AGRISERVE

Consultancy for Sustainable Agriculture

Report

# Land and Soil Suitability Assessment for Agribusiness Park Establishment in Gambari Agricultural Zone

**Project:** Land and soil survey and suitability assessment for the Gambari and Opara Agricultural Development Zones, Oyo State, Nigeria

**Project code:** PJ 002947 (IITA)

**Client:** Oyo State Government

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## Acknowledgement and Contributions

We gratefully acknowledge Oyo Sate Government and the Governor of Oyo State for commissioning IITA for conducting a 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. Before commissioning IITA for this study a working group was established to prepare the content of the assignment. 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 Rasheed I. Oyeranmi, Director Planning Research & Statistics

IITA representatives in the WG on Agribusiness Park development:
Mr Frederick Schreurs, CEO of the Business Incubation Platform

- Godwin Atser
- Oluwadare Odusanya
- Jeroen Huising

An important part of the field work was carried out by a team from IAR&T. We acknowledge the contributions of:

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- 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
- Jeroen Huising, BIP/AgriServe, project leader and coordinator

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# Acronyms

| | |
|---|---|
| AoI | Area of interest |
| BIP | Business Incubation Platform |
| FR | Forest reserve |
| GFR | Gambari forest reserve (also named Onigambari) |
| ADZ | Agricultural Development Zone |
| IITA | International Institute of Tropical Agriculture |
| OYSG | Oyo State Government |
| masl | meters above sea level |

# INTRODUCTION/ BACKGROUND:

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 possible location is the Onigambari Forest Reserve that is located to the south of Ibadan and the other possible 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. The Opara Forest Reserve (the northern part) measures around 150,000 ha and from this OYSG aims to identify 20,000 ha to be allocated for business park development. From the Gambari Forest Reserve area around 6000 ha approximately have been allocated for agricultural development, to be referred to as the Agricultural Development Zone (ADZ).

OYSG has approached IITA to conduct a land and soil survey to establish the suitability of the land and the soil for agricultural use for planting various types of crops and using modern farming techniques and/or to identify the most suitable area for this purpose. Preliminary field visits (two to Opara Forest Reserve and three to Gambari Forest Reserve) have been made to get a better impression of the opportunities and challenges these areas may present (land and soil, access, land use and settlements, etc.), to get a better understanding of the requirements for the land and soil survey. To this end, we made video recordings using a drone. Reports have been made and shared of these visits, including the videos that were recorded. Based on this information the proposal was developed and submitted to Oyo State Government.

Notification of approval of the proposal was received by letter from the Permanent Secretary, dated June 11, 2018. Part of the funds 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, but not adding up to the full contracted amount.

The priority for the land and soil survey was earlier set for the survey of the Gambari area, being closer to Ibadan and more easily accessible. Preparations were made and the field survey of the Gambari ADZ was carried out. For the survey of the Opara Forest Reserve no further plans, or preparations for the survey has been made so far, because we have concentrated on the Gambari study and further plans will be pending final payment

This report presents the results and finding form the land and soil survey conducted in Gambari Agricultural Development Zone. It is the final report in which the comments have been processed that were given during two meetings where the results of the study were presented.

# METHODS and DATA SOURCES

**Approach**

IITA was asked to make an assessment of the suitability of the land and soils for commercial farming without specifying the crops. Rather, the understanding is that the assessment will specify the crops for the land is suitable. Otherwise, the suitability assessment will take into account 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

Rather than applying formal criteria that would allow for a quantitative assessment and rating of the suitability, at this stage, and until specific requirements can be formulated, a qualitative assessment of the land and soil for the factors mentioned above is done. We assume and 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 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
- Administrative boundaries, restricted areas

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 sampling design included 100 sampling locations using a fixed grid sampling approach to determine the locations in the field. The observations in the field are done according to a standard operating procedure and data was recorded electronically using ODK Collect and forms designed for this purpose and adapted to this particular study. The data collected can be used for ground truthing for the image interpretation and for the validation of data and maps generated.

At each point of observation soil samples are taken from the top soil (0-20cm) and subsoil (20 -50 cm) for analyses in the lab. Measure gravel – soil texture, soil carbon and Total N using, pH 1:2.5, chemical properties using spectral analyses and wet chemistry analysis (P, K, Na, Ca, Mg, S, Mn, Zn, B, Cu), ECEC is determined by adding exchangeable basis and exchangeable acidity

**Activities**

Activities have been carried out in the chronological order as indicated in the table below.

*Table 1. Chronology y of activities for Gambari land and soil suitability assessment*

| | |
|---|---|
| January – June 2018 | Reconnaissance field visit to both Okpara and Gambari Forest Reserve areas |
| 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 |
| 29 Nov 2018 – 10 Jan 2019 | Field survey and sample collection by IAR&T |
| 23 Nov 2018 – 17 Jan 2019 | Field survey and sample collection by IITA -GIS team |
| 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 |

**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 (1984 & 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

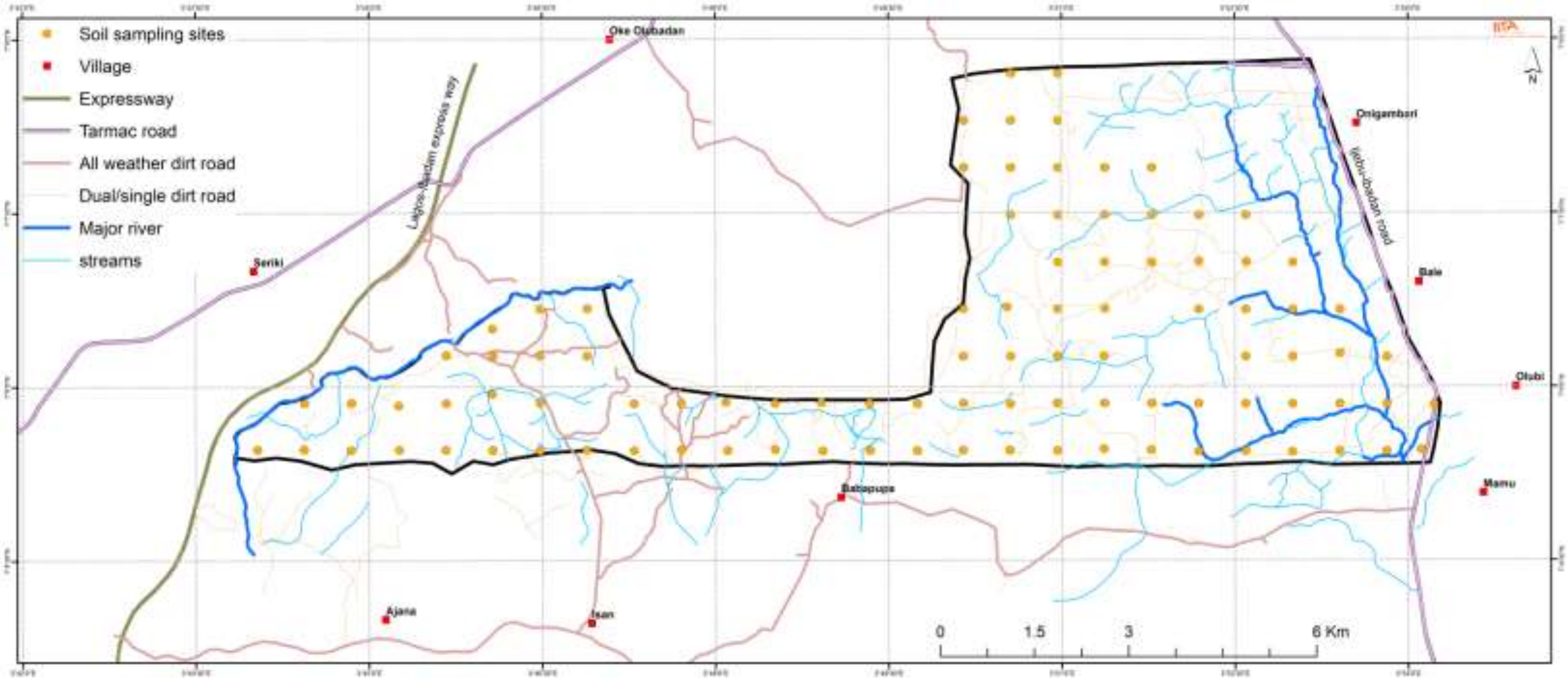
**Location and general landscape characteristics of the Area of Interest**

The area is located about 30 km south of Ibadan and sandwiched between the A1, the old highway to Lagos, to the west and the Ijebu Ode-Idi Ayunre road to the east. The Onigambari forest reserve originally is a quite extensive area of around 14600 ha, but large parts especially to the west have been allocated for other purposes, viz. commercial farming. In a large part to the east and north is we find a large teak plantation, which reportedly was established over 100 years ago.

The area of interest (AoI) for this study covers only a part of the original Onigambari forest reserve and is the area to be allocated for agricultural development. The AoI boundary has been provided by Oyo State Government and is depicted in Map 1 below. The area measures approximately 6000 ha. The southern border is clearly visible on the satellite imagery. It forms a straight line and is associated with a marked transition in land use and land cover (forest cover and dense wooded vegetation on the other side of the boundary. The Oyo-Ogun state boundary (as depicted in Google maps) runs in parallel about 700 meters to the south, which seems to suggest that the boundary of the forest reserve coincides with the state boundary, and that the state boundary as indicated on Google maps is probably an error. However, in the field the boundary is not demarcated and not directly visible, which prompted the government representative to have the land surveyor officially establish the boundary and also to demarcate the boundary in the field.

A considerable part of AoI is still covered by the teak plantation, but the remainder of the area is largely cultivated. We find some spots of forest remnants and densely wooded areas that have been part of the teak plantation formerly. It seems that the major transition from forest or densely vegetated area into cultivated land has taken place since 2006. For the western part this transition has taken place since the mid 80’s. See plate 2 for changes in land use depicted based on the false colour satellite imagery from the various platforms for the dates 1984, 2006 and 2019.

The landform and soils we find are typically those that are derived from the basement rock complex, which consist of hard crystalline and metamorphic rocks (granite and gneisses), on which soils have developed in-situ. The landscape is classified as undulating to rolling with slope classes ranging from ‘flat to almost flat’ to ‘sloping’. The elevation ranges from around 80 masl to 170 masl, but with the relief intensity fairly low because of the longer slopes and fairly low drainage density, because of which we see little inversion of the slope. The higher elevation area runs from north to south in the middle of the terrain and the land is loping down to the west and east at which extremities we also find the rivers and major streams. At the higher elevation we find large rock outcrops. Smaller rock outcrop can also be found in the other part of the area. The soils developed on this type of rock are generally of lighter texture, and the soil depth generally depends on the amount of erosion that has occurred in the past, which will depend on the land cover and slope.




*Map 1. Map of the Gambari Forest Reserve Area of Interest, with the boundary of the study area, road and tracks, drainage network and locations of the sampling points*

**Access to the terrain, Road and Tracks**

The Gambari ADZ can be accessed from the east through the Ijebu-Ibadan road which is tarmacked. From the north access is provided through an improved all-weather road, which branches of from the A1 and runs through the teak plantation. From the west the AoI cannot be reached. There are some roads that branch of the A1 but they stop at the river and do not cross over to the other side. The western part of the AoI can currently only be reached from the south. There is a road that branches off from the express way and that has a bridge to cross the river. This is an improved all-weather road, but the condition (of the bridge) is poor and will not support heavy duty trucks. From this road a number of roads, branches of into the western section of the area of interest. These are all improved or at least all-weather roads. There are two access roads to the south-eastern section of the terrain, also branching off from the southern bypass. But these are unimproved and probably not all-weather condition.

The different sections of the ADZ can only be reached from outside. Inside the AoI the connection is poor, and you cannot reach the western section from the east or connect from north to south across the eastern part. Within the eastern part we only find tracks and paths. In as far as you are in the teak plantation the roads have two tracks but are of very poor condition and require a 4WD to traverse, but it is still is very difficult to reach the inner sections. Also, there are some streams to cross that may cause difficulties during some period in the rainy seasons. Inside the area, once you have left the teak plantation there are only single-track paths or trails/paths.

The whole western section is having a better road infrastructure. The area is well serviced by a network of unimproved roads that however seem to be all-weather roads. Furthermore, there is a fine network of tracks that seem to be in good condition. Only the extreme western part seems to be less serviced and seems to be more difficult to access. The road network is mapped in Map 1.

In conclusion, major efforts are required to improve the access to the terrain, and that include the access roads and the internal road infrastructure. Hereby the whole eastern section is off higher concern.

**Water resources and drainage network**

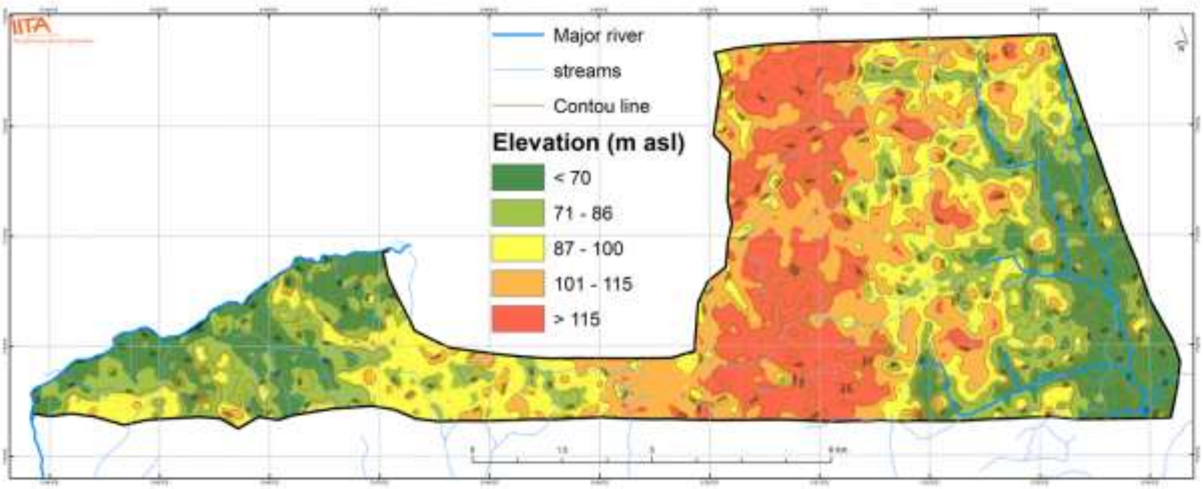
The drainage divide runs from north to south in the middle of the AoI. East of this divide we have some few first order streams that drain in easterly direction and where they join other streams to form secondary and tertiary streams and flow in southerly direction only after they reach the valley bottom and that is within the teak plantation. All the streams in the upland area are seasonal and do not carry any water during the dry season. The stream in the valley bottom is a permanent stream, but because it drains only a small catchment it does not carry much water.

The same applies for the western section of the AoI, only we have a fairly small strip of land that stretches for east to west. We have first order and second order streams which are also seasonal and that will also carry a limited amount of water in the rainy season. But these drains into a larger river that runs at the border of the AoI and that can provide for an important source of water. Ground water could be a source of water, but likely to be found at depth beyond 30m. It should be investigated further.

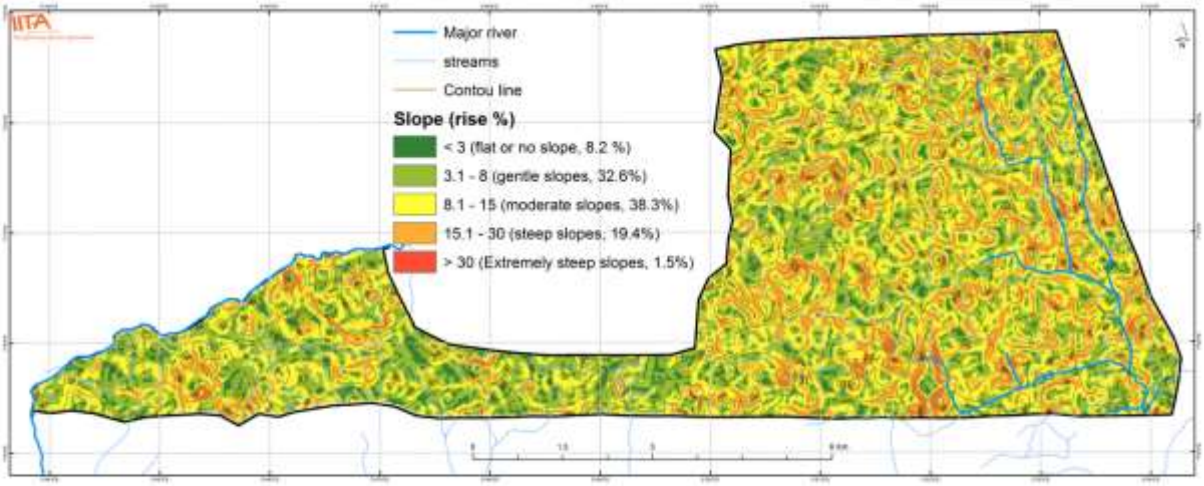
**Topography**

The elevation ranges from around 80 to 170 masl, with the highest elevation found in the centre of the AoI running from north to south. In this landscape developed on the basement complex rocks we find a landform that is characterised by hills and an undulating to rolling landform with a radial pattern in the direction of the slopes (slopes are diverging). The shape of the slopes in this eastern section is convex, and the length may be up to 750 meters but is generally less. We see very little flat terrain and most of the land is sloping with slopes ranging from almost flat on the upper slopes to sloping and even to moderately steep slopes on the mid- and foot slopes (see Map 3 for slope steepness, Figure 1 for the profile of the elevation in the south to north-east transect and Figure 2 for the elevation profile from the far western end to the far eastern end in the southern region of the AoI). The section from 3,500m to 9,000m in Figure 1 (the section referring to the eastern part of the AoI) we see that on probably more than half of the area we find slopes that are considered too steep for mechanised agriculture (slopes more than around 8%)

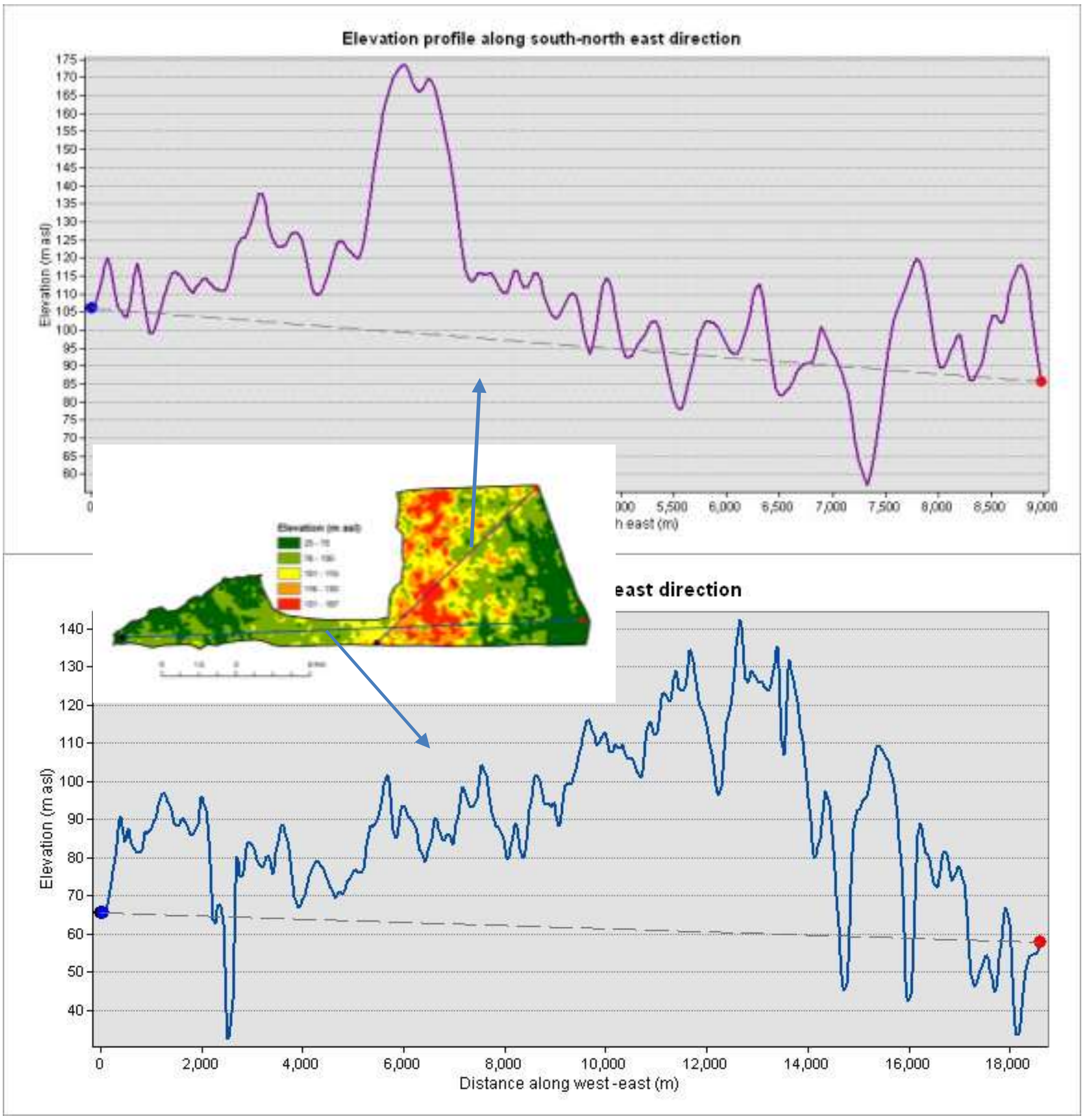
The situation in the western section is different, this side is part of a more developed and broader valley system. The landscape is undulating, with more 'gently sloping' terrain. We see less variation in the elevation class on short distance and the slope map (Map 3) shows relatively more green colours. The elevation profile for this section (Figure 2) also shows less dissected terrain and lower relief intensity. Though, also in this section we find, little really flat terrain. We do see larger contiguous areas that are flat to gently sloping and that lend themselves well for mechanised agriculture from that perspective. We see from Figure 2 that the slopes for the western part (from 0 to 12 km along the transect) that the slope steepness is within the acceptable range, apart from the slope along the one deeply incised stream. We observe that the eastern section is strongly dissected by streams that have carved themselves deep into the landscape.



*Map 2. Elevation in meters above sea level and contour lines*




*Map 3 Slope steepness classes (rise in %) and contour lines*




*Figures 1 & 2 Elevation profiles along the south to north-east transect and along the west to* *east transect positioned as indicated in the overview map.*

**Land use and Land cover and rock outcrop**

Most of the land has been cleared and is used for cultivation. For the most part this seems to have occurred in the last 10 to 15 years (See Maps 4, 5). As a result, we see trees still dispersed in the field and we find stumps of trees that have been cut but the stumps not removed, especially in the more recently cleared land. These are often more the bigger trees, with a diameter of the stem that may measure up to 35cm. Tree density (including stumps) in this area may amount to 125 trees per ha and higher. That is more than one tree per 100 $m^2$ and means that the land needs to be cleared to allow mechanised farming operations, even though it looks like open maize or cassava field.

There are a few large patches of the forest vegetation remaining. It is not clear whether these are waiting to be cleared, or whether there is a special reason why these have not been cleared. The forest patch in the eastern lowland area seems to have been cultivated in 1984 (Map 4) but has been reforested in the subsequent period probably because it is too wet and risk of flooding is too high. We find dense tree cover (from 500 to up to 3000 trees per ha and more) and may reach a height of around 25m. In the northern part we find heavy logged-over forest. Otherwise there are smaller patches of densely wooded vegetation found within the area. These sometimes relate to teak woodlots or otherwise wooded areas that remain from the previous forest because of the poor soil conditions.

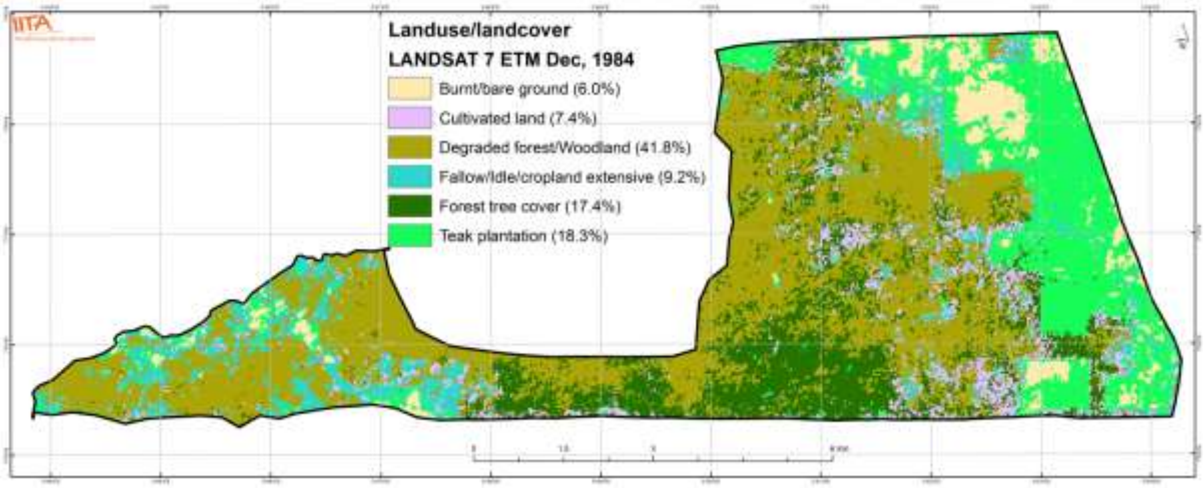
In the western section we also find an extensive area of secondary forest, riparian forest and thicket. We find occasional big trees of 60 m height, but generally more in the order of 10 to 25 meters, with varying tree density and with thick undergrowth. The soils are well drained and there do not seem to be major constraints for agricultural use.

The cultivated land is mainly used for maize and other grains and cassava. But we find a variety of crops like potatoes, cocoyam, plantain and other. We find people have settled in the area, with some individual homesteads here and there, but we have not encountered any settlements.

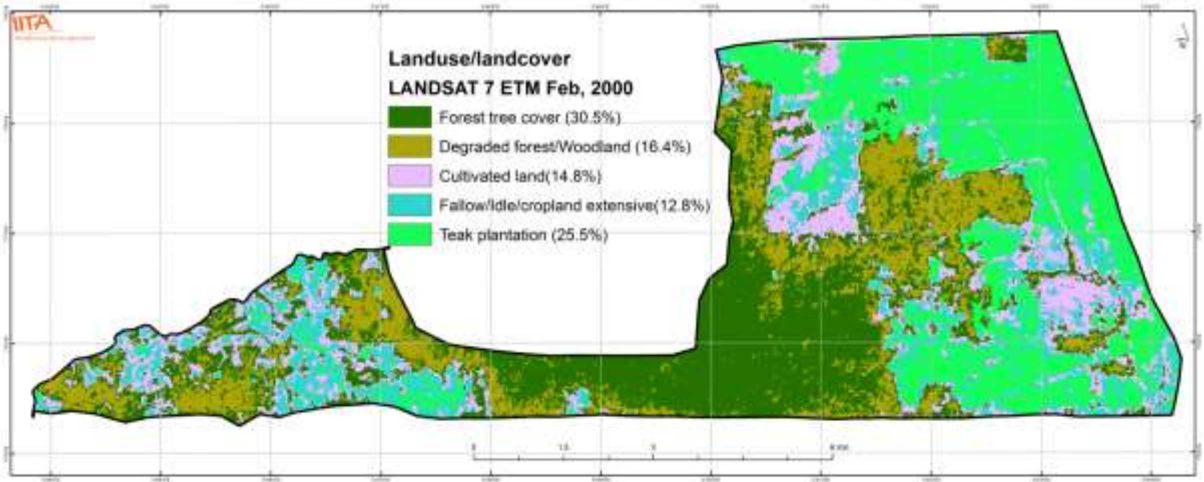
**Soil characteristics**

## Soil depth and texture

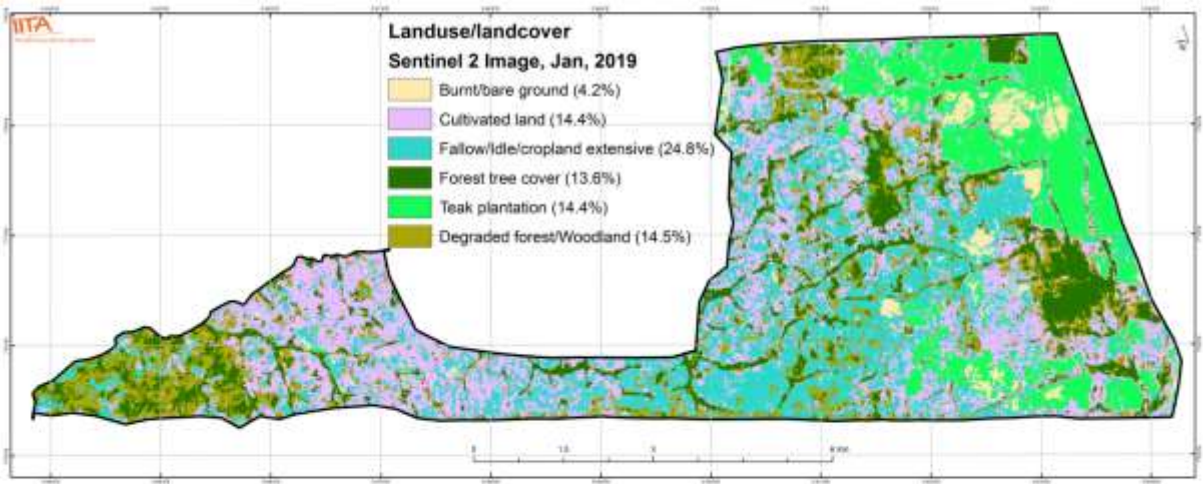
The soils of Onigambari ADZ generally fall within four (4) textural classes, namely: sandy clay, sandy clay loam, sandy loam and clay loam. Quite a number of soils have a textural composition that puts them on the transition between the loamy sand and sandy loam textural classes. In general, the soils are quite sandy. Soil texture is determined for the soil after sieving; in which soil particles larger than 2 mm (e.g. gravel and other coarse fragments) have been removed. We have not determined the gravel content for all soil samples, but for those we did all had gravel to a varying degree. On average the gravel content was around 20%. This implies that the soils effectively have a lighter texture than indicated by the analysis and that for the interpretation of the data in as far as hydrological properties are concerned (i.e. water holding capacity, infiltration rate and drainage) we need to take the effective lower clay and silt percentage into account. A gravel content of 20% is often taken as the limit for which arable cropping is suitable. Based on the current results of the particle size analysis, about 64% of the AoI falls outside the desired soil texture classes and this will only be higher if we correct for the gravel content. The gravel content will be associated with the soil depth. The shallower the soil, the higher the gravel content is likely to be. In the western part of the AoI, deep soils with no rooting restrictions (90 -150 cm depth) occupies about 64% of the area, 27% has moderately deep soils (from 50 cm - 90 cm), and the remaining 9% is either shallow or very shallow.




*Map 4: Map of land use and land cover as at 1984*




*Map 5: Map of land use and land cover as at 2000*




*Map 6: Map of land use and land cover as at 2019*

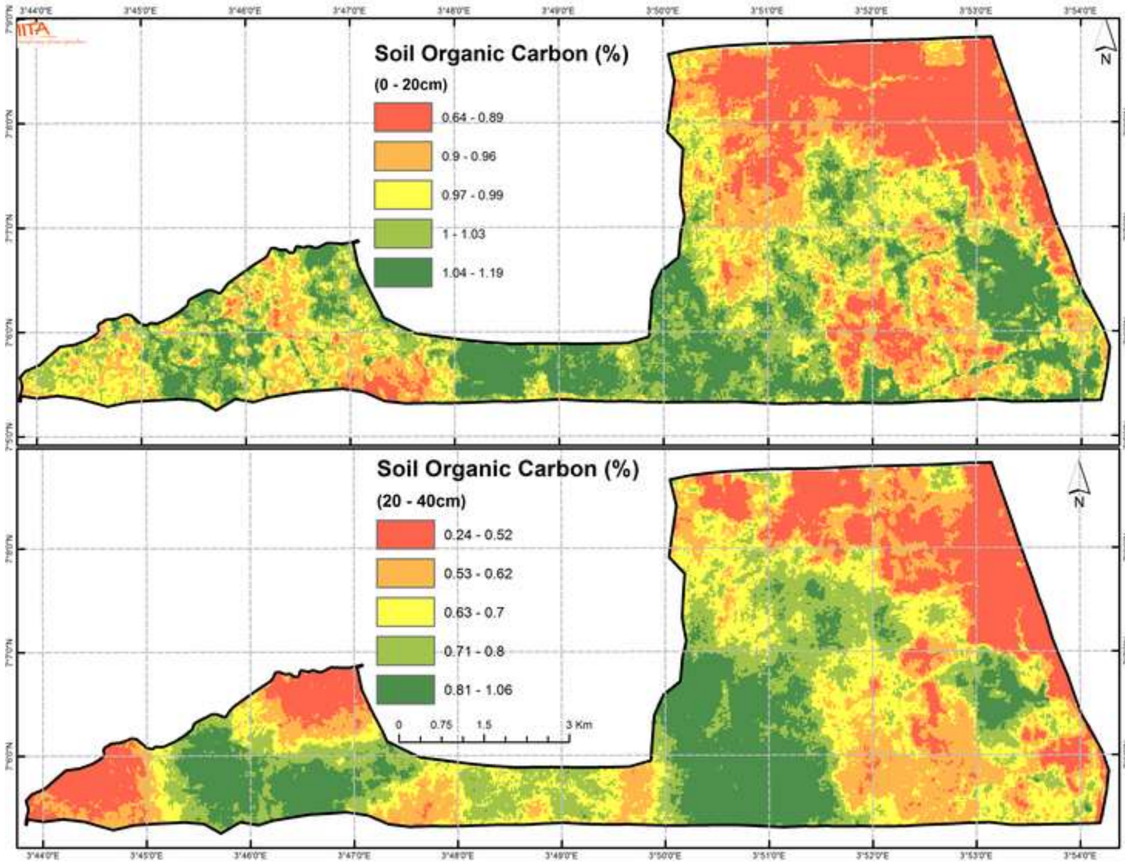
For the Eastern part, 17% of the area is very shallow (less than 25 cm) and 22% is classified as shallow (25 cm < x <50 cm). Besides rooting depth restrictions, hydrological constraints due to the high gravel content will play major role in the eastern part of the AoI. Eighty-eight (88) percent of the AoI does not have stones on the soil surface (or in the soil profile), while 12% contains stones to some degree that may interfere with the mechanised operations, especially land preparation. Six (6) % is classified as 'stony' [0.01 – 0.1% soil cover] and 6% is classified as 'very stony' [0.1 -3% soil cover]) with the size of the stones classified as gravel (<8cm in diameter) mainly.

### Soil organic carbon and soil fertility aspects

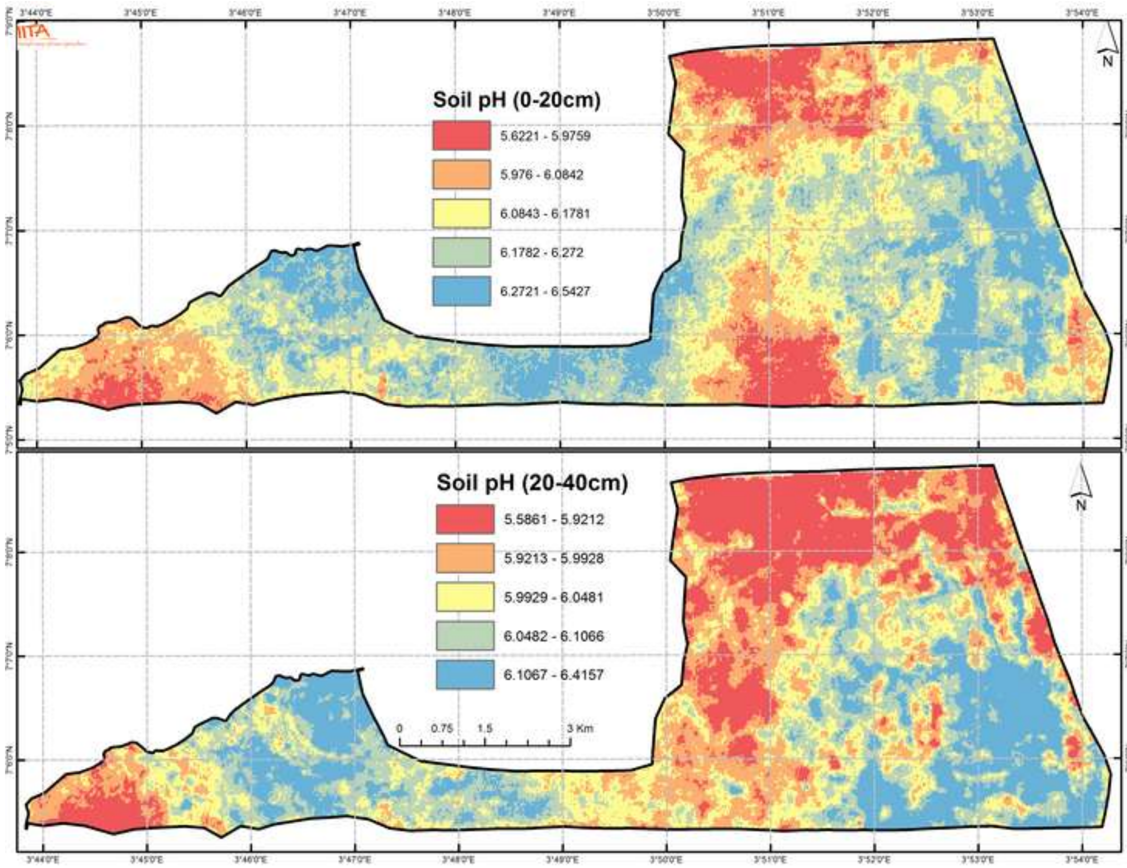
The soil contains considerable amounts of gravel and the gravel percentage is used for correction of the soil nutrient concentrations to better reflect the effective amounts of plant nutrients available for uptake. The rating of sufficiency levels is based on these corrected or adjusted values.

The soil organic carbon is an important soil component and quality indicator as it supplies many plant nutrients and regulates many other soil properties. In the AoI, 38% has very low soil organic carbon percentage, 46% has low, 14% has optimum and 2% of the AoI has high soil organic carbon (See Map 7). The capacity of the soil to hold nutrients (CEC), which for this type of soils is strongly related to the soil organic carbon content, is considered critically low in 88% of the cases with the remaining 12% having low ability to hold plant nutrients. The soil reaction (pH) varies from optimum to neutral in 64% and 36% of the cases respectively (Map 8). Though, the neutral pH being slightly above the optimum level but is still suitable for most agricultural crops without the need for soil amendment. There are no particular constraints related to soil acidity. Nitrogen, a major nutrient for vegetative growth is limiting in the AoI.

Available phosphorus is critically low in 96% of the AoI. Potassium is critically low in 68% but optimum in only 3% of the AoI. Most of the soil micronutrients are limiting with the exception of iron which is at optimum level in 68% of the AoI (See maps 9 and 10). The low soil nutrient status of the AoI can be mediated with fertilizer applications and sound agronomic practices. Tables and maps of soil nutrients characteristics are included in the Appendix 1, 2 and 3.




*Map 7. Spatial variation in soil organic carbon percentage within the AoI*




*Map 8. Distribution of soil pH values within the AoI*

## Land use zoning and suitability assessment

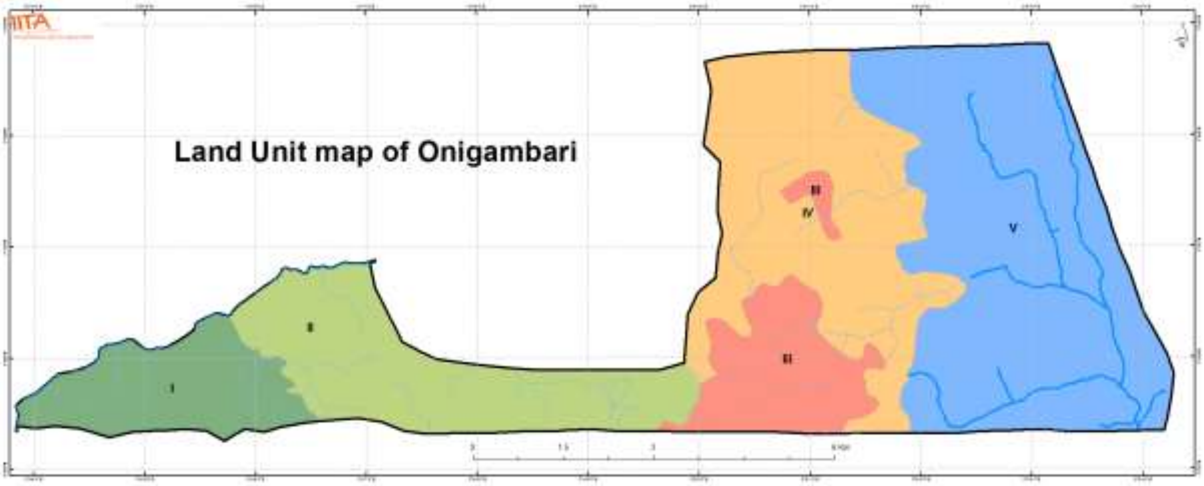
Land units have been defined based on the criteria mentioned above that allows for an integrated evaluation of the suitability for commercial agricultural use. The land units are described in terms of the land physiographic characteristics, land use and the various soil characteristics, but also in terms of the access, for example.

**Land unit 1**

Land unit 1 is located at extreme end of the western section of the AoI (see map 11). The land is gently sloping to sloping and not very dissected, which makes is suitable for mechanised, larger scale farming operations. The land use is not used for agriculture, but rather we find secondary forest, riparian forest and thicket and land clearing will require heavy machinery. Access to the area is limited with a low density of tracks within the area. We find deep, in some case moderately deep (no rooting depth restrictions), well drained soils. These are light textured soil, predominantly of loamy sand texture and therefore these soils are outside the range of desired textural classes. Soil organic carbon percentage rates low but relatively high compared to other parts of the AoI. The pH rates as moderately acid. Soil fertility status is poor, and will require attention for management of macro and micro nutrients especially for annual, high nutrient demanding crops.

**Land unit 2**

Land unit 2 is a section in the western part of the AoI that ranges between 80 and 110 meters above sea level (see map 11). The land is gently sloping to sloping in some parts and not dissected by streams (less relief intensity compared to the other land units), which make it suitable for mechanised farming operations, thought slope length may be limiting in some cases. This land has been cleared for (subsistence) agricultural use around the year 2000. We find with trees dispersed in the landscape and some patches of secondary vegetation. The access to this area is relatively good and there is a dense network of dirt roads and tracks within the area. The soils are moderately deep to deep, with higher incidence of moderately deep soils compared to land unit 1, but do not present any major restrictions to rooting depth. The texture is predominantly loamy sand and sandy loam, with higher incidence of sandy loam soils compared to land unit 1. Sandy loam has a higher clay percentage and is a more desirable texture class than loamy sand, with better water holding capacity, but still considered marginal. The pH is slightly acid and does not present any constraint for crop production. Soil organic carbon is relatively high for this area, but still rated as low. Soil fertility status is poor.




*Map 11. Land management unit*

**Land unit 3.**

Land unit 3 is the area around the hill tops in the south-central part of the AoI. Here we find a major rock outcrop. The elevation ranges from around 100 m to 170m on top of the rock. The area around the rock may vary from 100m to 135m with slope classes ranging from gently sloping to moderately steep slopes, which makes it impractical for mechanized farming on large scale. This land was still densely vegetated in 2000 but has been cleared since. We find an open agricultural landscape of subsistence farming, with a woody cover of less than 4% and occasionally higher. Access to this area is difficult and there are not many dirt roads within the area. Soils seem to have generally higher clay content and majority of the soil classify as loam soils, with others as sandy loam and loamy sand. The loamy sand falls outside the desired textural range, and that may also apply to the sandy loams, depending on the specific clay, silt and sand content. The loam soils are entirely within the desired texture range. The incidence of shallow soils (depth between approx. 20 cm to approx. 65cm) is higher than the previous units. So, we might find rooting depth restrictions in places, maybe even up to 15% - 20% of the area. Water resources are limited.

**Land unit 4.**

Land unit 4 is the higher elevated area ranging from around 75masl to 140masl that stretches to the north and north-east of land unit 3. It has partly the same characteristics of land unit 3 but also includes the mid-altitude range in the landscape. The relief intensity is high and slope classes range from almost flat to even steep slopes and that would not qualify for mechanised agriculture at larger scale. We do find parts in the terrain where the landscape is undulating with gentle slopes and slopes of considerable length that would allow for mechanised operations. The land was already partly deforested in 2000, but we still find larger parts of (degraded) forest remaining and there are areas of active deforestation. The woody cover in the agricultural land may vary from absent to some 15% and with tree densities varying from 10 to a few hundred per ha. We find woodlots with teak amongst others), patches of dense wooded vegetation and thicket with varying tree density. The recently converted land often has tree stumps remaining in the field. Access to the area is difficult and would require major improvements to the access roads. Within this land unit we find a relatively extensive network of trails and tracks, but these are all single track and not motorable.

The soil textures are classified as loamy sand, sandy loam, loam and as sandy clay loam in particular cases. We find a higher incidence of very shallow (<20cm) and shallow soils (20cm<depth<50cm) that represent rooting depth restrictions and that may also interfere with mechanised operations. The incidence may be as high as one third. Most of the land with (very) shallow soils will have been left idle, or under some kind of tree crop. Soil organic carbon is relatively low for the larger part of this unit, but still qualifies as low with SOC% ranging from 0.6 to 1.0%. The pH qualifies as optimum with values ranging between 5.6 and 6.5.

**Land unit 5**

Land unit 5 coincides with the lower elevation area in the east of the AoI and the bottom of the small drainage basin where the stream and small rivers flow. The elevation may range from 60 masl to 120 masl with the latter corresponding to the hill tops. Streams have carved in relatively deep because of which we find changes in elevation of 60m or more over relative short distances (< 500m). Consequently, we find moderately steep to steep slopes, with here and there some more gently sloping area. In this unit we find the teak plantation. The teak plantation is very old but use mainly for harvesting poles. The trees are 15 to 20 meters high, but the old stem on which they grow may be up to 60cm in diameter, indicating that there will be a quite extensive root system. We also find a large area of riverine forest. We find very little of the field pattern that we see in the other units and conclude that this land is not used for agricultural purposes. We have little information on the soil texture, but depth restrictions of 20, 40 and 50 cm are regularly mentioned. The area seems to be very wet, with drainage classes varying from very poor, to imperfectly drain. The SOC percentage is relatively low under the teak plantation, but relatively high under the riparian forest and the pH seems relatively high and qualifies as optimum.

## CONCLUSIONS and RECOMMENDATIONS

In summary, there are some major constraints for the development of this area and to make it suitable for commercial agricultural use. In the end it is about weighing the options for the commercial exploitation of the land, considering the conditions and investment required to amend the constraints to make the land suitable of the potential and intended use. To determine the most suitable land use options requires further consultations of the domain experts. At this point we have indicated and mapped the constraints and we give a general recommendation as to the type of land use that can be considered.

Access to this land is constrained and will require major improvements to the service roads. Improvements of the access roads are required as well as of the road infrastructure within the area. Most of the land that is suitable for agricultural use has been cleared. There may be secondary regrowth and shrubs and bushes, but it will not require heavy machinery for land clearing. There are parts of the area that are still forested or have dense woody vegetation that will require heavier machinery. Most of the land that is still covered with dense woody vegetation and the teak plantation is not considered suitable as arable land.

The topography is such that large scale mechanized crop production is excluded, but otherwise there do not seem to be any major constraints for mechanized operations. For slope class 1 'Flat to almost flat' there are no impediments. When the surface of the land is irregular it may require levelling, but that seems hardly to be the case. For slope class 2 'Gently sloping land' there is also no impediment, though light measures for soil conservation may be required (e.g. ploughing along the contour lines to limit runoff). However, because of the light texture this risk is still limited. For slope class 3 'Moderately steep slopes' there are still no major restriction for tractor operation, though it becomes less practical and less efficient. More far-reaching measures will need to be taken to control erosion, like strip cropping or use of vegetation strips or terracing. The possibilities for terracing in this case may be limited because of the relative shallow soils. The possibilities for the steeper slopes (slope class 4) maybe limited for this reason.

The soil condition requires attention. Where soil depth is a constraint little can be done. The light texture, sandy soils in combination with the low soil organic carbon content, requires careful management of the soil to increase the soil organic matter and herewith also the fertility of the soil. It makes this type of soil less suitable for high demanding crops like maize. The soil fertility is generally low but can be corrected with fertilizer applications but will still require sound agronomic practices to make sure that there is proper response to the fertilizer application.

Of the various land units that have been identified, Land Unit II has the most favourable conditions, and this refers to the access to the land, the topography, land use and land cover, the water resources possibly and soil condition. On the gently sloping to moderately steep lands soil conservations measures need to be considered, but this will not be very far-reaching. The area seems suitable for arable cropping, for grain crops and root and tubers, but attention should be given proper agronomic practice in relation to the relatively low soil fertility status and light texture of the soil (susceptibility to drought). These conditions make the land more suitable for less demanding crops like sorghum and millet and cassava as root and tuber crop. Grain legumes would also be an option and would be advised from the perspective of soil fertility management. The light texture makes the soil suitable for horticulture crops that is cultivated in the open, but attention should be given the possibilities for irrigation, which are likely to be limited. This area should be given priority if further land development is considered.

Land unit I seems to have the same potential as land unit II, with the difference that it requires clearing of the forest and dense woody vegetation. We have not investigated whether there are valuable tree species in this area. This will require considerable investment and it should be investigated whether the investment will pay off.

Land unit III and IV are less suitable for arable cropping. The steeper slopes require measures to control erosion and the occurrence of shallow soils limits the possibilities for terracing. There may be patches of land that are suitable, but these are not very extensive. The low soil fertility is a further limitation. Under these conditions a tree crop would likely be more suitable solution. Cashew with its lateral root system would probably do well. Citrus and other tree crops could probably be considered as could teak.

Land unit V is considered marginally suitable. It can be considered for the cultivation of oil palm where we have wetter conditions and where the shallow ground water table may help to satisfy the water requirements of oil palm in the dry season. Otherwise, perennial crops that can stand shallow groundwater tables could be considered. Banana and plantain also require moist and humid conditions but can’t stand wet feet and the ground water table should be a 50cm at least. This may require artificial drainage, and otherwise careful selection of the sites will be needed, because the sandy texture of the soils will not hold much moisture.

## Appendix 1: Basic soil quality indicators for some of the AoI

| Lat | long | ID | sand | clay | silt | Texture | pH ($H_2O$) | OC (%) | ECEC (cmol+/kg) |
|---|---|---|---|---|---|---|---|---|---|
| 7.090913 | 3.761087 | A5, 0-20 | 51 | 34 | 15 | sandy clay loam | 5.5 | 1.11 | 5.11 |
| 7.090913 | 3.761087 | A5, 20-40 | 49 | 40 | 11 | sandy clay | 5.7 | 0.99 | 4.69 |
| 7.090875 | 3.795057 | A10, 0-20 | 81 | 12 | 7 | sandy loam | 5.9 | 0.76 | 4.87 |
| 7.090767 | 3.829148 | A15, 0-20 | 69 | 16 | 15 | sandy loam | 5.8 | 1.36 | 1.99 |
| 7.09085 | 3.8629 | A20, 0-20 | 57 | 20 | 23 | sandy clay loam | 6.0 | 1.10 | 4.70 |
| 7.09085 | 3.8629 | A20, 20-40 | 61 | 20 | 19 | sandy clay loam | 6.1 | 0.98 | 3.41 |
| 7.090683 | 3.896883 | A25, 0-20 | 67 | 18 | 15 | sandy loam | 6.2 | 0.41 | 6.55 |
| 7.097618 | 3.761143 | B4, 0-20 | 75 | 16 | 9 | sandy loam | 6.0 | 0.56 | 3.01 |
| 7.097643 | 3.795058 | B9, 0-20 | 69 | 18 | 13 | sandy loam | 6.2 | 1.59 | 7.53 |
| 7.097643 | 3.795058 | B9, 20-40 | 81 | 12 | 7 | sandy loam | 6.2 | 0.58 | 6.29 |
| 7.097508 | 3.829157 | B14, 0-20 | 65 | 16 | 19 | sandy loam | 6.2 | 1.05 | 4.41 |
| 7.097533 | 3.86295 | B19, 0-20 | 65 | 16 | 19 | sandy loam | 6.3 | 1.09 | 3.11 |
| 7.097467 | 3.896917 | B24, 0-20 | 33 | 32 | 35 | clay loam | 6.4 | 2.52 | 5.97 |
| 7.104428 | 3.78147 | C4, 0-20 | 81 | 10 | 9 | sandy loam | 6.2 | 0.61 | 10.55 |
| 7.104428 | 3.78147 | C4, 20-40 | 81 | 10 | 9 | sandy loam | 6.3 | 0.55 | 5.34 |
| 7.104283 | 3.87655 | C11, 0-20 | 79 | 12 | 9 | sandy loam | 6.4 | 0.96 | 4.65 |
| 7.11124 | 3.78148 | D2, 0-20 | 81 | 11 | 8 | sandy loam | 6.7 | 1.04 | 2.70 |
| 7.11124 | 3.78148 | D2, 20-40 | 81 | 12 | 7 | sandy loam | 6.8 | 0.51 | 4.02 |
| 7.117874 | 3.849442 | F2, 0-20 | 47 | 36 | 17 | sandy clay | 6.8 | 2.20 | 3.00 |
| 7.117833 | 3.883367 | F7, 0-20 | 65 | 22 | 13 | sandy clay loam | 7.0 | 0.90 | 3.35 |
| 7.117833 | 3.883367 | F7, 20-40 | 77 | 16 | 7 | sandy loam | 7.0 | 0.53 | 7.18 |
| 7.12465 | 3.86979 | G5, 0-20 | 67 | 20 | 13 | sandy clay loam | 6.8 | 1.21 | 4.49 |
| 7.13146 | 3.85622 | H4, 0-20 | 66 | 19 | 14 | sandy loam | 6.9 | 1.13 | 3.94 |
| 7.14505 | 3.842667 | J1, 0-20 | 64 | 23 | 12 | sandy clay loam | 6.8 | 1.84 | 2.50 |
| 7.14505 | 3.842667 | J1, 20-40 | 66 | 23 | 10 | sandy clay loam | 6.9 | 0.55 | 2.91 |

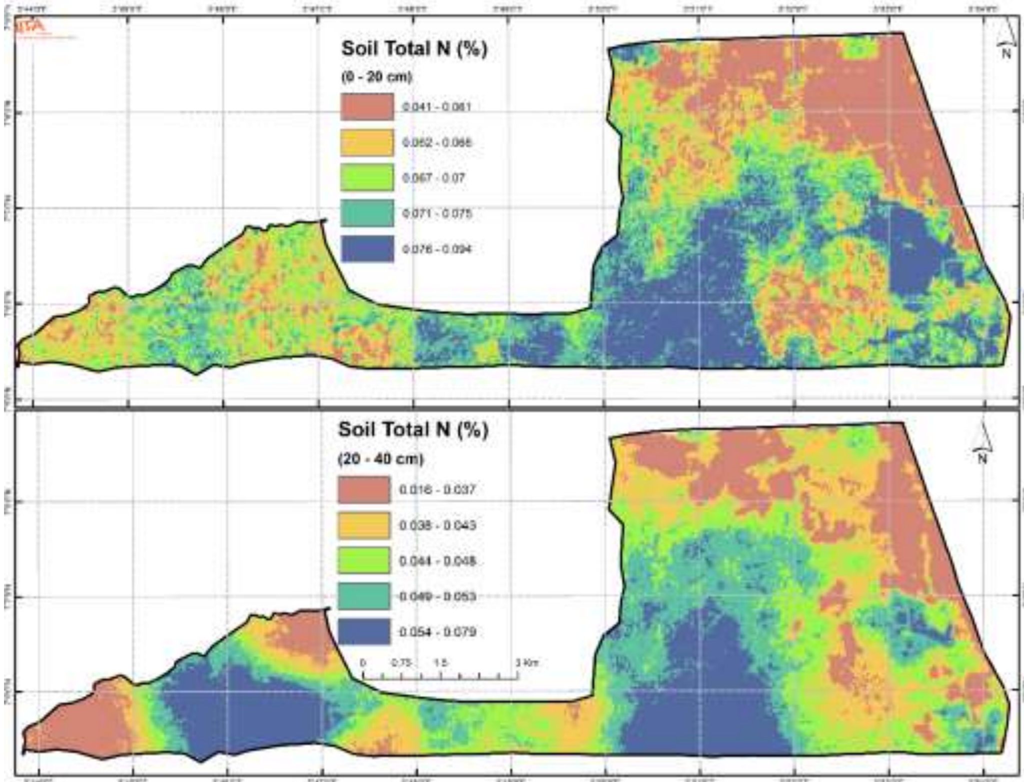
## Appendix 2: Nitrogen, phosphorus and Potassium concentrations of some of the soils

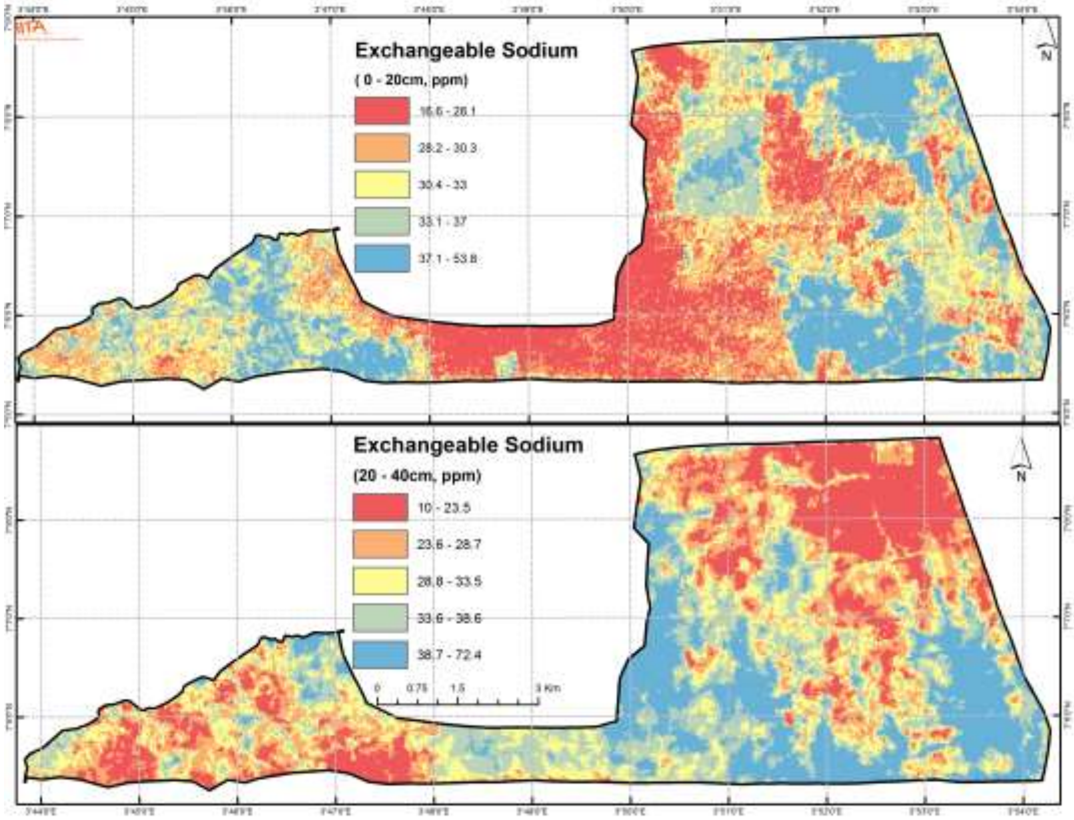
| Lat | long | ID | N (%) | Meh P (ppm) | K (cmol+/kg) |
|---|---|---|---|---|---|
| 7.090913 | 3.761087 | A5, 0-20 | 0.174 | 4.67 | 0.07 |
| 7.090913 | 3.761087 | A5, 20-40 | 0.143 | 2.05 | 0.04 |
| 7.090875 | 3.795057 | A10, 0-20 | 0.080 | 11.65 | 0.02 |
| 7.090767 | 3.829148 | A15, 0-20 | 0.138 | 2.28 | 0.08 |
| 7.09085 | 3.8629 | A20, 0-20 | 0.190 | 4.87 | 0.13 |
| 7.09085 | 3.8629 | A20, 20-40 | 0.102 | 1.24 | 0.05 |
| 7.090683 | 3.896883 | A25, 0-20 | 0.144 | 2.28 | 0.22 |
| 7.097618 | 3.761143 | B4, 0-20 | 0.120 | 2.05 | 0.07 |
| 7.097643 | 3.795058 | B9, 0-20 | 0.167 | 2.05 | 0.25 |
| 7.097643 | 3.795058 | B9, 20-40 | 0.062 | 1.28 | 0.10 |
| 7.097508 | 3.829157 | B14, 0-20 | 0.084 | 13.61 | 0.17 |
| 7.097533 | 3.86295 | B19, 0-20 | 0.149 | 2.67 | 0.07 |
| 7.097467 | 3.896917 | B24, 0-20 | 0.238 | 3.87 | 0.08 |
| 7.104428 | 3.78147 | C4, 0-20 | 0.130 | 7.93 | 0.05 |
| 7.104428 | 3.78147 | C4, 20-40 | 0.056 | 2.44 | 0.11 |
| 7.104283 | 3.87655 | C11, 0-20 | 0.132 | 4.20 | 0.08 |
| 7.11124 | 3.78148 | D2, 0-20 | 0.109 | 7.33 | 0.11 |
| 7.11124 | 3.78148 | D2, 20-40 | 0.056 | 3.03 | 0.09 |
| 7.117874 | 3.849442 | F2, 0-20 | 0.245 | 8.45 | 0.04 |
| 7.117833 | 3.883367 | F7, 0-20 | 0.193 | 1.09 | 0.19 |
| 7.117833 | 3.883367 | F7, 20-40 | 0.067 | 1.67 | 0.11 |
| 7.12465 | 3.86979 | G5, 0-20 | 0.122 | 8.31 | 0.09 |
| 7.13146 | 3.85622 | H4, 0-20 | 0.100 | 1.28 | 0.10 |
| 7.14505 | 3.842667 | J1, 0-20 | 0.189 | 2.28 | 0.03 |
| 7.14505 | 3.842667 | J1, 20-40 | 0.062 | 1.87 | 0.07 |

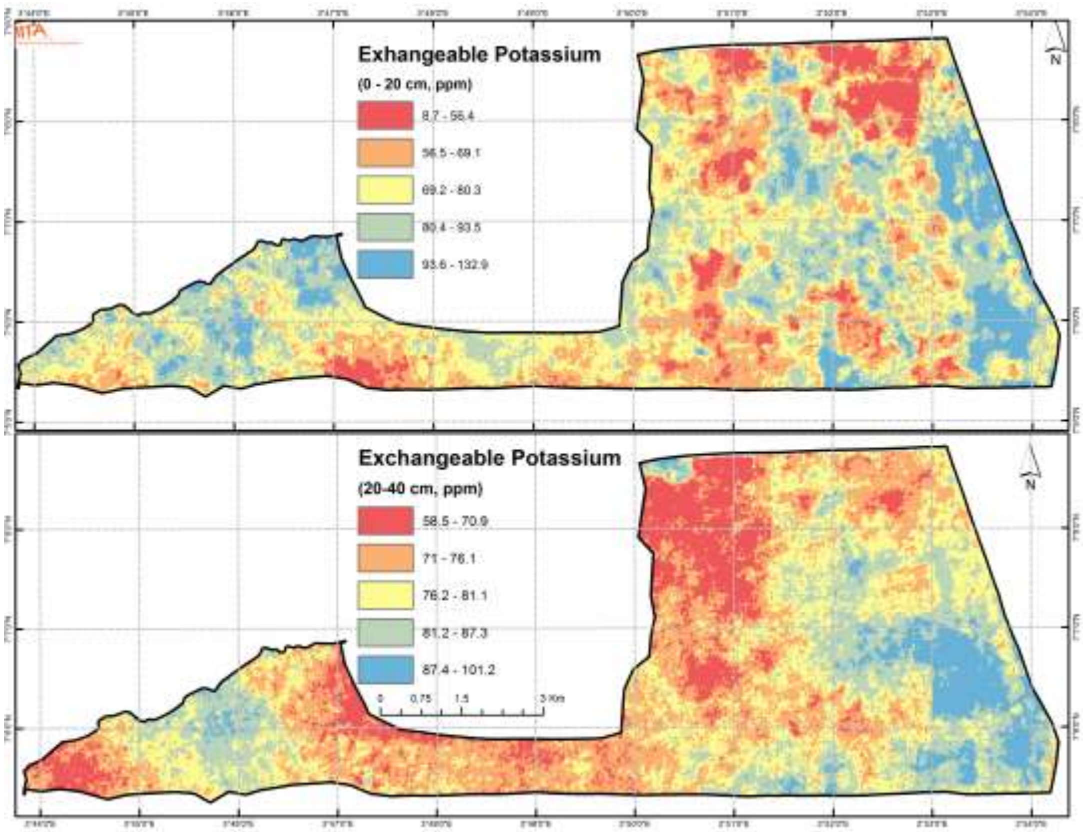
## Appendix 3: Other major essential nutrients and micronutrients content of some of the soils

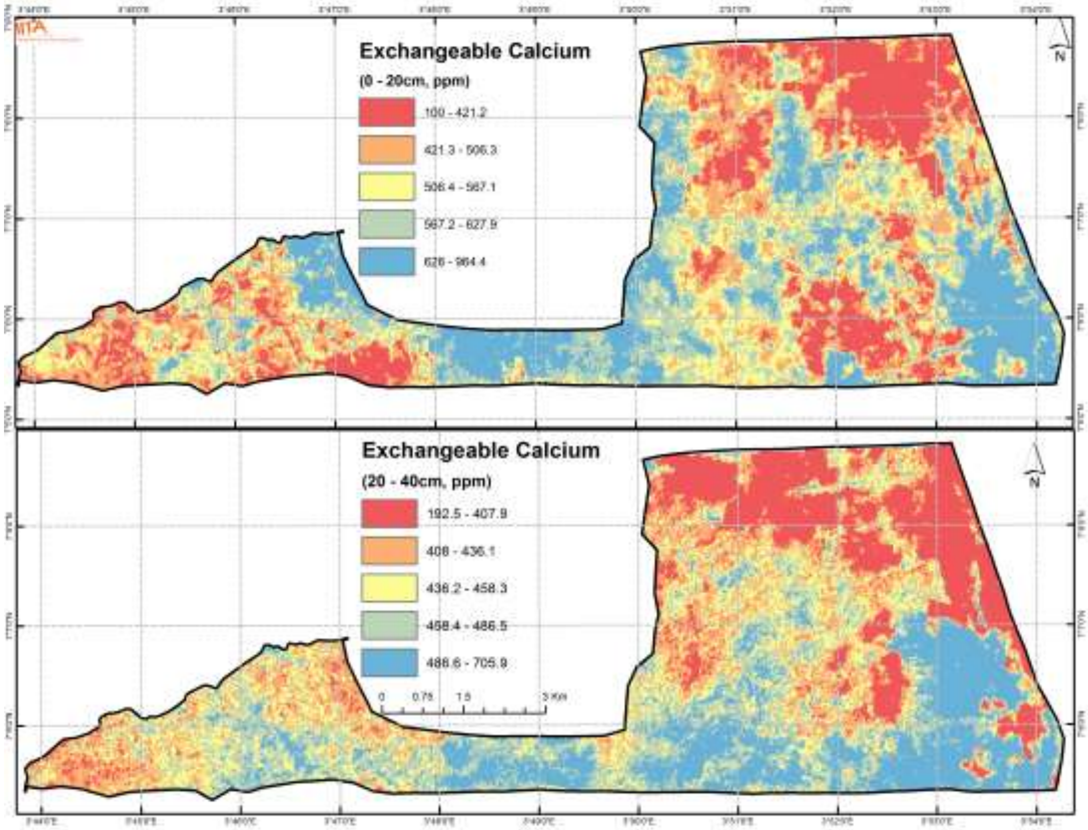
| Lat | long | ID | Ca (cmol+/kg) | Mg (cmol+/kg) | Na (cmol+/kg) | Zn (mg/kg) | Cu (mg/kg) | Mn (mg/kg) | Fe (mg/kg) |
|---|---|---|---|---|---|---|---|---|---|
| 7.090913 | 3.761087 | A5, 0-20 | 3.73 | 1.30 | 0.03 | 5.77 | 3.13 | 210 | 173 |
| 7.090913 | 3.761087 | A5, 20-40 | 4.16 | 0.47 | 0.03 | 4.07 | 1.56 | 127 | 37 |
| 7.090875 | 3.795057 | A10, 0-20 | 3.78 | 1.03 | 0.05 | 3.62 | 2.19 | 153 | 39 |
| 7.090767 | 3.829148 | A15, 0-20 | 1.53 | 0.36 | 0.04 | 1.80 | 0.62 | 81 | 49 |
| 7.09085 | 3.8629 | A20, 0-20 | 3.74 | 0.82 | 0.04 | 7.25 | 2.81 | 201 | 118 |
| 7.09085 | 3.8629 | A20, 20-40 | 2.59 | 0.74 | 0.04 | 1.91 | 1.25 | 106 | 60 |
| 7.090683 | 3.896883 | A25, 0-20 | 5.52 | 0.81 | 0.04 | 5.21 | 1.25 | 141 | 41 |
| 7.097618 | 3.761143 | B4, 0-20 | 2.25 | 0.68 | 0.03 | 3.62 | 0.94 | 121 | 41 |
| 7.097643 | 3.795058 | B9, 0-20 | 6.36 | 1.03 | 0.03 | 19.75 | 6.56 | 251 | 156 |
| 7.097643 | 3.795058 | B9, 20-40 | 5.22 | 0.92 | 0.05 | 4.07 | 0.94 | 120 | 40 |
| 7.097508 | 3.829157 | B14, 0-20 | 3.41 | 0.79 | 0.06 | 4.41 | 1.56 | 143 | 40 |
| 7.097533 | 3.86295 | B19, 0-20 | 2.59 | 0.44 | 0.02 | 1.57 | 0.94 | 130 | 46 |
| 7.097467 | 3.896917 | B24, 0-20 | 5.02 | 0.86 | 0.03 | 8.16 | 3.13 | 249 | 152 |
| 7.104428 | 3.78147 | C4, 0-20 | 7.59 | 2.85 | 0.06 | 4.52 | 1.56 | 145 | 94 |
| 7.104428 | 3.78147 | C4, 20-40 | 3.81 | 1.37 | 0.05 | 2.82 | 2.19 | 120.60 | 38 |
| 7.104283 | 3.87655 | C11, 0-20 | 3.70 | 0.85 | 0.03 | 6.57 | 0.31 | 100 | 43 |
| 7.11124 | 3.78148 | D2, 0-20 | 2.12 | 0.44 | 0.04 | 2.02 | 0.62 | 99 | 42 |
| 7.11124 | 3.78148 | D2, 20-40 | 2.81 | 1.06 | 0.06 | 1.57 | 2.19 | 128 | 50 |
| 7.117874 | 3.849442 | F2, 0-20 | 2.51 | 0.43 | 0.04 | 3.05 | 1.88 | 243 | 154 |
| 7.117833 | 3.883367 | F7, 0-20 | 2.47 | 0.70 | 0.04 | 11.80 | 2.19 | 210 | 128 |
| 7.117833 | 3.883367 | F7, 20-40 | 5.56 | 1.49 | 0.04 | 7.14 | 2.50 | 166 | 30 |
| 7.12465 | 3.86979 | G5, 0-20 | 3.65 | 0.74 | 0.04 | 5.77 | 0.31 | 135 | 35 |
| 7.13146 | 3.85622 | H4, 0-20 | 3.06 | 0.77 | 0.03 | 4.98 | 2.50 | 120 | 48 |
| 7.14505 | 3.842667 | J1, 0-20 | 1.76 | 0.67 | 0.04 | 2.02 | 1.88 | 151 | 106 |
| 7.14505 | 3.842667 | J1, 20-40 | 2.42 | 0.40 | 0.04 | 3.05 | 0.62 | 86 | 37 |

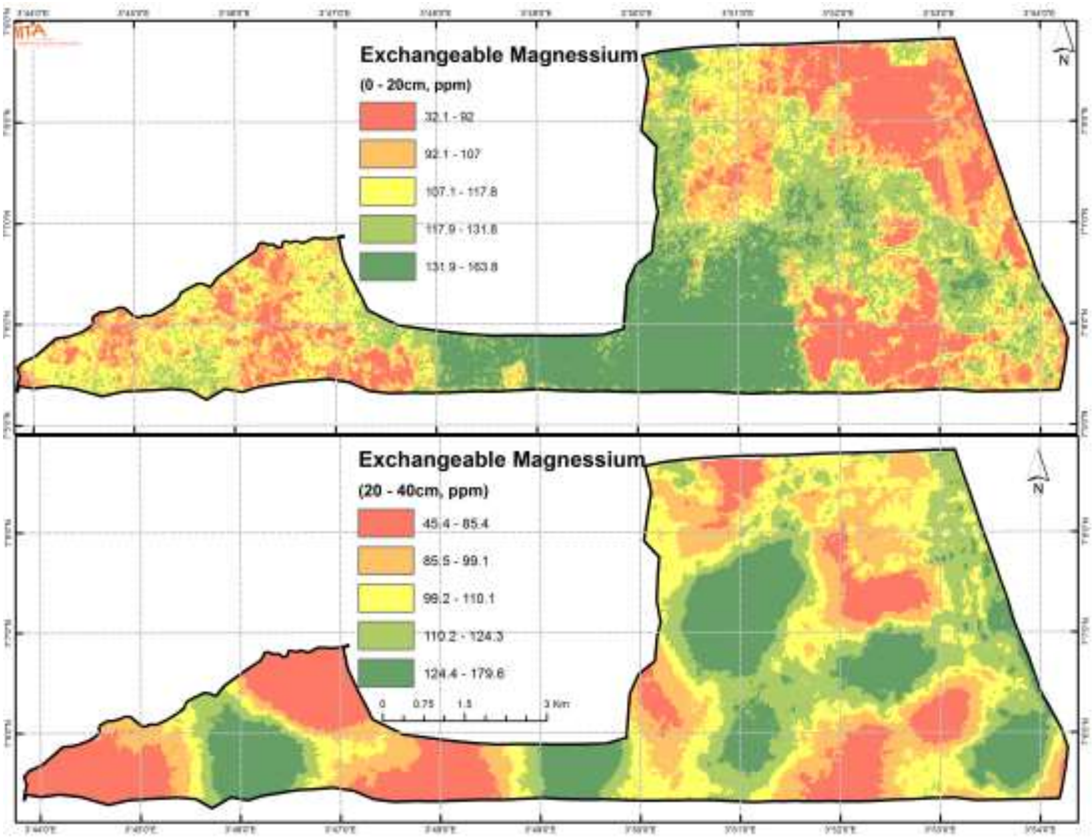
## Appendix 4: Maps of soil nutrient characteristics of Onigambari

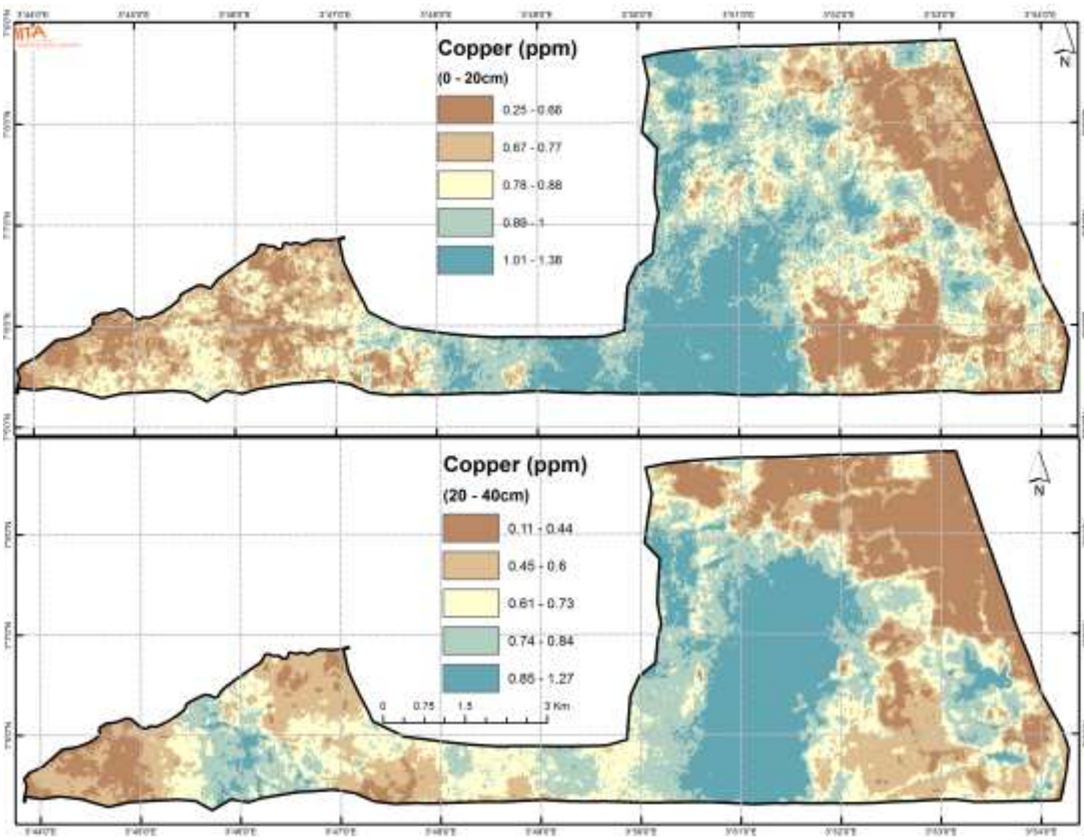


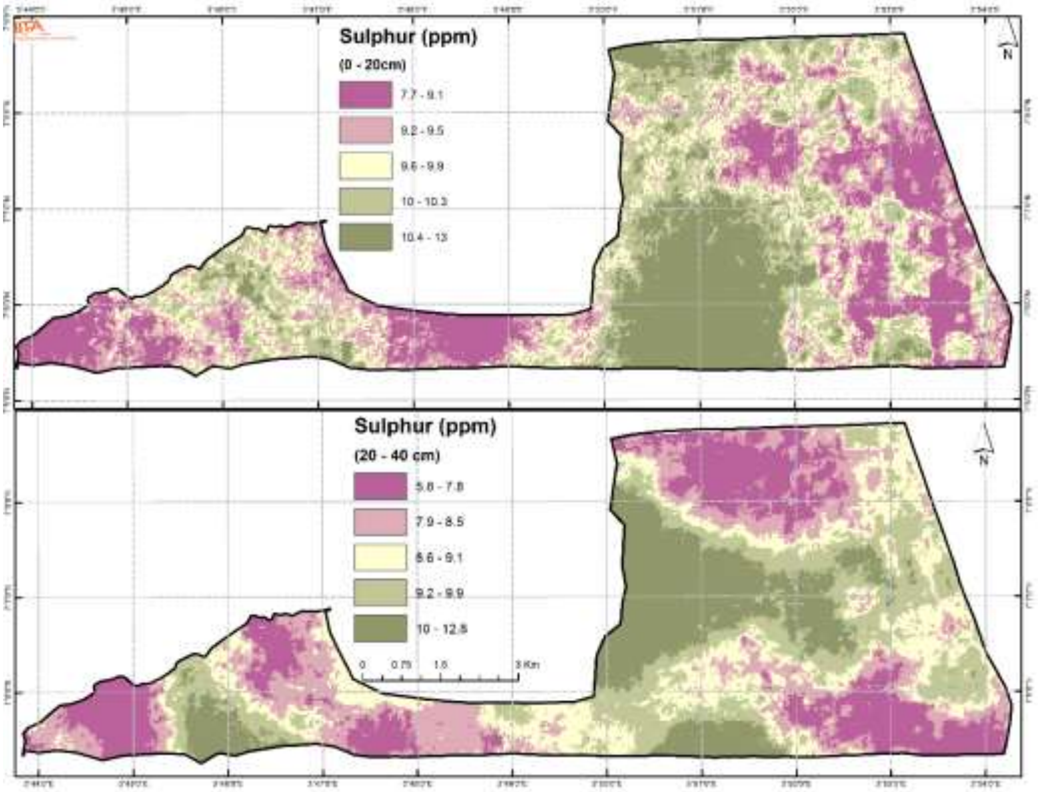



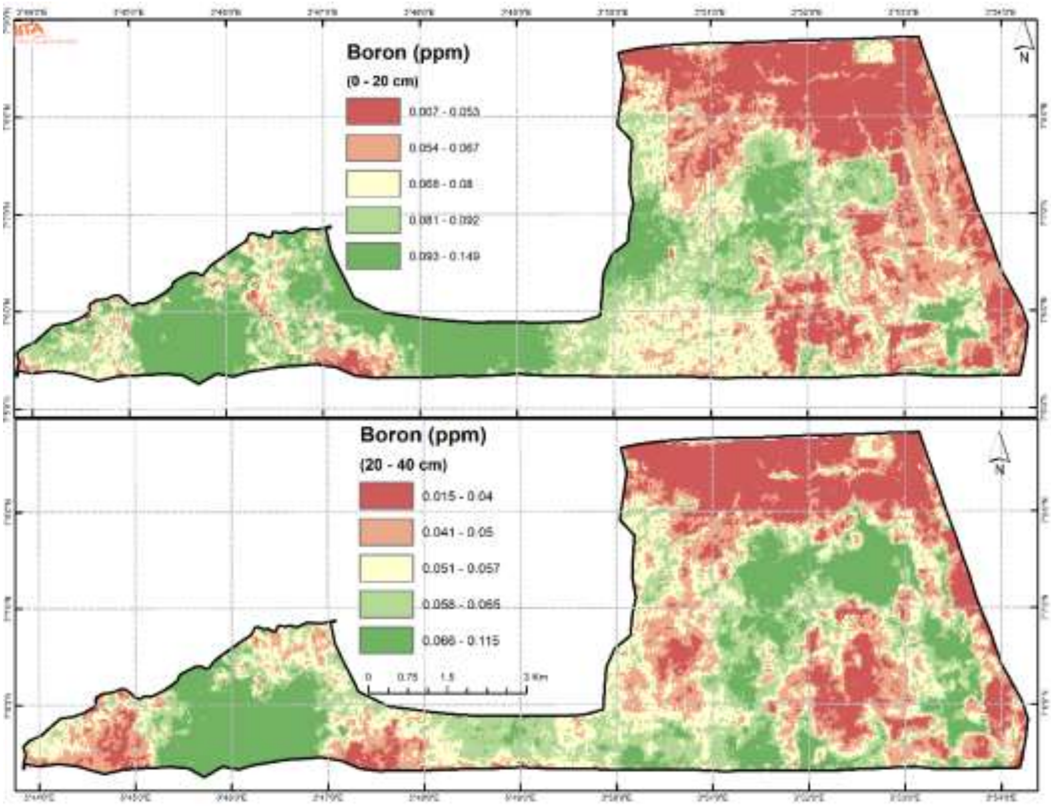

Exhangeable Potassium
(0 - 20 cm, ppm)
8.7 - 56.4
56.5 - 69.1
69.2 - 80.3
80.4 - 93.5
93.6 - 132.9
N
Exchangeable Potassium
(20-40 cm, ppm)
58.5 - 70.9
71 - 76.1
76.2 - 81.1
81.2 - 87.3
87.4 - 101.2
0 0.75 1.5 3 Km
N

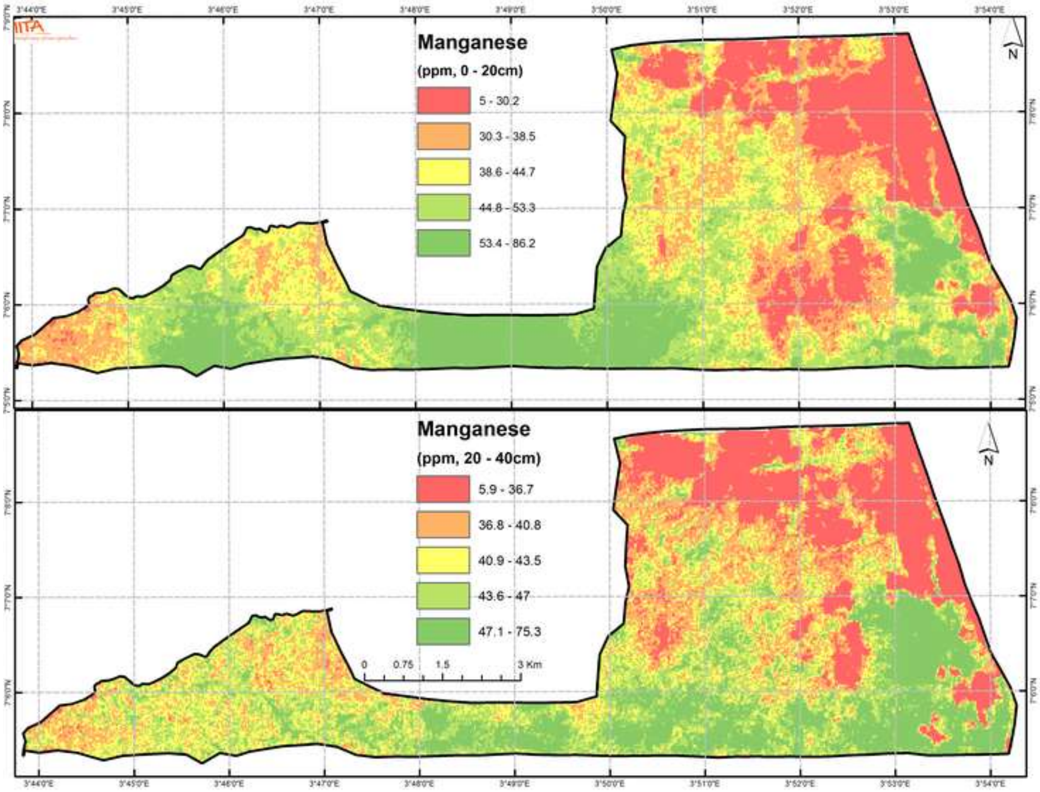

Exchangeable Calcium
(0 - 20cm, ppm)
100 - 421.2
421.3 - 506.3
506.4 - 567.1
567.2 - 627.9
628 - 964.4
N
Exchangeable Calcium
(20 - 40cm, ppm)
192.5 - 407.9
408 - 436.1
436.2 - 458.3
458.4 - 486.5
486.6 - 705.9
0 0.75 1.5 3 Km
N


Exchangeable Magnessium
(0 - 20cm, ppm)
32.1 - 92
92.1 - 107
107.1 - 117.8
117.9 - 131.8
131.9 - 163.8
N
Exchangeable Magnessium
(20 - 40cm, ppm)
45.4 - 85.4
85.5 - 99.1
99.2 - 110.1
110.2 - 124.3
124.4 - 179.6
0 0.75 1.5 3 Km
N

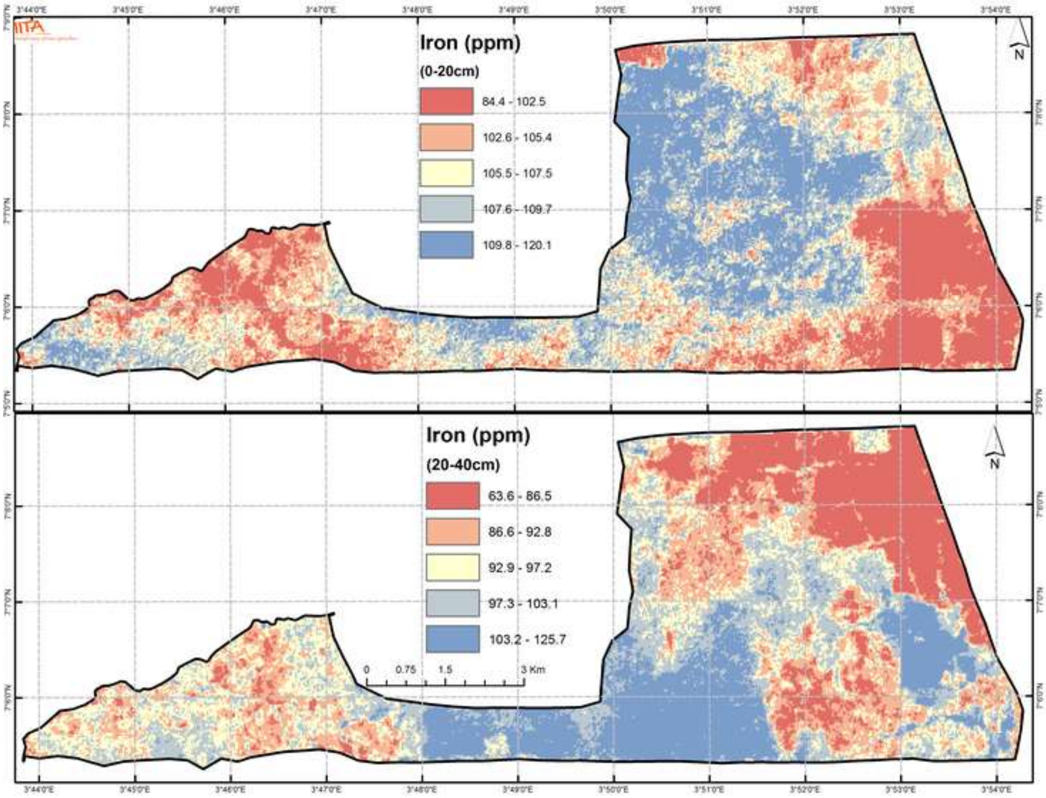

Copper (ppm)
(0 - 20cm)
0.25 - 0.66
0.67 - 0.77
0.78 - 0.88
0.89 - 1
1.01 - 1.38
N
Copper (ppm)
(20 - 40cm)
0.11 - 0.44
0.45 - 0.6
0.61 - 0.73
0.74 - 0.84
0.85 - 1.27
0 0.75 1.5 3 Km
N


Sulphur (ppm)
(0 - 20cm)
7.7 - 9.1
9.2 - 9.5
9.6 - 9.9
10 - 10.3
10.4 - 13
Sulphur (ppm)
(20 - 40 cm)
5.8 - 7.8
7.9 - 8.5
8.6 - 9.1
9.2 - 9.9
10 - 12.8


Boron (ppm)
(0 - 20 cm)
0.007 - 0.053
0.054 - 0.067
0.068 - 0.08
0.081 - 0.092
0.093 - 0.149
Boron (ppm)
(20 - 40 cm)
0.015 - 0.04
0.041 - 0.05
0.051 - 0.057
0.058 - 0.065
0.066 - 0.115




*Map 9. Map of manganese distribution*




*Map 10. Iron distribution*