International Journal of Current Engineering and Technology
©2015INPRESSCO®, All Rights Reserved
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161
Available at http://inpressco.com/category/ijcet

Research Article

Impact Assessment of Land Use Land Cover Change on Soil Erosion Status in Phewa Lake Watershed of Nepal

R.R. Regmi[†*] and S.K. Saha[‡]

[†]Tribhuvan University, Institute of Forestry, Pokhara Campus, Pokhara, Nepal
[‡]Indian Institute of Remote Sensing (NRSA), Deharadun-248 001, Uttarakhand, India

Accepted 16 May 2015, Available online 20 May 2015, **Vol.5, No.3 (June 2015)**

Abstract

The paper assessed the impact of land use land cover (LULC) change on soil erosion status in Phewa Lake watershed of Nepal using a geographic information system-based soil erosion modeling approach with LULC change detection to quantify the influence of changing LULC on erosion risk. Four LULC maps were generated for a 15-year period (1995 through 2010) at 5-year intervals to assess LULC change and to predict the projected (2015 and 2020) LULC scenario. Revised Morgan, Morgan & Fenny (RMMF) soil erosion model was used in GIS (Geographic Information System) environment to predict soil erosion loss and also map soil erosion risk. The results of sub-watershed wise erosion status revealed that the average soil loss rate increased in all sub-watersheds from 1995 to 2020 of each change study periods. In Mid (MS) sub-watershed highest soil loss was observed while, North Flowing System (NFS) sub-watershed showed lowest soil loss in all study periods. Other sub-watershed soil loss rates lied in between. The result of prioritization of sub-watersheds in terms of soil conservation planning showed that Mid (MS) and South Flowing System (SFS) Sub-watershed are falling in highest priority class while other sub- watersheds are falling in medium to least priority in all study periods. The erosion increased in Open Forest, Bush/Scrub and Waste Land from 1995 to 2010 because of some unscientific cultivation practice, deforestation and settlement expansion. In case of other LULC classes, erosion was slightly lower during the period due to conservation practice. Similar trends of change were seen for predicted 2015 and 2020. The increasing Waste Land bush/Scrub and Open Forest leads to increased soil erosion risk, which matched with LULC change. This study highlights the interaction of changes in land use with soil erosion potential. Soil erosion risk can be quantified by incorporating various erosion factors such as LULC, soil, rainfall, terrain – slope and rainfall with geographic information system and remote sensing, which could serve as a tool for the rapid assessment of effects of LULC change on erosion risk for land/watershed management planning.

Keywords: *Soil erosion modeling, RMMF model, Remote sensing, GIS, erosion risk assessment*

---

1. Introduction

The Phewa watershed has been degrading mainly due to soil erosion; deforestation; unplanned rural road construction; land slide and also of rapid changes in land use/land cover (LULC). Therefore, for sustainable development and management of Phewa watershed, spatial inventories on trends in past LULC; future prediction of LULC change and its impact on soil erosion status are vital**.** Land use/land cover (LULC) change is a dynamic and complex process that can be exacerbated by a number of human activities. Factors driving LULC change include an increase in human population and population response to economic opportunities (Lambin*et al*., 2001). Despite the social and economic benefits of LULC change, this conversion of LULC usually has an unintended consequence on the natural environment. For example, LULC change has been shown to have negative effects on stream water quality (Zampella*et al*., 2007; Tang *et al*., 2005), quantity (White and Greer, 2006) and stream ecosystem health (Wang *et al*., 2000; 2001). Changing land use has also been shown to influence weather patterns (Stohlgren*et al*., 1998) and the generation of stream flow (Bronstert*et al*., 2002; Weng, 2001). Also, a number of studies have shown that change in agricultural land use has direct consequences on sedimentation, nutrients and pesticides in streams (Osborne and Wiley, 1988; Soranno*et al*., 1996). Land use change detection is, therefore, a critical requirement for the assessment of potential environmental impacts and developing effective land management and planning strategies.

LULC change modeling is growing rapidly in scientific study of sustainable development. There are many modeling techniques in the use but the

---

*Corresponding author: **R.R. Regmi**

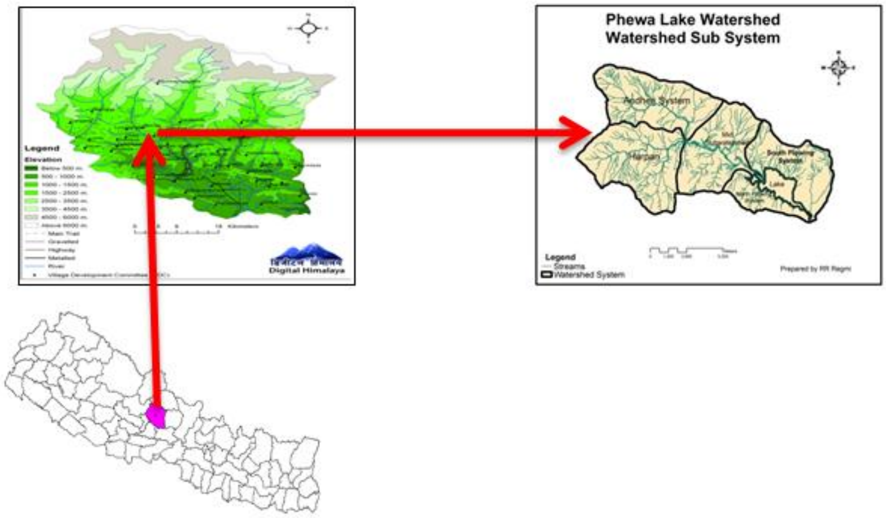


Figure 1 : Location Map of the Study Area

performance of different models is difficult to compare because LULC change models can be fundamentally different in a variety of ways (Pontius and Chen, 2006). Among the numbers of land use modeling tools and techniques, the commonly used models are the Cellular Automata - Markov (CA_MARKOV) and GEOMOD. GIS based several predictive modelling techniques have been employed by several researchers for effectively predicting future LULC based on information of satellite derived past trends in LULC change. Future prediction of LULC is very important for making sustainable LULC planning for conservation of natural resources and protection of environment.

Soil erosion in adjoining hills of Pokhara valley is intense.Integrated use of satellite RS and GIS has been proven very effective tool in modelling erosional soil loss utilizing remote sensing derived inputs like soil, LULC, terrain parameters and other ancillary inputs like meteorological data. Soil erosion is directly affected by land use / land cover change. So, the modeling of LULC change is important with respect to the prediction of soil erosion status in the future.

Several empirical and physical models are applied for the assessment of soil erosion status. The application of Universal Soil Loss Equation (USLE) to steep slopes and extreme texture in mountainous terrain where the erosive forces are primarily from overland flow is still controversial (Shrestha, 1997). ANSWER and WEPP require huge data, which is difficult to acquire in mountainous watershed of Himalaya. Similarly AGNPS is also not adapted well enough in mountain conditions (Kettner, 1996). Morgan, Morgan and Finney (MMF) model (Morgan *et al*., 1984) have strong physical base and is simple and flexible to use (Shrestha, 1997).AGNPS in particular is not adapted well enough to the Nepalese Middle Mountain conditions (Kettner, 1996). On the other hand, modeling results may be often impressive but difficult to interpret (Meyer and Flanagan, 1992) and to validate because of model complexity. Considering all these, the revised Morgan –Morgan-Finney model (Morgan, 2001) has been used in the present study to assess the impact of LULC change on soil loss in the mid hill belt of Nepal. It was selected because of its simplicity, flexibility and strong physical base. This article focuses on the assessment of effects of changing LULC and examines the risk of erosion potential caused by changing LULC.

Materials and methods

Study area

Phewa lake watershed is located between 28°11'39 to 28°17'25 N latitude and 83°47'51 to 83°59'17 E longitude covering 120 km^2 area of Kaski district in western Nepal (Figure 1). Its east-west length is 17 km and width 7 km on an average. Phewa Lake itself covers 4.55 km^2. The watershed belongs to a semi-agricultural watershed in mid-hill belt (789-2508 above msl) of mountain ecosystem. Phewa Lake is silted up by 180,000 cu m annually due to rapid change of anthropogenic factors such as road and trail construction without conservation, unscientific agricultural practices and deforestation in upper stream (JICA/SILT, 2002)

Data

The main data used in the study included temporal satellite data of Landsat TM of the years 1995, 2000, 2005 and 2010 (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 scale and digital topographic data with contour interval of 20 m published by the Survey Department, Government of Nepal, soil and plant parameter and meteorological rainfall data summarized from (LRMP, 1986), Morgan (2001) and the office of the meteorological station, Pokhara, Nepal 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.

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

LULC Mapping and prediction

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. 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.

The 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 115 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 references 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. The studied watershed was delineated into five sub-watershed considering topographical parameters derived contour lines and drainage system. Preparation of LULC map for four periods using temporal satellite data, identification and quantification of LULC changes was carried out. The spatial layers of ancillary database including different socioeconomic and biophysical drivers of LULC changes were prepared using data from topographic map and relevant information (CBS, 2004).

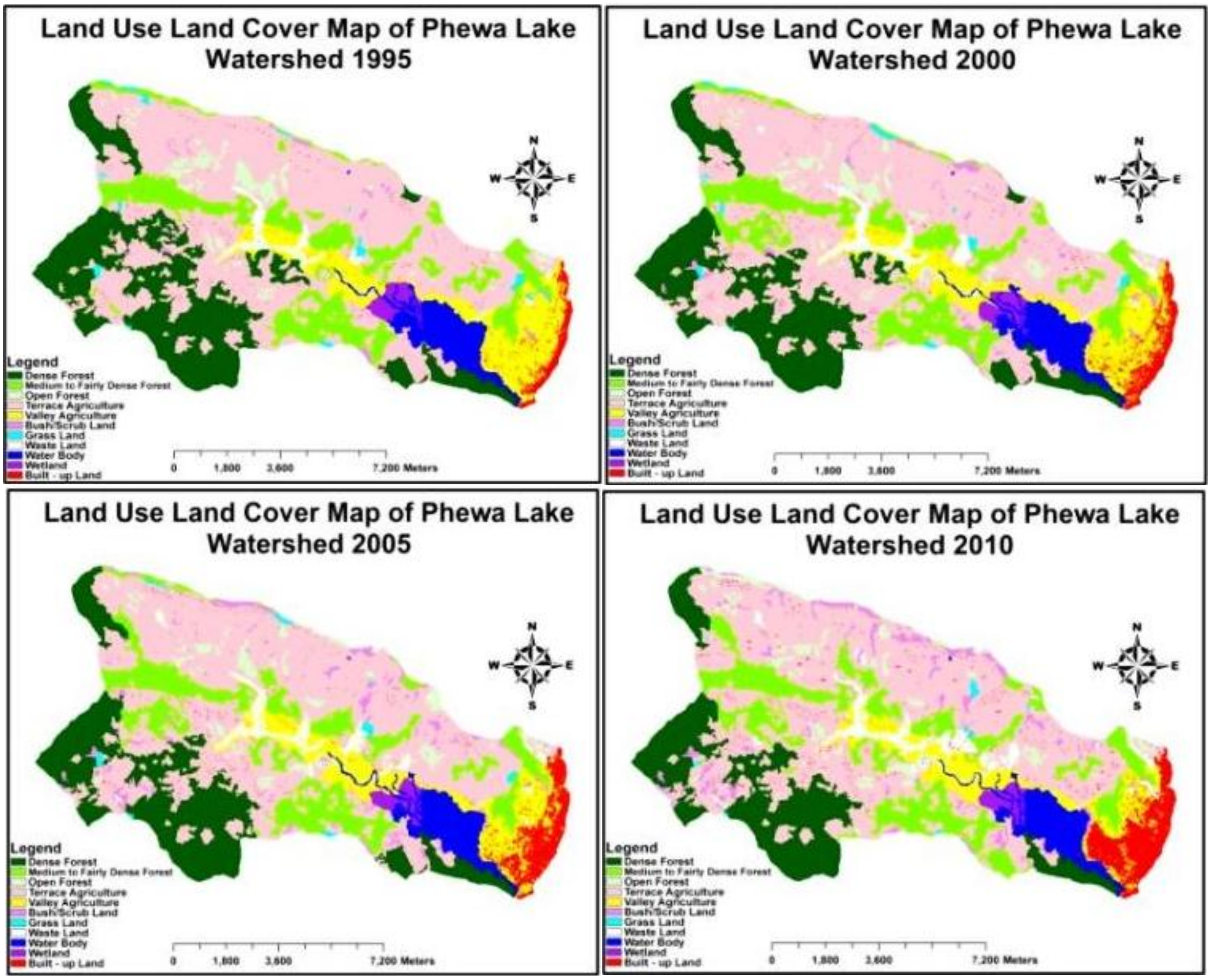
CA–Markov model was employed to predict future LULC dynamics in the watershed using a multi-criteria decision-making approach. This task was accomplished by using IDRISI software package developed by Clark Lab. The 2000 LULC image of Phewa lake watershed was used as the base ($t1$) image while 2005 LULC map as the later ($t2$) 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, 2009). The validation results of the projected LULC 2010 against real 2010 map in CA Markov model of Kno, Klocation, KStrata and Kstandard are 0.8895, 0.8749, 0.8749 and 0.8625, respectively.

Predicting present and future soil erosion risk

A revised version of the Morgan-Morgan-Finney model was used for predicting present and future soil erosion risks. This model has proved to be simple to use, and is able to give reasonable estimates of annual runoff and erosion. The erosion process is carried out in two steps: detachment of soil particles from the soil mass by raindrop impact and the transport of those particles by runoff. The model was designed to evaluate erosion where rates are likely to be accelerated by human impact and incorporated in the model is Geographical Information System domain using Remote Sensing. Different maps such as LULC maps of different periods 1995, 2000, 2005 and 2010, and also, predicted LULC 2015 and 2020, surface soil texture and digital elevation model/slope map have been prepared. All these maps have been converted into raster maps and imported in Integrated Land and Water Information System (ILWIS), a raster based GIS software. Rainfall and rain-day maps are generated in ILWIS from the equation by drawing the graph between elevation vs. rainfall and also elevation vs. rain- day. Attributes values were assigned based on remote sensing data, ground truth and from Morgan *et al.*, (1984) and (Morgan, 2001).



Land Use Land Cover Map of Phewa Lake Watershed 1995

Land Use Land Cover Map of Phewa Lake Watershed 2000

Land Use Land Cover Map of Phewa Lake Watershed 2005

Land Use Land Cover Map of Phewa Lake Watershed 2010

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

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**

Results and Discussions

LULC dynamics

All lands in the watershed were classified into 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 for years 1995, 2000, 2005 and 2010 (Figure 2).

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. 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 study periods (Table 2).

Table 3: Area statistics for Sub-watershed wise LULC classes

LULC Class			DF	MF	OF	TA	VA	BA	GS	WS	WB	WE	BU	Total
1995	**Area(ha)**	**HS**	1809.2	69.8	21.5	1196	42.7	20.1	15.9	39.9	-	-	8.5	3223.4
		AS	254.2	467.6	170.6	1798.8	23.2	20	34.6	39.2	-	-	6.8	2815.1
		MS	169.8	522.6	26.3	1304	327.5	18	23.3	95.1	46.3	38.7	7.4	2579.1
		SFS	-	286	28.5	784.5	794	17.3	23.1	11.3	-	38.1	167	2150
		NFS	251.8	128.7	-	271.2	17.6	14.2	-	-	-	50.8	3.6	738
2000	**Area(ha)**	**HS**	1610.9	225.7	27	1179.7	33.4	69.1	15.3	52.7	-	-	9.6	3223.4
		AS	247.5	470.5	175	1785.1	13	26.6	28.2	57.4	-	-	11.8	2815.1
		MS	144.3	526.6	52.1	1240.3	321.3	62.6	22.3	142.9	36.1	20.2	10.4	2579.1
		SFS	-	290.7	54.9	782.2	650.4	37.7	13.3	25.8	-	29	266	2150
		NFS	242.6	135.7	-	256.9	17.5	32.6	-	-	-	46.1	6.6	738
2005	**Area(ha)**	**HS**	1608.7	230.6	35.8	1149.1	33	84.4	13.1	53.6	-	-	15	3223.4
		AS	232.7	470.7	177.8	1762.1	12.1	71.4	16.2	58.8	-	-	13.3	2815.1
		MS	71.2	528.2	79.8	1233.3	317.3	87.6	22.2	170.7	35.6	20	13.1	2579.1
		SFS	-	299.4	57.7	772.9	517	41.3	8.7	56.3	-	24.2	372.5	2150
		NFS	239.8	138.6	-	250.9	16.9	38.9	-		-	44.9	8	738
2010	**Area(ha)**	**HS**	1590.2	236.6	46.5	1137.9	31.3	96.5	9.7	55.3	-	-	19.4	3223.4
		AS	173.6	472.2	188.6	1752.2	11.6	133	2	61	-	-	20.9	2815.1
		MS	39.3	529.8	101.3	1201.6	310.7	90.4	22	209.9	33.4	18.7	22.1	2579.1
		SFS	-	321.1	60.8	745.7	352.1	42.3	2.5	91.4	-	20.3	513.8	2150
		NFS	186.4	196.9	-	246.6	14.2	40.3	-	-	-	44	9.6	738

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.

Table 4: Area Statistics of Actual for the year 2010 and CA-MARKOV Model Predicted LULC classes for the year 2015 and 2020

	Area in (ha)		
LULC Class	**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 Land	5182.74	5143.50	5103.18
Valley Agriculture Land	723.60	663.84	603.45
Bush/Scrub Land	395.55	441.00	485.31
Grass Land	33.30	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**

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 219.0 ha, while Medium to Fairly Dense Forest and Open Forest increased by 7.2 ha, 75.0 and 166.9 ha, 25.0 ha in Mid and Harpan Sub-watersheds respectively from 1995 to 2010 (Table 3). Overall classification accuracy for all the four time period maps was more than 85%.

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

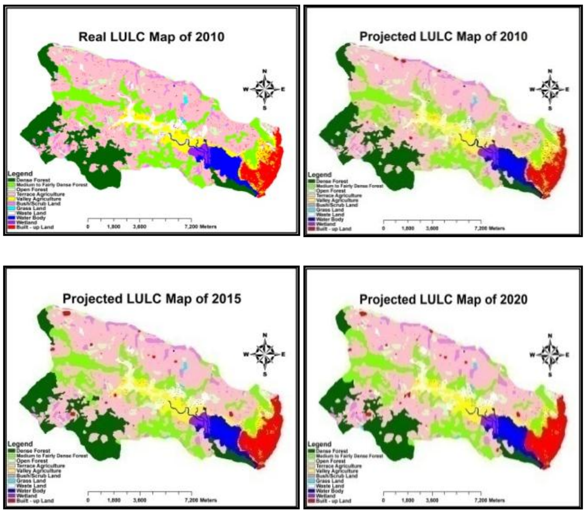


Figure 3 Predicted LULC maps for 2010, 2015 and 2020

Table 5: Comparisons of sub-watershed wise LULC Changes (2010 - 2015 and 2010 -2020)

LULC	2010- 2015					2010 - 2020				
	Change in Area (ha)					Change in Area (ha)				
	HS	AS	MS	SFS	NFS	HS	AS	MS	SFS	NFS
DF	-44.9	-49.5	-15.7	0.0	-16.0	-136.5	-79.2	-18.6	0.0	-20.2
MF	51.3	29.6	0.3	11.1	1.5	113.4	43.2	0.9	16.0	4.5
OF	1.1	12.6	12.9	5.0	-	10.5	23.8	16.6	5.4	-
TA	-3.8	-69.5	-17.0	-10.6	-2.9	-4.9	-80.5	-31.3	-16.2	-3.0
VA	-0.8	-2.3	-11.0	-105.2	-0.2	-2.5	-2.7	-29.9	-155.0	-0.6
BA	0.3	33.8	10.9	5.4	16.2	18.9	34.0	35.2	9.3	16.9
GS	-5.9	-0.1	-0.2	-0.8	-	-6.6	-0.2	-1.1	-1.8	-
WS	1.0	29.2	17.4	9.2	-	2.1	44.6	29.1	21.6	-
WB	-	-	-0.2	-	-	-	-	-5.0	-	-
WE	-	-	-0.2	-2.0	-3.8	0.0	0.0	-0.5	-3.2	-4.3
BU	1.7	16.4	2.9	87.9	5.2	5.7	16.9	4.6	123.9	6.7

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.

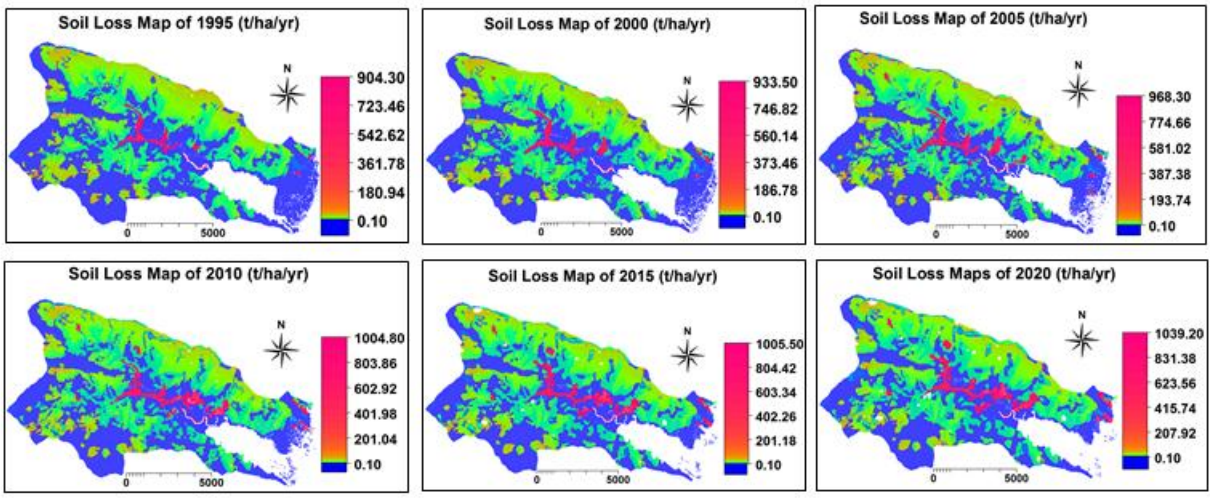


Figure 4 Soil Loss Maps of the Phewa Lake Watershed under Past, Current and Future Scenarios

Dense Forest, Open Forest, Bush/ Scrub, Terrace Agriculture and Valley Agriculture (Table 4).

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 3.

The pattern of change for predicted LULC has been observed the same as there was in real 1995, 2000, 2005 and 2010. Dense Forest, Terrace Agriculture, Valley Agriculture, Wetland and Grass Land are predicted to decrease by 174.60 ha, 39.24 ha, 59.76 ha, 8.91 ha and 2.07 ha, respectively, while Medium to Fairly Dense Forest, Open Forest, Bush / Scrub, Waste Land and Built-up- Land are projected to increase by 50.85 ha, 28.80 ha, 45.45 ha, 50.85 ha and 115.65 ha, respectively between the years of 2010 to 2015. Similar patterns of changes of these LULC classes are predicted by CA-MARKOV model between the years of 2010 to 2020. The sub-watershed-wise change in predicted LULC in 2015 and 2020 from real 2010 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 during all periods in all Sub-watersheds (Table 5).

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, Bush/Scrub and Built-up Land. It could be due to expansion of settlements, construction of roads/ 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 and land use land cover change of watershed. It was observed that the expansion of Built-up Land, Bush/Scrub and Waste Land is responsible for loss of Agriculture, Wetland, Water Body and Grass land, and an increase in Medium to Fairly Dense Forest and Open forest leading to decrease in Dense Forest in the watershed are likely to continue in future.The driving force for these change were settlements'

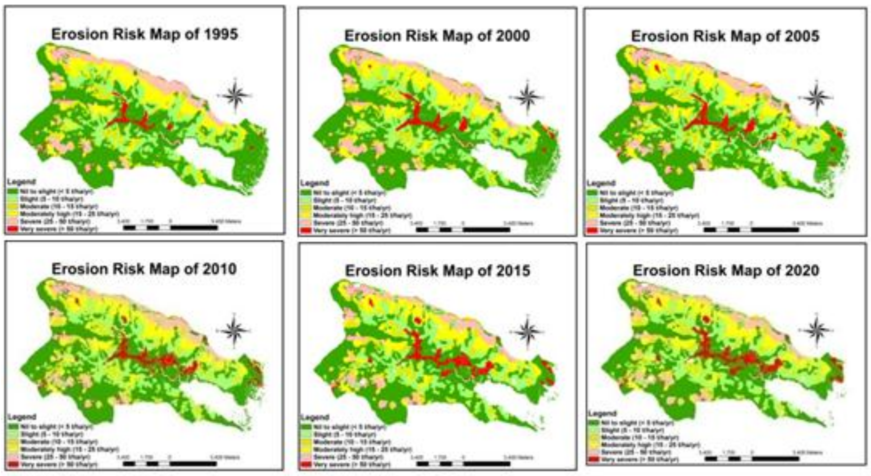


Figure 5 Erosion Risk Maps of the Phewa Lake Watershed under past, Current and Future Scenarios

Table 6: Areal extent of soil erosion risk of the whole watershed

Erosion class		Nil to slight	Slight	Moderate	Moderately high	Severe	Very severe	Excluded area (WB, WE, and BU)	Total
Average rate of soil loss (tones/ha/yr)		<5	5 to 10	10 to 15	15 to 25	25 to 50	>50		
1995	**Area (ha)**	5661.09	1782.27	775.35	1507.23	1146.6	258.03	858.96	11989.53
	%	47.22	14.87	6.47	12.57	9.56	2.15	7.16	100
2000	**Area (ha)**	5482.53	1796.76	788.13	1480.5	1140.39	352.17	949.05	11989.53
	%	45.73	14.99	6.57	12.35	9.51	2.94	7.92	100
2005	**Area (ha)**	5302.86	1809.66	791.91	1453.77	1130.13	452.97	1048.23	11989.53
	%	44.23	15.09	6.61	12.13	9.43	3.78	8.74	100
2010	**Area (ha)**	5088.87	1867.32	805.23	1426.41	1086.84	505.89	1208.97	11989.53
	%	42.44	15.57	6.72	11.9	9.06	4.22	10.08	100
2015	**Area (ha)**	4925.16	1921.05	830.61	1423.26	1045.44	535.32	1308.69	11989.53
	%	41.08	16.02	6.93	11.87	8.72	4.46	10.92	100
2020	**Area (ha)**	4791.67	1968.21	832.23	1408.95	1004.49	575.64	1408.34	11989.53
	%	39.97	16.42	6.94	11.75	8.38	4.8	11.75	100

(Note: WB = Water Body; WE = Wetland and BU = Built-up Areas)

expansion, unscientific agriculture practice, steep slope, unscientific road and trial construction and increase in population (JICA/SILT, 2002). 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 and considering the impact of biophysical and socio-economic drivers in watershed showed the potential of modeling exercise for LULC change in the watershed.

Soil Erosion Risk Assessment

The RMMF model estimated annual potential soil erosion loss for the whole Phewa Lake watershed varied from 0.1 to 904.3 t/ha/yr; 0.1 to 933.5 t/ha/yr; 0.1 to 968.3 t/ha/yr; 0.1 to 1004.8 t/ha/yr; 0.1 to 1005.5 t/ha/yr and 0.1 to 1039.2 t/ha/yr, for the years of 1995, 2000, 2005, 2010, 2015 and 2020, respectively. While the weighted average soil loss for the whole watershed varied over the periods such as 19.20 t/ha/yr, 24.90 t/ha/yr, 28.50 t/ha/yr, 34.10 t/ha/yr, 39.07 t/ha/yr and 42.17 t/ha/yr for the year 1995, 2000, 2005, 2010, 2015 and 2020, respectively. The maps of soil loss for past years (1995, 2000, 2005 and 2010) and future years (2015 and 2020) are presented in Figure 4.

The six soil erosion risk classes were made based on the potential soil loss values and these classes are - < 5 t/ha/yr (Nil to slight), between 5 and 10 t/ha/yr (Slight); between 10 and 15 t/ha/yr (Moderate); between 15 and 25 t/ha/yr (Moderately high); between 25 and 50 t/ha/yr (Severe) and > 50 t/ha/yr (Very severe) The maps of soil erosion risk with various risk classes for the past study periods (1995, 2000, 2005 and 2010) and predicted years (2015 and 2020) are shown in Figure 5.

Table 7: LULC wise Soil Loss of the watershed under past, current and future scenarios

LULC			DF	MF	OF	TA	VA	BA	GS	WS
1995	Soil loss (t/ha/yr)	Range	0.1-2.6	0.1-4.7	0.5-20.0	7.0-70.0	0.1-4.7	0.5-17.9	0.3-12.2	429.1-904.3
		Average*	0.2	0.5	1.1	17.8	0.3	3.7	3.6	586.6
2000	Soil loss (t/ha/yr)	Range	0.1-2.6	0.1-4.7	0.5-20.0	7.0-70.0	0.1-4.7	0.5-17.9	0.3-12.2	429.1-933.5
		Average*	0.2	0.5	1.3	17.7	0.3	4.3	3.5	591.3
2005	Soil loss (t/ha/yr)	Range	0.1-2.6	0.1-4.7	0.5-20.0	7.0-70.0	0.1-4.7	0.5-17.9	0.3-12.2	429.1-968.3
		Average*	0.2	0.5	1.6	17.6	0.3	4.5	3	591.5
2010	Soil loss (t/ha/yr)	Range	0.1-2.6	0.1-4.7	0.5-20.0	7.0-70.0	0.1-4.7	0.5-17.9	0.3-12.2	429.1-1004.8
		Average*	0.2	0.5	2	17.5	0.3	5.1	2.6	616.9
2015	Soil loss (t/ha/yr)	Range	0.1-2.6	0.1-4.7	0.5-20.0	7.0-70.0	0.1-4.7	0.5-17.9	0.3-12.2	442.2-1005.5
		Average*	0.2	0.5	2.1	17.4	0.3	5.4	2.5	656.6
2020	Soil loss (t/ha/yr)	Range	0.1-2.6	0.1-4.7	0.5-20.0	7.0-70.0	0.1-4.7	0.5-17.9	0.3-12.2	442.2-1039.2
		Average*	0.2	0.5	2.2	17.3	0.3	5.5	2.4	661.6

(Note: * LULC wise weighted average soil loss; 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).

Table 8: Sub-watershed wise soil conservation priority classes in Phewa Lake in different study periods Watershed

SW		HS	AS	MS	SFS	NFS
1995	Average soil loss (t/ha/yr)	14.9	22.5	31.9	10	4
	Priority classes	IV	III	II	V	V
2000	Average soil loss (t/ha/yr)	17.5	27.6	43	15.7	4.1
	Priority classes	III	II	II	III	V
2005	Average soil loss (t/ha/yr)	19.3	27.8	47.8	27.9	4.2
	Priority classes	III	II	II	II	V
2010	Average soil loss (t/ha/yr)	19.5	28.8	61.8	46.2	4.3
	Priority classes	III	II	I	II	V
2015	Average soil loss (t/ha/yr)	19.8	36.3	68.8	55.6	4.5
	Priority classes	III	II	I	I	V
2020	Average soil loss (t/ha/yr)	20.1	38.8	72.1	62.9	4.7
	Priority classes	III	II	I	I	V

(Note: HS = Harpan System, AS = Andheri System, MS = Mid Sub watershed, SFS = South Flowing System, NFS = North Flowing System, SW = Sub watersheds).

The areal extent of soil erosion risk classes for the whole watershed is presented in Table - 6.

The data presented in (Table - 6) and (Figures – 5) indicated that overall, Nil to Slight erosion was decreased by 1.5, 1.5, 1.8, 1.4 and 2.5 percentages of total area from 1995-2000, 2000-2005, 2005-2010, 2010-2015 and 2010-2020 respectively due to conservation practice, awareness campaigns about soil erosion for the local people in the forest area. Similarly Slight and Moderate erosion area increased by 0.2, 0.11, 0.6, 0.6 and 1.0 percentages due to unscientific cultivation practices, deforestation and settlement expansion whereas Moderately high erosion area decreased on all study periods due to conservation practice adopted in the study area. While on the other hand overall, severe erosion area decreased by 0.2, 0.2, 0.2, 0.01 and 0.1 percentages and Very severe erosion area increased by 0.8, 0.8, 0.4, 0.2 and 0.6 percentages respectively in all change study periods in abundant Terrace Agriculture and Waste Land due to unscientific cultivation practices, deforestation and as well as sloppy nature landscape. The data pertaining to LULC class wise soil erosion risk classes are presented in Table – 7 for all the study periods.

The data presented in Table –7 and Figures – 4 and 5 indicated thataverage soil losses are very low (0.2 –2.2 t/ha/yr) under LULC types such as Dense Forest, Medium to Fairly Dense Forest and Open Forest for all study periods. The average soil loss was highest (586.6, 591.3, 591.5, 616.9, 656.6 and 661.6 t/ha/yr) for 1995, 2000, 2005, 2010, 2015 and 2020 respectively in areas under Waste Land. The lowest soil losses (< 2.6 t/ha/yr) recorded in Dense Forest area for all study periods. The annual soil loss rates are very high (up to 70 t/ha/yr) for all study years in the areas with abundant terrace cultivation located in steep to very steep sloping areas of the watershed. The results of soil erosion status in the current and future scenario revealed that the considerable rates of soil erosion are observed in Terrace Agriculture, Bush/Scrub and Grass Land areas. But soil erosion was observed very high in Waste Land in the study area. Soil erosion was observed to increase in Open Forest, Bush/Scrub Land and Waste Land and decreased in Terrace Agriculture and Grass Land for all study periods. The soil loss rate was moderately high to high and severe in abundant Terrace Agriculture Land due to steep slope and absence of projective vegetation cover.

The result of soil erosion modeling showed that from each five years time interval from 1995 to 2010, the soil erosion increased due to increase of areal extent of several LULC classes such as Open Forest, Medium to Fairly Dense Forest, Bush/Scrub and Waste land and decreased of areas under Dense Forest, Terrace Agriculture, Valley Agricultural and Grass Land and hence change of soil erosion matched with LULC change in the study watershed. Similar trends of erosional soil loss were also observed for the predicted periods of 2015 and 2020.

Soil erosion risk in the watershed (Table – 6 and 7) revealed that 100% percent area of Waste Land and abundant Terrace Agriculture Land was in Very severe and severe erosion risk respectively for all study periods. Therefore, about (75 – 81%) of total area of watershed found under Nil to Slight (<5 t/ha/yr) to moderately high erosion risk (25 t/ha) of soil erosion class for all study periods. 11.7 – 13.2 % of the total area of watershed are predicted to be vulnerable to severe to very severe soil erosion risk class on all study periods. The sub-watershed wise soil erosion loss results and their prioritization status are presented in Table - 8.

The data in Table – 8 indicated that out of five sub watersheds, MS sub-watershed has highest weighted average soil erosion loss for all the study periods. Moderate to severe erosional soil loss are estimated in AS, HS and SFS sub-watersheds for all study periods. The least erosional soil losses are estimated for NFS sub-watershed at all study periods. The result of relative prioritization status of the sub-watersheds in Phewa Lake watershed revealed that Mid (MS) Sub-watershed is falling medium priority class in 1995, higher priority class in 2000 and 2005 and very high priority class in 2010, 2015 and 2020. Similarly, South Flowing system (SFS) Sub-watershed is falling lowest priority class in 1995 and medium class in 2000, higher class in 2005 and 2010 and highest priority class in predicted 2015 and 2020. Also, Andheri (AS) Sub-watershed is falling in medium priority class in 1995 and higher priority class in rest of the periods while Harpan (HS) and North Flowing (NFS) Sub-watersheds are falling in medium class and lowest priority class respectively, in all the study periods.

Conclusion

Form the results of the study following conclusions are drawn:

- Digital supervised classification technique using Landsat TM was found effective for the preparation of temporal LULC maps with good accuracy. Use of temporal satellite data are very useful, time saving and cost effective for the preparation of LULC maps and change analysis.
- Last 15 years (195-2010) significant changes in various LULC are observed in the studied Phewa watershed of Nepal and this information would provide useful inputs to LULC planners for effective management of the watershed. Remarkable increase in Medium to Fairly Dense Forest was noticed due to positive impacts of implementation of community forest management program. Open Forest areas are increasing and Dense Forest areas are decreasing in all study periods. Appreciable areas of the Terrace Agriculture, Valley Agriculture, Bush and Grass Land areas were converted into Built-up and Waste lands.
- The major causes of negative LULC changes are deforestation activities, soil erosion in sloping mountainous areas; poor management of terrace agriculture, rapid urbanization, unplanned infrastructure development such as road and building etc and population pressure.
- Remote sensing derived inputs of past spatial trends of LULC and GIS tool are very effective to analyze and model the future (2015 and 2020) LULC dynamics in the watershed using CA–Markov predictive modeling technique with good accuracy.
- Predicted LULC scenarios for 2015 and 2020 indicated that major LULC such as Medium to Fairly Dense Forest, Open Forest, Bush/Scrub, Waste Land and Built-up area were in increasing trend while other LULC classes were in decreasing trend. The LULC predictive modeling technique CA-Markov is very useful tool for planning sustainable management strategies based on model predicted future LULC change scenarios.
- RMMF model using remote sensing derived inputs viz. LULC, soil and other ancillary information (DEM derived slope, rainfall data, soil and vegetation characteristics etc.) and GIS aided analysis found very useful tools for assessment of soil erosion risk based on soil loss estimates in the watershed for the past, present and future LULC scenarios.
- Soil erosion modeling results indicated that 56.39% to 62.09% are under Nil to slight (soil loss: <5 t/ha/yr) and Slight (soil loss:5-10 t/ha/yr) soil erosion risk; 18.69% to 19.04% under Moderate (soil loss:10-15 t/ha/yr) and Moderately High (soil loss:15-25 t/ha/yr) erosion risk , and 11.71% to 13.18% of the watershed under Sever (25-50 t/ha/yr) to Very Severe (> 50 t/ha/yr) soil erosion risk classes for the study periods. Lower erosional soil loss rates (0.2 – 2.2) were predicted in forested LULC classes, while higher soil loss predicted for terrace agriculture and highest in waste land areas.
- Out of 5 sub-watersheds, 2 sub-watersheds (MS and SFS) are under Very high (Class I) soil conservation priority class with weighted average soil loss (> 50 t/ha/yr. predicted for the years 2010, 2015 and 2020). AS and HS sub-watersheds are categorized as High priority class (Class II, average soil loss – 25 to 50 t/ha/yr.) and Medium priority class (Class-III, average soil loss – 15 to 25 t/ha/yr), respectively.

References

Anderson, J. R., Hardy, E. E., Roach, J. T. and Witmer, R. E. (1976).*A land use and land cover classification system for use with remote sensor data*. US Geological Survey Professional Paper, 964: 11– 92

Bronstert, A., Niehoff, D. and Bürger, G. (2002). Effects of climate and land use change on storm runoff generation: Present knowledge and modeling capabilities. *Hydrological Processes*, 16(2): 509–529

CBS, (2004).Handbook of environment statistics.Central Bureau of Statistics, Kathmandu.

Eastman, J. R. (2009). *Idrisi 16 Taiga, Guide to GIS and Image Processing*, Clark University; Worcester: 01610-1477, USA.

JICA/SILT, (2002).*Conservation Development study on the environmental conservation of Phewa Lake in Pokhara, Nepal*. Final report submitted by SILT Consultants to JICA/ Nepal, Kathmandu.

Kettner, A. (1996). *Simulated man-induced erosion in the Middle Mountains of Nepal, a case study on the relation between land use, land tenure and erosion with the use of the AGNPS-model in the MahadevKhola watershed.*Msc. Thesis, Dept. Of Soil and Water Conservation and Irrigation, Agricultural University, Wageningen

Lambin, E. F., Turner, B. L., Geist, H. J., Agbola, S. B., Angelsen, A., Bruce, J. W., Coomes, O.T., Dirzo, R., Fischer, G., Folke, C., George, P. S., Homewood, K., Imbernon, J., Leemans, R., Li X, B., Moran, E. F., Mortimore, M., Ramakrishnan, P. S., Richards, J. F., Skanes, H., Stefeen, W., Stone, G. D., Svedin, U., Veldkamp, T. A., Vogel, C. and Xu, J. C. (2001). The causes of land-use and land-cover change: moving beyond the myths. *Global Environ. Change*,11(4): 261–269.

LRMP, (1986). Land Resources Mapping Project. Kenting Earth Science: Kathmandu.

Meyer, C. R. and D. C. Flanagan, (1992).Application of case-based reasoning concepts to the WEPP soil erosion model. AI Applications, 6(3): 63 – 71

Morgan, R .P. C. (2001). A simple approach to soil loss prediction: a revised Morgan–Morgan–Finney model. Catena, 44(2): 305–322.

Morgan, R. P. C., Morgan, D. D. V. and Finney, H. J. (1984).A predictive model for the assessment of erosion risk.*J. Agric. Eng. Res.* 30: 245 – 253.

Osborne, L. L. and Wiley, M. J. (1988). Empirical relationships between land use/ cover and stream water quality in an agricultural watershed. Journal of Environmental Management 26: 9–27.

Pontius Jr, R. G. and Chen, H. (2006).*Land Change Modeling with GEOMOD*. Clark University, Worcester, USA.

Shrestha, D. P. (1997). Assessment of soil erosion in the Nepalese Himalaya, A case study in likhukhola valley, middle mountain Region. Land Husbandry, 2(1): 59-80.

Soe, W. M. and Le, W. (2006).Multicriteria decision approach for land use and land cover change using Markov chain analysis and a cellular automata approach.*Canadian Journal of Remote*, 32(6)**:** 390–404.

Soranno, P. A., Hubler, S. L., Carpenter S. R. and Lathrop, R. C. (1996). Phosphorus loads to surface waters: A simple model to account for spatial pattern of land use. *Ecological Applications,* 6(3): 865–878.

Stohlgren, T. J., Chase, T. N., Pielke, R. A., Kittel, T.G. F. and Baron, J. S. (1998).Evidence that local land use practices influence regional climate, vegetation, and stream flow patterns in adjacent natural areas.*Global Change Biology*, 4: 495–504.

Tang, Z., Engel, B. A., Pijanowski, B. C. and Lim, K. J. (2005). Forecasting land use change and its environmental impact at a watershed scale. *Journal of Environmental Management* 76: 35–45.

Wang, L., Lyons, J., Kanehl, P. and Bannerman, R. (2001).Impacts of urbanization on stream habitat and fish across multiple spatial scales.*Environmental Management*, *28*(2): 255-266.

Wang, L., Lyons, J., Kanehl, P., Bannerman, R. and Emmons, E. (2000).Watershed urbanization and changes in fish communities in southeastern Wisconsin streams.*Journal of the American Water Resources Association*,36(5): 1173–1189.

Weng, Q. (2001). Modeling urban growth effects on surface runoff with the integration of remote sensing and GIS. *Environmental Management*, *28*(6): 737-748

White, M. D. and Greer, K. A. (2006).The effects of watershed urbanization on the stream hydrology and riparian vegetation of Los Peñasquitos Creek, California.*Landscape and UrbanPlanning*, 74(2): 125–138.

Zampella, R. A., Laidig, K. J. and Lowe, R. L. (2007).Distribution of diatoms in relation to land use and pH in blackwater coastal plain streams. Environmental Management, 39: 369–384.