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# Large Scale Environmental Assessment and Degradation Management: The Case of Food Insecurity in Ethiopia

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## Abstract

The aim of this study is large scale environmental assessment and ecosystem degradation management in Ethiopia. To achieve this aim, eight years (2001-2008) of 500 meter MODIS Collection 5 global land cover type classification maps of the International Geosphere-Biosphere Programme (IGBP) were used to assess land cover changes in Ethiopia. Based on detailed assessment of the data and our aim, we chose nine out of a possible 54 land cover type transitions for modelling ecosystem degradation. We tested bio-physical, imaged-based, climatic and surrogate socio-economic independent variables to model the nine transitions that were grouped into categories of worsening and improving ecosystem trends. Separate logistic regression analyses were successfully conducted for the transition modelling. The changes were then predicted in an integrated dynamic way for the year 2013 to provide a basis for examining trends in ecosystem condition. Proximity to roads, main towns and urban areas and villages, and distance to croplands and barren lands were the most influential variables in the changing cover types. These variables are also directly manageable for controlling the downgrading trends in the country. The study provided a paradigm for further in depth studies and was linked with available results on climate assessment. Thus, the results can be joined to scenarios of climate and socio-economic changes to provide a platform for informed attempts in reversing the unwanted trends in land use/cover changes in Ethiopia.

***Keywords***: Land Use, Cover Change, Modeling, Ecosystem Downgrading

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## 1. Introduction

Ethiopia is the second most populous country in Africa, with around 40% of the population suffering from food shortages and more than four million people requiring emergency food assistance (FEWS NET Ethiopia Food Security Outlook Update, October 2011). Optimal targeting and distribution of such massive quantities of food aid is managed through complex analyses of demographics, livelihoods, and seasonal climate outlooks. The United States Agency for International Aid Development (USAID) Famine Early Warning System Network (FEWS NET) was developed to assess food insecurity using such a framework. FEWS NET might also benefit from assessments of ecosystem condition and trends at sub-national scales. This study presents one such pilot study, focused on Ethiopia. In this paper, we analyse land cover transitions in Ethiopia, and link the observed drivers to food security and climate trends.

In recent years, the link between ecosystem components and food security has attracted much attention (see for example Fraser, 2006; Toledo and Burlingame, 2006; Wardlow *et al.,* 2006; Amsalu *et al.,* 2007; Jakobsen *et al.,* 2007; Brussaard *et al.,* 2010; Tscharntke *et al.,* 2010; Fraser, 2011; Powlson *et al.,* 2011; Thenkabail *et al.,* 2012). Of particular interest are models focused on predicting and explaining land cover changes through regression and spatial transition-based model types (Theobald and Hobbs, 1998). These models can inform policy (what might be the land use impact associated with building a road), and assist in medium term planning (what might land use look like in fifteen years?). For example, Lu *et al.* (2012) conclude that change detection is useful in better planning and managing land resources and examining the impacts of population migration and changing economic conditions on land use/cover transformation and for assessing shifts in environmental conditions due to these changes. Studies worldwide have shown the relevance of land use/cover transition modelling to top soil protection, surface water and run off and underground water management, soil nutrients, productivity, ecosystem health and prosperity of human altered regions of the earth.

Obviously, some of the causes of ecosystem degradation can be traced back, to such factors as climate change, water imbalance, soil erosion and nutrients depletion. The likely effects of land use change and climate variability on water balance, surface runoff, soil water capacity and evapotranspiration and nitrate and soil nutrient depletion have been shown to be meaningful (Legesse *et al.,* 2003; Braimoh and Vlek, 2005, Li *et al.,* 2009; Jensen and Veihe, 2009). Among their findings, Legesse *et al.* (2003) demonstrated that converting the present day dominantly cultivated/grazing land in their studied river basin to woodland would decrease the discharge at the outlet by about 8%. Focusing on Ethiopia, Garedew (2010) found that the dramatic trends in land use and land cover changes were associated with rapid population growth, recurrent droughts, rainfall variability and declining agricultural productivity.

While the value of detailed studies, such as that carried out by Garedew (2010), are clear for development, their limited spatial dimension and considerable cost make them prohibitive for routine applications at national or international scales. It is, however, observed that utilization of available low resolution remotely-sensed imagery such as that provided by the Moderate Resolution Imaging Spectroradiometer (MODIS) on board NASA's Aqua and Terra satellites for land cover change assessments in Ethiopia has been limited. This is in spite of the fact that these data provide at least a time span of 10 years and has enormous capabilities in terms of change assessment, prediction and modelling (see for example Wardlow *et al.,* 2006; Xiao *et al.,* 2006; Dheeravath *et al.,* 2010; Vintrou *et al.,* 2012).

In this paper, we analyse MODIS Collection 5 global land cover changes in Ethiopia. The change in land cover types are estimated over the time period 2001-2008, and are related to ecological and surrogate socio-economic factors such as proximity to roads and rural and urban areas. The cover types selected in our study are those directly or indirectly related to drought and ecosystem degradation. We use Idrisi's Environmental Modeller (Eastman, 2009) to perform a comprehensive and dynamic land use/cover change modelling and prediction. We finalize our research by providing maps of ecosystem deterioration and enhancement, based on changes in selected cover types combined with population pressure. We also link loosely our results to recent climate change analyses for the area, providing an integrated assessment of the situation in Ethiopia.

## 2. Material and methods

### The Study Area

The study area chosen for this analysis is Ethiopia, a country affected by poor environmental and food security conditions. The country has a surface area of about 1.1 million square kilometres and a population of about 80 million. The country has a high central plateau with an elevation that varies from 1800 to 3000 meters above sea level, with some mountains reaching 4620 meters. A number of rivers cross the plateau--notably the Blue Nile flowing from Lake Tana. The climate is temperate on the plateau and hot in the lowlands. The country receives most of its rainfall between March and September. Ethiopia is routinely listed as a highly food insecure country. Recently, only the west of the country was assessed to be generally food secure, while large areas in the north, east and southeast were evaluated as moderately, highly or extremely food insecure (FEWS NET Ethiopia Food Security Outlook Update, October 2011).

### Data Used in the Change Assessment and Modelling

Maps of nine major transitions of land cover types during 2001-2008 were used as dependent layers in individual and simultaneous logistic regression analyses. A data base of independent variables including bio-physical, image-based, surrogate socio-economic factors and climatic variables (Table 1) were used as potential predictors.

**Table 1.** Data layers used in the change modelling for Ethiopia

| Categories | Parameters | Source, Original Resolution |
|---|---|---|
| Bio-physical | Elevation | DEM, 90 m |
| | Slope | DEM, 90 m |
| | Distance to Rivers | DEM, 90 m |
| Image-Based | AVHRR Tree% | AVHRR, 1000 m |
| | Max NDVI | Spot Veg. 1000 m |
| | NDVI Fragmentation Index | Spot Veg. 1000 m |
| | Cover Type Diversity | MODIS, 500 m |
| | Distance to Cover Types | MODIS, 500 m |
| Socio-Economic | Distance to Roads | VMAP01, Vector |
| | Distance to Urban Areas | VMAP01, Vector |
| | Distance to Villages | VMAP01, Vector |
| | Population Density | LandScan$^{TM}$, 1000 m |
| Climatic Variables | Mean Annual Temperature | WorldClim, 1000 m |
| | Mean Annual Rainfall | WorldClim, 1000 m |
| | Precipitation of the Driest Month | WorldClim, 1000 m |

A digital elevation model (DEM) of the country at 90 m resolution was accessed through the CGIAR Consortium (http://srtm.csi.cgiar.org/) and degraded to 500 m resolution and used together with the derived slope layer in the later analyses. A river network was extracted from the DEM and amended by the available hydrology layers. The analysis also used the 1 km Advanced Very High Resolution Radiometer (AVHRR) continuous fields of vegetation; each pixel in the layer has a value between 10 and 80%, representing density of forest cover. The initially 1000 m resolution pixels were re-sampled to 500 m resolution. Normalized difference vegetation index (NDVI) layers of the whole continent in 1000 m resolution provided by SPOT (http://free.vgt.vito.be) were accessed for 16 day combinations, 12 for each year, encompassing the years 2001-2003. The data were re-sampled to 500 m resolution and were subjected to a “mode” filter to capture the most frequent NDVI values in the three years span. Then, the maximum NDVI and NDVI fragmentation index layers were generated for use in later analyses. The fragmentation index measures the number of different classes in a spatial window which was 5 by 5 in our case. Studies show that NDVI values and their spatial change may be related to land cover transitions, as they represent direct and indirect human modifications of the landscape and natural vegetation characteristics (Kogan, 2000; Salman Mahiny and Turner, 2003; Salman Mahiny, 2005).

MODIS collection 5 data (LP DAAC Modis) were used to identify land cover changes. MODIS operates on both the Terra and Aqua spacecraft, has a viewing swath of 2330 km, and observes the entire surface of the Earth every one to two days (LP DAAC Modis Overview). The MODIS Land Cover Type product contains multiple classification schemes of which we used the primary land cover scheme with 17 land cover classes defined by the International Geosphere Biosphere Programme (IGBP), which includes 11 natural vegetation classes, three developed and mosaicked land classes, and three non-vegetated land classes (Table 2).

**Table 2.** Initial IGBP land cover classes used in modelling cover changes in Ethiopia

| Code | Land Cover |
|---|---|
| 0 | Water |
| 1 | Evergreen Needleleaf Forest |
| 2 | Evergreen Broadleaf Forest |
| 3 | Deciduous Needleleaf Forest |
| 4 | Deciduous Broadleaf Forest |
| 5 | Mixed Forest |
| 6 | Closed Shrublands |
| 7 | Open Shrublands |
| 8 | Woody Savannas |
| 9 | Savannas |
| 10 | Grasslands |
| 11 | Permanent Wetlands |
| 12 | Croplands |
| 13 | Urban and Built-up |
| 14 | Cropland/Natural Vegetation Mosaic |
| 15 | Snow and Ice |
| 16 | Barren and Sparsely Vegetated |
| 254 | Unclassified |

The forested classes of the IGBP categories were merged and smoothed using 5 by 5 moving windows and three year composites. The first composite period corresponds to the beginning of the study period (2001-2003) and the second corresponds to the last three years (2006-2008). For each 500m pixel, 75 land cover values (from the surrounding 25 pixels, for each of the three years) were examined, and the most frequent cover type estimated. This approach was used to dampen the impacts of inter-annual climate variations, and to focus on the large scale patterns in land cover/land use changes. We also subjected the final maps to 5 by 5 diversity filter. This composite layer helped in the assessment of the relationships between diversity of land cover types in each window and their probability of change (Salman Mahiny and Turner, 2003).

Initially, a number of Boolean layers of different land use and cover types were generated as “Design Variables” (Hu and Lo, 2007). These layers were later changed into evidence likelihood. Also, for each change category, the area of “from” in the “from-to” transition space was used as a mask to confine modelling to the extent of possible changes. Distance to various cover types under human influence or the man-made cover types such as croplands and grasslands was also created and used in the modelling process.

Distance from the roads network layer, built up areas and villages obtained from VMAP01 (www.mapability.com) was computed as surrogate socio-economic layers. Land Scan TM data depicting the population density was another layer used in our modelling and in this data, the census counts (at sub-national level) were apportioned to each grid cell based on likelihood coefficients. These coefficients are based on proximity to roads, slope, land cover, night-time lights, and other information (www.ornl.gov/sci/landscan).

World Clim data set (Hijmans *et al.,* 2006) that contain 18 different layers of climatic variables were assessed for correlation, out of which three including mean annual temperature, mean annual precipitation and precipitation of the driest month were used in later analyses. All other data layers were also assessed for correlation before use in logistic regression modelling.

## Modelling and predicting land cover changes in Ethiopia

The combined maps of the start and the end dates were cross-tabulated that showed 54 transitions out of which nine were deemed meaningful in terms of: (1) amount of change (more than 20000 hectares over the whole country), (2) pattern of change and (3) the aim of this study (Table 3).

**Table 3.** Change classes used in the modelling

| From | To | |
|---|---|---|
| Forest | Cropland | Degrading |
| Forest | Mix of Natural Veg. and Cropland | |
| Open Shrubland | Grassland | |
| Closed Shrubland | Open Shrubland | |
| Open Shrubland | Barren | |
| Barren | Open Shrubland | Improving |
| Barren | Closed Shrubland | |
| Open Shrubland | Closed Shrubland | |
| Grassland | Open Shrubland | |

Initially, separate logistic regression analyses were applied to each class of change. To do this, the transition areas for the nine categories were used as dependent variables against 18 independent variables. To remove the effect of autocorrelation which is normally expected in spatial data, a thinning procedure was undertaken with a 5 by 5 window size. Then, the thinned out layers were used in the regression analyses.

Logistic regression (LR) is a special case of multiple regression in which the dependent variable is discrete (Hosmer and Lemeshow, 1989) such as land cover types. In logistic regression, generally two parameters are used to assess the success of the modelling: Pseudo R2 and relative operating characteristic (ROC). A Pseudo R2 of 1 indicates a perfect fit, whereas a Pseudo R2 equal to 0 indicates no relationship. Clark and Hosking (1986) comment that a Pseudo R2 greater than 0.2 can be considered as a relatively good fit (Eastman, 2009).When there is a perfect match between reality map and the modelled one, the ROC takes a value of one. In the case where there is no spatial agreement between the two maps, the ROC value equals 0.5. After obtaining satisfactory results from the individual logistic regressions, we used the Land Change Modeller (LCM) of Idrisi to conduct a comprehensive simultaneous change assessment and prediction. The LCM allows multiple changes to be evaluated, the location and amount of change be determined and transitions be predicted for a foreseeable future in an integrated dynamic fashion.

The combined map of the years 2001, 2002 and 2003 was used as the earlier date, and that of the years 2006, 2007 and 2008 as the later date. After studying the spatial trends of changes, transition sub-models were selected based on Table 3. The LCM allows static and dynamic roles for the variables of the independent variables, we allowed distance to urban areas, to roads and to villages be dynamic. In this way, through the modelling process, these layers were re-evaluated at each stage of change, adjusted accordingly and then used in the model. As we were using full independent and dependent layers in the LCM environment, we applied a stratified random sampling of 10% to the layers to remove the effects of auto-correlation. This procedure had the same effect of the previously mentioned layer thinning.

A Markov Chain was used to calculate the amount and percentage of change between the land-types included in the nine change categories. The end date for prediction was set at 2013, as we postulated that given the middle year of the earlier and later maps, there was a five year interval in the change detection process conducted. We used nine dynamic variable recalculation stages, three per each dynamic variable. Then, a soft prediction mapping using "Logical Or" was implemented which resulted in a soft map showing the likelihood of change for each pixel and also a hard map of the possible distribution and areal coverage of land cover types for the year 2013 was created.

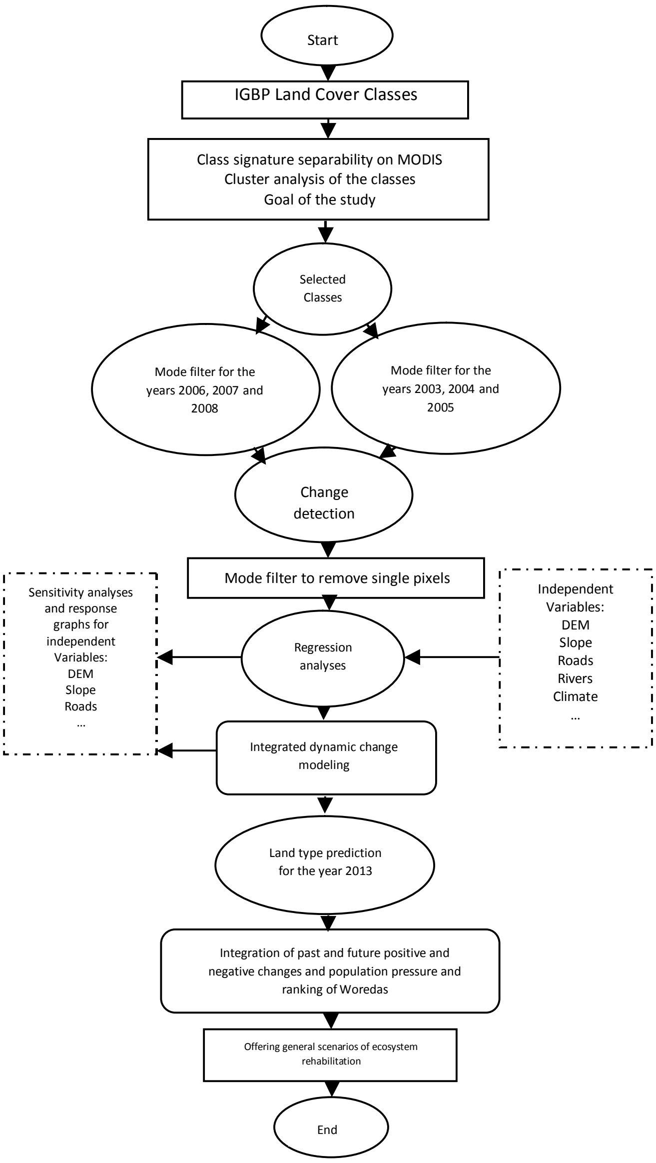

**Figure 1.** Flowchart of the study

The changes happened between the years 2001-2003 and 2006-2008 and those that were predicted to happen were used to assess the major negative and positive trends in Ethiopia. These were then associated with the provincial boundaries of Ethiopia (Woredas) to provide a basis for early warning in ecosystem degradation.

In other words, we measured those changes in land cover types per province in Ethiopia that were negative for ecosystem health and used the results relative to the population size of each province. This process resulted in a ranking of provinces in terms of ecosystem degradation balanced by their population (Figure 1). Woredas are administrative boundaries of Ethiopia for which we provide maps of ecosystem deterioration and enhancement. The negative changes in the cover types are taken as precursors of ecosystem degradation. Also, the population size of each management unit in Ethiopia is considered a factor related to the carrying capacity of that unit. Hence, we expect the ranking should depict in some way the environmental insecurity likelihood in Ethiopia.

## 3. Results

We designed our analysis to focus on distinct class transitions. Assessment of land cover classes showed that the mix of croplands and natural vegetation can be confused with the cropland sites. We also found that the grasslands could be taken as croplands and vice versa. Transitions between closed shrublands and savanna, woody savanna and savanna, forest and woody savanna, cropland and woody and non-woody savanna were not highly reliable. We merged these classes such that they best fit our aim, which was assessment of negative changes in the country that could ultimately be linked to ecosystem degradation. The net change during the years 2001-2008 is shown in Figure 2.

It can be seen that the net change in categories of our interest including barren areas, mix of natural vegetation and croplands, grasslands, closed shrublands and forest areas are negative and those of the croplands and open shrublands are positive. Of these transitions, we identified forest to croplands, forest to mix of natural vegetation and croplands, closed to open shrublands and open shrublands to barren areas as degrading ecosystem conditions while the other four transitions were defined as improving ecosystem conditions.

Transitions in the nine selected categories were successfully modeled through logistic regression (higher than 0.2 in pseudo R square and above 0.9 for ROC) using the suite of independent layers. To assess the condition of each Woreda in terms of negative and positive trends in the cover classes, the area of change in each cover class was extracted. Positive changes including “barren to open shrubland”, “barren to closed shrubland”, “grassland to open shrubland” and “open shrubland to closed shrubland” were divided by the area of the corresponding cover types to calculate the ratio of change in cover type. The same procedure was undertaken for the negative changes that included “forest to cropland”, “forest to mix of natural vegetation and cropland”, “closed shrubland to open shrubland” and “open shrubland to barren”. The difference between the negative and positive changes provided a basis for a raw assessment of ecosystem degradation in the country as detected from the past and modelled change for future. The detected and modelled change in the land cover types were calculated over each Woreda.

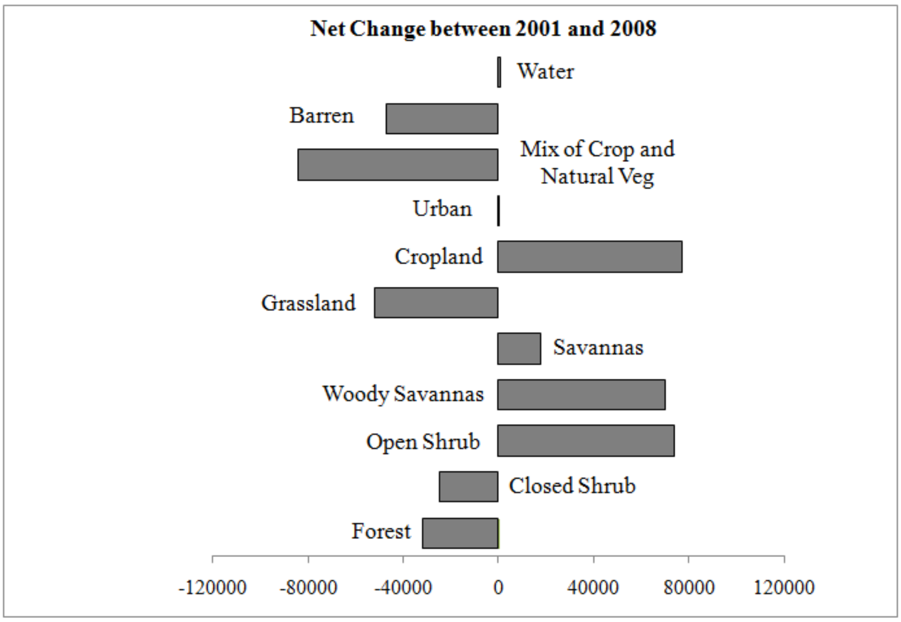

**Figure 2.** Net change in cover types between 2001 and 2008 using mode filtered maps

We treated all changes in the cover types as equal to simplify the calculations. However, the cover types are not equal in terms of their role in deterring or accelerating ecosystem deterioration. To address this issue properly, there is a need for more accurate land cover classification, comprehensive data on the effects of the selected cover types on surface water runoff, water infiltration, soil protection, soil nutrient cycling, food and fodder production and so forth.

We postulated that the human population interacting with rainfall in the country is one of the factors contributing to or exacerbating the effects of ecosystem degradation (Figure 3). We went further in our analysis by combining analysis of recent Ethiopian climate trends with land use maps. These intersection maps can be used to help guide policy and climate change adaptation strategies. For details of the spatial interpolation procedure used to produce these maps, please see Funk and Michaelsen (2010). Ethiopia has two rainy seasons, namely the belg and the meher. The belg rains which occur during the boreal spring (March-April-May-June, MAMJ), providing beneficial moisture to the southern third of the country. As the inter-tropical front travels north during the summer (June-July-August-September, JJAS), the main rainy season (the meher) begins in earnest. Careful analysis of dense gauge data from the Ethiopian meteorological agency has revealed considerable downward trends during both the MAMJ and JJAS seasons (Fig. 4). In Figure 4, the shaded areas between these two contours identify areas experiencing climate transitions; places where the new normal may not support productive agriculture. In MAMJ, we see a broad contraction of the MAMJ contour line, with the most striking impacts across the eastern highlands, directly east of Addis Ababa. During JJAS, this same very densely populated region in southern Ethiopia may be facing increasing drought.

In terms of population, we divided the population of each Woreda derived from the Land ScanTM data by the area of that Woreda and the result was used as a factor in the assessment of negative or positive trends. Multiplying the population per unit area of each Woreda to the difference of the negative and positive changes in cover types made it possible to rank the Woredas in terms of their food security situation in light of the climatic trends briefly outlined above. Table 4 shows the process undertaken to rank the Woredas here for 10 units. The trend of change for the whole country in terms of ecosystem degradation and improvement with and without human population pressure is depicted in Figure 5.

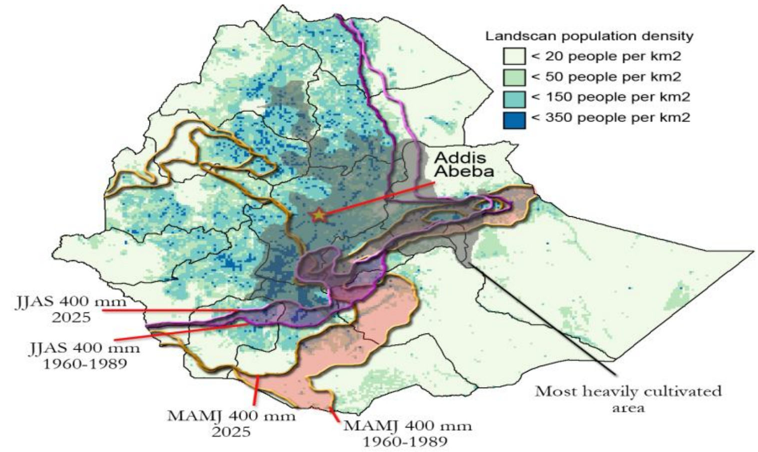

**Figure 3.** Landscan population with overlays relating to MAMJ rainfall change (yellow lines), JJAS rainfall change (purple lines) and the densest region of cultivation (gray polygon).

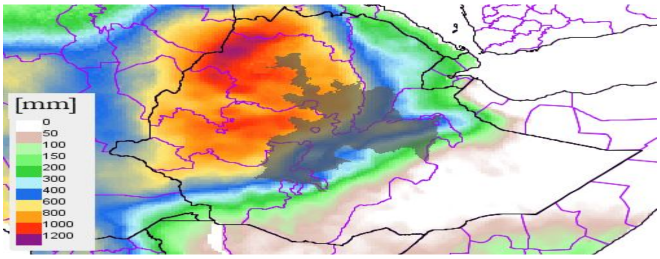

**Figure 4.** Projected 2010-2039 JJAS rainfall, with an overlay showing the area of highest land cultivation, based on the 2001-2008 land cover classification.

**Table 4.** The process of ranking Woredas for ecosystem change and population pressure

| | | Ecosystem Changes Only | | | Ecosystem Changes and Population Pressure | |
|---|---|---|---|---|---|---|
| Woredas | Area_Sq K | All Negative Changes/ Area | All Positive Changes/Area | Difference between Negative and Positive | Population/ Area | Trends = Difference* Area Adjusted Population |
| 1 | 5214.53 | 72.79 | 0.04 | 72.75 | 429.95 | 31278.76 |
| 2 | 13053.24 | 65.99 | 25.21 | 40.78 | 574.42 | 23424.85 |
| 3 | 7809.41 | 130.56 | 0.97 | 129.59 | 330.67 | 42850.43 |
| 4 | 25436.01 | 8.82 | 54.97 | -46.14 | 49.32 | -2276.02 |
| 5 | 59024.96 | 2.24 | 127.19 | -124.95 | 28.78 | -3595.88 |
| 6 | 5602.82 | 5.10 | 0.00 | 5.10 | 306.15 | 1561.60 |
| 7 | 11014.55 | 23.11 | 68.07 | -44.96 | 185.53 | -8342.10 |
| 8 | 26095.58 | 4.96 | 89.18 | -84.22 | 57.21 | -4818.08 |
| 9 | 5609.40 | 44.76 | 1.56 | 43.20 | 517.98 | 22374.39 |
| 10 | 7813.95 | 117.05 | 1.61 | 115.44 | 321.52 | 37115.60 |

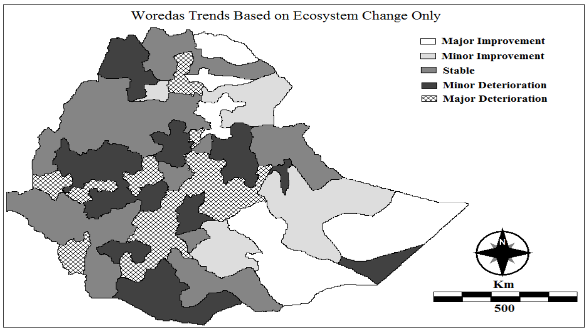

**Figure 5.** Trends of Woredas in Ethiopia based on ecosystem change (top) and mix of ecosystem change and population pressure (bottom)

The impact of independent variables in the logistic regression analyses were also assessed (Table 5) using sensitivity analyses of the logistic regression models based on Pseudo R2. In the process, independent variables were dropped one at a time and the change in Pseudo R2 was noted. The independent variables were then ranked for their strengths in the modelling applications (Rank in Table 5).

**Table 5.** Importance of independent variables in modelling cover types transitions

| | Cover Type Transitions | | | | | | | | | Rank |
|---|---|---|---|---|---|---|---|---|---|---|
| | Forest to Cropland | Forest to Mix of Natural Veg and Cropland | Closed Shrubland to Open Shrubland | Open Shrubland to Grassland | Open Shrubland to Barren | Barren to Open Shrubland | Barren to Closed Shrubland | Open Shrubland to Closed Shrubland | Grassland to Open Shrubland | |
| Cover Type Frequency | **F*** | **F*** | **O**, Cl***** | **G*** | **B**** | **B***** | **C*** | **Cl**, O****** | – | **1** |
| Distance to Villages | ***** | – | – | **** | – | – | – | – | * | **2** |
| AVHRR Tree % | **** | * | – | – | – | – | * | ** | * | **3** |
| Population Density | ** | **** | – | – | * | – | – | * | – | **4** |
| Distance to Cover Types | C* | **M***** | – | **G**** | – | – | – | **M*** | – | **5** |
| Distance to Urban Areas | – | * | ** | – | – | * | * | ** | – | **5** |
| Mean Annual Temperature | *** | * | – | – | * | – | * | – | * | **5** |
| Precipitation of the Driest Month | – | – | – | ** | *** | * | – | – | * | **5** |
| Slope | – | * | * | * | – | – | ** | – | – | **6** |
| Distance to Roads | ** | * | – | – | * | * | – | – | – | **6** |
| Mean Annual Rainfall | – | – | – | – | – | ** | – | – | ** | **7** |
| NDVI Range | – | – | * | ** | – | – | – | – | – | **8** |
| NDVI Fragmentation Index | – | – | – | – | – | * | ** | – | – | **8** |
| Elevation | – | – | – | * | – | – | – | * | – | **9** |
| Distance to Rivers | – | – | – | – | * | – | * | – | – | **9** |
| Cover Type Diversity | – | – | – | – | – | – | – | * | – | **10** |

F= Forest, C= Cropland, M= Mix of Natural Veg and Cropland, O= Open Shrubland, Cl= Closed Shrubland, G= Grassland, B= Barren,
*Shows importance of the variables, the more asterisks, the higher the importance of the variables
Rank= Based on the strength of parameters used

As can be seen from Table 5, cover type frequency which is the number of different cover types in a 5 by 5 window, has the highest rank in causing or acting as a surrogate of change in land covers studied here. As far as the logistic regression modelling has been able to relate independent variables to the dependent variable, this indicates that transitions in cover types is primarily a matter of frequency of occurrence for each cover type. Distance to villages is ranked second showing the effect of people living in small communities on the change in cover types. Percentage of tree cover as estimated through the AVHRR imagery is ranked third and population density is ranked fourth showing the effect of human population in cover type transition. It seems that at the scale of this study, covering the whole of Ethiopia, the higher the number of people per area, the higher the likelihood of cover type change which is a reasonable conclusion.

Distance to cover types was ranked fifth and included croplands (C), mix of natural vegetation and cropland (M), and grasslands as a proxy of croplands (G). This clearly shows the effects of human activities in the area, as these cover types are all manmade or man-altered ecosystems. In other words, where humans have been active in the area cropping for food and other commodities, there has been a tendency in expanding the cultivated area and modifying surrounding natural ecosystems. Distance to urban areas and mean annual temperature factors were both rated fifth. Precipitation of the driest month was ranked fifth and this independent variable was found important in open shrubland transition to grasslands and to barren areas. It seems that the logistic regression has performed correctly in finding this variable affecting the transitions, as the two cover types are both dependent on the amount of rainfall.

While there is no control over the slope of the areas, distance to roads can be managed such that unwanted changes are harnessed. Table 5 shows distance to roads affects transition of forest to cropland and open shrubland to barren areas, a sign of human impact in the country. Mean annual rainfall was rated seventh and NDVI fragmentation and NDVI ranges both were ranked eighth. The higher the fragmentation of the vegetation and its change during the year, the higher it is the chance of that area for transition to other cover types. In fact, these latter two independent variables show the effect of edge density in making cover types prone to transition. The open shrublands and barren areas were found responding to the edge density in the logistic regression modelling.

Elevation and distance to rivers were found important in open shrublands and barren areas. Also, cover type diversity was ranked 10th for transition of the open shrublands to closed shrublands. The higher the diversity of cover types, the more likely it is that this transition occurs in the country.

As can be seen in Table 5, to generate Figure 3, the area of change in each selected cover type was calculated and divided by the total area of that cover type in each Woreda. Then, the negative changes were subtracted from the positive changes and the results were ranked for each Woreda. This placed the Woredas in the improving and degrading categories. The Woredas were ranked in five categories based on natural breaks in data, and are shown in Figure 3. In order to incorporate the effect of population size which has some bearing on the degradation of ecosystems, the number of people calculated through the LandScanTM layer was divided by the area of each Woredas and multiplied to the net changes. This resulted in a classification of the Woredas based on a combination of ecosystem change and human pressure.

As is apparent from Figure 3, the worsening Woredas are all situated in the centre and towards south west. Removing the effect of population size generated the same pattern, although for a somewhat different set of Woredas. This shows that in the central parts of the country, human population and high demand for food sources and other required materials constantly put the ecosystems under threat, during which the natural ecosystems retreat and manmade systems make ground. The trend in the long term may as well lead to a point where ecosystems cannot bear the pressure and collapse in which case natural disasters may occur in an elevated fashion and the number of people adversely affected increase accordingly. Also, it is clear from Figure 3, that eastern and northern areas are likely to experience the improving trends. These areas are also the least populated in Ethiopia.

We can conclude that the higher the population density, the higher it is the likelihood of modification of the natural ecosystems that eventually lead to ecosystem degradation in the longer term. This is also true for the croplands. For the road layer, we see that some of the least populated areas have a high proportion of road networks. However, due to low population density, the ecosystems located in these areas are less likely to be affected by the adverse human effects. However, as the road density increases in the centre of the country up to a threshold, coupled with the increase in population size, the negative effects of accessibility and human presence become apparent. Of course, there is a lot of interplay between the independent factors and for simplicity we only refer to the direct effects of some of the highly impacting variables.

Our results are supported by the fact that most of the improving Woredas are those that line up with the less densely populated, less cropped and low road density areas. Population size, accessibility, suitability for cropping be it high quality or marginal, proximity to disturbed natural vegetation and distance to already cropped areas are at work causing ecosystem degradation in Ethiopia.

## 4.Conclusion

At the country scale, the IGBP classification of land use and cover types were generally useful for assessing cover type change through time. Based on past experience, we found that some of the classes should be merged to be used for analyses and that some of the classes could be confused with each other. Hence, we only considered those land use/cover types that were related to our aim and that changed meaningfully in terms of our modelling application.

We were able to describe change in the nine land use/cover types using the bio-physical, image-based, climatic and surrogate socio-economic variables through logistic regression. Most of the changes in cover types were very well related to image-based and surrogate socio-economic variables such as cover type frequency, proximity to man-made cover types, distance to urban areas and villages and distance to roads. Change in the selected cover types also showed sensitivity to climatic variables such as mean annual temperature, mean annual precipitation and precipitation of the driest month. The modelling approach also provides a platform to devise scenarios of climate change in future. In this way, the decision makers can plug in their scenarios of climate change and see the results in a "what if" manner. This prepares the managers well in advance of the unwanted changes or disasters that may happen in the country.

A combined past and future predicted change provided a framework for ranking improving and worsening Woredas as administrative units in Ethiopia. We based the assessment of condition on ecosystem deterioration and population pressure, the two factors that are generally related to drought and food insecurity. For the change assessment and modelling to be more useful to evaluation of drought and food insecurity in the country, extensive analysis of the cover types and their relation to factors producing or exacerbating these disasters is required.

Central and south western parts of Ethiopia were found to be deteriorating based on ecosystem degradation and population pressure. Also, eastern and northern parts were found to experience improving trends. As such, other ecosystem and drought assessments such as climatic trends monitoring can be compared with the current study to validate the results and provide relationships between the two.

Our study suggests that 'population pressure' embodies a very important type of social impact. People will tend to change the landscape around them; and conversions into cultivated lands tend to track closely with population distributions. In the absence of planning, rapid population growth will be accompanied by increasing environmental degradation in south-central Ethiopia. This same region seems likely to experience continuing declines in rainfall (Funk *et al.* 2008, Funk *et al.* 2011, Williams *et al.* 2012). In this region, intensification of agriculture using more water-efficient, higher yielding crop varieties will help increase food security and diminish the loss of natural habitats. The dense population in central Ethiopia is reliant on limited natural resources. There is a need to direct the pressure to less threatened areas that have higher natural carrying capacity and can bear the pressure of the new establishments.

Our analysis finds that proximity to cover types and population density played the key roles in land cover transitions. It is very likely, therefore, that in the absence of planning and governmental leadership, agriculture will continue to encroach into increasingly semi-arid south-central Ethiopia. From climate and ecosystem degradation perspectives, agricultural development in the northwest of the country seems sustainable. Comprehensive land use planning based on the results of this study and others for Ethiopia that target food insecurity, flood, and ecosystem degradation could help improve Ethiopia's resiliency while reducing poverty and hunger.

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