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## **PREDICTED LAND USE AND LAND COVER OUTLOOK FOR SEMI-ARID LOKERE AND LOKOK CATCHMENTS IN KARAMOJA REGION, UGANDA**

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### **ABSTRACT**

The semi-arid Lokere and Lokok catchments in northeastern Uganda are experiencing land use and land cover (LULC) change driven by policies and actions aimed at pastoralist sedentarisation. While these efforts present a trajectory of a landscape dominated by farming, livestock herding or grazing persists. The objective of this study was to project medium, and long-term LULC for Lokere and Lokok catchments in Karamoja, Uganda. We applied automatic multi-perceptron neural network, built on Markov chain modeling method, along with multi-criteria evaluation strategies; all embedded in the IDRISI Land Change Modeler (LCM) to project the catchments' LULC to the year 2030 and 2050. The model was trained using 1994 and 2003 LULC, and validated with 2013 LULC. Results of three modelled policy scenarios; business as usual (BAU), pro-livestock and pro-farming; to the years 2030 and 2050 showed that small scale farming (SSF) would increase in all scenarios, even if policy shifts to promote livestock rearing. Pro-farming policies would, in both 2030 and 2050, result in reduction of grassland as SSF increases; doubling the 2003 land area by 2050. The results of this study facilitate assessment of potential impacts of the future LULC and policy evaluation in the catchments.

*Key Words:* Land Change Modeler, land policy evaluation, pastoralism, sedentarisation

### **RÉSUMÉ**

Les bassins versants semi-arides de Lokere et de Lokok dans le nord-est de l'Ouganda connaissent un changement d'utilisation des terres et de couverture terrestre (UTCT) motivé par des politiques et des actions visant la sédentarisation des pasteurs. Si ces efforts présentent une trajectoire d'un paysage dominé par l'agriculture, l'élevage ou le pâturage persiste. L'objectif de cette étude était de projeter une UTCT à moyen et long terme pour les bassins versants de Lokere et Lokok à Karamoja, en

Ouganda. Nous avons appliqué un réseau neuronal multi-perception automatique, construit sur la méthode de modélisation de chaîne de Markov, ainsi que des stratégies d'évaluation multicritères; tous intégrés dans le modèle IDRISI Land Change Modeler (LCM) pour projeter le UTCT des bassins versants jusqu'en 2030 et 2050. Le modèle a été formé à l'aide de 1994 et 2003 UTCT, et validé avec UTCT de 2013. Résultats de trois scénarios de politique modélisés; business as usual (BAU), pro-bétail et pro-agriculture; a montré que l'agriculture à petite échelle (SSF) augmenterait dans tous les scénarios, même si les politiques changeaient pour promouvoir l'élevage pour les années 2030 et 2050. Des politiques favorables à l'agriculture entraîneraient, en 2030 et 2050, une réduction des prairies à mesure que les champs de culture augmentent; doubler sa superficie de 2003 d'ici 2050. Les résultats de cette étude facilitent l'évaluation des impacts potentiels de UTCT future et l'évaluation des politiques dans les bassins versants.

*Mots Clés* : modèleur de changement foncier, évaluation de politique foncière, pastoralisme, sédentarisation

## INTRODUCTION

Arid and semi-arid areas of Eastern Africa are particularly experiencing land use and land cover (LULC) change driven, among others things, by climatic variability and change, and community and government response to either mitigate and adapt (Olson, 2006; Tsegaye *et al.*, 2010; Rufino *et al.*, 2013). Society and government responses are influenced by the prevailing bio-physical, social and economic factors (Bürgi *et al.*, 2004). The direction chosen, will hugely influence future LULC, and with attendant ramifications.

In Uganda's dryland strip codenamed the "cattle-corridor", particularly in the semi-arid Karamoja in the northeast, land use and land cover change associated with shifting from livestock (grazing) production to cropping and degazettement of protected areas, is increasing (Majaliwa *et al.*, 2012). Over the last 60 years, livestock herding in Karamoja had been characterised by seasonal movement, due to natural causes, particularly shortage of water and pasture (Waiswa *et al.*, 2019); but also seasonal movement to safety due to insecurity particularly inter-communal conflicts that were characterised by violent raids (Burnett and Evans, 2014). These factors have often contributed to loss of livestock due to disease, shortage of water and feed, and theft/raids.

The region has also been labeled the poorest without comparing the financial value of their

livestock with income of counterpart households in other rural areas of Uganda (Aklilu, 2016). In addition to the official report of high poverty (UBOS, 2019), the seasonal mobility of livestock in search of pasture and water has been considered primitive and unproductive (Waiswa *et al.*, 2019). As a result of the aforementioned, development agencies have focused on policies aimed at pastoralist sedentarisation and introduction of alternative livelihoods (ACTED, 2010; Stark, 2011). The disarmament campaign of the government from 2006 - 2011 that included introduction of protected kraal system led to concentration of livestock in confined space (Burnett and Evans, 2014). Furthermore, following the return of relative peace, there is increased exploration and development of mines, especially by private companies on land that was previously used livestock by the local population (Burnett and Evans, 2014; Aklilu, 2019). This has pushed small scale farmers and others to mining activities, and also private companies have fenced large areas for mining, thus reducing grazing land and favouring sedentarisation.

Sedentarisation may be defined as the settling of pastoralists; who would traditionally freely move with their herds in search of water and pasture, to practice mixed crop-livestock farming and derive livelihoods from other non-pastoral activities (Wurzinger *et al.*, 2009). Sedentarisation driven LULC conversion in

Karamoja has seen a decline in woody vegetation, and an increase in land under cultivation. Nakalembe *et al.* (2017) reported a 299 percent increase in cropland area in Karamoja, between 2000 and 2011. Osaliya *et al.* (2019) reported an annual rate of increase of land under small-scale farming in Lokere and Lokok Catchments, during 1984-2013 at a rate of 2.1 percent; while the annual rate of loss of woodland in the same period was 2.6 percent. With peace and sedentarisation, there is development or growth of new centres, which have made it become more of a market place, especially for meat. This movement of people has contributed considerably to the development of the urban centres in the catchments and the region (Aklilu, 2019).

Although poverty levels, insecurity and a poor understanding of pastoral livelihoods have contributed to a policy environment where sedentary cropping has been favoured, households with livestock survive shocks, particularly drought better than their farming counterparts (Aklilu, 2016). Livestock is part of culture in the region and is also an intervention that supports resilience of pastoral livelihoods (Rota and Sperandini, 2009; Muhereza, 2017). Nonetheless, the policy view that sedentary crop farming is more productive than mobile livestock herding and part of a solution to insecurity and cattle rustling is likely to continue as the government seeks to maintain security in the region and eradicate poverty.

Therefore, both sedentarisation based policies and pastoral, agro-pastoral or related livestock based strategies as a means to cope with the variability and instability of rangeland environments contribute to change in LULC in Lokere and Lokok catchments. However what is not known is what the outlook of land use change in the medium and long term would be. The changes in land use will impact water resources in an area that is already experiencing significant water stress due to recurrent droughts. Climate models are further showing significant rise in temperature and minimal increase in precipitation (Egeru *et al.*,

2019). The rates of evapotranspiration induced by change in climate in this area are high resulting in intensified water scarcity within the region's key water catchments, Lokok and Lokere (Gavigan *et al.*, 2009), which could jeopardise efforts to improve food security, reduce poverty and reduce vulnerability of communities to water stress. It is, therefore important to understand the likely overall future direction of LULC to aid in the assessment of impacts as well as planning for sustainable livelihood strategies and catchment management. The objective of this study was to project the medium to long-term outlook of LULC for Lokere and Lokok catchments in Karamoja, in order to facilitate assessment of likely impacts on water resources.

## MATERIALS AND METHODS

**Study area.** This study was conducted in the Lokere and Lokok Catchments of northeastern Uganda. They comprise the main watershed in the Karamoja sub-region, connecting downstream to part of Teso sub-region in Uganda's dryland strip, codenamed the "Cattle Corridor". Karamoja sub-region is part of the Karamoja cluster, an area of land that straddles the borders between southwestern Ethiopia, north-western Kenya, south-eastern South Sudan and north-eastern Uganda (Gaur and Squires, 2018).

Lokere and Lokok Catchments vegetation generally consists of savannah grasslands, woodlands, thickets and shrublands, which largely contain *Acacia-Combretum-Terminalia* species associations, with principally C4 grass species (Egeru, 2014). The Karamoja sub-region's topography consists of a plain sloping south-west ward, intermixed with isolated highlands (Mt. Moroto, Mt. Iriri, Mt. Kadam, Mt. Labwor) in the higher elevated west. These consist of rocks of the crystalline basement complex. Rivers and streams in the catchment originate from the highlands, and are ephemeral upstream and perennial in the downstream south-west. The catchment streams are important sources of water in this

semi-arid area, especially during the dry season (Mbogga, 2014). Catchment hydrology oscillates with the stochastic climate events in the sub-region. Consequently, streamflow in most of the rivers in the region are dominated by the baseflow component for much of the year, with a correlative response pattern to groundwater. More often than not, standing water with slow seepage characteristics is retained in the valley areas by underlying low permeability clay rich soils of the region (Gavigan *et al.*, 2009).

The sub-region experiences hot and dry weather, characteristic of most semi-arid regions in Eastern Africa. Rainfall in Karamoja sub-region is unimodal, occurring from March to November, and ranging from < 500 mm in eastern Karamoja, 500-800 mm in central Karamoja to 700-1000 mm in west Karamoja and the isolated highlands (Mbogga, 2014). The Karamoja region, which includes the upstream of the catchments, has uneven rainfall and high run-off. Downstream of the catchments falls in Teso subregion, that has mean annual rainfall of about 1100-1200 mm, distributed between two seasons of March to July and September to November (Kisauzi *et al.*, 2012). Temperatures are generally high throughout the year, with an annual average of 28-33°C for minimum and maximum temperature, respectively; leading to high evapotranspiration levels averaging 2072 mm per annum (Gavigan *et al.*, 2009).

Land use and land cover in the catchments has traditionally been characterised largely by grazing in a landscape dominated by grasslands, cultivation, hunting and settlement (Osaliya *et al.*, 2019); and has included conservation, since the 1964 when three game reserves (Matheniko, Bokora and Pian-Upe) were gazetted in Karamoja, parts of which are found upstream of the catchments (Rugadya and Kamusiime, 2013). However, LULC change over the last three to four decades in the catchments has resulted in conversion of woodlands and bushlands into small-scale croplands, increase in grassland due to degradation of woodland and bushlands, and

degazettement of protected areas (Majaliwa *et al.*, 2012). This saw small scale farming and grassland area increase from 10 and 44 in 1984 to 16 and 60 percent in 2013 (Osaliya *et al.*, 2019).

**Variables and data sets.** Land use and land cover for 1994, 2003 and 2013 prepared by Osaliya *et al.* (2019) for the catchments were used as the data for this study. The 1994 and 2003 layers were used for model calibration, while the 2013 layer was used for model validation. Commonly applied drivers of LULC change were listed from literature (Serneels and Lambin, 2001; Veldkamp and Lambin, 2001; Agarwal *et al.*, 2002; Linkie *et al.*, 2004; Wilson and Weng, 2011; Ahmed and Ahmed 2012; Nyeko, 2012; Sleeter *et al.*, 2012). However, for this study the drivers used were obtained from Osaliya *et al.* (2019).

According to Osaliya *et al.* (2019), the community (among other actors) perceived that the return of peace in the sub-region was among the drivers of land cover and land use change, particularly, the increase in cultivated land and reduction in woody and bushy lands. For a region that had volatile insecurity due to cattle rustling, including episodes of raids by the neighbouring Pokot from Kenya, security is a key factor in the use of land. This study assumed that the prevailing security would remain uninterrupted. The promotion of crop cultivation and use of new agricultural technology was considered a policy intervention and an exogenous change that was causing a shift to increased cropping in a region otherwise traditionally dominated by pastoralism (grazing). This provided a basis for the assumption that sedentarisation policies could result in increased land area under small scale farming. Evidence likelihood of LULC change was included as an explanatory variable, to account for practices and decisions that influence change; and that would possibly not be explained by the model, as described by Eastman (2016 a and b). Evidence likelihood of change was created by determining the relative frequency with which

different LULC types occurred within the areas that transitioned from 1994 to 2003.

Nine explanatory variables/drivers and sources of data were utilised in this study. Five of the drivers were applied to model both transition to small scale farming and to grassland. These are : (a) distance from streams calculated from streams vector layer obtained from a digital elevation model (DEM) based catchment delineation in ArcSWAT; (b) distance from roads, calculated in ArcGIS from a layer of road network obtained from the Uganda National Bureau of Statistics (UBOS); (c) slope calculated from a 30 meters Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) which was downloaded from <http://www2.jpl.nasa.gov/srtm/> portal and projected to the UTM WGS 1984 zone 36N; (d) population density layer calculated to sub-county level in ArcGIS, by using the administrative boundaries layer and population from the 2002 Census, obtained from UBOS; and (e) distance from small towns and urban centres within and close to catchment boundary calculated from a layer obtained from UBOS. In addition, distance from small scale farms was calculated after extracting the land cover in question from the 1994 LULC layer; and evidence likelihood for change to small scale farming was used only in modelling transmission to small scale farming. On the other hand, total livestock values (TLU) and evidence likelihood for change to grassland were used only in modelling transmission to grassland. The evidence likelihood for change layers were prepared in IDRISI's TerrSet Geospatial Monitoring and Modeling System as described under "Preparation and selection of explanatory variables" below, from 1994 and 2003 LULC layers. Distance layers were calculated using the "Euclidean distance" tool in ArcGIS 10.3 Spatial Analyst.

All the input datasets, that is, drivers also called factors, constraints and incentive, and LULC layers were prepared at a 30-meter spatial resolution, to the same number of rows (5153) and rows (7194), background values

and projected to the UTM WGS 1984 zone 36N, for consistency that is required for executing overlay in GIS environments. These derivations were executed in ArcGIS 10.3, converted into GeoTiff format, and imported into IDRISI's TerrSet Geospatial Monitoring and Modeling System for transformation and modelling in accordance with desired scenarios.

#### **Modeling land use and land cover change.**

A number of modeling techniques have been developed to evaluate and project LULC that could result from different growth and policy scenarios (Agarwal *et al.*; 2002; Wainger *et al.*, 2007). They include (a) empirical-statistical models, (b) stochastic models, (c) optimisation models, (d) dynamic process-based simulation models, and (e) the connectionist models (Gonzales, 2009). The suitability of a modelling approach selected depends on the intended use (Wilson and Weng, 2011).

As a selected modelling approach should capture the most critical aspects of LULC particularly heterogeneity, interactions, and dynamics (Plantinga *et al.*, 2006), projection was attained by applying a combination of methods embedded in the IDRISI Land Change Modeler (LCM) software, as described by several reports (Pontius *et al.* 2004; Eastman, 2009; Bernetti and Marinelli, 2010). The methods are: (a) identifying historical LULC change (transitions) by cross-comparison of two images; (b) multivariate analysis of transition potential using artificial neural networks, particularly the multiperceptron neural network (MLP), to develop an empirical model of relationship between the historical LULC transitions and a set of explanatory variables; (c) future LULC demand calculation by the Markov chains; and (d) multi-objective land allocation. While the LCM has three empirical model development tools, the MLP was chosen because is capable of modelling complex nonlinear relationships between variables, able to detect and model interaction effects among variables, and is robust for

modelling the potential transitions (Eastman, 2009 and Nor *et al.*, 2017). The LCM was chosen because of its ability to combine these methods and handiness of its interface through the organisation of key modeling tasks into tabs for change analysis, transition potentials, change prediction and planning. The study applied these tools to postulate that future (2030 and 2050) LULC would result from a combination of local bio-physical and socio-economic drivers that can be extrapolated by analysis of long term (1994 – 2003) past occurrences, the exogenous changes caused by the implementation of long-term land policies and by land use constraints and incentives. The tools were applied as described below.

**Identification of major transitions.** Major LULC transitions that occurred in the 1994–2003 period were identified by cross-comparison (Pontius *et al.* 2004 and Bernetti and Marinelli, 2010) of 1994 and 2003 LULC raster images in the LCM change analysis tab. The LCM was set up to ignore transitions less than 20 Km<sup>2</sup> (Eastman, 2016b). Thus,

transitions involving the built-up areas were ignored (Fig. 1).

The LCM transition tab allows for the organisation of transitions into transition sub-models can consist of a single land cover transition or a group of transitions that have the same explanatory variables and can be modelled in one go, using the LCM's MLP (Eastman 2016a). To model increased small scale farming, it was assumed that only transitions from all of the other LULC types to crop farms would be important. Thus, these were grouped into a single transition sub-model, "All\_to\_Farm". Likewise, to model increased grazing, only transitions to grassland were assumed to be important, and were grouped into one transition sub-model, "All\_to\_Grass".

**Preparation and selection of explanatory variables.** The candidate explanatory variables, drivers (Fig. 2) were not subjected to Cramer's V coefficient test, as LULC transitions were modelled using the Multi-Layer Perception neural network, which has a much stronger evaluation procedure

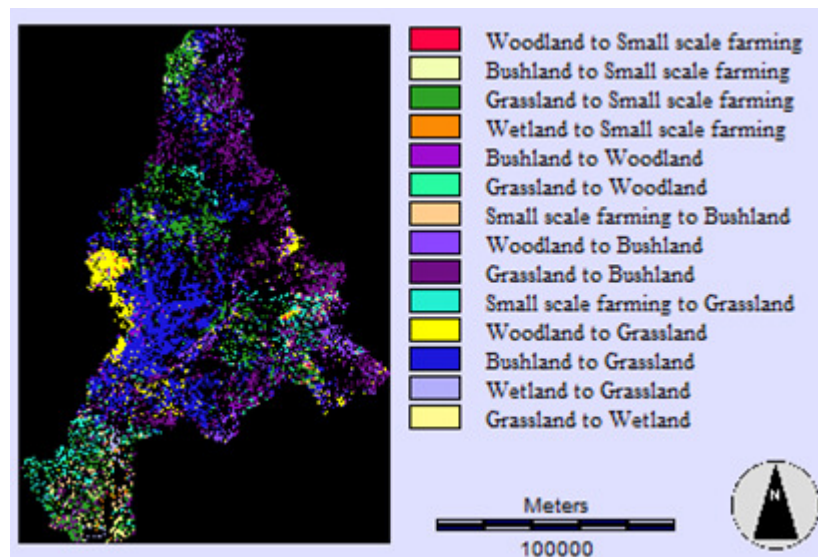
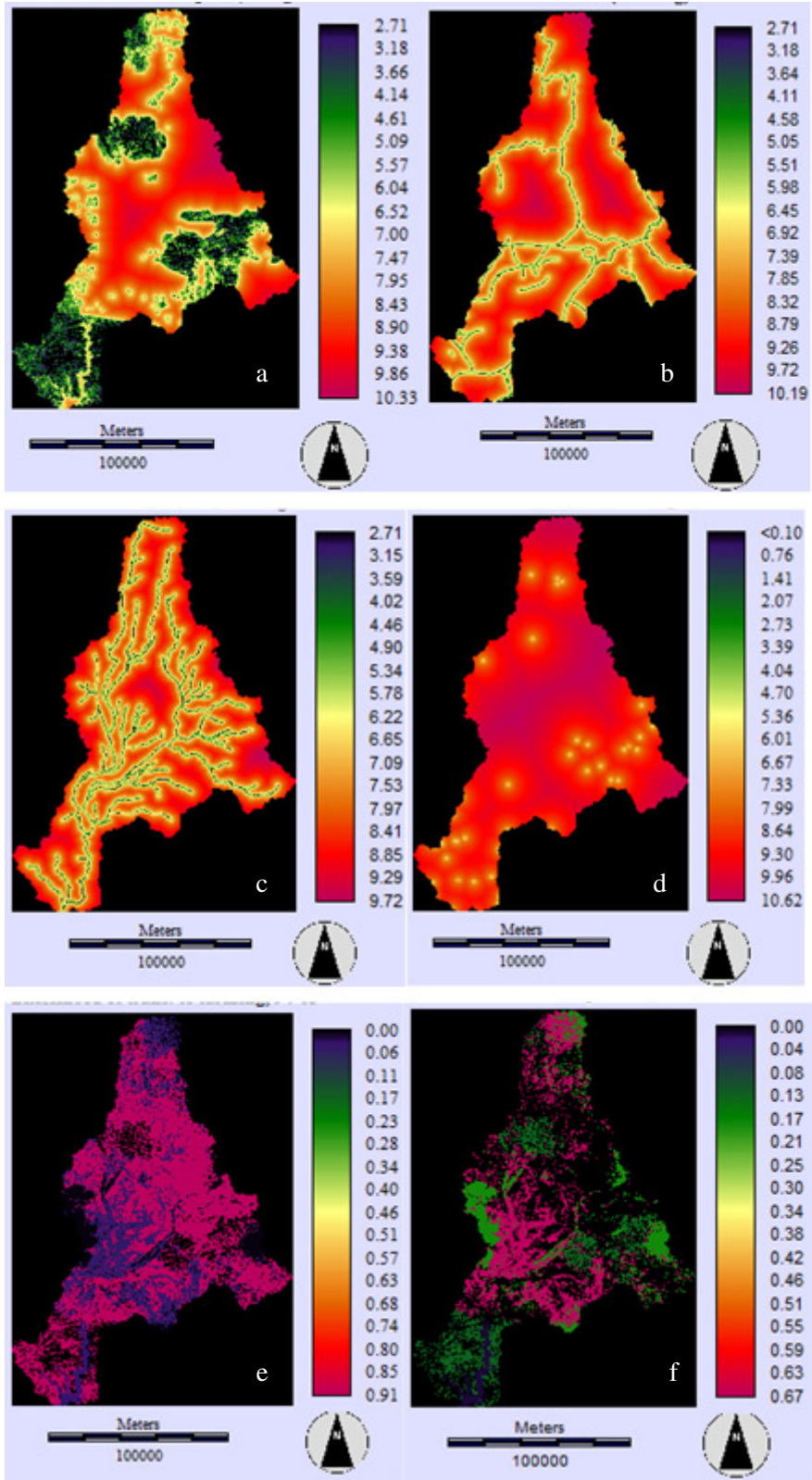


Figure 1. Land use and land cover transitions (greater than 20- Km<sup>2</sup>) from 1994 to 2003 Lokere and Lokok Catchments in Karamoja region, Uganda.



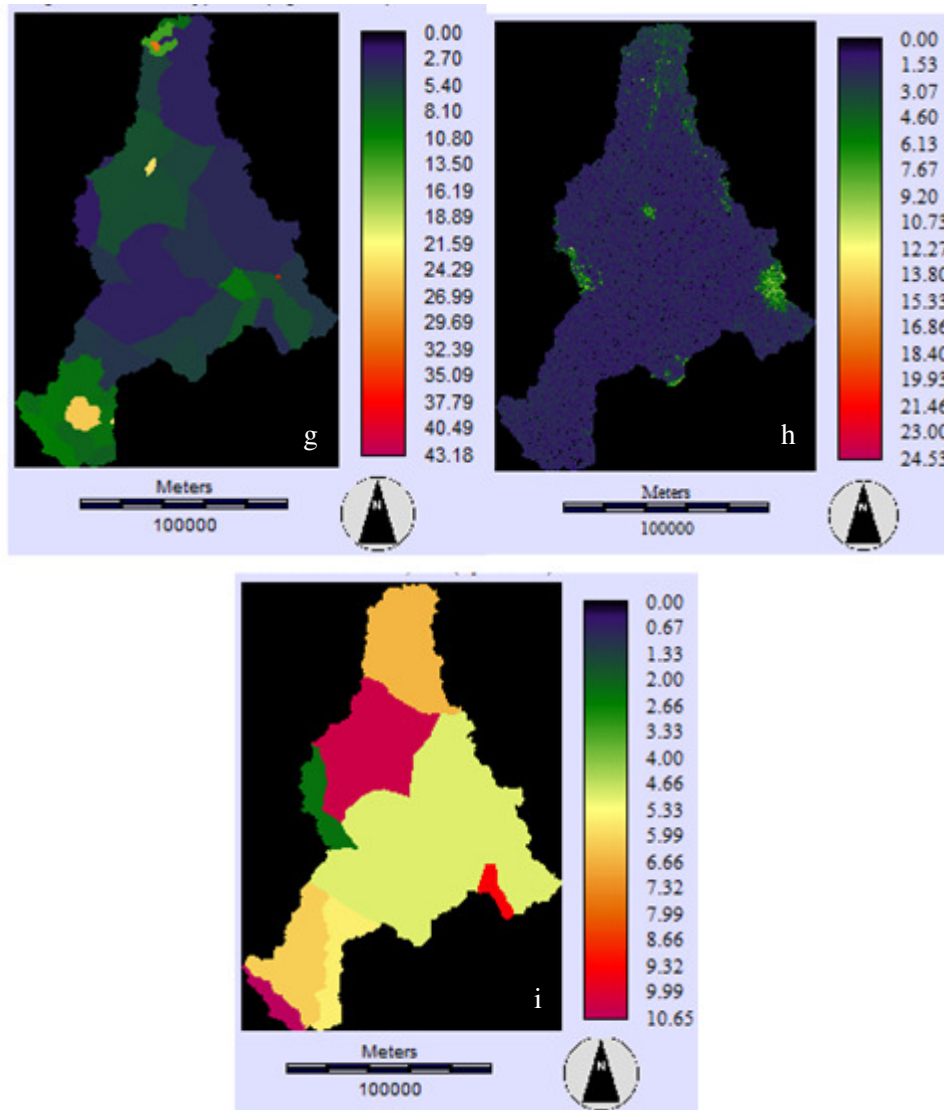


Figure 2. The candidate explanatory variables used in land use and land cover modeling (a) distance from small scale farming in 1994, (b) distance from roads, (c) distance from streams, (d) distance from towns, (e) evidence likelihood of transition to small scale farming, (f) evidence likelihood of transition to grassland (g) population density, (h) slope, and (i) total livestock value in 2002.

incorporated into its development process (Eastman, 2016a). Although the MLP does not require variable layers to be transformed as it does not require variables to be linearly related, transformation could enhance its performance and accuracy, particularly where there is strong non-linearity (Eastman, 2016a). Thus, the Variable Transformation Utility of the LCM which is a natural log transformation was

applied to the distance layers as recommended for distance decay variables (Eastman, 2016a). The root-square transformation was applied on the population density, slope and Total Livestock Units (TLUs) density layers.

Evidence likelihood of change layers were prepared by (i) obtaining layers of transition of all LULC classes in 1994 to small scale farming, and to grassland in 2003, using the



Change Analysis module of LCM; (ii) using the RECLASS module in Terrset to obtain Boolean images of transition; and (iii) using the Boolean images with the 1994 layer as the input image variable name, to derive the evidence livelihood of change of LULC to small scale farming and grassland, respectively. The most sensitive variables were selected after running the MLP and are presented under “modelling of transition potentials” below.

**Modelling of transition potentials.** Using the drivers and historical land cover and land use images, transition raster images were developed, using the MLP neural network. The MLP was chosen due to its ability to model non-linear process and run multiple transitions, up to 9, per sub-model (Eastman, 2012a).

The LCM’s Multi-layer Perceptions (MLPs) has a back-propagation learning algorithm (Li and Yeh, 2002; Eastman, 2009; Bernetti and Marinelli, 2010). MLP neural network consisted of three layers; namely input (*I*), hidden (*H*) and output (*O*) (Fig. 3) and was implemented through training and simulation. The minimum sample of cells that transitioned from other LULC classes during the 1994–2003 period was 22,625 and 43,615 for “all\_to\_farming” and “all\_to\_grass” sub-models, respectively, while 209,116 persisted. The MLP uses one half of the sample for

training and the other for testing of model skill and accuracy (Eastman, 2016a).

Training involves the definition of inputs into the ANNs for the simulation, which is cell-based. Thus, each cell has a set of  $n$  attributes or variables as the inputs into the ANNs. It was hypothesised that the probability of transition from one LULC to another was determined by site attributes or variables discussed above.

The MLP output includes an analysis of model sensitivity to independent variables, as well as their interactive prediction skill. This enabled the selection of explanatory variables that were applied in the prediction.

Tables 1 and 2 show how the “all\_to\_farming” and “all\_to\_grass” sub-models, respectively, performed when one variable was held constant, and when run with the less influential variables held as constant, starting with holding the least influential alone and continuously removing the remaining least influential. The “all\_to\_farming” sub-model, performed worst when evidence livelihood of change to farming was excluded from model run, indicating that it was the most influential variable. It was followed by distance from small scale farming and population density. Distance from roads was the least influential variable. It was, therefore, removed and re-trained the model with six variables for parsimony.

The “all\_to\_grass” sub-model, holding population density (2002), distance from towns and total livestock values each at a time, as well as all of them together, had the least effect on model performance in that order (Table 2). These model variables were removed from the model that was trained for the prediction for model parsimony. The variables that had the most influence were evidence likelihood of change to grassland, slope, and distance from town, in that order.

Although presently, there is not a specific acceptable threshold for the Skill measure, user experiences show that “any value greater than 0.5 is generally acceptable and values greater

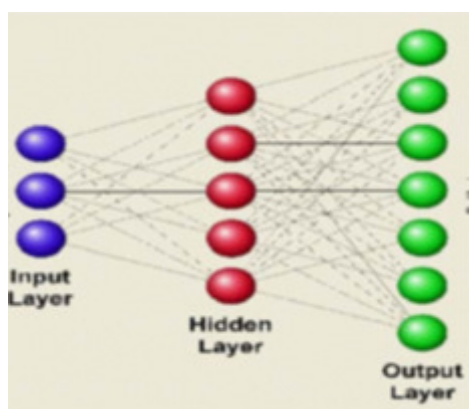


Figure 3. Example of architecture of artificial neural network (Adopted from Eastman, 2012b).

TABLE 1. Variation in “all\_to\_farming” sub-model skill with different combinations of variables, or one, held constant

Model with one variable held constant				Model skill with less influential variables held constant			
Variable held constant	Accuracy (%)	Skill measure	Influence order	Variables held constant	Variables included	Accuracy (%)	Skill measure
None	73.36	0.6956	N/A	None	All variables	73.36	0.6956
[1]	73.16	0.6932	7	Step 1: [1]	[2,3,4,5,6,7]	73.16	0.6932
[2]	72.89	0.6902	6	Step 2: [1,2]	[3,4,5,6,7]	72.79	0.689
[3]	72.42	0.6848	5	Step 3: [1,2,3]	[4,5,6,7]	72.6	0.6868
[4]	70.15	0.6588	4	Step 4: [1,2,3,4]	[5,6,7]	71.01	0.6687
[5]	65.76	0.6087	3	Step 5: [1,2,3,4,7]	[5,6]	55.65	0.4931
[7]	63.03	0.5775	2	Step 6: [1,2,3,4,7,5]	[6]	37.16	0.2818
[6]	19.15	0.076	1				

Numbers in parenthesis represent variables: 1 is distance from roads, 2 is distance from towns, 3 is distance from streams, 4 is slope, 5 is population density (2002), 6 is evidence likelihood of change to small scale farming, and 7 is distance from small scale farming in 1994

TABLE 2. Variation in “all\_to\_Grass” sub-model skill with different combinations of variables, or one, held constant

Model with one variable held constant				Model skill with less influential variables held constant			
Variable held constant	Accuracy (%)	Skill measure	Influence order	Variables held constant	Variables included	Accuracy (%)	Skill measure
None	64.98	0.5998	N/A	None	All variables	64.98	0.5998
[1]	64.16	0.5904	7	Step 1: [1]	[2,3,4,5,6,7]	64.16	0.5904
[7]	64.1	0.5897	6	Step 2: [1,7]	[2,3,4,5,6]	64.6	0.5955
[5]	62.94	0.5764	5	Step 3: [1,7,5]	[2,3,4,6]	62.11	0.567
[2]	62.61	0.5727	4	Step 4: [1,7,5,2]	[3,4,6]	58.46	0.5252
[6]	60.26	0.5459	3	Step 5: [1,7,5,2,6]	[3,4]	56.23	0.4997
[3]	59.11	0.5327	2	Step 6: [1,7,5,2,6,3]	[4]	50.12	0.4299
[4]	18.46	0.0681	1				

Numbers in parenthesis represent variables: 1 is population density (2002), 2 is distance from roads, 3 is slope, 4 is evidence likelihood of change to grassland, 5 is total livestock values, 6 is distance from towns, 7 is distance from streams

than 0.7 are quite good.” (Jamieson, Clark Labs, communication through the Terrset Support Center in response to Request #1345 on performance threshold, 09:41 EDT, Mar 26 2018). Thus, the performance of the MLP during the test was satisfactory (Table 3) because it attained accuracy of 73.4 and 65.0 percent; and skill measures of 0.70 and 0.60; for the “all\_to\_farming” and “all\_to\_grass” sub-models respectively. The MLP runs prediction with the identified variables attained an accuracy of 74.6 and 65.3 percent, and a skill measure of 0.71 and 0.60 for the “all\_to\_farming” and “all\_to\_grass” sub-models, respectively.

future and creates a transition probabilities matrix (Eastman, 2009, 2016a; Bernetti and Marinelli, 2010). The probability of moving from one state,  $i$  to another state,  $j$  is called a transition probability,  $P_{ij}$ , and it is given for every ordered set of states. These probabilities can be represented in the form of a *transition matrix*,  $P$ , as in the Markov equation:

$$P = \begin{bmatrix} p_{11} & p_{12} & \dots & p_{1n} \\ p_{21} & p_{22} & \dots & p_{2n} \\ \dots & \dots & \dots & \dots \\ p_{n1} & p_{n2} & \dots & p_{nn} \end{bmatrix}$$

**Prediction of land cover and land use change.** In the LCM, future demand for (quantity of) land cover and land use change in each transition was modelled using a Markov Chain analysis. Markov chains method determines the amount of change using the earlier/past and later/present LULC images along with the specified future date based on a projection of the transition potentials into the

In order to define the geographical localisation of transitions obtained from the Markov chain procedure, the multi-objective land allocation algorithm (Eastman *et al.*, 1995) and cellular automata, built in the IDRISI’s Land Change Modeler was used. As the process involves using suitability maps for spatial allocation of predicted time transitions, the aggregation of transition potentials of all selected sets of

TABLE 3. Multi-Layer Perceptron performance for Lokere and Lokok Catchments for Karamoja region in Uganda

Parameter	All_to_Farming		All_to_Grass	
	Test	Prediction	Test	Prediction
Input layer neurons	7	6	7	5
Hidden layer neurons	7	7	7	6
Output layer neurons	8	8	8	8
Requested samples per class	10000	10000	10000	10000
Final learning rate	0.0001	0	0	0
Momentum factor	0.5	0.5	0.5	0.5
Sigmoid constant	1	1	1	1
Acceptable RMS	0.01	0.01	0.01	0.01
Iterations	10000	10000	10000	10000
Training RMS	0.2126	0.2173	0.2376	0.2383
Testing RMS	0.2145	0.2172	0.2387	0.2392
Accuracy rate (percent)	73.36	74.81	64.98	65.34
Skill measure	0.6956	0.7121	0.5998	0.6038

transition, to obtain the predicted LULC was achieved through calculation of the “logical OR”.

**Model validation.** The Relative Operating Characteristic (ROC) (Eastman, 2009; 2016b; Pontius and Schneider, 2001; Eastman, 2009) module of the IDRISI GIS, was used to validate the quality of LULC prediction. The ROC technique measures how well a modelled continuous map of suitability of the likelihood of a land cover and land use class occurring predicts locations given the actual map of distribution of the class (Pontius and Schneider, 2001 and Eastman, 2016b).

Therefore, Boolean images of change from all classes in 2003 to small scale farming, and to grassland, in 2013, were respectively used in the ROC module as reference images (actual LULC layer) along with their corresponding soft prediction images as input images, to validate the trained sub-models for predictions of changes to farming and grassland. No constraints or incentives were applied in predictions for validation purposes. Using default settings and 100 as the number of thresholds, the ROC analysis showed that the models’ prediction of transitions to small-scale farming and to grassland was strong, with ROC values of 0.83 and 0.94, respectively; illustrating the robustness of the prediction. (Pontius and Schneider, 2001). The validated model was then used to generate LULC for 2030 and 2050, after incorporating scenarios.

**Incorporation of scenario development into prediction.** The LCM planning module was used to incorporate three policy scenarios by defining constraints and incentives for change allocation and prediction (Eastman, 2016a and b). Handled or prepared in the same manner, constraints and incentives layers were used to bar (constraints, with values of 0 on the layer), discourage (incentive, with values less than 1 but greater than 0) or encourage (incentives, with values greater than 1) change in the specified locations, in favour of, or

against, small scale farming or grassland (grazing).

In defining scenarios that were modelled, major historical, present and plausible future LULC were considered, along with endogenous and exogenous influences in the catchment in particular, and the region in which it is located. Lokere and Lokok catchments, particularly upstream, falls in a rangeland, characterised by climate variability, where livestock herding, mainly pastoralism, has over the years been the economic or livelihood mainstay of the people. Although cropping had also been practiced, it was limited to traditional crops, mainly sorghum, grown on a very small scale; making grassland and grazing the dominant land cover and land use over the years. (Largely endogenous aspects.)

Recent developments in the sub-region particularly following disarmament exercise between 2001 and 2002 (OPM, 2007), have seen aggressive promotion of agriculture by Government and non-state actors. For example, Karamoja subregion, in 2016, had 54 non-governmental organisations (NGOs) which were implementing 142 active projects (Karamoja Resilience Support Unit, 2016). Government Policy analysis has blamed among others, overreliance on livestock resources as one of the causes of poverty and chronic food insecurity in the sub-region, and has embarked on developing and implementing programmes that, while seeking to improve on quality of livestock, promote growing and marketing of a diversity of crops (OPM, 2007; 2009), with the Karamoja Integrated Disarmament and Development Programme (KIDDP), being the main development program for the region. (Largely exogenous aspects.)

**Business as usual scenario.** The BAU scenario assumed that trends of land use/cover change between 1994 and 2003 will continue as influenced by the identified and evaluated drivers of LULC change. This development would not occur in forest reserves, wildlife reserves, and wetlands – thus assumes



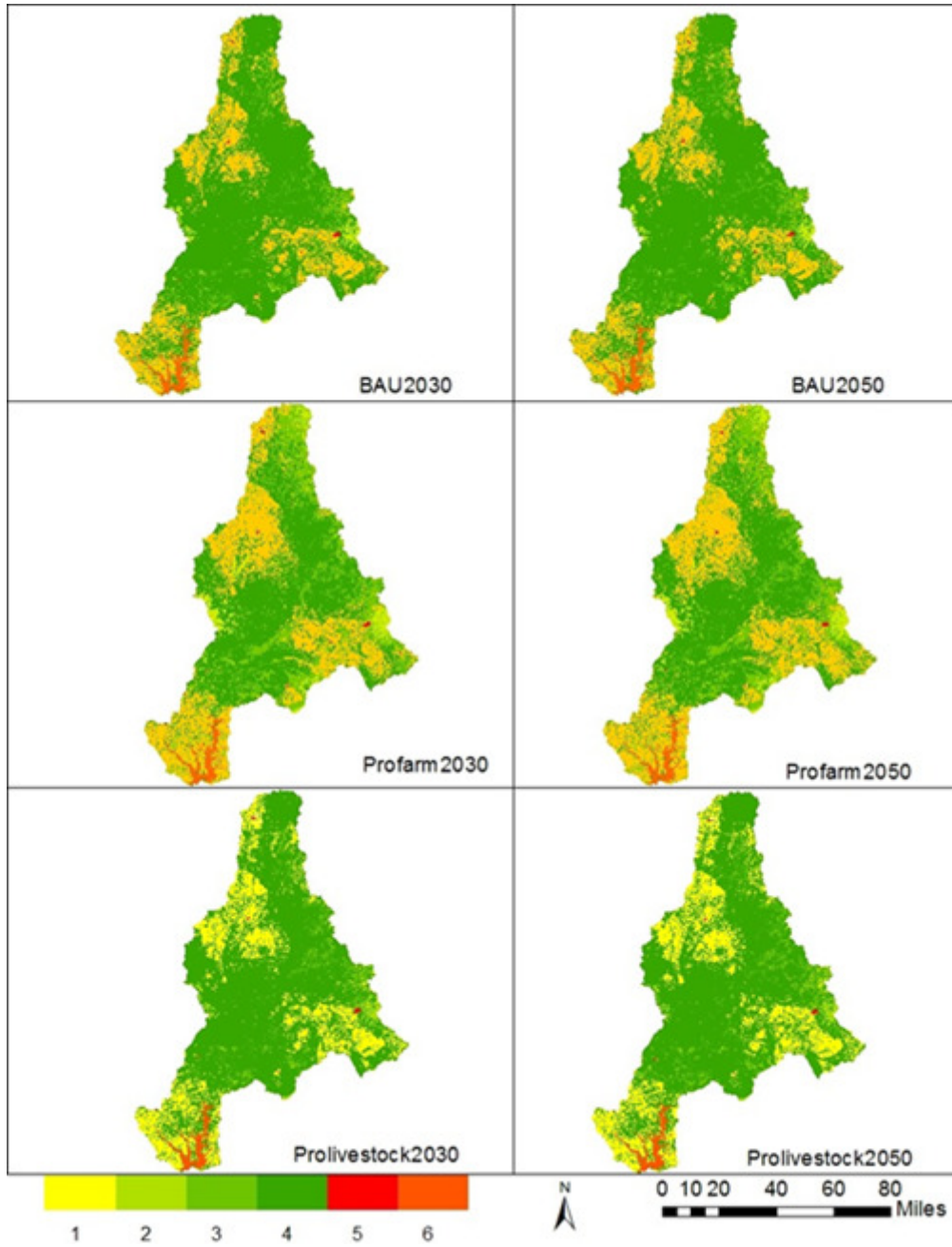


Figure 4. Projected LULC to the years 2030 and 2050 (1 = small scale farming, 2 = woodland, 4 = grassland, 5 = built-up, 6 = wetland; BAU = Business as usual scenario, profarm = pro-farming scenario, prolivestock = pro-livestock scenario).

increase, and the increase would be highest in the pro-farming policy scenario, by 14.2 and 16.5 percentage points in 2030 (Fig. 5) and 2050 (Fig. 6). This suggests that small scale farming would under the pro-farming policy scenario in 2050 cover more than double (30.3 percent) the 2003 land area (13.8 percent, Table 5).

Grassland would increase under the BAU and pro-grazing scenarios, by 11.8 and 11.7 percent in 2030 (Fig. 5), and 10.9 and 9.6 percent in 2050 (Fig. 6). However, in the pro-farming policy scenario, grassland would

reduce by 10.8, from 58.1 to 47.3 percent in 2030 and, 11.8 to 46.3 percent in 2050, as respective areas under small scale farming will increase from 13.8 to 28 and 30 percent, respectively. Bushland will reduce in all scenarios and future years (Figs. 5 and 6). The decline in bushland could be substantially higher in the BAU and pro-grass scenarios, by 16.5 and 16.1 percentage points in 2030; and 16.4 and 14.7 percentage points in 2050, respectively, compared to only 2.8 in 2030 and 3.8 in 2050 in the pro-farming scenario. There will also be a slight decline in area under

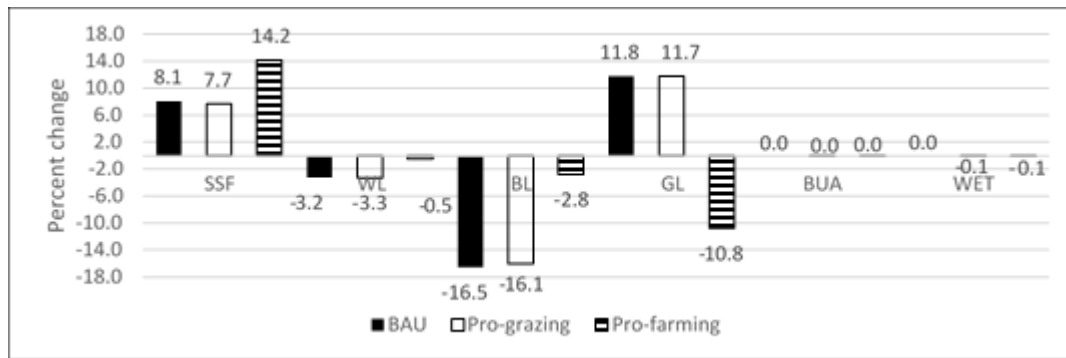


Figure 5. Change in Land use and land cover from the baseline under the Business as usual (BAU) and pro-farming and prolivestock policy scenarios in 2030 and in the Lokere and Lolok catchments in Karamoja in Uganda.

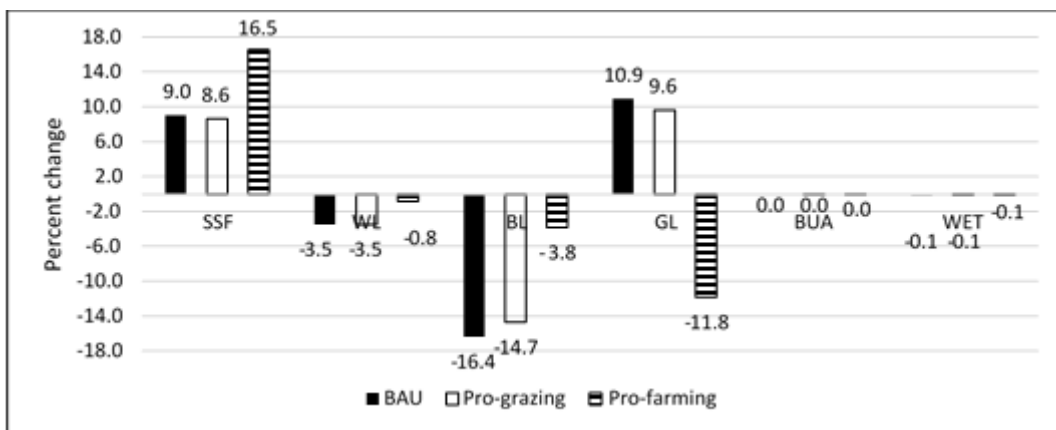


Figure 6. Change in Land use and land cover from the baseline under the Business as usual (BAU) and profarming and prolivestock policy scenarios in 2050 and in the Lokere and Lolok catchments in Karamoja in Uganda.



TABLE 5. Projected LULC for pro-grazing, pro-farming and business as usual scenarios (percentage) and in the Lokere and Lolok catchments in Karamoja in Uganda

LULC type	2003 <sup>a</sup>	2030			2050		
	Baseline	BAU	Pro-grazing	Pro-farming	BAU	Pro-grazing	Pro-farming
Small scale farming	13.8	21.9	21.5	28	22.8	22.4	30.3
Woodland	4.7	1.5	1.4	4.2	1.2	1.2	3.9
Bushland	21.4	4.9	5.3	18.6	5	6.7	17.6
Grassland	58.1	69.9	69.8	47.3	69	67.7	46.3
Built-up areas	0.12	0.1	0.1	0.1	0.1	0.1	0.1
Wetland	1.9	1.9	1.8	1.8	1.8	1.8	1.8
Total	100	100	100	100	100	100	100

<sup>a</sup>Based on Osaliya *et al.* (2019)

woodland in all scenarios and years, ranging from 0.5 in the pro-farming scenario in 2030 to 3.8 percent in the pro-grazing and BAU scenarios in 2050.

## DISCUSSION

The results show that small scale farming would increase in the medium and long term under all policy scenarios, ranging from 7.7 and 8.6 percent in the pro-livestock policy scenario to 14.2 and 1.6.5 percent in the pro-farming policy scenario, in 2030 and 2050 respectively (Fig 2 and 3). Increase in small scale farming in the business as usual scenario (BAU) was expected because the model is predicting past trends to continue. While increase in small scale farming in the pro-grazing scenario would not be surprising, similarity in the amount of increase with that in the BAU scenario suggests that the present influence to farm would persist to the year 2050, even if policy shifts to promote livestock rearing. This would be consistent with reports that the people of the semi-arid Karamoja have practiced agropastoralism since the 1880s, with crop farming and transhumance livestock keeping being mutually reinforcing (Cullis, 2018). However, the large decline in grassland,

from 58.1 to 47.3 percent in 2030 and 46.3 percent in 2050 (Table 3), as small scale farming doubles in the pro-farming scenario would result in a huge reduction in land for grazing as greater effort is placed on cropping.

Reliance on cropping could increase vulnerability of the population to climate variability in the catchments and the greater semi-arid Karamoja region (Aklilu, 2016) where herding has been both a culture and a coping mechanism (Muhereza, 2017), unless pro-farming policies are backed with strategies to mitigate short-fall in crop production. And, as cultural practices are difficult to change, and transhumance livestock herding has been reported as more suited to semi-arid environments (Rota and Sperandini, 2009), strategies that improve both crop and livestock production could be more beneficial to population. Such strategies could cover on-farm and catchment water management practices, crop science, and feed and pasture management (Ben-Gal *et al.*, 2006 and Adugna and Aster, 2007; Tilahun *et al.*, 2017).

Although decline in bushland and woodland as grassland and small scale farming increase would be consistent with past historical trends established in the catchments (Osaliya *et al.*, 2019), the lower change in their percentage

(Fig. 3) in the pro-farming scenario where increase in small scale farming was highest contradicts this trend. This trajectory would spur restoration of degraded lands and protection of woodlots, especially in protected areas (Matheniko, Bokora and Pian-Upe).

Grassland would also remain the most dominant LULC in 2030 and 2050, even under the pro-farming policy scenario, where its land area would have declined to 47 and 46 percent, respectively; compared to 58 percent in 2003 (Table 3). This could support livestock herding to allow the communities to continue to benefit from this more climate resilience livelihood (Aklilu, 2016); however likely fragmentation due to increasing croplands could disconnect the formerly intact grasslands, and hinder mobility of livestock (Galvin, 2009) and sharing of grazing grounds. Nonetheless, livestock herding strategies that allow for coping with the variable semi-arid environment could still be possible.

### CONCLUSION

This study shows that land under small scale farming would increase in the medium (2030) and long term (2050) if present LULC trends continue (business as usual policy scenario), policies promote cropping or livestock herding; and that influence of present efforts to promote crop cultivation would persist to the year 2050 even if policy shifts to particularly promote livestock rearing. The increase in small scale farming land area could by 2050 be double its 2003 land area if pro-farming policies dominate livelihood and development programs, as a large reduction in grassland and substantial increase in small scale farming would occur, in 2030 and 2050. However, grassland would still be more dominant but could be less supportive to livestock herding due fragmentation by cropland and restriction to sharing of grazing grounds. Reliance on cropping in a semi-arid area where mobile herding is more adaptive to climate variability could increase vulnerability of the population,

unless effective strategies that mitigate short-fall in crop production are implemented. Strategies that improve both crop and livestock production could be more beneficial to the population. Such strategies could cover on farm and catchments water management practices, crop science, and feed and pasture management. Research on these aspects should be part of the policy and development agenda for the semi-arid catchments. The projected LULC, and insights on likely change over the next one to three decades provide useful data for assessing potential impacts on water resources and, information for planning and policy evaluation in Lokere and Lokok Catchments.

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