

Projecting Land Use Transitions in the Gin Catchment, Sri Lanka

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Abstract: Gin catchment located in the Southern region of Sri Lanka has its land primarily used for natural and planted forest, agriculture and settlements. Though there exist a vital need to investigate how the prevailing land use in the catchment is going to alter subsequent to various anthropogenic activities, so far there have been no such attempts made. This study aims at carrying out spatially explicit land use change analysis across the Gin catchment in order to project the potential land use change in the year 2020 using a logistic regression approach based on Geographic Information System (GIS). In this study, probability of occurrence of a certain land use type was predicted by the socioeconomic, proximity and biophysical driving factors. Allocation of land use change was made in an iterative procedure given the probability maps, the spatial policies and restrictions in combination with the observed land use map in 1983 and the demand for the different land use types. Observed land use map in 1999 was used in validating the predictions. The results envisaged a predominant replacement of cultivations by forest and homestead/garden which seems to have driven jointly by the change in agricultural practices and increase in population.

Keywords: Driving factors, Gin catchment, land use change, logistic regression, spatial analysis

INTRODUCTION

Land use changes are a complex and dynamic processes that link together natural, economic, social and cultural factors in time and space (Koomen *et al.*, 2007) and various tools are needed to understand and explain these processes. Land use change modeling, especially if done in a spatially explicit, integrated and multi scale manner, is an important technique for the projection of alternative pathways into the future, for conducting experiments that test our understanding of key processes in land use changes (Veldkamp and Lambin, 2001). Thus the land cover and land use changes are considered as an important part of global change which affects many parts of human environment systems. Environmental management and land use planning therefore need information about the dynamics of land use. Models can help to understand these dynamics and project near future land use trajectories in order to target management decisions (Schoonenboom, 1995). Spatially explicit modeling approaches including statistical regressions have been successfully applied to investigate land use change processes. Logistic regressions are a statistical technique to determine the significance, direction and strength of an independent variable on a dichotomous dependent variable (Hosmer and Lemeshow, 2000). Logistic regressions have been

successfully applied to analyze the causes of deforestation (Chomitz and Gray, 1996; Mertens and Lambin, 2000) and cropland abandonment (Mueller and Munroe, 2008). Beside the assessment of land use and land cover changes, analysis of the underlying processes is much more complicated. Several concepts have been proposed that describe the relationship, functioning and feedbacks of land cover, land use and socio-cultural background (Geist and Lambin, 2001; Briassoulis, 2000). A deeper understanding of the change processes is possible through modelling of the system as relationships of driving forces and land use change are established and verified (Veldkamp and Lambin, 2001).

Impacts of land use change such as deforestation, plantations and human settlements have been identified as affecting water resources in Sri Lanka including pollution of water bodies (U.N. Environment Programme, 2001). However, no exhaustive information available at the catchment level on spatial dynamics of land use change and socioeconomic, proximity and biophysical backgrounds which could possibly alter basin wide land use status. One of the reasons for this might be the difficulty in finding the past land use data and principal driving factor records at reasonably fine spatial resolution. Nevertheless the knowledge of spatially explicit land use change

trajectories and possible future conditions yield important information for effective environmental management and land use planning. Thus, this study aims at investigation of the spatial pattern of land use transitions and projection of the potential land use change in year 2020 using a Geographic Information System (GIS) based logistic regression approach. The resulting spatially explicit insights provide useful information for decision makers and could be used as input into spatially targeted land use planning activities.

STUDY CATCHMENT AND DATA

Gin is predominantly a natural catchment characterized by its mountainous slopes in upper reaches, covered with forest canopy. The catchment's land is primarily used for natural and plantation forest, agriculture and settlements. Gin catchment lies approximately between 80°08" E to 80°40" E and 6°04" N to 6°30" N. The total catchment area is 932 km² of which 83% lies in Galle district. The catchment partially encompasses four districts with a total population of about 600,000. Most of the population is concentrated in middle and lower reaches of the catchment, with the upstream sparsely populated. The Gin River, one of the main sources of drinking water to the Southern region of Sri Lanka originates in the central highlands of the country having an elevation of over 1300 m and flows to the Indian Ocean at Ginthota in Galle district.

Gin catchment's land use data in 1983 and 1999 were acquired from the Surveying Department, Sri Lanka. To facilitate the analysis, it was reclassified the available land use types in the catchment into five classes that represent the main land use types of the area; 'forest', 'paddy cultivation', 'other cultivation', 'homestead/garden' and 'other'. 'Other cultivation'

category includes export-oriented crops; tea, rubber and cinnamon. Tea and rubber are cultivated mostly in the upper and middle area of the catchment, while cinnamon is cultivated in the lower reach of the catchment. 'Other' category basically includes water bodies and assumed to stay constant and at the same location.

METHODOLOGY

Future land use in the Gin catchment was predicted using a GIS based statistical regression approach. Statistical method has been employed in a spatially explicit manner in which the driving factors of land use were correlated with the five major classes of land use. Land use suitability maps can be created through logistic regression (Schneider and Pontius, 2001) and the statistical method used in the study included logistic regression analysis. The output from a logistic is the probability of occurrence of an event, using the independent variables as predictor values (Garson, 2000). In this study the occurrence of a certain land use type (dependent variable) was predicted by the independent variables (driving factors). Using the logistic regression analysis, relationship between the spatial distribution of each land use type and its driving factors was determined and the probability maps were produced. Land use types were then predicted considering the produced probability maps, actual land use maps, spatial policies and restrictions and future land use demands for different land use types. Methodology adopted included two distinct components, namely a non-spatial demand determination and a spatially explicit allocation procedure. The schematic representation of land use change prediction is presented in Fig. 1 (Verburg *et al.*, 2002; Ty, 2011).

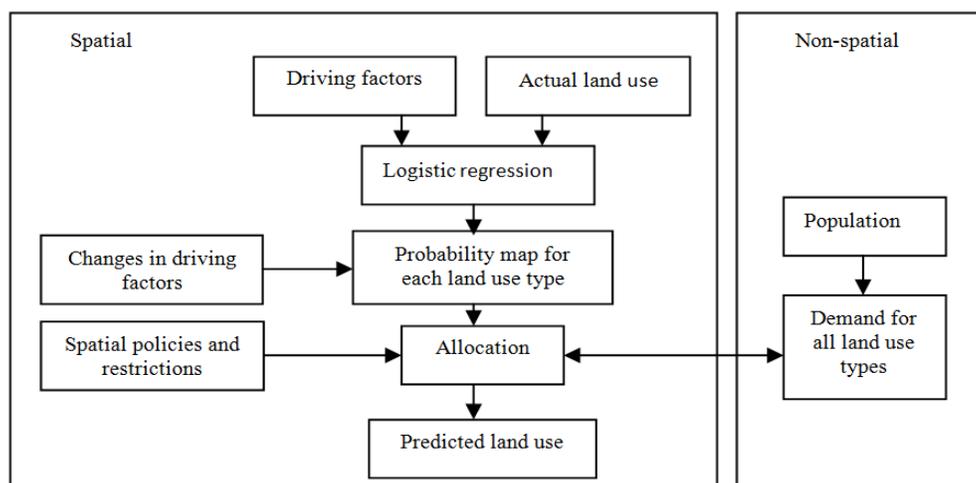
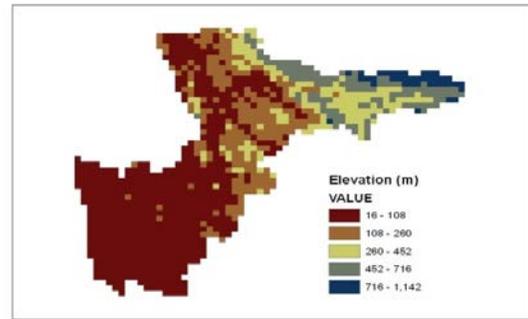


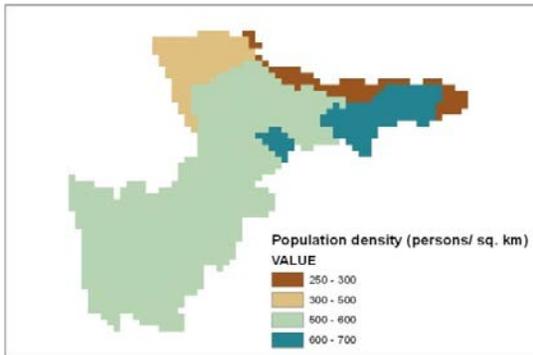
Fig. 1: The schematic representation of land use change prediction
 In the 'spatial' component, all the driving factors and land use data were aggregated to pixel size of 1×1 km

Table 1: Land use change driving factors

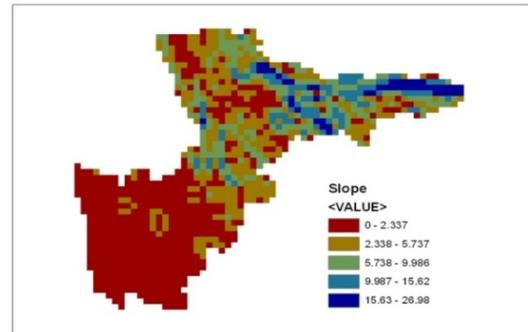
| Type | Driving factor | Description |
|---------------|---------------------------|---|
| Socioeconomic | Population density | Population density (persons/km ²) |
| Proximity | Distance to nearest river | Direct distance to nearest river (m) |
| | Distance to nearest road | Direct distance to nearest road (m) |
| Biophysical | Altitude | Elevation above the mean sea level (m) |
| | Slope | Slope (based on 1-km DEM) |
| | Soil texture | Sandy clay loam soil Clay loam soil Clay soil |



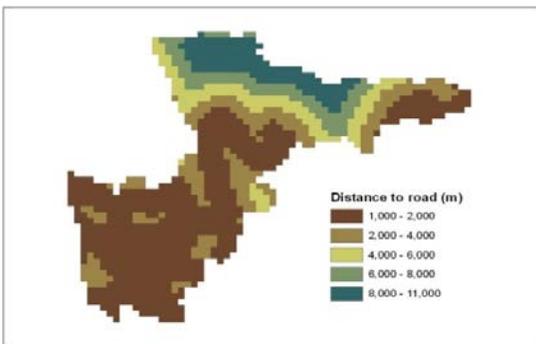
(d) Elevation



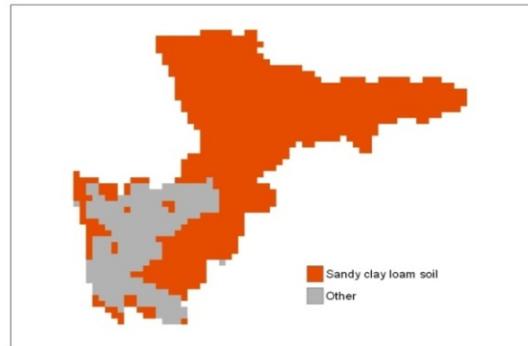
(a) Population density



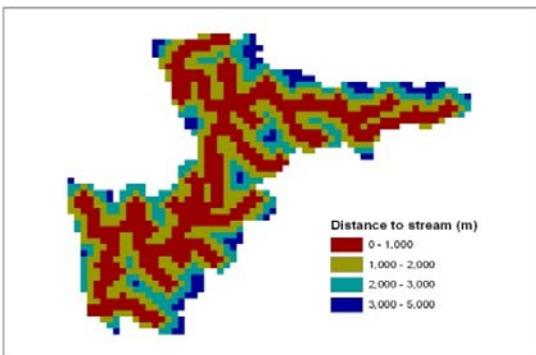
(e) Slope



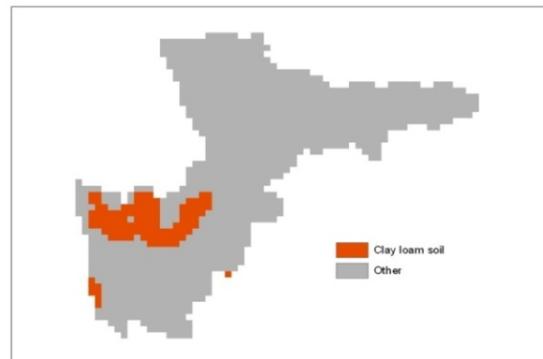
(b) Distance to road



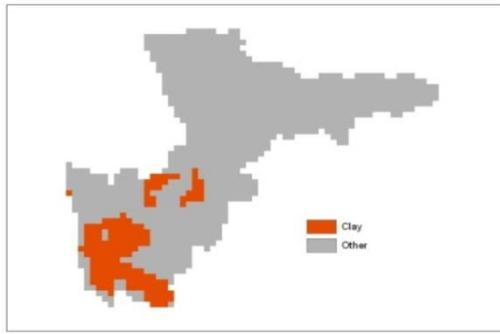
(f) Sandy clay loam soil



(c) Distance to stream



(g) Clay loam soil



(h) Clay soil

Fig. 2: Spatial distribution of driving factors

- **Land use demand:** The non-spatial demand module calculates the area change for all land use types at the aggregate level. A number of factors operating at regional scale can be expected to influence the future land use changes. The significant factor contributing to continuous land conversion has been the population growth and the change seems to have driven jointly by human population dynamics and change in agricultural practices.

A common technique used to calculate the land use demand is extrapolation of trends in land use change of the recent past into the near future. In this study, the land use demand was quantitatively determined using the population forecast along with the growth ratio; the ratio of developed land growth to population growth (Craig *et al.*, 2007):

$$A_2 = A_1 \left\{ 1 + R \left(\frac{P_2 - P_1}{P_1} \right) \right\} \quad (1)$$

where, A_2 and A_1 are future and current area of considered land use type (km^2), respectively; P_2 and P_1 are future and current population, respectively; and R is the growth ratio, the ratio between growth rate of considered land use type between (1983 and 1999%) and population growth rate (%). Past and present population of the area and the average annual population growth rates were obtained from the census of 1981 and 2011 (Census of Population and Housing-2011, 2012). Future population up to year 2020 was determined according to the 'standard' rate of growth of population, Sri Lanka (De Silva, 2007).

Area covered by the different land use types, on yearly basis were calculated under the land use demand. Land use demands that change very little between the 1983 and 2020, for example, 'other' category, were adjusted to remain constant.

- **Spatial policies and restrictions:** Spatial policies and restrictions mostly indicate the areas where the

land use changes are restricted through policies or tenure status. No land use changes were allowed for protected natural areas including Sinharaja natural forest and wildlife reserve in the upstream catchment area.

- **Land use type specific conversion settings:** Decision rules for land use changes decide the conditions under which the land use type is allowed to change and the study accommodated these land use type specific conversion settings in two ways as conversion elasticity and conversion matrix. The conversion elasticity is related to the reversibility of land use change. The conversion matrix defines the other land use types to which the present land use type can be converted. Conversions restricted by the above spatial policies were indicated in the Gin catchment's land use conversion matrix. Relative elasticity value was assigned to each land use type which ranges from 0 to 1; 0 for the most dynamic and 1 for the most stable land use types, respectively. Based on the local knowledge and observed land use change behavior in the recent past, elasticity values of 0.8, 0.2, 0.2, 0.2 and 0.8 were assigned for the land use types of forest, paddy cultivation, other cultivation, homestead/garden and other, respectively.

- **Location characteristics (driving factors of location):** Set of potential driving factors which affected the change in current and past land use patterns were compiled using methodology available in literature and knowledge on catchment specific characteristics. These dominant factors determine the relative suitability of a location for specific land use types considered. The influence of different driving factors on each land use type was calculated using logistic regression analysis. Table 1 presents the possible land use change driving factors. The spatial distributions of the above factors are shown in Fig. 2.

- **Logistic regression analysis:**

- **Probability maps:** Based on the conditions of driving factors of a location, the relative probability of finding the different land use types at that location is defined. The function between these probabilities and the socioeconomic, proximity and biophysical location characteristics was defined using the binary logistic regression which used to link the location factors to the land use distribution. The regressions attempt to quantify the relationships between the location of all land cover types (dependent variables) and a set of driving factors (independent variables). The binary logistic regression was used due to its appropriateness when the dependent variable is a dichotomy. The probability of a certain grid cell to be devoted to a land use type given by:

Table 2: Summary of the logistic regression analysis-regression coefficients and the ROC statistics

| | | Land use type | | | | |
|----------------|----------------------|---------------|----------|-------------------|------------------|----------|
| | | Forest | Paddy | Other cultivation | Homestead/garden | Other |
| Driving factor | Elevation | 0.00219 | -0.00334 | -0.00082 | -0.00496 | - |
| | Slope | 0.07248 | -0.16124 | - | - | - |
| | Population density | -0.00235 | - | 0.00245 | 0.00815 | - |
| | Distance to road | 0.00033 | -0.00022 | -0.00010 | -0.00022 | - |
| | Distance to stream | 0.00052 | -0.00038 | -0.00019 | - | -0.00109 |
| | Sandy clay loam soil | 0.81997 | - | 0.75078 | - | - |
| | Clay loam soil | - | - | - | - | - |
| | Clay soil | - | - | - | - | 1.62358 |
| | Area under ROC | 0.875 | 0.780 | 0.620 | 0.734 | 0.757 |

∴ The regression coefficients that are not significant at 95% level

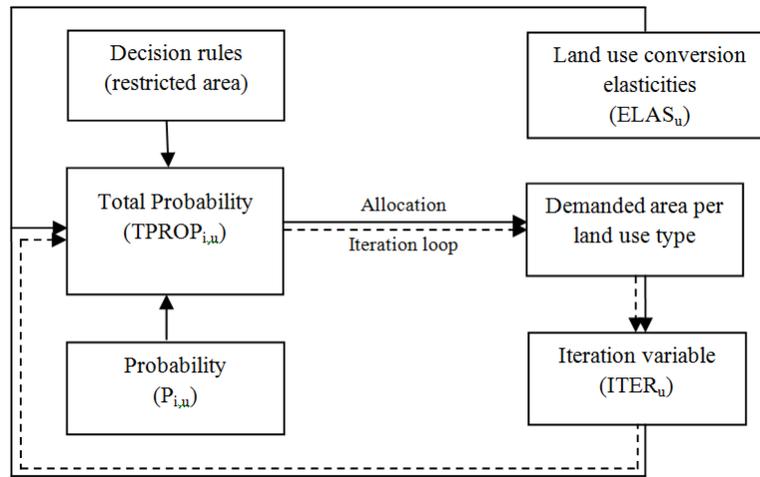


Fig. 3: Representation of the iterative procedure for land use change allocation

$$\log\left(\frac{P_{i,u}}{1-P_{i,u}}\right) = \beta_{0,u} + \beta_{1,u}X_{1,i} + \beta_{2,u}X_{2,i} + \dots + \beta_{n,u}X_{n,i} \quad (2)$$

where,

$P_{i,u}$ = Probability of grid cell i for the occurrence of the considered land use type u

β 's = Regression coefficients

X 's = Driving factors

Variables that have no significant contribution to the explanation of the land use pattern are excluded from the final regression equation (Verburg *et al.*, 2002). The regression coefficients were estimated using maximum likelihood estimation having the actual land use pattern as the dependent variable.

Spatial relationships between the land use and the selected driving factors were quantified in a two-step procedure using the binary logistic multiple regression analysis. In step one, significantly contributing driving factors were selected with a stepwise forward regression, using the 0.05 significance criterion. In step two, this set of driving factors was used to construct multiple regression equations. The regression analysis was performed separately for each land use type and

probability map was developed for each land use type. Results of the logistic regression analysis performed for each land use type with the driving factors are given in Table 2.

- **Statistical significance and goodness of fit:** Validation of logistic regression analysis was tested using the Relative Operating Characteristic (ROC) analysis. The ROC is a measure of the goodness of fit of a logistic regression model (Pontius and Schneider, 2001). ROC values range between 0.5 and 1; 0.5 for completely random and 1 for the perfect fit, respectively. The statistically significant regression coefficients along with the driving factors and the ROC statistics are listed in Table 2. The spatial distribution of all land use types could well be explained by the selected driving factors as indicated by the comparatively high ROC test statistics (Table 2).
- **Allocation of land use change:** Allocation of land use change was made in an iterative procedure given the probability maps, the decision rules in combination with the actual land use map and the demand for the different land use types. Grid cells that are allowed to change were determined. The total probability ($TPROP_{i,u}$) for each grid cell i

was calculated for each of the land use type u according to:

$$TPROP_{i,u} = P_{i,u} + ELAS_u + ITER_u \quad (3)$$

where, $P_{i,u}$ is the probability of grid cell i for the occurrence of the considered land use type u , $ITER_u$ is an iteration variable that is specific to the land use and $ELAS_u$ is the relative elasticity for change of land use specified in the decision rules. The total allocated area for each land use was compared to the demand by appropriately varying the value of the iteration variable. Iteration was carried out until the total allocated area for each land use was equaled to the demand. Representation of the iterative procedure for land use change allocation is shown in Fig. 3 (Verburg *et al.*, 2002).

RESULTS AND DISCUSSION

Observed and predicted land use: Observed land use in 1983 and 1999 and predicted land use in 1999 and 2020 are shown in Fig. 4.

Land use types were calibrated against the observed land use map in 1983 and validated to the observed land use map in 1999. Validation of predicted land use change is important since it provides a measure of the reliability. By the validation, it was revealed that the general pattern of land use change in the catchment was reasonably represented. The result of validation for 1999 predicted land use data was evaluated as a percentage of correction measured by locations predicted correctly as shown in the correlation matrix of validation (Table 3). Agreement between the observed and predicted land use in 1999 was quite good and the spatial dynamic of land use patterns was realistic. Overall, the percent of total pixels being correctly projected ranged from 58 to 72%. Paddy cultivations aggregated towards the lower catchment area while forest cover has been the dominating land use in the upper catchment area in both observed and predicted land use in 1999. Area occupied by the other cultivations and homestead/garden showed rather patchy pattern in the 1999 predicted land use map and this could be attributed to the patchy nature of these land use types in the observed land use map in 1983 which used as the base map. Moreover, comparisons

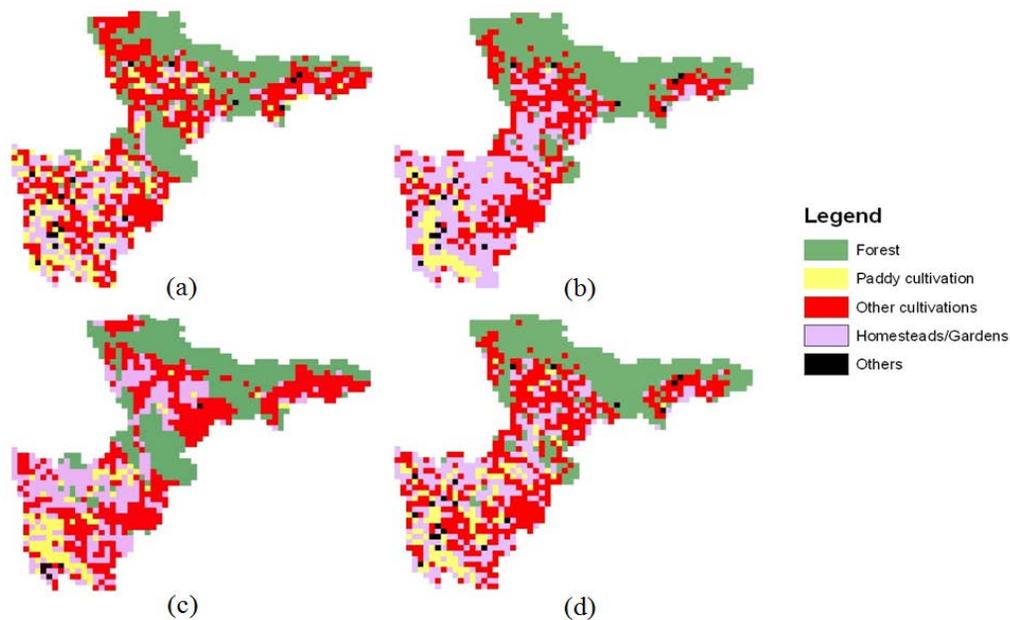


Fig. 4: Observed and predicted land use, (a) 1983 observed land use, (b) 2020 predicted land use, (c) 1999 observed land use and (d) 1999 predicted land use

Table 3: Correlation matrix of validation

| Observed land use 1999 | Predicted land use 1999 | | | | | Total |
|------------------------|-------------------------|-------------------|-------------------|------------------|-------|-------|
| | Forest | Paddy cultivation | Other cultivation | Homestead/garden | Other | |
| Forest | 272 (72%) | 12 | 57 | 37 | 2 | 380 |
| Paddy cultivation | 2 | 50 (60%) | 15 | 11 | 5 | 83 |
| Other cultivation | 72 | 19 | 254 (63%) | 56 | 5 | 406 |
| Homestead/garden | 15 | 21 | 86 | 176 (58%) | 8 | 306 |
| Other | 0 | 3 | 2 | 1 | 0 | 6 |
| Total | 361 | 105 | 414 | 281 | 20 | |

Unit is 'number of pixels'; Percent of total pixels being correctly projected are shown within parenthesis

were made for each land use type in the 1999 predicted land use map relative to the 1999 observed land use map. The comparison results were reasonable for all the land use types except for paddy cultivation which was slightly over projected.

Land use dynamics: 1983-2020: Usually land use types easily shift location when the location becomes more suitable for other land use types. However the land use types with high capital investment are not easily be converted to other uses as long as there is sufficient demand. Changes in cultivated areas and homestead/garden have been the dominating land use changes in Gin catchment. The continuing reduction of cultivated areas appears to be widespread on sloping land in the upper catchment area. Paddy cultivations gradually aggregated towards the lower catchment area facilitated by the permanent irrigation facilities with few patches remain in the middle of the catchment. Some 9% paddy cultivated area has been switched to homestead/garden between 1983 and 2020. During the same period, homestead/garden area grew into area occupied by other cultivations by about 4%. These changes took place more likely at higher elevations with low natural potential for crop growth. In addition to the environmental determinants, neighbouring land use exerted a large influence on patterns of change of cultivated areas. Small and isolated cultivated lands were more likely to be changed than those in close proximity to other cropland areas. Other cultivation covering about 8% of the area has been affected by forest expansion and this occurrence mostly appears to take place at the forest frontiers. Mostly the primary forest may exist unchanged whereas the secondary vegetation showing a more dynamic spatial behaviour including new secondary re-growth occurring in abandoned lands. Abandoned agricultural lands at the forest frontier were converted to forests starting from the early 1980's, continuing into 2020. It was indicated about 5% of the dwelling area for the growing population was acquired through extension of homestead/garden at the expense of forest cover mostly at the middle of the catchment.

Reliability of the projection-year 2020 land use: Since year 2020 land use projection cannot be validated, observations of land use change in the recent past and knowledge on catchment specific characteristics were used to validate the accuracy of the projected land use. As the Fig. 4 shows, in year 2020 most of the areas with change in land use occurred in the middle and lower area of the catchment. For the entire catchment, the area under homestead/garden is expected to rise from 18% in 1983 to 32% in 2020. This principally reflects the rapid expansion of homestead/garden to keep pace with population growth. The forest area is also predicted to increase, from 29% in 1983 to 32% in 2020. This could be due to the strict protection policy of the natural areas in force and government intervention through tree planting

campaigns. Decline of cultivated areas was the most dominant change process observed. From 1983 to 2020 drop from 51 to 34% was observed. This continuing reduction heavily relies on the country's economic transformation from agriculture-based economy towards a market oriented open economy which altered agriculture-based subsistence of majority of population.

Although a quantitative validation of the results in this study is not feasible, it remains interesting to compare projected results in the study with the recent quantitative estimation of land use change carried out in the Galle area based on the aerial photos, other studies and statistics. Changing trends in homestead/garden and cultivated areas including paddy and tea plantations from early 80's to mid 90's as presented in ADB (2009) were in line with the trends revealed in the study in projecting year 2020 land use. According to the ongoing national protected areas policy in the country, strict protection of the natural areas including Sinharaja natural forest and wildlife reserve in the upstream catchment area were considered in the study. If policies do not change in the near future, it may assume that the forest cover of the catchment could be almost similar to that of the near past.

CONCLUSION

Gin catchment's land use change can be summarized over the past forty years as the result of change in agricultural practices and increase in population.

About 29% forest cover in the early 80s has been increased closer to 30 and 32% in the late 90s and in 2020, respectively. Expansion of forest area occurred basically at the forest frontiers. This might be due to the ongoing national protected areas policy in the country which possesses strict protection of the natural areas including Sinharaja natural forest and wildlife reserve in the upstream catchment area.

Paddy cultivation has been practiced generally in the Gin catchment, while export-oriented agriculture (other cultivation) has predominated during early 80's. About 7% of the paddy cultivated areas that existed in 1983 had been converted to other land uses by 2020. Similar decline can be found for the other cultivation. About 40% of land devoted to the other cultivation decreased to 30% between 1983 and 2020. This enormous reduction in agricultural areas is supported by the country's economic policies which changed in late 70s. The government policy has been of support for market oriented open economy encouraging private enterprise, changing peoples' preferences from farming to other employments.

Homestead/garden area expanded by 14% between 1983 and 2020 as a consequence of the growing population. These expansions of dwelling zones were taking place in small and isolated cultivated lands in close proximity to existing homestead/garden.

Results of the spatially explicit land use change analysis of the Gin catchment provide a framework for regional and national level authorities to construct decision support tools for different stakeholders. Projected spatial information may serve to target policy attention and measures as well assist to identify priority areas for further analysis. Also the spatially explicit land use change analysis provides useful context to the numerous undergoing quantitative land use change estimations.

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REFERENCES

- ADB, 2009. Southern highway corridor profile. Technical Assistance Consultant's Report. Asian Development Bank, Project Number: 26522-03 (TA 7065).
- Briassoulis, H., 2000. Analysis of Land Use Change: Theoretical and Modelling Approaches. The Web Book of Regional Science. Retrieved from: <http://www.rri.wvu.edu/WebBook/Briassoulis/contents.htm>.
- Census of Population and Housing-2011, 2012. Population of Sri Lanka by district. Department of Census and Statistics, Sri Lanka. Preliminary Report (Provisional)-1.
- Chomitz, K.M. and D. Gray, 1996. Roads, lands use and deforestation: A spatial model applied to Belize. *World Bank Econ. Rev.*, 10: 487-512.
- Craig, E.C., A. Jeffery and S.L. Kang, 2007. Modeling Growth and Predicting Future Developed Land in the Upstate of South Carolina. Strom Thurmond Institute, Clemson University. Retrieved from: http://www.upstateforever.org/newsviews_other/Growth_Projections_Cherokee.pdf.
- De Silva, W.I., 2007. A Population Projection of Sri Lanka for the Millennium 2001-2101: Trends and Implications. Institute for Health Policy, Colombo, Sri Lanka.
- Garson, G.B., 2000. PA 765 Statnotes: An Online Textbook. Retrieved from: <http://faculty.chass.ncsu.edu/garson/PA765/logistic.htm>. (Accessed on: February 15, 2013).
- Geist, H.J. and E.F. Lambin, 2001. What drives tropical deforestation? A metaanalysis of proximate and underlying causes of deforestation based on subnational case-study evidence. LUCR Report Series No. 4, LUCR International Project Office, Louvain-la-Neuve.
- Hosmer, D.W. and S. Lemeshow, 2000. Applied Logistic Regression. Wiley, New York.
- Koomen, E., J. Stillwell, A. Bakema and H.J. Scholten, 2007. Modelling Land-use Change: Progress and Applications. Springer, Dordrecht.
- Mertens, B. and E.F. Lambin, 2000. Land-cover change trajectories in southern Cameroon. *Ann. Assoc. Am. Geogr.*, 90: 467-494.
- Mu'ller, D. and D.K. Munroe, 2008. Changing rural landscapes in Albania: Cropland abandonment and forest clearing in the postsocialist transition. *Ann. Assoc. Am. Geogr.*, 98: 855-876.
- Pontius, R.G. and L.C. Schneider, 2001. Land-cover change model validation by an ROC method for the Ipswich watershed, Massachusetts, USA. *Agric. Ecosyst. Environ.*, 85: 239-248.
- Schneider, L. and Jr. R.G. Pontius, 2001. Modeling land-use change: The case of the Ipswich watershed, Massachusetts, USA. *Agric. Ecosyst. Environ.*, 85: 83-94.
- Schoonenboom, I.J., 1995. Overview and State of the Art of Scenario Studies for the Rural Environment. In: Schoute, J.F., P.A. Finke, F.R. Veenenklaas and H.P. Wolfert (Eds.), Scenario Studies for the Rural Environment. Kluwer Academic Publishers, Dordrecht.
- Ty, T.V., 2011. Development of a comprehensive approach for water resources assessment at various spatio-temporal scales. Ph.D. Thesis, Global Center of Excellence (GCOE), University of Yamanashi, Japan.
- U.N. Environment Programme, 2001. State of the Environment Sri Lanka. United Nations Environment Programme, Regional Resource Centre for Asia and the Pacific (UNEP-RRCAAP).
- Veldkamp, A. and E.F. Lambin, 2001. Predicting land use change. *Agric. Ecosyst. Environ.*, 85: 1-6.
- Verburg, P.H., W. Soepboer, A. Veldkamp, R. Limpiada, V. Espaldon and S.S.A. Mastura, 2002. Modeling the spatial dynamics of regional land use: The CLUE-S model. *Environ. Manage.*, 30(3): 391-405.