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A Dynamic Simulation Model of Land-Use, Population, and Rural Livelihoods in the Central Rift Valley of Ethiopia

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Abstract The dynamic interactions between society and land resources have to be taken into account when planning and managing natural resources. A computer model, using STELLA software, was developed through active participation of purposively selected farm households from different wealth groups, age groups and gender within a rural community and some members of Kebelle council. The aim of the modeling was to study the perceived changes in land-use, population and livelihoods over the next 30 years and to improve our understanding of the interactions among them. The modeling output is characterized by rapid population growth, declining farm size and household incomes, deteriorating woody vegetation cover and worsening land degradation if current conditions remain. However, through integrated intervention strategies (including forest increase, micro-finance, family planning, health and education) the woody vegetation cover is likely to increase in the landscape, population growth is likely to slow down and households' income is likely to improve. A validation assessment of the simulation model based on historical data on land-use and population from 1973 to 2006 showed that the model is relatively robust. We conclude that as a supporting tool, the simulation model can contribute to the decision making process.

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Introduction

There is a strong and complex relationship between natural resources and rural livelihoods. Rural people in low income countries depend on the availability and access to natural resources for supporting their livelihoods (Ellis and Allison 2004). A livelihood comprises the assets (natural, physical, human, financial and social capital), the activities and the access to these (mediated by institutions and social relationships) that together determine the living gained by the individual or household (Ellis 2000).

The increasing global concerns about the sustainable management of natural resources which followed the UN summit in Rio de Janeiro in 1992 have not visibly reduced the pace of deforestation in the tropics, which is caused by a complex mixture of demographic, economic, technological, cultural and institutional factors (Hartemink and others 2008; Lambin and others 2003). In the international discourse on natural resources conservation, there are diverse relationships between conservation strategy and poverty reduction that reflect conflicting paradigm positions in the current debate conservation (Adams and others 2004). The proponents of the so-called "zero conservation" or ''fortress conservation'' approach advocate protection measures that seeks to exclude local people from natural resources (Hutton and others 2005; Sanderson and Redford 2003). However, others still equally have different views, community based management projects can make both development and conservation economically viable and attractive for the local communities to maintain biodiversity and integrity of nature (Singh 2008; Sunderland and others 2008). Furthermore, Robbins and others (2006) and Romero and Andrade (2004) suggested that the exclusion of communities from conservation ultimately leads to social conflict and noncompliance with conservation-related regulations (Chan and others 2007). The combining of participatory modeling and livelihood studies could contribute to sustainable natural resource management and livelihood improvement by building shared understanding of critical issues and helping to focus on conservation and development interventions (Campbell and others 2008).

Africa is already a region under pressure from climate stresses and is highly vulnerable to the impacts of climate change (UNFCCC 2007). Thus, African countries working in the conservation-development nexus need to take active part in the current global and regional processes on climate change adaptation.

Ethiopian subsistence agriculture is heavily dependent on rain-fed production. The erratic nature of rainfall leads to reduced crop production. The main reason is the daily, seasonal and inter-annual rainfall variability (Segele and Lamb 2005). In Ethiopia, widespread land degradation has led to severe challenges for the people (Amsalu and de Graaff 2006; Argaw 2005; Mahmud and others 2005; Taddese 2001). Socio-economic and institutional factors, such as population pressure, poverty and land tenure arrangements are the main contributors to land degradation. Population growth raises the demand for subsistence cropland and for biomass (fuel and fodder). Both are leading to deforestation. People's lack of access to alternative sources for livelihood exacerbates this, and, therefore increases the problems of erosion and nutrient depletion (Haile 2004; Nyssen and others 2009).

In Ethiopia, land tenure is a disputed issue. All rural land is owned by the state and part of this land is allocated to farmers on a use-right basis (Bogale and others 2006). The rural land reform policy strictly prohibits the transfer of land by sale or mortgage. However, it does allow transfer of use-right in the form of gift, inheritance, restricted leasing and sharecropping (Crewett and others 2008). Most debates and studies on land ownership of the state mainly revolve around questions of insecurity (redistributions) of landholdings, degradation of soil quality, unsuitable land use practice and fragmentation of farms. The federal government and the regional states have started a process of land registration and certification to address farmers rural land insecurity (Deininger and others 2008).

The rapidly growing population in Ethiopia adds approximately two million people per year and population is predicted to be more than double current levels by the year 2050 (United Nations Population Division 2009). Internal migration in Ethiopia is high and associated with education, demographic, economic and environmental and security reasons (Mberu 2006). Historically rural-to-urban, urban-to-rural and rural-to-rural migration has varied dramatically with famines and political reforms (Ezra 2001; Tegenu 2003). Households living in the rural areas such as the Rift Valley are faced with a number of constraints, including erratic rainfall, recurrent droughts, rapid population growth, deforestation, soil degradation, food insecurity and low education (Garedew and others 2009). People are the main agents of environmental degradation and they are also the victims. Villagers who were involved in previous research with the same authors acknowledged the importance of a continuous discussion on the sustainable use of forests and other natural resources, which enabled them to move towards more sustainable practices. Farmers realized that they over used the local woodland. Recurrent drought and the constrained subsistence agriculture drove people to overuse the forest as safety net strategy, because other livelihood options than dry-land agriculture are very limited in the study area. High population increase would have a major impact on the remaining forests. Further, we experienced that farmer's still perceive land tenure as insecure. The establishment and successful implementation of a forest restoration site by the Forestry and Natural Resource College and an action research project on the community land has had a positive impact on the behavior of the surrounding farmers towards forest increase. Accordingly, people are increasingly aware of the importance of woodland forests as a safety net during recurrent droughts and of the need to manage them sustainably. During discussions, villagers have also expressed interest in increasing the forest cover and forest area on the landscape. Some of them already have woodlots around their homesteads which is an encouraging drive to others.

Further depletion of the environment, low agricultural production and worsening socio-economic conditions, including rapid population growth could be foreseen if current trends remain. The objective of this study is to explore a participatory dynamic simulation modeling approach based on a dialogue with farmers in order to test different development strategies (scenarios). The approach would include the generation of forward projections (from 2006–2036) of land-use, population and income under various assumptions discussed with the farmers and should contribute to the debate on how to address social-economical and environmental changes.

Material and Methods

Study Area

The study area is "Keraru" Kebelle (Kebelle is the lowest administration unit in the government structure) in the

"Arsi-Negele" district of Oromiya National Regional State located between 205 and 210 km south of Addis Ababa (Fig. 1). It covers 2932 ha and represents a semi-arid flat land of the district's lowland climatic zone and is situated below 1800 m ASL (Garedew and others 2009). The nearby climate data from the National Meteorological Services Agency for the years' 1972–2005 shows that the annual rainfall ranges between 264 mm and 968 (the mean is 710 mm), while the mean annual minimum and maximum temperatures are 13.5 and 27.7°C, respectively. The study area had a population of 3647 in 2004, the population density was 124 persons per km^2, the annual population growth rate was 2.5% ± 0.2 and the rural-urban migration was low (Garedew and others 2009). The people in the area are farmers, most of them from the Oromo ethnic group, who practice Islam and live in polygamous families. The mainstay of their livelihoods is agriculture including mixed livestock raising and rain-fed crop production. Major crop types grown are maize, wheat and tef (*Eragrostis tef*). The government extension service is minimal. The natural woody vegetation was dominated by woodland's and wooded-grassland of *Acacia* trees, but the area has experienced a rapid deforestation at a rate of 1% per year with cropland successively replacing woodland and wooded-grassland *Acacia* forests (Garedew and others 2009).

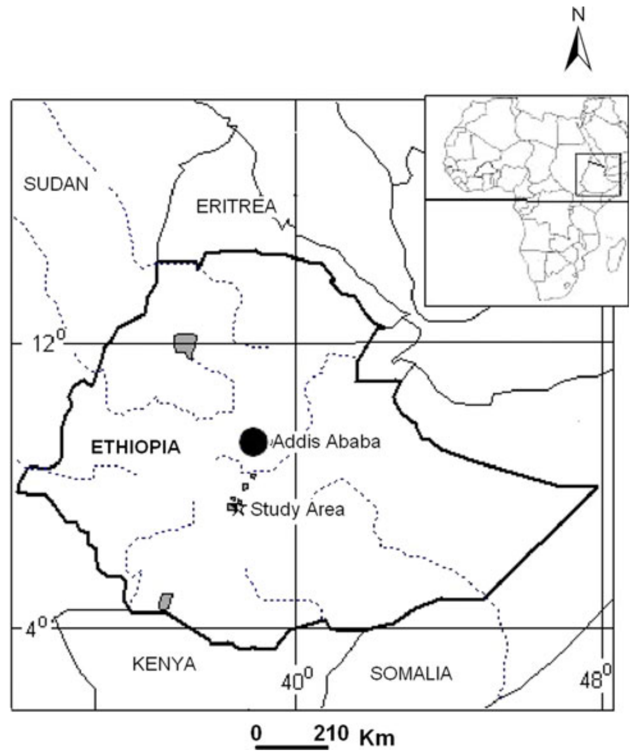

Fig. 1 Map of Ethiopia, shows location of the study area

Methods

We based the participatory modeling on an approach described by the Center for International Forestry Research (CIFOR) (http://www.cifor.cgiar.org/conservation/_ref/research/index.htm). A system dynamics model was built using the stock- and- flow model software (STELLA v.8) with an icon based interface and availability of array functions (Costanza and Voinov 2001; High Performance Systems Inc. 1996). System dynamics is a concept that considers the dynamic interaction between the elements of the studied system and can help to understand their behavior over time, build models, identify how information feedback governs the behavior of the system and develop a strategy for better management of the studied system (Doerr 1996).

The study was conducted in 2009 using data inputs and assumptions from a previous study (Garedew and others 2009), farmers and experts from the district Agricultural & Rural Development Bureau were involved, unpublished data and other sources (Tables 1, 2 3). The present study involved a process of model building with active participation of 20 informants (focus group) representing purposively selected households from diverse categories of wealth, age and gender within the community to obtain diverse information. The selection was made with the help of the Kebelle council by picking up those individuals who had formal education and considered reasonably able to understand the topics, express feelings, opinions and perspective on the situations. Some members of the Kebelle council were also involved in the study. Repeated meetings and discussions were also made with the entire community to triangulate the data obtained from the focus group. The purpose was to obtain good understanding of their objectives in resource management and building on their knowledge about the trends of the local environment and livelihood (Sayer and Campbell 2004). Wherever data was lacking, information was provided through the focus group dialogue and consensus. This helped to improve the input data of the different sectors of the model for exploring reasonable socio-economical and environmental pathways.

Three main scenarios were elaborated. The first one was named "business as usual" and did not assume any significant change in the future conditions or stakeholders' behavior. In the second scenario, "strategies for socio-economic development", a number of assumptions reflecting government (MoFED 2007) and local efforts for socio-economic change, including micro-finance, better family planning, better health and better education services, were made. The third scenario, "forest increase" was put in focus and modeled as a pathway for restoring the woody vegetation in the landscape through an area closure strategy (e.g., by excluding cattle). Woodland forest is a source of firewood, charcoal, construction material for the local farmers' consumption, and also fodder for livestock. This scenario

Table 1 Data inputs and assumptions for 'land-use model sector' in studying the trends of land-use using various scenarios

Data	Assumption		Data Sources
	With forest increase strategy	Without forest increase strategy	
Total area = 2932 ha	1. 0.001% S transfer to WGL	1. No transfer	Garedew and others (2009), with small modification
Farmland (FL) = 57.6%	2. No transfer from FL to GL	2. 0.3% transfer	
Grassland (GL) = 26.2%	3. 5% WGL transfer to WL	3. 0.1% transfer	
Woodland (WL) = 6.6%	4. No transfer from SL to BL	4. 1% transfer	
Shrubland (SL) = 5%	5. 10% SL transfer to WGL	5. No transfer	
Wooded-grassland (WGL) = 1.6%	6. No transfer from WL to WGL	6. 5% transfer	
Bareland (BL) = 1.6%	7. No transfer from WL to BL	7. 0.5% transfer	
Settlement (S) = 1.4%	8. 0.1% GL transfer to BL	8. 1% transfer	
	9. 2% GL transfer to WGL	9. 0.7% transfer	
	10. 0.5% BL transfer to SL	10. No transfer	
	11. No transfer from WGL to BL	11. 0.5% transfer	
	12. No transfer from WL to SL	12. 0.2% transfer	
	13. No transfer from WL to FL	13. No transfer	
	14. No transfer from WL to GL	14. 2% transfer	
	15. No transfer from WGL to FL	15. No transfer	
	16. No transfer from GL to WL	16. 0.5% transfer	
	17. No transfer from GL to FL	17. No transfer	
	LULC conversion is mainly driven by the motivation of farmers to increase forest cover and area, and by the population growth		
	Communities' motivation for forest increase could help raise forest income to households		
	Transfer of farmland to settlement is based on the area demand from new household increases		
	The demand for additional FL can increase but the transfer of GL to FL does not exceed 0.3%		
	No suitable land for crop is available to convert from WL		
	If business continuous as usual further environmental degradation is expected		

was initiated by the farmers themselves in order to express the availability of wood for households' consumption, improve livestock productivity and reduce soil erosion (water and wind) and resuming of additional forest cash income for livelihood. Currently, the woodland forest is almost disappearing and the important forest income and biomass collection (firewood and charcoal for sale and consumption and livestock fodder) are shrinking rapidly.

The model structure included several sub-models or sectors representing components of the socio-economical and environmental systems. These are land-use, human population, rainfall and a variety of incomes from crop and livestock production and non-farm activities (Fig. 2). The model simulated all variables over a period of 30 years. In the model the land-use stock is described as a function of changes in different categories of land-uses, human population dynamics and forest increase scenario. Land-use data inputs and assumptions are presented in Table 1. Those assumptions were based on historically observed trends and a discussion with the local farmers on what would be reasonable in the dynamics of land-use. The human population size is described as a function of growth rate, death rate and emigration. The population growth is influenced by the proposed family planning, health and education scenarios. The livestock number and livestock income are modeled as a function of the estimated losses and increases in livestock number, the carrying capacity (feed resources) of the area in terms of tropical livestock unit (TLU), human population dynamics and rainfall. Livestock carrying capacity was calculated based on the total animal feed available from different sources: grassland, crop residues and forest land (Table 3). Crop production is based on farm size of the households, human population dynamics, the variability of rainfall and the availability of micro-finance. Furthermore, non-farm income is based on the human population and land-use dynamics, the availability of micro-finance and educational conditions.

The model was built for an average household whose farm size is 1.5 ha, with a cropping area of maize (65%), wheat (25%) and tef (10%). The estimated average annual

Table 2 Data inputs and assumptions for 'human population model sector' in studying the trends of population using various scenarios

Data	Assumption	Data Sources
Population size = 3840 in 2006		Data interpolation from Garedew and others (2009)
Growth rate = 2.5%	Population increase is mainly determined by birth	Garedew and others (2009) 2006/07 HH survey, and authors calculation
	Immigration is negligible	
Household size = 6		
	With better family planning strategy, projected birth rate = 3.0% while current birth rate = 3.86%	World Population Prospects, 2008 revision
	With better health service, death rate = 0.85% while with current health service death rate = 1.2%	
	Emigration is negligible with the current educational status while with better education, Emigration is assumed to be 0.3%	
	We also assumed, Emigration will likely occur due to landlessness, 0.1%	

crop productivity of maize was 1.25 ton/ha (varying between 0.7 and 2.2) while wheat was 1.1 ton/ha (varying between 0.5 and 1.4) and tef 0.5 ton/ha (varying between 0.2 and 0.7). On the farmland, food crops are grown for subsistence and cash needs of the farming households. Crop net income (both consumption and cash) was calculated by subtracting the estimated crop cost and loss (30% of total crop income) from the total household crop income. In the study area, an average household owns five cattle, three goat/sheep, one donkey and two chickens which generate household livestock income, including sale of livestock products (mainly milk and eggs), sale of livestock, plough oxen rent, transport rent and consumption uses. All farmers do not have all kind of livestock goods throughout the year but buy and exchange internally for their own use while they also supply to the market. The economic contribution of the livestock sector is considerable and accounts for 15% of the total household income. In the study, non-farm income comprises wage labor, forest-based activities, small scale fishing, sale of salt-rich soil for cattle feed, petty trading, sale of sand for construction, sale of traditional drink, government safety net transfer and remittance (little was reported). A household averagely enrolled in at least the three of these non-farm income generation sources. All monetary values are reported in Ethiopian Birr, where USD $1 = ~11.50 in 2009.

Model testing was an essential part of the model development process. If the model is to be used, it should provide relatively accurate information about the system being modeled. In this study, the model could be validated by using land-use data from 1973 and the actual population data of the Kebelle from 1975 as input variables (Garedew and others 2009) and modeling of the period 1973/75–2006. The resulting simulated land-use values for three occasions (1986, 2000 and 2006) and simulated population values for four occasions (1984, 1994, 2004 and 2006) could then be compared to observed conditions and values derived from Garedew and others (2009).

Result

Dynamics in Population

The population sector model simulates natural population growth annually. Table 4 shows the simulations of population growth based on various intervention strategies, including "business as usual" and "better family planning", "better health", "better education" and a combination of the three latter. Over the simulation period (2006–2036), the total population growth varies between 68% and 136% among the simulated strategies. However, when compared to "business as usual", the scenario "better health" actually rise population growth (through reduced mortality), while "better family planning" (implying reduced birth rate), "better education" (meaning increased emigration) and the combined scenario significantly reduce population growth, Apparently, better family planning and the combined scenarios would be the best pathways for a balanced population growth compared to other strategies if considering the carrying capacity and the sustainable use of natural resources.

Dynamics in Land-Use

The simulations of the two land-use scenarios "with" and "without" the forest increase strategy were based on assumptions of land-use change as specified in Table 1. The simulation outcome as presented in Table 5 illustrate that small modifications in the assumptions of annual land transfers in the scenario "with forest increase strategy" (as

Table 3 Data inputs and assumptions for 'income' and 'rainfall' sector models in studying the trends of income and rainfall using various scenarios

Data	Assumption	Data Sources
1. Crop income Current crop income = 60%	With micro-finance strategy farmers could able to use modern inputs (chemical fertilizer and improved seeds), we assumed crop productivity is likely doubled. Thus, crop income is increasing	Garedew and others (2009), 2006/07 household survey, and authors estimation

2. Livestock income
Current livestock income = 15%
	Livestock income is dependent on the number of livestock owned by each household and the amount of available fodder/feed.
	Thus, the average number of livestock for the household was modelled based on the total carrying capacity of the area in terms of number of tropical livestock unit (TLU).
	In turn the total carrying capacity is calculated based on the total animal feed available from different sources: grassland and crop residues (both are mainly dependent on rainfall amount and distribution) and forest land:
	cc_tlu = initial number household * cc_tlu estimate * cc reduction.
	cc_tlu estimate = initial total tlu * 2;
	cc reduction = total f /initial total f;
	total f = (area_gl * gl_fr/ha) + (area_fl * fl_ fr/ha) + total sf;
	initial total f = (initial area_gl * gl_fr/ha + initial total sf + initial area_fl * fl_fr/ha;
	total sf = [(land area for maize * yield_maize residues /ha) + (land area_teff * yield _teff residues /ha) + (land area_wheat * yield _wheat residues/ha)] * number of household.
	Where, cc_tlu is the total tlu carrying capacity, f = animal feed in kg, gl_fr = animal feed resource from grassland is estimated based on random rainfall, fl_fr = animal feed (biomass) resource from forest land is estimated 600 kg/ha, sf = stover feed and is measured in kg.
	With micro-finance use livestock growth rate likely to double, from 0.1% to 0.2% for cattle while from 0.5% to 1% for goat/sheep and from 0.5% to 1% for chicken	

3. Non-farm income Current non-farm income = 25% Household's involved in at least three non-farm activities 14% households involved in petty trading 69% households involved in forest cash income	With micro-finance, we assumed that, every year an additional 2% households are likely to become involved in petty trading Forest increase assumption is likely to increase cash income from the forest and an additional 2% of households are expecting to earn this additional income	
4. The total household income is around 7811 Birr	Better education is likely to result in 2% of households earning additional income from remittance	
5. Rainfall	Annual rainfall, as a random variable based on the minimum (264 mm) and maximum (968 mm) values, likely influencing agricultural production and the total household income levels	

compared to the scenario "without") gave as an outcome that the area of woodland increased quite considerably (203%) at the expense of other land-use types over a 30 years period. For the villagers who initially defined what they want to achieve, (e.g., increased woodland) the interesting part ("the result") would be what input data generate that output (e.g., more woodland) and how to go about to harmonize the input data in their daily life situation.

The different rates of population growth in different scenarios affect the settlement area and the farm size per household (see Figs. 3, 4). Overall, the total area of settlements is increasing throughout the simulation period while the increments follow different pattern of pathways for different intervention strategies (Fig. 3). For instance, area of settlement dramatically increases with better health scenario compared to other intervention strategies. While the farm size per household tends to decrease throughout the simulation years irrespective of intervention strategy (Fig. 4). Here also better family planning and the combined scenario options are the best alternative pathways to slowing down the trends of decreasing farm size of households.

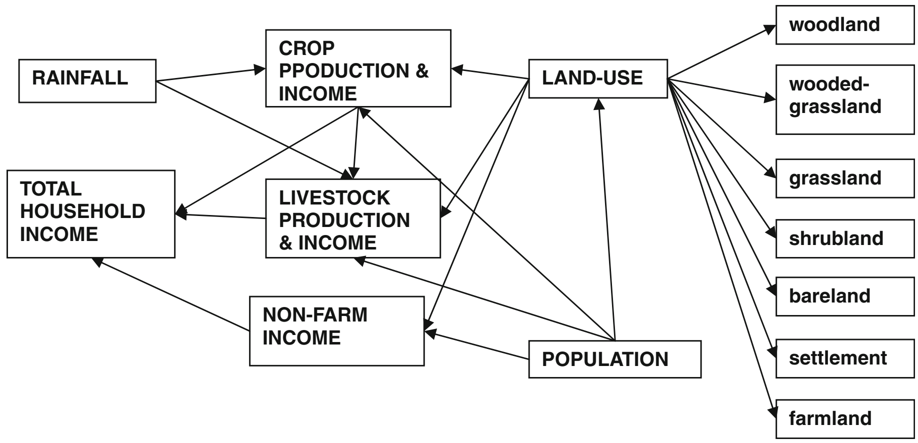

Fig. 2 The general structure of the model

Table 4 Simulation of human population growth based on the different strategies

Years	Business as usual (BAU)	Better family planning	Better health	Better education	Combined (without BAU)
2006	3840	3840	3840	3840	3840
2009	4143	4039	4185	4106	4045
2012	4469	4249	4561	4391	4261
2015	4821	4469	4971	4696	4489
2018	5201	4701	5418	5021	4729
2021	5610	4945	5905	5369	4981
2024	6053	5201	6435	5742	5247
2027	6529	5471	7014	6140	5528
2030	7044	5755	7644	6566	5823
2033	7599	6053	8331	7021	6134
2036	8197	6367	9079	7508	6462

Livelihood Strategies and Income Dynamics in the Households

Over the last three decades the households have mainly followed an increasingly extensive mixed agricultural livelihood strategy (crop and livestock). Farmers have recognized that recurrent droughts, erratic rainfall and soil degradation have influenced the agricultural productivity and food security. As those droughts occurred and the population increased, the forest cover has decreased when farmers tried to compensate the declining crop productivity by opening new croplands for subsistence agriculture. At this stage no more suitable land is left for cropland expansion. The demand for land by new households has also increased and as a result farm size per household is diminishing. During normal rainfall seasons high costs for agricultural inputs (chemical fertilizer and improved seeds) and lack of plow oxen exacerbate the challenges for the crop production sector. Households' efforts to diversify incomes through non-farm economic activities in order to buy food for the dry season can only provide marginal opportunities to fill the food gap.

The simulation of the average household income from crops and livestock (Table 6) followed a range of patterns between different intervention strategies. For agricultural income, all of the intervention strategies, both the micro-finance and the combined scenarios, considerably improved household incomes in the long-term but they had no regular patterns over the separate years of simulation. The reason is that households' income is regulated by the amount of income generated from agricultural production, which is largely dependent on the amount of rainfall and its distribution within the growing season, since agriculture is mostly rain-fed in the study area. A rainfall model was produced by a random generator providing annual rainfall values between 250 mm and 950 mm. The simulated output shows that the magnitude of agricultural income (in particular income from crops) per household varies with the amount of rainfall in the area (Fig. 5). On the other hand, nonfarm income (Table 7) was constant throughout

Table 5 Simulation of land-use types (ha) based on without (A) and with (B) forest increase strategies

Years	Grassland	Woodland	Shrubland	Wooded-grassland	Bareland	Farmland	Settlement
A							
0	769	192	145	48	48	1696	42
3	735	174	153	89	72	1672	45
6	707	159	159	123	94	1650	49
9	683	145	163	152	115	1628	53
12	665	134	167	176	134	1608	57
15	650	123	170	196	152	1589	61
18	638	114	172	212	168	1570	66
21	628	106	173	226	184	1552	71
24	621	99	174	237	198	1536	75
27	615	93	175	247	211	1519	80
30	611	88	175	254	223	1504	85
B							
0	769	192	145	48	48	1696	42
3	756	214	123	78	44	1679	45
6	745	242	108	97	40	1660	49
9	735	274	96	108	37	1638	53
12	725	309	87	114	34	1614	57
15	716	348	81	116	31	1587	61
18	706	389	76	116	29	1558	66
21	697	433	73	115	26	1525	71
24	688	480	70	113	24	1490	75
27	679	530	67	111	22	1451	80
30	670	583	65	109	20	1410	84

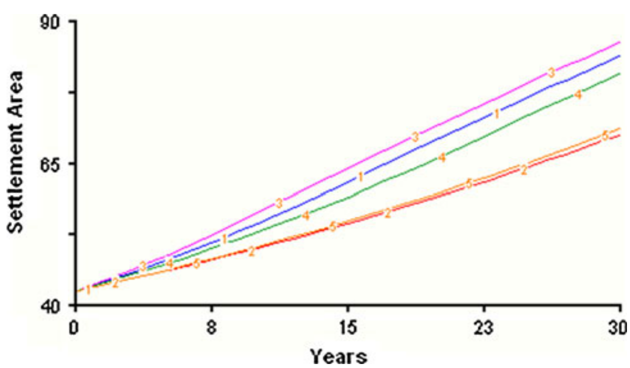

Fig. 3 Simulation of settlement areas under five different integrated strategies of scenarios: 1 = business as usual, 2 = better family planning, 3 = better health, 4 = better education, 5 = combined scenarios (2, 3 & 4)

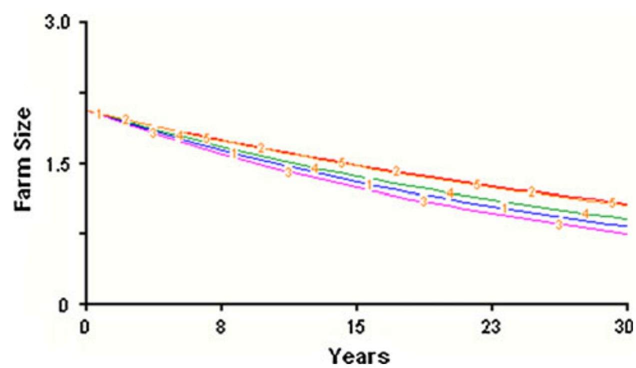

Fig. 4 Simulation of per household farm size under five different integrated strategies of scenarios: 1 = business as usual, 2 = better family planning, 3 = better health, 4 = better education, 5 = combined scenarios (2, 3 & 4)

the simulation period at a level specific for each of the strategies. Informants reported that in the past many households had been involved in forest activities and generate substantial non-farm income from sale of firewood, charcoal and other forest-based products. As an example, 69% of the households of the study are extracting some income from the remnant *Acacia* forest. Hence, the modeling output showed that there would be an increasing non-farm income through the "forest increase" strategy and this was simulated to be doubled when compared to the "business as usual" strategy.

Model Validation

Figures 6, 7, 8 and 9 show the comparisons between the historical development and simulated model for changes in

Table 6 Simulation of farm household incomes (Birr) based on different strategies

Years	Crop income		Livestock income			
	Business as usual (BAU)	Micro-finance	Business as usual (BAU)	Forest increase	Micro-finance	Combined (without BAU)
2006	3248	7307	2562	2562	2562	2562
2009	3518	8457	3043	3043	3175	4657
2012	4480	8681	3054	3054	3496	4093
2015	3297	9898	2790	2790	3195	5110
2018	3702	10270	2917	2917	3581	4342
2021	3869	9570	3007	3007	3300	3754
2024	5075	8650	2998	2998	3297	4008
2027	2844	11528	2535	2535	2742	4268
2030	3127	8805	2685	2685	2965	3810
2033	5409	5668	2405	2405	2510	3793
2036	2796	7017	2188	2188	2576	3465

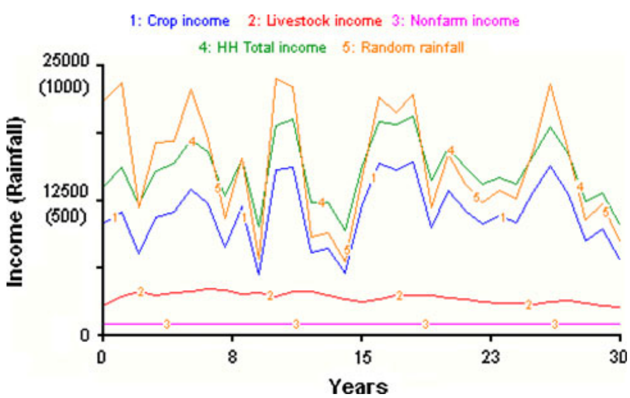

Fig. 5 Relationships between the simulated rainfall (mm) and household income under the micro-finance strategy

population size and areas of woodland, wooded-grassland and farmland. Generally, the simulated curves approximately match the historical development of all studied variables.

Discussion

The tested model, STELLA, provides a basis for better understanding of socio-economic and environmental interactions. The model was built based on assumed relationships between different variables. The outcome of a simulation is entirely dependent on those relationships and the input data. Therefore, any output always needs to be analyzed in relation to those input assumptions. The use of a simulation model to predict the future development of the dynamic system under various conditions (or to study what input data generate a certain desired output) is important in developing effective strategies. There are many examples of similar system models that could contribute to the environmental management practices (Helldén 2008; Kassa and others 2009; Sandewall and Nilsson 2001; Sayer and others 2007; Stéphenne and Lambin 2001). A participatory approach in scenario modeling is also an excellent platform for discussing strategies among different concerned stakeholders. If research data on historical trends are available it adds quality to the discussion on future developments.

We emphasize that a simulation model is not a forecasting instrument but a planning and analysis tool. It generates questions to be asked rather than direct answers. If a scenario suggests that farmers need to convert a certain cropland to woodland the question would be what efforts, resource inputs or strategies are required to achieve that. If that is not possible the question would be what other strategies could achieve an acceptable result. A more technical type of questions would be if the scenario or even the model accurately responds to or describes to the real world changes or if the model needs to be adjusted. One simple example of the later could be changes in birth rate as a result of "family planning" which may not happen instantly but change gradually over time.

In our model testing, it was not possible to undertake a strict statistical evaluation of the model because of the nature of the input data sets that encompasses a few separate years only. Therefore, instead of calculating error variance we used a graphical approach. The simulation outcomes are rough indications rather than very precise predictions. Validation with the historical development of some of the variables indicates that the model responds to key input variables more or less in a correct way.

The relationship between population growth and environmental changes is still an area of active debate (Alexandratos 2005; Carr and others 2005; Grau and others 2008; Jha and Bawa 2006; Nyssen and others 2004). In Ethiopia, population growth increases the demand for arable land and encourages the conversion of forests to agriculture. It also increases the demand for wood. The link between population growth and land degradation are

Table 7 Simulation of non-farm household income (Birr) based on different strategies

Years	Business as usual (BAU)	Forest increase	Micro-finance	Better education	Combined (without BAU)
2006	795	1230	811	796	1247
2009	795	1230	811	796	1247
2012	795	1230	811	796	1247
2015	795	1230	811	796	1247
2018	795	1230	811	796	1247
2021	795	1230	811	795	1247
2024	795	1230	811	795	1247
2027	795	1230	811	795	1247
2030	795	1230	811	795	1247
2033	795	1230	811	795	1247
2036	795	1230	811	795	1247

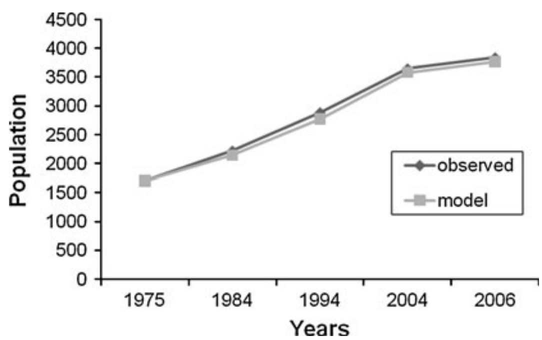

Fig. 6 Comparison of simulated and actual population size

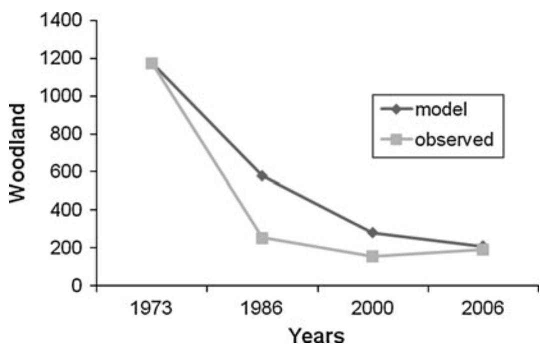

Fig. 7 Comparison of simulated and actual woodland size in hectare

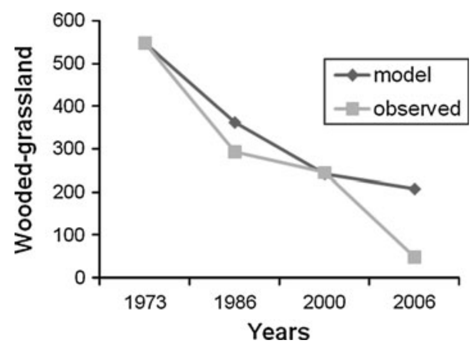

Fig. 8 Comparison of simulated and actual wooded-grassland size in hectare

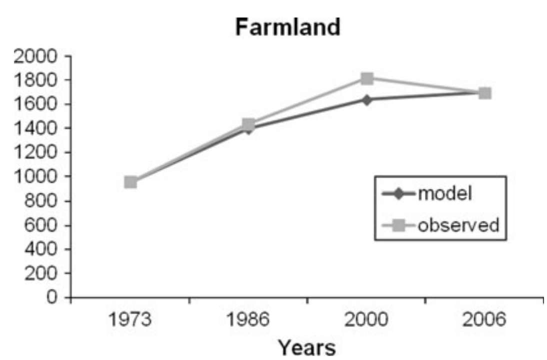

Fig. 9 Comparison of simulated and actual farm size in hectare

thought to be very strong (Bishaw 2001; Dessie and Christiansson 2008; Feoli and others 2002; Hans and others 2005; Taddese 2001; Teketay 2001). A previous study of land-use dynamics in the study area documented rapid population growth, declining crop productivity and rapid deforestation (Garedew and others 2009). In the present study, the output of the simulation indicates a further rapid population growth, declining farm size and worsening environmental degradation and socio-economic conditions if "business as usual" continues. However, through strategies such as those indicated in the other scenarios, there could be an opportunity to reverse environmental degradation and reduce population growth. It requires, however among other things, that farmers are motivated to participate in increasing the forest in the landscape and that the government actively promotes family planning, health, education, micro-finance, securing of land property rights and sustainable natural resource management. There are encouraging experiences of natural resource restoration (flora, fauna and soil) through local people participation in different degraded dry-land regions of Ethiopia and other developing countries (Lamb and others 2005; Mengistu and others 2005; Verdoodt and others 2009). A scenario based study in a forested part of Ethiopia suggested that participatory forest management (PFM) could provide higher forest cover and more sustainable household incomes for the local community (Kassa and others 2009).

In southern and eastern African countries, farm sizes have been declining over time and a quarter of the agricultural households are controlling less than 0.10 hectares per capita (Jayne and others 2003). In Ethiopia, the availability of land suitable for agriculture is shrinking due to land degradation, while the amount of land required to feed the growing population is steadily increasing (Haile 2004; Teketay 2001). Food security continues to deteriorate, the country has not been food self-sufficient for the last 3 decades and the gap has been filled by food-aid (Kirwan and McMillan 2007). In the present study, household farm size could decline due to population growth. As a result, low per capita income in the households is a major hindrance in providing adequate food to the members in the household. Household food security is likely deteriorating severely if crop productivity per unit area is unable to improve simultaneously with the rapidly increasing population. Informants have been mentioned repeatedly that erratic rainfall and shortage of land for crop production contributes to the challenge faced by the people living in the study area. In this respect, improving agriculture and diversifying livelihood options can help to reduce people's economic difficulties.

Conclusions

The model predicts an extensive land-use change, largely based on both the decisions of the community and natural population growth. The study simulates rapid population growth, declining household farm size, declining household income, further deterioration of forest cover and worsening land degradation if current practices continue.

The outlined "forest increase scenario" suggests a pathway that might possibly improve the restoration of forest cover in the landscape and subsequently raising household income. It addresses a critical issue but is not an easy way to go, which in practice requires the right decisions, confidence and interplay among farmers as well as government in order to bring back the forest.

The scenarios suggest that the level of population growth could be reduced with various strategies of family planning and education. This has an implication on the land-use patterns, the per capita household income and thereby on household food security. The amount of household income is largely dependent on the amount and distribution of rainfall and use of micro-finance. There was a strong relationship between rainfall variability and agricultural production.

Although, the simulation outcomes are predicted values, the study illustrates that the model can be used as a valuable supporting tool which can aid in the decision making processes in natural resource management. Local or regional planners can easily adapt the model and change variables following additional knowledge and discussions with interested stakeholders in the local area.

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