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Research Article

Geospatial Analysis of Land Use Land Cover Change Modeling at Phewa Lake Watershed of Nepal by using Cellular Automata Markov Model

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Abstract

Improper practices of land use/ land cover (LULC) are deteriorating watershed conditions. Remote sensing and GIS tools were used to study LULC dynamics using Cellular Automata (CA)–Markov model and predict the future LULC scenario for years 2015 and 2020, in terms of magnitude and direction, based on past trend in Phewa Lake watershed, Kaski district, Nepal. The analysis of LULC pattern during 1995, 2000, 2005 and 2010 using satellite-derived maps has shown that the biophysical and socio-economic drivers including slope, road network and settlements proximity have influenced the spatial pattern of the watershed LULC. These lead to an accretive linear growth of Medium to Fairly Dense Forest, Open Forest, Bush/Scrub, Waste Land and Built-up Land but decrease in other LULC classes. Annual rates of increase from 1995 to 2010 in Medium to Fairly Dense Forest, Open Forest, Bush/Scrub, Waste Land and Built-up land were 9.16, 8.14, 20.66, 15.27 and 27.77 ha/year respectively, while the rates decrease in Dense Forest, Terrace Agriculture, Valley Agriculture and Grass Land were 39.17, 10.30, 23.32 and 3.78 ha/year respectively. Subwatershed-wise LULC change showed decrease by 130.5 ha and 65.4 ha of Dense Forest, and increase in Medium to Fairly Dense Forest by 7.2 ha, 68.2 ha and Open Forest by 75.0 ha and 0.0 ha in mid and North flowing Subwatershed respectively from 1995 to 2010. Medium to Fairly Dense Forest is predicted to increase by 51.3 ha and 113.4 ha and Dense Forest is predicted to decrease by 44.9 ha and 136.5 ha from 2010 to projected 2015 and 2020 in Harpan Subwatershed. The predicted LULC scenario for 2015 and 2020, with reasonably good accuracy would provide useful inputs to the LULC planners for effective management of the watershed.

Keywords: *GIS, sub-watershed, biophysical drivers, socio-economic drivers, Open Forest, Built-up land*

Introduction

The land use/land cover pattern of a region is an outcome of natural and socioeconomic factors and their utilization by man in time and space. Knowledge of land cover and land use change is important for many planning and management activities (Lillesand and Kirfer 1999). Land use is the human use of land and land cover refers to physical and biological cover on the surface of land (Rimal 2011). In the mountain geography, micro level accurate mapping on the surface of parameters, such as surface morphometry, land use, land cover resources and population parameters is often a big problem, but mandatory for watershed management (Poudel 2010). In Nepal, forestry and land use change alone contribute about 85% of national account of green house gases emission. These complexities necessitate a systematic approach to find out the proper utilization techniques and sustainable management plans (Gautam et al. 2003). The capability of GIS to analyze temporal and spatial data helps in quantifying the land use changes (Awasthi 2002).

Land-Use and Cover Change modeling is growing rapidly in scientific field. There are many modeling tools in use but the performance of different modeling tools is difficult to compare because LULC change models can be fundamentally different in a variety of ways (Pontius and Chen 2006). Among many land use land cover modeling tools and techniques, the commonly used models are the Cellular Automata (CA) Markov, Markov chain, GEOMOD, etc. In this study the CA Markov available in Idrisi was implemented to predict and compare the land uses for some further period. This may require more advanced spatial techniques supported by the policy makers involving shifting of emphasis from basic geographic data handling into manipulation, analysis and modeling in order to solve the real problem (Ramachandran 2010). This paper focuses on analysis of LULC change modelling by using remote sensing and GIS techniques and CA–Markov model in Phewa Lake watershed of Nepal.

Materials and methods

Study area

Phewa Lake watershed is located between 28˚9'N and 28˚19'N latitude and 83˚45' and 84˚00'E longitudes covering 120 km^2 area of Kaski district in western

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Table 1 Satellite data specifications

Year	Satellite	Resolution (m)	Path /row	Band combination	Date of Procurement
1995	Landsat, TM	30	142/040	1.2.3.4.5.6.7	20-Nov-95
2000	Landsat, TM	30	142/040	1.2.3.4.5.6.7	13-Nov-00
2005	Landsat, TM	30	142/040	1.2.3.4.5.6.7	8-Nov-05
2010	Landsat, TM	30	142/040	1.2.3.4.5.6.7	7-Nov-10

Nepal (Figure 1). Its east-west length is 17 km and width 7 km on an average. Phewa Lake area covers 4.55 km^2. The watershed belongs to a semi- agricultural watershed in mid-hill belt (800-2500 above msl) of mountain ecosystem. Phewa Lake is silted up by 180,000 cu m annually due to rapid change of anthropogenic factors (SILT Consultants (P) Ltd. 2002).

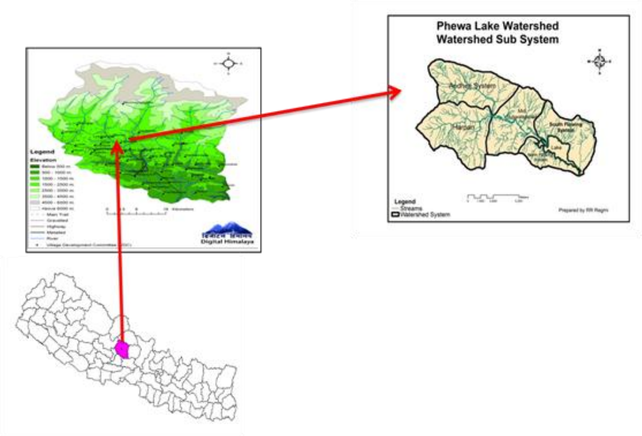

Figure 1 Location Map of the Study Area

Satellite data

The main data used in the research included temporal satellite data of Landsat TM of the years 1995, 2000, 2005 and 2010 for the past 15 years with 5 years interval for LULC mapping (Table 1). All the images were of the month of November.Sufficient GPS points are taken in the entire study area for LULC mapping, which are also used for accuracy assessment. Topographic maps of 1:25,000 scales and digital topographic data with contour interval of 20 m published by the Survey Department, His Majesty´s Government of Nepal (HMGN) were used as ancillary data. The Landsat satellite data provided by Global Land Cover Network (GLCN) was radiometrically and geometrically (orthorectification with UTM/WGS 84 projection) corrected.

LULC Mapping

In the present study datasets were geo-referenced in UTM/WGS 84 projection. The study area was extracted from the acquired satellite images using digital topographical maps of 1:25000 scale and field data from Subset tools in Erdas Imagine. A classification scheme was developed to obtain a broad level of classification to derive various LULC classes, such as Dense Forest, Medium to Fairly Dense Forest, Open Forest, Terrace Agriculture, Valley Agriculture, Bush/Scrub, Grass Land, Waste land, Water Body, Wetland and Built-up Land (Figure 2). Forests were classified with FCD Mapper software and verified with ground truth for accuracy. The fields were visited to complete reconnaissance survey, ancillary data collection, LULC classification, sub-watershed area statistics, validation and % LULC change. LULC classification was performed using supervised classification technique for years 1995, 2000, 2005 and 2010 (Figure 2). In the study accuracy for all four classified maps were assessed with the test samples generated from ground truth data against high resolution references. The overall test samples generated were 98 for each of the 1995, 2000, 2005 and 2010 classified maps. Eye bird satellite of high resolution 2010, Google Earth, ESRI online, digital topographic map and other layers were used as reference due to lack of high resolution satellite data. The LULC Maps of all periods were imported in ARCGIS 9.3 in which five Sub-watersheds were delineated whose area statistics is presented in (Table 3). The LULC change modeling for 2015 and 2020 period was carried out using Idrisi Taiga. The studied watershed was delineated into five sub-watershed considering topographical parameters derived contour lines and drainage system

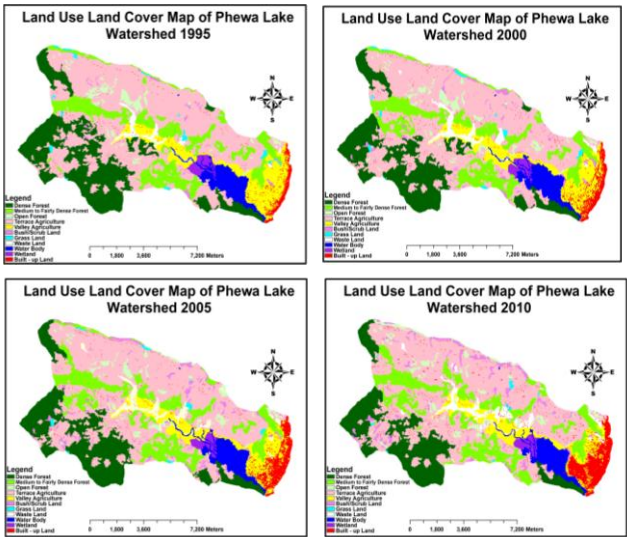

Figure 2 LULC classifications for years 1995, 2000, 2005 and 2010

Preparation of LULC map for four periods using temporal satellite data, identification and quantification of LULC changes and prediction of LULC for 2015 and 2020 for both real and projected periods have been studied sub-watershed wise over the entire study area. The spatial layers of ancillary database including different socioeconomic and biophysical drivers of LULC change were prepared using data from topographic map and relevant information (CBS 2004). CA–Markov model was employed to predict future LULC dynamics in the watershed using a multicriteria decision-making approach. This task was accomplished by using IDRISI software package developed by Clark Lab.

Multi-criteria evaluation (MCE) technique

It is impossible to find a single solution to multiple problems of watershed simultaneously. The decisions that were needed generally include site selection or land allocation decisions that satisfy multiple objectives, each relating to its own suitability level of land conversion (Soe and Le 2006). To achieve the said objective, multi-criteria evaluation approach was adopted, which deals with situations in which a single decision-maker is faced with a multiplicity of usually incompatible criteria or in which a number of decision-makers must consider criteria, each of which depends upon the decisions of all the decision-makers (Ademiluyi and Otun 2009). Here socioeconomic data (road network and settlements) was integrated with biophysical data (DEM and SLOPE) of the watershed through MCE technique for CA–Markov. To use MCE technique, it is necessary need to develop criteria for making decision about various land uses.

Criterion development: Constraints / factors

Different criteria were considered to determine, which LULC classes of watershed are suitable for changing from one class to another with time including proximity from road and settlement, socio-economic drivers, and biophysical drivers (slope). In this study these criteria were divided into different types: factors /constraints can pertain either to attributes of the individual or to an entire decision set.These principles generally should be based on the government policy formulated according to environmental and socio-economic consideration. The development of Built-up areas should mostly be preferable to underutilized places but, these kinds of areas are rarely available in the cities. So, agricultural areas having relatively flat slopes are being extensively utilized nowadays for urban development. It is also supposed that the urban development takes place closest to existing road networks and developed unoccupied areas. However, as the distances of such areas increase, they are less preferred due to cost effectiveness. Nearness to Dense Forest and Water Body should also be avoided for urban development. Considering these general principles the factors with Non Boolean condition of WLH approach were standardized into "fuzzy" rule, i.e. suitability of contiguous range of 0 = least suitable to 255 = most suitable using MCE in Idrisi.

The fuzzy module available in Idrisi is characterized to standardization of Boolean factors into entire range of criteria of "none" to "full" possibilities to transform into either a binary (0 and 1) or a byte (0 to 255) output data format without sharp boundaries as 0 = lowest to 255 = highest suitability for growth where the latter output data format option is recommended because the MCE module has been optimized for using a 0-255 level of standardization (Eastman 2006). The Idrisi supported monotonically increasing, monotonically decreasing, symmetric and asymmetric variants and the fuzzy set membership functions: sigmoid, j-shaped and linear (Eastman 2006), are available to be utilized as control points for the set membership function. The selection of these variants and range of control points fully depends on the analyst's familiarity to the study area. The perfectness of selection can be measured in the model validation stage. The following factor images were derived from the processes as described above in a continuous scale (Figure 3).

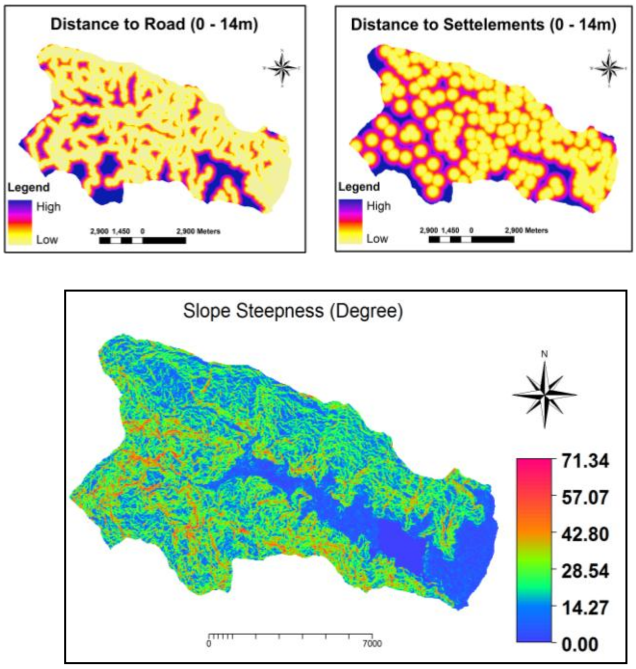

Figure 3 Watershed LULC change driver distance from road and settlements and slope

Analytical Hierarchy Process (AHP) and fuzzy standardization of factors

MCE process was used by involving criteria of varying importance according to decision makers and information about the relative importance of the criteria. This is usually obtained by assigning a weight to each factor. Different factors have different importance affecting LULC change while creating overall suitability. Therefore, the weight to each of the factor image was assigned according to its importance for each land use class. The Analytic Hierarchy Process (AHP) is a theory of measurement through pair wise comparisons and relies on the judgments' of experts to derive priority scales. This process requires weighting factors rate from extremely "less important" (1) to "more important" (9). Consistency ratio (CR) is calculated as the AHP ratings are filled out to identify the inconsistencies in the pair-wise comparison ratings. (Eastman 2006) and (Satty and Vargas 2001) indicate that CR greater than 0.1 should be re-evaluated.

The assignment of rating needs analyst's intuition and repetition unless the consistency is acceptable.

Table 2 LULC distributions in 1995, 2000, 2005 and 2010

LULC Class	1995		2000		2005		2010	
	Area (ha)	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**
Dense Forest	2460.24	20.52	2231.01	18.61	2082.24	17.37	1872.72	15.62
Medium to Fairly Dense Forest	1622.43	13.53	1663.74	13.88	1713.96	14.30	1759.86	14.68
Open Forest	275.85	2.30	303.75	2.53	350.01	2.92	397.98	3.32
Terrace Agriculture	5337.27	44.52	5290.65	44.13	5234.49	43.66	5182.74	43.23
Valley Agriculture	1073.43	8.95	983.79	8.21	853.83	7.12	723.60	6.04
Bush/Scrub Land	85.59	0.71	205.20	1.71	308.16	2.57	395.55	3.30
Grass Land	90.00	0.75	80.37	0.67	60.12	0.50	33.30	0.28
Waste Land	185.76	1.55	281.97	2.35	338.49	2.82	414.81	3.46
Water Body	529.29	4.41	512.10	4.27	496.08	4.14	485.19	4.05
Wetland	129.87	1.08	120.51	1.01	111.33	0.93	107.37	0.90
Built up Land	199.80	1.67	316.44	2.64	440.82	3.68	616.41	5.14
Total	**11989.53**	**100.00**	**11989.53**	**100.00**	**11989.53**	**100.00**	**11989.53**	**100.00**

Table 3 Area statistics for Sub-watershed wise LULC classes

	1995					2000					2005					2010				
	Area(ha)					Area(ha)					Area(ha)					Area(ha)				
LULC	HS	AS	MS	SFS	NFS	HS	AS	MS	SFS	NFS	HS	AS	MS	SFS	NFS	HS	AS	MS	SFS	NFS
DF	1809.2	254.2	169.8		251.8	1610.9	247.5	144.3		242.6	1608.7	232.7	71.2		239.8	1590.2	173.6	39.3		186.4
MF	69.8	467.6	522.6	286.0	128.7	225.7	470.5	526.6	290.7	135.7	230.6	470.7	528.2	299.4	138.6	236.6	472.2	529.8	321.1	196.9
OF	21.5	170.6	26.3	28.5		27.0	175.0	52.1	54.9		35.8	177.8	79.8	57.7		46.5	188.6	101.3	60.8	
TA	1196.0	1798.8	1304.0	784.5	271.2	1179.7	1785.1	1240.3	782.2	256.9	1149.1	1762.1	1233.3	772.9	250.9	1137.9	1752.2	1201.6	745.7	246.6
VA	42.7	23.2	327.5	794.0	17.6	33.4	13.0	321.3	650.4	17.5	33.0	12.1	317.3	517.0	16.9	31.3	11.6	310.7	352.1	14.2
BA	20.1	20.0	18.0	17.3	14.2	69.1	26.6	62.6	37.7	32.6	84.4	71.4	87.6	41.3	38.9	96.5	133.0	90.4	42.3	40.3
GS	15.9	34.6	23.3	23.1		15.3	28.2	22.3	13.3		13.1	16.2	22.2	8.7		9.7	2.0	22.0	2.5	
WS	39.9	39.2	95.1	11.3		52.7	57.4	142.9	25.8		53.6	58.8	170.7	56.3		55.3	61.0	209.9	91.4	
WB			46.3					36.1					35.6					33.4		
WE			38.7	38.1	50.8			20.2	29.0	46.1			20.0	24.2	44.9			18.7	20.3	44.0
BU	8.5	6.8	7.4	167.0	3.6	9.6	11.8	10.4	266.0	6.6	15.0	13.3	13.1	372.5	8.0	19.4	20.9	22.1	513.8	9.6
Total	3223.4	2815.1	2579.1	2150.0	738.0	3223.4	2815.1	2579.1	2150.0	738.0	3223.4	2815.1	2579.1	2150.0	738.0	3223.4	2815.1	2579.1	2150.0	738.0

Note: HS= Harpan System, AS=Andheri System, MS=Mid Sub watershed, SFS=South Flowing System and NFS= North Flowing System, DF=Dense Forest, MF = Medium to Fairly Dense Forest, OF=Open Forest, TA=Terrace Agriculture, VA= Valley Agriculture BA=Bush/Scrub land, GS =Grass Land, WS=Waste Land, WB=Water Body, WE=wetland, BU=Built-up Land.

As an example, Dense Forest suitability map was prepared by assigning weights to factors like slope, road and settlement distance as 0.0778, 0.4353 and 0.4869 respectively. The larger the weight, the more important the criterion is in the overall utility (Malczewski 1999).

The weights assigned to different factors were obtained by AHP. To provide a systematic procedure for developing factor weights, AHP was used in which a pair-wise comparison matrix was created by setting out one row and one column for each factor (Satty and Vargas 2001). In developing the weights, an individual factor compared with every other possible pairing, entered the ratings into a pair-wise comparison matrix. To illustrate this process, first few ratings were considered. It was observed that settlement distance was more important than slope, and thus, received a rating of 7. Importance of settlement distance relative to other factors, such as road distance was rated more. This procedure then continued until all of the cells in the lower triangular half of the matrix were filled. In this study, Weighted Linear Combination (WLC) method was used for aggregation of parameters. This process carries the lowest possible risk as the areas considered suitable are those considered suitable with all criteria fulfilled. The effect of 'order of weights' is most easily understood in terms of levels of risk and trade off. It was neither extremely risk-averse nor extremely risk-taking (Soe and Le 2006). Here, the suitability of areas was determined with consideration of drivers or factors, i.e., slope and distance from road and settlements.

Markov chain and Cellular Automata

A Markovian process is one in which the state of a system at time (*t*2) can be predicted by the state of the system at time (*t*1) (Thomas and Laurence 2006). In this study, Markovian process was used to obtain a transition area matrix from transition probability matrix. In a transition probability matrix, the transition probabilities express the likelihood that a pixel of a given class will change to any other class (or stay the same) in the next time period. It is a text file that records the probability that each LULC category will change to every other category. A transition area matrix expresses the total area (in cells) expected to change in the next time period. It is also a text file that records the number of pixels that are expected to change from one LULC type to other over the specified number of time units. It is produced by multiplication of each column in transition probability matrix by number of pixels of corresponding class in the later image. Transition probability matrix is represented in a text file that records the probability that each LULC category would change to any other category; while the transition area matrix, also represented in a text file records the number of pixels that are expected to change from one LULC type to the other over specified number of time units. The transition area matrix obtained from two time periods was used as the basis for predicting the future LULC scenario.

The 2000 LULC image of Phewa Lake watershed was used as the base (*t*1) image while 2005 LULC map as the

Table 4 Accuracy assessments of classified LULC maps in 1995, 2000, 2005 and 2010

LULC classes	1995		2000		2005		2010	
	PA	UA	PA	UA	PA	UA	PA	UA
Dense Forest	90.91	90.91	90.91	90.91	90.91	90.91	90.91	90.91
Medium to Fairly Dense Forest	93.75	93.75	93.75	93.75	93.75	93.75	93.75	93.75
Open Forest	85.71	85.71	85.71	85.71	85.71	85.71	85.71	85.71
Terrace Agriculture	86.67	81.25	90.00	84.38	87.10	84.38	87.50	87.50
Valley Agriculture	80.00	92.31	84.62	84.62	91.67	84.62	91.67	84.62
Bush/Scrub	66.67	80.00	66.67	80.00	66.67	66.67	66.67	66.67
Grass -Land	75.00	60.00	60.00	60.00	75.00	75.00	75.00	75.00
Waste- Land	71.43	71.43	75.00	75.00	75.00	85.71	75.00	85.71
Water Body	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Wetland	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Built up- land	83.33	83.33	83.33	83.33	83.33	83.33	83.33	83.33
Year	**1995**		**2000**		**2005**		**2010**	
Overall Classification Accuracy	86.09		86.96		86.96		87.83	
Overall Kappa Statistics	0.85		0.85		0.85		0.86	

Note: UA=User Accuracy, PA=Producer Accuracy

Table 5 Area estimates of LULC change in the watershed (% area) (-ve sign indicates decrease in area)

LULC Class	Change area in (ha) %				
	1995-2000	2000-2005	2005-2010	1995-2010	Annual rate of change (ha/year)
DF	-229.23(-1.91)	-148.77(-1.24)	-209.52(-1.75)	-587.52(-4.90)	-39.17
MF	41.31(0.34)	50.22(0.42)	45.9(0.38)	137.43(1.15)	9.16
OF	27.90(0.23)	46.26(0.39)	47.97(0.40)	122.13(1.02)	8.14
TA	-46.62(-0.39)	-56.16(-0.47)	-51.75(-0.43)	-154.53(-1.29)	-10.30
VA	-89.64(-0.75)	-129.96(-1.08)	-130.23(-1.09)	-349.83(-2.92)	-23.32
BA	119.61(1.00)	102.96(0.86)	87.39(0.73)	309.96(2.59)	20.66
GS	-9.63(-0.08)	-20.25(-0.17)	-26.82(-0.22)	-56.7(-0.47)	-3.78
WS	96.21(0.80)	56.52(0.47)	76.32(0.64)	229.05(1.91)	15.27
WB	-17.19(-0.14)	-16.02(-0.13)	-10.89(-0.09)	-44.1(-0.37)	-2.94
WE	-9.36(-0.08)	-9.18(-0.08)	-3.96(-0.03)	-22.5(-0.19)	-1.50
BU	116.64(0.97)	124.38(1.04)	175.59(1.46)	416.61(3.47)	27.77

Note: DF=Dense Forest, MF = Medium to Fairly Dense Forest, OF=Open Forest, TA=terrace Agriculture, VA= valley Agriculture BA=Bush/Scrub land, GS =Grass Land, WS=Waste Land, WB=Water Body, WE=wetland, BU=Built-up Land.

later (*t*2) image in Markov model to obtain the transition area matrix between 2000 and 2005 years for prediction of LULC in 2010. The same image of 2005 was used as base image to obtain the transition area matrix between the years 2005 and 2010 for prediction of LULC of 2015 and the image of 2000 as base image to obtain the transition area matrix between 2000 and 2010 for prediction of 2020. The Markov's module in IDRISI created conditional probability images that report the probability of any LULC class to be found at a location. Even though, the transition probabilities were accurate on a per category basis, there was a *salt and pepper* effect in the output image, since this model did not consider the spatial distribution of the occurrences within each category (Soe and Le 2006). The real 2010 LULC map was used as the base map for estimating future LULC scenario for 2015 and 2020.

Model validation

After any model generates a simulated map, it is desirable to validate the accuracy of the prediction. Therefore, model validation is one of the important stages in the prediction regime of land uses. The VALIDATE module involves a comparative analysis of the simulated and real maps based on the Kappa Index. However, it is different from traditional Kappa statistics in that it breaks the validation into several components, each with special form of Kappa such as Kno, Klocation, Kstandard, etc. and the associated statistics (Pontius and Chen 2006) and (Eastman 2006). The validation results of the projected LULC 2010 against real 2010 map of Kno, Klocation, KStrata and K standard are 0.8895, 0.8749, 0.8749 and 0.8625 respectively.

Results and Discussions

LULC dynamics

The LULC change dynamics of Phewa Lake watershed was studied over more than a decade from 1995 to 2010.The results of LULC distribution in 1995, 2000, 2005 and 2010 showed that Terrace Agriculture, Dense Forest and Medium to Fairly Dense Forest were the dominant LULC category (Table 2). Overall, Medium to Fairly Dense Forest, Open Forest, Bush/Scrub, Waste Land and Built-up Land increased, whereas other land uses decreased significantly during all periods (Table 2).

Sub-watershed-wise Harpan system occupied maximum area (3223.4 ha) and north flowing system minimum (738.0 ha) whose overall increasing trend was observed for Medium to Fairly Dense Forest, Open Forest, Bush/Scrub, Waste land and Built-up land in all Sub-watersheds. Other LULC classes such as Dense Forest, Terrace Agriculture and other classes are in decreasing order in all periods.Sub-watershed-wise, Dense Forest decreased by 130.5 ha and 65.4 ha, while Medium to Fairly Dense Forest and Open Forest increased by 7.2 ha, 68.2 and 75.0 ha, 0.00 ha in Mid and North flowing Sub-watersheds respectively from 1995 to 2010 (Table 3).

Overall classification accuracy for all the four time period maps was more than 85% (table 4).Medium to Fairly Dense Forest, Open Forest, Bush/Scrub, Waste Land and Built-up Land increased by 9.16, 8.14, 20.66, 15.27 and 27.77 ha/year respectively from 1995 to 2010, while Dense Forest, Terrace Agriculture, Valley Agriculture and Grass Land decreased by 10.30, 23.32, and 3.78 ha/year respectively (Table 5).

The changes in Dense Forest, Waste Land and Bush/Scrub Land classes during 1995 to 2000 were very high when compared with the change between 2000 and 2005 and 2005 and 2010 while the change of Open Forest, Valley Agriculture, Grass Land and Wetland were very high in 2005 and 2010. Also the change Medium to Fairly Dense Forest and Terrace Agriculture was high in 200 and 2005 (Table 5).

LULC prediction and validation

The results of area distribution for predicted LULC 2015 and 2020 by CA Markov showed that the major change was found in Dense Forest, Medium to Fairly Dense Forest, Open Forest, Terrace Agriculture and Valley Agriculture. Dense Forest, Terrace Agriculture, Valley Agriculture, Grass and Wetland Land decreased by 174.60 ha, 39.24 ha, 59.76 ha, 8.91 ha and 2.07 ha respectively, and Medium to Fairly Dense Forest, Open Forest, Bush/Scrub, Waste Land and Built-up Land increased by 50.85 ha, 28.80 ha, 45.45 ha, 50.85 ha and 115.65 ha respectively from 2010 to 2015. Similar rates of changes are predicted from 2010 to 2020 (Table 6).

Table 6 Area statistics of predicted LULC

LULC Class	Area in (ha)		
	2010	2015	2020
Dense Forest	1872.72	1698.12	1530.13
Medium to Fairly Dense Forest	1759.86	1810.71	1860.39
Open Forest	397.98	426.78	454.41
Terrace Agriculture	5182.74	5143.5	5103.18
Valley Agriculture	723.6	663.84	603.45
Bush/Scrub	395.55	441	485.31
Grass- Land	33.3	31.23	28.98
Waste- Land	414.81	465.66	515.34
Water Body	485.19	478.17	472.05
Wetland	107.37	98.46	91.35
Built- up Land	616.41	732.06	844.94
Total	**11989.53**	**11989.53**	**11989.53**

The Real 2010 LULC map was used as the base map for estimating future LULC scenario for 2015 and 2020, which are shown in Figure 4.

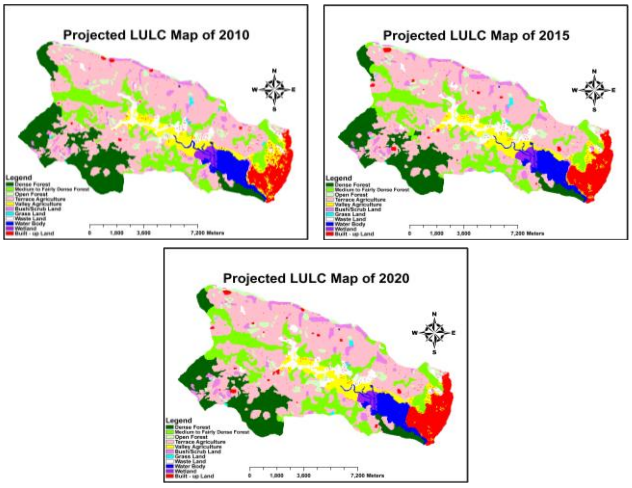

Figure 4 Predicted LULC maps for 2010, 2015 and 2020

Table 7 shows the sub-watershed-wise area statistics of predicted LULC 2015, 2020 and real LULC 2010. The pattern of change for predicted LULC has been observed the same as there was in real 1995, 2000, 2005 and 2010.The rate of land use change was found high in Built-up, Terrace Agriculture, Valley Agriculture, Waste Land, Open Forest, Medium to Fairly Dense Forest and Dense Forest. Minor changes were observed in Grass Land and Bush/Scrub Land. The Dense Forest is predicted to decrease by 44.9 ha, 49.5 ha, 15.7 ha, 0.00 and 16.0 ha, Medium to Fairly Dense Forest and Open Forest increased by 51.3 ha 29.6 ha, 0.3 ha, 11.1 ha, 1.5 ha and 1.1 ha, 12.6 ha, 12.9 ha, 5.0 ha and 0.0 in Harpan system, Andheri system, Mid sub-watershed, South flowing system and North flowing system, respectively from 2010 to 2015. Similar rates of changes were predicted from 2010 to 2020. The result of change in area statistics of predicted LULC in 2015 and 2020 from real 2010 sub-watershed.

Wise showed overall increasing trend for Medium to Fairly Dense Forest, Open Forest, Bush/Scrub, Waste Land and Built-up Land and decreasing trend for other LULC classes in all periods in all Sub-watersheds (Table 7).

In assessing LULC classification accuracy (Table 4), it was observed that only Water Body, Wetland and Built-up Land provided the highest producer's accuracy (100%) and user's accuracy respectively. The forest and agriculture categories reached above 80% producer's accuracy and user's accuracy. The lowest producer's accuracy and user's accuracy below (75%) were produced by Waste Land, Bush/Scrub Land and Grass Land. It could be due to some overlap between Bush/Scrub and Grass Land. While in Waste Land lower accuracy was observed due to seasonal variations of Waste Land by river course, which results in over prediction of waste land in 2010.

In the prediction of future LULC scenarios, the expected area to change in transition area matrix was observed to be Dense Forest, Medium to Fairly Dense Forest, Open Forest, Terrace Agriculture and Built-up Land.

Table 7 Sub-watershed-wise predicted LULC classes

	2010					2015					2020				
	Area(ha)					Area(ha)					Area(ha)				
LULC	HS	AS	MS	SFS	NFS	HS	AS	MS	SFS	NFS	HS	AS	MS	SFS	NFS
DF	1590.2	173.6	39.3	-	186.4	1545.3	124.1	23.6	-	170.4	1448.6	94.4	20.7	-	166.2
MF	236.6	472.2	529.8	321.1	196.9	287.9	501.8	530.1	332.2	198.5	350.0	515.4	530.7	337.1	201.4
OF	46.5	188.6	101.3	60.8	-	47.6	201.2	114.2	65.8	-	57.0	212.4	117.9	66.2	-
TA	1137.9	1752.2	1201.6	745.7	246.6	1134.1	1682.7	1184.6	735.1	243.7	1133.0	1671.8	1170.3	729.5	243.6
VA	31.3	11.6	310.7	352.1	14.2	30.5	9.3	299.7	246.9	14.0	28.8	8.9	280.8	197.1	13.6
BA	96.5	133.0	90.4	42.3	40.3	96.8	166.8	101.3	47.7	56.5	115.4	167.0	125.6	51.6	57.2
GS	9.7	2.0	22.0	2.5	-	3.8	1.9	21.8	1.7	-	3.1	1.8	20.9	0.7	-
WS	55.3	61.0	209.9	91.4	-	56.3	90.2	227.3	100.6	-	57.4	105.6	239.0	113.0	-
WB	-	-	33.4	-	-	-	-	33.2	-	-	-	-	28.4	-	-
WE	-	-	18.7	20.3	44.0	-	-	18.5	18.3	40.2	-	-	18.2	17.1	39.7
BU	19.4	20.9	22.1	513.8	9.6	21.1	37.3	25.0	601.7	14.8	30.1	37.8	26.7	637.7	16.3
Total	3223.4	2815.1	2579.2	2150.0	738.0	3223.4	2815.1	2579.2	2150.0	738.0	3223.4	2815.1	2579.2	2150.0	738.0

Note: HS= Harpan System, AS=Andheri System, MS=Mid Sub-watershed, SFS=South Flowing System and NFS= North Flowing System, DF=Dense Forest, MF = Medium to Fairly Dense Forest, OF=Open Forest, TA=Terrace Agriculture, VA=Valley Agriculture BA=Bush/Scrub land, GS =Grass Land, WS=Waste Land, WB=Water Body, WE=Wetland, BU=Built-up Land.

It could be due to settlements expansion, construction of road trials, unscientific agriculture practices and involvement of both socio-economic and biophysical drivers. In multi-criteria decision-making process, different biophysical and socio-economic drivers, and their relative importance for change in watershed dynamics were considered. The present study investigated the human induced LULC patterns, land cover change and hydrologic change in LULC of watershed. It was observed that the expansion of Built-up Land and Waste Land for loss of Agriculture, Bush and Grass land, and an increase in Medium to Fairly Dense Forest and Open forest leading to decrease in Dense Forest and Bush/ Scrub Land in the watershed are likely to continue in future.

The prediction of LULC in watershed in 2015 and 2020 was based on change in driver's impact with time and trend of LULC change from 2000 to 2010 and the weight applied for different factors in LULC prediction for years between 2005- 2010 and 2000-2010. It was found that the integration of Markov model and Cellular Automata were effective in projecting future LULC scenario. It produced Kappa value of above 85% when compared to predict LULC map with the real LULC 2010.This is well above the acceptable limit of accuracy (Anderson et al.1976). Hence, the projected LULC change based on the four time period 1995, 2000, 2005 and 2010 LULC changes (more than five years) and considering the impact of biophysical and socio-economic drivers in watershed showed the potential of modeling exercise for LULC change in the watershed.

Conclusion

The present study demonstrated utilization of remote sensing and GIS tools to analyze and model the LULC dynamics in Phewa Lake watershed using CA–Markov and predicted the future LULC scenario in 2015 and 2020 with reasonably good accuracy. Future LULC change scenarios were addressed based on the past more than a decade old LULC change trends considering biophysical and socio-economic drivers. Long term land use change analysis from 1995 to 2010 showed that major land use such as Medium to Fairly Dense Forest, Open Forest, Bush/Scrub, Waste Land and Built-up area were in increasing order and other land uses such as Dense Forest, Terrace Agriculture, etc. were in decreasing order for all periods. The integration of the topographic and remotely sensed data within a GIS environment provided an effective means of assessing LULC change modeling within the watershed. This study has demonstrated some guidelines to foresee and examine possible future LULC growth in the watershed with different suitability rankings in multi-criteria decision-making in relation to different environmental, economic, planning and land development settings with effective use of the CA–Markov. It would be helpful for planning and management of watershed resources also for restoring water availability, and improving ecological condition of watershed by the identification of areas suitable for water and soil conservation structures to restore the watershed dynamics. The LULC management prescriptions for the Phewa Lake watershed can include construction of small water and soil conservation structures, such as check dams, percolation ponds, etc.; participation of rural people and stakeholders to prevent further land degradation, and to reduce soil erosion; and improvement in agriculture production following better agricultural practices.

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