Application of Remote Sensing and Participatory Soil Erosion Assessment Approach for Soil Erosion Mapping in a Watershed

Krishna Prasad BHANDARI* **and Rotchanatch DARNSAWASDI**

Faculty of Environmental Management, Prince of Songkla University, Songkhla 90110, Thailand

(*Corresponding author's e-mail: bhandarikrishna@hotmail.com; rotchanatch.d@psu.ac.th)

Received: 5 June 2014, Revised: 22 October 2014, Accepted: 22 November 2014

Abstract

This research addresses the problem of soil erosion in the Phewa watershed, Pokhara, Nepal, through remote sensing application of the Revised Universal Soil Loss Equation (RUSLE) model, and Participatory Geographic Information System (PGIS) based Erosion Damage Assessment (EDA). Acceleration of soil erosion is due to anthropogenic factors, such as construction of roads without conservation, intensive agriculture, and socio-economic activities. The aim of the study is to identify the major causes of soil erosion by application of remote sensing; RUSLE and PGIS based EDA for soil erosion reduction management. The methodologies employed include structured questionnaires, focus groups, stakeholders' sketches, and application of remote sensing and GIS on RUSLE model. The RUSLE model results indicate that the rate of soil erosion in the Phewa watershed varies from 0 to 206.78 t/ha/yr, and the mean annual rate of soil loss was 14.71 t/ha/yr in 2010. The PGIS based EDA resulted in different classes of severity (stable, slight, moderate, severe, very severe) which were similar to the quantified results of RUSLE, except for the dense forest class in Land Use and Land Cover (LULC). Erosion-prone maps were developed through PGIS based EDA by stakeholders and use of the RUSLE model. Maps showed that the soil erosion risk areas were similar on both maps. The stakeholders' sketched map, with knowledge gained from PGIS based EDA, RS and GIS technology for their conservation practices, could help to reduce soil erosion. The study identifies that the major issues are soil and agriculture management practices, and concludes that there is a link between RS and GIS and the estimated erosion by the RUSLE model. Thus, the RS and GIS techniques and PGIS based EDA approach can benefit stakeholders in applying better measures for soil erosion management.

Keywords: Participatory geographic information system (PGIS), revised universal soil loss equation (RUSLE), erosion damaged assessment (EDA), soil erosion, land use and land cover (LULC)

Introduction

The Phewa watershed is one of the most important bases for tourism and agricultural production in Nepal. The construction of roads without conservation, intensive agriculture, and socio-economic pressure has accelerated the rate of soil erosion. Accelerated soil erosion causes reduction of agricultural productivity, and has environmental impacts, such as nonpoint-source pollution; Lal [1]. Erosion is usually a geological occurrence, in which soil particles are transported elsewhere by water and wind; this erosion rate-is significantly increased by human activities. The risk area can be assessed by PGIS based EDA and erosion modeling. The further development of the soil erosion can be assessed by the integration of the existing soil erosion models, RS data through GIS and field data, as seen in Droogers and Kite [2].

Remotely sensed data, in the form of aerial photographs and satellite sensor data, has been used in mapping and assessing landscape attributes to control soil erosion, such as physiographic, soils, land use and land cover, relief, and soil erosion pattern; see Pande *et al.* [3]. Remote sensing can be used to facilitate study of the thematic factors, such as soil type, slope gradient, drainage, geology, and land cover. Digital Elevation Models (DEMs), a most vital factor in soil erosion modeling, can be created by analysis of stereoscopic optical and microwave (SAR) remote sensing data. RS and GIS techniques were used in several studies for quantitatively assessing erosional soil loss; see Saha *et al.* [4], Saha and Pande [5], Mongkosawat *et al.* [6]. Remote sensing and GIS are important geo-spatial tools and methods, oriented to represent people's spatial knowledge, using physical or virtual media to help in the learning, discussion, and exchange of information in the analysis and decision-making process; see Rambaldi *et al*. [7]. PGIS based EDA mapping emphasizes the use of RS and GIS as a bottom-up empowering process for the public and grass roots communities. It provides an opportunity for stakeholders to discuss their differences and learn about each other's preferences. PGIS based EDA mapping helps to provide a balanced representation of information from social groups and key informants, to identify soil erosion problems and their management.

This study area comprises the watershed of the middle mountain of Nepal. Analysis of geomorphometric parameters, such as drainage density and length of overland flow, of the Phewa watershed show it has been subjected to high erosion problems in the past, and is still susceptible to lateral surface erosion and soil degradation, Awashthi *et al*. [8]. The Phewa lake area has been reduced more than 50 % within a time frame of 5 decades due to human activities and natural erosion (JICA/SILT, 2002) [9]. The rate of construction of roads without conservation measures has rapidly increased and has been recognized as major cause of degradation through soil erosion. However, previous soil erosion studies did not consider scientific attention of broad socio-economic factors, using an RS and PGIS based EDA approach, which includes the participation of stakeholders in the decision making process. Therefore, this research explores the participatory soil erosion assessment approach for soil erosion mapping and management, as well as the scientific approach. This research has 3 broad aims: (i) to assess the study area of the status of soil erosion and conservation through RS and PGIS based EDA; (ii) to identify the soil erosion area with participation of stakeholders and RS and PGIS based EDA, and (iii) to compare results of the RUSLE model and the PGIS based EDA.

Materials and methods

Study area

The Phewa watershed exemplifies a relative subsidence zone in between the Greater Himalayas and the Mahabharat range at 83º 47'51'' - 83º 59''E and 28º 11'39'' - 28º 17'25''N, and has a drainage area of about 123 km^2 (**Figure 1**). The Phewa watershed expands partially or fully over the areas of 6 Village Development Committees (VDCs) (Sarangkot, Kaskikot, Dhikurpokhari, Bhadaure Tamagi, Chapakot, and Pumdi Bhumdi), and the south western part of Pokhara Sub-Metropolitan City, in the Kaski district of Nepal. It is a humid subtropical monsoon region, with an elevation of the terrain ranging from 793 m to 2508 m above mean sea level.

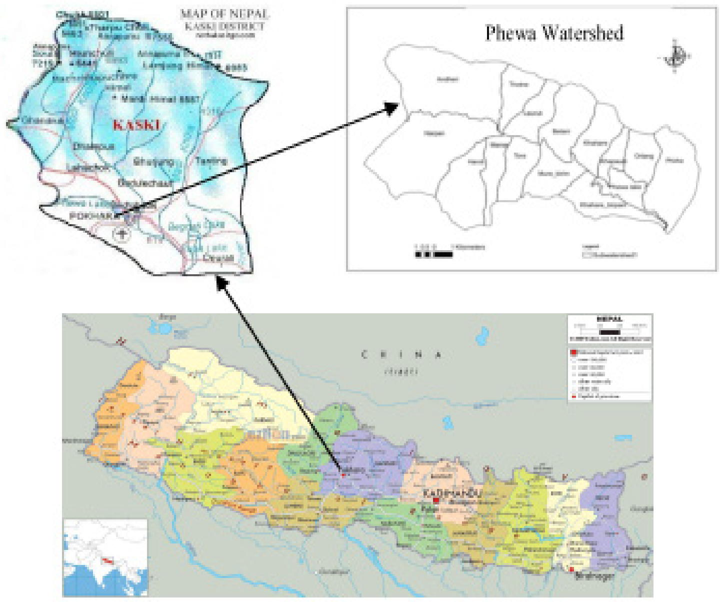

Figure 1 Map of the study area.

Field data

Data were collected from the field and by household questionnaire survey. The basic data sources were the Meteorological Department and the Central Bureau of Statistics (CBS, 2002) [10], a topographic map of 1:25000 from the Survey Department, Government of Nepal, and 6 VDC profiles. Intensive fieldwork was carried out in the catchment area during the rainy season (June - August) of 2012.

Methodology

LULC classification

Remote sensing techniques and field surveys were applied to interpret land use of the study area from the satellite image obtained from Landsat ETM (1995 and 2010). Single band images were grouped together by layer stack technique in ERDAS Imagine for further processing. Geometric corrections were performed to remove scattered clouds in the image. Both images were projected to the Universal Traverse Mercator (UTM) coordinates zone 45. The spheroid and datum were also referenced to WSG84. The images were displayed as false-color composites (4, 3, 2) in the order of RGB. A topographic map of 1:25000 from the Survey Department, Government of Nepal, was considered as the main secondary tool for supervised classification of the study area. LULC classes, such as dense forest, open forest, scrubland, terrace cultivation, single crop, double crop, barren land, grassland, water bodies, built up, and wet land, were identified, as seen in **Figure 2**, and their coordinates were recorded with a Garmin GPS device to support the accurate analysis of the classified image. The image was cross-referenced with ground truth, the topographic map, and other ancillary data, to make the classification as accurate as possible. A nonparametric signature was used, based on an Area of Interest (AOI) that defines the specific feature on the image file being classified. The classification was done repeatedly, to make the classification as accurate as possible. A total of 125 field data were used to validate the classification result through a confusion matrix /error matrix. A confusion matrix is the standard way of finding the accuracy of land cover from remote sensing imagery; Alexis [11]. The confusion/error matrix consists of rows and columns, with classification values and fact values respectively, from the field. The diagonal line of the error matrix represented classified pixels. The overall accuracy was calculated from correctly classified pixels divided by the total number of pixels checked. The producer accuracy index was obtained by dividing the number of correctly classified pixels by the total number of ground truth pixels. Land use classes and validate points with coordinates in the text format were imported as true classes. A users' accuracy index was obtained from the total number of correctly classified pixels of the same class divided by the sum of the values of the rows. The confusion matrix was generated by showing the ground truth points from independent sources. Accuracy was quantified by developing a confusion matrix for each image and computing the corresponding users' accuracy, producers' accuracy, overall accuracy, and the kappa statistic of agreement.

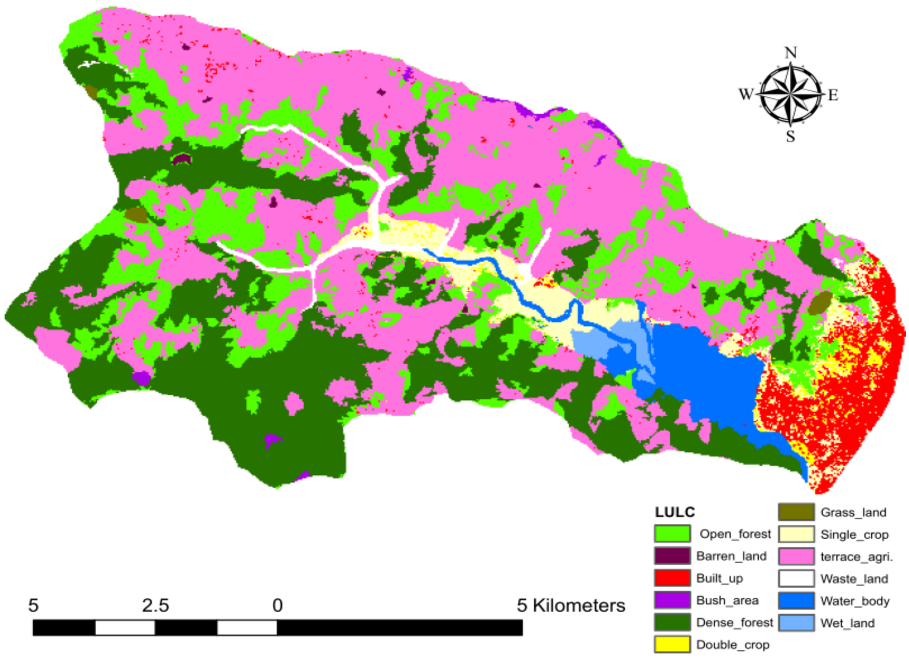

Figure 2 Land use land cover map of 2010.

Soil erosion assessment

The RUSLE model is the extensive version of the Universal Soil Loss Equation (USLE), and was used for estimating average annual soil loss based on sample plot data. It was later found to be possible to use remotely sensed data in the soil erosion estimation, because of the capture of the surface characteristics at the time of the image acquisition. The RUSLE model is expressed as;

$$A = R \times K \times LS \times C \times P \tag{1}$$

where A is the average annual soil loss, R is the rainfall-runoff erosivity factor, K is the soil erodibility factor, LS is the slope length steepness factor, C is the cover management factor, and P is the erosion control (conservation support) practices factor. Each factor is briefly described as follows:

a. Rainfall data (*R*-factor)

The mean annual rainfall data of 3 meteorological stations in the watershed over 15 years (1995 - 2010) were collected and the R factor estimated. The elevation of the meteorological stations was correlated with the rainfall data. Regression technique was applied to obtain the equation for the rainfall distribution map. The equation of the rainfall map was;

$$\mathrm{Y} = 0.967x + 2901 \tag{2}$$

where Y is the amount of rainfall (mm) and x is the elevation (m). The above formula was applied to the map calculation function of Arc GIS 10.0 software. The relationship between elevation and annual rainfall was found to be ($R^2 = 0.821$). The R value estimation Eq. (3) Renard and Freimund [12] was as follows;

$$\mathrm{R} = 587.8 - 1.219\times\mathrm{P} + 0.004105\times\mathrm{P}^2 \tag{3}$$

where P is the annual rainfall (mm) and R is the rainfall erosivity (MJ mm ha^{-1} yr^{-1}).

b. Soil Erodibility factor (*K*-factor)

A K factor map was prepared from the soil texture map from the Forest Research Assessment project, Nepal, with 4 major textural classes: sandy loam, loamy, silt loam, and silt clay loam. The K-factor of each unit was estimated by using a nomograph; Wischmeier and Smith [13]. K values ranged from 0.13 to 0.38 th MJ^{-1} mm^{-1}.

c. Topographic factors (*LS*)

The L-factor represents the effects of the slope length. RUSLE makes no difference between rills (shallow channels created by flowing water) and inter rill erosion. The S-factor computes the effects of slope steepness on soil loss; Renard *et al*. [14], KC [15]. A GIS spatial analyst tool was used to compute the LS factor. DEM was prepared by 20 m interval digitized contours from the topographical map produced by the Survey Department, Government of Nepal. The L-factor was estimated by using a flow accumulation theme. The flow accumulation and slope steepness were computed from the DEM using ArcGIS spatial analyst and Arc Hydro extension software. The LS factor was calculated by means of the ArcGIS spatial analyst extension with DEM following the Eq. (5) of Moore and Burch [16]. The LS factor was computed using Eqs. (4) from Schawb *et al*. [17] and (5):

$$LS = \left(\frac{A}{22.13}\right)^{0.4} \times \left(\frac{SinB}{0.0896}\right)^{1.4} \tag{4}$$

where A is flow accumulation *cell size, and B slope angle in degree.

The corresponding map algebra expression is;

$$\mathrm{LS} = \left[\mathrm{Pow}\ \left([\text{flow accumulation}]\times\frac{cell\ size}{22.13}, 0.6\right)\times\mathrm{Pow}\ \left(\frac{\mathrm{Sin}([\text{Slope\_degree}]\times 0.01745)}{0.0896}, 1.4\right)\right] \tag{5}$$

The LS factor ranged from 0 - 737.5 (**Figure 3**).

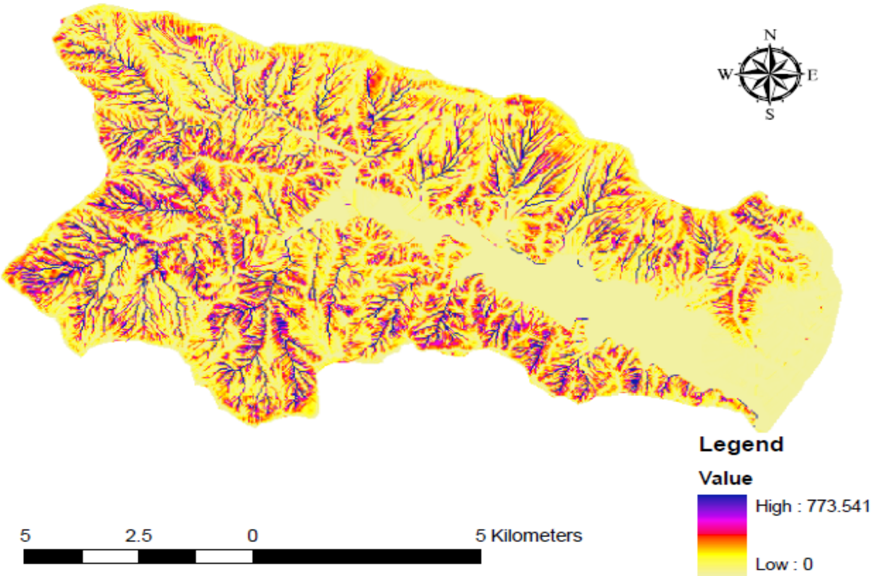

Figure 3 Slope length and steepness factor 'LS' raster.

d. The Cover factor (*C*)

Crown coverage, ground cover, crop sequence, length of the growing season and tillage practice, etc. are the drivers to measure the cropping management factor 'C'. A LULC layer was generated by supervised classification and using Visual Interpretation (VI). This layer was converted to a C layer through reclassification of each cover type into its corresponding C values (**Table 1**).

Table 1 Adopted value of C for different land use.

S. N.	Land covers	Average C value	S. N.	Land covers	Average C value
1	Open forest	0.07	7	Bush and scrub	0.02
2	Double crop	0.37	8	Grass/fallow land	0.03
3	Single crop	0.55	9	Terrace cultivation	0.55
4	Built up land	0.05	10	Waste land /land slide	1.00
5	Water body	0.0	11	Dense mixed forest	0.001
6	Wet land	0.0	12	Barren land	1.00

Sources: Roose [18], Hurni [19], Morgan [20], Hashim and Wong [21], and field observation.

e. The conservation factor (*P*)

Ploughing or tilling along the contour lines, either against the slope length or perpendicular to the slope length, is the general practice in local farming cropland. The conservation practice P can be computed from the Eq. (6) Schawb *et al*. [17] (**Table 2**).

$$P = P_c \times P_S \times P_t \tag{6}$$

where P_t is the terrace sedimentation factor, P_S is the contouring factor based on slope, and P_c is the strip cropping factor for crop strip widths. The P factor for agriculture according to the slope and other land use type has a value of 1, because there was no control measure in place. A combined map, 'CP', of the (C) factor and the (P) factor was produced (**Figure 4**).

Table 2 Adopted value of the practice management in different land use.

Land use type	Slope %	*Pc*	*Ps*	*Pt*	*P factor*
Agriculture	1 - 4	0.57	0.55	0.5	0.11
	5 - 10	0.65	0.55	0.3	0.09
	11 - 20	0.80	0.55	0.6	0.19
	21 - 40	0.95	0.55	0.2	0.0
	> 40	1.00	0.55	0.4	0.20
All		1.00	1.00	1.00	1.00

Source: Schwab *et al*. [17] and field observation.

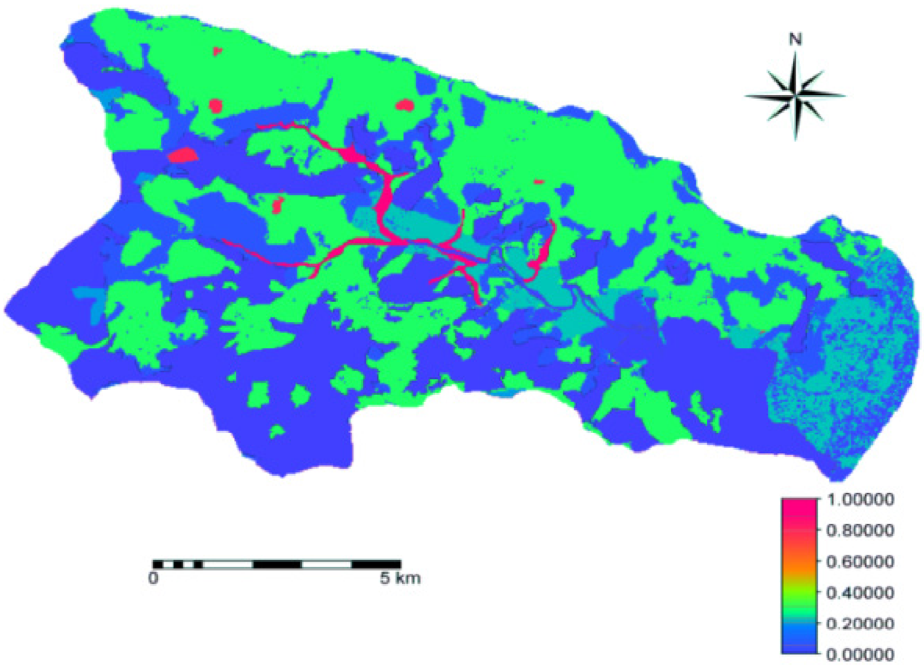

Figure 4 Cover management and support practice factors.

PGIS based erosion damage assessment

The village leaders from the each of the sub-watershed of the study area were invited to discuss the mapping of soil degradation in their villages. Village leaders sketched out the lines of the catchment on a topographic map. A field by field soil erosion status survey was done by using erosion indicators on the soil surface. Erosion hazard was characterized by the observation of the effect of erosion features on plots after rain. The guidelines for evaluating the erosion hazard and specific features from Okoth [22] were used to collect data to assess the occurrence of soil erosion. Erosion feature classification was carried out based on severity classes (**Table 3**). Erosion damage assessment was done qualitatively, according to visible features of the water erosion process, including the depth of root exposure, flow channel, surface litter translocation, depth of the rills, depth of the stem wash, and depth of soil movement. The severity of erosion classes ranged from slight, moderate, severe, and very severe, according to the information of the amount of soil eroded from 30 plots of size 2.5 m width and 10 m length. Out of 30 plots, 10 plots were in terrace cultivation (maize), 5 plots were in open forest, 6 were in single crops, and 3 plots were for each erosion proxy, viz. dense forest, barren land, and grassland plots. The mean values of the measured erosion features were converted to the severity of erosion classes.

Table 3 Soil erosion severities, conditioned by the different erosion features.

Erosion feature	Severity class				
	Stable	**Slight**	**Moderate**	**Critical**	**Severe**
Flow channels (%)	0 - 2 %	2 - 10 %	10 - 25 %	25 - 50 %	> 50 %
Surface litter (%)	0 - 2	2 - 10	10 - 25	25 - 50	> 50
Soil movement (cm)	0 - 1.5	1.5 - 3.0	3.0 - 5.0	5.0 - 8.0	> 8.0
Root exposure	0 - 0.5	0.5 - 2.0	2.0 - 3.0	3.0 - 5.0	> 5.0
Stem washing	0 - 1.0	1.0 - 3.0	3.0 - 5.0	5.0 - 7.0	> 7.0
Rills width (cm)	< 10	10 - 25	25 - 45	45 - 80	> 80
Depth (cm)	0 - 4	4 - 8	8 - 12	12 - 20	> 20

Source: Adopted and modified from Okoth [22], Clark [23].

The focus group discussions drew PGIS based erosion damage maps of areas of soil erosion, conservation, and the natural resources harvested in the topographic map, based on stakeholders' knowledge and researcher's feedback. A PGIS based EDA map was prepared using related data captured in the ArcGIS10.0 and ERDAS 9.3 software. Qualitative information collected from focus groups and key informants' surveys were manually processed and used in analysis to complement quantitative information.

Results and discussion

Soil erosion based on PGIS based erosion damage assessment and RUSLE model

Erosion severity was analyzed from the observed mode values of erosion features (**Table 4**). The results found that one class shifted compared to the result obtained by mode in almost all of the erosion proxies. Erosion prediction was classified based on maximum function, so it would be preferable for the recommendations on soil and water conservation planning to cover erosion risk. It is recommended so because of PGIS erosion damage in an area specific approach. Maximum mode function of all 6 types of features was assigned by severity class. The spatial unit factors influenced erosion damage along the slope profile. Foot paths, animal tracks, roads were hidden by the surface cover with permanent vegetation grassland, bush or forest. Uncontrolled water influenced the erosion damage.

The areas adjacent of damage field, upslope and down slope of 30 plots were influenced by erosion factors. The RUSLE Model was run (in MS Excel) at each observation site of PGIS based erosion damage survey to predict soil loss. The factors in the surrounding areas adjacent of the observed plots were classified by upslope and down slope, and their effects on soil erosion were interpreted and analyzed based on the PGIS based EDA and RUSLE soil loss assessment. The RUSLE and PGIS based EDA used in observed damaged fields from adjacent upslope areas estimated the average soil loss and determined the frequencies of each factor. Barren lands and stream banks contributed to the highest levels of severity class of soil loss, even though there was low frequency damage, as measured by the RUSLE and PGIS based EDA.

Table 4 Occurrences of erosion severity classes of various erosion proxies.

Land use land cover classes	Sample size	Occurrence of severity classes of soil loss		
		PGIS based EDA	RUSLE	
		Erosion classes / No. of plot assessed	Erosion classes	Average soil loss (t/ha)
Terrace cultivation (Maize)	10	Stable / 2 Slight / 3 Moderate / 4 Severe / 1 Very Severe / -	Severe	20.29
Single crop	6	Stable / 1 Slight / 1 Moderate / 3 Severe / 1 Very Severe / -	Severe	18.34
Grass land	3	Stable / - Slight / - Moderate / 2 Severe / 1 Very Severe / -	Severe	32.49
Barren land	3	Stable / - Slight / - Moderate / - Severe / 1 Very Severe / 2	Very Severe	
Open forest	5	Stable / 1 Slight / 2 Moderate / 2 Severe / - Very Severe / -	Moderate	13.03
Dense forest	3	Stable / 2 Slight / 1 Moderate / - Severe / - Very Severe / -	Stable	4.67

Table 5 shows that the comparison of PGIS based EDA assessed erosion in plot and soil loss at land scale by RUSLE. The samples of erosion damage were collected from up-, mid- and downland slopes,

and averaged and compared with average soil loss in different types of LULC from RUSLE models (**Table 5**). The LULC class mean annual rate of soil loss is presented in **Table 5** and **Figure 5**. Stakeholders sketched the soil erosion affected area on a topographic map based on their knowledge, and the PGIS based erosion damage result was captured and is represented in the map on soil erosion.

Table 5 Comparison of PGIS based EDA assessed erosion in plot and soil loss at land scale by RUSLE.

Erosion proxies	**Sample size No of plots**	**Erosion classes**				
		Stable	**Slight**	**Moderate**	**Severe**	**Very severe**
		Mode	**Mode**	**Mode**	**Mode**	**Mode**
Maize plot	10	2	3	4	1	-
Single crop	6	1	1	3	1	-
Grass land	3	-	1	1	1	-
Open forest	5	1	3	1	-	-
Dense forest	3	2	1	-	-	-
Barren land	3	-	-	1	2	-

Figure 5 showed that the 2010 RUSLE predicted erosion map was similar to the PGIS based EDA map after the knowledge transfer from researcher to stakeholders. Thirty test sites of erosion damage assessment, sampled at different types of LULC, were taken to verify the model results. Model predicted soil erosion was compared with soil erosion assessed with erosion damage by evaluating soil erosion features.

Soil erosion map and PGIS based erosion damage map

The RUSLE model erosion map (**Figure 5**) showed that high soil erosion occurs near riverside, roads and construction without waterways. Near Lauruk, Betani, the North of Tora, the North West of Marse, and the North East of Harpan, the sub watershed has severe soil erosion, due to landslide and river side erosion. Landslides and moderate soil erosion occurs near forests and agriculture land. The RUSLE model was used to estimate the soil erosion in the watershed based on physical factors. The total annual soil loss and average annual soil loss was 181,889 ton/year and level 14.71 t/ha/yr, respectively. The farmers and other stakeholders considered soil erosion was severe only in gullies and streams before PGIS based EDA (**Figure 6**). Large areas of terrace cultivation suffered from acute rill erosion. The focus group discussions and PGIS based EDA were aimed at understanding the use of natural resources, road construction and agricultural land without conservation contributing to soil erosion. Vector layers of soil erosion were created from focus group sketches on topographical maps. These were integrated with a base map, prepared from RS data.

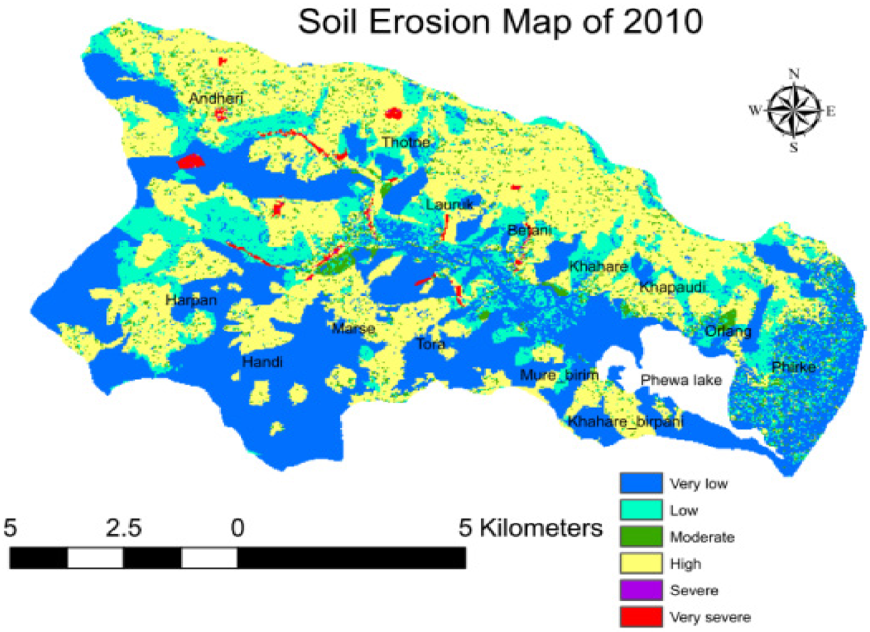

Figure 5 Soil erosion map based on RUSLE model.

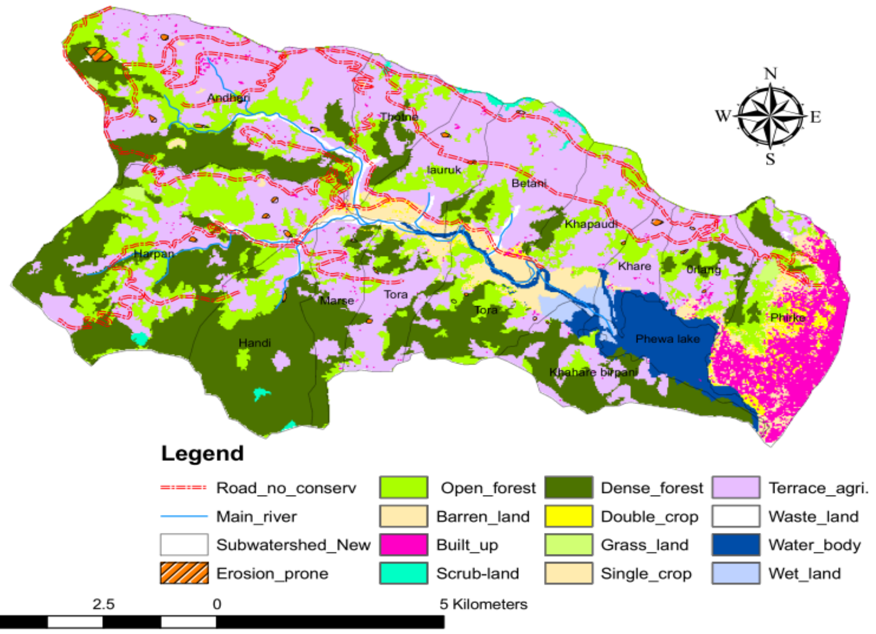

Figure 6 Soil erosion map based on PGIS based EDA.

Comparison of the RUSLE model map and the PGIS based EDA map showed that stakeholders had knowledge and awareness of soil susceptibility factors contributing to soil erosion, such as increasing sheet and rill erosion on terrace cultivation due to lack of conservation practices. These results were helpful in understanding the importance of the PGIS based erosion damage approach and modelling contribution for soil erosion management.

Average soil loss in the watershed was 14.71 t/ha/yr. This rate of soil erosion is higher than the natural rate of soil formation (i.e., higher than "T" values). Soil erosion is a natural process; there are clearly limits of tolerance in particular locations. Soil loss tolerance ("T") value (Wischmeier and Smith [9]), or permissible soil loss (Pender and Kerr [24]) is considered to be an acceptable rate of soil erosion, if soil erosion is equal to or less than soil formation. Research in the Indian region showed a rate of soil erosion ranging from 5 - 10 t/ha/yr for the hilly terrain, dissected hill pediment and pediment planes of Illukpitiya and Gopalakrishnan [25]. "T" values for the Loess Plateau, Northern black land, and rocky and hilly regions were 11.2 and 5 t/ha/yr, respectively, established by the Water Conservation Department of China (Ervin and Ervin [26]. In particular, lack of conservation in the rainy season increased the erosion levels in mountain and terrace cultivation. This research could be taken as baseline information from the remote sensing data and PGIS based erosion damage approach and applied in the formulation of policies and soil conservation programs.

Conclusions

The soil erosion risk area was mapped based on the stakeholders' perceptions of soil erosion and PGIS based EDA. PGIS based EDA and knowledge of the physical factors (e.g., slope, type of the soil, and conservation practices) could make stakeholders understand soil erosion effects on their terrace cultivation and other public areas of the watershed. This study showed that soil erosion was influenced by slope steepness. This research provided knowledge to the stakeholders about soil erosion effects and environmental degradation on their terrace farmland. The PGIS based erosion damage map developed by RS and the GIS tool is helpful to the stakeholders in understanding the issues surrounding soil erosion and the possibilities for improved management in soil conservation. The RUSLE model showed that the soil erosion risk area was similar to stakeholders' sketches, with knowledge gained from PGIS based EDA approach aiding their conservation practices in those areas to reduce soil erosion. This research explores the erosion status of riverside and land slide area being similar to the scientific and stakeholders' perception, bur Agricultural land and open forest is shown as being different from the stakeholders and scientific approach. In future research, PGIS based erosion damage maps prepared by stakeholder and focus groups can be improved through engaging more stakeholders in the field. In doing so, PGIS based erosion damage methods, along with the application of remotely sensed imagery, can be enhanced. The recommendation of this research can lead to important policy implications for active participation of all stakeholders for soil erosion reduction of the watershed.

Acknowledgements

We would like to thank all of the participants who contributed to our study. We would like to acknowledge an anonymous reviewer for a review which helped to improve the earlier version of this manuscript. Although this manuscript improved greatly from the knowledge and support of others, any errors are our own.

References

[1] R Lal. Soil erosion impact on agronomic productivity and environment quality. *Crit. Rev. Plant Sci*. 1998; **17**, 319-464.

[2] P Droogers and G Kite. Remotely sensed data used for modeling at different hydrological scales. *Hydrolog. Process.* 2002; **16**, 1543-56.

[3] LM Pande, J Prasad, SK Saha and C Subramanyam. Review of remote sensing applications to soils and agriculture. *In*: Proceedings of the Silver Jubilee Seminar, Indian Institute of Remote Sensing, Dehradun, 1992.
[4] SK Saha, M Kudrat and SK Bhan. Erosional soil loss prediction using digital satellite data and universal soil loss equation. *In*: Proceedings of the Applications of Remote Sensing in Asia and Oceania-Environmental Change Monitoring. Asian Association of Remote Sensing, Tokyo, 1991.
[5] SK Saha and LM Pande. Integrated approach towards soil erosion inventory for environmental conservation using satellite and agro-meteorological data. *Asia Pac. Rem. Sens. J.* 1993; **5**, 21-8.
[6] C Mongkolsawat, P Thurangoon and S Sriwongsa. Soil erosion mapping with universal soil loss equation and GIS. *In*: Proceedings of the 15th Asian Conference on Remote Sensing, Bengaluru, India, 1994.
[7] G Rambaldi, APK Kyem, M Mccall and D Weiner. Participatory spatial information management and communication in developing countries. *Electron. J. Inform. Syst. Develop. Countr.* 2006; **25**, 1-9.
[8] KD Awasthi, BK Sitaula, BR Singh and RM Bajacharaya. Land-use change in two Nepalese watersheds: GIS and geomorphometric analysis. *Land Degrad. Dev.* 2002; **13**, 495-513.
[9] JICA/SILT. *Conservation Development Study on the Environmental Conservation of Phewa Lake in Pokhara, Nepal*. Final Report Submitted by SILT Consultant to JICA/Nepal Kathmandu, 2002.
[10] CBS. *HMG/N, National Planning Commission Secretariat*. Central Bureau of Statistics, Kathmandu, Nepal, 2001.
[11] JC Alexis. Geographically weighted methods for estimating local surfaces of overall, user and producer accuracies. *Rem. Sens. Lett.* 2013; **4**, 373-80.
[12] KG Renard and JR Freimund, Using monthly precipitation data to estimate the R-factor in the revised USLE. *J. Hydrol.* 1994; **157**, 287-306.
[13] WH Wischmeier and DD Smith. *Predicting Rainfall Erosion Losses: A Guide to Conservation Planning*. US Department of Agriculture, Agriculture Handbook, Washington DC, 1978, p. 1-85.
[14] KG Renard, GR Foster, GA Weesies, DK Mccool and DC Yoder. *Predicting Soil Erosion by Water: A Guide to Conservation Planning in the Revised Universal Soil Loss Equation (RUSLE)*. Agriculture Handbook, US department of Agriculture, Washington DC, 1997, p. 1-251.
[15] KB KC. Mapping soil erosion susceptibility using remote sensing and GIS: A case of the upper Nam Wa watershed, Nan province, Thailand. *Environ. Geol.* 2009; **57**, 695-705.
[16] ID Moore and GJ Burch. Physical basis of the length-slope factor in the universal soil loss equation. *Soil Sci. Soc. Am. J.* 1986; **50**, 1294-8.
[17] G Schawb, D Fangmeier, W Elliot and R Frevert. *Soil and Water Conservation Engineering*. John Wiley & Sons, New Jersey, 1993, p. 1-507.
[18] EJ Roose. *Application of the Universal Soil Loss Equation of Wischmeier and Smith in West Africa*. *In*: DJ Greenland and R Lal (eds.). Soil Conservation and Management in the Humid Tropics. Wiley, London, 1997, p. 177-87.
[19] H Hurni. *Erosion - Productivity - Conservation Systems in Ethiopia*. *In*: IP Sentis (ed.). Soil Conservation and Productivity. Centre for Development and Environment, 1987, p. 654-74.
[20] RPC Morgan. *Processes and Mechanics of Erosion*. *In*: DA Davidson and RPC Morgan (eds.). Soil Erosion and Conservation. Longman, London, England, 1986, p. 12-39.
[21] GM Hashim and NC Wong. *Erosion from Steep Land under Various Plant Covers and Terrains*. *In*: TH Tay, AM Mokhtaruddin and AB Zahari (eds.). Steep Land Agriculture in the Humid Tropics. Malaysian Society of Soil Science, Kuala Lumpur, 1984, p. 24-61.
[22] PF Okoth. 2003, A Hierarchical Method for Soil Erosion Assessment and Spatial Risk Modeling: A Case Study of Kiambu District in Kenya. Ph. D. Thesis Wageningen University, Netherland.
[23] R Clark. *Erosion Condition Classification System*. US Department of the Interior, Bureau of Land Management, Technical Note No. 346, Denver Centre, Denver, Colorado, USA, 1980.
[24] JL Pender and JM Kerr. Determinants of farmers' indigenous soil and water conservation Investments in Semi-Arid India. *Agr. Econ.* 1998; **19**, 113-25.

[25] P Illukpitiya and C Gopalakrishnan. Decision-making in soil conservation application of behavioral model to potato farmers in Sri Lanka. *Land Use Pol.* 2004; **21**, 321-31.
[26] CA Ervin and DE Ervin. Factors affecting the use of soil conservation practices: Hypotheses, evidence, and policy implications. *Land Econ.* 1982; **58**, 277-92.