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Mountain Agrarian Systems

Modeling of land cover changes with CLUE-S in Cho Don District

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Abstract

Cho Don is a district of Bac Kan province in the Red River Basin. Its population of 46,200 inhabitants belongs primarily to the Tay (75%), Dao (11%) and Kinh (9%) ethnic groups. The total area of the district is 91,590 hectares, of which paddy fields accounts for 239 hectares. The majority of the population is dependent upon agriculture. Population growth has caused pressures on the land and on the natural resource base. Because of the limited availability of flat land suitable for agriculture, hillsides have gradually been converted into agricultural land for food production. Thus far, this practice appears to be meeting the needs of an increasing population, but sloping agriculture raises concerns about long-term sustainability of the natural resource base. To protect the fragile mountain environment, the Vietnamese Government has banned slash-and-burn cultivation. In the last decade, Vietnam has seen a lot of changes. The most remarkable change has been land allocation to individual households, giving full responsibility to farmers for their land. Therefore, land use changes are no longer driven by governmental planning agencies but by the cumulative effects of individual farmers' decisions. As a result, new tools and methods to support effective land use policies are required. The application of CLUE-S modeling (the Conversion of Land Use and its Effects at Small regional extent) in Cho Don District provides such a tool. By using different policy scenarios with CLUE-S, planners can define those areas that will remain stable or those with a high probability of change in the foreseeable future. Scientific information derived from simulations revealed CLUE-S's usefulness in formulating relevant land use policies.

Keywords: upland agriculture, land cover changes, CLUE-S, simulation model, Vietnam.

1. Introduction

Short-term predictions are necessary for land use planners. Accurate predictions result in appropriate policies that meet actual demand. Conversion of land cover (land use) is an issue that concerns both researchers and managers. Land cover systems are complex and are closely related to social and ecological systems. Land cover is not only defined as the "layer of soil, including its support of biomass and human structures, that covers the land surface". Land use changes do not always benefit human livelihoods. Forest burning and intensified cultivation on slopes cause soil degradation and decrease land productivity, while making environmental degradation impossible to control. A modeling approach such as CLUE-S can anticipate and thus prevent negative outcomes of land cover changes.

2. Methodology

In this study, we define land use change as "the replacement of a land cover type by another". Land use change occurs from the direct or indirect impact of:

- Forces that directly affect the rate and quantity of land use (e.g. forests are invaded by agricultural land because of population pressure);
- Factors that determine land use allocation (e.g. if land is suitable for lowland rice cultivation).

CLUE-S utilizes empirical methods (i.e. correlation and regression analyses) to reveal how land uses change as a result of these factors. This approach makes it possible to represent quantitatively complex systems with a wide range of interactions and scale dependencies.

Land use depends on a variety of environmental components such as soil characteristics, climate and topography while human factors determine where and why certain land uses change. To define factors affecting land use structures, we built a database including all factors that can have an impact on land uses. Most of the data were collected by the SAM-Regional program through village surveys or from the Cho Don district statistical service. Biophysical data was derived from maps and climatic data was obtained from meteorological stations. The land use map was created from interpretations of a SPOT satellite image from 1998.

To generate the regression equations, initially maps and multi-scale datasets were transformed into a grid with a 250 x 250-meter resolution. Each cell was characterized by a number of attributes such as soil type, population density, elevation, slope and accessibility. The dependent variables in the regression were seven land use types from the 1998 land use map.

In the case CLUE would be applied to the entire country with a coarse spatial resolution (large pixel size), land cover classes would be represented by the percentage of each land use type in the grid, e.g. 30% cultivated land, 40% grassland and 30% forest. But for our Cho Don case study, the CLUE-S (the Conversion of Land Use and its Effects at Small regional extent) model was applied. Because of the fine resolution, we could approximate land cover classes by the dominant land coverage in each cell. After converting to a grid format, only one type of land coverage was presented in each grid (i.e. dependent variables were represented by 1 (presence) or 0 (absence) in each cell). Main components of CLUE-S are shown in Figure 1.

2.1. The main components

Probability. As dependent variables in the model are dichotomous, statistical modeling in CLUE-S is based on logistic regression analyses so as to identify and quantify driving forces of land uses. The analyses are implemented on current land use for each land use type. The regression coefficients are used to calculate the probability of a certain cell of a certain land use type in the analysis year.

Protection. This component shows which cells are included in the simulations of land use change. All other cells are not included because they are seen as stable land uses. This module is used to define which cells fall within protected areas, in which it is assumed that no land use change will take place during simulations.

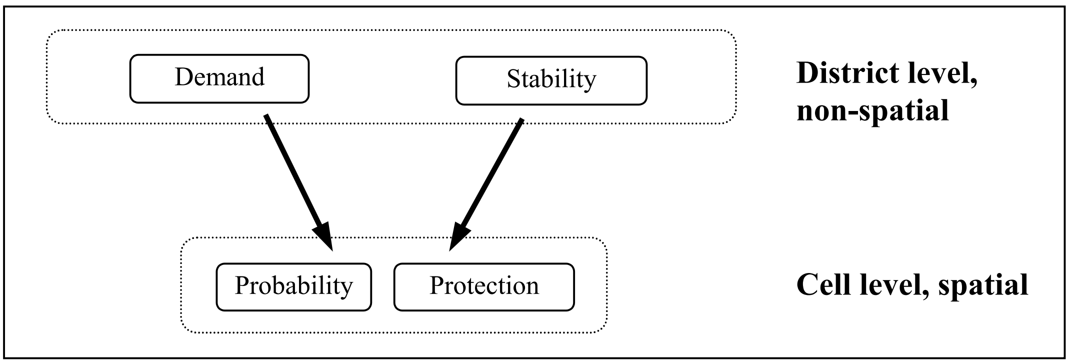

Figure 1. Main components of CLUE-S model

Demand. As we are studying land use changes, a temporal factor is included in the model. The demand module defines each land use type needed for each year at the regional (district) level without concern for the spatial configuration within the area. This non-spatial input can be identified by an economic model, future policies and/or orientations or by a simple linear extrapolation of the growth of land use area.

Stability. Stability settings present how easily a certain land use type is changed. The settings provide elasticity to conservation. In other words, how easy the conservation of a certain land use type is to another type. The stability value varies between 0 and 1, with 0 for the most dynamic land use type and 1 for the most stable land use type. The stability input is a non-spatial component identified for each land cover type at the regional level. These stable factors are difficult to parameterize; therefore, they need calibration based on the history, or in combination with expert knowledge.

Conversion Matrix. This matrix identifies allowed land use conversion. In the matrix, rows indicate current land use types and columns indicate potential future land use types. The value of 1 indicates allowed conversion and the value of 0 prohibits conversion. This matrix also shows a minimum or maximum time a land use type needs to be stable before changing. The minimum time is shown with 100 + time and the maximum time is shown with -100 - time. In the first time step of the model, land use types are assumed to have already existed for five years.

2.2. Land allocation procedure in CLUE-S

When running CLUE-S, different land uses are allocated to different cells of the simulation area. Land allocation proceeds as follows (Figure 2):

1. All cells allowed to change are defined (protected areas and stable land use types are excluded).
2. For other cells, the total probability is calculated in accordance with regression outputs, stability settings and iteration factors. The iteration factors can change the total probability if allocated land uses do not cover demand.
3. The first allocation takes place with the equal value of iteration variables by allocating the land cover types with the highest probability in each cell.
4. All allocated land use types are compared with the demand. If the allocated areas are smaller than the demand, the values of iteration variables are increased.
5. Step 2 and 5 are repeated when the demand is not satisfied. When the allocation is equal to the demand the final allocation is saved and calculations continue for the next year.

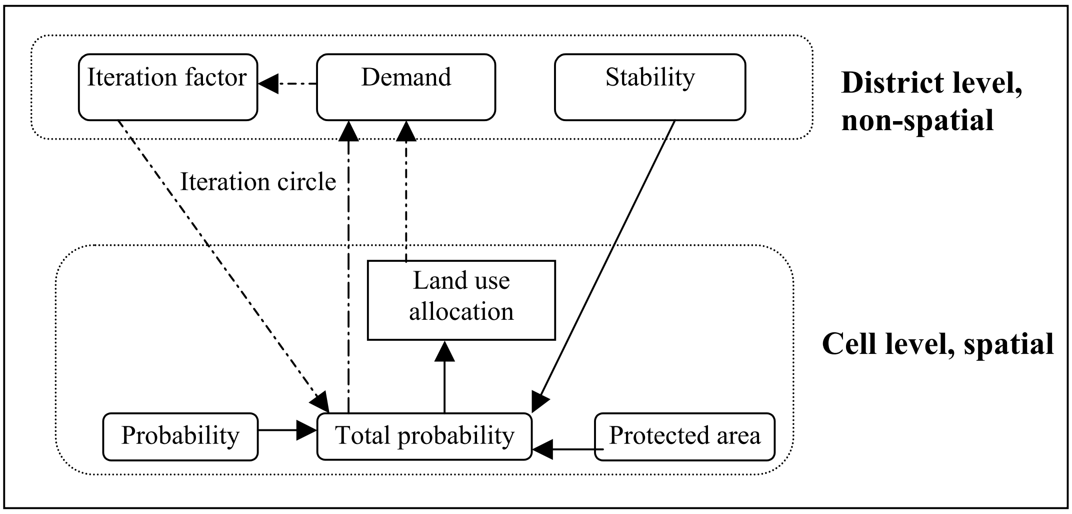

Figure 2. Land allocation in the CLUE-S model

2.3. Statistical method

An important part of the CLUE-S model is logistic regression calculations, which are used when the dependent variables are binary (0 or 1) and the independent are continuous or categorical. Each land use type (the dependent variables) in CLUE-S with a value of 0 or 1 indicates the absence or presence of the land use type in a grid cell. The logistic regression function is formed as follows:

$$Log(P_i / 1\text{-}P_i) = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots + \beta_n X_{ni}$$

Of which, P_i is the occurrence probability of studied land use and X represents driving factors. Stepwise regression methods enable us to select relevant factors within a set of factors that are assumed to relate to land use structures. Regression coefficients are derived from the model. In this multi logistic regression model, in order to decrease multicolinearity only the most significant variables in a set of independent variables are imported into the model. The multicolinearity is the correlation between the independent variables and driving factors. The correlation is assumed to be 0, but still occurs when related variables are used; for example, fluvisol and distance to water bodies. Nonetheless, it is impossible to entirely eliminate the multicolinearity of the model with this method.

The accuracy of the multi linear regression model can be described by interpretation of variance (R^2). The R^2 tells whether the regression curve explains data accurately or not (Figure 3). An appropriate approach to evaluate the logistic regression equation is to use ROC (Relative Operating Characteristics), which describes the relationship between true and false predictions for various cut-off values of the probability.

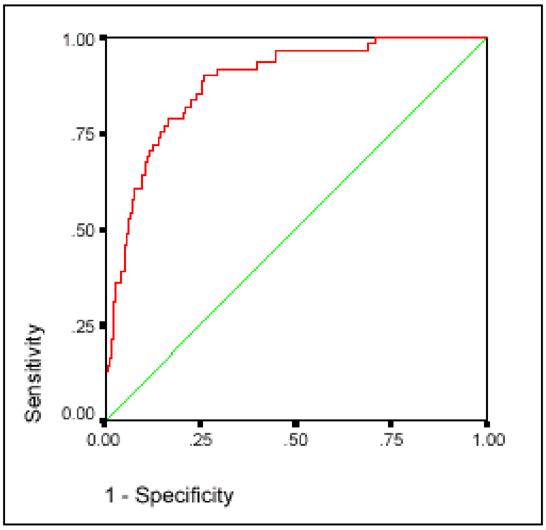

Figure 3. The ROC curve for "shrub", the area under the curve (AUC) is 0.875

The cut-off value is set at 0.5, which means that values smaller than 0.5 signify the absence of land use type. Thus, the smaller the cut-off value, the more area of predicted land use. The most ideal model brings out the curve with the largest area under the curve (AUC). The AUC varies from 0.5 to 1. If the model does not more accurately predict the occurrence of a land use type than a random occurrence, the AUC equals 0.5 (indicated by the diagonal line in the graph).

2.4. Data requirements

Different components of the model require different data. Therefore, it is necessary to prepare an appropriate dataset. The selection method is shown in Figure 4.

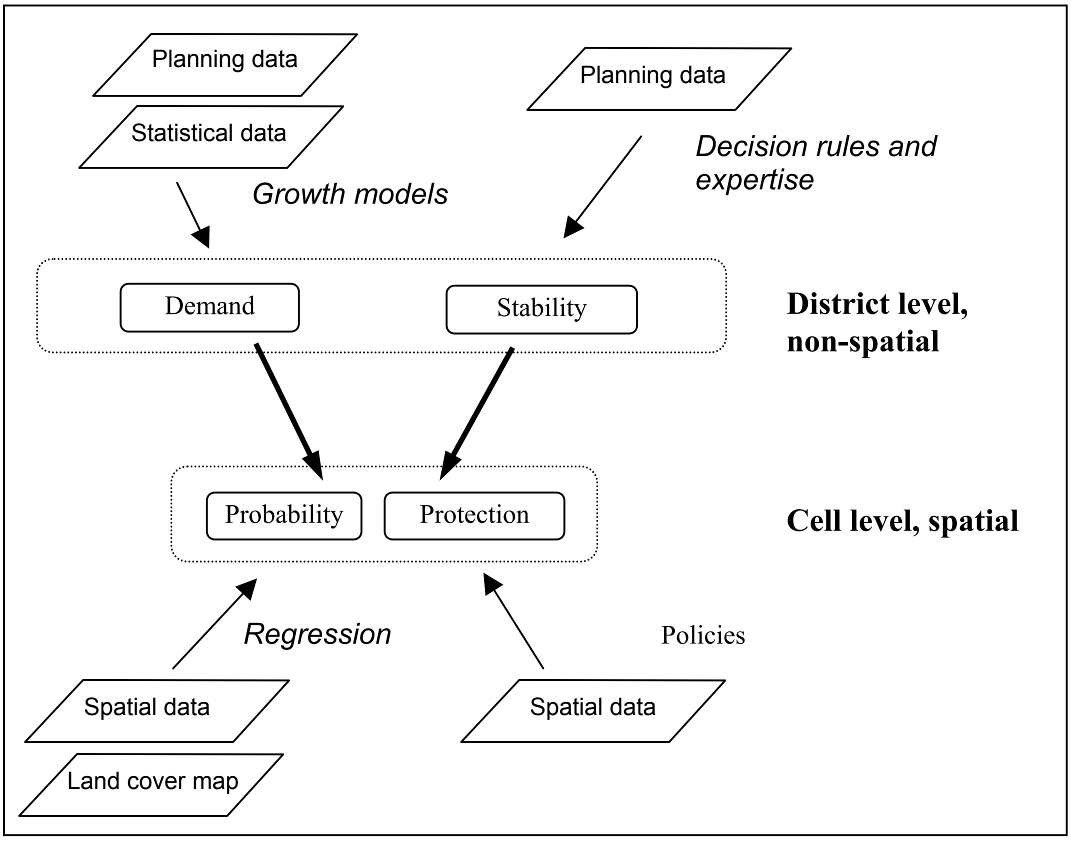

Figure 4. Input data needed for the CLUE-S model

3. CLUE-S application in Cho Don District

3.1. Data preparation

Land use data were extracted from the 1998 land use map. The independent variables consist of biophysical, socio-economic, accessibility and climate data. The selection of input data for the model depends on the main causal factors of change. In mountainous areas of northern Vietnam, the following problems were taken into consideration:

- Environment (elevation, slope, soil degradation, uneven rainfall distribution, etc.)
- Infrastructure (transportation and communication systems)
- Economy (dependency upon agriculture; poorly developed markets)
- Population (high demographic growth and unemployment)
- Education (low education background; diversity of ethnic groups)

Factors included in Table 1 were regarded as key issues that may impact land use changes because of their relation to the above constraints. They were selected as independent variables for regression calculations.

Geographic data were processed using ArcView software. Socio-economic data were related to commune or village level administrative maps. Geological, climatic, geographical and accessibility data were taken from results of other studies. Then all maps were converted into a raster grid of 250 x 250 meters. Finally, all variables were exported to ASCII files that were imported into SPSS software for statistical analysis.

Dependent variables

The 1998 land use map, produced by the SAM-Regional program from interpretations of SPOT satellite images, consisted of 7 land cover types: lowland rice, upland rice, mosaic, shrub, grassland, forest and residential area (Figure 5).

Table 1. Variables used for the CLUE-S application in Cho Don district.

Variables	Type	Unit	Classes
Dependent			
Land cover	Binary	0 - 1	Lowland rice Upland crop Mosaic Grass land Forest Shrubs Residential
Independent			
Soil, Geology, Relief			
Soil type	Binary	0 - 1	Cambisols Leptosols Fluvisols Regosols
Geology	Binary	0 - 1	Schist Sandstone Granite Limestone
Soil degradation	Binary	0 - 1	Non Slightly Moderate
Elevation	Discrete	meter	
Slope	Category	0 - 1	Non Small Medium Moderate
Socio-economy			
Population	Discrete	Population / village	
Population density	Discrete	Average people / ha	
Poverty rate	Discrete	% household / village	
Illiteracy rate	Discrete	% people / commune	
Percentage of Dao	Discrete	% household / village	
Percentage of Tay	Discrete	% household / village	
Percentage of Kinh	Discrete	% household / village	
Cattle	Discrete	number head per / village	
Cattle density	Discrete	number head / ha	
Pigs		number head / village	
Pig density	Discrete	number / ha	
Electricity	Binary	0 – 1 (absent / connected)	
Property	Discrete	T.V. set and radio / village	
Accessibility			
Distance to water sources	Continuous	Meter	
Travel time to markets, healthcare stations, schools and people's committee	Continuous	Minute	
Travel time to administrative center	Continuous	Minute	
Number of teachers and doctors in the area	Discrete	People	
Climate			
Number of dry months	Binary	0 - 1	3 months 4 months
Number of dry months	Binary	0 - 1	0 month 1 month

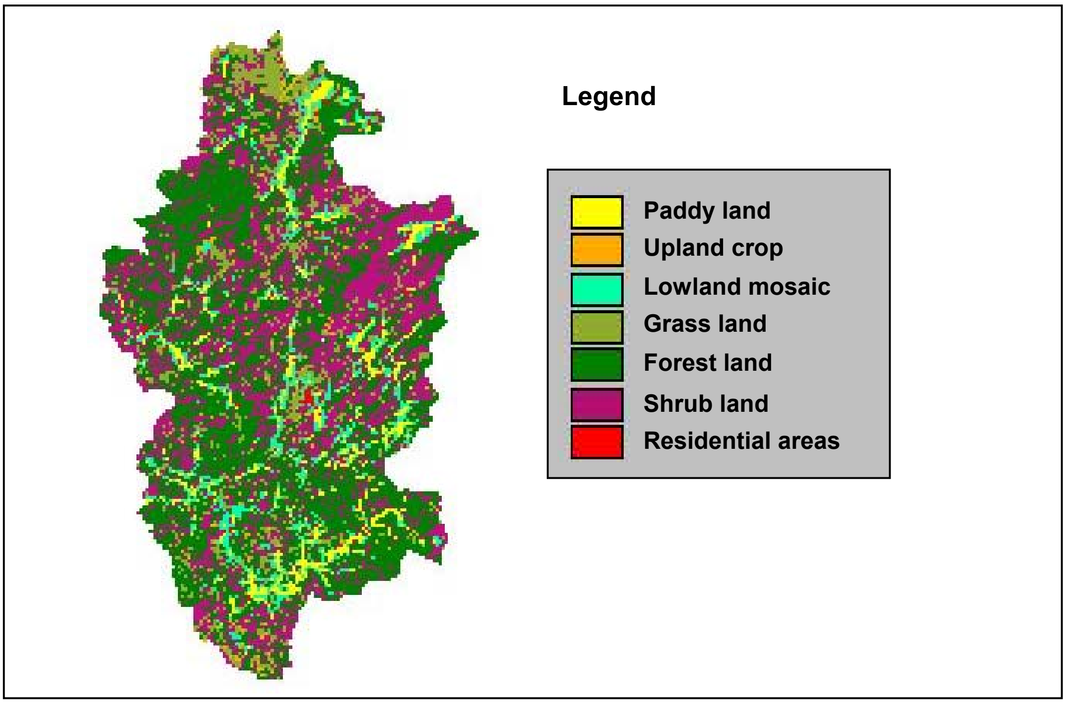

Figure 5. Land cover map of Cho Don District 1998

<u>Independent variables</u>

Soil degradation: After reclassification, features such as erosion and various levels of soil degradation were divided into more simple classes: non, slightly, and moderate.

*Population**:*** Number of inhabitants per village.

Population and livestock density: Population density is equal to total population divided by village area. The livestock (cattle and pig) densities were also calculated in this way.

*Poverty rate**:*** A household is classified as poor if its income is lower than 15 kg of rice/person/month (poverty standard 1998). The poverty rate is the percentage of poor households per village.

Illiteracy rate: Percentage of illiterate people under 35 years of age.

*Percentage of Tay, Kinh and Dao**:*** Percentage of Tay, Kinh or Dao families per village.

Distance to water sources: Distance in meters from each cell to water sources computed from maps.

Travel time to markets, healthcare stations, schools and people's committees: The average travel time to the nearest market, health care station, school and people's committee by the fastest means of transport.

Travel time to administrative center: Travel time to the district administrative center.

Number of teacher and doctor in the area: Number of teachers or doctors within a 60-minute drive.

Soil types: There were 12 soil types in the available soil map for the entire Bac Kan province. To reduce the number of variables, we reclassified them according to 4 main soil types: cambisol, leptosol, fluvisol and regosol.

Geological classes: There were 40 types of geological classes in the Bac Kan province geological map. Re-classification reduced them to 4 main classes: schist, sandstone, granite, and limestone.

Elevation and slope: Derived from the digital elevation model.

Climate: Data on monthly rainfall and average temperatures were compiled for the last 25 years (source: LUPAS). Dry months were when rainfall was less than 50 mm and cold months were when average temperatures were under 12^0C.

3.2. Scenarios

Two scenarios were tested, based on policy and land use planning strategies provided by district authorities.

Scenario 1: Ensuring food sufficiency for the district's increasing population while achieving reforestation targets.

We predicted Cho Don's annual population growth rate based on the 1998 Cho Don population data and provincial population growth rates. As a result, demand on agricultural land should increase. According to the district development plan until 2010, forest cover area, which accounts for 45%, should reach 60%. This increase in forest area was computed in generating the demand matrix (Table 2). Forest area is assumed to develop from shrub land. Rice-cropping area will increase due to terracing upland fields located close to water sources (for irrigation). If technical factors were applied (i.e., rice productivity increases) the agricultural area would increase slightly.

Scenario 2: Improving livestock development while reaching reforestation targets.

In addition to achieving reforestation targets, there will be an increase in grassland in order to develop livestock raising activities to increase meat production and improve farmers' incomes (Table 3).

Protected area

We have delineated the protected areas, territories that will not change during a CLUE-S run because of physical constraints (non-suitable soil type or slope) or government policies. For example, because the Government has banned deforestation, it is impossible to turn forested areas into another land use type. In Cho Don district, forest is seen as protected area.

Time period

In the model, the time period for simulation is set at 12 years, from 1998 to 2010, because policy makers often designate 2010 as the last year for achieving their targets. Thus, we can produce 12 forecast maps for each scenario.

Table 2. Demand matrix for scenario 1

Year	Population	Lowland rice	Forest
1998	42783	5075.0	39687.5 (45%)
1999	43703	5098.7	40847.1
2000	44643	5208.4	42006.7
2001	45604	5320.4	43166.3
2002	46585	5434.9	44325.8
2003	47587	5551.8	45485.4
2004	48610	5671.2	46645.0
2005	49656	5793.2	47804.6
2006	50512	5893.1	48964.2
2007	51383	5994.7	50123.8
2008	52269	6098.0	51283.3
2009	53170	6203.2	52442.9
2010	54087	6310.1	53602.5 (60%)

Table 3. Demand matrix for scenario 2

Year	Population	Rice	Forest	Number of cattle	Grassland
1998	42783	4406.3	39687.5 (45%)	21737	7212.5
1999	43703	5098.7	40847.1	23065	7653.1
2000	44643	5208.4	42006.7	24474	8120.6
2001	45604	5320.4	43166.3	25969	8616.6
2002	46585	5434.9	44325.8	27555	9142.9
2003	47587	5551.8	45485.4	29238	9701.4
2004	48610	5671.2	46645.0	31024	10294.0
2005	49656	5793.2	47804.6	32919	10922.8
2006	50512	5893.1	48964.2	34930	11590.0
2007	51383	5994.7	50123.8	37064	12298.0
2008	52269	6098.0	51283.3	39328	13049.2
2009	53170	6203.2	52442.9	41730	13846.3
2010	54087	6310.1	53602.5 (60%)	44279	14692.1

<u>Stability settings (conversion ability)</u>

Land use plans and local rules for natural resource management influence stability settings of different types of land cover. Therefore, stability settings reveal whether it will be difficult or easy to convert a land cover type into another. In this model, the settings are as follows:

Land use types	Stability settings
Lowland rice	1
Upland crops	0.3
Mosaic	0.3
Grassland	0.25
Forest	0.75
Shrubs	0.2
Residential area	1

According to experts we interviewed in Bac Kan, there are two kinds of grassland. The first one is on poor acid soils (stability settings may reach 0.4 because the soil quality is hard to improve). The second type, typical of fallow land, is not stable. With stability settings at 0.1, it is easy to turn this type of land into upland crops, shrubs, forest, mosaic or residential areas. However, because it is impossible to distinguish the two types of grassland by image interpretation, we set the average stability to 0.25. Shrub is more stable than grassland (SI = 0.2), as it is easily turned into upland fields, grassland or can be converted into forest. Inversely, forests can easily turn into other land uses when outside of protected areas. Lowland areas have mostly been cultivated into paddy and play an important role in fulfilling food production. Thus, they cannot be converted into other land uses (SI = 1). The same SI value applies to residential areas.

Convergence criterion

Convergence criterion defines the maximum deviation allowed between the percentage of demand changes and current land allocation changes. Setting this criterion to high values will increase the convergence speed of the simulation model. In the model, the default setting is 0.35%, but it can vary according to each model. For Cho Don, we set it at 0.2.

Outcomes from the statistical analysis

Regression analyses were run repeatedly with random samples of the total dataset (250m cells covering the entire district) in order to get the stability indicator of the model. After running several regression functions with different random samples, the outcomes were not stable (i.e. different variables with different regression coefficients appearing on the same land cover). To increase the stability of the model, we applied the following measures:

1. Some factors with little variation within the district and unclear explanations in the regression analysis were excluded from the model;
2. We lowered the criteria for entry and removed the values of variables to reduce multicolinearity. The entry and removal values were fixed at $p = 0.01$ and $p = 0.02$, respectively;
3. Various sample sizes were analyzed to check if they impacted the stability of the model. The smaller the cell sample size, the less it represented the dataset. Some land cover types were displayed on just a few grid cells; to ensure these land cover types represent the dataset, at least 75 cells must be displayed. The land use type with the least displayed cells was the residential area (124 cells), thus, 60% of random sample were already selected.

To make the model as compact as possible, only variables clearly affecting land use changes were retained; variables with regression coefficients of 0.0001 or lower were removed from the model. If the ROC decreased by 0.01 or more due to eliminating variables, then they were retained in the model.

The results of regression analyses were tested for level of fitness by means of the ROC. The level of fitness was indicated by values between 0.5 and 1, with the value of 1 indicating the perfect fit indicator. Regarding the dataset of Cho Don district, ROC was calculated from 0.635 for forest to 0.85 for lowland rice. Low values of ROC resulted from: the accuracy of image interpretations, insufficient inclusion of causal factors in the model, or inappropriate classifications of the causal factors.

To indicate the importance of causal factors upon land use types, the exponent (B) was calculated to show that the probability of a certain land use in a cell increased (higher than 1) or decreased (less than 1) when increasing the number of independent variables.

A disadvantage of exponent (B) is that it was computed based on a 1 unit increase of independent variables. Therefore, an increase of 1 in binary variables was likely to have greater influence than an increase of 1 in B of continuous or discrete variables, which always have larger ranges in value.

Negatively correlated factors, which can reduce the probability of a certain land cover type, will have an exp (B) between 0 and 1 while an exp (B) of positively correlated factors increases the probability that a certain land cover type will have a value higher than 1. Thus, to compare the exp (B) of factors with positive impacts to those with negative impacts, the following equations were used:

$\exp(B*\text{range})$ = relative influence (for $B>1$)
$-1/\exp(B*\text{range})$ = rel. influence (for $B<1$)

Regression analysis outcomes are displayed as follows:

	Paddy rice	Upland crops	Mosaic	Grass land	Forest	Shrubs	Residential areas
Soil types							
Cambisol*							
Leptosol			-0.36			0.19	
Fluvisol	0.95	-4.62		-0.69	-0.79	-0.76	
Regosol	1.84		1.33		-0.96	-1.25	
Geology							
Schist*							
Sandstone				-0.37	0.22	-0.24	
Granite							
Limestone	2.50		1.71		-0.59		2.28
Elevation	-0.01		-0.01	-0.001		0.002	-0.005
Slope 1	0.88	-0.97	0.21			-0.21	1.50
Slope 2					-0.36		
Slope 3*							
Slope 4							
None soil degradation			0.41	-0.45	0.27	-0.52	
Slightly soil degradation*							
Moderate soil degradation				0.47	-0.66	0.30	
Socio-economic							
Electricity/None					-0.17	0.24	
Population	0.006		0.003				
Population density			0.41				0.40
Total household							
Illiteracy rate			0.08		-0.04	0.02	
Poverty rate					-0.006	0.004	
Percentage of Dao			0.005		0.006		
Percentage of Kinh				-0.02	0.018	0.005	
Percentage of Tay	0.01		0.007	-0.01	0.008		
Number of cattle	-0.01				0.001		
Number of pigs	0.005						
Cattle density/ha	0.73				-0.76	0.53	
Pig density/ha							0.004
Number of T.Vs and radios		-0.02	-0.005	-0.01			
Accessibility							
Distance to water sources							
Average travel time to commune PC, healthcare stations and schools.				-0.012	0.006		
Number of teachers and doctors within 60 minute drive			0.002	0.007			
Travel time to district center							
Climate							
Dry months: 3	-0.54	1.06		0.79	-0.27		
Cold months							
ROC	0.8497	0.6899	0.7895	0.6742	0.6345	0.6675	0.7979

Variables with (*) were not included in the regression calculation, as they would result in linear dependence between instances within a same variable set.

Variables: Total households, slope 4, granite and distance to water sources were not retained in the regression analyses, so they cannot be considered as driving forces of land use changes. Slope 4 variable is the steepest type of incline, making it very difficult for farmers to exploit this land for agricultural production, thus, it is considered to be mostly unchangeable. Granite soils account for small areas of the district, so it is also not considered a main cause of land use change. Distance to water sources is calculated by measuring the distance from a grid cell to a river or a stream on the map; however, this indicator is not very reliable because geology is ignored.

Residential areas are characterized by flat terrain, slight elevation, high population densities, and limestone soil. Lowland rice is marked by slight or moderate elevation, percentage of the Tay ethnic group, cattle density, slightly sloped land, and limestone, fluvisol and regosol soil types. Generally speaking, some beneficial characteristics of a land use type negatively affect other land use types. Nonetheless, these factors are not sufficient to precisely explain all land use types, as ROCs are not high.

Apart from land use predictions, CLUE-S can also produce probability maps for each land use type. These maps present the probability of occurrence of each land use type on grid cells. This probability is a result of logistic regression analyses and is based on the input variables of the model. On the probability map, we can define for each cell the probability of occurrence for each land use type. The more similar the probability map and land use map, the higher the ROC. By comparing these two kinds of maps we will know if the logistic regression analyses has accurately explained land use types, and if sufficient input variables have been taken into account.

3.3. CLUE-S simulations outputs

CLUE-S was run for the two different scenarios mentioned above. Scenario 1 aimed at ensuring food sufficiency for the increasing population of the district, while increasing the forest cover area from 45% in 1998 to 60% in 2010 (Figure 6). According to this scenario, paddy area increased mainly on cells adjacent to the 1998 paddy fields that were close to water sources. The upland crops that used to be scattered among forest and shrub patches in 1998 gradually expanded near lowland fields and mosaic areas during the simulation, which is consistent with the current observed trend. Many forest areas have been opened, mostly in the western and southwestern parts of the district, where a greater number of water sources exist. Shrub land was scattered across the district in 1998. However, in the CLUE-S simulation, it tends to be concentrated in the western and northwestern parts where elevation is higher than other parts of the district. Grassland areas remained limited and were mainly located in the western part of the district. This is perhaps related to the specific soil types in this area, cambisoil and sandstone. In this scenario, forest was seen as protected area and, therefore, was not allowed to change into other land uses.

Besides the district's targets for food-sufficiency and increasing forest cover area to 60%, a province target is to increase the total number of cattle heads from 108,000 in 1998 to 220,000 in 2010, an annual growth rate of 6.1%. The total cattle herd in Cho Don district was 21,737 in 1998. If the growth rate is achieved, it will result in a relative increase in grassland area as included in scenario 2. Forest and grassland will develop from previous shrub areas. In this scenario, forest is also considered a protected area. According to scenario 2, by 2010, grassland area will rise due to demand for grass for livestock feeding, but grassland areas will not spread out too far beyond the hydrological system. It will spread mostly in northern and southern parts of the district and will also be scattered around lowland fields. Shrubs will remain in limited areas, mostly in the northeast and a small part in the northwest of the district where the elevation is high (Figure 7). Based on predicted maps for 2010 of scenario 2, it can be deduced that mosaic areas will expand in limestone areas, which is consistent with our field observations. Intensive cropping systems will mostly concentrate in these types of soil after mosaic areas have decreased, which matches logistic regression results.

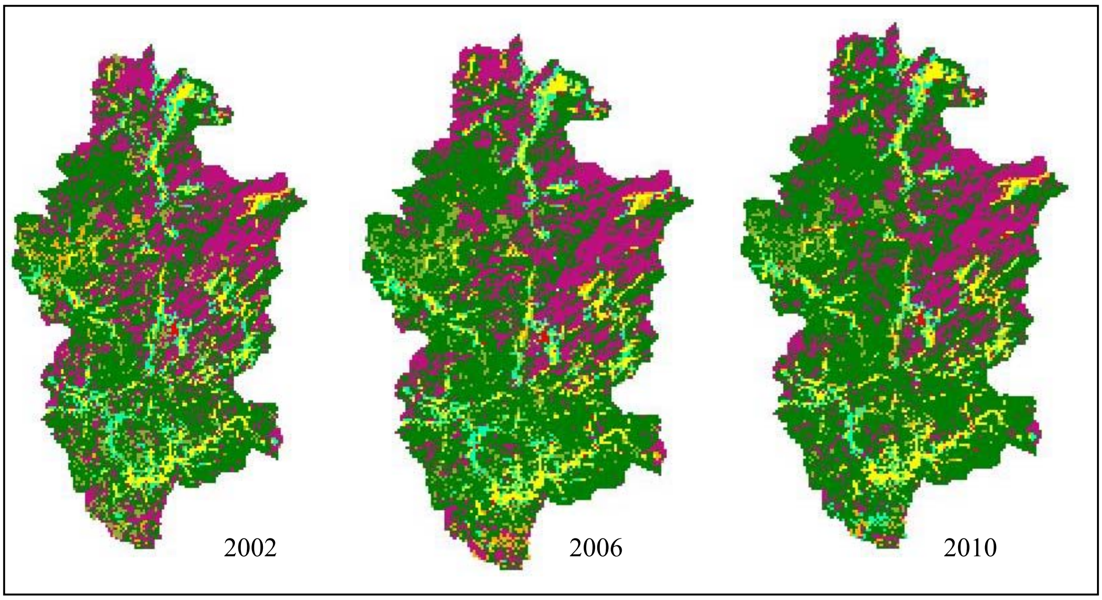

Figure 6. Results of the CLUE-S simulation of land cover changes in Cho Don District based on scenario 1

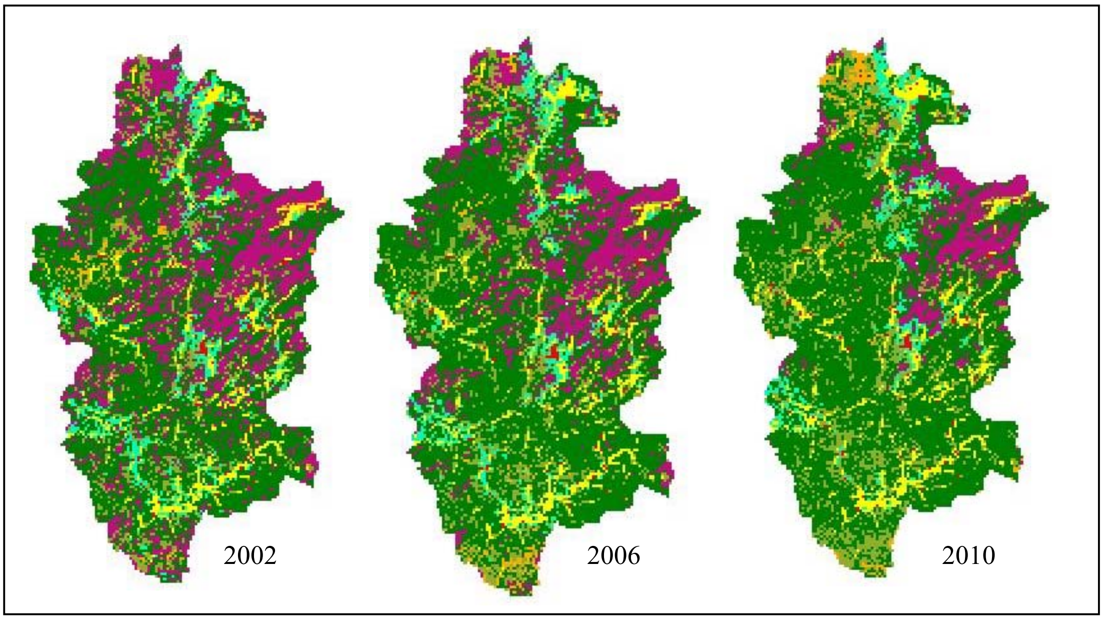

Figure 7. Results of the CLUE-S simulation of land cover changes in Cho Don District based on scenario 2

4. Conclusions

CLUE-S simulates land use changes based on a series of conditions defined by the biophysical and socio-economic environment and driven by demand scenarios. Based on regression analysis results, driving forces that impact land use types can be identified. If government policies are one of these factors, it is certain that land use changes will be greatly affected. Planners and policy makers can learn from maps that can predict which areas will change and which ones will remain stable in creating policies to meet land use demands. Consequently, we can evaluate projected policies and understand how they will affect land uses.

CLUE-S was successfully applied to Cho Don district, a very heterogeneous landscape that made for a challenging exercise. However, due to very rapid changes that have occurred in Cho Don over the past decades, the model would have been better as an exploration tool than a predictive tool. The time period of the simulation may be limited to a few years to ensure results are realistic. Moreover, the intrinsic error of the model is due to: (i) the assumption of homogeneous land use for each 250 x 250 m cell; and (ii) the unstable land cover classifications from satellite images, which requires some caution in using it. We consider it more as a negotiation/discussion support mechanism among development agencies to explore policy options than a tool for planners to design future land uses.