used for grazing; herbaceous layer of grasses and 'stubborn weed' (loc. 8°26'21.2"N, 2°58'57.0"E)

Picture 5 Dense, Anogeissus dominated secondary regrowth on formerly cultivated land (loc. 8°26'26.4"N, 2°59'01.8"E)

Picture 6 Small cassava field for home consumption; Minor road in good condition (photo taken on 25/7/19 at 8°52'30.3"N, 2°52'59.6"E)

Picture 7 Soybean field with many burned dead trees still remaining in the field (8°27'58.5"N, 2°54'19.2"E)

Picture 8 Point L1 (LU6) Maize field in very gently undulating terrain.

Picture 9 Point V1; Picture of the very gently undulating landscape of LU9; area classified as cropland in the LULC map

Picture 10 Point S3 (LU30) showing site of settlement and some of the occupants of the land

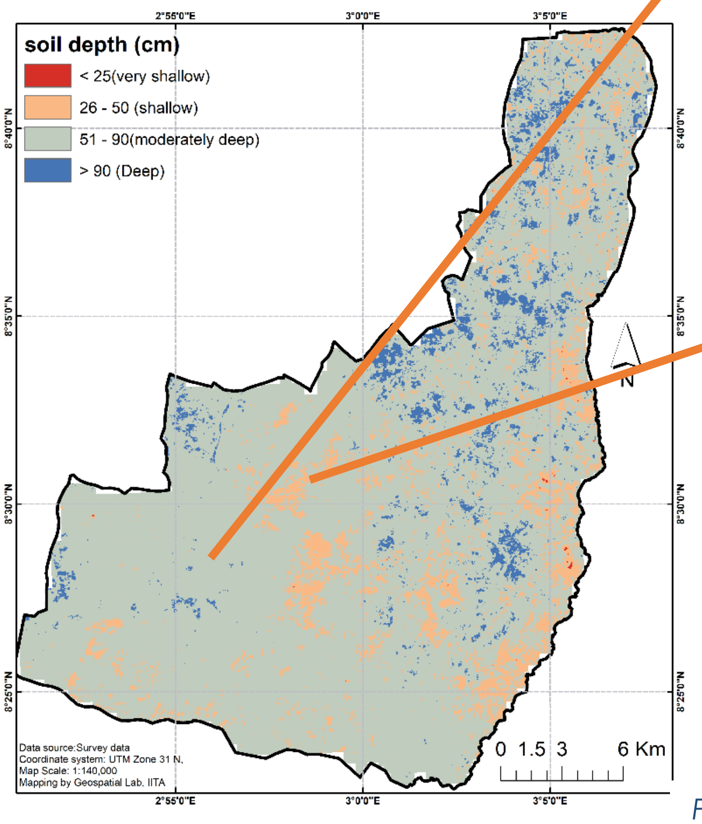
Picture 11 Point W1 (upper northern part of LU13) showing the presence of rock outcrops and shallow soils; Area classified as open woodland in the LULC map

Soil Characteristics

Soil depth and texture

Soils in this area are derived from the Basement Rock Complex, which generally results in light textured soils. We find predominantly soils which fall within sandy loam (31% of the AoI) and loamy sand (37% of the AoI) textural classes. Occasionally we find soils with a higher clay content that moves the texture class into sandy clay loam (11%) or even clay. There is a tendency that the clay content increases with the depth, but that may not always be apparent because also the gravel content in some cases increases as well. The sand fraction consists of course sand and the soils contain gravel in varying amounts from 0% (no gravel, 100% soil) to 76% (high gravel content with soil less than 30%). Map 12 indicates that there are few soil depth restrictions in the area.

Picture 12 Soybean field with many dead trees still remaining in the field (8°27'58.5"N, 2°54'19.2"E)



Map 12: Map of soil depth

Picture 13 Soil type on the shallow and gravelly soils in the locations. Soil taken at increments of 10cm with depth

We have measured the depth restrictions by augering, indicating the depth at which you cannot further drill down in the soil. It is not exactly the same as rooting depth restriction but does give an indication of effective soil depth. Restrictions do generally occur because of the increasing gravel content with depth or where you hit the rotten rock. Occasionally, on the more clayey soils, the soils are too firm and compact to auger any further. Root will also have difficulties penetrating such soil layers. The soil depth within Opara area varies from very shallow to deep. Large portion of the land falls within the moderately deep category. There are few patches of very shallow (3% of the land area) and shallow soils (22% of the land) scattered within the land area (Picture 13). The very shallow soils are unsuitable mechanised agriculture. There are considerably more deep soils (43% of the land) and this predominate the northern part of the land compared to other parts.

The A-horizon (the surface layer at which organic matter accumulates) generally varies from 20 to 45cm and has a nice dark colour indicating a relatively high soil organic carbon content (SOC). Basically, the topsoil colour varies from black to very dark brown. Soil fertility in light textured soils is strongly dependent on the soil organic matter and it is therefore an important characteristic.

The results of the soil analyses reveal that about 49% of the area has very low SOC, 28% has low SOC, and 14% of the area has adequate level while 10% has high level of SOC (Table 4). The adequate to high levels of SOC is concentrated towards the centre of the AoI (Map 13) and this distribution of SOC is associated with the pattern of land use and land cover. The soil pH condition is favourable to most crops (Map 14). A high portion (93%) of the AoI has optimum pH levels. About 7% of the land is strongly acidic (pH<4.5) with possible adverse effects on nutrients availability. This condition is more prevalent in the extreme Southwestern part of the land.

Nitrogen is critically low in about 78% of the land whereas additional 14% of the land has low level of nitrogen (Map 15). Nitrogen was only adequate in about 7% of the AoI, which coincides with areas of adequate level of soil organic carbon, found at the centre of the AoI.

There is low level of phosphorus in the soil (Map 16). About 89% of the soils in the AoI is critically low in available P while less than 2% of the land is of adequate level in phosphorus availability. There is adequate to high levels of potassium in about 60% of the land and these areas are majorly the southern part of the AoI (Map 17). Thus, making potassium the most abundant major essential nutrients (NPK) and phosphorus the most deficient nutrient in the land area. We find iron-manganese concretions in the soil at some locations which are indications of P-fixation or low availability of P in the soil as reflected in the laboratory analyses.

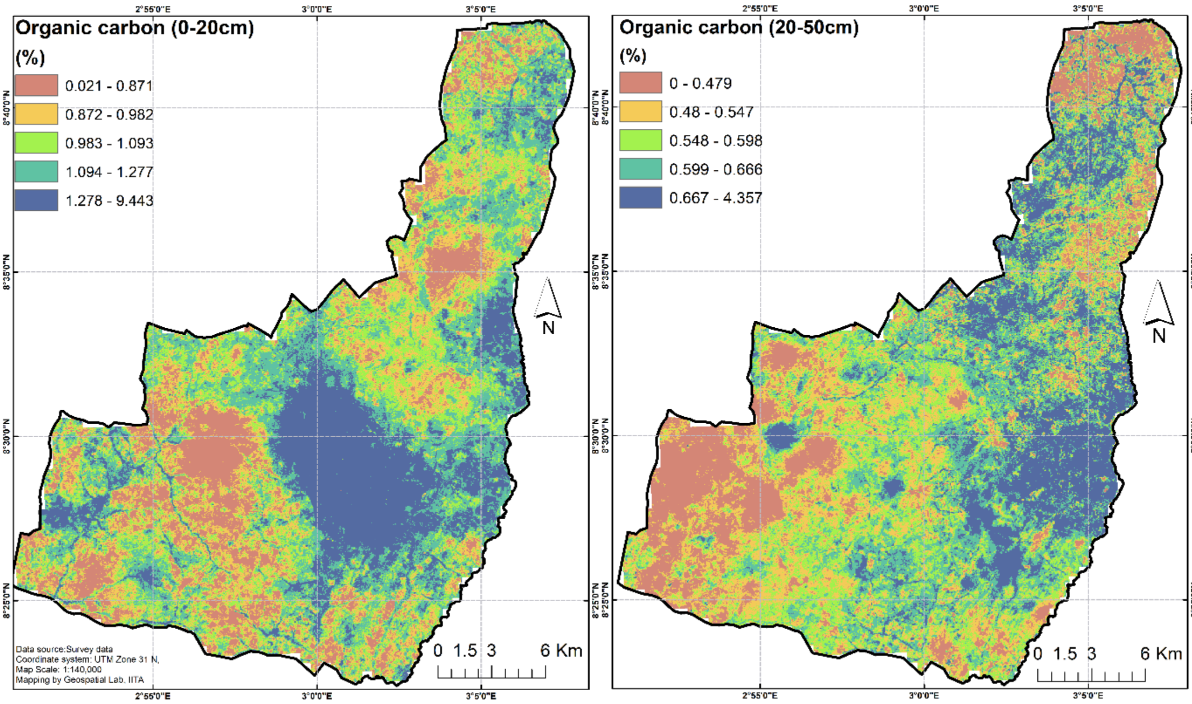
Apart from these major nutrients, there are other nutrients that play vital roles in crop growth and development. These nutrients, among others, include calcium, magnesium and sodium. These three nutrients along with potassium and exchangeable acidity constitute the soil cation exchange capacity (CEC) and this is defined as the ability of the soil to hold nutrients. The effective cation exchange capacity (ECEC) of the soil varies from being critically low (59%) to adequate (5%). Majorly, ECEC is at moderate to optimum level in the south-eastern part of the land area (Map 18).

Calcium is optimum in about 58% and low in about 36% of the land area. Magnesium is considered low in a large portion of the land (98%) and is only adequate in 2% of the AoI. We find low level of sodium in about 99% of the land. Sulphur was critically low in 95% of the AoI.

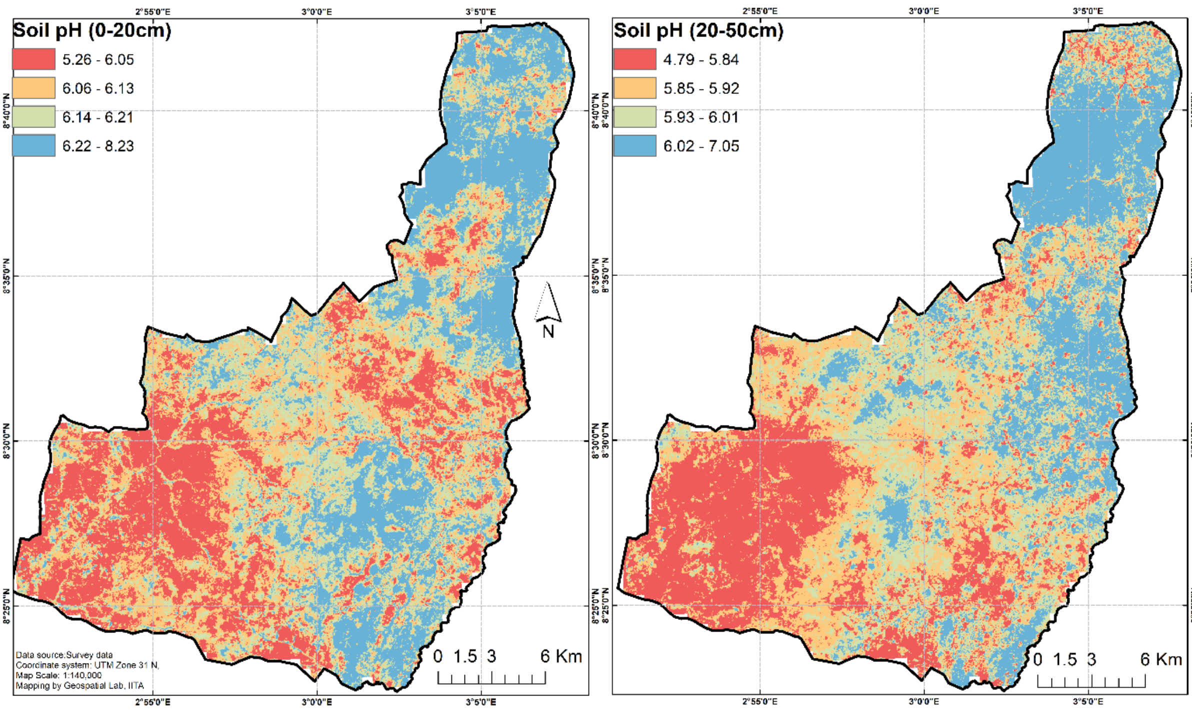
We also examined some of the soil micronutrients and we find manganese and zinc to be very low in 81% and 64% of the cases; iron was optimum in about 56% of the land. Copper is optimum in about 28% and very low in 37% of the AoI. Thus, zinc appears to be the most limiting micronutrients in the area. The maps of some of the micronutrients are presented in Appendix B. The summary statistic on nutrient availability is presented in Table 4.

Table 4: Summary statistics of the soil fertility of the AoI

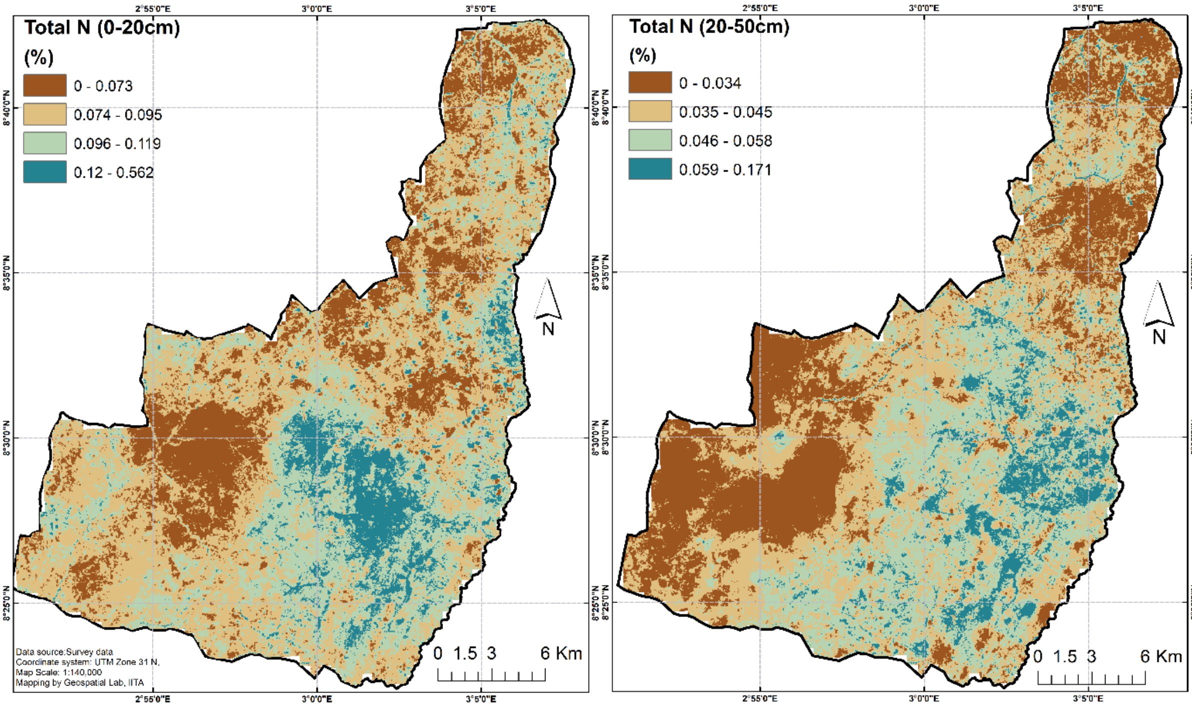
	pH	Ca	Mg	K	Na	ECEC	Mn	P	T.N	Org. C	S	Fe	Cu	Zn
Very low	0%	4%	54%	18%	92%	59%	81%	89%	78%	49%	95%	26%	37%	64%
Low	7%	36%	44%	21%	7%	36%	13%	11%	14%	28%	5%	18%	35%	29%
Adequate	93%	46%	2%	60%	0%	5%	7%	1%	7%	14%	0%	56%	28%	7%
High	0%	12%	0%	0%	0%				0%	10%		0%	0%	0%



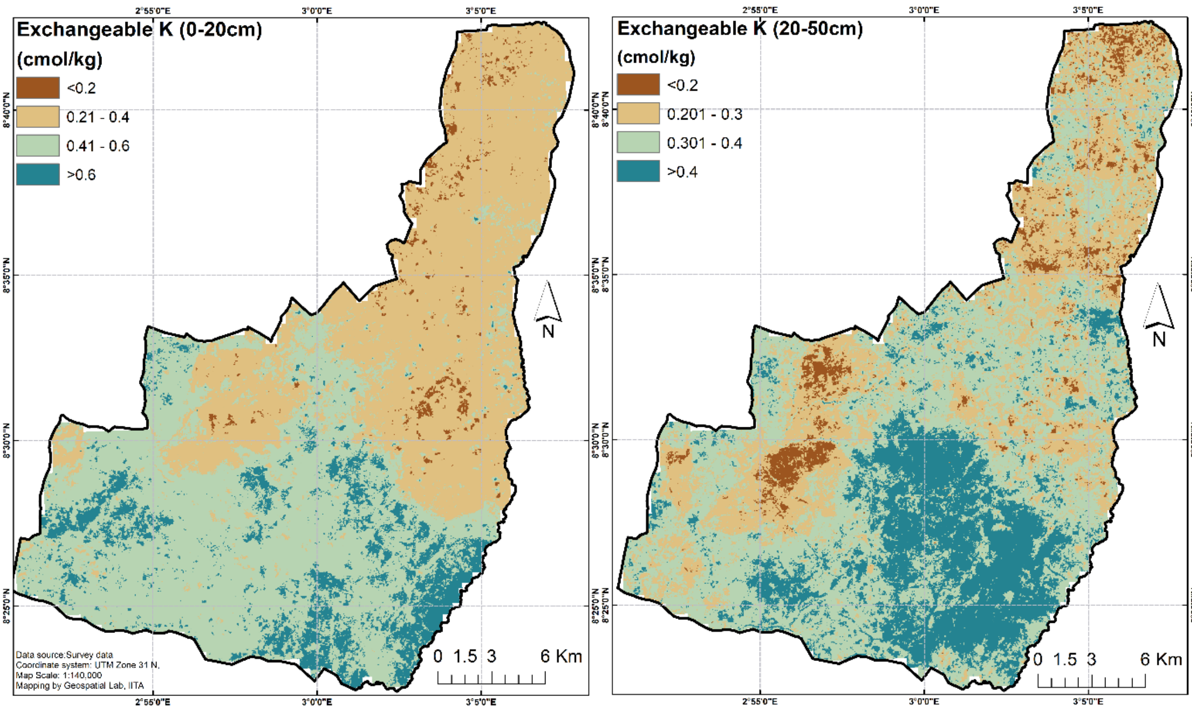
Map 13: Soil organic carbon distribution within the AoI



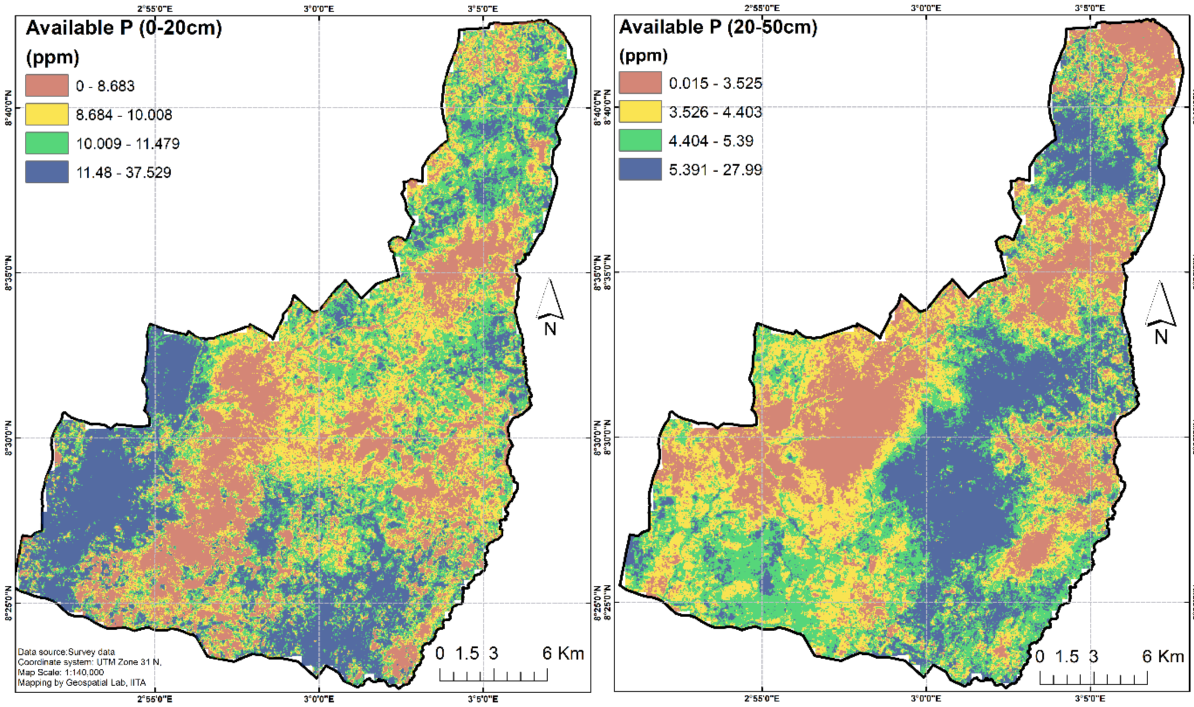
Map 14: Soil pH distribution within the AoI



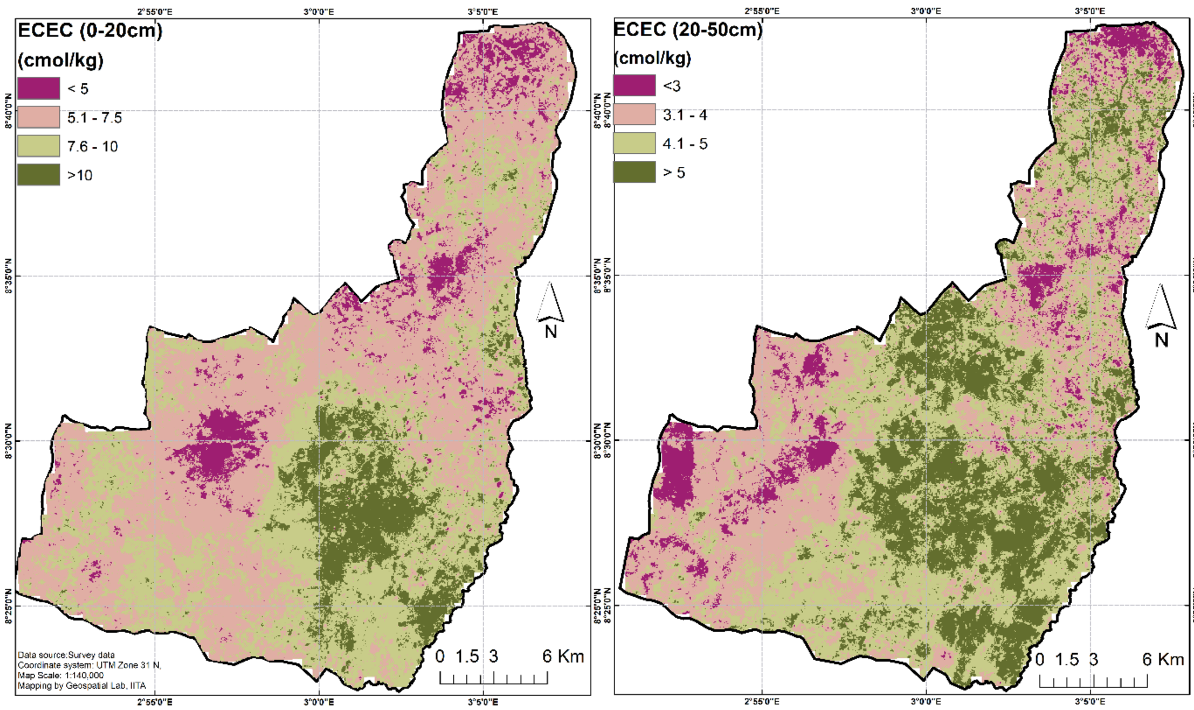
Map 15: The distribution of total nitrogen in the soils



Map 16: Potassium distribution within the AoI



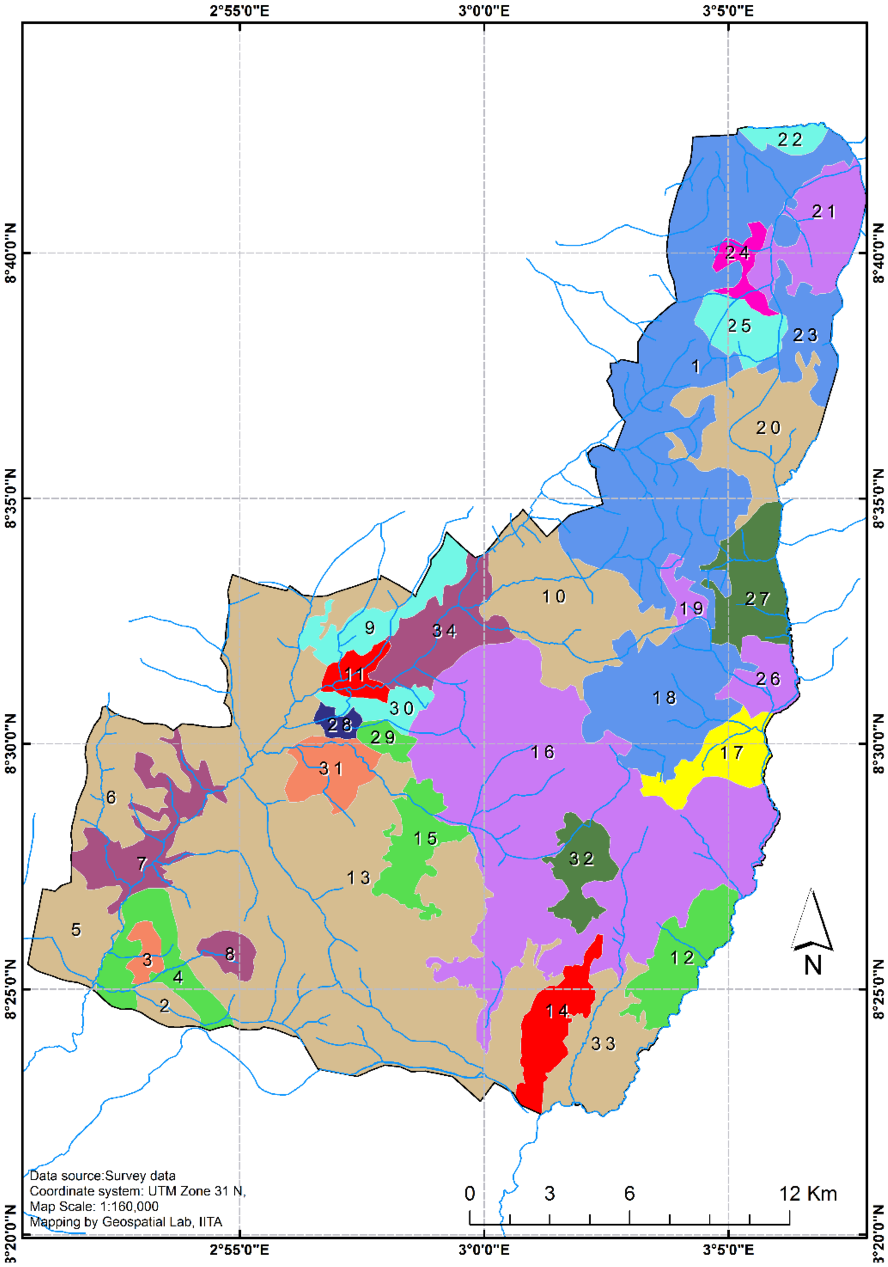
Map 17: The distribution of available phosphorus



Map 18: Effective cation exchange capacity of the soils

Land use zoning and suitability assessment

The land units (see Map 19) are defined based on land use and land cover characteristics, paying special attention to soil and landscape characteristics. The soil main properties we consider as distinguishing factors are, soil depth, soil organic carbon and soil potassium status. Rather than potassium we usually consider the soil pH as a distinguishing factor but in this case we find very little variation in soil pH. We considered slope and elevation along with the land use and land cover as the main landscape characteristics. These criteria allow for an integrated evaluation of the suitability of the land for commercial agricultural use, in particular with respect to mechanised arable cropping. All units are labelled and are grouped based on these characteristics and are described in terms of their relative location within the AoI, elevation and slope, occurrence of streams and rivers, land use and land cover, soil depth and texture, organic carbon, NPK content, ECEC and the acreage.



Map 19: Land unit map

LU 1

This unit 1 is an extensive area of land covering most of the northern section of the AoI. It starts from the northwest border and stretches south. This is a high elevation area but with flat to almost flat and very gentle undulating terrain. This type of terrain is very suitable for mechanised operations. There are streams, mainly river tributaries, that run in different directions. The seasonality of the streams makes water availability a challenge, particularly during the dry season. The land use is predominantly continuous croplands with few scattered shrubs. The soils are moderately deep and deep in most cases. The sand fraction of the soil increases towards the north from about 74% to 80% resulting into less desired soil textures which in this case vary from sandy loam to loamy sand but with more incidence of sandy loam soils. Sandy loam has a higher clay percentage and is a more desirable texture class than loamy sand, with better water holding capacity, but is still considered marginal. The soil pH is optimum for most arable crop and tree crops. The soil organic carbon is low, while nitrogen and phosphorus levels are very low. Potassium level varies from being low to adequate. The effective cation exchange capacity of the soil which is the ability of the soil to hold nutrients is rated low, varying in values from 5.1 to 7.5 cmol/kg. The unit is suitable for cultivation of many arable crops but sound agronomic practices will be needed to improve and sustain the soil fertility.

This unit measures an area of 6690.6 ha.

LU 2 & LU 5

These land units are around the southwestern corner of the AoI. These are low elevation areas with gentle slopes, making mechanisation a possibility without major restrictions. There is a seasonal stream that runs in the middle of LU 2 while LU 5 has a seasonal stream that cuts across in the southern part and another that runs along the east border from north to south. The land use is that of a continuous cropland. The soils are moderately deep and deep in LU 5, while in LU 2 the soils are shallow in some cases and in other cases moderately deep. The texture is loamy sand. The soil organic carbon is low in both land units. The soils are strongly acidic and may require liming. The soil nitrogen content very low. Phosphorus is relatively high though still within the low threshold. Potassium is at adequate level. The ECEC is low for both land units. If low soil fertility is addressed, the units can be used for many arable crops. LU 2 measures an area of 273.5 ha while LU 5 measures 1038.2 ha.

LU 3 & LU 4

These land units are located in the southwestern part of the AoI. LU 3 is encapsulated in LU 4. The units are within the low elevation areas of the AoI. LU 3 has steep slopes while LU 4 is gently sloping. There are two seasonal streams which run from east to west of the units. The land is predominantly being used for crop production. Shallow soils are more prevalent in LU 3 than in LU 4. The soils are of light texture (loamy sand) with about 10% clay content. The soil pH is relatively low but still adequate for most crops. The soil is low in organic carbon. Nitrogen and phosphorus are critically low but potassium is adequate in both land units. The ECEC varies from 7.6 to 10 cmol/kg and is considered low. LU 3 measures an area of 214.5 ha while LU 4 measures 986.8 ha.

LU 6

This occupies the upper section of SW corner of the AoI. The unit falls within the low elevation area. The terrain is gently sloping and slope direction is towards the southeast. There is a seasonal stream that runs through the unit from north to south. The land use is continuous cropland in which most of the trees have been killed. The soils are either deep or moderately deep but with light texture (loamy sand) with about 14% clay content. This implies that the water and nutrient holding capacities of the soils will be low. The soils are low in organic carbon and nitrogen content very low. Phosphorus is relatively high though still within the low threshold. Potassium is at adequate level. The ECEC is also low indicating a generally low fertility level. LU 6 measures an area of 1337.3 ha.

LU 7, LU 34

LU 7 is situated within the SW of the AoI and lies in the low elevation area. LU 7 coincides with the main river course and its distributaries in the Western section. The soils are of light texture (sandy loam) though with a relatively high clay content of about 16% clay, making the soil texture to fall within the desirable class. The soils are deep, strongly acidic (pH <5.5) and contain relatively high levels of organic carbon, nitrogen, phosphorus and potassium. The soil organic carbon and potassium levels are high. These make the soil fertility is highly suitable for agricultural activities. Consequently, the soil is more fertile owing to the decomposition of debris deposited along and around the river course. LU 7 is suitable for the cultivation of many arable crops but with preference for rice owing to the relatively high availability of water. LU 7 measures an area of 1246.7 ha.

LU 34 in the upper west of the AoI is identical to LU 7 and measures an area of 1228.3 ha.

LU 8

This unit of land is encapsulated within LU 13. It has similar soil and landscape characteristics as LU 7. LU 8 measures an area of 273.5 ha.

LU 13

This is an extensive area of land dominating the south-western section of the AoI. The topography varies from flat to almost flat to gently sloping. The upper part of this unit are low elevation areas while the lower part are relatively high elevation areas. The unit is well supplied with drainage networks and the rivers run from north to south of the AoI, though most of the rivers are seasonal. There is only one river towards the west of the unit which is more of a permanent river but even this do not carry much water during the dry season. The vegetation structure consists of trees, shrubs and grasses. There are alternating large patches of croplands. There is a number of villages within this unit. The soils are deep in most parts and moderately deep in other parts. There is more textural variation in this unit than there are with any other units. The soil texture varies from loamy sand in the south to sandy clay loam in the centre and to sandy loam in the north of the unit. Accordingly, the clay content varies from 14% to 25%. The soil pH is optimum for the growth of most arable crops. The soil is low in soil organic carbon, nitrogen and phosphorus but with adequate level of potassium. The ECEC is rated low but relatively high compare to the northern part of the AoI. LU 13 measures an area of 13211.3 ha.

LU 14

This is a fairly narrow unit that stretches towards the north on the high elevation area of the SE section of the AoI. The relief intensity is high with short and steep slopes. This relief feature renders LU 14 unsuitable for crop production. There are no streams running within the unit. The area consists of open woody vegetation consisting of shrubs, grasses and few dispersed trees. The soils are deep having a sandy loam texture of about 14% clay content. The soils have adequate levels of pH and organic carbon. The nitrogen and phosphorus content are relatively high. The potassium level is also optimum for most crops. The soil capacity to hold nutrients is relatively high, implying that crop production is possible but the steep nature of the topography renders LU 14 unsuitable for sustainable crop production. The unit measures an area of 856.6 ha.

LU 16 & LU 21

LU 16 dominates the central part of the AoI, stretching from the east through the central to the south and to the upper west of the AoI. The topography is flat to gently sloping with long slopes that suitable for mechanisation. There are few streams running within the area, most of which are seasonal in nature; making water availability a problem in this unit. Majorly, the central part of this unit is covered with dense single layer of trees which are mainly composed of *Anogeissus leiocarpus*. The fringes of the unit and some isolated patches are presently cultivated with yam and maize. Aleniboro village, the most populous of the villages and the administrative centre of the AoI, is situated within LU 16. The soil depth varies from very shallow to deep and belongs to the loamy sand textural class. Most of the soils are however moderately deep. The soil pH is optimum for most arable crops. The soil organic carbon is at adequate level and can be considered relatively high. The soils contain more nitrogen than any other units within the AoI. Phosphorus content is low but the potassium level varies from adequate to high. Consequently, the ECEC is relatively high and the general soil fertility level can be rated as adequate for most crops. Thus, the unit is highly suitable for production of many arable crops. LU 16 measures an area of 9227.4 ha.

LU 21 is identical to LU 16 but located in the north of the AoI and is under more intense continuous cultivation. LU 21 measures 1269.8 ha.

LU 10

This unit is located to the northwest of LU 16. The topography is flat to almost flat to gently sloping. The topography is suitable for mechanised operations and do not pose any major restrictions to mechanised agriculture. There are three seasonal streams that crosses the entire unit of land. The land use is more of a continuous cropland. The soils are deep soils with a clay percentage of 24, the texture is sandy clay loam. This type of medium textured soils is able to hold more water and nutrients than the light textured soils. The soil pH and organic carbon levels are adequate for crop production. The nitrogen and phosphorus levels in the soil are low though phosphorus is relatively high compared to most units within the AoI. The soil is rich in potassium. The ECEC is higher in the subsoil than in the topsoil. The soil fertility is rated moderate, making the cultivation of many agricultural crops a possibility though sound agronomic practices are needed to sustain productivity. LU 10 measures 2436.2 ha.

LU 20, LU 33

LU 20 is located in the north arm of the AoI while LU 33 lies in the extreme southeast corner of the AoI. They both have the same soil and landscape characteristics as those of LU 5 but with a somewhat higher clay content (14%).

LU 20 measures 1807 ha while LU 33 measures 1341.2 ha.

LU 18 & LU 23

LU 18 is located south of LU 1 and has the same soil and landscape characteristics as those of LU 1 only that LU 18 has relatively more woody vegetation consisting of single and multi-layered dense trees. LU 18 may require heavier machinery for clearing of the land. LU 23 also has the same soil and landscape characteristics as those of LU 1. LU 18 measures an area of 2318.2 ha while LU 23 measures 819.5 ha.

LU 17, LU 27 & LU 26

These are situated at the eastern border of the mid-section of the AoI. LU 17 consists of flat to almost flat terrain while LU 27 has gently sloping terrain. Both units are suitable for mechanised operations. There are two seasonal streams flowing in both units. The land use and land cover consist of open woodlands and shrub lands with some patches of alternating croplands. The soils of these units vary from being very shallow to shallow in depth and fall within the sandy loam textural class. This textural class is considered marginal in its capacity to hold water and nutrients for plant uptake. The soil pH is within the suitable range for most crops. The soil organic carbon is adequate in both units. Nitrogen and potassium are at adequate levels while phosphorus content of the soils is critically low. The capacity of the soil to hold nutrients (ECEC) is low, requiring some attention to ensure sustainable crop production. LU 17 measures an area of 813.1 ha while LU 27 measures an area of 1156.1 ha. LU 26 has the same characteristics as LU 17 only the soils are deeper in LU 26 than those in LU 17. LU 26 measures an area of 589.3 ha. LU 32 is identical to LU 26. LU 32 measures an area of 682.1 ha.

LU 12, LU 15 & LU 29

LU 12 is located to the north of LU 33. This is an area of low elevation with gently sloping terrain and long slopes. There is a stream that runs through the middle of the unit from east to west. The unit is mainly composed of shrub land and croplands. The soils are shallow and medium textured. The pH is optimum for crop production. The soil organic carbon varies from low to high. Nitrogen is relatively high but phosphorus is low. Potassium level is optimum for most crops. The capacity of the soil to hold nutrients is relatively high. These units of land are suitable for the production of many agricultural crops. LU 12 measures an area of 1058.1 ha. LU 15 and LU 29 are identical to LU 12. LU 15 measures 842.7 ha while LU 29 measures 217.3 ha.

LU 24, LU 22, LU 25

These units are located in the north of the AoI. The topography consists of short and steep slopes, making it impractical for mechanised operations. There are two seasonal streams that run across the unit. There are alternating patches of croplands but with more incidence of shrubs. The soils are shallow and are in the loamy sand class, which are outside the desirable range. The pH of the soil is optimum for most crops. The soil organic carbon, nitrogen and phosphorus are low but not very low. Potassium is adequate and ECEC is relatively high compared to the neighbouring units. Generally, the units are not considered suitable for crop production.

LU 22 and 25 are identical to LU 24 only that the former are more intensely cultivated than the latter. LU 22, LU 24 and LU 25 measure 260.9 ha, 333.9 ha and 613.2 ha, respectively.

LU 9, LU 11, LU 28, LU 30 & LU 31

These units are located in clusters within the western section of the AoI. The topography consists of flat to almost flat terrain. The units are well supplied with streams and rivers. The units have been open for cultivation since the 1990s though there are still some riparian vegetation around the stream channels. The soils are shallow with some spots of deep soils. The soils are generally loamy sand and are outside the desired range for crop production. The pH and potassium are the only soil characteristics at adequate level for crop production. This might be related to the intensity of crop cultivation in the area. Collectively, the units measure 4472.8 ha.

Table 5 presents the suitability status of the various units for agricultural production. Six criteria namely, slope, soil depth, texture, pH, soil organic carbon and soil fertility, were used to compute the suitability value (SV) from which the suitability index (SI) is derived. Each of the factors rates as highly suitable (S 1), moderately suitable (S 2), marginally suitable (S 3) and unsuitable (NS). The summation of these values for a particular unit gives the SV. Suitability index (SI) is computed as a percentage of the SI to the maximum possible scores. The lower the SI the better the suitability status. Units that rate 'NS' for either slope, soil depth, texture, or organic carbon are considered unsuitable for agricultural crop production irrespective of the values of the other evaluation criteria. Among the 34 land units only 8 units are not suitable for crop production due to either steep slopes or very low soil organic carbon.

We further examined the soil quality status of the various units which ranked suitable in the suitability evaluation. In this, we consider the soil fertility parameters which include total nitrogen, phosphorus, potassium, calcium, magnesium, sodium, manganese, iron and zinc (Table 6). Where any of the parameters rank '2' it indicates adequate supply or reserve for that nutrient whereas when any of the parameters rates '0' it implies deficiencies and inadequate reserve for the particular nutrient. The summation of all the rating values for each of the land units gives the total soil quality (TSQ) values. The soil quality status is computed by dividing the TSQ values with the maximum possible values for each unit. The higher the values the higher the soil quality for any of the units. Generally, the units vary in their soil quality potential from high to low and there are more units with moderate soil quality.

Table 5: Overview of the suitability of the various units for agricultural crop production

Land Unit	Slope	Soil depth	Texture	pH	SOC	Soil fertility	SV	SI	General Suitability
LU14	NS	1	1	1	1	NA	4	NS	Not suitable
LU8	1	1	1	1	1	1	6	0.33	High
LU10	2	1	1	1	1	1	7	0.39	High

LU13	1	1	1	1	2	2	8	0.44	High
LU31	1	1	3	1	NS	NA	6	NS	Not suitable
LU32	1	1	2	1	1	2	8	0.44	High
LU34	1	1	1	3	1	1	8	0.44	High
LU7	2	1	1	3	1	1	9	0.50	High
LU20	2	1	1	1	2	2	9	0.50	High
LU26	1	2	2	1	1	3	10	0.56	High
LU28	1	2	3	1	NS	NA	7	NS	Not suitable
LU29	2	2	2	1	NS	NA	7	NS	Not suitable
LU33	2	1	1	1	2	2	9	0.50	High
LU1	1	1	3	1	2	2	10	0.56	Moderate
LU3	NS	2	1	2	2	NA	7	NS	Not suitable
LU12	2	3	2	1	1	2	11	0.61	Moderate
LU15	2	3	2	1	1	1	10	0.56	Moderate
LU16	2	2	3	1	1	1	10	0.56	Moderate
LU17	1	3	2	1	1	2	10	0.56	Moderate
LU18	1	1	3	1	2	2	10	0.56	Moderate
LU19	2	2	3	1	1	1	10	0.56	Moderate
LU21	2	2	3	1	1	2	11	0.61	Moderate
LU23	1	1	3	1	2	2	10	0.56	Moderate
LU25	NS	2	3	1	2	NA	8	NS	Not suitable
LU27	2	2	2	1	1	2	10	0.56	Moderate
LU6	2	1	1	3	2	2	11	0.61	Moderate
LU11	1	2	3	1	2	3	12	0.67	Moderate
LU22	NS	3	3	1	2	NA	9	NS	Not suitable
LU24	NS	3	3	1	2	NA	9	NS	Not suitable
LU30	1	2	3	1	2	2	11	0.61	Moderate
LU4	2	2	1	2	2	3	12	0.67	Moderate
LU9	1	3	3	1	2	2	12	0.67	Moderate
LU2	1	2	3	3	2	2	13	0.72	Low
LU5	2	1	3	3	2	2	13	0.72	Low

Slope: 1=flat to almost flat, 2=gently sloping, 3=moderately sloping, NS=steep and very steep slopes. Soil depth: 1=deep, 2=moderately deep, 3=shallow, NS=very shallow. Texture: 1=most desired, 2=acceptable, 3=least desired, NS=not desired. SV=suitability value, SI=suitability index

Table 6: Overview of soil quality status of the various units considered suitable for crop production

Land Unit	TN	Na	K	Mg	Ca	P	Mn	Fe	Zn	TSQ	SQI (%)	Status
LU8	2	0	2	1	1	1	0	1	1	9	64	High
LU34	2	0	2	1	1	1	0	1	1	9	64	
LU7	2	0	2	1	1	1	0	1	1	9	64	
LU10	0	0	2	1	1	1	1	1	1	8	57	
LU15	2	0	1	1	1	1	0	1	1	8	57	
LU16	2	0	2	1	1	1	0	1	0	8	57	
LU19	2	0	2	1	1	1	0	1	0	8	57	
LU13	0	0	1	1	1	1	1	1	1	7	50	Moderate
LU6	0	0	1	1	1	1	1	1	1	7	50	
LU17	1	0	1	1	1	1	0	1	1	7	50	
LU18	0	0	1	1	1	1	1	1	1	7	50	
LU20	0	0	1	1	1	1	1	1	1	7	50	
LU32	1	0	1	1	1	1	0	1	1	7	50	
LU33	0	0	1	1	1	1	1	1	1	7	50	
LU9	0	0	1	1	1	1	1	1	1	7	50	
LU12	2	0	1	0	1	1	0	1	1	7	50	
LU21	2	0	2	0	1	1	0	1	0	7	50	
LU1	0	0	1	0	1	1	1	1	1	6	43	
LU23	0	0	1	0	1	1	1	1	1	6	43	
LU2	0	0	1	0	1	1	1	1	1	6	43	
LU5	0	0	1	0	1	1	1	1	1	6	43	
LU27	1	0	1	0	1	1	0	1	1	6	43	
LU30	0	0	1	0	1	1	1	1	1	6	43	
LU26	1	0	1	0	1	1	0	1	0	5	36	Low
LU4	0	0	1	0	1	1	0	1	1	5	36	
LU11	0	0	1	0	1	1	0	1	0	4	29	

‘2’ adequate reserve of nutrient. ‘1’=moderate supply. ‘0’=deficient level. TSQ=total soil quality, SQI=soil quality index.

Summary and Recommendations

There are no major constraints for the development of this area in terms of its suitability for commercial agricultural use. Access to this land is constrained and will require major improvements to the road infrastructure to and within the area. There are three road classes within the area, which are secondary roads, minor roads and tracks. The main secondary road is the one that crosses through the centre of the AoI and connects to the Benin border. The road crosses a number of streams, for which no further provisions have been made to cross (there are no bridges). The road is in a poor state due to heavy duty trucks that ply the road day and night conveying rice and other commodities in and out of Nigeria. The feeder roads, which are the minor roads are in relatively good state but crossing of streams may also require attention. There are numerous tracks that have been created by the activities of farmers and the nomadic herdsmen in the area. Improvement of the access roads from Ago-Are is required, some improvements of the road infrastructure within the area are required.

The topography is such that large scale mechanized crop production is possible, without any major constraints on mechanized operations. The slope classes are 'flat to almost flat', 'gently sloping' and 'moderate sloping', with most of the land falling within the range from flat to very gently sloping terrain (less than 5-6% slope). The areas with moderately steep slopes seem to be concentrated in one particular area in the southeast corner of the AoI and is associated with one particular valley system. For the remaining part of the AoI the moderately steep slopes do not cover more than a few percent. The drainage density is low resulting in larger stretches of uninterrupted land surfaces that is required for large scale mechanized operations.

A considerable part of the land (approximately 30%) is cleared and currently in use. A good portion of the AoI (by approximation 32%) has dense woody vegetation composing of either woody vegetation with a single structural layer or of multi-layered woody vegetation. The single-layered woody vegetation results from regrowth after fields have been cultivated. It consists of small trees (light vegetation) that could be cleared with relatively light machinery. The dense multi-layered woody vegetation in most cases also relates to secondary vegetation that has established on previously cultivated land and still does not represent a major obstacle for clearing of the land. The remaining 38% percent of the land is under open woodland and shrubland in which case it is not always evident that the land has been cleared and cultivated before, or whether this type of land cover is associated with the condition of the terrain and soil. In any case, there is very little left of the original derived-savanna vegetation. It would be useful to identify those spots of original forest and savanna vegetation and to see how these could be preserved.

There are large continuous stretches of land which are cultivated with yam, soybean and maize. There are also parts where cropland is alternated with woodland or shrubland resulting in a patchy distribution pattern. The cropland area is closely linked to the settlement pattern, but we do not know what factors have been driving the colonization of this area. That is, which factors explain the different patterns we observe. For example, whether the colonization pattern is explained by the search for suitable land, or whether it is the results of roads that have been constructed to connect to the border that provided access to the land and opportunity. We do hope that current assessment contributes to a more planned development of the area that leads to a sustainable use of the land resources.

Water resources are very limited and probably represent the greatest challenge to commercial crop production within the AoI, not only during the dry season. Most of the streams are river tributaries and are seasonal. There are no rivers, natural ponds or lakes within the area. Groundwater in some of the valley bottoms may provide some solution but should be further investigated. Even if the streams were permanent, they would not carry much water. Water will be an important consideration in any further development plans for the area.

The soil condition is fairly good, not requiring major attention. There are large areas of moderately deep and deep soils. Careful management is however required to increase and maintain the soil fertility and physical characteristics. The management of soil organic matter will play a crucial role. The soils are predominantly of light texture indicating their low capacity to hold water and nutrients for crop uptake. Where fertility is low, nutrient limitations can be corrected with fertilizer application in principle but will still require sound agronomic practices to make sure that there is sufficient response to fertilizer application. These soils can be considered vulnerable because they are susceptible to loss of soil organic carbon.

Most of the land units are suitable for agricultural crop production. A few units are considered unsuitable and thus should be excluded from crop production. Those land units classified as "suitable" are in principle suitable for different arable crops whether cereals, legumes, root and tuber crops. The results of the soil quality assessment reveals that the soil quality indices of the suitable land units vary from high to low with many of the land units being of moderate fertility. The land is very suited for perennial crops (tree crops) and permanent grassland, that makes more efficient use of the resources and that provides for a possible more sustainable alternative because of the permanent cover it provides.

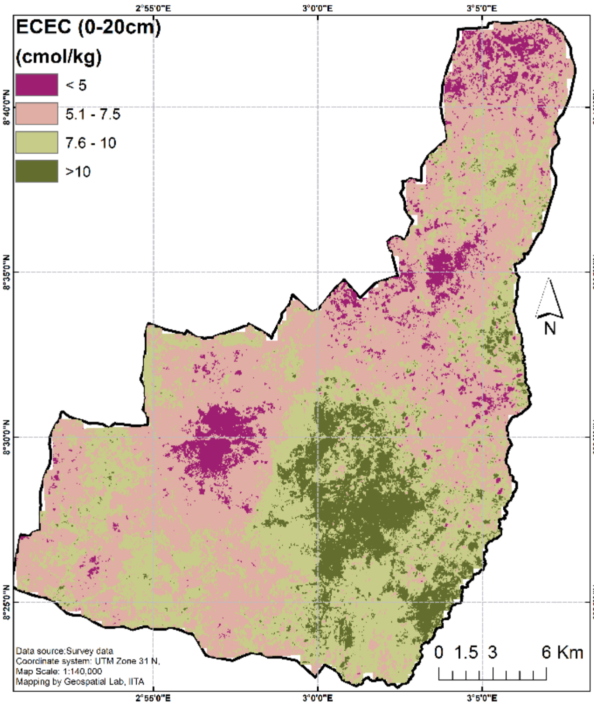
In all 52,561 has out of the 56,100 has surveyed are considered suitable for agricultural use, more in particular arable crops. However, we have also indicated some constraints and mentioned that these soils are vulnerable and require careful management. Further detailed assessment would be required to determine the options for and possibilities of establishing viable agricultural enterprises on each of the particular parts of the land.

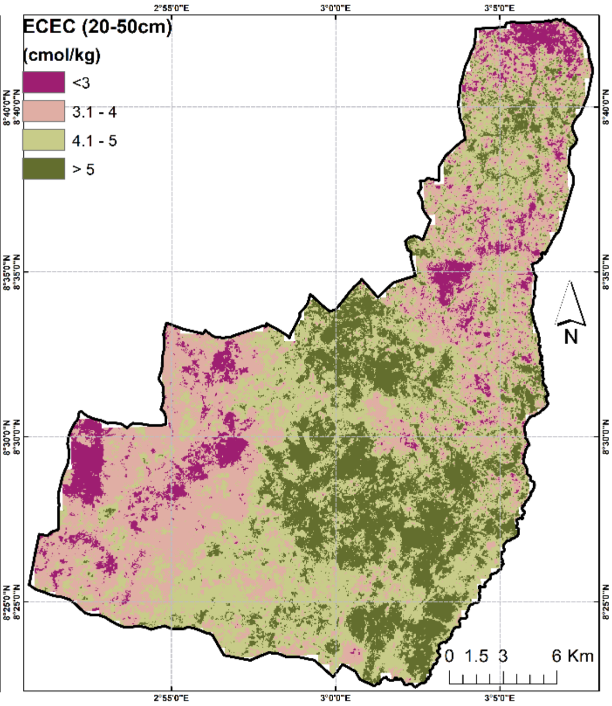
IITA had a clear assignment for this study, to assess the suitability for mechanised agriculture. However, this assessment is to some extent be considered a general assessment that characterises the area in various ways and for different purposes. The assessment can be used for developing alternative land use plans or land use zoning plans, having another purpose in mind than the development of the area for commercial agricultural enterprises. This could be preservation, reforestation, guided development of the area for smallholder agriculture or a combination of those. If the objectives for the land use planning change and if this would require reinterpretation of the data and results of the survey, AgriServe would happy to assist. If the objectives remains the establishment of an Agricultural Development Zone, and develop this area for investment in modern mechanised agriculture, AgriServe will be happy to support further planning of possible pilot projects or general planning for the development of the area.

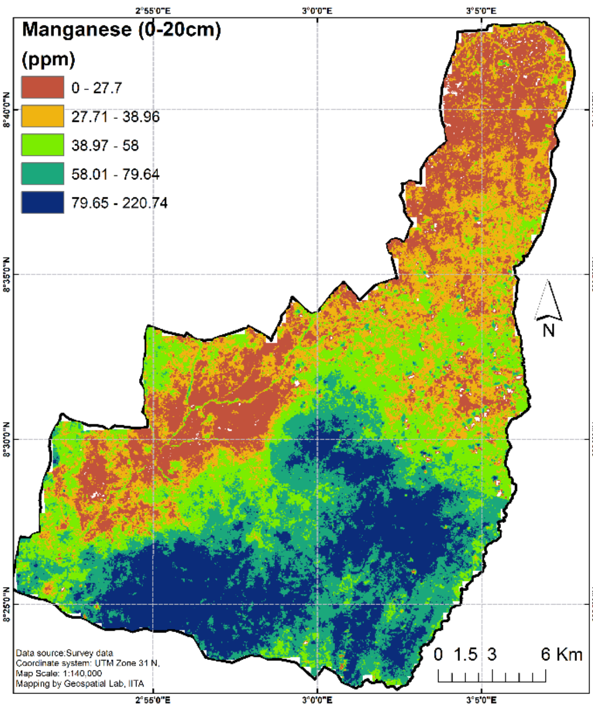
Appendix A. Wet chemistry analytical results of some of the soil samples taken at the various sampling points across the AoI.

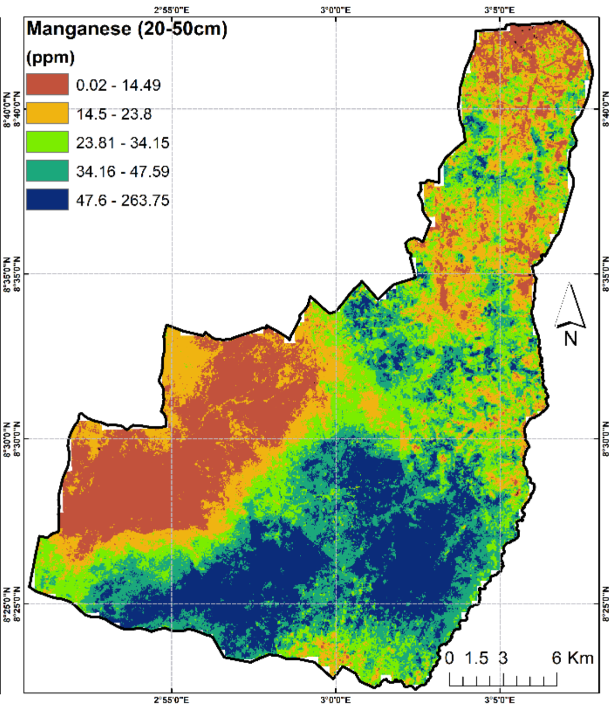
Sample	Depth	Latitude	Longitude	pH(H2O)	OC	N	Meh P	Particle size				Ca	Mg	K	Na	xch. Acidit	ECEC	Zn	Cu	Mn	Fe
Name				01:02.5	(%)	(%)	ppm	%SAND	%SILT	%CLAY	Texture	---------------cmol+/kg---------------						ppm	ppm	ppm	ppm
A3	0-20	8.3923	3.0059	6.2	0.73	0.051	11.06	72	14	14	Sandy loam	2.84	0.39	0.13	0.05	0	3.41	0.94	0.46	13.5	390.09
AA5	0-20	8.5907	3.0810	6.9	0.81	0.081	9.3	70	16	14	Sandy loam	3.85	0.51	0.25	0.06	0	4.67	1.26	0.32	64.99	43.88
B5	0-20	8.4010	3.0313	6.8	0.87	0.071	1.07	SNE	SNE	SNE		3.57	0.87	0.08	0.19	0	4.71	0.84	1.17	63.66	158.54
BB1	0-20	8.6323	3.0623	8.3	0.64	0.058	6.36	69	11	20	Sandy loam	7.84	0.37	0.11	0.08	0	8.4	1.37	0.6	68.54	57.17
C4	0-20	8.4163	3.0543	7	0.96	0.078	7.14	SNE	SNE	SNE		4.63	1.29	0.33	0.04	0	6.29	1.48	1.31	127.93	113.12
CC1	0-20	8.6560	3.0821	7.3	1.08	0.088	4.01	82	8	10	Loamy sand	3.96	0.8	0.39	0.12	0	5.26	2.23	0.32	96.86	49.42
D4	0-20	8.4223	2.9078	6.9	1.62	0.129	5.57	SNE	SNE	SNE		5.8	1.07	0.38	0.03	0	7.28	1.37	0.6	92.42	79.88
DD5	0-20	8.6921	3.0980	6.9	0.75	0.057	4.99	79	9	12	Loamy sand	2.94	0.57	0.16	0.05	0	3.73	1.05	0.32	141.25	61.05
E1	0-20	8.4276	2.9675	6.8	0.52	0.036	3.42	78	8	14	Loamy sand	1.62	0.49	0.13	0.04	0	2.28	0.62	0.18	83.54	67.14
F1	0-20	8.4295	3.0493	6	0.47	0.03	2.24	79	11	10	Loamy sand	1.47	0.42	0.27	0.04	0	2.19	0.73	0.6	10.61	132.51
G3	0-20	8.4634	3.0208	8.4	0.96	0.072	2.05	SNE	SNE	SNE		7.82	0.49	0.11	0.02	0	8.45	0.94	0.46	110.18	44.43
H3	0-20	8.4651	2.8991	6.6	0.63	0.05	10.08	80	10	10	Loamy sand	2.45	0.48	0.22	0.1	0	3.26	1.16	0.32	65.66	73.24
I1	0-20	8.4707	2.9261	5.9	1.71	0.176	5.38	54	26	20	Sandy clay loam	5.82	1.79	0.16	0.34	0	8.11	2.01	0.89	110.18	165.19
J3	0-20	8.4703	2.9859	6.5	0.86	0.081	1.65	78	8	14	Loamy sand	3.23	0.71	0.2	0.03	0	4.17	1.16	0.32	203.4	79.33
K4	0-20	8.4693	3.0016	6.9	1.4	0.129	3.61	SNE	SNE	SNE		6.57	0.89	0.26	0.02	0	7.75	1.69	0.46	190.08	71.57
L2	0-20	8.4805	2.8675	6.7	0.6	0.052	4.01	76	10	14	Loamy sand	2.79	0.46	0.22	0.05	0	3.53	0.62	0.32	83.54	64.93
M4	0-20	8.4821	2.9267	6.6	1.68	0.188	1.07	56	19	25	Sandy clay loam	6.24	2.68	0.14	0.1	0	9.16	1.37	4.97	207.84	71.02
N5	0-20	8.4908	2.9472	6.8	0.68	0.049	2.44	78	8	14	Loamy sand	2.5	0.58	0.28	0.05	0	3.41	0.94	0.46	101.3	72.13
O1	0-20	8.4930	3.0015	7.1	0.87	0.071	8.12	78	10	12	Loamy sand	4.47	0.53	0.21	0.02	0	5.24	0.84	0.32	127.93	72.68
P4	0-20	8.4954	3.0658	8.1	1.12	0.098	4.01	68	12	20	Sandy loam	11.5	1.28	0.18	0.04	0	13	3.83	1.17	190.08	119.77
Q3	0-20	8.5072	2.9325	7	0.58	0.057	8.51	78	11	11	Loamy sand	3.15	0.61	0.09	0.05	0	3.89	0.73	0.46	114.62	109.8
R1	0-20	8.5141	2.9198	6.6	0.58	0.059	7.34	78	10	12	Loamy sand	3.07	0.44	0.16	0.06	0	3.74	0.62	0.18	79.1	62.16
S5	0-20	8.5147	2.9701	6.9	1.13	0.088	9.1	74	10	16	Loamy sand	6.6	0.97	0.3	0.07	0	7.93	1.26	0.75	105.74	99.83
T6	0-20	8.5198	3.0215	6.6	1.07	0.098	1.07	60	16	24	Sandy clay loam	5.23	1.11	0.28	0.08	0	6.69	1.48	3	261.1	150.23
U1	0-20	8.5266	3.0768	7.1	1.07	0.081	7.14	68	18	14	Sandy loam	4.84	0.74	0.23	0.05	0	5.85	2.23	0.46	212.27	80.99
V6	0-20	8.5348	2.9571	7.9	1.34	0.082	8.12	70	14	16	Sandy loam	7.82	1.26	0.2	0.04	0	9.32	2.01	1.45	318.81	78.78
W2	0-20	8.5418	2.9308	6.7	0.93	0.086	5.38	74	12	14	Sandy loam	5.12	0.78	0.55	0.08	0	6.53	0.94	0.6	53.45	82.65
X5	0-20	8.5652	3.0985	7	0.98	0.074	7.93	72	12	16	Sandy loam	4.89	0.71	0.22	0.12	0	5.95	1.16	0.89	114.62	76.01
Y4	0-20	8.5870	3.0542	6.5	0.85	0.071	6.16	72	14	14	Sandy loam	3.36	0.58	0.18	0.07	0	4.19	1.26	0.6	101.3	61.6
Z4	0-20	8.5973	3.0458	6.2	0.67	0.063	6.75	74	12	14	Sandy loam	3.44	0.61	0.2	0.07	0	4.32	1.37	0.46	105.74	62.16
AA5	20-50	8.5907	3.0810	6.2	0.54	0.042	3.22	72	14	14	Sandy loam	2.27	0.35	0.19	0.08	0	2.89	0.94	0.46	62.99	54.4
M4	20-50	8.4821	2.9267	6.6	0.99	0.13	2.63	64	12	24	Sandy clay loam	3.52	2.27	0.09	0.09	0	5.96	0.62	3.56	132.37	53.85
E1	20-50	8.4276	2.9675	6.5	0.27	0.021	2.63	SNE	SNE	SNE		0.79	0.3	0.22	0.02	0	1.33	0.51	0.46	127.93	68.8
C4	20-50	8.4163	3.0543	6.1	0.55	0.055	1.85	SNE	SNE	SNE		4.19	1.13	0.1	0.07	0	5.49	0.73	2.01	247.79	114.23
DD5	20-50	8.6921	3.0980	6.9	0.46	0.031	6.16	80	10	10	Loamy sand	2.12	0.49	0.18	0.05	0	2.84	0.62	0.32	136.81	59.39

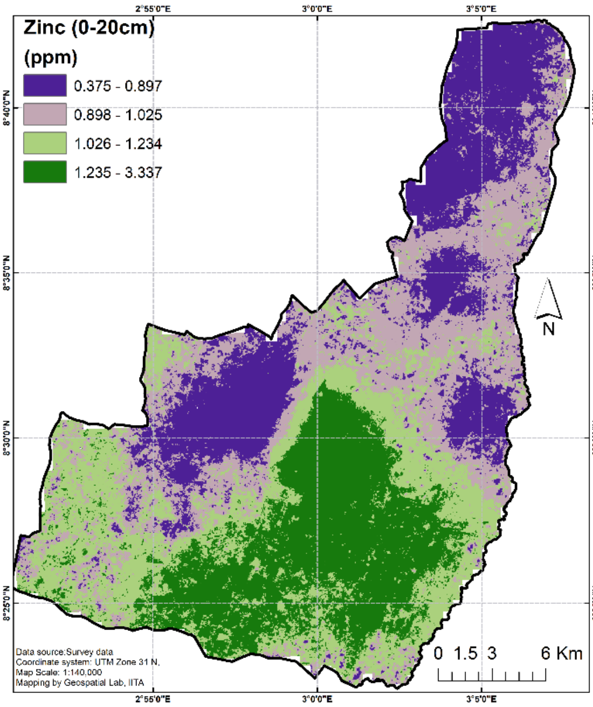
Appendix B: Maps of ECEC, Manganese, Zinc and Copper availability

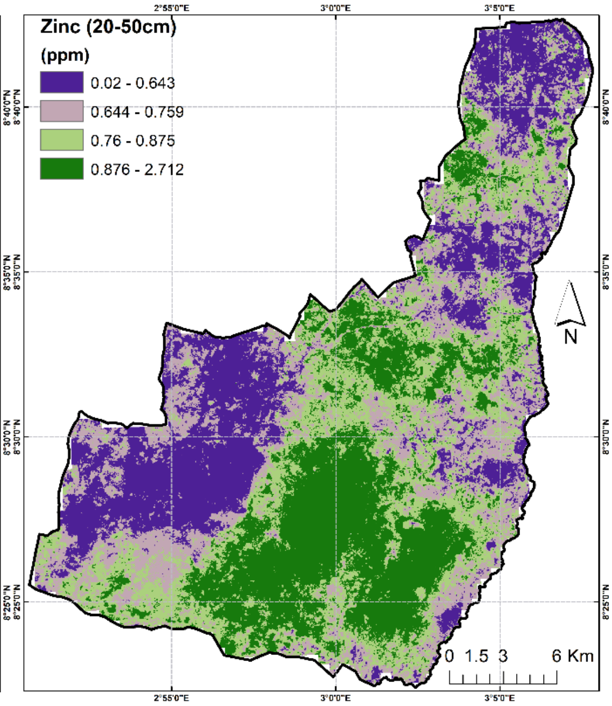


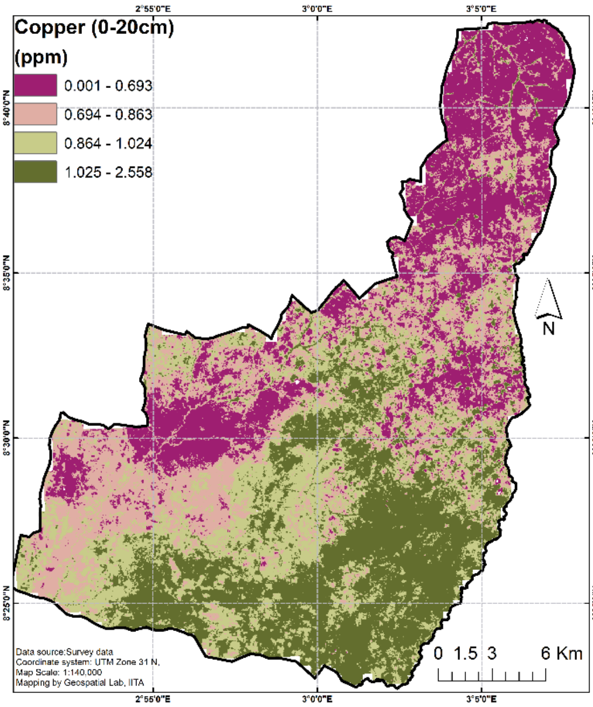


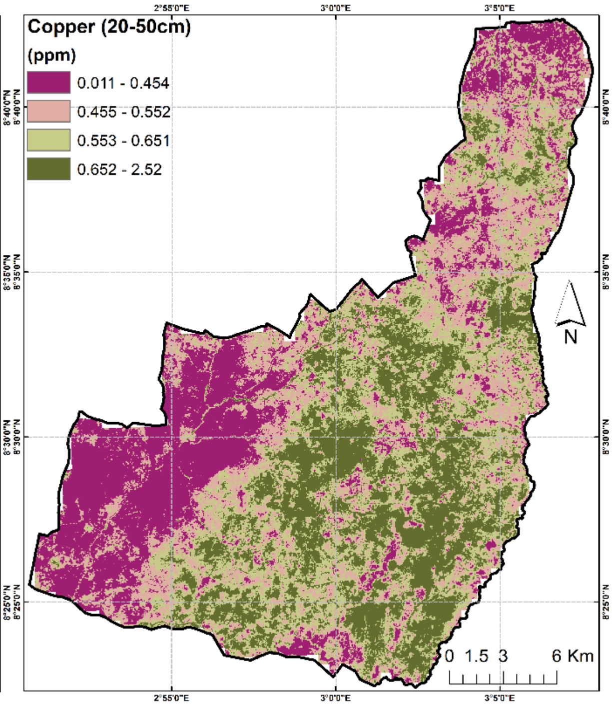





Zinc (0-20cm)
(ppm)
0.375 - 0.897
0.898 - 1.025
1.026 - 1.234
1.235 - 3.337
N
0 1.5 3 6 Km
Data source:Survey data
Coordinate system: UTM Zone 31 N,
Map Scale: 1:140,000
Mapping by Geospatial Lab, IITA


Zinc (20-50cm)
(ppm)
0.02 - 0.643
0.644 - 0.759
0.76 - 0.875
0.876 - 2.712
N
0 1.5 3 6 Km


Copper (0-20cm)
(ppm)
0.001 - 0.693
0.694 - 0.863
0.864 - 1.024
1.025 - 2.558
N
0 1.5 3 6 Km
Data source:Survey data
Coordinate system: UTM Zone 31 N,
Map Scale: 1:140,000
Mapping by Geospatial Lab, IITA


Copper (20-50cm)
(ppm)
0.011 - 0.454
0.455 - 0.552
0.553 - 0.651
0.652 - 2.52
N
0 1.5 3 6 Km

Appendix C: Description of the data files related to the land and soil survey and suitability assessment

All the maps the maps and data generated in this study can be accessed here. This folder contains the data and maps for both the Gambari and the Opara ADZ.

All geographical data (the maps) are contained in the folder **Shapefiles_Rasters,** in which we have separate folders for the Onigambari and Opara data. The vector data are exported as ESRI shape files. This is the format of the files used in the ARCGIS software of ESRI but is a widely used standard for the exchange of geographical information and can be read by most GIS software. The data is stored as a set of related files, with the extension **.shp**, **.dbf**, **.prj**, **.sbn**, and **.sbx** that contains the vector data, the tabular data and different kind of meta data like information on the projection etc. The vector data refers generally to rivers, the road network, land unit boundaries and other that has been digitized generally from the screen.

The raster data (gridded maps) are exported as GEOTIFF files, which is likewise a common file format used for the exchange of raster data/images. It comes in the same way as a set of files that contains the raster data itself and some additional metadata that might not be included in the header of the raster files, like the geolocation of the raster (origin of the file/raster in the real world, size and rotation of the pixels, etc.), like statistical information on the raster, projection, coordinate system, the pyramids (organisation of the data) etc. The files come with the extension **.tif**, **.tif.aux.xml**, **.tif.ovr**, and **.tfw**. and should be used when importing the data in any image processing or GIS software. The raster data generally refers to the soil data (maps of the individual soil properties) and data derived from satellite imagery, like the land use and land cover classification.

Table 7. List of raster and vector maps in the data repository for Gambari and Opara study sites

Onigambari folder and area			
Vector		**Raster**	
Contour_5m	Contour lines with a 5m elevation interval	Aluminium(ppm)_topsoil	Predicted Aluminium levels in the topsoil
Contour_20m	Contour lines with a 20m interval as separate map layer	Aluminium(ppm)_subsoil	Predicted aluminium
Land_characteristics	Land unit map	Available_Phosphorus_subsoil	Predicted available P levels
New_boundary	Boundary of the Gambari ADZ	Available_Phosphorus_topsoil	

	mandate/study area		
Onigambari_boundary		Boron_subsoil	Predicted Boron content
Rivers	Rivers classified in first, second and third order streams	Boron_topsoil	Predicted Boron content
Roads	With indication of the road class	Copper_subsoil	Predicted copper levels
Rock_outcrop	Delineation of rock outcrop area as can be observed from the SI	Copper_topsoil	Predicted copper levels
Soil_Sampling_sites	Map of the locations of the observation and sampling point in the field	Elevation (m asl)	DEM with elevation in meters above sea level
Villages	Villages located outside the ADZ	Exchangeable_Calcium_subsoil	Predicted
		Exchangeable_Calcium_topsoil	Predicted
		Exchangeable_Magnesium_subsoil	Predicted
		Exchangeable_Magnesium_topsoil	Predicted
		Exchangeable_Potassium_subsoil	Predicted
		Exchangeable_Potassium_topsoil	Predicted
		Iron (ppm)_subsoil	Predicted
		Iron (ppm)_topsoil	Predicted
		Landsat7_false_color2000Feb	Satellite imagery without classification; vegetation shows up in red
		Landuse_Landcover1984	Land use and land cover classification based on 1984 satellite imagery
		Landuse_Landcover2000	Land use and land cover classification based on SI of 2000
		Landuse_Landcover2019	Land use and land cover classification based on SI of 2019
		Manganese_subsoil	Predicted values

		Manganese_topsoil	Predicted values
		Sentinel_Isodata_class_jan12019	Satellite data from ESA (sentinel platform)
		Slope	Raster data with slope in percentage derived from SRTM data
		Sodium_subsoil	Predicted values
		Sodium_topsoil	Predicted values
		Soil Organic_Carbon_topsoil	Predicted values
		Soil Organic Carbon_subsoil	Predicted values
		Soil pH (0-20cm)	Predicted values
		Soil pH (20-40cm)	Predicted values
		Sulphur_topsoil(ppm)	Predicted values
		Sulphur_subsoil(ppm)	Predicted values
		Total_Nitrogen_topsoil	Predicted values
		Total_Nitrogen_subsoil	Predicted values
		Zinc_subsoil(ppm)	Predicted values
		Zinc_topsoil(ppm)	Predicted values
Opara folder and area			
Vector		**Raster**	
Boundary	Boundary of the intended Opara ADZ as provided to us	Copper	Predicted values
Landunit	Land unit map of the area	Landsat7_Dec27_1990_Falsecolor_RED vegetation	Composite of three spectral bands of Landsat imagery in which the NIR band is displayed in red, making vegetation to appear in red on the imagery
Landuse_landcover19	Landuse and land cover map with	Landsat7_feb2000_REDVegetation	Composite of Landsat 7 imagery

	the units delineated (polygons)		of 2000 in which vegetation appears in red
Major_towns	Towns outside the Opara ADZ	Soil depth (cm)	Predicted
Rivers	Rivers/streams classified as first, second and third order streams	Soil pH (0-20cm)	Predicted value of pH in topsoil
Roads	Roads classified as secondary, minor roads and tracks	Soil pH (20-50cm)	Predicted value of pH in subsoil
Settlements	Location of individual settlements within the Opara ADZ	Total N (0-20)	Predicted total nitrogen value
Soil_Sampling_Sites	Map with location of the points of observation and sampling points	Total N (20-50)	Predicted total nitrogen value of subsoil
		Zinc (0-20cm)	Predicted value of Zinc in ppm
		Zinc (20-50cm)	Predicted value of Zinc in ppm
		"Soil" folder	
		Available P (0-20cm)	Available phosphorus in topsoil in ppm
		Copper (0-20cm)	Copper in topsoil (ppm)
		ECEC (0-20cm)	Effective Cation Exchange Capacity topsoil (includes exchangeable acidity)
		ECEC (20-50cm)	Effective Cation Exchange Capacity subsoil (includes exchangeable acidity)
		Exchangeable K (0-20cm)	Exchangeable potassium topsoil
		Exchangeable K (20-50cm)	Exchangeable potassium subsoil
		Manganese (0-20cm)	Manganese (predicted) ppm topsoil
		Manganese (20-50cm)	Manganese (ppm) predicted for subsoil

		Organic carbon (0-20cm)	Soil organic carbon (%) topsoil
		Organic carbon (20-50cm)	Soil organic carbon (%) subsoil
		Soil depth(cm)	Soil depth (restriction in augering depth in cm)
		Soil pH (0-20cm)	Soil pH (1:2.5 H_2O) of topsoil – predicted values
		Soil pH (20-50cm)	Soil pH (1:2.5 H_2O) predicted
		Total N (0-20cm)	Total nitrogen topsoil (%)
		Total N (20-50cm)	Total nitrogen subsoil (%)
		Zinc (0-20cm)	Zinc (ppm) topsoil
		Zinc (20-50cm)	Zinc (ppm) subsoil

Apart from the maps, the folder also contains the data files from the observations in the field (the data recorded using the ODK forms), with result from the wet chemistry soil analysis and the predicted soil property values based on the spectral analysis of the soil samples. Table 8 gives the description of these files.

Table 8 Overview of the data files that can be accessed through the link provided

File name	Extension/File type	Description/content
BIP soil collection_Opara survey	xls	Contains Opara land and soil survey information including GPS coordinates of the sample points, vegetation assessment data, land and soil characteristics data
Opara Soil data_MIR_adjusted for gravel content_COLORCODED	xlsx	Contains Opara soil analysis data predicted from MIR. The data have highlighted in different colours based on the sufficiency levels of each of the parameters

Wetchem_colourcoded_Opara	xlsx	Contains Opara soil analysis data wet chemistry analysis which has been colour coded based on the sufficiency levels of each of the parameters
Onigbambari soil status_MIR_annot	xlsx	Contains Gambari soil analysis data predicted from MIR. The data have higlighted in different colours based on the sufficiency levels of each of the parameters
Gambari_surveydata_SAM_latest_27_03_orig	xls	Contains Gambari land and soil survey information including GPS coordinates of the sample points, vegetation assessment data, land and soil characteristics data
Gambari wetchem_EJH	xlsx	Contains Gambari soil analysis data wet chemistry analysis with an indication of the sufficiency levels of each of the parameters