Western Kenya Integrated Ecosystem Management Project

Katuk-Odeyo Baseline Report

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TRANSFORMING LIVES AND LANDSCAPES

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1. Aims and scope of the report

One very important purpose for a baseline assessment is to assist in project implementation (see the attached GEF monitoring and evaluation guidelines for biodiversity and international water projects). For example, one of the stated goals of the Western Kenya Integrated Ecosystem Management Project (WKIEMP) is to "enhance above- and below-ground carbon sequestration in the project area" (WKIEMP PIP, 2005). The major questions for implementation relate to how, where and to what degree additional carbon sequestration could be achieved over a large and diverse project landscape. Where, for example, are priority areas for afforestation (or reforestation) located in the landscape? Are there any special biophysical constraints that apply? Are the proposed interventions socially and economically acceptable, and to what degree are the communities in the project area going to participate? Similar questions are likely to arise in the context of other WKIEMP objectives, such as increased agricultural income generation, erosion control and biodiversity conservation, all of which require careful consideration of the existing ecological and socioeconomic constraints.

The other important purpose of a baseline is to provide a starting point for monitoring, reliable change detection and project impact attribution (also see GEF guidelines). For example, the question "to what degree have project initiated aforestation activities increased carbon storage in the landscape", can only be answered reliably by measuring carbon stocks on at least two occasions, and on both non-intervention, and afforested project sites. An assessment of the spatial variability of existing carbon stock stocks is essential in this regard, as this will determine to what degree (of precision) changes can subsequently be detected and attributed to project activities over time. Again, similar issues will arise in the context of the other WKIEMP objectives that require monitoring and impact attribution.

Thus, the main aims of this report are twofold. The first aim is to synthesize a quantitative description of the baseline project situation along the ecological and socioeconomic dimensions that are relevant for project implementation. In this context, flexible strategies for selecting priority intervention areas and households at the landscape/population scale are proposed. The second aim is to lay a foundation for monitoring, change detection and impact assessment that considers spatial variability explicitly.

1.1. *Indicators*

There are two types of indicators measured in this baseline. Conditioning indicators are those indicators that the project may not influence directly, but that create possibilities or set limitations on the ability of a project to affect change. Impact indicators are those that the project expects to influence and that can be used for monitoring or impact assessment.

The starting point for any project is to define the nature and extent of the problem that the project wants to address, and a baseline is the information that helps the project do this. The baseline is the situation at the start of a project before any work has been carried out. When the project is clear about the nature and extent of a problem it is going to address in a particular block, it can then set clear objectives. Once it has clear objectives, it can choose impact indicators appropriately.

Objectives are specific statements that can be measured and state exactly what is to be achieved. They must be written so that they can be measured. For this to take place they should be SMART, which means that they are:

- Specific – all objectives should have specific outcomes;
- Measurable – the outcome of an objective should be able to be measured;
- Achievable – within the timescale and resources set for the project;
- Realistic – objectives describe something that can actually be done; and
- Timebound – a timescale should be set for when the objective is to be achieved.

The other major aim of a baseline is to provide a starting point for reliable change detection and project impact assessment over time. Even the SMARTest objectives can go wrong and can have negative environmental or socioeconomic impacts that were not foreseeable at the start of the project. Conversely, the project could have spillover effects that amplify positive impacts. The baseline should thus provide an assessment of the initial conditions and their trajectory without the project, against which both positive and negative changes can be evaluated and attributed.

1.1.1. Land resource indicators

The central role of land resource indicators is to measure changes in the condition or state of the land, and in particular to monitor land degradation, or its converse land improvement. Additionally, combinations of land resource indicators may be used to target specific project activities and interventions on the ground. Included in the current assessment are measurements of land cover, woody vegetation cover and abundance (plant density and biovolume), perennial grass cover, vegetation life form diversity, physiography, soil texture, the prevalence of soil depth restrictions and inherent degradation risk, soil infiltration capacity, soil spectral characteristics and degradation prevalence. For some of these indicators (e.g. woody vegetation cover and soil spectral characteristics), it proved possible to link ground surveys to remote sensing data, and correspondingly maps of these indicators are provided.

1.1.2. Household indicators

The main role of household indicators is to measure changes in the composition, and socioeconomic status of the human population in the block. Additionally, combinations of indicators may be used to identify particularly vulnerable segments of the population that should receive special attention from the project. For example, thatch roofed households with a large proportion of children and seniors might constitute such a group. Included in the current assessment are measures of household demography (e.g., household size, no. of widow(er) headed households and dependency ratios), agricultural labor availability, off-farm employment, indicators of household well-being (e.g., “thatched” vs. other housing), household resource endowment (e.g. farm size and livestock ownership), no. of months of food deficits and annual household expenditure profiles (i.e., farm improvement, veterinary care, food purchases, water, home improvement, education and other expenditures). Finally, household demand for trees using a simple contingent valuation procedure is assessed.

1.1.3. Ancillary indicators

To provide historical context, also included in the current assessment are long-term monthly rainfall records (from VasClimo, 2004) covering the period 1951–2000, and Landsat (MSS, TM and ETM+) archival data covering the period 1972 – 2002.

1.2. *Not included in the current assessment are:*

- *Historical indicators*, such as stable carbon and nitrogen isotope analyses that are indicative of long-term land cover changes, and radionuclide assays (i.e., Cesium-137 and Lead-210) that provide information about soil erosion/deposition dynamics in the landscape.

- *Land resource survey indicators,* such as QuickBird satellite imagery and image derivatives (e.g., woody vegetation cover maps and household identification), estimates of above- and below-ground carbon stocks, plant species diversity, non-CO_2 greenhouse gases, and soil water retention characteristics.

- *Household survey indicators,* such as estimates of fuelwood consumption and drinking water quality.

Notably, both the land resource survey and household datasets presented here are particularly information rich and warrant further analysis and interpretation. Certainly, missing indicator sets, such as the QuickBird satellite data, should be followed up by the project and integrated into the current assessment.

Importantly, the baseline reported here is only one of nine of such baselines envisaged by the WKIEMP. In essence, one 10,000 ha block represents one (unreplicated) sampling unit within the overall project design. Given this design, regional context and policy relevance can only be achieved by comparing baselines, changes and project impacts across different project blocks. So as the project continues to cover more blocks, it is important to retain consistency and comparability in the data collection and analysis. To facilitate consistency in data collection and tracking, MS-Access databases with data entry interfaces have been developed (see attached `LandResourceSurvey.mdb` and `HouseholdSurvey.mdb`). All data analyses have been conducted in the S-Plus statistical software package, and indicative S-Plus code is provided in an annex to this report.

2. Survey methods

2.1. *Land resource survey*

The land resource survey in the Katuk Odeyo block was conducted over a ~4 week period between Jun-Jul. 2006, by a team of 6 ICRAF staff. A total of 160 (1000 m^2) **plots** were surveyed. Plot locations were selected prior to initiating the field survey using a spatially stratified random sampling procedure. The 10,000 ha block was initially partitioned into 16 (2.5 ´ 2.5 km, or 625 ha) **survey units**. Within each survey unit 10 (1000 m^2) plots were double randomized within a 1 km^2 circular area that is referred to as a **cluster**. Initially the cluster centroid was randomly selected within each survey unit. Plot locations were then randomized away from the cluster centroid using a polar coordinate conversion that ensures reasonably equal (circular) area coverage of the cluster. Each sampling location was subsequently labeled with a cluster and plot identifier (e.g., KO.1.1, referring to Katuk Odeyo Block, cluster 1, plot 1).

Details of this procedure as well as MS-Excel code for generating the randomized coordinates are provided in an attached document (`Field sampling procedures.doc`). The randomized locations were then loaded into a GPS unit which the survey crew used for field navigation. In general, reasonably accurate navigation was achieved to within < 15 m of the specified location ~90% of the time. The actual survey locations were subsequently logged by averaging GPS position estimates for several minutes, and are shown in Figures 1&2.

On each plot detailed observations and measurements describing land cover and soil condition were recorded, following the guidelines provided in the “Field sampling procedures” document. Vegetation cover and abundance and soil characteristics were measured on 4 (100 m^2) **subplots** per plot. The recovered soil samples were pooled by depth increment such that each plot generally contains 1 pooled topsoil (0 – 20 cm) and 1 pooled subsoil (20 – 50 cm) sample.

2.2. *Household survey*

The household survey in the Katuk Odeyo block was conducted over a ~4 week period between Jun-Jul. 2005 by a team of 5 ICRAF enumerators supervised by Rohit Jindal from the University of Michigan. A total of 169 households were surveyed, distributed across 6 administrative locations (see Figure 1). Unlike in the land resource survey, households were not selected randomly prior to conducting the survey. Instead, the survey team selected a central survey location on a given day, and then randomly selected 5 – 10 households in proximity to that point. In the future this procedure may be improved, by selecting a sample of households from QuickBird satellite images. The advantage of this would be that households could be sampled in proportion to their occurrence in the landscape, and that the total number of households and their locations could be established to a high level of accuracy within the block. For the time being the main dwelling of the household was georeferenced by averaging GPS position estimates for several minutes.

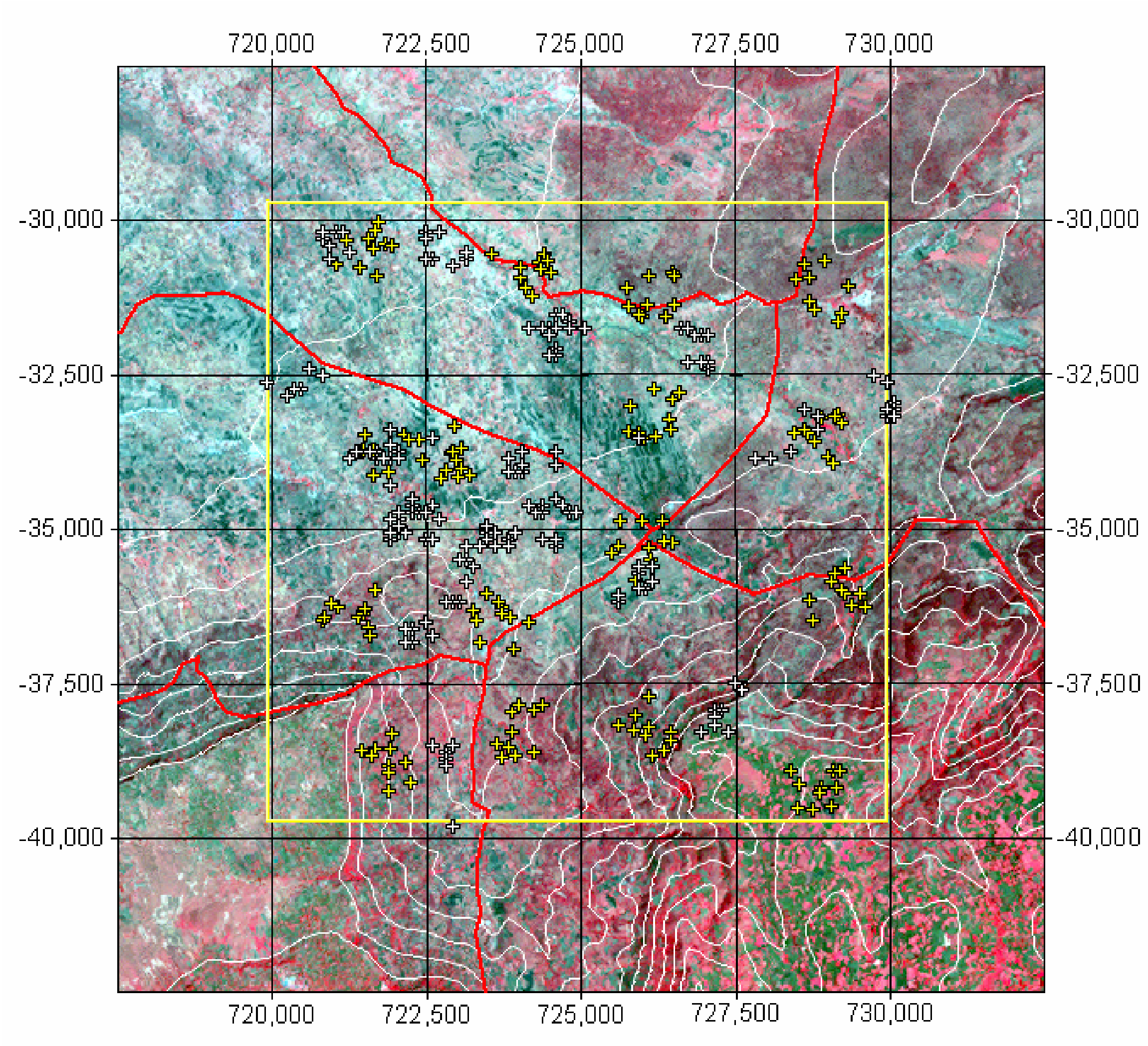

Figure 1. Overview map of the Katuk Odeyo block including land (yellow crosses) and household (white crosses) survey sampling locations. The background image is an orthorectified Landsat ETM false color composite (Ch. 4,3,2) dating from Feb. 2002. Note that photosynthetically active vegetation is shown in red, bare soil in shades of green, magenta or black. White (50 m) contour lines were generated from Shuttle Radar Topography. Administrative boundaries, to level of location, are based on Kenya Central Bureau of Statistics census tracts (red lines; CBS, 1999). Grid coordinates are given in meters relative to UTM zone 36N and the WGS84 ellipsoid.

3. Analytical methods

3.1. *Analytical framework overview*

The analyses of particularly the land resource survey data presented here utilize linear, generalized linear and non-linear mixed model formulations extensively. This mixed model analysis is one of the innovative dimensions of our approach. In mixed model analyses, the random part of the model, or what is often referred to as the “error”, has structure. In the analyses presented here the structure arises from the spatially nested design in which, for example, subplots are nested within plots, plots are nested within clusters, and clusters are nested within blocks. This structure to the error is useful in allowing us to make spatial estimates of important parameters at the different levels of nesting. Each level represents a different spatial scale at which a given land resource indicator may be or measured as given per the table below.

Level	**Area (ha)**
Block	10,000
Cluster	100
Plot	0.1
Subplot	0.01

These levels of scale do not represent fixed, repeatable factors like an experimental treatment; they are a sample drawn from a larger population of possible observations at similar levels and are therefore considered to be random effects. Ideally, we would like to generalize our limited observations and measurements to the population of clusters in the block, and ultimately to the population of blocks in the WKIEMP project area. Models are needed to achieve this because of the random variability that occurs at each level.

The main advantages of using mixed model analysis are that: project baselines can be evaluated at different levels of spatial scale, providing a means for targeting interventions in different areas in the landscape, and the fact that the models can easily incorporate covariates and changes over time that provide the means for monitoring change detection and impact assessment at the whole project-level. In other words, the same basic analytical framework can be applied over the entire project cycle, integrating spatial scale, temporal variability and management impacts in one general model.

3.2. *Baseline models*

The starting point of any project is to define the nature and extent of the problem that is to be addressed. A baseline helps to do this by providing a quantitative description of the "before-project[1]" situation. The following is an extended example of how to estimate and use baseline information for project planning, monitoring and evaluation.

In Katuk-Odeyo the density of "trees" (i.e., woody plants > 3 m in height) was measured using a total count on four 100 m^2 subplots in each of 10 randomly selected 1000 m^2 plots nested within 16 randomly selected 1 km^2 clusters (the plot and cluster locations are shown in Figures 1 and 2). There are two nested grouping levels in this example: *cluster* and *plot within cluster*. The objective of the study was to estimate the average before project (i.e., 2006) tree density in the block, the variance components associated with the different levels of nesting and the *within-plot* error (heterogeneity).

[1] In this context, the term "project" refers to a set of planned activities designed to achieve a particular set of objectives within a specific geographic location.

A basic multi-level linear mixed-effects model to describe tree density, y_{ijk} measured on the k^{th} subplot within the j^{th} plot and the i^{th} cluster is:

$$\ln(y+1)_{ijk} = \mu + b_i + b_{i,j} + \varepsilon_{ijk}, \quad i = 1...16,\ j = 1...10,\ k = 1...4$$
$$b_i \sim N(0,\sigma_1^2), \quad b_{i,j} \sim N(0,\sigma_2^2), \quad \varepsilon_{ijk} \sim N(0,\sigma^2)$$

for which μ is the average tree density in the block. The *cluster* level random effects are assumed to be independent for different clusters, the *plot within cluster* random effects are assumed to be independent for different clusters and plots and to be independent of the *cluster* and the *within-plot* errors. The error terms, ε_{ijk}, are assumed to be independent for different clusters, plots and subplots, and to be independent of the random effects. The model is computed for logarithmic transformed tree data because the data are highly skewed and this transformation stabilizes the variance. The results of fitting this model (the S-Plus code is provided in the Appendix) to the data (see `KOtrees.xls`) are shown in the table below.

Model parameter	**Lower**	**Estimate**	**Upper**
Mean(μ)	1.1	2.4	4.5
SD cluster(σ_c)	0.8	1.4	3.0
SD plot within cluster($\sigma_{c/p}$)	2.0	2.7	3.7
Error of the estimate (ε)	3.8	4.3	4.9

The parameter estimates and their 95% level confidence intervals (Lower & Upper) are in actual units of trees ha^{-1}. Thus, the average tree density in Katuk-Odeyo lies between 1-5 trees ha^{-1} and the current best estimate of the average tree density in Katuk-Odeyo is 2.4 trees per ha^{-1}. The confidence intervals of the random effect standard deviations are well-bounded and significantly different from 0, which indicates the importance of including them in the model. The estimate of the error term is about the same order as that for the plot within cluster in this landscape indicating relatively fine-scale clustering of trees in this landscape.

This model may be flexibly extended to include covariates (Table 6 in the Land Resource Survey results section below provides an example of this) in which estimates of tree densities were stratified on a Landsat based assessment of woody vegetation cover.

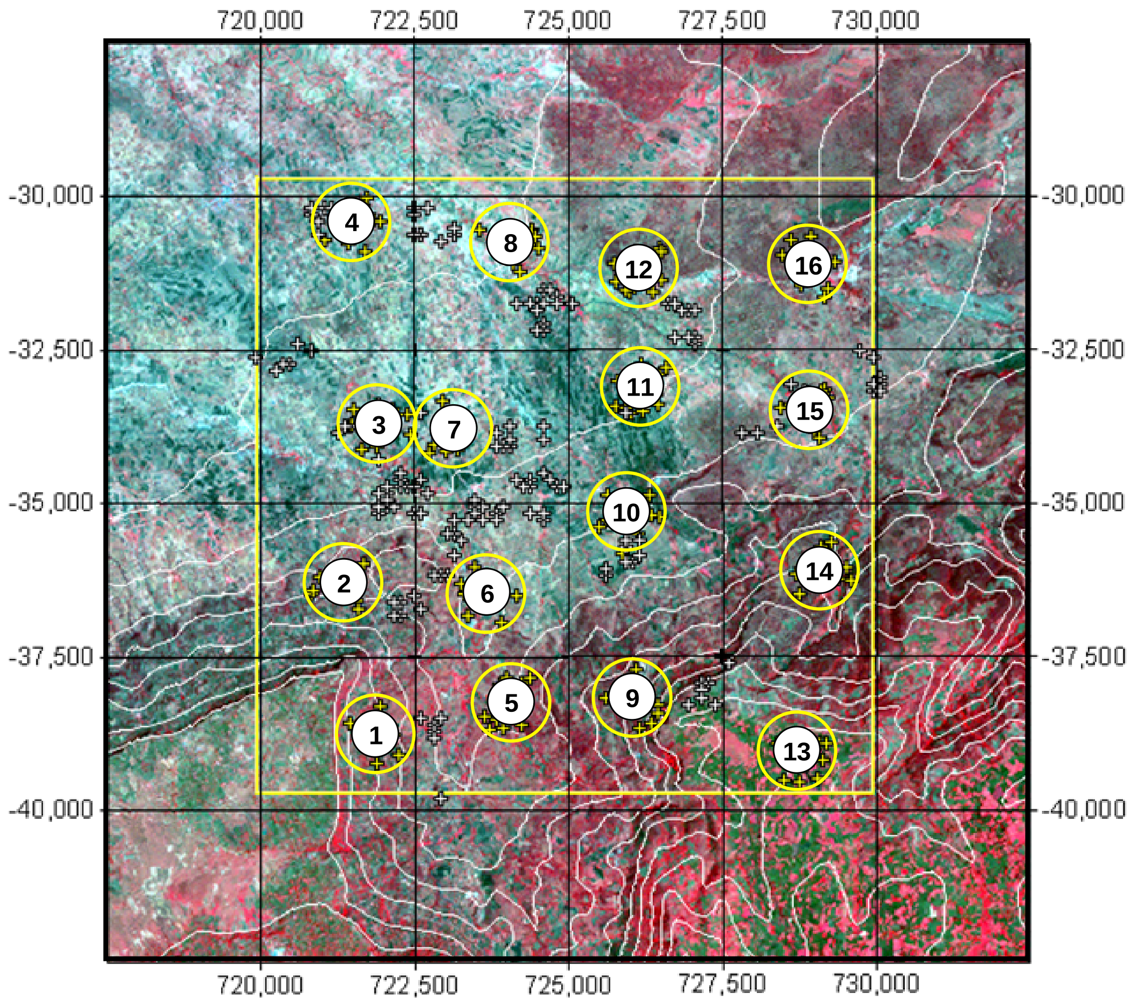

Figure 2. Centroid locations of land resource survey cluster locations (i.e., 1 km^2 sampling areas) in the Katuk Odeyo block.

4. The Baseline

4.1. *Historical rainfall*

The seasonal climate over the Lake Victoria basin is governed by the passage of the inter-tropical convergence zone (ITCZ) that separates the North Easterly and South Easterly monsoons. The ITCZ crosses East Africa twice every year, once during March-April-May (MAM) and again during October-November-December (OND). While the incursion and retreat of the ITCZ is responsible for the two main rainfall seasons in the region, this general relationship is modified locally by convective rainfall generated by evapotranspiration over Lake Victoria. A 50 year record (taken from the VasClimo, 2004 database) of monthly precipitation events for the Katuk Odeyo block is shown in Figure 3.

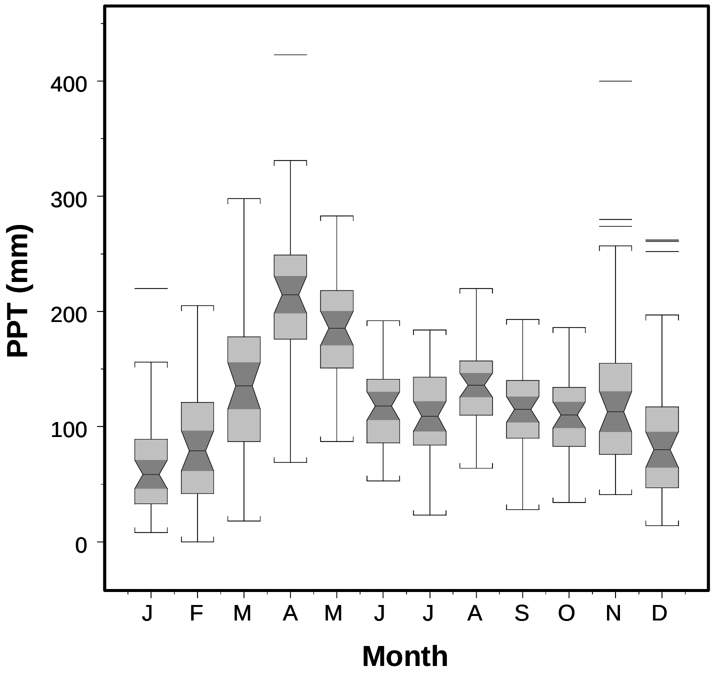

Figure 3. Distribution of 50-year (1951–2000) monthly rainfall estimates for the Katuk Odeyo block (data source: VasClimo, 2004, also see dataset `KOrain.xls`). Notches (dark grey) are the 95% CI of the median monthly rainfall. Light grey hinges are the upper and lower quartiles. Whiskers are the mean maxima and minima. Stripes indicate extreme rainfall events.

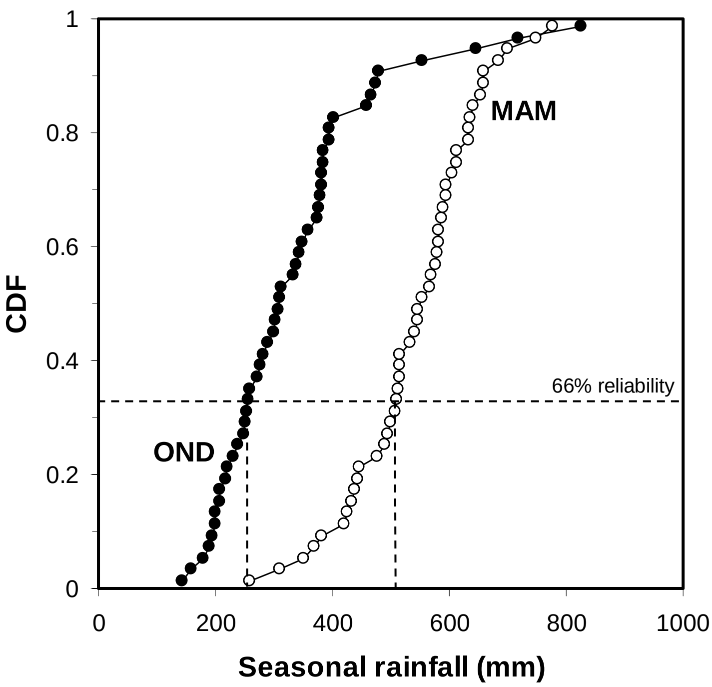

Figure 4. 50-year cumulative distributions and 66% reliability estimates of seasonal rainfall in the Katuk Odeyo block.

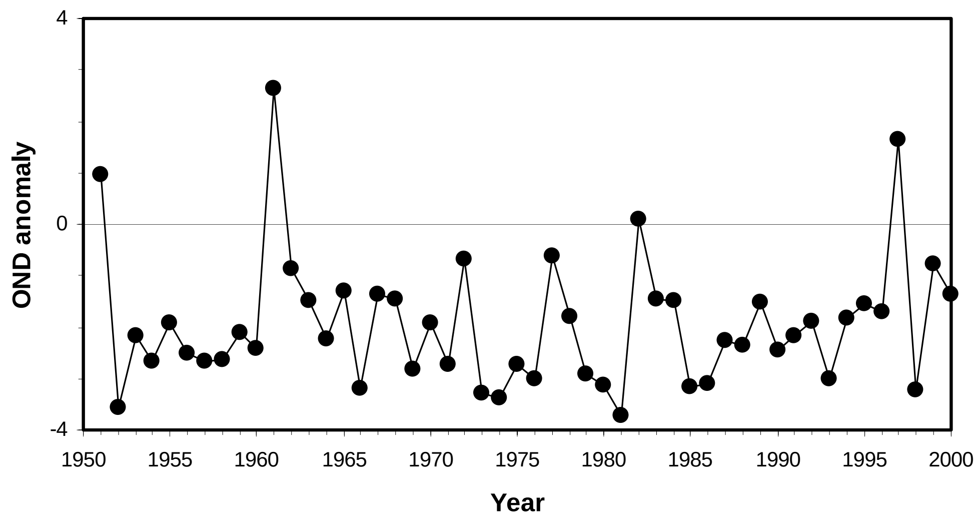

Figure 5. OND rainfall anomalies between 1951 – 2000 in the Katuk Odeyo block. The graph is scaled to z-scores as (OND – ave. MAM)/ SD MAM. Note that in 1961 OND rainfall was ~2.9 standard deviations above average MAM rainfall.

The average annual rainfall (1951 – 2000) for Katuk Odeyo is **1,507 mm yr^{-1}** (95% CI = 1,453 – 1,560 mm yr^{-1}). The main rainy season during MAM, averages **542 mm** (95% CI = 512 – 571 mm). Average rainfall during OND is substantially lower, averaging **333 mm** (95% CI = 295 – 371 mm). Seasonal distributions for MAM and OND rainfall are shown in Figure 4.

Above average OND rainfall in East Africa is a result of a teleconnection of warmer than normal sea surface temperatures in the Pacific and Indian Oceans. During major El Nino events OND rainfall can be extreme. This tendency can be seen in Figure 4, but is more clearly illustrated in Figure 5. Big (i.e., ~10 year return period events) such as those that occurred in 1951, 1961, 1982 and 1997 typically cause flooding and large scale erosion.

4.2. *Land resource survey results*

The Land Resource Survey is the instrument used to collect biophysical data. This survey differs from traditional baseline surveys as it focuses on important local ecological indicators necessary for an ecosystems approach to land management. The data should be used by the project to set targets for priorities identified through the development of Participatory Action Plans. The survey is not designed to prescribe interventions, but to assist the project team in setting realistic goals once priorities have been agreed upon with communities.

This section summarizes some of the key indicators from the field survey and laboratory analysis. It s not an exhaustive analysis of the database. Further analysis will be required as the project sets priorities and goals.

For each indicator we will give the results of fitting the model. These results show variability between clusters as well as the overall averages. In many cases, results were determined on the linear scale used in fitting the model for skewed data and then back-transformed to units that can be directly interpreted. Beneath each table are key statistics calculated from these results.

4.2.1. Land Cover and Land Use

The first section of the baseline assesses land cover and land use in the block. We collected data on each dominant vegetation and management of each plot..

Table 1. Estimates of proportions of cultivated areas in the Katuk-Odeyo block. Model family is `Binary`, response variable is `ln(p(Cult)/(1-p(Cult))`. The covariate in the analysis was the possible number of observed topsoil restrictions between 0 – 40 cm depth. See attached dataset (`KOcult.xls`). *REE* (Random Effects Estimate) indicates whether the cluster is above or below population average and the magnitude of the deviation from the block mean.

Cluster	*REE*	Proportion of cultivated area per cluster	*Model results*			
			Parameter	*Lower*	*Est.*	*Upper*
1	0.25	0.41	σ_c	0.062	0.36	2.1
2	-0.22	0.27	*Intercept*	-0.76	0.35	1.5
3	-0.21	0.36	*No. restrictions*	-0.11	-0.060	-0.0058
4	0.12	0.51				
5	-0.10	0.28				
6	0.24	0.31				
7	0.014	0.29				
8	0.011	0.19				
9	-0.065	0.35				
10	-0.065	0.35				
11	0.033	0.48				
12	-0.054	0.14				
13	0.24	0.31				
14	0.13	0.20				
15	-0.15	0.32				
16	-0.18	0.13				

- The current estimate of the area under cultivation in the Katuk-Odeyo block is:

3,020 ha (95% CI = 2,130 – 4,090 ha)

- Conversely, estimate of the area under (semi) natural vegetation cover in the Katuk Odeyo block is:

6,980 ha (95% CI = 5,910 – 7,870 ha)

- FAO Land Cover Classification System classes (see attached documentation, `LCCS.pdf`) other than cultivated or managed terrestrial areas and (semi) natural vegetation were not observed in the Katuk Odeyo block.

- There is considerable spatial variation in the distribution of cultivated areas in the block that is negatively associated with the occurrence of topsoil (0–20 cm) depth restrictions at the cluster (i.e. 1 km^2) level of observation. These are likely to limit normal tillage operations and root penetration by crops.

  Given the strongly negative association between the occurrence of cultivated areas and soil depth restrictions in the block, farmers have either preferentially selected areas for cultivation where topsoil depth restrictions occur with less frequency, or alternatively, currently restricted areas may have been abandoned due to hardsetting and/or accelerated soil erosion.

- The occurrence of cultivated areas appears to be conditionally independent of slope and soil texture class (model results not shown, see attached dataset `KOcult1.xls`).

- Given the extensive nature of topsoil (as well as additional subsoil, 20–50 cm) depth restrictions in the block, it is unlikely that opening up substantive areas of new cultivated lands would be technically feasible (see attached dataset `KOdepth.xls`).

Table 2. Estimates of the proportion of area under dense woody vegetation cover (`Woody cover score > 3`) in the Katuk-Odeyo block. Model family is `Binary`, response variable is `ln(p(WC)/(1-p(WC))`, see attached dataset (`KOcover.xls`).

Cluster	*REE*	Proportion of the cluster under semi-natural woody vegetation	*Parameter*	*Lower*	*Est.*	*Upper*
1	0.20	0.09	σ_c	0.96	1.6	2.8
2	0.81	0.16	$\sigma_{c/p}$	1.6	1.9	2.4
3	-1.52	0.02	*Block average*	-3.4	-2.5	-1.5
4	-1.52	0.02				
5	0.87	0.16				
6	-0.96	0.03				
7	-1.52	0.02				
8	-1.52	0.02				
9	0.22	0.09				
10	-1.52	0.02				
11	-0.72	0.04				
12	1.52	0.27				
13	1.43	0.26				
14	2.67	0.54				
15	0.09	0.08				
16	1.43	0.26				

- The current estimate of the area under dense (i.e. >60%) above-ground woody vegetation cover in the Katuk Odeyo block is:

759 ha (95% CI = 308 – 1,765 ha)

- Though some woody vegetation is present on most sites in the Katuk-Odeyo block, it is typically sparse and of low browse, fuelwood or other commercial value.

- Dense woody vegetation has a very distinctive Landsat reflectance signature which can be used to map its spatial distribution. Model estimates are shown in Figure 6.

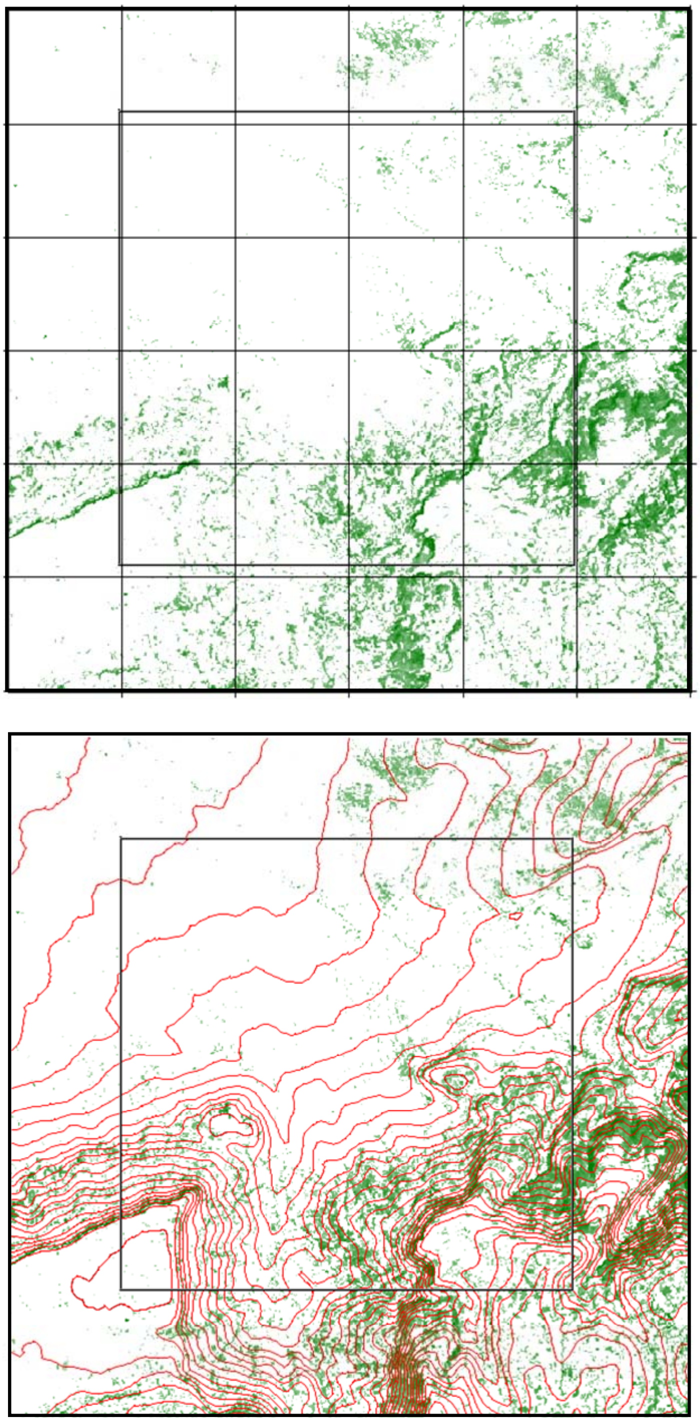

Figure 6. (top panel) Distribution of dense woody vegetation cover in the Katuk Odeyo block based on Landsat ETM (Feb. 2002) data and ground survey. (bottom panel) w. 20 m contour overlay; note that dense woody vegetation cover typically occurs on steep slopes.

Table 3. Estimates of the area under dense perennial grass cover (`Presence of perennial grasses && Herbaceous cover score > 3`) in the Katuk-Odeyo block. Model family is `Binary`, response variable is `ln(p(Per)/(1-p(Per))`, see attached dataset (`KOperen.xls`).

Cluster	*REE*	Proportion of the cluster under perennial grass cover	*Parameter*	*Lower*	*Est.*	*Upper*
1	0.36	0.53	σ_c	0.43	0.97	2.2
2	-0.07	0.51	$\sigma_{c/p}$	1.8	2.1	2.5
3	-0.74	0.36	*Semi natural*	-1.2	-0.46	0.23
4	0.29	0.52	*Cultivated*	-2.6	-1.6	-0.67
5	-1.47	0.23				
6	-0.97	0.29				
7	-0.09	0.48				
8	0.16	0.55				
9	0.27	0.56				
10	0.16	0.54				
11	1.71	0.79				
12	0.36	0.61				
13	0.36	0.55				
14	0.26	0.55				
15	0.22	0.56				
16	-0.83	0.36				

- The current estimate of the area under dense perennial grass cover (i.e. >60% aerial cover) in the Katuk Odeyo block is:

  3,121 ha (95% CI = 2,018 – 4,489 ha)

- Dense perennial grass cover is estimated at **17%** (95% CI = 7 – 34%) for cultivated areas (e.g. on fallow land), and at **39%** (95% CI = 24 – 56%) for (semi) natural vegetation types.

4.2.2. State of Woody Vegetation

Table 4. Estimates of tree density in the Katuk-Odeyo block. Model family is `Gaussian`, response variable is `ln(Dens+1)`, see attached dataset (`KOtree.xls`). Density estimates given in number of individuals per hectare.

Cluster	*REE*	Tree Density (*Trees ha^{-1}*)	*Parameter*	*Lower*	*Est.*	*Upper*
1	0.13	22	σ_c	0.18	0.98	1.5
2	0.85	46	$\sigma_{c/p}$	1.1	1.4	1.6
3	0.51	30	*m*	-2.3	-1.7	-1.1
4	-0.22	15	*WC*	0.35	0.81	1.3
5	0.11	22				
6	-0.29	14				
7	-0.16	16				
8	0.34	26				
9	0.42	29				
10	-1.37	5				
11	-1.40	5				
12	0.98	60				
13	-1.57	5				
14	1.32	115				
15	0.31	26				
16	0.04	22				

- The current estimate of the total number of trees (i.e., woody plants > 3 m in height) in the Katuk-Odeyo block is:

208,045 trees (95% CI = 110,803 – 388,680)

- Areas under dense woody vegetation cover have an estimated **40 trees ha^{-1}** (95% CI = 21 – 80); whereas, areas under open to sparse woody vegetation cover have an estimated **18 trees ha^{-1}** (95% CI = 10 – 33) on average.

- Cultivated areas have an estimated 10 trees ha^{-1} (95% CI = 5 – 23); whereas, (semi) natural vegetation types have 28 trees ha^{-1} (95% CI = 15 – 51; analysis not shown, see attached dataset `KOtrees.xls`).

- There is additional spatial variation in tree densities at both the cluster (i.e., 1 km^2 scale) and the plot (i.e., 1000 m^2) levels of observation that is independent of the difference between land cover types. For example cluster 14 has a relatively high estimated tree density (at ~115 trees ha^{-1}); whereas, clusters 10 & 11 have low estimated densities (at ~5 trees ha^{-1}). These differences should be exploited for targeting and prioritizing AR activities within the block.

Table 5. LDSF survey estimates of timber volume (`TV = BA × Height × Dens`) in the Katuk-Odeyo block. Model family is `Gaussian`, response variable is `ln(TV+0.1)`, see attached dataset (`KOtree.xls`). TV in units of number of m^3 per 100 m^2.

Cluster	*REE*	Timber Volume (m^3 $100m^{-2}$)	*Parameter*	*Lower*	*Est.*	*Upper*
1	-0.032	0.03	σ_c	0.058	0.13	0.31
2	0.158	1.07	$\sigma_{c/p}$	0.28	0.35	0.44
3	0.064	0.97	ε	0.62	0.66	0.70
4	0.026	0.93	*Block average*	-2.14	-2.04	-1.94
5	-0.022	0.88				
6	-0.063	0.84				
7	-0.058	0.84				
8	0.128	1.04				
9	0.007	0.91				
10	-0.113	0.79				
11	-0.113	0.79				
12	0.061	0.96				
13	-0.113	0.79				
14	-0.016	0.88				
15	0.129	1.04				
16	-0.045	0.86				

- The current estimate of the average timber volume in the Katuk-Odeyo block is:

3.0 m^3 ha^{-1} (95% CI = 1.8 – 4.4 m^3 ha^{-1})

- Notably, timber volume can be converted to estimates of above-ground tree biomass, once suitable allometric equations become available.

Table 6. Estimates of live shrub density in the Katuk-Odeyo block. Model family is `Poisson`, response variable is `ln(Dens)`, see attached dataset (`KOshrub.xls`). Density in units of number of individuals per 100 m^{-2}

Cluster	*REE*	Shrub Density *(individuals 100m^{-2})*	*Parameter*	*Lower*	*Est.*	*Upper*
1	1.07	21	σ_c	0.81	1.0	1.2
2	0.12	21	$\sigma_{c/p}$	1.1	1.2	1.4
3	-1.02	6.1	*Semi-natural*	2.7	3.2	3.8
4	-1.41	2.0	*Cultivated*	0.43	1.06	1.7
5	0.97	40				
6	-0.13	8.1				
7	-0.21	11				
8	-0.19	13				
9	0.22	16				
10	-1.44	3.2				
11	-1.47	2.3				
12	0.22	23				
13	1.16	27				
14	1.26	43				
15	0.20	18				
16	0.65	42				

- The current estimate of the total number of live shrubs (i.e., woody plants < 3 m high) in the Katuk-Odeyo block is:

12.9 $\times 10^6$ **plants** (95% CI = $7.14 \times 10^6 - 23.4 \times 10^6$)

- The average shrub density of cultivated and managed areas is estimated at **288 plants ha^{-1}** (95% CI = 154 – 542 plants ha^{-1}). Shrub density in areas under semi natural terrestrial vegetation is estimated at **2503 plants ha^{-1}** ((95% CI = 1444 – 4338 plants ha^{-1}).

Table 7. Estimates of shrub biovolume (`SBV = BV × Dens`) in the Katuk-Odeyo block. Model family is `Gaussian`, response variable is `ln(SBV+0.1)`, see attached dataset (`KOshrub.xls`).

Cluster	*REE*	SBV	*Parameter*	*Lower*	*Est.*	*Upper*
1	0.14	3.5	σ_c	0.33	0.51	0.80
2	0.11	3.4	$\sigma_{c/p}$	0.43	0.56	0.71
3	-0.63	1.1	ε	1.0	1.1	1.2
4	-0.51	1.3	*Block average*	0.81	1.1	1.4
5	0.32	4.4				
6	0.17	3.7				
7	-0.36	1.8				
8	-0.63	1.1				
9	0.28	4.2				
10	-0.64	1.1				
11	-0.48	1.4				
12	0.45	5.2				
13	0.37	4.7				
14	0.69	6.9				
15	0.14	3.5				
16	0.57	6.0				

- The current estimate of the average shrub biovolume in the Katuk-Odeyo block is:

297 m^3 ha^{-1} (95% CI = 215 – 407)

- Notably, estimates of shrub biovolume can be converted to estimates of above-ground shrub biomass, once suitable allometric equations become available.

4.2.3. State of soils

Table 8. Proportions of areas with high inherent soil degradation risk in the Katuk-Odeyo block. Soil degradation risk is defined as (`DR = presence of soil depth restriction to 50 cm, or SC, LC soil texture, or slope >30%`). Model family is `Binary`, response variable is `ln(p(DR)/(1-p(DR))`, see attached dataset (`KOdr.xls`).

Cluster	*REE*	Proportion of the area within each cluster that has high risk for soil degradation	*Parameter*	*Lower*	*Est.*	*Upper*
1	0.01	0.77	σ_c	0.66	1.1	1.8
2	0.52	0.85	$\sigma_{c/p}$	1.3	1.6	1.9
3	-0.83	0.59	*Block average*	0.55	1.2	1.8
4	-1.69	0.38				
5	-0.27	0.72				
6	0.00	0.77				
7	0.81	0.88				
8	0.58	0.85				
9	0.35	0.82				
10	-0.88	0.58				
11	-1.88	0.34				
12	1.06	0.91				
13	0.15	0.79				
14	0.69	0.87				
15	-0.06	0.76				
16	1.45	0.93				

- The current estimate of the area with high inherent soil degradation risk (i.e., areas with soil depth restrictions to 50 cm, sharp texture contrasts between topsoil and subsoil, or on steep, >30%, slopes) in the Katuk Odeyo block is:

7,675 ha (95% CI = 6,348 – 8625 ha)

- The main inherent soil degradation risk factor, in this area is soil depth restriction. An estimated **5,115 ha** (95% CI = 3,705 – 6,125 ha) are expected to show soil depth restrictions to 20 cm (analysis not shown, see attached dataset `KOdepth.xls`). A further **2,254 ha** (95% CI = 800 – 3,340 ha) are expected to show subsoil (i.e. 20–50 cm) restrictions. In part the restrictions are due to stoniness/rockiness, particularly on sloping lands; however, in lowland areas, typically below 1,200 m a.s.l. depth restrictions due to hardsetting soils predominate.

Soils with sharp texture contrasts (i.e, Loam or Sand over Clay) occupy only a small aerial fraction (< 5%) of the Katuk Odeyo block. Steeply sloping lands (>30% slope) are found in proximity to the Kisii and Nyabondo escarpments and occupy ~10% of the Katuk Odeyo block.

Table 9. Estimates of proportions of areas with topsoil (0–20 cm) depth restrictions in the Katuk-Odeyo block. Model family is `Binary`, response variable is `ln(p(R20)/(1-p(R20))`, see attached dataset (`KOdepth.xls`).

Cluster	*REE*	Proportion of each cluster with soil depth restrictions	*Parameter*	*Lower*	*Est.*	*Upper*
1	-0.41	0.41	σ_c	0.59	1.0	1.7
2	-0.12	0.48	$\sigma_{c/p}$	1.2	1.5	1.8
3	-0.80	0.32	*Block average*	-0.53	0.047	0.63
4	-1.30	0.22				
5	-0.05	0.50				
6	0.26	0.58				
7	0.06	0.53				
8	0.88	0.72				
9	-0.52	0.38				
10	-0.52	0.38				
11	-1.20	0.24				
12	1.48	0.82				
13	0.22	0.57				
14	1.04	0.75				
15	-0.39	0.42				
16	1.37	0.80				

- The current estimate of the amount of area with topsoil (0–20 cm) restrictions in the Katuk Odeyo block is:

5,115 ha (95% CI = 3,705 – 6,125 ha)

- A further **2,254 ha** (95% CI = 800 – 3,340 ha) is expected to show subsoil (i.e. 20–50 cm) restrictions. Hence, **~74%** of the Katuk Odeyo block is likely to exhibit soil depth restrictions within the top 50 cm of the soil profile.

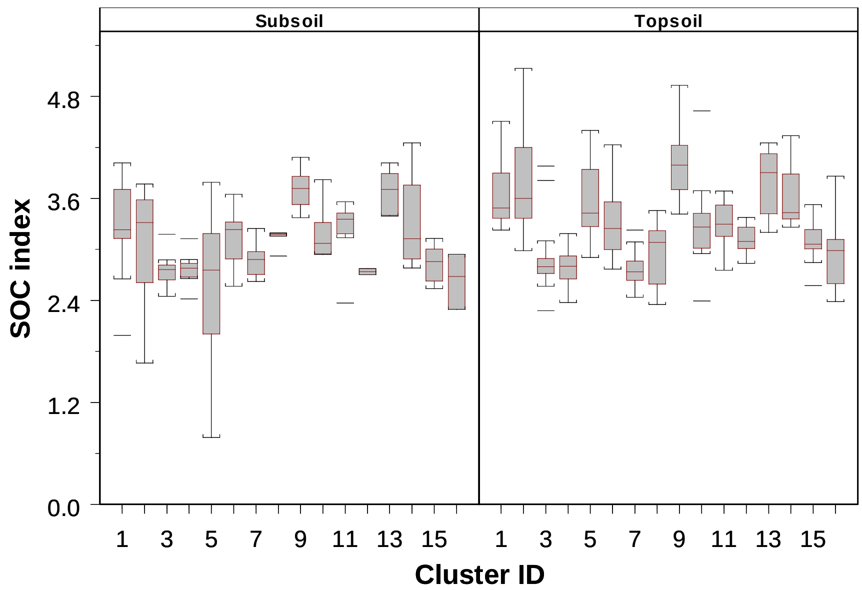

Figure 7. Spectrally estimated topsoil (0- 20 cm) and subsoil (20 – 50 cm) soil organic carbon. Note that SOC index is given on a log(e) scale because the distributions are very skewed on a linear scale. Note the spectral calibration is based on exponential decay function with depth.

Table 10. Estimates of soil organic carbon content (SOC, g kg^{-1}) as a function of mean depth (cm) in the soil profile. Model family is `Gaussian`, response variable is `ln(SOC)`, see attached dataset (`KOsoc.xls`). Int = ln(intercept) Depth = percentage decline with depth per cm

Cluster	Int	Depth	SOC at Surface *(g kg⁻¹)*	SOC at 20 cm *(g kg⁻¹)*	*Parameter*	*Lower*	*Est.*	*Upper*
1	3.8	-0.016	44.7	32.5	σ_c	0.29	0.43	0.63
2	3.9	-0.018	49.4	34.5	$\sigma_{Depth/c}$	0.0044	0.0076	0.013
3	3.0	-0.0047	20.1	18.3	$\sigma_{c/p}$	0.28	0.34	0.40
4	2.8	-0.0016	16.4	15.9	$\sigma_{Depth/p}$	0.0098	0.012	0.015
5	3.8	-0.024	44.7	27.7	ε	0.15	0.18	0.20
6	3.4	-0.0079	30.0	25.6	*Intercept*	3.2	3.4	3.6
7	2.8	0.0003	16.4	16.5	*Depth*	-0.014	-0.0098	-0.005
8	3.0	-0.0033	20.1	18.8				
9	4.1	-0.014	60.3	45.6				
10	3.3	-0.008	27.1	23.1				
11	3.4	-0.0068	30.0	26.2				
12	3.2	-0.0079	24.5	20.9				
13	3.8	-0.012	44.7	35.2				
14	3.7	-0.013	40.4	31.2				
15	3.2	-0.0086	24.5	20.7				
16	3.1	-0.0094	22.2	18.4				

- An average soil profile in Katuk Odeyo is estimated to contain **30 g C kg^{-1} soil** (95% CI = 25 – 37 g kg^{-1}) at the profile surface. SOC concentration is estimated to decline by ~**1%** (95% CI = 0.5 – 1.4%) with every centimeter of depth in the profile.

Table 11. Parameter estimates for the Horton infiltration function, see attached dataset (`KOinfilt.xls`).

Model parameter	*Lower*	*Est.*	*Upper*
a	-22	-9.2	3.5
b	3.7	7.2	11
k	37	53	68
r	-3.0	-2.8	-2.7
σ_s	10	13	16
σ_k	43	53	65
σ_r	0.33	0.44	0.58
ε	2.0	2.1	2.2

The Horton infiltration equation is given by:

$$i(t) = s + (k - s) \cdot \exp(-\exp(r \cdot t))$$

$$s = a + b * \ln(soc)$$

for which i is the observed infiltration rate (cm hr^{-1}), s is the saturated infiltration capacity, k is the initial infiltration capacity and r is a rate parameter.

- The current estimate of the average saturated infiltration capacity in the Katuk Odeyo block is:

  15.3 cm hr^{-1} (95% CI = 11.3 – 19.5 cm hr^{-1})

  * Note that Hortonian overland flow is expected to occur when the rate of rainfall exceeds this value.

- The saturated infiltration rate of soils is strongly associated with the organic carbon content of soils. From the table above:

$$s = 7.2 \cdot \ln(SOC) - 9.2$$

Table 12. Estimates of the area of severely eroded land in the Katuk-Odeyo block. Response variable is `ln(p(Ero)/(1-p(Ero))`, see attached dataset (`KOsoilcond.xls`).

Parameter	*Lower*	*Est.*	*Upper*
Intercept	-5.0	-3.6	-2.2
ETM (1*rst* PC)	0.0083	0.015	0.021
σ_p	1.4	1.6	1.9

- Current estimate of the area of severely degraded land in the Katuk-Odeyo block.

5720 ha (95% CI = 5072 - 6375)

- Severely eroded land has a very distinctive Landsat reflectance signature which can be used to map its spatial distribution. Model estimates are shown in Figure 7.

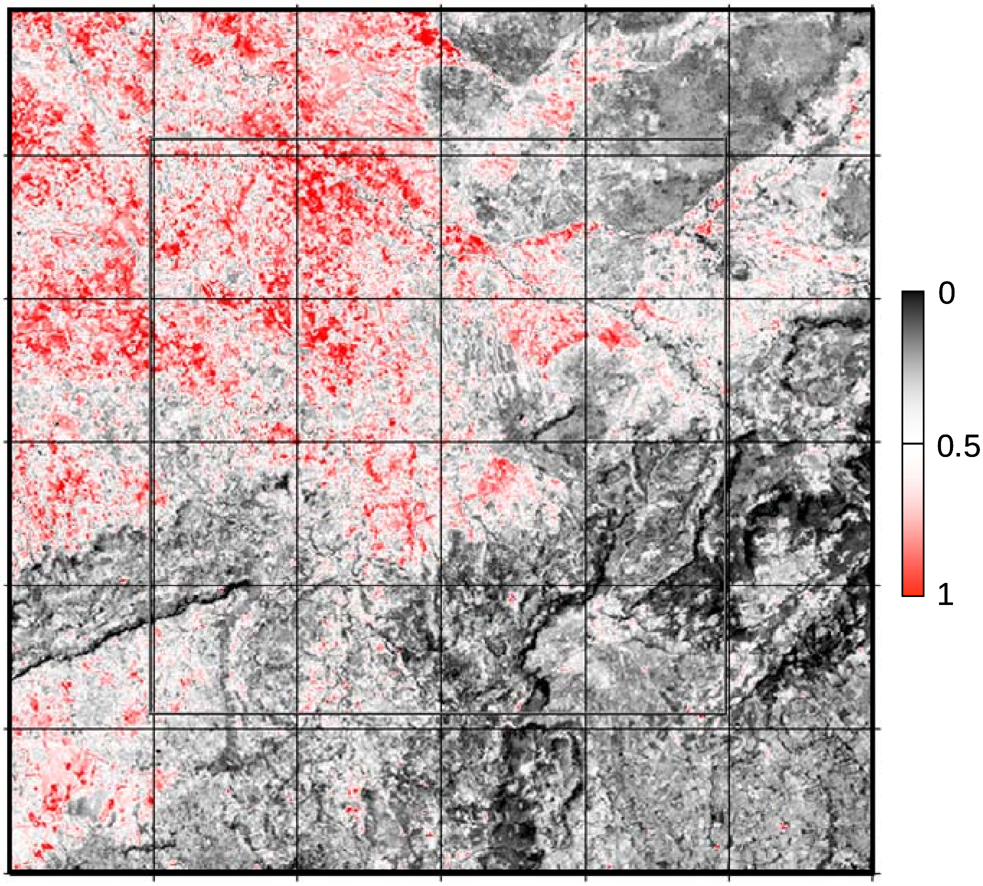

Figure 8. Distribution of severely eroded soils based on Landsat ETM (Feb. 2002) and spectral soil condition index. Image is scaled to probability values.

4.3. *Interpretation of the land resource survey results*

Selection of priority intervention sites should be based on a readily observable description of the state of the land. For example, in Table 13 below, sites which are currently not cultivated, and that have sparse woody vegetation cover and high inherent soil degradation risk should be targeted for afforestation/reforestation interventions.

Additionally, cultivated sites with high soil degradation risk should be targeted for soil conservation and soil fertility management, agroforestry or other practices that minimize tillage and increase soil cover during the onset of the OND rainy season.

Table 13. Decision matrix for selecting priority intervention sites in the Katuk Odeyo block. Cell counts represent the number of 100 m^2 subplots (n = 640) encountered during the baseline survey. Priority intervention sites (351/640) are shown in bold.

		High inherent soil degradation risk ?	
Site cultivated ?	**Woody vegetation cover >60% ?**	*No*	*Yes*
No	*No*	77	**259**
No	*Yes*	9	99
Yes	–	104	**92**

- The current estimate of priority areas for “afforestation/reforestation” in the Katuk Odeyo block is:

3,541 ha (95% CI = 2,356 – 4,935 ha)

- The current estimate of priority areas for “conservation agriculture” in the Katuk Odeyo block is:

773 ha (95% CI = 461 – 1,256 ha)

4.4. *Household survey results*

The Household Survey is the instrument used to collect socioeconomic data. This survey differs from traditional baseline surveys as it focuses on indicators that should be responsive to changes and that can be measured quickly and cheaply. The data should be used by the project to set targets for priorities identified through the development of Participatory Action Plans. Some of the variables surveyed are conditioning variables and will likely not be impacted by the project, but they will predispose the project to different types of interventions. This survey is also not designed to prescribe interventions, but to assist the project team in setting realistic goals once priorities have been agreed upon with communities.

This section summarizes some of the key indicators from the questionnaire that can be found in Annex III. It s not an exhaustive analysis of the database. The project will need to set priorities to guide future analysis. For example, will the project focus on the poorest segment of the population or on the segment of the population that s willing to participate?

For each indicator we will give the results of fitting the model. Whereas this was the first survey in the project, not all of the procedures were properly followed by the survey team, unfortunately. Thus, households were not surveyed by cluster in this block. Analysis by villages showed no natural clustering in the data. There was also no spatial continuity in the data (semivariogram analysis), so these spatial effects were left out of the models. Thus there is no means for interpreting the socioeconomic surveys and biophysical survey together spatrially in this block. This has been rectified in the subsequent surveys.

Results are given on both the linear scale used in model fiting and the back-transformed scale which can be directly interpreted. Beneath each table are key statistics calculated from these results.

4.4.1. Household wellbeing

Table 14. Decision matrix for identifying particularly vulnerable segments of the population; i.e., children and seniors living in thatched roof households or in households without external income sources (n = 412/1305, or ~32% of the population), also see attached dataset (`KOvulnerable.xls`). Cell counts represent the number of individuals in the sampled population (n =1305 individuals distributed within 169 sample households).

		No. household members employed off-farm		
Thatched roof household ?	**Age class ?**	*None*	*1*	*>1*
No	*Children* (< 15 yrs)	**228**	74	78
	Adults	345	94	151
	Seniors (> 65 yrs)	**22**	5	5
Yes	*Children* (< 15 yrs)	**123**	**26**	**5**
	Adults	103	24	10
	Seniors (> 65 yrs)	**8**	**0**	**0**

- The current estimate of the proportion of thatched roof households in the Katuk Odeyo block is:

  27.2% (95% CI = 21.0 – 34.4%)

- The current estimate of the proportion of households in which at least one person has off-farm employment is:

  30.8% (95% CI = 24.3 – 38.1%)

  The current estimate of the proportion of households in which more than one person has off-farm employment is **13.6%** (95% CI = 9.2 – 19.6%).

- Thatched roof households are **2.2** (95% CI = 1.5 – 3.2) times less likely to contain a household member who has off-farm employment than households with metal roofs. Widow(er) headed households are **3.1** (95% CI = 1.3 – 7.1) times less likely to contain a member who has off-farm employment than married households.

Table 15. Analysis of widow headed households and roofing material as an indicator of household wealth.

	Widow headed	
Thatched	*No*	*Yes*
No	36/86	7/37
Yes	8/33	1/13

- The current estimate of average number of persons per household in the Katuk Odeyo block is:

6.2 persons Hh^{-1} (95% CI = 6.2 – 7.3 persons Hh^{-1})

- Overall household size is strongly associated with both housing type (i.e., thatched roofs vs metal roofs) and off-farm employment. Metal roofed households in which >1 persons are employed off-farm tend to be ~50% bigger than thatched roof households in which no one is employed off-farm. Linear model estimates of the main effects are summarized in the following table.

Table 16. Dependency ratio (the proportion of children and seniors) per household.

Model parameter	Estimate	SE
Intercept	-1.87	0.0591
Thatched roof	-0.103	0.105
No. employed off-farm (1)	0.137	0.130
No. employed off-farm (>1)	0.400	0.127
ε		0.527

* note reponse variable is ln(HHsize)

- The average dependency ratio (i.e., the proportion of children and seniors) per household in the Katuk Odeyo block is estimated at: **44.3%** (95% CI = 41.5 – 47.1%, mixed-model analysis not shown).

- Notably thatched roof households have a substantially higher proportion of dependents (**55.7%**, 95% CI = 50.0 – 61.1%) than do households with metal roofs (**40.8%**, 95% CI = 37.7 – 43.9%). No substantial differences in dependency ratios between households with or without off-farm employment were detected after controlling for thatched roofs.

4.4.2. Food Security

Table 17. Estimates of the number of months per year in which Katuk Odeyo households report food deficits. Model family is `Binomial`, response variable is `ln(MFD/12/(1-MFD/12))`, see attached dataset (`KOfood.xls`).

Model parameter	Estimate	SE
Intercept	0.300	0.125
No. employed off-farm (1)	-0.533	0.126
No. employed off-farm (>1)	-0.318	0.150
Widow headed	0.189	0.107
Dependency Ratio > 0.5	0.235	0.104
Household size (no. members)	0.0440	0.0137
Farm size (ha)	-0.0604	0.0178
Herd size (TLU)	-0.0223	0.0141

- The current estimate of average duration of food deficits per year reported by households in the Katuk Odeyo block is:

  7.2 months per year (95% CI = 6.9 – 7.4 months per year)

- The reported duration of months with food deficits is strongly associated with household-level characteristics such as: off-farm employment (none, 1 member, >1 member), widow(er) vs. married households, the number of children and seniors vs the number of adults in the household (Dependency ratio > 0.5), household size (no. of household members), farm size (ha), and household livestock herd size (in Tropical Livestock Unit equivalents).

- The (recall) estimated average annual food expenditures per household in the Katuk Odeyo block is:

  6,152 Ksh Hh^{-1} yr^{-1} (95% CI = 4,322 – 8,757 Ksh HH^{-1} yr^{-1})

- Average annual household food expenditures are positively associated with household size and the number of months per year for which households report food deficits. Notably in the current assessment larger households reported lower per capita expenditures per month of food deficit than did smaller households.

- Looking at the size of the parameters for agricultural resources, compared to those for off-farm employment, it would take an extra 8.8 ha or 24 cows to increase food security to the same extent as one person working off farm, at the current rates of productivity.

Table 18. Household expenditures on food grains (ln shillings). MFD = months of food deficit

Model parameter	**Estimate**	**SE**
Intercept	3.8	0.68
Household size (no. members)	0.25	0.084
Reported food deficits (months yr^{-1})	0.59	0.086
HHsize × *MFD*	-0.022	0.011
ε		1.7

- Average HH expenditure on grain is KSh 6,000. This suggests that farmers do not greatly supplement what they grow on the farm with purchased grains.
- Taken in the context of table 17, these results suggest that on-farm resources are essential for survival, but irrelevant to getting out of poverty.

4.4.3. Livestock Ownership

This analysis uses tropical livestock units (TLU's) to find equivalence between the different types of livestock kept by the farmers. TLU's are calculated on the basis of 350 kg live weight equivalents. These numbers can be used to assess livestock herd resource requirements, which can be compared against vegetation resources within the block. These values can also be used to assess other interesting elements, for example, the CH_4 emissions from livestock.

Table 19. Conversion factors

Livestock type	**TLU**
Camels	1.1
Cattle	
Adults	0.8
Calves	0.25
Donkeys	0.8
Smallstock	0.2
Poultry	0.01

Table 20. Herd size correlates LnTLUs

Model parameter	Estimate	SE
Intercept	0.72	0.090
Widow headed	-0.23	0.094
Household size (no. members)	0.059	0.0078
Farm size (ha)	0.069	0.0087

* response variable is log(TLU)

- An average household in the Katuk Odeyo block owns **3.9** Tropical Livestock Units (95% CI = 3.6 – 4.2 TLU).
- Livestock ownership is positively associated with household and farm size. Widow headed households have substantially fewer livestock than married households.

On-farm interventions for project activities should target the most vulnerable segments of the population.

5. Using baseline information for setting project objectives

Use of the baseline data will depend on the priorities that the project team establishes in each block with the communities. For example, using an area expansion factor of 10,000 ha the number of trees in the Katuk-Odeyo block is estimated to lie between 10,663 and 45,328 trees at a 95% level of confidence. This estimate provides the baseline that is needed for setting project targets, for planning interventions and for resource allocation.

For example, the project intends to promote aforestation/reforestion (AR) interventions to increase tree density and cover in Katuk-Odeyo. For project planning purposes this requires setting clear targets as to how many tree seedlings need to be produced, distributed and planted over a 3 year time horizon to achieve a certain level of AR impact in the project area.

The decisions that are made in this regard will have implications for human and financial resource allocation in the project and will determine which monitoring and evaluation activities need to be undertaken and what the likely impacts in terms of carbon sequestration, biodiversity and soil erosion control are likely to be.

5.1. Assessing tree demand and setting realistic project implementation targets

A major factor in determining what can be realistically accomplished in terms of AR activities (or any other activities) in Katuk-Odeyo will depend what it is that the community is willing to do and which types of activities it is willing to invest labor and resources.

In the case of AR activities, we have attempted to assess this using a simple contingent valuation to assess the demand for additional trees (see Table below) in Katuk-Odeyo. A total of 169 household heads where asked how many trees they would be willing to plant in the upcoming planting season under three different scenarios: the first scenario involved receiving **free** seedlings from the project, the 2nd involved **paying** 10 KSh per seedling and the 3rd involved **receiving** 10 KSh from the project for each seedling that is planted and which survives to 1 year following planting.

Table 21. Estimates of household-level tree demand in the Katuk-Odeyo block. Model family is Gaussian, response variable is `ln(Trees+1)`, see attached dataset (`KOtreedem.xls`).

Model Parameter	*Lower*	*Est.*	*Upper*
Intercept	2.5	3.0	3.5
Incentive level (KSh tree^{-1})	0.073	0.087	0.10
Widow(er) headed	-0.98	-0.50	-0.016
Household size (no. members)	0.019	0.074	0.13
$\sigma_{Intercept}$	1.2	1.3	1.5
$\sigma_{Incentive}$	0.033	0.050	0.077
ε	0.97	1.1	1.2

The following generalized linear model was used to evaluate responses to the three scenarios including fixed-effects covariates on widow(er) headed households (binary, widowed or married) and household size (count, no. of household members) in the evaluation, which to a large part determine household labor availability and resource endowment for the i^{th} household and j^{th} incentive level (j = -10, 0 or +10 KSh per seedling) as follows:

$$\ln(y_{ij}+1) = \beta_0 + \beta_1 C_j + \beta_2 W + \beta_2 S + b_i + b_{ij} C_j + \varepsilon_{ij}$$

for which the β's are fixed effects and the b's are random effects at the household level. This model contains a single level of grouping at the household level of observation, and the response variable in $\ln(y_{ij} + 1)$ units is assumed to follow a Gaussian distribution.

Based on fitting the model to the data, the average demand for additional trees in Katuk-Odeyo is currently estimated at approximately 30 trees per household (95% CI = 23 – 38 trees per household), provided that there are no incentive payments or compensation for planting (see Table 21). Widow headed households that constitute an estimated xx% of the population of households in Katuk are likely to plant

Furthermore, based on household survey data an average household owns or manages 1.5 – 2 ha of land, and assuming that 100% of the land is owned or managed by a household, there are approximately 5000 – 6700 resident households in the block. Correspondingly **the total estimated demand for additional trees lies in the vicinity of 150,000 – 201,000 trees during the first planting season in Katuk-Odeyo**. It is currently not clear whether this demand structure would change over time; however, this could easily be assessed through repeated household surveys, once the initial demand for trees has been has been met. Assessing changes in tree demand, and indeed the overall service delivery within the project would need to be incorporated into the monitoring and evaluation component of the project.

5.2. Spatial targeting and priority setting

An additional major consideration for project planning is where in the landscape should the proposed AR activities occur. Not all places in the landscape will be equally suitable. For example, ~3,020 ha of the Katuk-Odeyo block are currently being cultivated (see Table 1), and may therefore not be suitable for aforestation/reforestation (AR) due to the existence of a competing land use.

There may also be particularly vulnerable portions of the landscape that warrant special attention and denser woody vegetation cover for environmental reasons, and/or areas that may already have dense woody vegetation cover (including shrubs and small trees) which should be excluded from project AR activities. So the following simple rule base for prioritizing project AR activities might be applied.

- If existing woody vegetation cover on the site is **less than 60%**, {and}
- the site is currently **not cultivated**, {and}
- the site has a **high soil degradation risk** (i.e., slope > 30%, {or} soil depth restriction to 50 cm, {or} sharp texture contrast between top and subsoil), {then}
- the site is a **priority site** for project AR activities.

The table below summarizes model estimates of the percentages of areas with dense woody vegetation cover, cultivated areas and areas with high soil degradation risk disaggregated at the cluster-level of observation. Also shown are the estimates of the percentage of area, which given the prioritization rule-base might be targeted with AR activities by the An estimated ~3,541 ha (95% CI = 2,356 – 4,935 ha) of the Katuk-Odeyo block would qualify for this type of intervention.

Cluster ID	% area WC > 60%	% area Cultivated	% area high SDR	**% area priority AR**	**Tree density (no. trees ha^{-1})**
1	9	41	77	21	1
2	16	27	85	53	5
3	2	36	59	50	4
4	2	51	38	18	1
5	16	28	72	38	2
6	3	31	77	43	1
7	2	29	88	65	1
8	2	19	88	73	3
9	9	35	82	45	3
10	2	35	58	48	0
11	4	48	34	23	0
12	27	14	91	45	15
13	26	31	79	15	0
14	54	20	87	10	41
15	8	32	76	45	3
16	26	13	93	60	3

6. Management Recommendations

This baseline report has documented the widespread risk of soil degradation and soil depth limitations in the block. The baseline has also documented that there would need to be a large increase in either cultivated area or livestock numbers to achieve food security and improve livelihoods. Whereas the project aspires to addressing poverty and food security, emphasis must be put on raising the productivity of the land, switching to higher value cropping systems, but ensuring that this does not put at risk the grain supply of the population.

The main management recommendations for the block are to focus on afforestation and reforestation on priority sites and focus on conservation soil management on croplands that are at risk. These areas make up over 75% of the block.

Figure 9 presents a spatial interpretation of the management recommendations. A small area in the southeastern and southwestern corners of the block should be prioritized for conservation agriculture interventions to avoid the future likelihood of degradation and to

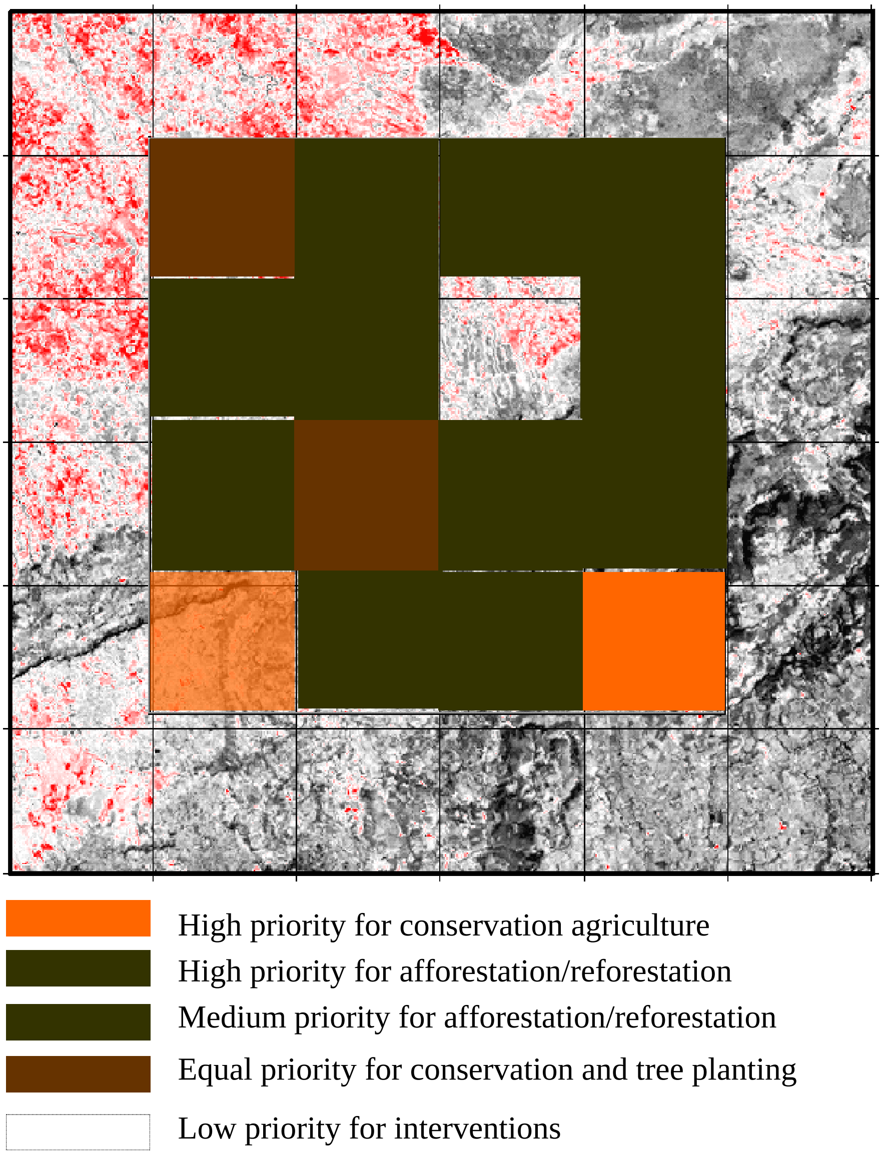

Figure 9. Spatial delineation of priority interventions in the Ketuk Odeyo block based upon the criteria in the decision matrix in Table 13.

both protect and increase crop productivity. We have identified two levels of priority for intervention with tree planting activities. High priority areas are those with extensive areas of abandoned and degraded land. These areas tend to be relatively flat, but the sodic soils and the advanced stages of hard setting in these areas call for prioritizing them for intervention. The steeper areas in the southeastern corner of the block tend to have higher tree cover and the soils are less degraded. Because of the steepness of the terrain, there has been less conversion to agriculture. Interventions should focus on increasing tree cover where possible and working with the communities to avoid devegetation. Finally, there are two areas where there is a significant amount of agricultural activity and where there is a significant amount of abandoned and degraded land. These areas are probably in a transition from widespread agriculture to widespread land degradation. The focus needs to be on rehabilitation of degraded lands and better management of agricultural lands in these areas.

Appendix 1. Sample S-Plus/R code

1. Estimating the proportion of land area under cultivation from LDSF survey data using a generalized linear mixed model with random effects grouping at the cluster level. (attached dataset: `KOcult.xls`)

```
# load the glme library

library(correlatedData)

# fit the model

KOcult.glme <- glme(cbind(Cult,n-Cult)~1, random=~1| Cluster,
family = binomial(link=logit), method=”REPQL”, dispersion=1,
data=KOcult)

# display the results

summary (KOcult.glme)

# estimate the confindence intervals

intervals (KOcult.glme)
```

2. Estimating the proportion of land area with soil depth restrictions to 20 cm from LDSF survey data using a generalized linear mixed model with random effects grouping at the Cluster/Plot levels. (attached dataset: `KOdepth.xls`)

```
# load the glme library

library(correlatedData)

# fit the model

KOdepth.glme <- glme(cbind(R20,n-R20)~1, random=~1| Cluster/Plot,
family = binomial(link=logit), method=”REPQL”, dispersion=1,
data=KOdepth)

# display the results

summary (KOdepth.glme)

# estimate and display the confindence intervals

intervals (KOdepth.glme)

# save the cluster level model intercepts
```

```
KOdepth.coef <- coef(KOdepth.glme, level=1)
```

3. Estimating the steady state infiltration capacity of soils from LDSF survey data using a mixed model version of the Horton infiltration equation, with grouping at the plot level (attached dataset: `KOinfilt.xls`).

```
# create a grouped data object

KOinf <- groupedData(IR~Time|ID, data=KOinfilt)

# display the raw data

plot(KOinf)

# fit the Horton model using the self starting nlme library function
SSasymp

KOinf.nlme <- nlme(IR~SSasymp(Time,f1,f2,f3), fixed=f1+f2+f3~1,
random=f1+f2+f3~1, data=KOinf)

# display the augmented predictions

plot(augpred(KOinf.nlme))

# examine the model residuals and fit

plot(KOinf.nlme)

plot(KOinf.nlme, IR~fitted(.))

# extract the model coefficients (f1, corresponds to the estimated
steady-state infiltration capacity

KOinf.coef <- coef(KOinf.nlme, augFrame=T)
```