Master Thesis

submitted within the UNIGIS MSc. programme

at the Department of Geoinformatics - Z_GIS

University of Salzburg, Austria Under the Provisions of UNIGIS Joint Study Programme with Kathmandu Forestry College (KAFCOL), Kathmandu, Nepal

Land Use Land Cover Changes and Sedimentation Levels in Kulekhani Watershed (Nepal) : 2002 - 2018

By

Ramashray Yadav

GIS_105256

A thesis submitted in partial fulfilment of the requirements of

the degree of

Master of Science (Geographical Information Science & Systems) – MSc (GISc)

Advisor:

Dr. Shahnawaz

Co-Advisor:

Dr. Him Lal Shrestha

Kathmandu, Nepal

July 2020

Science Pledge

By my signature below, I certify that my report is entirely the result of my own work. I have cited all sources of information and data I have used in my thesis report and indicated their origin.

Kathmandu, Nepal, July 1, 2020

Place and Date	Signature

Acknowledgements:

I would like to express my sincere gratitude to my supervisor Dr. Shahnawaz and Co-supervisor Dr. Him Lal Shrestha, for their critical analysis, valuable feedback, comments, guidance and suggestions. Without their guidance, this work would have not been come to this form. I would also like to thank independent researcher Mr. Prashid Kandel, DSCO Mr. Sher Bahadur Shrestha, Nepal Electricity Authority (NEA) officer of Kulekhani hydropower, Mr. Ram Kumar Yadav, Er. of Kulekhani hydropower, Mr. Suman Shrestha for their valuable support in data collection from field and offices as well as sharing information. Similarly, I would like to express special thanks to the NEA Central Office, Durbar Marg, Kathmandu for providing data and publications about the Kulekhani hydropower. Finally, I would like to express my sincere thanks to my wife Mrs. Manju Kumari Yadav, other family members and friends for their continuous support and encouragement throughout the study.

Ramashray Yadav, GIS_105256

UNIGIS Student, mar2018

Kathmandu, Nepal

Abstract:

The present study was conducted in Kulekhani watershed of Makwanpur district under Bagmati Province of Nepal to understand the effects of land use land cover (LULC) change on sedimentation level of the Kulekhani reservoir. The result LULC assessment was found that the forest increased continuously during 2002, 2010 and 2018 having 4860 (ha), 5354 (ha) and 5491 (ha) respectively. Similarly, the grass and shrub land cover was found increased continuously within these three time period having 1748 (ha), 2936 (ha) and 3494 (ha) respectively. In the contrast, the agriculture and built up area was found decreased within these period having 5449 (ha), 3816 (ha) and 3013 (ha) correspondingly. Unlikely, the others two land cover classes barren land water bodies have been found decreased first in 2010 but increased in 2018 with low amount. The achieved overall classification accuracies were 85.6%, 94% and 90% as well as the overall Kappa coefficient (K statistics) as 0.7739, 0.9071 and 0.8750 respectively for the classification of 2002, 2010 and 2018 images selected for the study.

The result on LULC change showed that the forest land cover was continuously increased at the rate of 10.2% from 2002 to 2010 and 2.6% from 2010 to 2018 to achieve overall increment as 13% from 2002 to 2018. On contrast, the agriculture and built up area was found continuously decreased at the rate of -30% from 2002 to 2010 and -21.1% from 2010 to 2018 to lose overall -44.7% from 2002 to 2018. Similarly, the grass and shrub land was found increased at the rate of 68% from 2002 to 2010 and 19% from 2010 to 2018 to achieve overall increment rate 99.9% from 2002 to 2018. Unlikely, the barren land cover was found decreased at the rate of -10.2% from 2002 to 2010 and again increased by 46.2% to overall gain 31.3% from 2002 to 2018. Likely, the water bodies was found decreased at the rate of -14.2% from 2002 to 2010 and gained by 8% from 2010 to 2018 to overall lose by -7.3% from 2002 to 2018. During the study period the all land use land cover classes were found converted from each other within the study period.

In overall, the two groups of the sub-watersheds were found clearly visible with respect to hold the comparative size of forest cover and agriculture and built up area. In the first, 50% of the sub-watersheds namely Salma Kulekhani, Chitlang, Simbhanjyang, Gharti and Khaiti were found to have the higher forest land cover area than agriculture and built up. On the contrast, the second 50% of the sub-watersheds namely Bisinkhel, Palung, Chuiliprang, Andheri and Sankhmool were found to have lower forest cover than the agriculture and built up within all the sub-watersheds.

The result showed that the annual sedimentation rate of the Kulekhani watershed was found continuously decreasing at the rate of 13.3 (t/ha/yr), 6.6 (t/ha/yr) and 4.8 (t/ha/yr) in the year 2002, 2010 and 2018 respectively. Similarly, the potential soil loss predicted by RUSLE was also found in decreasing at the rate of 157.0 (t/ha/yr), 100.0 (t/ha/yr) and 83.7 (t/ha/yr) in the three temporal analyzing year. On contrast, the sediment retention capacity of the watershed was found increasing at the rate of 3058.5 (t/ha/yr), 3065.2 (t/ha/yr) and 3067.0 (t/ha/yr) in those three year 2002, 2010 and 2018 respectively. The sub-watersheds namely Palung, Andheri, Simbhanjyang and Sankhmool determined as most sensitive were not only due to a single factor of having greater value of agriculture and built up land cover but also due to a combined effects of rainfall erosivity index (R factor), soil erodibility (K) factor including steep slope of the sites within the watershed. Among the four sub-watersheds, Palung, Sankhmool and Andheri seem to occur within relatively moderate to high R factor values. Likely, the Simbhanjyang was found to occur within moderate R factor values. Similarly, the Palung has been almost occurred within the higher soil erodibility (K) factor and the remaining sub-watersheds belong to have lower to high values of K factor. Furthermore, the correlation coefficient (r = 0.31579) between sediment yield measured in the Kulekhani reservoir and predicted by the model shows that the result of the InVEST SDR_{max} model has been found in right direction within its limitations.

Table of Contents

List of Tables

List of Figures

List of Maps

Abbreviation

DEM	Digital Elevation Model
DSCO	District Soil Conservation Officer
DSCWM	Department of Soil Conservation and Watershed Management
Er.	Engineer
GIS	Geographic Information System
GWh	Giga watt hour
h	Hour
h MJ^{-1}	Hour per Mega Joule
ha	Hectare
InVEST	Integrated Valuation of Ecosystem Service
IPCC	International Panel on Climate Change
LULC	Land Use Land Cover
m^3	Meter Cube
Max	Maximum
MJ.mm.$(ha.h.yr)^{-1}$	Mega Jule per hectare per Hour per Year
Min	Minimum
Mm^3	Million Meter Cube
MW	Mega Watt
masl	Meter Above Sea Level
N/A	Not Available
NEA	Nepal Electricity Authority
no	Number
RoR	Runoff River
RUSLE	Revised Universal Soil Loss Equation
SDR	Sediment Delivery Ratio
SOTER	Soil and Terrain
SRTM	Shuttle Radar Topography Mission
SWAT	Soil and Water Assessment Tool
t/ha/yr	Ton per Hectare per Year
WEPP	Water Erosion Prediction Project

Chapter-1: Introduction

This chapter deals with a brief introduction of reservoir and its importance, watershed, sedimentation, land use land cover and their relation with sedimentation for reservoir with respect to sub-watershed. It also explains the need of this study.

1.1. Background

An area of land in which all the water or snowmelt drains to a single streams, river, lake or reservoir is known as watershed or drainage basin. It can also be assumed as a smooth, clean and shiny porcelain bowl (Goodman, 2011, p. 3). Its management is like a holistic approach to manage watershed reservoir to integrate forestry, agriculture, pasture and water for sustainable management of natural resources (Pandit et al., 2007, p. 67). In broader sense, the watershed management is an effort for ensuring hydrological, soil as well as biotic regime based on which the water development projects are planned, maintained or even enhanced to prevent it from deterioration. Now, we are well-known about water and soil regimes of any watershed are affected by the changing land use pattern of that site (Biswas, 1990, p. 240).

As sub-watershed is considered as the appropriate unit of watershed management, this management approach has been followed by the government of Nepal since ninth five year plan (from 1997/98 to 2001/02) in which the sub-watershed needs to be ranked by erosion severity (DSCWM, 2015, pp. 11–14).

Watershed manager and planners need to develop common consensus in operation level with clearly defined physical boundary because not the all parts of the watershed may need urgent attention at a time. Hence, a micro or sub-watershed level development model need to be adopted to solve the watershed related problems (Poudel, 2020, pp. 126–127).

Undoubtly, watershed management project is considered in terms of reservoir sedimentation. As the problem is global in nature, its magnitude of problems varies from country to country, site to site within the same country. Though, all rivers carry sediments, their concentration varies from one to another (Biswas, 1990, p. 241).

Reservoirs are essential for storing water and providing necessary head to run turbines for a conventional hydroelectric power (Bodaly et al., 2004, pp. 347A-348A). The siltation of reservoirs is one of the most important off-site impacts of soil erosion (Sharma, 1998, pp. 121–132) that are closely linked to desertification problems like reservoir sedimentation, flooding problems, the loss of fertile foot slopes and floodplains, nutrient loss, eutrophication and the destruction of ecological habitats (Vanmaercke et al., 2011, p. 1,8,18).

The crucial ecosystem services (e.g., ecotourism, biodiversity, food production, and sediment retention) would be affected by land-use changes (Liang et al., 2017, pp. 12–13). The processes of soil erosion, sediment retention, and sediment transport are the key components and functions of the watershed area (Morgan, 2005, pp. 113–115).

Kulekhani hydro electricity plant (KHEP) is the first and only reservoir based hydropower plant in Nepal, which was accomplished in 1980s. Despite having a century long history of electricity generation and consumption, half of the population is still deprived from use of electricity and other half is facing long hours of power cut (NEA, 2011a, p. 13). Because of the increased sedimentation level, the water level of this reservoir to be increased though the precipitation has been observed declining (Ghimire et al., 2019b, p. 52). Sediment data, general knowledge and the physiographical characteristics of the river basin should be considered while planning new reservoirs (Shrestha, 2012, pp. 1–2).

Sedimentation level, as seen after measurement of sediment in the reservoir, indicates a serious threat on the life span of Kulekhani reservoir and demands urgent environmental solution. The problem seems in the reservoir but its causes and sources are around in its watershed or catchment area. For sustainable use of these natural resources, urgent need for environmental conservation and management of sub-watersheds is necessary. Due to limited available resources, it is not possible to manage a programme throughout the whole watershed area at a time (Dhakal, 2011, p. 19). To overcome this problem Robinson (1977, p. 163) suggested for estimating sediment yields by multiplying the estimated total erosion on hillslopes with a sediment delivery ratio (SDR) of InVEST model where it is generally estimated as a function of catchment area, topography and the drainage network.

Bouguerra et al. (2017, p. 4170) applied the InVEST SDR_{max} model in which it spatially examined and considered the three water erosion dynamics, which are soil loss, sediment exported and sediment retention service to prioritize critical erosion area. This model also examined the impact of management and conservation techniques on water erosion dynamics in Rmel river basin situated in the Northeast of Tunisia.

The sedimentation related studies for the Kulekhani watershed have been carried out by previous researches having different perspective, methods and results. Amatya (2004, p. ii) studied about sedimentation rate in Kulekhani for 1997 to 2002 using Geo-WEPP (Water Erosion Prediction Project) model and obtained result as mean annual soil loss rate of 52.42 t/ha/year. The result of the study showed the sediment yield less than the actual sedimentation in the reservoir before 2000 compared to that of the more after 2000. The sedimentation rate for 2002 was obtained as 50.90 t/ha/year for the watershed. As the study was focused on the soil erosion on land use types and there was found higher rate of soil erosion (95.36 t/ha/year) in cultivated land compared to that of the others. Similarly, Shrestha (2016, pp. 32, 72) studied for soil erosion and payment for sediment retention in Kulekhani watershed using Geo-WEPP model for 1989 , 2000 and 2013 and found average sediment yield on cultivated land as 84.86 t/ha/year, for forest land 2 t/ha/year, for shrub land as 4.87 t/ha/year, for grass land as 4.06 t/ha/year, for barren land 166.6 t/ha/year and built up area as 6.94 t/ha/year having total soil loss estimation 2.492 Mm^3/year from the watershed.

Ban et al. (2016, p. 323) studied about estimation of soil erosion using RUSLE (Revised Universal Soil Loss Equation) model for conservation planning from Kulekhani reservoir catchment in 2016 and obtained the result as average soil erosion rate of the watershed as 195.11 t/ha/year. They also found higher severity of soil erosion scattered all over the watershed and recommended conservation measures to be implemented to the whole catchment area. Likely, Bokan (2015, pp. 72–73) studied focusing only two sub-watersheds (Palung khola and Chitlang khola) of the Kulekhani watershed with respect to simulation of sediment yield for 2004 using SWAT model and obtained sediment yield 137.4 tons/km^2 and 57.6 tons/km^2 in Palung khola and Chitlang khola respectively. Shrestha (2012, pp. 4–18, 4–21) also studied about the sedimentation rate in the Kulekhani reservoir for 2009 to 2010 and found average annual loss rate of about 1 percent of the original capacity of the reservoir having average sediment deposition volume as 0.56 percent of the total capacity of the reservoir (85.3 million m^3). But all of the researches have not been found studied about prioritizing the sub-watersheds with respect to severity for sediment retention, sediment exporting to the stream and potential soil loss among the whole watershed area .

Hence, this study intended to use the SDR of InVEST model as an efficient tools to provide geospatial data on sediment retention ecosystem services (Srichaichana et al., 2019, p. 17) to determine the most sensitive sub-watershed area of the reservoir.

1.2. Rationale of the Study

The Kulekhani reservoir (also known as Indrasarobar) is the source of water to the Kulekhani hydropower generation of 92 MW (60MW from Kulekhani-I and 32 from Kulekhani-II) in running and 14 MW from Kulekhani-III under final stage of completion. However, out of the total available energy (6394.38 GWh), the NEA still import 37.25% electrical energy from India (NEA, 2019, p. 12,21-22). The total original storage capacity of the Kulekhani reservoir is 85.3 million m^3. Out of this total capacity, 73.3 million m^3 was allocated as live storage and the remaining 12 million m^3 was allocated as dead storage. The reservoir was designed for 50 year life span with expected life 100 years (Sthapit, 1996, p. 1) having expected annual sedimentation rate of 7 m^3/ha/year. The total reservoir storage capacity has been reduced to 59.99 Mm^3 that shows the 25.31 million m^3 sediment deposition in the reservoir up to September 2010 in 27 years period. Out of that total remaining storage capacity, only 54.6 Mm^3 being in the live storage (NEA, 2011b, p. 5; Shrestha, 2012, pp. 4–7).

It has been found about 1% annual loss in storage capacity of the Kulekhani reservoir (Shrestha, 2012, pp. 4–7), whereas the annual storage capacity loss of the reservoir at the rate of 1% is likely to be an over estimate for larger reservoirs (Biswas, 1990, p. 245).

The storage capacity of any reservoir decreases with time. If the rate of sedimentation is higher than that of the expected, the life span of the reservoir reduces and its economic effectiveness of the project becomes questionable. Out of the various causes, the rainfall characteristics and land use change pattern are considered as major affecting factors for soil erosion (Biswas, 1990, pp. 242–246).

Monsoon has shortened the days with increasing intensity and hence the Kulekhani is receiving same amount of rainfall on lesser number of days (Dhakal, 2011, p. i). Large rainfall events can generate a lot of sediment from hillslopes. The whole amount of sediments displaced from the hillslopes is not transferred to the river channels, but its large share is stored for certain duration at different levels of the slope or at the contact with the channel (Dumitriu et al., 2017, pp. 633–643). However, when a certain threshold value is exceeded or when land use changes significantly, these stored sediment can be released and can result in high sediment yields (Cammeraat, 2004, pp. 317–332).

The rate of soil degradation depends upon the rate of land-cover degradation, which is sequentially influenced by both hostile climatic conditions and land-use management changes. Furthermore, the plant cover, land use types, and intensity of land use are visible key factors for controlling the intensity and the frequency of overland flow and surface erosion (Zuazo & Pleguezuelo, 2008, p. 69).

Because of the existent of sediment load in Nepalese rivers among the highest in the world, the sedimentation is considered as the major challenges for hydropower development in Nepal (Shahi, 2015, p. 11).

The all-existing hydropower plants belong to the character of run off river (RoR) types plants except the Kulekhani power plant in Nepal. That is why, to fulfil the demand in loadsheding hours in dry season in Nepal mainly depends on this reservoir (Shrestha, 2012, pp. 5–1).

The past studies and research shows that the soil erosion or sedimentation is a natural phenomenon that cannot be fully stopped but minimized to fulfil the requirements. For this scenario, the participatory approach for planning and management of watershed resources need prioritizing sub-watersheds as an appropriate and fundamental unit for watershed management to conserve natural resources. During the watershed conservation work, due to limited budget, programs and human power, it is not possible to take the whole area of the watershed at once to implement the programs at a time. The prioritization is commonly followed by criteria having across land use, land system and socio-economic parameters using remote sensing and GIS. Hence, the prioritization of sub-watershed is considered as a vital parts of the watershed conservation which needs immediate attention (DSCWM, 2015, pp. 14–15). The above sedimentation scenario of the Kulekhani reservoir compel to put the watershed management in higher priority. Hence, the present study was intended to delineate the sub-watersheds based on drainage basin, prioritize the most sensitive sub-watersheds as well as quantifying land use land cover changes and rate of sedimentation in sub-watershed level for Kulekhani watershed that could contribute to the watershed manager, policy makers and other similar watersheds for its proper conservation and management.

1.3. Objectives of the Study

The objectives of the study are:

- To quantify land use land cover change occurred on sub-watershed level of Kulekhani Watershed in 2002, 2010 and 2018
- To estimate sedimentation rate in sub-watershed level in 2002, 2010 and 2018
- To determine the most sensitive sub-watershed area of the catchment.
- To identify the relationship between the sedimentation rates predicted through the model and collected temporal measured sedimentation rate of the reservoir.

1.4. Description of Study Area

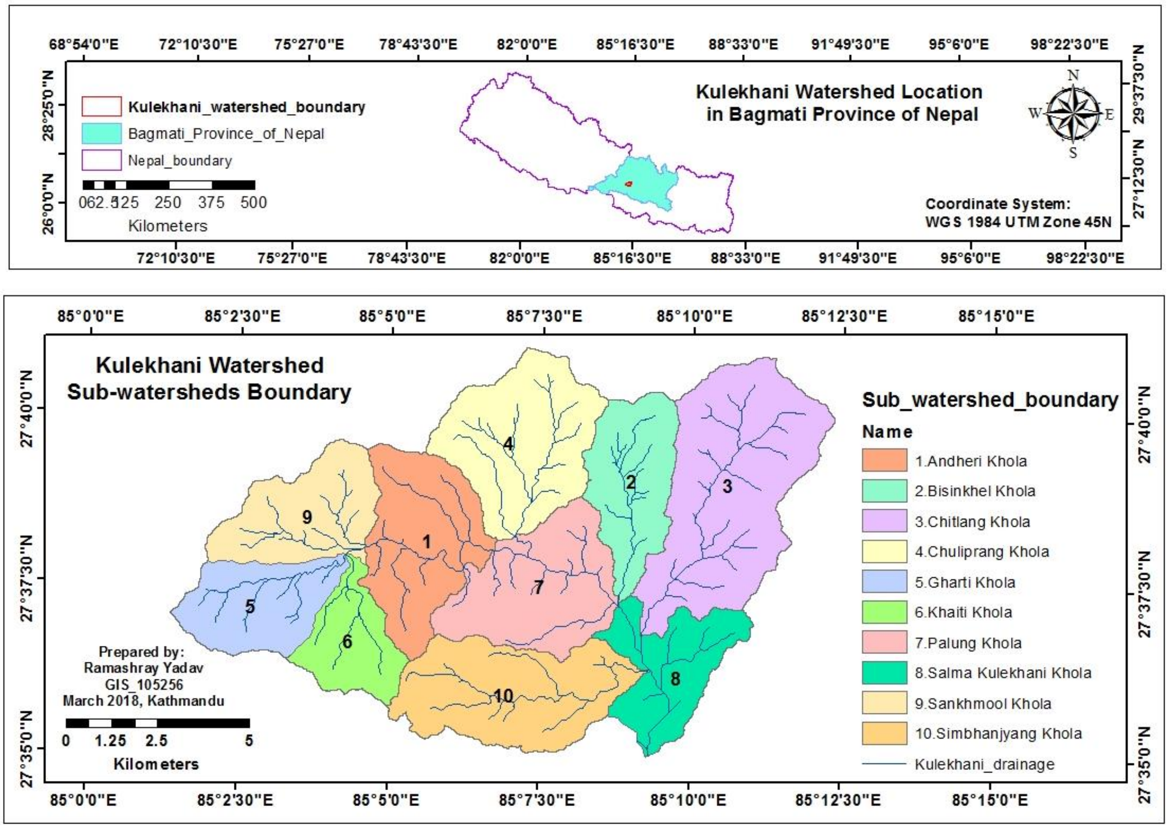
The Kulekhani watershed area of the Kulekhani reservoir was selected for this study. It is situated in Makwanpur district under Bagmati Province of Nepal. The reservoir is synonymously known as Kulekhani hydropower (only a reservoir type hydropower in Nepal) at present context. Out of total three stations, this study was limited to the Kulekhani-I. The total area of the watershed is 124.67 km^2 (12467 ha). Geographically, it is extended from 27°34'52" N to 27°40'59"N and 85°01'21"E to 85°12'20"E (Map 1.1, Map 1.2 and Map 1.3).

Geomorphologically, the area has been considered to be divided in to the Mahabharat range and the midlands valley; the first one is characterized by steep topography whereas the second one is relatively flat (Map 1.3). High variation in altitudes is considered as dominant feature of this watershed where its elevation ranges from 1534m at dam site and 2533m at peak of Simbhanjyang area (Map 1.2). Precambrian to Cambrian metamorphic rocks of the Markhu formation, Kulekhani formation, Chisapani formation, Kalitar formation and granites compose the geology of the Kulekhani watershed (Stöcklin & Bhattarai, 1977, p. 86). According to Dijkshoorn & Huting (2009, p. 10), the watershed area is covered by two types of dominated soils namely Eutric Cambisols and Chromic Cambisols.

Because of the variation in topography, the climate of Kulekhani also varies from subtropical to temperate i.e. from low lands to higher elevations. However, watershed has four distinct seasons like pre-monsoon (March to May), monsoon (June to September), post-monsoon (October to November) and winter (December to February); it has been found mainly affected by monsoon season. The average annual rainfall has been found recorded as 1863mm/year.

The river system of this watershed is as tributary of the Bagmati river that belongs to the second category in the middle mountain. The system has been created by the network of the eight rivers namely Palung khola, Sankhmool khola, Tistung khola, Bisinkhel khola, Chitlang khola, Reservoir, Simbhanjyang khola and Tasar khola where each of them represent the separate sub-watershed like Palung, Kitni, Kunchhal, Bisinkhel, Tubikhel, Simlang, Nalibang and Tasar correspondingly (Dhakal, 2011, p. 14).

Tamang, Magar, Gurung, Chhetri and Brahmin are the major ethnic groups to make a heterogeneous composition. The watershed cover total 17779 HHs having 102058 population those livelihood and daily life mainly depends on agriculture to meet their basic needs for food, fodder, wood, firewood, fiber and shelter (Sthapit, 1996, p. 1).

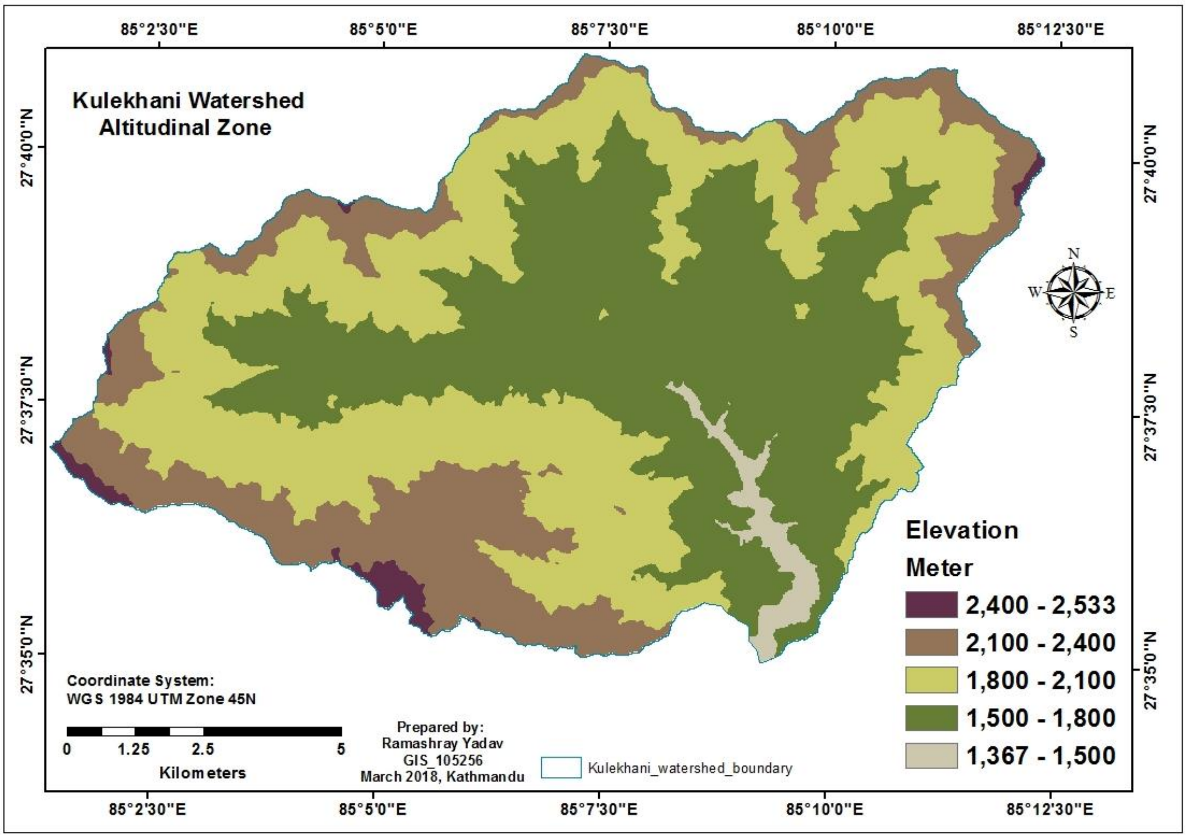


Map 1. 1 Location map of study area

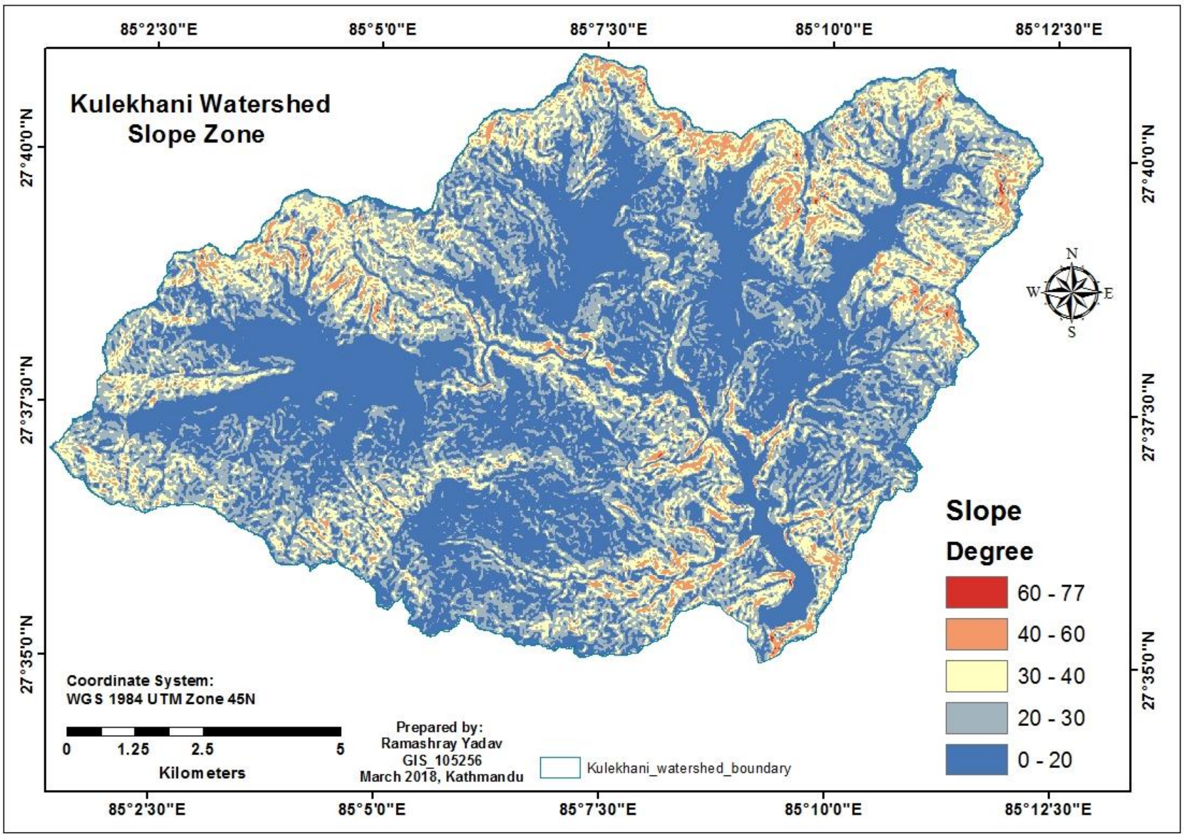
1.5. Limitation of the Study

This study is based on a InVEST SDR_{max} model. So, the relative limitations of the study could be expressed as below:

- The InVEST model relies on the USLE equation (Renard et al., 1997, pp. 14–16) that is widely used with limited scope and represent only rill/inter-rill erosion process occurred in the watershed. The sources of sediment yield like gully erosion, streambank erosion and mass erosion (landslides) has not covered within the result of the model (NCP, 2017, p. 139) of this study.



Map 1. 2 Elevation of the Study area



Map 1. 3 Slope of the Study area

The map1.2 shows the altitudinal variation within the study area where the absolute value range from 1367 to 2533 masl. The average elevation class of 300m shows maximum area seem to cover within the range of 1500 to 1800 masl where the lower elevation range (1367m-1500m) and uppermost elevation range (2400m -2533m) seem covered the minimum area of the site.

Similarly, the Map 1.3 shows the slope variation of the study area. The five classes of the slope in degree was made as to meet the requirement of data prescribed for support practice factor by previous researchers (Table 1.1, Appendix-2 and Pokharel & Thapa, 2018).

Table 1. 1 Name and area of delineated sub-watersheds within Slope Categories

Sub-watersheds		**Slope Category in Degree**					**Total area**
ID	**Name**	**0 - 20**	**20 - 30**	**30 - 40**	**40 - 60**	**>60**	**Ha**
1	Andheri Khola	628.8	435.0	219.1	29.2	0.1	**1312.1**
2	Bisinkhel Khola	499.3	274.2	143.9	64.8	0.6	**982.7**
3	Chitlang Khola	850.1	813.3	521.9	114.9	2.5	**2302.6**
4	Chuliprang Khola	767.9	497.2	212.8	49.6	0.4	**1528.0**
5	Gharti Khola	389.4	318.7	169.2	19.8	0.0	**897.1**
6	Khaiti Khola	301.6	245.6	101.6	12.7	0.0	**661.5**
7	Palung Khola	686.8	446.8	182.1	36.0	0.2	**1351.8**
8	Salmakulekhani Khola	362.2	295.3	180.9	53.1	1.3	**892.8**
9	Sankhmool Khola	386.9	331.3	240.9	62.3	0.3	**1021.7**
10	Simbhanjyang Khola	783.6	490.0	194.7	48.4	0.0	**1516.8**
Total Area_ha		**5656.5**	**4147.3**	**2167.0**	**490.9**	**5.3**	**12467.0**
Total Area_%		**45.37**	**33.27**	**17.38**	**3.94**	**0.04**	**100**

Chapter-2: Literature Review

This chapter is related to reviewing relevant literatures for the study under major heading of land use land cover (LULC) classification and methods for estimating sedimentation rate in the watershed.

2.1 Land use land cover classification and change detection

LULC change is global phenomenon that is considered as accurate and updated information for detailed eco-system studies having hydrological modeling (Usman et al., 2015, p. 1503). Land cover is defined as physical condition and biotic components of the earth surface; whereas the land use is defined as the modification of the land cover based on human needs and actions (Prakasam, 2010, pp. 150–151). Similarly, the land use land cover change detection is known as identifying these modifications over time series (Anderson, 1977, pp. 143–152). LULC data is highly recognized to be used for water resource management through its wide application in hydrological modeling studies (Schilling et al., 2008, p. 10).

2.1.1 Selecting Land Use Land Cover Classification Method

There is found their own advantage and disadvantage with different classifiers for land use land cover classification and selection of the best suitable depends on a variety of factors like complexities of methods for processing, availability of software and availability of image data sets (Lu et al., 2004, p. 730). Conventional LULC classification follows mainly two methods. They are:

a) **Unsupervised Classification:** It offers number of classes based on the natural grouping present in the image values having the cover type close together in the quantity space.

b) **Supervised Classification:** It provides the classes based on the training samples taken to guide category by assigning spectral values to achieve appropriate informative class. Out of total methods under supervised classification approach, the maximum likelihood classifier deals the highest accuracies. It examines the likelihood function of a pixel for each of the categories with the highest probability having assumptions that the training statistics for each class have a normal distribution (Rajalakshmi et al., 2013, pp. 66–69). Hence, this method was used in this study.

2.1.2 Land Use Land Cover Classes

According to IPCC (2003, p. 2.4-2.5), land use is renowned as crop land and settlements whereas the land cover contains forest land, grass land, wetlands. Based on these land use land cover, the six land categories have been proposed. They are:

i) **Forest land**: It contains all land with woody vegetation having threshold used to define forest land category.

ii) **Crop land**: It contains arable land, tillage land and agro-forestry system where vegetation falls below the threshold.

iii) **Grass land**: It contains range lands and pasture lands that does not belong to crop land. It also includes wild lands, recreational and silvi-pastural systems.

iv) **Wetlands:** It includes the area covered or saturated by water for whole year or partial time, reservoir but not including forest land, crop land, and grass land or settlement category.

v) **Settlements:** It contains the all developed lands having transportation, infrastructure and human settlements of any types and size.

vi) **Other land**: It contains bare soil, ice, rock and all other unmanaged area those are not involved in other five categories above.

Based on the purpose and requirement, it is good practice to combine or disaggregate the existing land classes of this system of land use classification in order to use. In spite of necessity of standard classification system, none of the current classification have been internationally accepted (FAO, 2016, pp. 4–6). The above broad categories give us a framework for the further sub-division, the activity, management regime, climatic zone and ecosystem types as we feel necessary to meet our needs of the methods (IPCC, 2003, p. 2.6; Congalton, 1988, p. 42). Following the idea, five LULC classes namely forest land, agriculture and built up, grass and shrub land. barren land and water bodies have been adopted in this study in local context.

2.2 Accuracy Assessment for Land Use Land Cover Classification

Accuracy assessment is considered as a vital step in the process of analyzing remote sensing data in which error matrix or confusion matrix or contingency matrix has been widely accepted method for reporting error of raster data (Nilsson, 1998, p. 1,11).

2.2.1 Sample size and Sampling Scheme for Accuracy Assessment

A lowest number of sample need be had that is yet a critical to maintain a large enough sample size so that the any analysis performed to be statistically valid. Traditional thinking of sampling usually does not apply due to the large number of pixels in a remotely sensed image. Therefore, at least 50 number of sample size for each class should be kept as a good rule of thumb. If the areas surpasses 500km^2 or the number of category is more than 12, then it should be at least 75-100 sample points per classes (Congalton, 1991, pp. 43–44).

Regarding the sampling scheme, simple random without replacement and stratified random sampling have been found provided adequate results. The use of kappa analysis assumes a multinomial sampling model; it is completely satisfied by only simple random sampling scheme. Furthermore, simple random sampling has been always performed adequately in the agriculture, range land and forest area and can be used in all situations. So, for using kappa coefficient in confusion matrix, a random sampling scheme should be chosen (Congalton, 1988, pp. 598–599; Congalton, 1991, p. 45).

2.2.2 Error Matrix for Accuracy Assessment

Error matrix is considered as truly representative for the entire classification. In case of this error matrix, simply, it is not a matter of correct or incorrect, but a matter of which categories are being confused as this confusion can be adequately represented by sufficient sample size. Confusion or error matrix is presently at the fundamental of the accuracy assessment literature. It is an easily interpretable guide to the overall accuracy of the classification. Although, there is no set standard method but a fair degree of consensus about the general format that accuracy assessment and reporting should proceed (Foody, 2002, pp. 187–188).

In a tabulated results of accuracy evaluation of the error matrix of land use land cover classification, the diagonal elements of the matrix represents counts correct and the kappa coefficient (K statistics) is adopted by the remote sensing community as a measure of accuracy for the thematic classification as well as for individual category (Rosenfield, 1986, pp. 223–226).

According to Nilsson (1998, pp. 12–13), the data in the matrix is listed in the columns and the classified data in the rows in which the main diagonal of the matrix offers the correctly classified pixels. There are two basic measures within the accuracy assessment. Those can be listed as Kappa coefficient (K statistics) and Overall accuracy.

Overall Accuracy:

The overall accuracy is calculated by dividing the correctly classified pixels or sum of values in the main diagonal by the total number of pixels checked.

Overall accuracy = correctly classified pixels (sum of values in the main diagonals)/Total number of pixels checked.

Under the overall accuracy, there are other two approaches of accuracy for individual class. They are:

Producer's accuracy and User's accuracy

The producer's accuracy is calculated by dividing the number of correct pixels in one class by the total number of pixels from reference data (i.e. column total). It can be presented as in equation (1) below:

Producer's accuracy (%) = 100% - error of omission (%). ……………….. (1)

Where,

Lower the producer's accuracy, the more existent of the error of omission.

Likely, user's accuracy is derived by dividing the correctly classified pixels in a class by the total number of pixels classified in that class. It can be presented as in equation (2) below:

User's accuracy (%) = 100% - error of commission (%)………………………….. (2)

Where.

Lower the user's accuracy, the more existent of the error of commission. It is a measure of reliability of the map. The critical value for required accuracy should be 85 percent (Nilsson, 1998, p. 21).

Kappa Coefficient (K statistics):

The word "Kappa" was born from psychiatric diagnosis with completely at random sampling that agrees obviously a purely chance result (Cohen, 1960, p. 18). It is a measure of overall agreement of a matrix. It is derived as the ratio of the sum of diagonal values to the total number of cell counts values in the matrix. The K statistics in a family of bivariate agreement is as in equation (3) below:

Agreement = 1- (Observed disagreement/Expected disagreement) …………………… (3)

Where,

The K statistics would be 0 for chance agreement, 1 for perfect agreement and –ve for less than chance agreement (Nilsson, 1998, p. 18).

Other researchers have also been found expressed knowledge and information about the error matrix and the K statistics. According to Adam et al. (2013, p. 3), in error matrix, the diagonal represents sites classified correctly according to reference data and off-diagonal are misclassified. They proposed the formulation as in equation (4) below:

Kappa = Observed accuracy- [(Chance agreement/ (1- Chance agreement)] ……….. (4)

Where,

Observed accuracy = determined by the diagonal in error matrix

Chance agreement = Incorporated by off-diagonal in error matrix

Likely, according to Bharatkar & Patel (2013, p. 81), overall accuracy is the most common error estimate whereas the K statistics is the measure of agreement of accuracy. The K statistics could be computed as in equation (5) below:

K = (Po – Pc)/ (1 – Pc) ……………………………………………………………….. (5)

Where,

Po = Proportion units that agree = overall accuracy

Pc = Proportion of units for expected chance agreement

They also stated that the general range for kappa values as If K<0.40 i.e. a poor kappa value, If o.40<K<0.75 i.e. a good kappa value and If K>0.75 i.e. an excellent kappa value. The kappa value 0.842 for maximum likelihood classifier indicates better classification for the land use map.

Similarly, according to Carletta (1996, p. 252), the K statistics measures pairwise agreement among category that is expressed as in equation (6) below:

K = [P (A) – P (E)] / [1 – P (E)] ………………………………………………………….. (6)

Where,

P (A) = The proportion of times that agrees

P (E) = The proportion of times that we would expect them to agree by chance.

Krippendorff (2004) stated that in association between two variability, the content analysis generally think to be K>0.80 as good reliability and 0.67<K<0.80 allowing tentative conclusion to be drawn.

2.3 Sedimentation and method of Estimating Sedimentation rate

Sedimentation is a process of depositing eroded particles of rock through transportation mainly by moving water relatively from higher elevation to lower elevation (Cook et al., 2014, p. 14).

2.3.1 Sedimentation management for reservoir

Sediment yield of a watershed is gained by measuring the magnitude of sediment leaved a watershed along the stream over time. Likely, the sedimentation rate in the reservoir shows that how much erosion has taken place in a watershed upstream and the sediment trap is considered as the efficiency of the reservoir (Morgan, 2005, pp. 103–104).

Reservoir sedimentation is globally faced issue for its sustainable management (Sangroula, 2007, p. 1); which is one of the most important off-site effects of soil erosion in the siltation of reservoirs, as it is directly connected with water availability (Vanmaercke et al., 2011, p. 9). Sedimentation management is considered as a vital factor for sustainable water resources. The strategies to control sedimentation can be broadly grouped into main three categories: i) Reduce its incoming to the reservoir ii) Prevent its deposition in the reservoir or iii) Evacuate the deposited sediment from the reservoir (Sangroula, 2007, p. 4). In general, we can measure the eco-system effects on sediment yield and flooding only in a small catchment and for small rainfall events (Brauman et al., 2007, pp. 6–7, 6–8).

Although, the reservoir with low capacity could be emptied and refilled quickly by using flushing to release sediment downstream through low level outlets, it needs higher cost of management and also inconvenient for larger reservoir. Instead, soil erosion control and sediment retention structure upstream does not require low level outlets or drawdown that might be applicable to all sizes of reservoirs (Wang et al., 2018, p. 2; Sangroula, 2007, pp. 6–7).

2.3.2 Method of Estimating Sedimentation Rate within the Watershed

Average annual sheet erosion for long-term period can be predicted by using Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1965, p. 3) that provide rate of soil erosion for each feasible alternative combination of crop system, land management practices having specified soil types, rainfall pattern and topography within specified limits. The eroded soil materials from a site might be dumped in the field boundary, terrace channels, depressional area or on flat area or on vegetated area traversed flow before reaching a river or stream. Further, the sediment dropped nearby its place of origin is not directly linked for water quality control (Wischmeier & Smith, 1978, p. 3).

Hydrological ecosystem service delivery highly depends on the characteristics of the watershed where the climate, land use land cover and topography rule over the guidelines for providing services (Brauman et al., 2007, p. 6.7-6.8). Therefore, it needs an approach that should have function of sediment retention service referred to the capacity of ecosystem for regulating the quantity of eroded sediment reaching to the stream network so as to provide benefits like maintaining soil and water quality and reservoir management (Bogdan et al., 2016, pp. 23–25).

Out of various simulation model used in science and practice to incorporate hydrological ecosystem services in decision-making process, the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) model was chosen in the present study. Because, this model is more user-friendly and requires fewer input data with lower training effort to apply the model compared to the others model like SWAT (soil and water assessment tool), RIOS (resource investment optimization system), Geo-WEPP (water erosion prediction project). It is also simple and fewer time consuming for pre-processing of input data compared to the others complex tools (Lüke & Hack, 2017, pp. 12–14).

2.3.3 InVEST Software

The InVEST is a standalone software that was developed by natural capital project (NatCap) to assess the impacts of changes in different ecosystems services due to land use land cover changes for calculating result annually based on land use land cover information. It needs the input data in the form of georeferenced raster or shape file and biophysical table containing coefficients for each LULC types for providing the results at local, regional or global scale (Vigerstol & Aukema, 2011, pp. 2405–2406). Though, the USLE model is considered as base for the InVEST modeling, it doesn't have sediment retention prediction function in itself (Cohen et al., 2011, p. 7,28).

Out of about 11 models having in it (Cohen et al., 2011, p. 24), the sediment delivery ratio (SDR) model was selected to meet the purpose of the present study. The SDR model was used to estimate overland sediment generation and its delivery to the stream. It offers the ecosystem of sediment retention within a watershed that is considered as significant for water quality and reservoir management. This model offers three major output results at a time with quantity and maps for several ecosystems. They are: amount of annual soil loss calculated with the RUSLE equation, amount of sediment exported to the stream and amount of sediment retained at sub-watershed level (Lüke & Hack, 2017, pp. 7–8).

The input data required to run the model are DEM, rainfall erosivity (R), soil erodibility (K) factor, land use land cover, watershed boundary map, biophysical table, threshold flow accumulation, drainage raster (optional), barselli k_b parameter, barselli Ic_o parameter and SDR_{max} value (NCP, 2017, p. 142). The detail information on input data preparation have been illustrated in chapter-3, methodology. Besides these, the detail on crop management factor (c-factor) and support practice factor (p-factor) referenced from literature review for the study have been given in Appendix-1 and 2.

Crop Management factor (C-factor):

It is the crop and management factor that shows the relative effectiveness of soil and crop management system with respect to prevent soil loss. It is considered as a ratio for comparing soil loss from a land under a specific crop management system to the corresponding loss from continuously fallow and clean tilled land (Stone & Hilborn, 2012, pp. 1–2). Minimum tillage or no tillage practice are considered to be more effective to reduce soil erosion by water (Nyakatawa et al., 2001, p. 213). The crop management factor obtained from different literature review for referencing has been presented in the Appendix-1.

Support Practice Factor (P-factor)

Initially, the p-factor was denoted as erosion control practice factor (Wischmeier & Smith, 1965, p. 46). This factor in RUSLE is known as the ratio of soil loss with a specific support practice to the respective soil loss with straight row up and downslope tillage. It also shows the control practice to reduce erosion potentialities of the runoff influencing on drainage pattern, runoff concentration, runoff velocity and hydraulic forces exerted by runoff on the soil. It mainly includes the effects of contouring, strip cropping or terracing (Kim, 2006, p. 52). The support practice factor obtained from different literature review for referencing has been presented in the Appendix-2.

Chapter-3: Methodology

This chapter describes about all the materials and methods have been used to conduct the study as well as procedures those were undertaken in this study.

3.1 Materials

Temporal satellite imagery data, GIS data layer and other collateral data were interpreted and maps showing changes were prepared. Lastly, various thematic maps such as rainfall erosivity index (R factor), soil erodibility (K) factor and land use land cover were integrated to run InVEST SDR_{max} model.

3.1.1 Data

There were used both spatial as well as numerical data having different level of processing in this study. Topographic data such as elevation and slope were derived from digital elevation model (DEM). Orthophoto images from Landsat 5, Landsat 7 ETM+ and Landsat 8 were used for land use land cover data.

3.1.1.1 Satellite Imagery

Satellite imagery of Landsat 7ET M+, Landsat 5 and Landsat 8 having path 141 and row 41 were downloaded from USGS home page (https://earthexplorer.usgs.gov/) for 2002, 2010 and 2018 respectively. The acquired date of these satellite images were selected almost same to match each other for getting more accuracy in land use land cover change detection as far as possible. The acquired date for all the images was last week of the month from 25th to 31st October of the year. The Landsat 5 and Landsat 7ET M+ having band1 to 5 and band7 as well as Landsat 8 having band2 to band7 with resolution 30m were used for the study except panchromatic band8 only for Landsat 7ET M+ and Landsat 8 with 15m resolution. The metadata of the satellite imagery has been presented in Table 3.1(Map 4.1, Map 4.3 and Map 4.5).

Table 3. 1 Metadata of Landsat images

Landsat	Path	Row	Acquired date	Bands used and wavelength (Micrometer)	Resolution
LANDSAT 7ET M+	141	041	27 October, 2002	B1: 450-520 (Blue)	30m
				B2: 520-600 (Green)	
				B3: 630-690 (Red)	
				B4: 770-900(NIR)	
				B5: 1.550 - 1.75 (SWIR1)	
				B7: 2.090 – 2.35 (SWIR2)	
				B8: 520 – 900 (Panchromatic)	15m
LANDSAT 5	141	041	25 October, 2010	B1: 450-520 (Blue)	30m
				B2: 530-610 (Green)	
				B3: 630-690 (Red)	
				B4: 780-900(NIR)	
				B5: 1.550 - 1.75 (SWIR1)	
				B7: 2.090 – 2.35 (SWIR2)	
LANDSAT 8	141	041	31 October, 2018	B2: 450-510 (Blue)	30m
				B3: 530-590 (Green)	
				B4: 630-670 (Red)	
				B5: 850-880(NIR)	
				B6: 1.570 - 1.650 (SWIR1)	
				B7:2.110 – 2.290 (SWIR2)	
				B8: 500 – 680 (Panchromatic)	15m

Source: (USGS, 2018)

The RGB bands for Landsat 7 ETM+ image (Map 4.1) and Landsat 5 (Map 4.3) were set as 3,4 and 5 respectively as common Landsat bands RGB composite guideline provided by USGS (2020). Similarly, the RGB bands for land sat 8 image (Map 4.5) was set as 2,4 and 6 respectively as common Landsat bands RGB composite guideline provided by USGS (2020). These RGB band composite was experienced appropriate to assign the training sample for LULC classification of the study area.

3.1.1.2 Digital Elevation Model

Digital Elevation Model (DEM) is a vital data for raster analysis and the most communal parameter in GIS application. It has main uses like generating contour lines, slope and drainage basin extraction of a particular area. The DEM with 12.5m resolution was downloaded from the ALOS PALSAR radiometric terrain correction website (https://search.asf.alaska.edu/#/) for the study area. The metadata of downloaded DEM has been presented in Table 3.2.

Table 3. 2 Metadata of downloaded DEM

Specification and projection	Details
Raster data	AP_16405_FBS_F0540_RT1_HH.tif
Projection	WGS_1984_UTM_Zone_45N
Acquired date	February 21, 2009
Raster format	TIFF
Resolution	12.5m
Linear unit	Meter
Datum	D_WGS_1984
Central meridian	87
False easting	500000
False northing	0
Scale factor	0.9996
Pixel depth	16 bit
Source	generic

Source: (ASF, 2009)

3.1.2 Equipment and software

Required software were used for image and statistical analysis including simple equipment in the present study.

The Garmin GPS 64s was used for checking and verifying the pour points of the dam site and others areas within the Kulekhani watershed. The software used for the completion of this study have been listed as in the Table 3.3. The ArcGIS10.6 software was used to create slope and delineating watershed as well sub-watersheds of the study area through spatial analyst tool and Arc Hydro Tool10.6 extension to this software. It was also used for layout of maps and further processing of data obtained as output from ERDAS Imagine 2018 environment and land use change detection. Likely, the ERDAS Imagine 2018 was used for image pre-processing and land use classification from the satellite image. The Microsoft Excel 2016 was used for data sorting, processing, simple statistical analysis and calculating land use wise area. Similarly, the Arc Hydro Tool10.6 was used as extension of ArcGIS10.6 to delineate watershed boundary and drainage basins. In same way, the InVEST SDR_{max} model was used to estimate sediment retention, sediment export and total potential soil loss at sub-watershed level ton per hectare per year.

Table 3. 3 Software used for completion of the study

S.N.	software	Purpose
1	ArcGIS10.6	spatial analysis and mapping
2	ERDAS Imagine 2018	Image processing and land use classification
3	Microsoft Excel 2016	Statistical calculation
4	Arc Hydro Tool10.6	Delineating watershed/sub-watershed boundary and drainage basin of the stream
5	InVEST software	To estimate sediment retention, sediment export and total potential soil loss at sub-watershed level
6	PAST software	Calculate correlation coefficient
7	QGIS version 2.12.2	To extract raster value in to the field as attribute of the polygon .shp automatically.

3.2 Methods

The methodology of the research comprised three types of major works namely data collection, preparation and data analysis. Those works could also be classified as pre-field work, fieldwork and post field works. Pre-field work was carried out for scheduling and coordinating for the works, collecting satellite images and downloading DEM for the study area. After then, the pre-processing of the downloaded images, parametric data collection for the model, watershed/sub-watersheds boundary delineation based on the drainage basin were performed. During the field work, the observed or measured data on sedimentation rate of the reservoir was collected as well as observation of the land use patterns and other land system in the watershed area was also done having interaction with concerned officers and local people. Under the data analysis, the land use classification, accuracy assessment for the land use classification for the three time line 2002, 2010 and 2018, parameter preparation required to run the InVEST SDR_{max} model, interpretation of the output obtained from running the model, land use change detection and comparison of the sedimentation rate between obtained from running the model and observed sedimentation rate of the reservoir was performed. The methodological flow chart of the study has been shown in the Figure 3.1. The flowchart explains the relationship of all elements in the form of input, process and output required to achieve the result of the study.

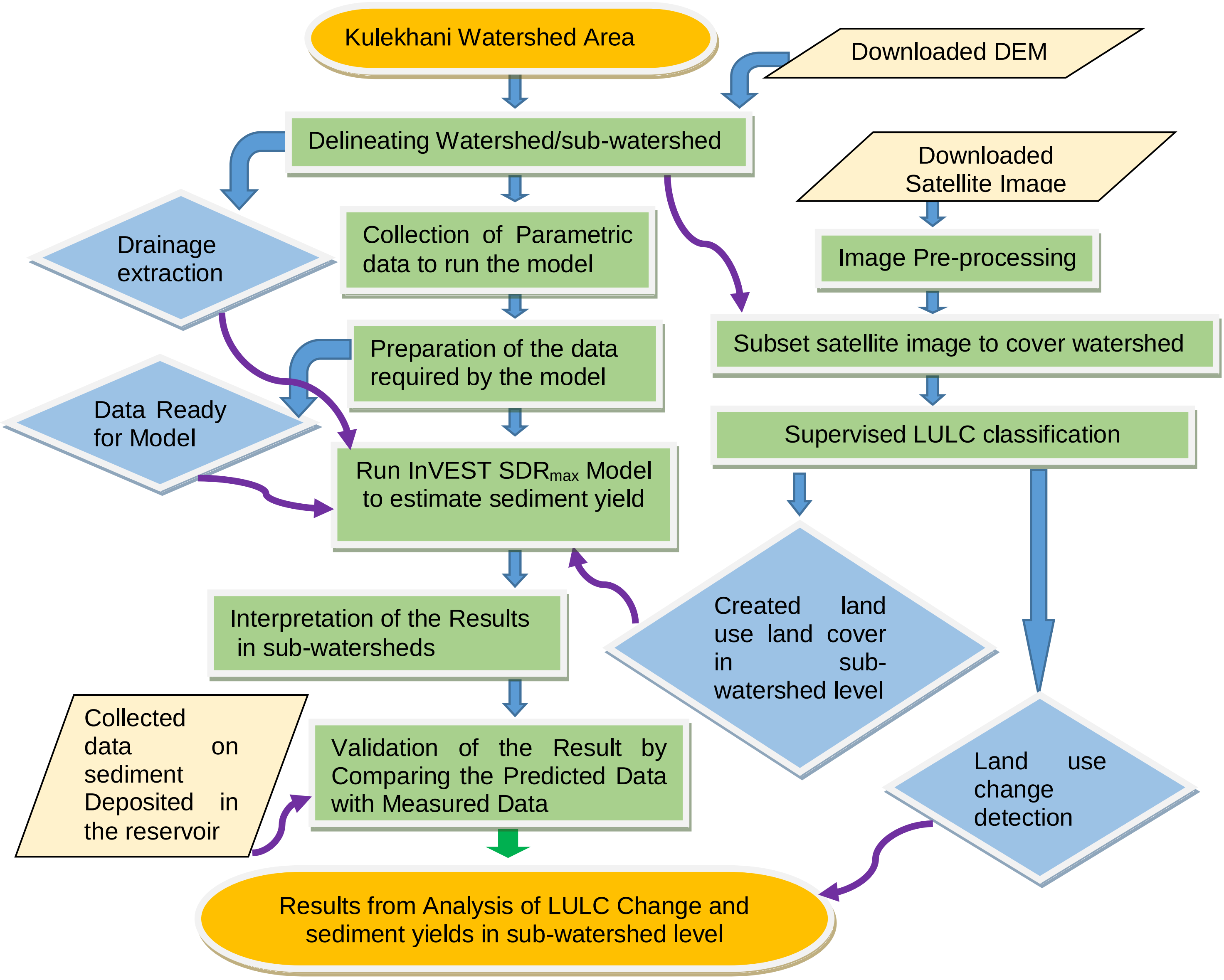


Figure 3. 1 Methodological flowchart for the study

3.2.1 Pre-Field Work

3.2.1.1 Delineating Watershed and Sub-watersheds Boundary of the Kulekhani Watershed

As watershed is a hydrological unit in which runoff causing from precipitation flows a single point into a large stream, river, lake, pond or reservoir that is considered as an ideal unit for managing natural resources like land, water and vegetation (Suryakant, 2017, p. 70), these factors were considered while delineating the watershed boundary.

The sub-watersheds boundary for the study area was delineated applying Arc Hydro Tool 10.6 as an extension of ArcGIS 10.6 using DEM with resolution 12.5m. To delineate the boundary of the sub-watershed, the following sequential process were followed under terrain processing tool of Arc Hydro Tool10.6 (Figure 3.2):

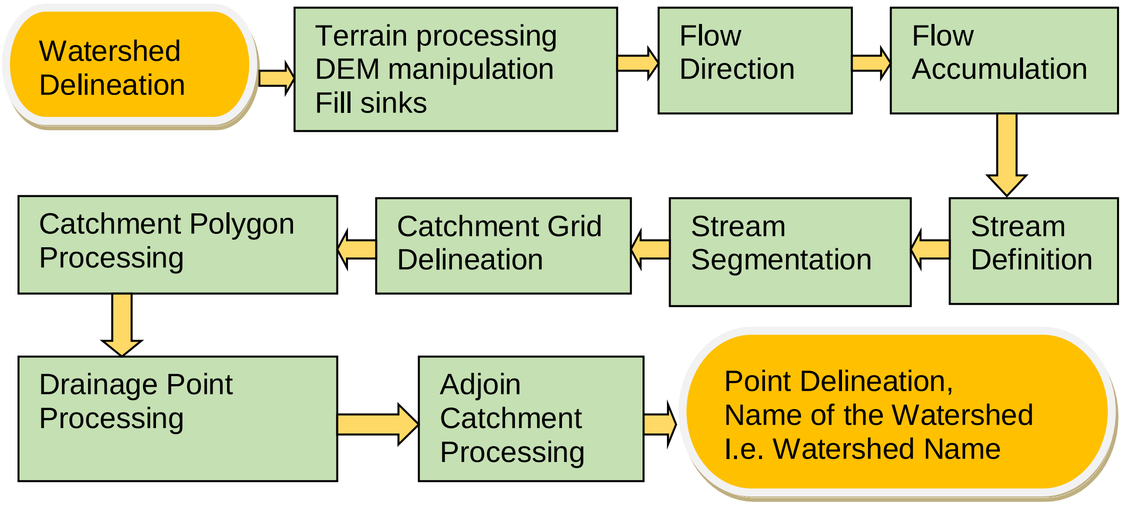


Figure 3. 2 Process of watershed delineation

The sub-watershed boundary was delineated on the basis of drainage basin, flow accumulation and adjacent boundary of the polygon created around and or within the drainage. Some previous researchers were found defined the number of sub-watersheds in the Kulekhani watershed. Four researchers, out of stated total, clearly defined the number and name of the sub-watersheds as six, eight, nine and fourteen; the others were found just focused the name of the kholas belong to the Kulekhani river system. The total area of the Kulekhani watershed has also been found different stated by them that may be due to using different software and DEM resolution in their processing (Table 3.4).

In the present study, the Kulekhani watershed was divided in to ten sub-watersheds based on the drainage basin, previous literature review and field expert consultation for better representation of the erosion problems within the watershed. The area of the sub-watersheds varies from 661.5 hectare to 2302.6 hectare being total area of the watershed as 12467 hectare (Table 1.1).

Table 3. 4 Sub-watersheds Details for Kulekhani Watershed Stated by Previous Researchers

S.N.	Area (KM^2)	No. of Sub-watershed defined	Use of DEM	Use of software	Research (Sources)
1	125.0	Six sub-watersheds	30m	Hec GeoHMS in ArcGIS10	(Shrestha et al., 2014)
2	117.2	Focused as two major tributaries Palung khola and Chitlang khola	SRTM 30m	Arc SWAT in ArcGIS10.2	(Bokan, 2015)
3	126.0	Fourteen sub-watershed	30m	GeoWEPP	(Amatya, 2004)
4	126.0	Focused as two major tributaries Palung khola and Chitlang khola	N/A	N/A	(Ghimire et al., 2019; Yogacharya, 2008)
5	124.2	N/A	N/A	N/A	(Pradhan et al., 2012)
6	126.0 and 152.1 as extended	Nine sub-watershed	N/A	N/A	(Shrestha, 2016)
7	124.8	Focused as three major tributaries Tasar, Bisinkhel and Chitlang khola	N/A	ArcGIS10.2	(Ban et al., 2016)
8	124.9	Eight sub-watersheds	N/A	N/A	(Dhakal, 2011)
9	125.0	Focused as major tributaries Tasar, Bisinkhel and Chitlang khola	N/A	N/A	(Sthapit, 1996)
10	126.0	Focused on six major kholas	N/A	N/A	(Dhital et al., 2014)
11	123.7	N/A	N/A	N/A	(Aryal et al., 2019)

Out of total area, 45% area belong to 0^0 to 20^0 slope, 33% belongs to 20^0 to 30^0 slope and remaining 21% to more than 30^0 slope within the watershed (Table 1.1 and Map 1.3). The area was also calculated in slope percent for matching the area with support practice factor prescribed by the previous researchers that shows 72% of the total area belonging to greater than 26.8% slope (Appendix-3).

3.2.2 Field Work

During the fieldwork, the dam site and others land used area were observed. The measured sedimentation rate data for the Kulekhani reservoir was obtained from the NEA office Durbar Marg, Ratna Park Kathmandu and local office at Markhu. After then, field observation was carried out to check, verify and notice the farming system adopted in the agricultural lands within the watershed area. Similarly, the delineated sub-watersheds boundary was shared with the local stakeholders, officers and experts and interacted to make understanding about agriculture crops and forest vegetation types in the area that could help on selecting crop management factor (C-factor) and land use practice support factor (P-factor) based on information from different but appropriate literatures.

3.2.2.1 Sedimentation Data for Kulekhani Watershed Reservoir

The data on sedimentation rate in Kulekhani reservoir was collected from the NEA office through NEA sedimentation survey report (2003, 2011 and 2018). The measured data on sedimentation of Kulekhani reservoir for 2002, 2010 and 2018 was found as 0.06 million m^3, 0.001 million m^3 and 0.06 million m^3 respectively. The dry density of sediment record for Kulekhani reservoir has been found adopted as 2.60 ton/m^3 (Shrestha, 2012, pp. 8–12). The sedimentation rate shows increasing trend up to year 1994 and decreasing trend afterwards (Table 3.5).

Table 3. 5 Sediment deposition data from 1982 to 2002, 2010 and 2018

Year	Sediment Deposition			Reservoir Capacity		
	Total (Mm^3)	Average (m^3/ha)	Cumulative Average (m^3/ha)	Total (Mm^3)	Live Storage Volume (Mm^3)	Dead Storage Volume (Mm^3)
1982	0.000	0.000	0.00	85.30	73.30	12.00
Till, Mar 1993	2.200	16.000	16.00	83.10	72.30	10.80
Dec. 1993	4.800	384.000	46.00	78.30	70.70	7.60
Sept.1994	10.500	840.000	107.00	67.80	61.30	6.50
Nov. 1995	4.000	320.000	122.00	63.80	68.00	3.00
Dec.1996	0.400	32.000	116.00	63.40	66.00	2.80
Nov. 1997	0.200	16.000	110.00	62.19	55.55	7.60
Nov. 1998	0.560	44.800	106.00	62.63	55.20	7.42
Nov. 1999	0.660	52.800	99.91	62.64	55.66	6.98
Nov. 2000	0.260	20.800	95.73	62.38	55.58	6.80
Nov. 2001	0.020	1.600	91.03	62.36	55.57	6.79
Nov. 2002	0.060	4.800	86.92	62.30	55.56	6.74
Sept. 2010	0.001	0.069	74.38	59.99	56.21	3.78
April.2018	0.060	-	-	61.66	-	-

Source: (NEA, 2003; NEA, 2011b, p. 5; NEA, 2018, p. 8; Upadhyaya, 2005, p. 16)

3.2.3 Data Analysis

The imagery data obtained from downloading were preprocessed and analyzed through using different relevant software like ArcGIS10.6, ERDAS Imagine 2018 and Arc Hydro Tool10.6 to get result required to meet the objectives of the study. The obtained numerical data were cleaned, compiled and analyzed through using Microsoft excel 2016. The brief explanations have been given as below:

3.2.3.1 Image Processing

Under the image processing the following works were performed:

3.2.3.1a Topographic Correction of the Images

The topographic correction was performed for the Landsat 7 ETM+ image using the topographic normalize tool under radiometric available in ERDAS Imagine 2018. The band wise topographic correction was done from band1 to 5 and band 7 with image characteristics information as sun azimuth value 149.53114845 and sun elevation value 44.68141390 having in text file of the downloaded image. To get the real correction, the DEM was used having resampled to 30m resolution for band1 to band5 and band7. This correction is done for the error in the image due to shadow effects in the mountainous region. Though, pre-processed imagery are freely available for various forest mapping works (Bodart et al., 2011, pp. 557–558), sometimes, the topographic shadow of irregular mountain becomes major obstacles to accurate land use classification (Pimple et al., 2017, p. 1). This correction was not needed for the Landsat 5 and Landsat 8 after visual interpretation and having found no major conflict in radiometric reflectance in land use classification.

3.2.3.1b Layer stacking of the Images

Layer stacking is the function of combining (making fusion of) bands of the image together to make a single image. It was performed by layer stack tool under spectral tool available in ERDAS Imagine 2018 within the similar spatial resolutions (30m) of the Landsat bands such as bands 2 to 7 for Landsat 8, bands 1 to 5 and 7 for the Landsat 7ETM+ and Landsat 5 image.

3.2.3.1c Atmospheric Correction of the Images

The atmospheric correction is processing of an image in which the influence of the atmosphere (primarily from water vapor) is removed or significantly decreased (Wang & DeLiberty, 2005, p. 1). Atmospheric haze causes a visibility to drop and modifies the spectral signatures of land cover class and decreases classification accuracy too (Ahmad & Quegan, 2016, p. 845). Furthermore, in haze, the solar radiation is affected by absorption and emission phenomena held during downwards and upwards trajectory detected by the satellite sensors that leads to distortion of the ground radiometric properties such as reflectance (López-Serrano et al., 2016, p. 1). Hence, the haze and noise reduction for the Landsat 7 ETM+ and only haze reduction for the Landsat 5 imagery was carried out using radiometric tool available in ERDAS Imagine 2018, whereas this correction was not required for the Landsat 8 image for this site. Though, the atmospheric correction is not necessary for the image classification with maximum likelihood classifier and training data having a single date image (Song et al., 2001, p. 232), it was carried out only for Landsat 5 and Landsat 7 ETM+ images to get a bit improved accuracy in classification and change detection.

3.2.3.2 Creating Subset of Image

Subset images for all the Landsat images selected for 2002, 2010 and 2018 were created using ERDAS Imagine 2018 having available tools like inquire box and subset image. The subset images were created a little greater size than that of the actual area of the watershed boundary so as to proper representation of the boundary while running the InVEST SDR_{max} model.

3.2.3.3 Land Use Classification

The supervised classification method with maximum likelihood was applied using ERDAS Imagine 2018 for land use classification of the images for 2002, 2010 and 2018 having five major classes namely **forest land, agriculture and built up, grass and shrub land, barren land and water bodies**. The land use class system should be mutually exclusive, exhaustive and hierarchical or any area to be classified should fall into one and only one category or class (Congalton, 1991, p. 42) and have to be used a classification scheme containing taxonomically clear definition of the land use class (Kim, 2016, p. 184). Hence, in the present study, the land use/land cover classification is compatible with the land use/land cover classification guidance provided by the (IPCC, 2003, p. 2.5-2.6). These five categories of land use/land cover classification for the Kulekhani watershed was also adopted by Ban et al. (2016, p. 326) in their study about estimating soil erosion in the Kulekhani watershed. Though, the surface characteristics of the two classes agriculture and built up are different in nature, they were combined together due to unavailability of higher resolution images, comparatively less area of built up almost covered around by agriculture having nature of rural area and uncomfortable to assign training samples with 30m resolution images.

3.2.3.4 Accuracy Assessment for the Land Use Classification

Accuracy assessment of the land use classification for 2002, 2010 and 2018 was carried out using accuracy assessment tool available in ERDAS Imagine 2018. This process is performed by comparison of the results obtained by remote sensing analysis to the ground truth data or a references for designated sample points (Congalton, 1991, pp. 43–44; Foody, 2002, pp. 187–188).

To accomplish the process, random points were created using random number generator available in ERDAS Imagine 2018 to get random x, y, coordinates within the study area. The total 250 points were created to be representative for the classes using simple random sampling as proposed by Congalton (1991, pp. 43–45). The all locations were evaluated using Google Earth (GE) map service system by connecting; linking and synchronizing to view in ERDAS imagine 2018 software. An error matrix was created for the accuracy assessment that provides the guarantee for the quality of the information obtained from remotely sensed data. It usually provides a detail assessment of the covenant between the classified results and reference data having information about how the miscalculation happened (Foody, 2002, pp. 187–188).

To evaluate the accuracy, overall classification accuracy and K statistics were calculated for land use classification to match three temporal images 2002, 2010 and 2018. The overall classification accuracy is the total number of correctly classified pixels divided by the total number of sample points, whereas the K statistics is known as a measure of overall statistical covenant of an error matrix that is taken on known diagonal elements into account. Furthermore, the kappa analysis is also renowned as a powerful method to evaluate a single error matrix that shows the probability of correct classification (Bharatkar & Patel, 2013, p. 80).

3.2.3.5 Parameter Preparation Required for the InVEST Model

InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) is used to quantify and map ecosystem services having a set of different models within it. It is an open source, stand-alone software developed by natural capital project and aims at assessment of LULC changed in large watershed to point out their change influence on ecosystem service. These functions are considered as the simplifications derived from common hydrological relationship (Vigerstol & Aukema, 2011, p. 2405).

Out of total model functions of the InVEST, the SDR model is used for estimating sediment creation and its delivery to the stream overland surface. The output of the model, it is able to exemplify ecosystem service with respect to sediment retention in a watershed as to be significant for water quality and reservoir management, where sediment export in a watershed could be influenced with changes in land use or modification in land management (Lüke & Hack, 2018, pp. 13–15). The total eleven types of parameters are required as input to run the InVEST SDR_{max} model (Figure 3.3).

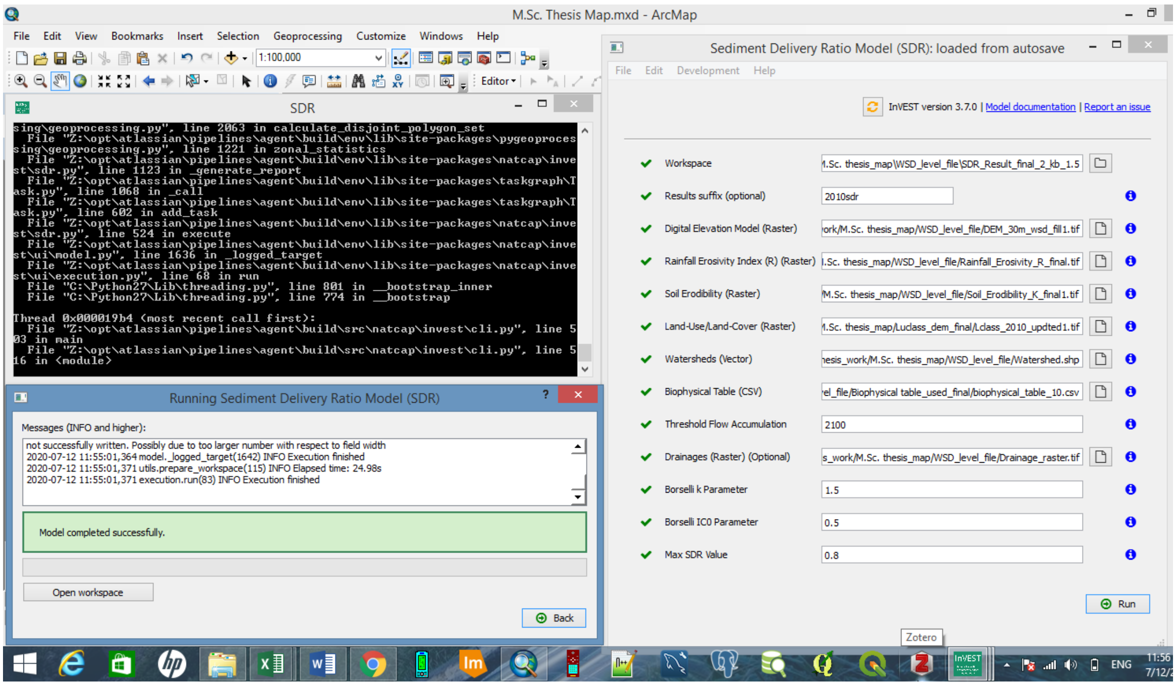


Figure 3. 3 Sediment Delivery Ratio Model Example

Out of them, the nine types of data are compulsory to be prepared locally to obtain the reliable output as far as practicable. The required input data are as follows:

3.2.3.5a Digital Elevation Model (DEM)

The DEM in raster format having spatial resolution 5m to 30m is required as input for the model. The DEM having 12.5m resolution was freely downloaded from ALOS PALSOR website. It needs the DEM to be filled to remove sink to obtain good results that was performed by using ArcGIS10.6 fill tool. The size of the DEM was made enough to be a bit larger than that of the watershed boundary for appropriate function having unit in meter.

3.2.3.5b Rainfall Erosivity Index (R)

The model needs the rainfall erosivity index (R factor) in raster format of the study area. It is the factor of rainfall and runoff with geographic location to show erosion potential

(Stone & Hilborn, 2012, p. 1). The R factor acts as the force for sheet and rill erosion without protection (Biswas & Pani, 2015, p. 4). It works on the basis of rainfall amount and intensity of a particular location (Koirala et al., 2019, p. 5). To achieve this purpose, the mean annual precipitation data from the rain gauge stations within and around the study area (Table 3.6) was acquired from the secondary literature sources already applied for the site from Ban et al. (2016, p. 326). Afterwards, the approach recommended by Parveen & Kumar (2012, pp. 589–590) for the sub-tropical region was applied to evaluate the R factor that has been presented as in equation (7) below:

$$R = 79+0.363P \quad (7)$$

Where,

R = Rainfall erosivity factor (MJ mm ha $^{-1}$ hr^{-1} year^{-1})

P = Mean annual precipitation in mm.

Table 3. 6 Mean Annual Precipitation Data of the Study Area, 2016

S.N.	Station Index	Station Name	Longitude	Latitude	Elevation (m)	Annual Precipitation (mm)	R Factor
1	915	Markhugaun	85.15	27.62	1514	1461	609.34
2	905	Daman	85.08	27.6	2328	1786	727.32
3	904	Bhimphedi	85.13	27.55	1219	2178	869.61
4	1015	Thankot	85.2	27.68	1893	1912	773.06
5	1038	Dhunibesi	85.18	27.72	976	1576	751.09
6	1075	Lele	85.28	27.58	1313	1847	749.46
7	1005	Dhading	84.93	27.87	1520	2121	848.92
8	920	Beluwa	84.84	27.55	365	2026	814.44

Source: Ban et al. (2016)

Further, the R factor was generalized for the site using the interpolation tool named Spline with Barrier available in ArcGIS10.6 software to locally suit enough to produce reliable result (Map 3.1 and Map 3.2). Similarly, the sub-watershed wise elevation and erosivity index (R factor) were obtained by using the zonal statistics tool available in the QGIS version 2.12.2 to process the data between raster data (DEM and R factor) and vector sub-watersheds polygon data.

3.2.3.5b1 Major Factors Affecting the Rainfall Erosivity Index (R)

It has been seen that topographical and climatic factor like distance from altitude, slope direction and through of low pressure affect the rainfall distribution pattern (Jo et al., 2018, p. 709). So, rainfall erosivity index (R factor) is significantly related with average annual precipitation and elevation that is also a significant predictor to influence the distribution of precipitation (Mielniczuk et al., 2019, p. 172). Likely, many authors have observed an average correlation coefficient (r) of 0.52 between elevation and the annual accumulation of precipitation (Ly et al., 2013, p. 402). However, the previous studies related to the study area and Nepal shows different scenario on rainfall distribution pattern. The study area belongs to middle hills that is also known as Mahabharat rage. The altitude of the middle hills varies from 1000m to 2500m masl. Nepal's precipitation has been found influenced by two major air movements i.e. one in monsoon season and the other in winter season. The monsoon rain comes from the Bay of Bengal during which the highest rainfall occurs in Nepal. The monsoon enters Nepal from southeast towards northwest direction that results higher precipitation in eastern to central parts than that of the western parts. But it was found no direct relation between annual precipitation and elevation (DHM, 2015, pp. 7–15, 32). Furthermore, monsoon rainfall occurrence is found comparatively higher at southeast facing slope and adjacent foothills regions of the Himalaya as well as its higher rate in middle mountain compared to the high mountain (Bhatt & Nakamura, 2005, p. 156).

Dhar et al. (1981, p. 253) also studied about the monsoon dynamic (the effects of elevation on monsoon rainfall distribution) in the central Himalaya and found no linear relationship between elevation and monsoon rainfall. The result was found also to show maximum rainfall occurrence near the foothills at the elevation from 2000m to 2400m , and then it decreases with increasing elevation (i.e. negative relation) continuously until reaching to the Himalayan range. The precipitation distribution has been found related with stream network and river basin. The precipitation intensities also increases significantly and mostly over and downstream of the mountain peaks (Kunz & Kottmeier, 2006, p. 1053). Generally, rainfall decrease with altitude that seems to vary from one river basin to another (Laraque et al., 2007, p. 1371).

3.2.3.5b2 Selection of Interpolation Method to Estimate Rainfall Erosivity Index (R)

There are found total 26 methods for spatial interpolation those have been grouped into three categories based on their feature as non-geostatistical (deterministic), geostatistical and combined (Li & Heap, 2008, p. 87). However, the estimated values by almost all the spatial interpolation methods represented as weighted average of sampled data (Webster & Oliver, 2007, p. 37). Selecting appropriate spatial interpolation method (SIM) for available data at hand is critical and not easy. Furthermore, no one interpolation method can stand out as being universally the best (Ly et al., 2013, p. 401). The method would be the best only for an specific situation (Li & Heap, 2008, p. 92; Isaaks & Srivastava, 1989, p. 268).

Many interpolation methods have been found used to estimate the spatial continuity of rainfall fields based on rain gauge measurement. These methods could be generally classified into two major groups like deterministic and geostatistical methods (Ly et al., 2013, p. 394). Based on the nature of the available datasets on precipitation, the major appropriate possible methodology was explored in the online sources. The possible methodologies were found as triangular irregular network related interpolation (TIN), inverse distance weighted (IDW), spline with barrier (SWB), simple cokriging (SCK), ordinary cokriging (OCK) and kriging with external drift (KED). The TIN, IDW and SWB are univariate and belong to deterministic category (Li & Heap, 2008, p. 87), whereas the SCK, OCK and KED are multivariate interpolation (Li & Heap, 2008, p. 176) those belong to geostatistical category.

Regarding the function of the possible SIMs, TIN is considered as more accurate than the nearest neighbour (NN) methods though each estimate by this method still depends on only three samples (Webster & Oliver, 2007, p. 38). Unlikely, the IDW perform well with regularly spaced data and is not able to account for spatial clustering of sampling (Isaaks & Srivastava, 1989, p. 276). While focussing on multivariate methods, the OCK has been seen to give better results than univariate methods in mountainous region having scale of about 10,000 km^2 (Phillips et al., 1992, pp. 119–141). If both the primary and secondary variables are measured at all the sample points , the OCK will not produce estimates (Isaaks & Srivastava, 1989, p. 405). In case of dense data points, many interpolation methods provides similar results. If the sample size is too small, then the interpolation methods either become unworkable or provide unusual results. According to the suggestions provided by some authors, there should be at least 150 data points to obtain satisfactory semi variance estimates (Smith et al., 2007, p. 306) in which the OCK gives more accurate results having sample size 70 (Li & Heap, 2008, pp. 832–841). If possible, the radar rainfall data is usually used as secondary variable in multivariate geostatistical analysis like KED and OCK that cannot be made in developing countries unless modern instruments are available to have installed as being costly (Ly et al., 2013, p. 403).

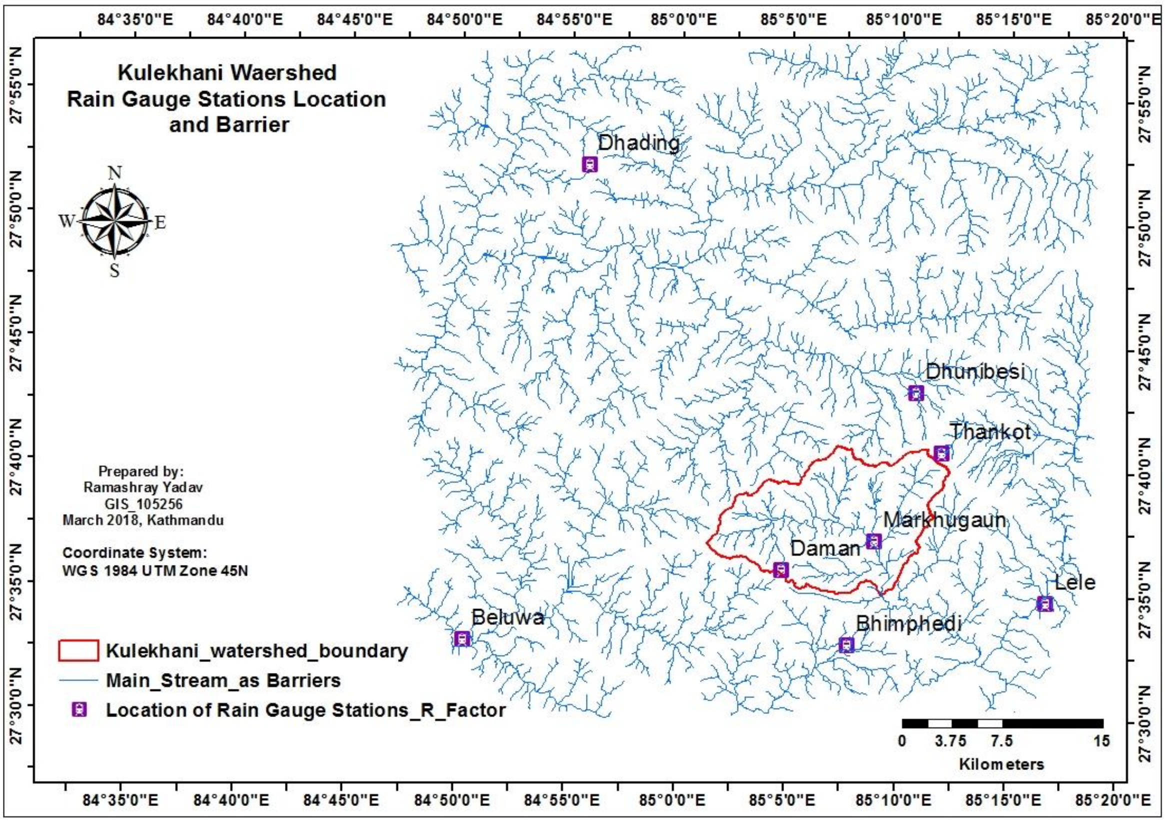
The selection of method mainly depends on nature and spatial structure of data for the primary variable, sample size and distribution, availability of secondary information and availability of software (Li and Heap, 2008, p-93). Ultimately, as the available data sets sample is sparsely distributed and smaller in size having annual precipitation of eight rain gauge stations i.e. eight sample points (Table 3.6), it needs the appropriate SIM that could estimate the rainfall erosivity index (R factor) with consideration of its influencing factors like topography, flow direction, aspect, slope or elevation of the site.

Hence, spline with barrier (SWB) interpolation was selected for the appropriate estimation of rainfall erosivity index of the study area. In this method, interpolation is used to produce an output raster that has values everywhere with discontinuous variables like water quality in a interweaved bendy stream. The barrier can be used in the form of either polygon or polyline feature class for defining the boundary of discontinuity (ESRI, 2018). As the rivers are known as the largest types of stream having movement of large amount of water from higher to lower elevation where the downhill movement takes variation with rock types, topography and other more factors (OER, n.d.), the main stream of the study area was used as barrier for this method. This tool was initially included in Spatial Analyst and 3D Analyst toolboxes as script tool i.e. Java Library to perform interpolation and then in ArcGIS pro 2.0. Now, it is available in ArcGIS 10.6. Weighting the points on the basis of the shortest distance around a barrier is considered as its advantage in which it utilizes all the points to make the prediction (ESRI, 2018).

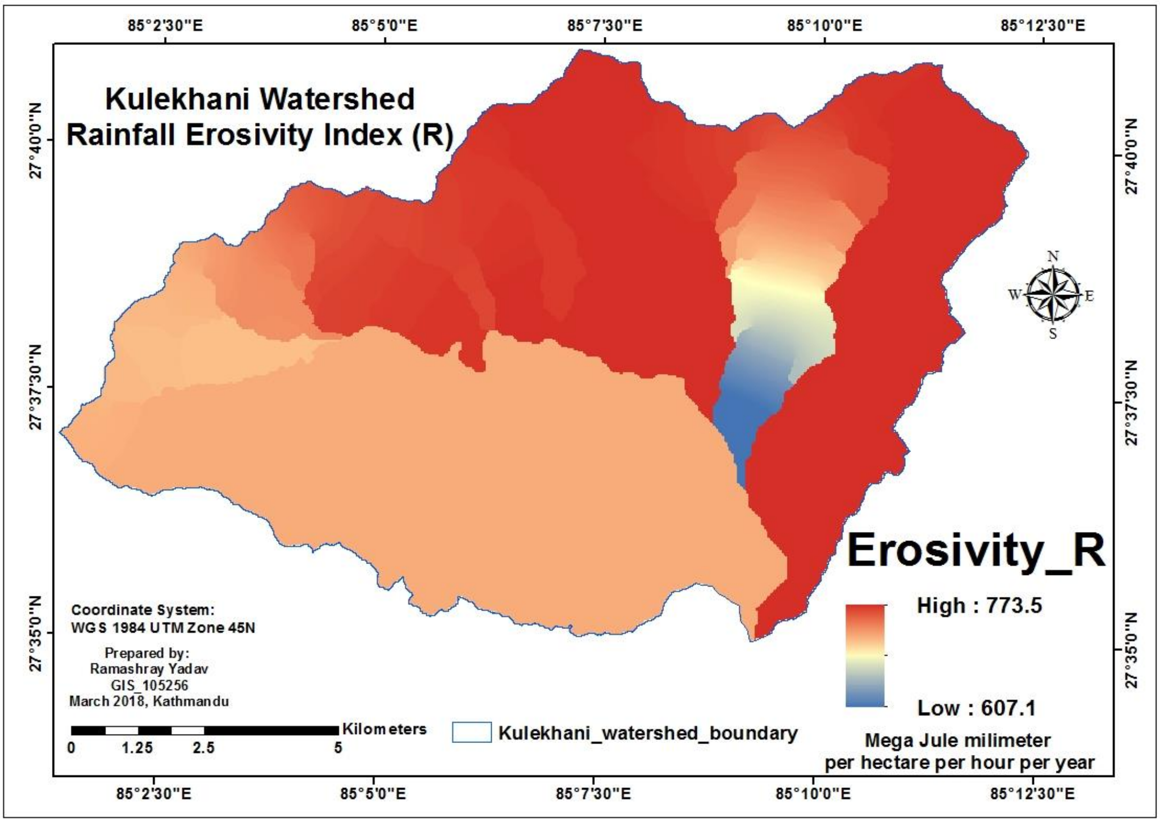
Table 3. 7 Eight Sub-watershed Wise Distribution of Rainfall Erosivity Index

Sub-watersheds (ID)	Sub-watersheds (Name)	Area (KM^2)	Elevation (m)	Rainfall Erosivity Index (R) MJ.mm.(ha.h.yr)-1
1	Andheri Khola	13.1	1880	750
2	Bisinkhel Khola	9.8	1770	742
3	Chitlang Khola	23.0	1897	755
4	Chuliprang Khola	15.3	1824	771
5	Gharti Khola	9.0	2037	726
6	Khaiti Khola	6.6	2073	727
7	Palung Khola	13.5	1783	740
8	Salmakulekhani Khola	8.9	1644	750
9	Sankhmool Khola	10.2	1964	739
10	Simbhanjyang Khola	15.2	2079	727

The acquired rainfall erosivity from the interpolation methods was obtained for the all ten sub-watersheds and found to have unique in value having appropriate correlation coefficient (r = -0.63673) between rainfall erosivity index (R factor) and elevation (Table 3.7).



Map 3. 1 Distribution of Rain Gauge Stations with Main Stream

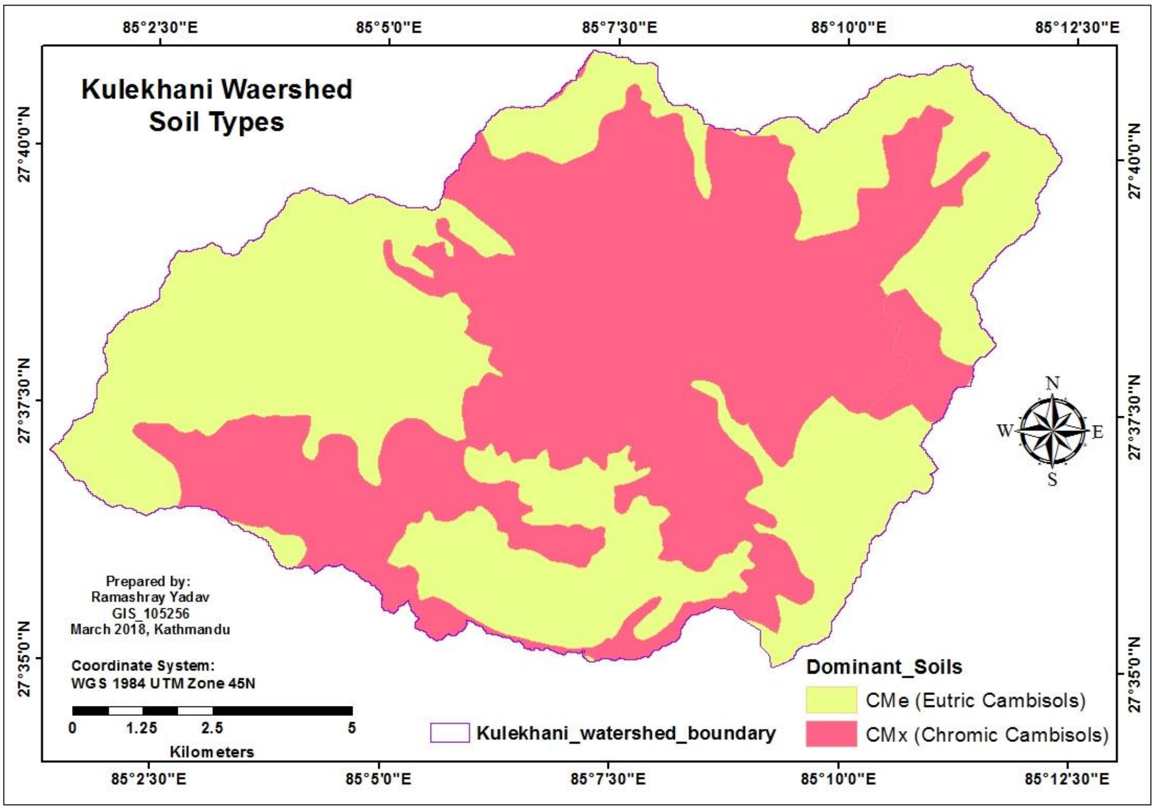


Map 3. 2 Rainfall Erosivity Index (R) of the Study Area

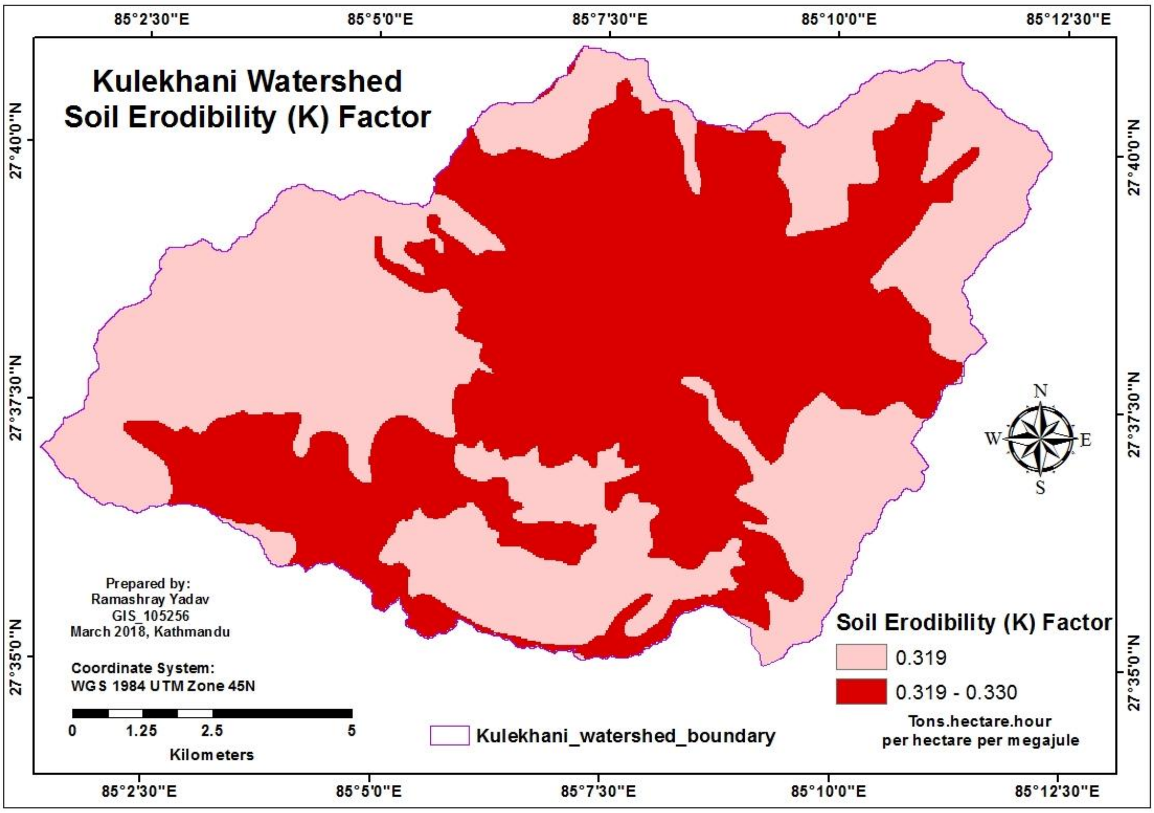
The Map 3.2 showed the clear visualization of relatively distinct value of rainfall erosivity index (R factor) within the ten sub-watersheds. Out of total sub-watersheds, Chuliprang seem to have been situated comparatively within the higher rainfall erosivity (R factor) values, whereas Gharti, Khaiti, and Simbhanjyang seem to occur within relatively moderate R factor values. Similarly, Sankhmool, Andheri and Palung seem to occur within moderate to high values. The remaining Salmakulekhani, Bisinkhel and Chitlang occur within relatively mixed with lower values to high values (Table 3.7, Map 1.1 and Map 3.2).

3.2.3.5c Soil Erodibility (K)

Soil erodibility is denoted by 'K' and known as K-factor. It is also considered as a measure of the inherent erodibility of a given area soil within the standard condition of USLE plot in continuous fallow. The K-factor values typically ranges from 0.10 to 0.45 (Renard et al., 1991, p. 31). It is also a sensitivity of agent to erosion that depends on soil types in terms of mathematical function of the percentage of silt, course sand, soil structure, permeability of soil and percent of organic matter. ArcGIS10.6 environment was used to calculate the K-factor to obtain soil unit's map of the Kulekhani watershed that was derived from soil and terrain (SOTER) data base for Nepal (Dijkshoorn & Huting, 2009) map at 1:50000 scale. Afterwards, overlaying the watershed boundary layer on the soil layer obtained from SOTER, it was found that the watershed is dominated by two types of soils namely Cme (Eutric Cambisols) and CMx (Chromic Cambisols) (Map 3.4). The soil erodibility factor (K) values proposed by Vopravil et al. (2007, p. 5) is 0.32 tons h MJ^{-1} for Eutric Cambisols and average value of 0.33 ton h MJ^{-1} for Chromic Cambisols was adopted for this study (Table 3.8). These values have also been found applied by Ban et al. (2016, p. 327) for soil erosion estimation using USLE model. These K factor values were added in the attribute field of the corresponding soil types of the soil map. As the model needs the K-factor in raster format, the soil map (vector file) was converted in to raster image assigning those K values by using 'polygon to raster' tool (available in ArcGIS 10.6) for the site with 30m resolution to be suited for the model (Map 3.4).



Map 3. 3 Soil Types in Kulekhani Watershed Area



Map 3. 4 Soil Erodibility (K) factor of the Kulekhani Watershed Area

Out of total sub-watersheds, the Khaiti, Palung, Bisinkhel and Chuliprang have been almost occurred within the higher soil erodibility (K) factor values. Similarly, the remaining sub-watersheds belong to have lower to higher values of K factor (Map 1.1 and Map 3.4).

Table 3. 8 Soil types and soil erodibility (K) factor of the study area

S.N.	x	y	Land form	Parent Material	Dominant Soil type	K factor
1	311488	3056150	TM	MA1	CMe	0.32
2	313240	3058750	TM	MB1	CMx	0.33
3	319926	3061860	TM	MA1	CMe	0.32
4	322733	3055660	TM	MB1	CMx	0.33
5	314041	3054430	TM	MA1	CMe	0.32

Where,
FAO codes for the soil types in the table are:

TM = High gradient mountain
MA1 = Quartzite
MB1 = Slate, phylite (peptic rock)
CMe = Eutric Cambisols
CMx = Chromic Cambisols

Source: Ban et al. (2016, p. 327); Dijkshoorn & Huting (2009, p. 10); Vopravil et al. (2007, p. 5)

3.2.3.5d Land Use Land Cover

Land use classification was done for the imagery of 2002, 2010 and 2018 and the all classified LULC maps were resampled to have 30m spatial resolution in the raster format to be used for the model with clear integer LULC code to each.

3.2.3.5e Watershed (Shape file)

The delineated sub-watersheds boundary map was coded with integer field named ws_id values for each sub-watersheds having shape file format.

3.2.3.5f Biophysical Table

This table needs to be in .csv (Comma separated values) format having at least three field values i.e. Lucode, usle_c-factor and usle_p-factor.

Lucode:

It needs unique integer for each LULC class having corresponding Lucode value in the biophysical table. The obtained land use land cover maps were prepared with unique integer lucode enough to be used for the model.

Usle C- factor:

It is cover management factor (c- factor) that needs to be in a floating-point value between o and 1. The value of c-factor depends on the vegetation types, stage of growth and percentage of cover. Its higher value means no cover effect, whereas lower values means very strong cover effect resulting in no erosion at that management status of the crop. So, it is also explained as crop management factor (LF et al., 2016, p. 4).

Usle P- factor:

It is a support practice factor that needs to be a floating point value between 0 and 1. It is considered as control practices to decrease the erosion potential caused by influence of runoff on drainage pattern , its concentration, velocity and hydraulic forces exerted by runoff on the soil surface (Renard et al., 1991, p. 32).

The c-factor and p-factor values could be either derived from object based image classification site specifically having used of remote sensing data from high resolution images or from previous studies or expert knowledge (Karydas et al., 2009, p. 28). As the image classification approach requires very high resolution remote sensing datasets and some experimental results (Panagos et al., 2015, p. 40) that is currently unavailable for the study area, the c-factor and p-factor values were prepared by referencing different relevant sources of literature review adopted by previous researchers in their studies with incorporating local condition to have biophysical table to run the model with reliable output (Table 3.9).

Regarding the c-factor of the classes, the c-factor value (0.001) was set for the forest as it has been found as mixed forest of both conifer and broadleaved within the watershed area that value is close to the value proposed by the previous researchers (Chadli, 2016, p. 6; Erencin et al., 2000, p. 15; Panagos et al., 2015, p. 40).

Table 3. 9 Biophysical table (Having C-values and P-values)

LULC_description	Lucode	Usle_C- factor		Usle_P- factor	
		Values	Source referenced	Values	Source referenced
Forest	17	0.001	(Chadli, 2016, p. 6; Erencin et al., 2000, p. 15; Panagos et al., 2015, p. 40)	0.50	(David, 1988, p. 60; Kim, 2006, p. 52; Li et al., 2014, p. 1552)
Agriculture and built up	11	0.15	(Erencin et al., 2000, p. 15; Koirala et al., 2019, p. 7; Panagos et al., 2015, p. 40)	0.20	(David, 1988, p. 60; Kim, 2006, p. 52; Li et al., 2014, p. 1552; Morgan, 2005, p. 123)
Grass and shrub land	14	0.01	(Erencin et al., 2000, p. 15; Koirala et al., 2019, p. 7)	0.60	(David, 1988, p. 60; Morgan, 2005, p. 123; Panagos et al., 2015, p. 26 ; Wischmeier & Smith, 1965, p. 37)
Barren land	13	0.1326	(Biswas & Pani, 2015, p. 6; Chadli, 2016, p. 6; Duru, 2016, p. 43; Panagos et al., 2015, p. 40)	0.95	(David, 1988, p. 60; Kim, 2006, p. 52; LF et al., 2016, p. 4; Morgan, 2005, p. 123; Panagos et al., 2015, p. 26)
Water bodies	12	0	(Biswas & Pani, 2015, p. 6; Chadli, 2016, p. 6; Duru, 2016, p. 43; Koirala et al., 2019, p. 7 ; LF et al., 2016, p. 4; Panagos et al., 2015, p. 40)	0.00	(LF et al., 2016, p. 4; Li et al., 2014, p. 1552)

The second land use class was combined class of agriculture land and built up to be agriculture and built up. The values adopted by previous researchers (Erencin et al. 2000, p. 15; Koirala et al., 2019, p. 7; Panagos et al., 2015, p. 40) was found ranged from 0 to 0.28 for different scenario. Hence, the value (0.15) was set for this class to match the local circumstances based on observation and literatures. Likely, the value for the third land use class (0.01) was set as the matching scenario adopted by the previous researcher (Erencin et al., 2000, p. 15; Koirala et al., 2019, p. 7). In this way, the fourth land use class is barren land. The value adopted by the relevant previous researches (Biswas & Pani, 2015, p. 6; Chadli, 2016, p. 6; Duru, 2016, p. 43; Panagos et al., 2015, p. 40) was found ranged from 0 to 0.35 in different scenario. Similarly, the value (0) for water bodies was also set based on the literatures (Biswas & Pani, 2015, p. 6; Chadli, 2016, p. 6; Duru, 2016, p. 43; Koirala et al., 2019, p. 7 ; LF et al., 2016, p. 4; Panagos et al., 2015, p. 40). Therefore, the appropriate value (0.1326) was set for this land use class as to match the local characteristics of the class with reference to literature.

Similarly, the support practice (p-factor) values of the classes was set by references of literature incorporating local conditions of the land use classes. The p-factor value (0.50) was set for the forest land class as the value proposed by the relevant previous researchers for the forest land having in the slope >25% (David, 1988, p. 60; Kim, 2006, p. 52; Li et al., 2014, p. 1552). The second land use class was combined class of agriculture land and built up to be agriculture and built up. The value adopted by previous researchers (David, 1988, p. 60; Kim, 2006, p. 52; Li et al., 2014, p. 1552; Morgan, 2005, p. 123) found ranged from 0.14 to 0.20 for different scenario like slopes (%) of the site and terracing types, irrigated crop land (10-20%, 20-30% slope) as well tied ridging. Hence, the value (0.20) was set for this class to match the local circumstances based on observation and literatures. Likely, the value for the third land use class (0.60) was set as the matching scenario adopted by the previous researcher (David, 1988, p. 60; Morgan, 2005, p. 123; Panagos et al., 2015, p. 26; Wischmeier & Smith, 1965, p. 37). In this way, the fourth land use class is barren land. The value adopted by the relevant previous researches (David, 1988, p. 60; Kim, 2006, p. 52; LF et al., 2016, p. 4; Morgan, 2005, p. 123; Panagos et al., 2015, p. 26) was found ranged from 0.95 to 1.00 in different scenario like slope(>25%) and contouring nature of the land use class. Similarly, the value (0) for water bodies was also set based on the literatures (LF et al., 2016, p. 4; Li et al., 2014, p. 1552). Therefore, the appropriate value (0.95) was set for this land use class as to match the local characteristics of the class with reference to literature.

3.2.3.5g Threshold Flow Accumulation

It is requisite that the number of upstream cells to flow into a cell before it is considered the part of a stream having used to classify the stream from the DEM. It is also known as threshold flow accumulation for the model. Its value should be chosen carefully so as the modeled streams to be close to reality as far as possible. Though, its value can vary generally depending on DEM resolution, local climate and topography and the stream derived from the DEM do not exactly match the real world but just comes to be as close as possible. So, its good integer value is '1000' to start the model with no comma or period (NCP, 2017, p. 143) that has been given as default value for this parameter (Cohen et al., 2011, p. 32). In simplest form, the flow accumulation is the number in upslope cells that flows into a specific cell whereas its threshold value could be applied to define the stream networks of the watersheds (Kilic & Soni, 2014, p. 43).

Initially, the model was run with flow accumulation value '1000' and its appropriate value was found to be used as '2100' after overlaying & comparing the flow accumulation raster and stream raster maps created by the model with real-world stream map in ArcGIS10.6 environment to get reliable output of the model.

3.2.3.5h K_b and IC_0

These two parameters are required to determine the shape of relationship that shows hydrologically the degree of connection from patches of land to the stream. These are also known as Barseli parameters. The default values for the K_b and IC_0 have been given as 2 and 0.5 respectively for the model (NCP, 2017, p. 143). These connectivity concepts could be helpful for correcting run off accumulation and sediment transporting capacity within the modelling (Verstraeten et al., 2007, pp. 442–443). According to Hamel et al. (2015, pp. 166–177) and Vigiak et al. (2012, p. 84), K_b was only the parameter used for calibration. Vigiak et al., (2012) suggested that IC_o is landscape independent. Therefore, the calibration should be based on K_b only. Hence, the value of K_b parameter was selected as 1.5 to get minimized relative difference between predicted and observed value for 2002, 2010 and 2018. This calibrated parameter value of K_b as 1.8 was also found adopted by Bogdan et al. (2016, p. 18) in their study on the assessment of regulatory ecosystem service.

3.2.3.5i SDR_{max}

It is known as the fraction of top soil particles finer than coarse sand i.e. 1000 micrometer (Vigiak et al., 2012, p. 76). It could be used for calibration in advanced studies. The default value for this parameter has been given as 0.8 (NCP, 2017, p. 143).

3.2.3.5j Drainage Layer

This layer is optional to use in raster format for the model that corresponds the pixels to be artificially connected to stream. Using this layer has to stop flow routing before reaching the stream network and having assumption with exported sediment to be reached the catchment outlets (NCP, 2017, p. 143).

3.2.3.6 Interpretation of the Output Obtained from the Model

The output from applying this model are obtained in the form of shape file map as well as in the raster images having attribute values with respect to sediment retention, sediment exported and potential soil loss including flow accumulation, drainage and stream of the watershed. They have been explained as below:

3.2.3.6.1 Watershed results (.shp)

The biophysical values for each sub-watersheds are provided in the attribute table having three fields as:

3.2.3.6.1a Sed_export (Units: tons/watershed)

The amount of sediment exported to the stream per sub-watershed per year was obtained in this field that should be compared to any observed data on sediment loads at the outlet of the watershed. The result was finally presented as sediment exported per unit (t/ha/yr).

3.2.3.6.1b Usle_tot (Units: tons/watershed)

This output is the total potential soil loss in each sub-watershed per year as calculated by the Revised Universal Soil Loss Equation (RUSLE) as presented in equation (8) as below:

A = R*K*LS*C*P ………………………………………………………………… (8)

Where,

A = Soil loss (t/ha/yr); R = Rainfall erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1});

K = Soil erodibility factor (t h MJ^{-1} mm^{-1});

LS = Slope – length and slope steepness factor (dimensionless);

C = Cover management factor (dimensionless);

P = Support practice factor (dimensionless)

The result was finally presented as total potential soil loss per unit (t/ha/yr).

3.2.3.6.1c Sed_retent (Units: tons/watershed)

This output is obtained from the difference between sediment amount delivered by the current sub-watershed and a hypothetical sub-watershed where the all land use land cover would have been converted to bare land. The result was finally presented as sediment retention per unit (t/ha/yr).

3.2.3.6.2 Watershed result in the form of raster images

The expected major raster forms of the results are as follows:

3.2.3.6.2a Sed_export (Raster, tif, units; ton/pixel)

This output provides the image with total amount of sediment exported from each pixel that reaches the stream.

3.2.3.6.2b Usle (Raster, tif, units; ton/pixel)

This output provides the image with total potential soil loss in the original land cover per pixel calculated from the RUSLE equation.

3.2.3.6.2c Sed_retention (Raster, tif, units; ton/pixel)

This output provides the map with sediment retention with reference to the watershed having the all land use land cover converted to bare land.

3.2.3.6.2d Stream (Raster image)

It is the stream network generated from the input DEM and threshold flow accumulation in which the value 1 is given for streams and 0 for non-streams pixel value. Further, it is used to obtain adjusted threshold flow accumulation by comparing with real-world stream map. The results regarding the raster images above are provided as tons/pixel that doesn't mean the sediment retained on each pixel. Instead, it should be interpreted as relative values and not as absolute values given where it is used to identify the areas with land use land cover contributing to retain the sediment with reference to the watershed (NCP, 2017, p. 144).

3.2.3.7 Land Use Change Detection

It is useful in various application related to LULC changing in watershed area. The LULC change detection needs prior classification of image using maximum likelihood classifier and accuracy assessment of the classification ought to be good enough to meet this requirement (Andualem et al., 2018, p. 3). The change detection was performed on the post classification of the images for 2002, 2010 and 2018 of the Kulekhani watershed.

The spatial resolution and number of column & row of the classified images were resampled to be similar to each other as resolution 30m and column & row as 604 & 370 respectively for all temporal images 2002, 2010 and 2018. The image pre-processing was also carried out prior to image classification that is also requirement of the change detection. The supervise classification of image was performed in ERDAS Imagine 2018 by assigning training samples using signature editor with connecting, linking and synchronizing google earth. After then, the classified raster images were converted in vector (polygon) format as well as transition matrix was created using ArcGIS10.6 with intersect spatial tool.

3.2.3.8 Comparison between Obtained and Observed Sedimentation Rate

The sediment exported (predicted) data by the model was compared with the available observed or measured sediment yield in the Kulekhani reservoir. For the comparison of the sedimentation rate, the unit was taken same as obtained from the InVEST SDR_{max} model (ton/ha/yr). In this case, the concentration data was converted to annual loads to match the time series as suggested by Hamel et al. (2015, pp. 166–177).

3.2.4 Statistical Analysis

Statistical analysis was performed by a simple statistical tools available in the Microsoft excel software and the correlation coefficient (r) was obtained by using PAST software.

3.2.4.1 Correlation between Sediment Yield Measured in the Reservoir and Predicted by the Model

The relation between the sediment yield measured in the Kulekhani reservoir and predicted by the model was shown by calculating correlation coefficient (r) between sediment measured (t/ha/yr) and sediment predicted (t/ha/yr). Correlation is a statistics used to measure the degree or strength of relationship. Its magnitude and direction might be positive or negative having range of value from -1 to +1. Correlation coefficient value 0 indicates no relationship. Its strength is neither dependent on the direction nor on sign. If the increment in first variable makes increment in the second variable, then it indicates positive relationship. Unlikely, the negative value indicates inverse relationship (Sthapit et al., 2009, p. 368). The summary of strength value of the relation prescribed by Sthapit et al., (2009) presented in Table 3.10.

3.2.5 Calibration and Validation

The sensitive input parameter for the InVEST SDR_{max} model was calibrated as suggestions provided by Welde (2016, pp. 37–38) and Vigiak et al. (2012, p. 85). After selecting the sensitive input parameters, the model was calibrated for threshold flow accumulation and parameter K_b. The model was calibrated by changing the parameter sequentially for obtaining optimum agreement between observed and simulated sediment yield values. The obtained predicted result on sedimentation yield was compared with the measured sedimentation yield of the reservoir.

Table 3. 10 Interpretation of strength in correlation coefficient (r)

Degree	Direction	
	Positive	**Negative**
Perfect	+1	-1
Significant (Very high)	+0.75 to +1	-0.75 to -1
High	+0.50 to +0.75	-0.50 to -0.75
Low	+0.25 to +0.50	-0.25 to -0.50
Insignificant (very low)	0 to +0.25	0 to -0.25
Absent	0	0

Source: Sthapit et al. (2009, p. 368)

Chapter-4: Result and Discussion

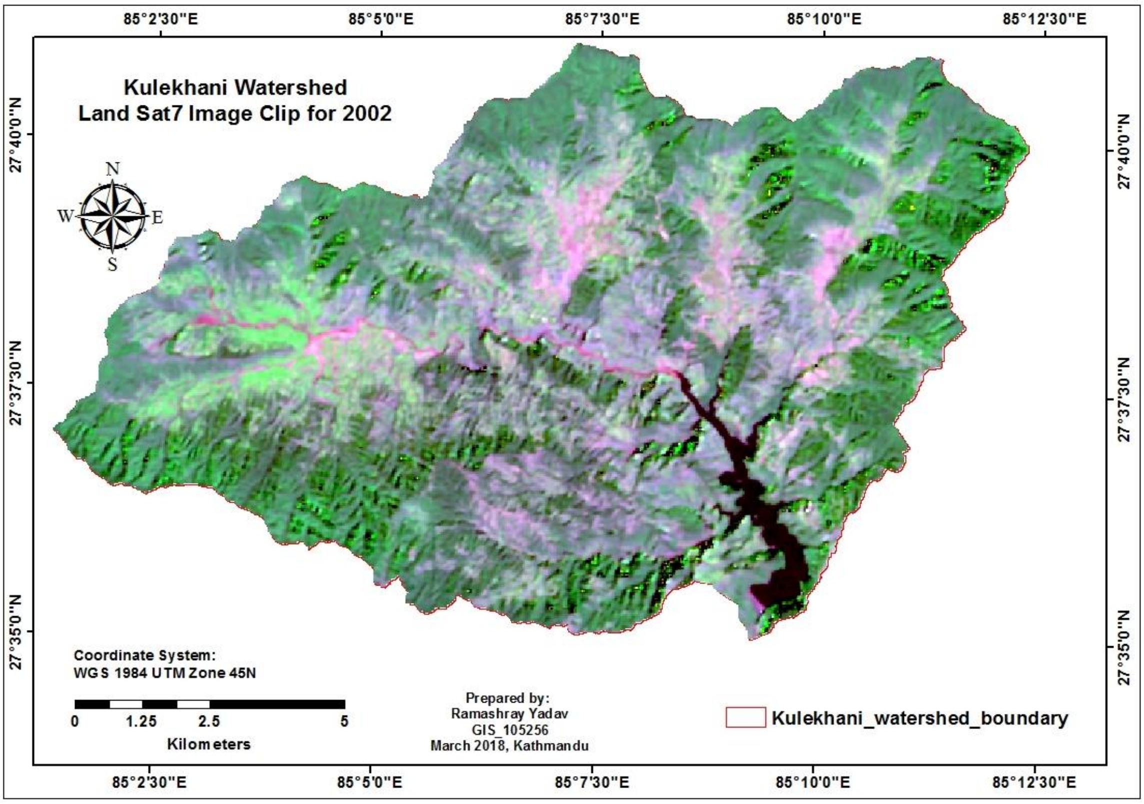
The main output presented in this chapter are land use land cover (LULC) classified for the watershed, LULC changes, sedimentation rate in watershed and sub-watersheds, most sensitive sub-watershed and comparison of predicted sedimentation rate with the observed sedimentation rate of the reservoir.

4.1. LULC of Kulekhani Watershed in 2002, 2010 and 2018

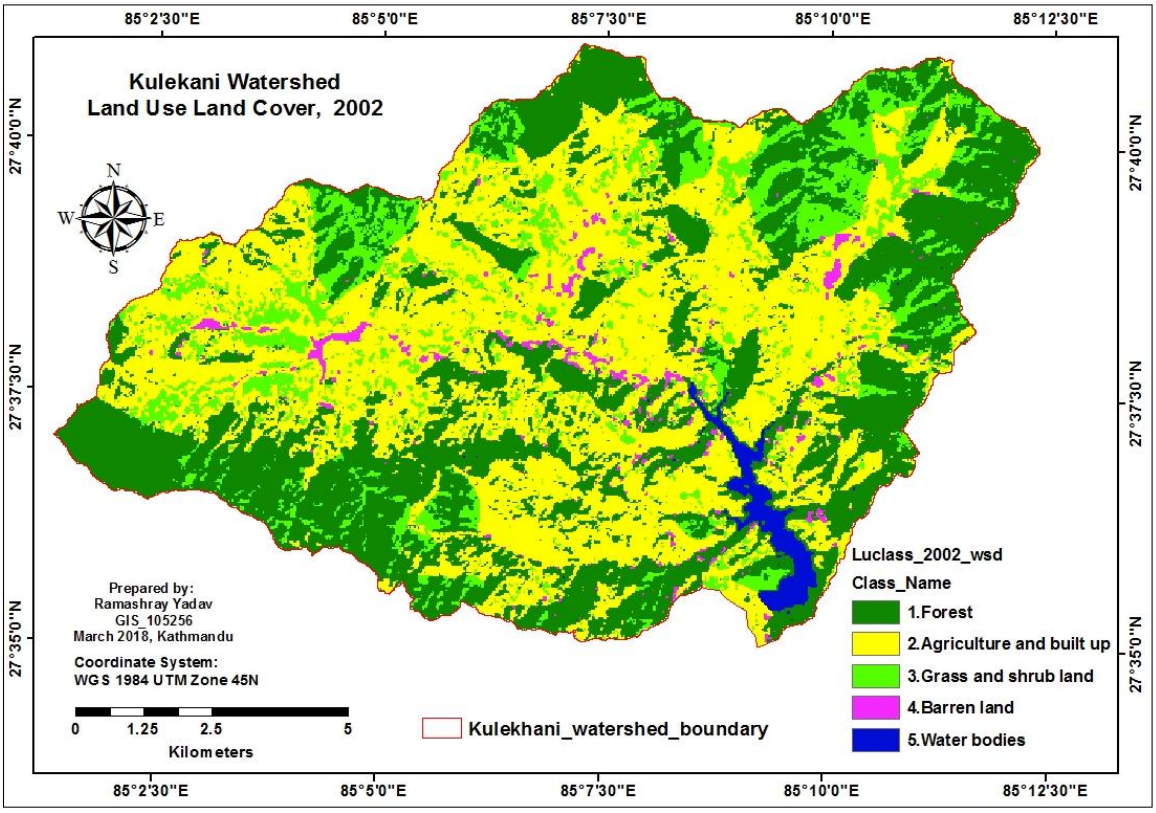
The result on temporal land use land cover assessment of the Kulekhani watershed was found that the land cover area of the forest increased with low amount but with continuous increment during 2002, 2010 and 2018 having 4860 hectare, 5354 hectare and 5491 hectare respectively. Similarly, the grass and shrub land cover was found increased continuously within these three time period having 1748 (ha), 2936 (ha) and 3494 (ha) respectively. In the contrast, the agriculture and built up area was found decreased within these period in parallel of the above two cover classes having 5449 (ha), 3816 (ha) and 3013 (ha) correspondingly. Unlikely, the others two land cover classes barren land water bodies have been found decreased first in 2010 but increased in 2018 with low amount. The agriculture and built up was found in first position 2002, second position in 2010 and third position in 2018 (Table 4.1, Figure 4.1, Map 4.1, Map 4.2, Map 4.4 and Map 4.6). The satellite images used for LULC classification in 2002, 2010 and 2018 have been given in Map 4.1, Map 4.3 and Map 4.5 respectively.

Table 4. 1 Land Use Land Cover Result at Kulekhani Watershed

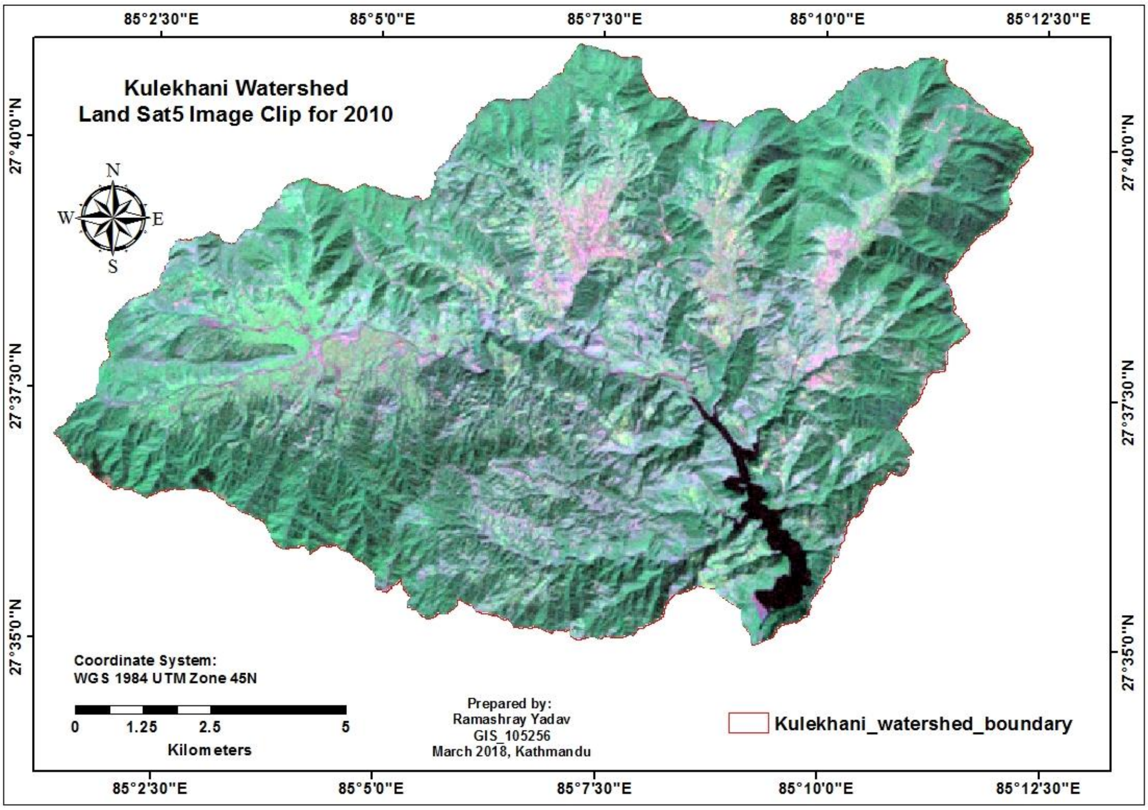
Class Name	**Land Use Land Cover Area**					
	2002		**2010**		**2018**	
	Ha	**%**	**Ha**	**%**	**Ha**	**%**
1.Forest	4860.3	39.0	5353.9	42.9	5491.3	44.0
2.Agriculture and built up	5448.5	43.7	3816.0	30.6	3012.6	24.2
3.Grass and shrub land	1747.8	14.0	2935.8	23.5	3494.4	28.0
4.Barren land	228.5	1.8	205.3	1.6	300.1	2.4
5.Water bodies	181.9	1.5	156.1	1.3	168.6	1.4
Total	**12467**	**100**	**12467**	**100**	**12467**	**100**



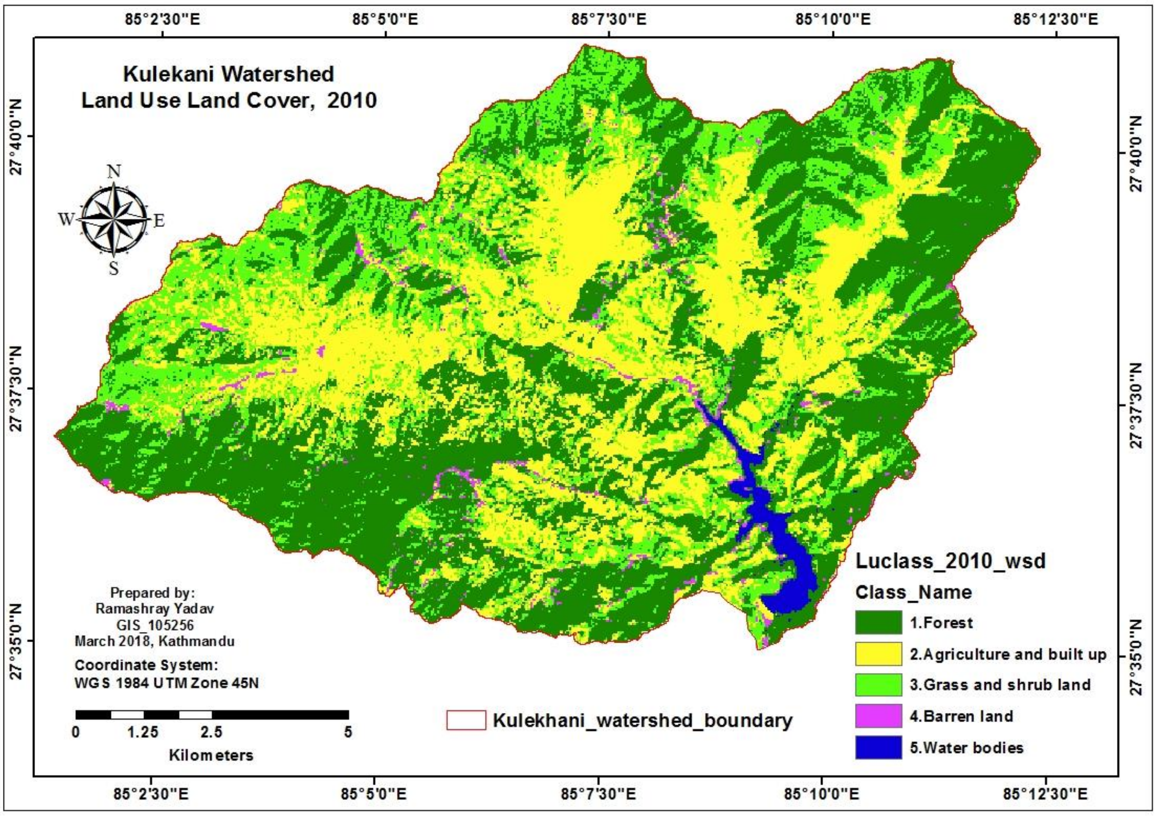
Map 4. 1 Satellite Image Clip of Study Area for 2002



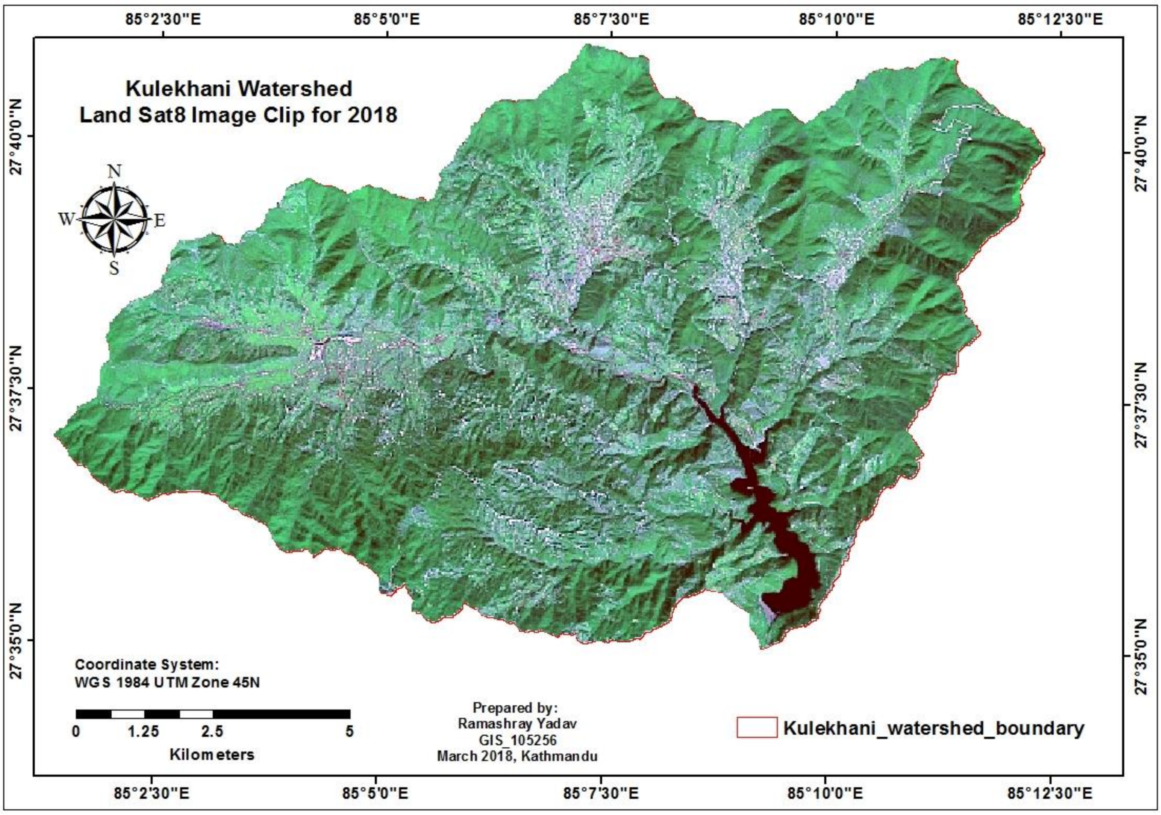
Map 4. 2 Land Use Land Cover Map of 2002



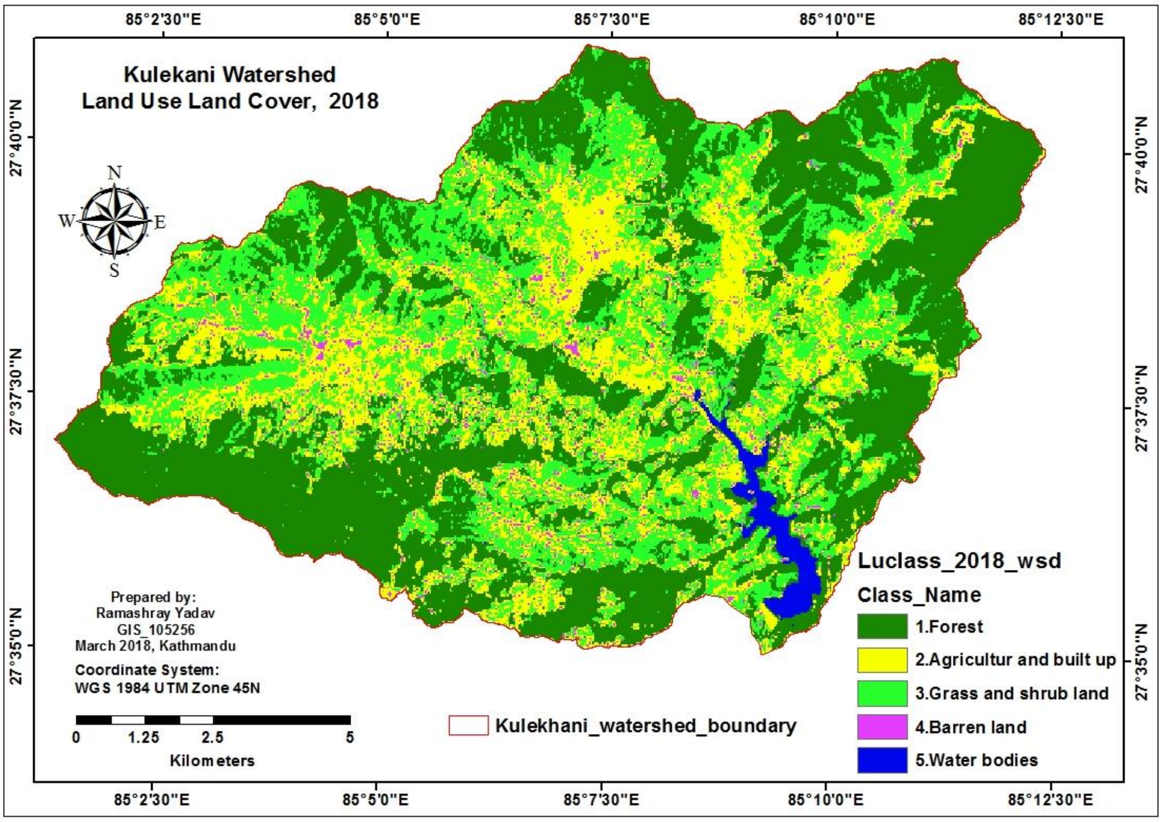
Map 4. 3 Satellite Image Clip of Study Area for 2010



Map 4. 4 Land Use Land Cover Map of 2010



Map 4. 5 Satellite Image Clip of Study Area for 2018



Map 4. 6 Land Use Land Cover Map of 2018

The above Map 4.2, Map 4.4 and Map 4.6 shows the hierarchical status of land use land cover classes within the study area in year 2002, 2010 and 2018 respectively. The similar colour was used in Figure 4.1 as it was used to denote the land use land cover classes in the Map 4.2, Map 4.4 and Map 4.6 for visualizing the result clear and to be understood easily.

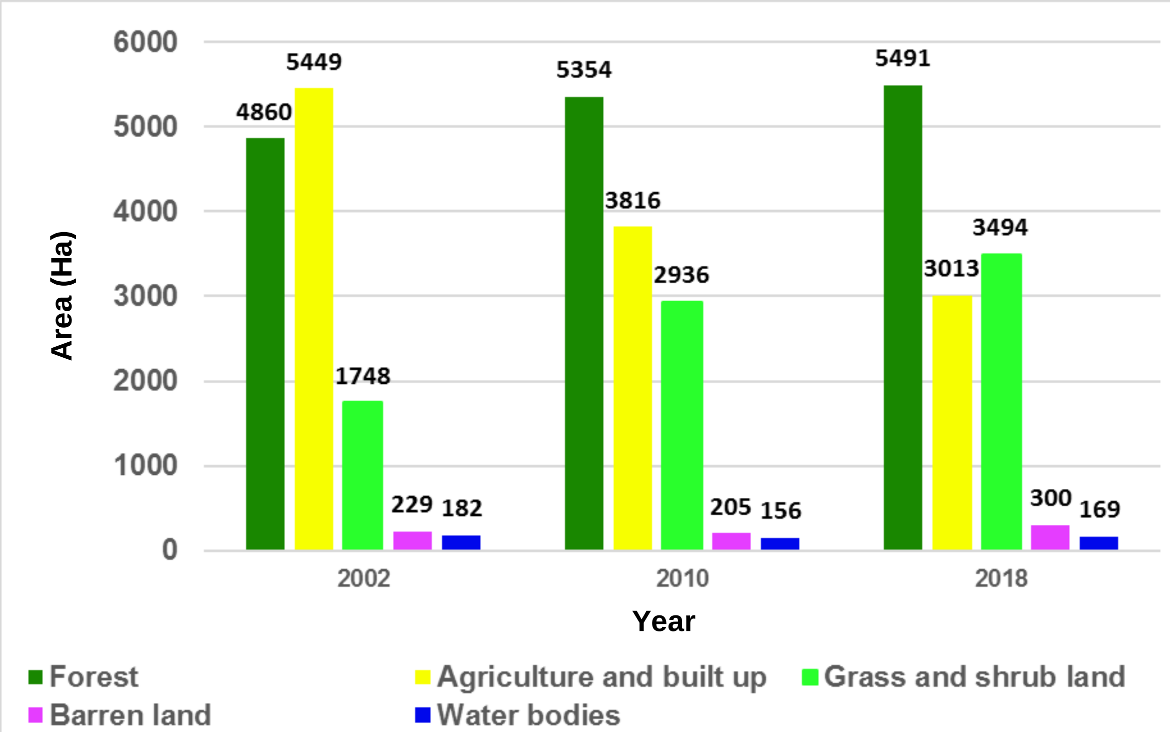


Figure 4. 1 Status of Land Use Land Cover in 2002, 2010 and 2018

4.1.1 LULC of Kulekhani Watershed at Sub-watersheds Level in 2002, 2010 and 2018

Out of total ten sub-watershed, the four of them Chitlang, Bisinkhel, Sankhmool and Gharti khola were found continuously increased their forest land cover within the three temporal analysis period. Next, four sub-watersheds Simbhanjyang, Chuliprang, Andheri and Khaiti khola were found ultimately increased their forest land cover. Unlikely, the other two sub-watersheds Salma Kulekhani and Palung khola were found ultimately decreased their forest land cover. These relatively gain and loss of the forest cover within the sub-watersheds was found with low amount in the analysis of the study (Table 4.2).

Regarding the agriculture and built up land cover, of the total, nine sub-watersheds were found continuously decreased their land cover except one (Khaiti Khola) of them found ultimately deceased its agriculture and built up land cover within the analysis period. Similarly, the eight sub-watersheds (Salma Kulekhani, Chitlang, Bisinkhel, Palung, Simbhanjyang, Chuliprang, Andheri and Shankhmool Khola) were found continuously increased their grass and shrub land cover; while the one (Gharti Khola) of them found ultimately increased its grass and shrub land. Unlikely, the Khaiti Khola was found ultimately decreased its grass and shrub land cover within the study period (Table 4.2).

In this way, out of total, the two sub-watersheds Bisinkhel and Simbhanjyang Khola were found decreased their barren land cover continuously where six of them found increased their barren land cover ultimately within the period. Unlikely, the two sub-watersheds (Chitlang and Shankhmool Khola) were found decreased their barren land cover ultimately in the study period. The water bodies (the fifth LULC class) was found extended about limited area within five sub-watersheds. Out of them, two sub-watersheds (Salma Kulekhani and Simbhanjyang khola) were found continuously decreased their water bodies cover whereas three of them (Chitlang, Bisinkhel and Palung khola) were found decreased their water bodies cover ultimately in the study period (Table 4.2).

In overall, 50% of the sub-watersheds Salmakulekhani, Chitlang, Simbhanjyang, Gharti and Khaiti were found to have the higher forest land cover area than agriculture and built up land cover within the LULC of those sub-watersheds. Among them, the forest cover of Salma Kulekhani was found to have 38.8% followed by agriculture and built up (25.8%), grass and shrub land (17.1%), water bodies (16.3%) and barren land (1.9%). Similarly, the Chitlang was found possessed forest cover 52.3% followed by agriculture and built up (24.3%); grass and shrub land (21.9%), barren land (1.2%) and water bodies (0.2 %). Likely, Simbhanjyang was found possessing forest cover 46.4% followed by agriculture and built up (32.7%); grass and shrub land (18.5%), barren land (2.1%) and water bodies (0.4%). Similar way, the Gharti was found possessed forest cover 54.6% followed by agriculture and built up (22.7%), grass and shrub land (21.4%), barren land (1.2%) and about no water bodies. The fifth among them, Khaiti was found to have forest cover 74.5% followed by agriculture and built up (15.3%), grass and shrub land (9.1%), barren land (1.1%) and about no water bodies. Furthermore, the Khaiti was found the highest forest cover holder (74.5%) followed by the Gharti, Chitlang, Simbhanjyang and Salmakulekhnai within all the sub-watersheds of the study area (Table 4.3).

On the contrast, the other 50% of the sub-watersheds namely Bisinkhel, Palung, Chuiliprang, Andheri and Shankhmool were found to have lower forest cover than the agriculture and built up within the all sub-watersheds. The Palung was found possessed the agriculture and built up area (45.2%) followed by forest cover (35.3%), grass and shrub land 15.8%). barren land (3.1%) and water bodies (0.5%). The trend of LULC was found similar to also other four sub-watersheds of this group. However, the Shankhmool was found the poorest to have forest cover only 24.1% followed by other of this poor group as Andheri (30.2%), Chuliprang (35.1%), Palung (35.3%) and Bisinkhel (36.7%) having possessed lower land use land cover values than the agriculture and built up area (Table 4.3).

4.2. Accuracy Assessment

The result of classification of 2002, 2010 and 2018 images were evaluated through the accuracy assessment process available in ERDAS Imagine 2018 under supervised classification. The process started with creating number of random test samples having total 250 points to be minimum 50 points for each classes as suggested by Congalton (1991, pp. 43–44). Those sample points with extent of classified image were sent to Google Earth (GE) by linking and synchronized view as illustrated in example of figure 4.1.

Table 4. 2 Land Use Land Cover Result at Sub-watershed Level

Sub-watershed		Forest (Area _Ha)			Agriculture and built up (Area_Ha)			Grass and shrub land (Area_Ha)			Barren land (Area_Ha)			Water bodies (Area_Ha)		
ID	Name	2002	2010	2018	2002	2010	2018	2002	2010	2018	2002	2010	2018	2002	2010	2018
1	Andheri Khola	359.8	427.8	402.4	755.7	531.4	395.7	168.0	332.6	475.2	29.0	20.8	39.1	0.0	0.0	0.1
2	Bisinkhel Khola	310.8	375.9	395.1	483.1	378.2	286.7	182.4	214.4	282.8	3.4	13.3	15.6	2.8	0.9	2.2
3	Chitlang Khola	1077.4	1202.4	1331.2	696.8	571.2	411.1	481.1	507.1	523.4	37.3	14.2	28.7	9.4	7.3	7.7
4	Chuliprang Khola	537.8	471.8	597.7	745.4	595.6	452.2	214.4	436.9	446.1	27.9	21.2	29.8	0.0	0.1	0.0
5	Gharti Khola	471.3	474.7	526.0	307.8	152.2	152.0	113.4	250.3	213.2	5.7	20.6	6.9	0.0	0.0	0.1
6	Khaiti Khola	458.4	516.9	506.1	130.9	84.1	88.5	64.3	58.0	58.8	8.8	3.5	9.1	0.0	0.1	0.0
7	Palung Khola	449.4	542.9	438.8	787.7	585.2	462.2	54.3	194.6	393.1	50.5	26.2	50.6	10.7	3.7	7.9
8	Salma Kulekhani Khola	347.9	357.3	335.1	323.1	205.8	164.0	55.5	171.5	232.2	14.0	20.9	16.0	152.9	138.1	146.0
9	Shankhmool Khola	182.8	247.3	307.8	575.4	337.1	257.2	238.0	422.2	432.6	23.8	12.9	22.1	0.0	0.1	0.0
10	Simbhanjyang Khola	655.8	770.1	685.3	722.7	418.3	346.8	117.9	285.5	438.2	15.2	37.7	42.3	6.8	6.6	5.8

Table 4. 3 Overall Mean value of LULC at Sub-watershed Level from 2002 to 2018

Sub-watershed	1.Area in		2. Area in		3. Area in		4. Area in		5. Area in		Total	
ID	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**
1	396.6	30.2	560.9	42.7	325.3	24.8	29.6	2.3	0.0	0.0	**1312.5**	100.0
2	360.6	36.7	382.6	38.9	226.5	23.1	10.8	1.1	1.9	0.2	**982.5**	100.0
3	1203.7	52.3	559.7	24.3	503.9	21.9	26.7	1.2	8.1	0.4	**2302.0**	100.0
4	535.8	35.1	597.7	39.2	365.8	24.0	26.3	1.7	0.0	0.0	**1525.7**	100.0
5	490.7	54.6	204.0	22.7	192.3	21.4	11.1	1.2	0.0	0.0	**898.0**	100.0
6	493.8	74.5	101.1	15.3	60.4	9.1	7.1	1.1	0.0	0.0	**662.4**	100.0
7	477.1	35.3	611.7	45.2	214.0	15.8	42.4	3.1	7.4	0.5	**1352.6**	100.0
8	346.8	38.8	230.9	25.8	153.1	17.1	17.0	1.9	145.6	16.3	**893.4**	100.0
9	246.0	24.1	389.9	38.2	364.3	35.7	19.6	1.9	0.0	0.0	**1019.8**	100.0
10	703.7	46.4	495.9	32.7	280.5	18.5	31.7	2.1	6.4	0.4	**1518.3**	100.0
Total	**5254.7**	42.1	**4134.5**	33.2	**2686.1**	21.5	**222.3**	1.8	**169.7**	1.4	**12467**	100.0

The white label of the created random points were found converted into orange colour (new code) after verification of the land use classes as assigned in classified images. Those points were confirmed by creating placement mark up in the GE tool making relation with the help of inquire tool available in ERDAS Imagine 2018 software to match the expected LULC class with respective cover in the GE. This process was followed for all the Landsat images for 2002, 2010 and 2018 by sliding respective historical date imageries in the GE.

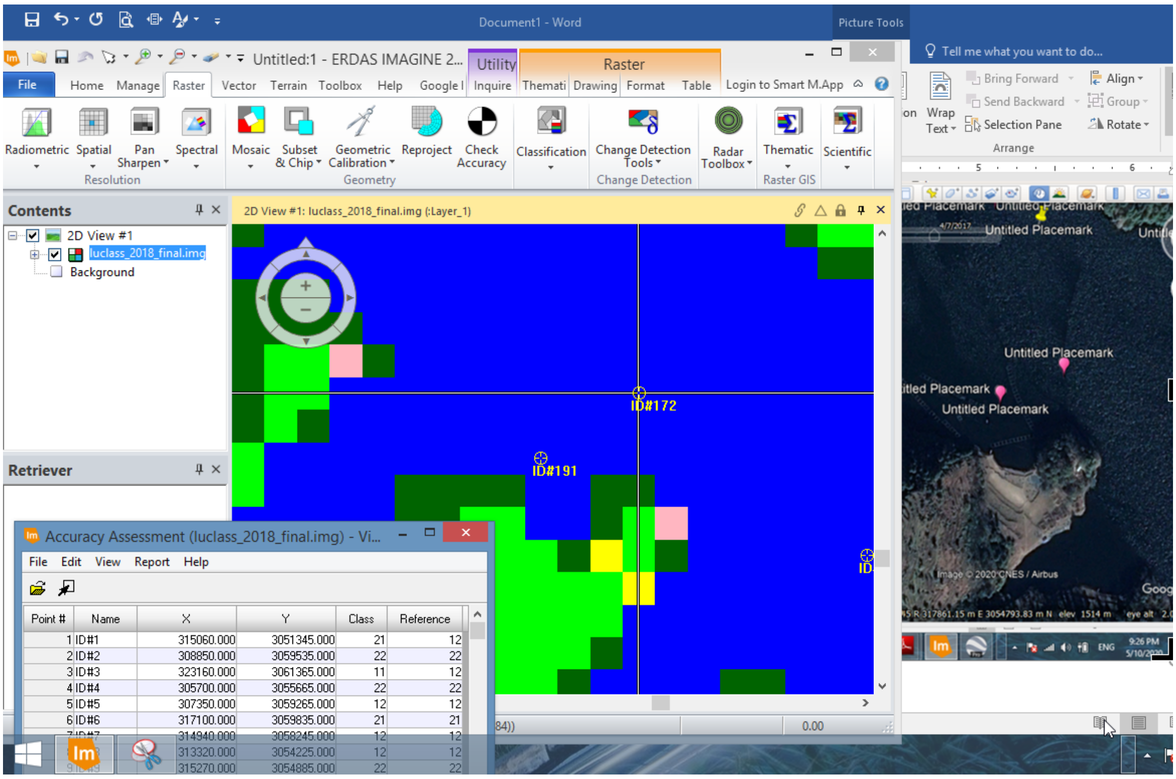


Figure 4. 2 Example sample of Accuracy Assessment Using Google Earth Link

4.2.1 Error Matrix

The error matrices were obtained as an output of accuracy assessment process using ERDAS imagine tool. Those matrices for the LULC classes for 2002, 2010 and 2018 have been illustrated having classified data against the reference data in Table 4.4, Table 4.5 and Table 4.6.

Table 4. 4 Error Matrix Table for LULC Classification, 2002

Classified Data	Reference Data					Row Total
	Forest	Agriculture and built	Grass and shrub land	Barren land	Water bodies	
Forest	104	2	1	0	0	107
Agriculture and built	11	80	19	0	0	110
Grass and shrub land	0	2	22	0	0	24
Barren land	1	0	0	4	0	5
Water bodies	0	0	0	0	4	4
Column Total	116	84	42	4	4	250

Table 4. 5 Error Matrix Table for LULC Classification, 2010

Classified Data	Reference Data					Row Total
	Forest	Agriculture and built	Grass and shrub land	Barren land	Water bodies	
Forest	119	5	3	0	0	127
Agriculture and built	0	45	4	0	0	49
Grass and shrub land	0	3	61	0	0	64
Barren land	0	0	0	6	0	6
Water bodies	0	0	0	0	4	4
Column Total	119	53	68	6	4	250

Table 4. 6 Error Matrix Table for LULC Classification, 2018

Classified Data	Reference Data					Row Total
	Forest	Agriculture and built	Grass and shrub land	Barren land	Water bodies	
Forest	48	1	1	0	0	50
Agriculture and built	0	38	12	0	0	50
Grass and shrub land	0	3	47	0	0	50
Barren land	0	1	6	43	0	50
Water bodies	0	0	0	1	49	50
Column Total	48	43	66	44	49	250

4.2.2 Kappa (K) Statistics as well as Producer's and User's Accuracy for LULC Classes

The indices used for the evaluation were overall accuracy, overall K statics as well as producer's and user's accuracy for individual LULC classes.

The ranges obtained for producer's accuracy for individual LULC were found as 52.38% - 100%, 84.91% - 100% and 71.21% - 100% whereas the ranges of user's accuracy were found as 72.73% - 100%, 91.84% - 100% and 76.00% - 98.00% respectively for the classification of 2002, 2010 and 2018 land sat images (Table 4.7).

Table 4. 7 Producer's and User's Accuracy for Individual LULC 2002, 2010 and 2018

Class Name	2002 (%)		2010 (%)		2018 (%)	
	Producer's	User's	Producer's	User's	Producer's	User's
Forest	89.66	97.20	100.00	93.70	100.00	96.00
Agriculture and built up	95.24	72.73	84.91	91.84	88.37	76.00
Grass and shrub land	52.38	91.67	89.71	95.31	71.21	94.00
Barren land	100.00	80.00	100.00	100.00	97.73	86.00
Water bodies	100.00	100.00	100.00	100.00	100.00	98.00

The results show that the achieved overall classification accuracies were 85.6%, 94% and 90%. Similarly, the overall K statistics were obtained as 0.7739, 0.9071 and 0.8750 respectively for the classification of 2002, 2010 and 2018 images (Table 4.8).

Table 4. 8 Overall Accuracy and Kappa (K) Statistics for LULC 2002, 2010 and 2018

Class Name	2002	2010	2018
	Kappa	Kappa	Kappa
Forest	0.9477	0.8798	0.9505
Agriculture and built	0.5893	0.8964	0.7101
Grass and shrub land	0.8998	0.9356	0.9185
Barren land	0.7967	1.0000	0.8301
Water bodies	1.0000	1.0000	0.9751
Overall Kappa (K) Statistics	**0.7739**	**0.9071**	**0.8750**
Overall Classification Accuracy (%)	**85.6**	**94**	**90**

4.3. Land Use Land Cover Change Occurred for 2002, 2010 and 2018

The result on LULC change showed that the forest land cover was continuously increased at the rate of 10.2% from 2002 to 2010 and 2.6% from 2010 to 2018 to achieve overall increment as 13% from 2002 to 2018. On contrast, the agriculture and built up area was found continuously decreased at the rate of -30% from 2002 to 2010 and -21.1% from 2010 to 2018 to lose overall -44.7% from 2002 to 2018. Similarly, the grass and shrub land was found increased at the rate of 68% from 2002 to 2010 and 19% from 2010 to 2018 to achieve overall increment rate 99.9% from 2002 to 2018. Unlikely, the barren land cover was found decreased at the rate of -10.2% from 2002 to 2010 and again increased by 46.2% to overall gain 31.3% from 2002 to 2018. Likely, the water bodies was found decreased at the rate of -14.2% from 2002 to 2010 and gained by 8% from 2010 to 2018 to overall lose by -7.3% from 2002 to 2018 (Table 4.9 and Figure 4.3).

Table 4. 9 Status of LULC Change Detection Based on 2002, 2010 and 2018

Land Use Land Cover	Area Change into Hectare			Area Change into Percent		
	2002-2010	2010-2018	2002-2018	2002-2010	2010-2018	2002-2018
1.Forest	493.6	137.4	631.0	10.2	2.6	13.0
2.Agriculture and built up	-1632.5	-803.4	-2435.9	-30.0	-21.1	-44.7
3.Grass and shrub land	1188.0	558.6	1746.7	68.0	19.0	99.9
4.Barren land	-23.2	94.8	71.6	-10.2	46.2	31.3
5.Water bodies	-25.8	12.5	-13.3	-14.2	8.0	-7.3

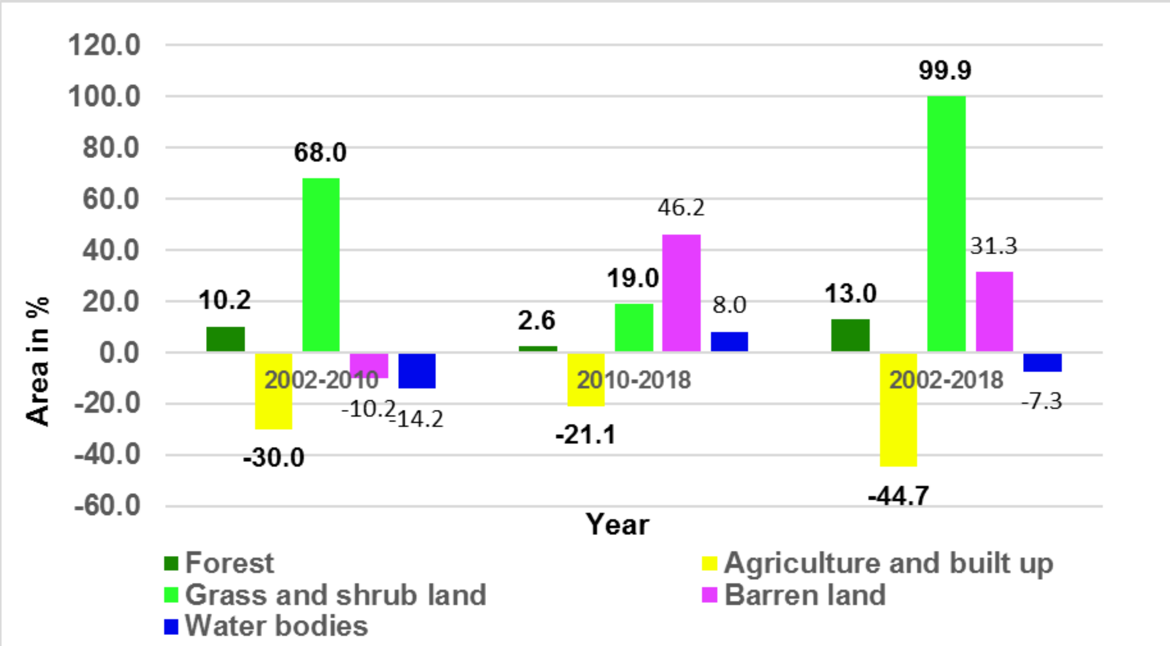


Figure 4. 3 LULC Change from 2002 to 2010, 2010 to 2018 and 2002 to 2018

4.3.1 Land Use Land Cover Change and Conversion from 2002 to 2010

The distribution of LULC conversion during 2002 to 2010 was found as follows in Table 4.10. Each class for the first year map was compared with the same location for next year map class. This result provided class wise land use and cover transformation areas from previous year to consecutive year. During 2002 to 2010, large amount of agriculture and built up area has been converted into forest (821 ha), grass and shrub land (1631ha) and barren land (98 ha) class categories amounting about 2550 hectares. There were also cases of conversion of other land use classes in 2002 into forest land class in 2010. The LULC class conversion was also huge from grass and shrub land (398 ha ha) to forest cover and 584 ha to agriculture and built. Unlikely, a measurable amount of the forest cover area was also found converted into agriculture and built and grass and shrub land by 139 hectare and 542 hectare respectively. Furthermore, the barren land was also found converted into forest (33 ha) and agriculture and built (152 ha). Little area of water bodies was also found converted into forest cover, barren land and agriculture and built up in this 8-year period.

Table 4. 10 Land Use Land Cover Change Matrix from 2002 to 2010

Land Use Class		Land Use 2002					Grand Total
		Forest	Agriculture and built up	Grass and shrub land	Barren land	Water bodies	
Land Use 2010	Forest	4115.3	821.4	397.7	33.0	21.7	5389.2
	Agriculture and built up	139.3	2975.7	584.3	152.2	6.0	3857.5
	Grass and shrub land	542.2	1631.0	682.9	14.4	1.6	2872.1
	Barren land	44.0	98.3	24.0	15.9	9.3	191.5
	Water bodies	12.8	0.0	0.0	0.1	143.8	156.7
	Grand Total	4853.6	5526.4	1689.0	215.5	182.5	12467.0

4.3.2 Land Use Land Cover Change and Conversion from 2010 to 2018

During the period of 2010 to 2018 (Table 4.11), the forest land cover was found converted to agriculture and built up, grass and shrub land, barren land and even in water bodies having about 528 (ha), 362 (ha), 28 (ha) and 17 (ha) respectively. A huge amount of agriculture and built up land cover (1674 ha) was found converted into grass and shrub land followed by its conversion into barren land cover (180 ha), forest cover (104 ha) and in to water bodies (3 ha). Similarly, a moderate amount of grass and shrub land cover was found converted in to forest cover (926 ha), into agriculture and built up land (509 ha) and into barren land (40 ha). Likely, the lower amount of barren land cover was found converted into forest cover (32 ha), agriculture and built up land (83 ha) and grass and shrub land cover (61 ha). The water bodies was also found converted into forest land in this period.

Table 4. 11 Land Use Land Cover Change Matrix from 2010 to 2018

Land Use Class		Land Use 2010					Grand Total
		Forest	Agriculture and built up	Grass and shrub land	Barren land	Water bodies	
Land Use 2018	Forest	4452.8	104.5	926.0	31.7	12.0	5527.0
	Agriculture and built up	528.7	1894.8	509.2	82.9	0.5	3016.0
	Grass and shrub land	362.7	1673.9	1396.2	61.2	0.1	3494.1
	Barren land	28.7	180.4	40.0	11.1	0.0	260.2
	Water bodies	17.1	3.2	0.5	4.8	144.1	169.7
	Grand Total	5390.1	3856.8	2871.8	191.6	156.7	12467.0

4.3.3 Overall Land Use Land Cover Change and Conversion from 2002 to 2018

The overall result on LULC conversion from 2002 to 2018 has been presented the table 4.12 below. The result showed that the forest cover was lost about 651 hectare by conversion into and gained about 1324 hectare from agriculture and built up land, grass and shrub land, barren land and water bodies. Similarly, the major amount of agriculture and built up land was converted into grass and shrub land (2383 ha) followed by its conversion into forest (738 ha) and barren land (193 ha) to loss total 3415 hectare and found gained about 805 hectare only by theses other LULC classes. Likely, the grass and shrub land cover was found lost total about 910 hectare and gained about 2716 hectare from other LULC classes. The barren land was also found lost about 195 hectare into and gained about 240 hectare from the other LULC classes. In similar way, the water bodies was found to have higher loss than gain in the study period.

Table 4. 12 Overall Land Use Land Cover Change Matrix from 2002 to 2018

Land Use Class		Land Use 2002					Grand Total
		Forest	Agriculture and built up	Grass and shrub land	Barren land	Water bodies	
Land Use 2018	Forest	4203.9	738.6	545.1	24.3	15.7	5527.6
	Agriculture and built up	315.8	2210.7	344.7	138.9	5.4	3015.5
	Grass and shrub land	298.2	2383.5	778.2	32.1	2.1	3494.1
	Barren land	25.8	192.8	20.4	20.1	1.0	260.1
	Water bodies	10.9	0.3	0.0	0.1	158.4	169.7
	Grand Total	4854.6	5525.8	1688.5	215.5	182.5	12467.0

4.4. Estimated Sedimentation Rate of Kulekhani Watershed in 2002, 2010 and 2018

4.4.1 Estimated Sedimentation Rate of Kulekhani Watershed in 2002, 2010 and 2018

The result obtained from running the model showed that the annual sedimentation rate of the Kulekhani watershed was found continuously decreasing at the rate of 13.3 (t/ha/yr), 6.6 (t/ha/yr) and 4.8 (t/ha/yr) for the year 2002, 2010 and 2018 respectively. Similarly, the potential soil loss predicted by RUSLE was also found in decreasing at the rate of 157.0 (t/ha/yr), 100.0 (t/ha/yr) and 83.7 (t/ha/yr) for the three temporal analyzing year. On contrast, the sediment retention capacity of the watershed was found increasing at the rate of 3058.5 (t/ha/yr), 3065.2 (t/ha/yr) and 3067.0 (t/ha/yr) for those three year 2002, 2010 and 2018 respectively (Table 4.13).

Table 4. 13 Annual Sedimentation Rate (Yield), Retention and Potential Soil Loss of Kulekhani Watershed

Total area of the watershed (ha)	Sedimentation Types	Year			Mean
		2002	2010	2018	
12467	Sediment exported (t/ha/yr)	13.3	6.6	4.8	8.2
	Sediment retention (t/ha/yr)	3058.5	3065.2	3067.0	3063.6
	Soil loss (t/ha/yr)	157.0	100.0	83.7	113.6

4.4.2 Estimated Sedimentation Rate of Kulekhani Watershed at Sub-watershed Level in 2002, 2010 and 2018

The result on estimation of sediment yield (exported to stream), sediment retention and potential soil loss in terms of ton per year per sub-watershed were obtained as absolute value from running the InVEST SDR_{max} model and it was converted into ton per hectare per year per sub-watershed to examine the status of each sub-watershed with respect to sedimentation phenomena. The results for 2002, 2010 and 2018 have been presented in Table 4.14, Table 4.15 and Table 4.16 respectively.

Regarding the result of 2002, out of total ten sub-watersheds, the Andheri Khola was found to have the highest contributor for sediment yield (22.5 t/ha/yr) followed by Palung (22.2 t/ha/yr), Simbhanjyang (21.5 t/ha/yr), Shankhmool (17.5 t/ha/yr), Gharti (10.2 t/ha/yr) and others (between 5.9 to 9.4 t/h/yr) for 2002. Unlikely, the Simbhanjyang was found most valuable for sediment retention (3681 t/ha/yr) followed by Palung (3669 t/ha/yr), Chitlang (3545 t/ha/yr), Salmakulekhani (3214 t/ha/yr), Khaiti (3133 t/ha/yr) and others (between 2020 to 3076 t/ha/yr). In similar way, the Sankhmool was found the most contributor for potential soil erosion (251 t/ha/yr) followed by Palung (247 t/ha/yr), Andheri (198 t/ha/yr), Simbhanjyang (176 t/ha/yr), Salmakulekhani (149 t/ha/yr) and others (between 82 to 127 t/ha/yr) for that year (Table 4.14).

Table 4. 14 Annual Sedimentation Rate at Sub-watershed Level in 2002

Sub-watershed		Sediment exported	Sediment retention	Soil Loss	Sediment exported/ area	Sediment retention/ area	Soil Loss/area
ID	Name	(t/yr)	(t/yr)	(t/yr)	(t/ha/yr)	(t/ha/yr	(t/ha/yr)
1	Andheri Khola	29498.0	4032499.3	258820.0	22.5	3076.4	197.5
2	Bisinkhel Khola	8225.0	2150061.0	119481.9	8.4	2190.2	121.7
3	Chitlang Khola	16154.5	8162161.9	235766.3	7.0	3544.8	102.4
4	Chuliprang Khola	12357.1	3084324.5	194245.0	8.1	2020.4	127.2
5	Gharti Khola	9123.9	2740865.8	105303.4	10.2	3051.6	117.2
6	Khaiti Khola	3939.4	2076176.8	54166.6	5.9	3133.4	81.7
7	Palung Khola	29928.4	4953743.5	333290.2	22.2	3668.6	246.8
8	Salmakulekhani Khola	8386.3	2873629.3	132941.3	9.4	3213.8	148.7
9	Sankhmool Khola	17817.3	3067460.5	255715.1	17.5	3004.5	250.5
10	Simbhanjyang Khola	32658.4	5592503.2	267133.8	21.5	3681.3	175.8

The result of sediment estimation for 2010 showed that the Andheri was the highest contributor for sediment yield (11.5 t/ha/yr) followed by Palung (10.7 t/ha/yr), Simbhanjyang (9.6 t/ha/yr), Salmakulekhani (6.3 t/ha/yr), Sankhmool and Bisinkhel (5.7 t/ha/yr) and others (between 1.8 to 5.2 t/ha/yr). Similarly, the Simbhanjyang was found most valuable for sediment retention (3693 t/ha/yr) followed by Palung (3680 t/ha/yr), Chitlang (3547 t/ha/yr), Salmakulekhani (3217 t/ha/yr), Khaiti (3138 t/ha/yr), Andheri

(3088 t/ha/yr) and others (between 2023 to 3058 t/ha/yr). Unlikely, the Palung was found the highest contributor for potential soil erosion (147 t/ha/yr) followed by Andheri (125 t/ha/yr), Shankhmool (121 t/ha/yr), Simbhanjyang (115 t/ha/yr) and others (between 38 to 98 t/ha/yr) for the year 2010 (Table 4.15).

Table 4. 15 Annual Sedimentation Rate at Sub-watershed Level for 2010

Sub-watershed		Sediment exported	Sediment retention	Soil Loss	Sediment exported/ area	Sediment retention/ area	Soil Loss/area
ID	Name	(t/yr)	(t/yr)	(t/yr)	(t/ha/yr)	(t/ha/yr	(t/ha/yr)
1	Andheri Khola	15038.6	4046958.7	163674.3	11.5	3087.5	124.9
2	Bisinkhel Khola	5640.3	2152645.8	90282.7	5.7	2192.8	92.0
3	Chitlang Khola	11873.9	8166443.0	189471.7	5.2	3546.6	82.3
4	Chuliprang Khola	7790.2	3088891.2	149860.6	5.1	2023.4	98.2
5	Gharti Khola	3675.7	2746314.4	71363.4	4.1	3057.6	79.5
6	Khaiti Khola	1183.5	2078932.6	24882.2	1.8	3137.5	37.6
7	Palung Khola	14507.7	4969164.6	198813.1	10.7	3680.0	147.2
8	Salmakulekhani Khola	5625.9	2876389.5	91793.7	6.3	3216.9	102.7
9	Sankhmool Khola	5783.4	3079494.3	123047.7	5.7	3016.3	120.5
10	Simbhanjyang Khola	14510.7	5610650.8	175101.1	9.6	3693.3	115.3

The estimated result on sedimentation for 2018 showed that the Palung was the highest contributing sub-watershed for sediment yield (9.0 t/ha/yr) followed by Andheri (6.9 t/ha/yr), Simbhanjyang (5.4 t/ha/yr), Shankhmool (5.4 t/ha/yr) and others (between 3.0 to 4.2 t/ha/yr). On contrast, the Simbhanjyang was found the most valuable for sediment retention (3697 t/ha/yr) followed by Palung (3682 t/ha/yr), Chitlang (3548 t/ha/yr), Salmakulekhani (3219 t/ha/yr), Khaiti (3136 t/ha/yr), Andheri (3192 t/ha/yr) and others (between 2025 to 3058 t/ha/yr). Unlikely, Palung was the highest contributing sub-watershed for potential soil erosion (133 t/ha/yr) followed by Sankhmool (107 t/ha/yr), Andheri (99 t/ha/yr), Simbhanjyang (85 t/ha/yr), Salmakulekhani (80 t/ha/yr) and others (between 53 to 75 t/ha/yr) for 2018 (Table 4.16).

Table 4. 16 Annual Sedimentation Rate at Sub-watershed Level for 2018

Sub-watershed		Sediment exported	Sediment retention	Soil Loss	Sediment exported/ area	Sediment retention/ area	Soil Loss/ area
ID	Name	(t/yr)	(t/yr)	(t/yr)	(t/ha/yr)	(t/ha/yr	(t/ha/yr)
1	Andheri Khola	9005.3	4052992.1	129375.3	6.9	3092.1	98.7
2	Bisinkhel Khola	4155.0	2154131.0	73448.1	4.2	2194.3	74.8
3	Chitlang Khola	7842.7	8170473.9	152531.8	3.4	3548.4	66.2
4	Chuliprang Khola	5127.1	3091554.5	112786.5	3.4	2025.1	73.9
5	Gharti Khola	3204.2	2746785.7	58673.0	3.6	3058.2	65.3
6	Khaiti Khola	2014.0	2078102.0	34833.2	3.0	3136.3	52.6
7	Palung Khola	12197.9	4971474.3	179294.9	9.0	3681.7	132.8
8	Salmakulekhani Khola	3373.4	2878642.1	71846.0	3.8	3219.4	80.4
9	Sankhmool Khola	5484.8	3079793.0	109584.0	5.4	3016.6	107.3
10	Simbhanjyang Khola	8145.2	5617016.6	129549.1	5.4	3697.4	85.3

4.5. Analysis of Sub-watersheds based on Sedimentation Rate

In overall, the Palung was found as the highest contributing sub-watershed for annual sediment yield (13.98 t/ha/yr) followed by Andheri (13.62 t/ha/yr), Simbhanjyang (12.14 t/ha/yr), Shankhmool (9.5 t/ha/yr) and others (between 3.59 to 6.48 t/ha/yr). Regarding the sediment retention, the Simbhanjyang was found the highest contributor for sediment retention (3691 t/ha/yr) followed by Palung (3677 t/ha/yr), Chitlang (3547 t/ha/yr), Salmakulekhani (3217 t/ha/yr), Khaiti (3136 t/ha/yr), Andheri (3185 t/ha/yr) and others (between 2023 to 3057 t/ha/yr). Similarly, the Palung was found the highest contributing sub-watershed for potential soil erosion (175 t/ha/yr) followed by Sankhmool (159 t/ha/yr), Andheri (140 t/ha/yr), Simbhanjyang (126 t/ha/yr), Salma Kulekhani (111 t/ha/yr) and others (between 57 to 96 t/ha/yr) for the study period from 2002 to 2018 (Table 4.17).

Table 4. 17 Overall Status of Sub-watersheds with Respect to Sedimentation Rate

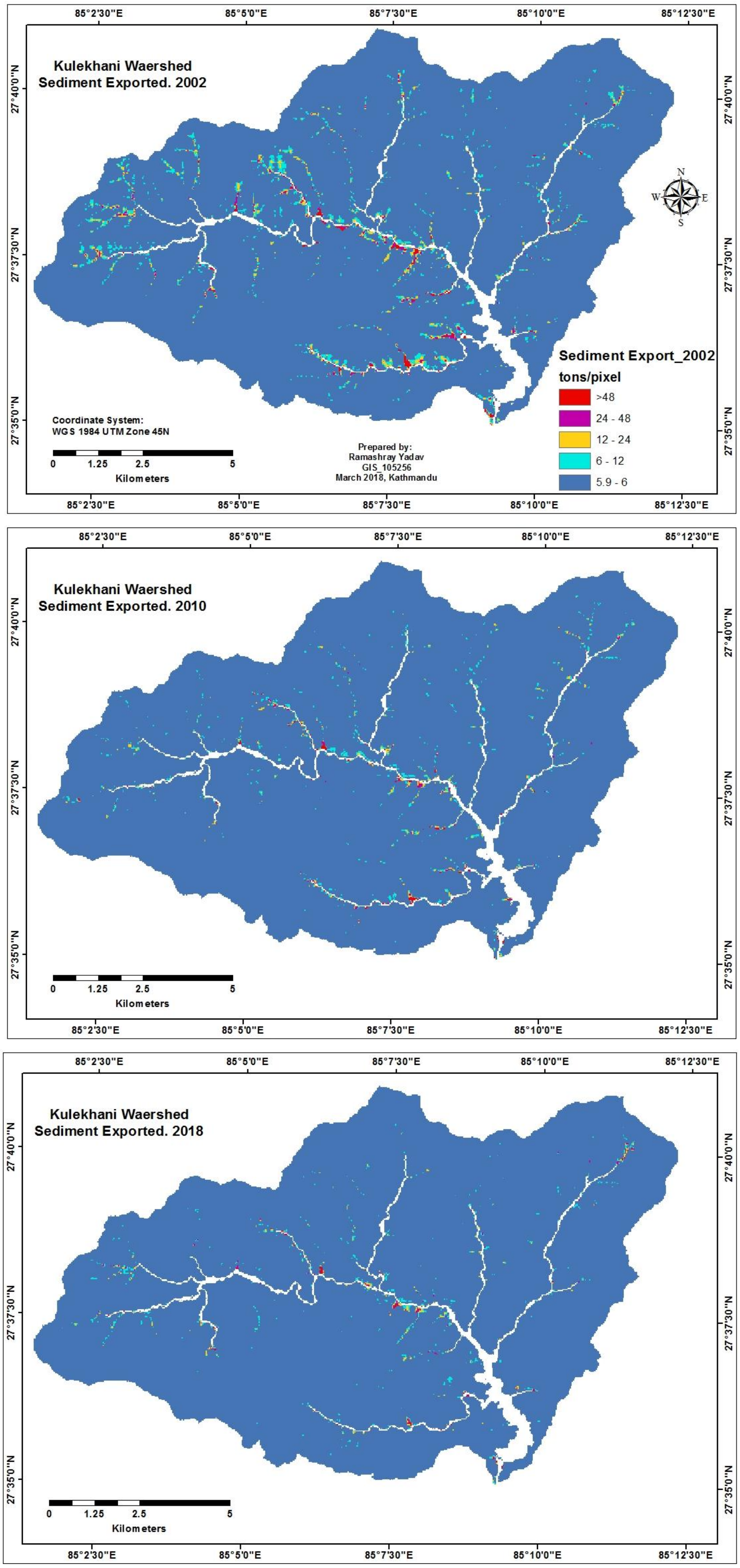
Sub-watershed		Sediment exported (t/ha/yr)			Sediment retention (t/ha/yr)			Soil loss (t/ha/yr)		
ID	Name	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
1	Andheri Khola	6.9	22.5	13.6	3076.4	3092.1	3085.3	98.7	197.5	140.3
2	Bisinkhel Khola	4.2	8.4	6.1	2190.2	2194.3	2192.5	74.8	121.7	96.2
3	Chitlang Khola	3.4	7.0	5.2	3544.8	3548.4	3546.6	66.2	102.4	83.6
4	Chuliprang Khola	3.4	8.1	5.5	2020.4	2025.1	2023.0	73.9	127.2	99.8

Sub-watershed		Sediment exported (t/ha/yr)			Sediment retention (t/ha/yr)			Soil loss (t/ha/yr)		
ID	Name	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
5	Gharti Khola	3.6	10.2	5.9	3051.6	3058.2	3055.8	65.3	117.2	87.3
6	Khaiti Khola	1.8	5.9	3.6	3133.4	2819.3	3135.7	37.6	81.7	57.3
7	Palung Khola	9.0	22.2	14.0	3668.6	3681.7	3676.8	132.8	246.8	175.6
8	Salmakulekhani Khola	3.8	9.4	6.5	3213.8	3219.4	3216.7	80.4	148.7	110.6
9	Sankhmool Khola	5.4	17.5	9.5	3004.5	3016.6	3012.5	107.3	250.5	159.4
10	Simbhanjyang Khola	5.4	21.5	12.1	3681.3	3697.4	3690.7	85.3	175.8	125.5

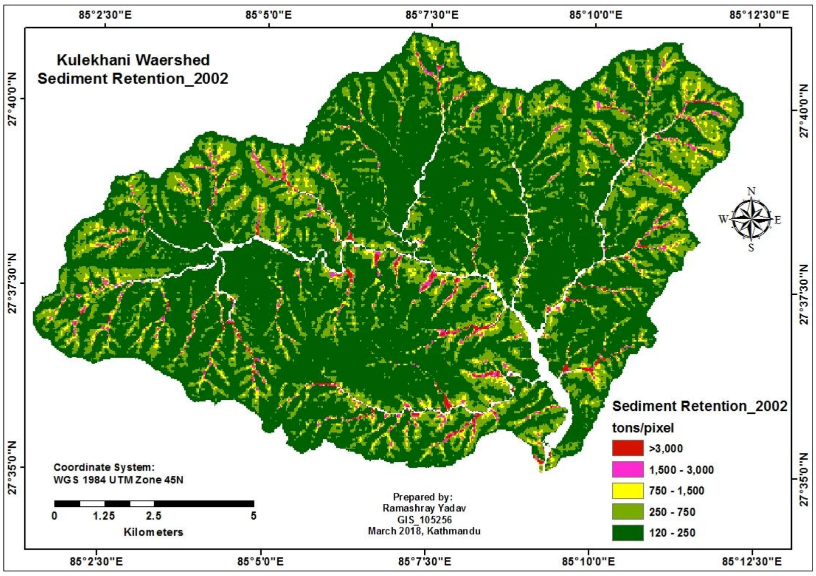
Ultimately, the scenario of sediment export and potential soil loss were found in decreasing trend whereas the sediment retention was found in increasing with low rate but continuously (Map 4.7, Map 4.8 and Map 4.9).

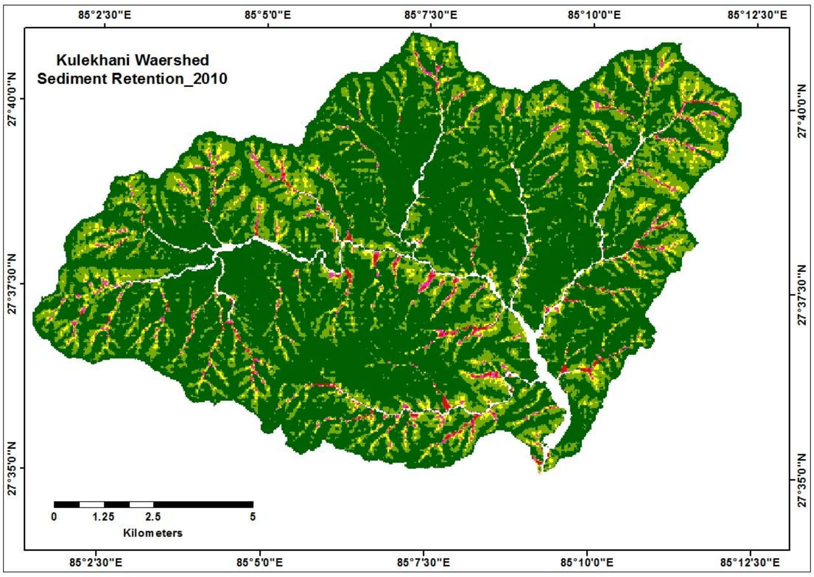
4.5.1. Most Sensitive Sub-watershed within the Watershed Based on Sediment Yield

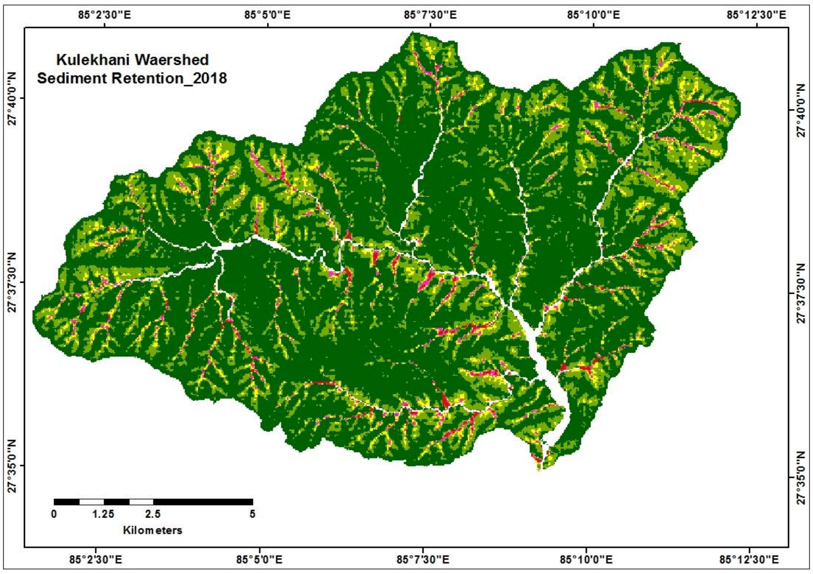
As the sediment export (yield) presence on a sub-watershed is considered as very important in developing management plan to preserve water storage capacity of the reservoir (Bouguerra et al., 2019, p. 4178), the sub-watersheds were primarily ranked on the basis of annual sediment yield rate exported by them. The values of annual sediment yield rate obtained from the analysis of result were sorted in descending order to assign the sensitivity rank for the sub-watersheds as suggested by Welde (2016, pp. 37–38). According to Borrelli et al. (2015, p. 8), the sub-watersheds having sedimentation rate from 1 to 5 (t/ha/yr) belong the moderate soil erosion risk and the greater than 5 (t/ha/yr) considered to be in high soil erosion risk in terms of sedimentation occurrence. Hence, the 90% of the sub-watersheds (rank 1 to 9 in table 4.18) belong to the high erosion risk remaining one sub-watershed (Khaiti). However, the Palung sub-watershed was found as the most sensitive in terms of sediment producers to the reservoir (13.98 t/ha/yr) followed by other three major sensitive sub-watersheds Andheri (13.62 t/ha/yr), Simbhanjiyang (12.14 t/ha/yr) and Shankhmool Khola (9.5 t/ha/yr) where their erosion risks are very much close to each other (Table 4.18).



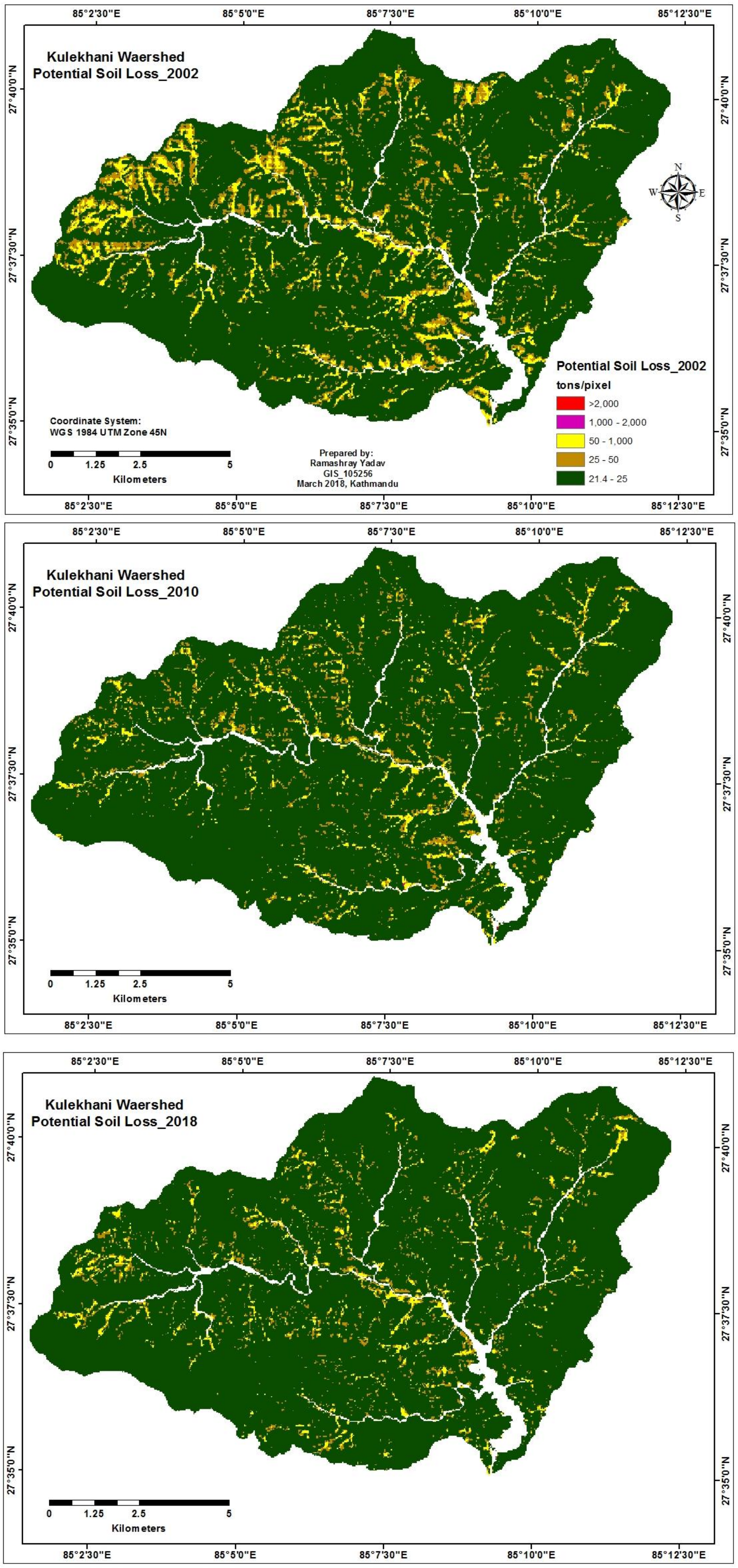
Map 4. 7 Sediment Export of Study Area in 2002 (Top), 2010 (Middle) and 2018 (Bottom)







Map 4. 8 Sediment Retention of Study Area in 2002 (Top), 2010 (Middle) and 2018 (Bottom)

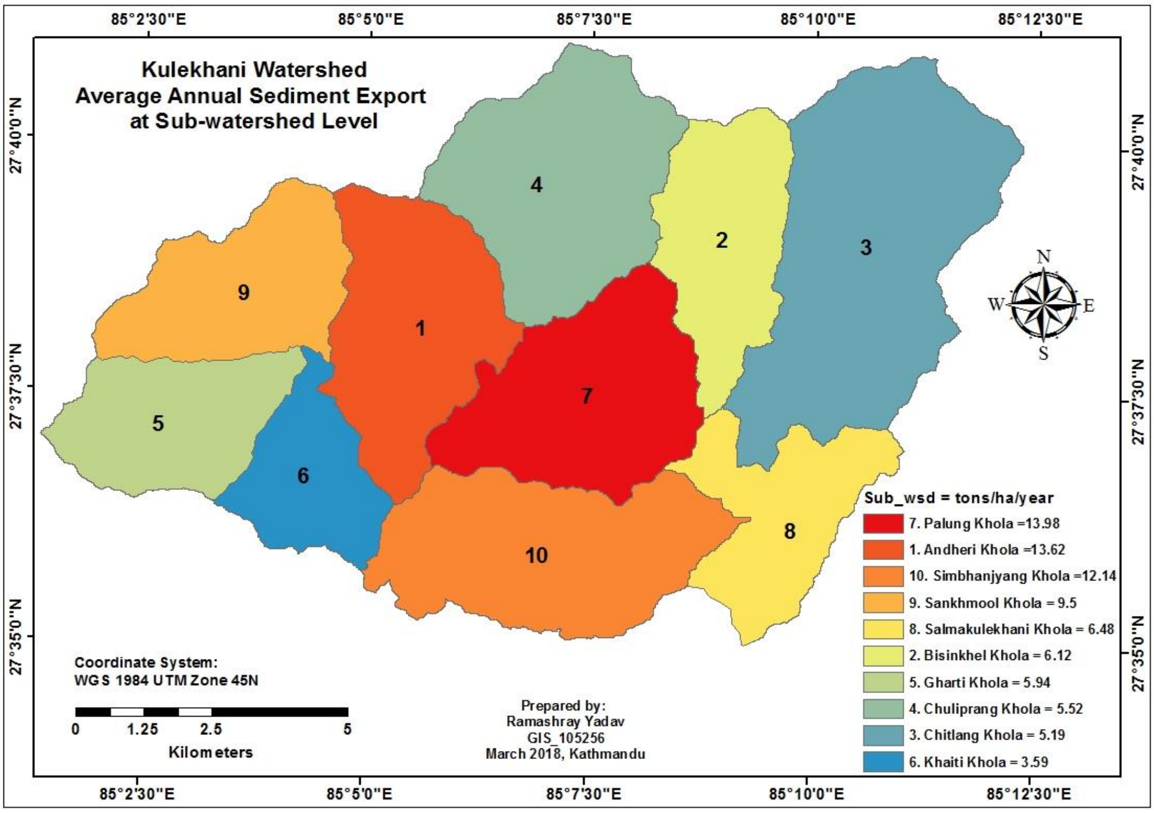


Map 4. 9 Potential Soil Loss of Study Area in 2002 (Top), 2010 (Middle) and 2018 (Bottom)

Table 4. 18 Prioritization of Sensitive Sub-watersheds Based on Annual Sedimentation Yield

Sub-watersheds	Dominant soil type	Sediment exported	Sensitivity Rank	FG LULC total area	AB LULC total area	Water bodies area	AB/FG	A/F
ID		(t/ha/yr)	Order	Ha	Ha	Ha	Ratio	Ratio
7	Eutric Cambisol and Chromic Cambislols	13.98	1	691.0	654.1	7.4	0.95	1.28
1	Chromic Cambislols only	13.62	2	721.9	590.5	0.0	0.82	1.41
10	Eutric Cambisol and Chromic Cambislols	12.14	3	984.3	527.6	6.4	0.54	0.70
9	Eutric Cambisol and Chromic Cambislols	9.50	4	610.3	409.5	0.0	0.67	1.59
8	Eutric Cambisol and Chromic Cambislols	6.48	5	499.9	247.9	145.6	0.50	0.67
2	Eutric Cambisol and Chromic Cambislols	6.12	6	587.2	393.4	1.9	0.67	1.06
5	Eutric Cambisol and Chromic Cambislols	5.94	7	682.9	215.0	0.0	0.31	0.42
4	Eutric Cambisol and Chromic Cambislols	5.52	8	901.6	624.0	0.0	0.69	1.12
3	Eutric Cambisol and Chromic Cambislols	5.19	9	1707.5	586.4	8.1	0.34	0.46
6	Eutric Cambisol and Chromic Cambislols	3.59	10	554.2	108.3	0.0	0.20	0.20

The ratio values (AB/FG) for combined area of agriculture and built up (A) and barren land (B) to the combined area of forest cover (F) and grass and shrub land (G) was calculated to know the factors more sensitive to influence the sedimentation. Similarly, the ratio values (A/F) of the absolute agriculture and built up (A) to the forest cover (F) was also calculated to support the above similar results. The sub-watersheds having sensitive rank order 1 to 4 were found to have relatively higher ratios values for AB/FG as well as A/F compared to the sub-watersheds having the lowest sensitive rank order from 8 to 10 (Table 4.18 and Map 4.10).



Map 4. 10 Average Annual Sediment Yield of Kulekhani Watershed at Sub-watershed Level

4.6. Relationship between the Sedimentation Rate Predicted and Observed in the Reservoir

The InVEST retention model provided three types of output annual sediment exported to the stream, sediment retention by vegetation or other control measures in the field and potential soil loss estimated by RUSLE in assumption of the field as bare land. Out of them, only the data on sediment exported to the stream as annual sedimentation yield is comparable with the measured or observed sedimentation yield for that respective year (NCP, 2017, p. 144). The measured data of sedimentation yield in 2002, 2010 and 2018 were derived from the NEA sedimentation report, 2003, 2011 and 2018 and converted to the similar unit as obtained from the model for comparison of the data on sedimentation yield. The collected data on sedimentation yield of the reservoir was in million m^3 unit that was divided by 1,000,000 to convert first into m^3 and then it was divided by the area (12467 ha) of the watershed to convert into m^3/ha unit. Finally the data was multiplied by dry density of sediment (2.6 t/m^3) adopted by Shrestha (2012, pp. 8–12) for the Kulekhani reservoir to convert into ton/ha/year for matching the unit of the data provided by the model.

The correlation between sediment yield measured in the Kulekhani reservoir and predicted by the model was found significant with low positive value having correlation coefficient r = 0.31579.

The result of the comparison showed that the data on sedimentation yield measured in the reservoir for 2002, 2010 and 2018 was found about close to each other in quantity with similar decreasing trend in their respective year. However, the data of 2010 was found relatively far from each other compared to that of for 2002 and 2018 (Table 4.19 and Figure 4.4).

Table 4. 19 Annual Sedimentation Yield Measured and Predicted for the Reservoir

Year	Annual sedimentation yield measured in the reservoir		Annual sedimentation yield predicted by the model
	Mm^3	ton/ha/year	ton/ha/year
2002	0.06	12.513	13.3
2010	0.001	0.209	6.6
2018	0.06	12.513	4.8

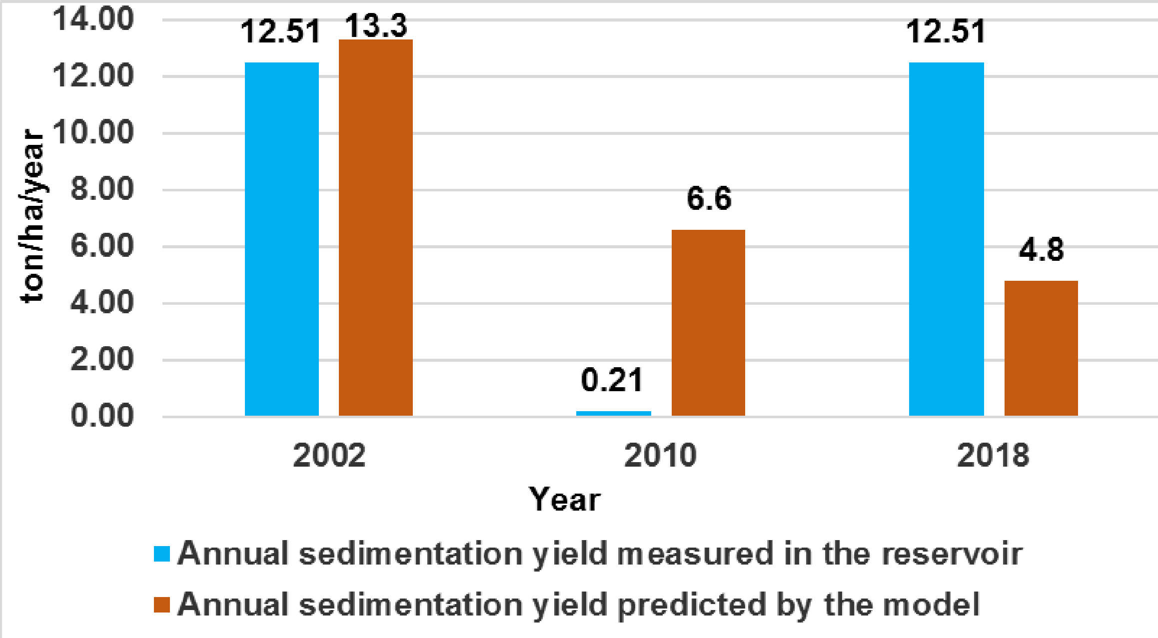


Figure 4. 4 Comparison of Predicted and Measured Sedimentation Yield of the Reservoir

4.7. Discussion

4.7.1. Scenario of Land Use Land Cover Change in the Kulekhani Watershed

We need Land use land cover to have accurate and updated information for detailed eco-system studies having hydrological modeling (Usman et al., 2015). The result on land use land cover assessment of the Kulekhani watershed was found that the land cover area of the forest increased continuously during 2002, 2010 and 2018 having 4860 (ha), 5354 (ha) and 5491 (ha) respectively. Similarly, the grass and shrub land cover was found increased continuously within these three time period having 1748 (ha), 2936 (ha) and 3494 (ha) respectively. In the contrast, the agriculture and built up area was found decreased within these period in parallel of the above two cover classes having 5449 (ha), 3816 (ha) and 3013 (ha) correspondingly. Unlikely, the others two land cover classes barren land water bodies have been found decreased first in 2010 but increased in 2018 with low amount. The agriculture and built up was found in first position for 2002, second position for 2010 and third position for 2018. This LULC status of the Kulekhani watershed is relatively supported by the previous studies carried out by Ban et al. (2016, p. 329) and Shrestha (2016, p. 48,53-58).

Regarding the evaluation of land use land cover classification work, the ranges obtained for producer's accuracy for individual LULC were found as 52.38% - 100%, 84.91% - 100% and 71.21% - 100% whereas the ranges of user's accuracy were found as 72.73% - 100%, 91.84% - 100% and 76.00% - 98.00% respectively for the classification of 2002, 2010 and 2018 land sat images. Similarly, the achieved overall classification accuracies were 85.6%, 94% and 90% as well as the overall K statistics as 0.7739, 0.9071 and 0.8750 respectively for the classification of 2002, 2010 and 2018 images. These obtained values of overall accuracy and overall K statistics have been taken as proved as the classification within the excellent range by Pontius (2000, pp. 1013–1014).

In overall, the two groups of the sub-watersheds were found clearly visible with respect to hold the comparative size of forest cover and agriculture and built up area. In the first, 50% of the sub-watersheds Salmakulekhani, Chitlang, Simbhanjyang, Gharti and Khaiti were found to have the higher forest land cover area than agriculture and built up land cover within the LULC of those sub-watersheds. Among them, the Khaiti was found the highest forest cover holder (74.5%) followed by the Gharti, Chitlang, Simbhanjyang and Salmakulekhnai within all the sub-watersheds of the study area. Shrestha (2016) also found in his study that the major part of the dense forest is located in Khaiti, Gharti and Chitlang sub-watersheds of the Kulekhani watershed.

On the contrast, in the second, 50% of the sub-watersheds namely Bisinkhel, Palung, Chuiliprang, Andheri and Shankhmool were found to have lower forest cover than the agriculture and built up within all the sub-watersheds. However, the Shankhmool was found the poorest to have forest cover only 24.1% followed by other of this poor group as

Andheri (30.2%), Chuliprang (35.1%), Palung (35.3%) and Bisinkhel (36.7%) having possessed lower LULC cover than the agriculture and built up area. Out of total, about 86% of the water bodies was found covered within the Salma Kulekhani followed by Chitlang (4.8%), Palung (4.4%), Simbhanjyang (3.8%) and Bisinkhel (1.1%) (Table 4.3).

The result on LULC change showed that the forest land cover was continuously increased at the rate of 10.2% from 2002 to 2010 and 2.6% from 2010 to 2018 to achieve overall increment as 13% from 2002 to 2018. On contrast, the agriculture and built up area was found continuously increased at the rate of -30% from 2002 to 2010 and -21.1% from 2010 to 2018 to lose overall -44.7% from 2002 to 2018. Similarly, the grass and shrub land was found increased at the rate of 68% from 2002 to 2010 and 19% from 2010 to 2018 to achieve overall increment rate 99.9% from 2002 to 2018. Unlikely, the barren land cover was found decreased at the rate of -10.2% from 2002 to 2010 and again increased by 46.2% to overall gain 31.3% from 2002 to 2018. Likely, the water bodies was found decreased at the rate of -14.2% from 2002 to 2010 and gained by 8% from 2010 to 2018 to overall lose by -7.3% from 2002 to 2018. During the study period the all land use land cover classes were found converted from each other annually. The scenario of these land use land cover changes on Kulekhani watershed has also been supported by previous study. In the previous study, forest area was found decreased from 1978 to 1992 and then in increasing trend whereas the past records for agriculture land has been found vice versa (Shrestha, 2016, p. 71).

4.7.2. Scenario of Land Use Land Cover Change and Sedimentation Level in the Kulekhani Watershed

The result showed that the annual sedimentation rate of the Kulekhani watershed was found continuously decreasing at the rate of 13.3 (t/ha/yr), 6.6 (t/ha/yr) and 4.8 (t/ha/yr) in the year 2002, 2010 and 2018 respectively. Similarly, the potential soil loss predicted by RUSLE was also found in decreasing at the rate of 157 (t/ha/yr), 100 (t/ha/yr) and 83.7

(t/ha/yr) for the three temporal analyzing year. On contrast, the sediment retention capacity of the watershed was found increasing at the rate of 3058.5 (t/ha/yr), 3065.2 (t/ha/yr) and 3067.0 (t/ha/yr) for those three year 2002, 2010 and 2018 respectively. The result revealed the scenario that higher the rate of sediment export means to have greater amount of sediment to be retained by the existing vegetation and anti-erosive activities (Bouguerra et al., 2019, p. 4179). The visible factors behind causing to reduce sedimentation was increasing rate of forest cover as well as grass and shrub land cover but decreasing rate of agriculture and built up area within the watershed (Table 4.18 and figure 4.5). The result was also evidenced by previous study as farm management practices like terrace improvement, conservation pond, grass planting, fruit tree planting, water source protection, irrigation canal improvement. torrent control, embankment protection has been found implemented in the watershed area (Sthapit, 1996, pp. 18–19). The previous studies also shows that the sediment yield of the reservoir changes over time and that function of change depends on watershed management, land use, sediment control measures, hydraulic structure, hydrology as well as other factors like changes in hydrologic variability. The changes in land use and their management affects to be variation in soil erosion rate where implementation of best management practice can reduce the erosion rate ultimately to reduce sedimentation rate (Randle et al., 2017, pp. 15–16). Similarly, Shrestha (2016, p. 2) found significantly positive relationship between increasing sediment deposition and agriculture land but negative relationship with the forest cover increment in the Kulekhani watershed area using RUSLE equation.

In overall, the Palung sub-watershed was found as the highest contributor for annual sediment yield (13.98 t/ha/yr) followed by Andheri (13.62 t/ha/yr), Simbhanjyang (12.14 t/ha/yr), Shankhmool (9.5 t/ha/yr) and others (between 3.59 to 6.48 t/ha/yr).

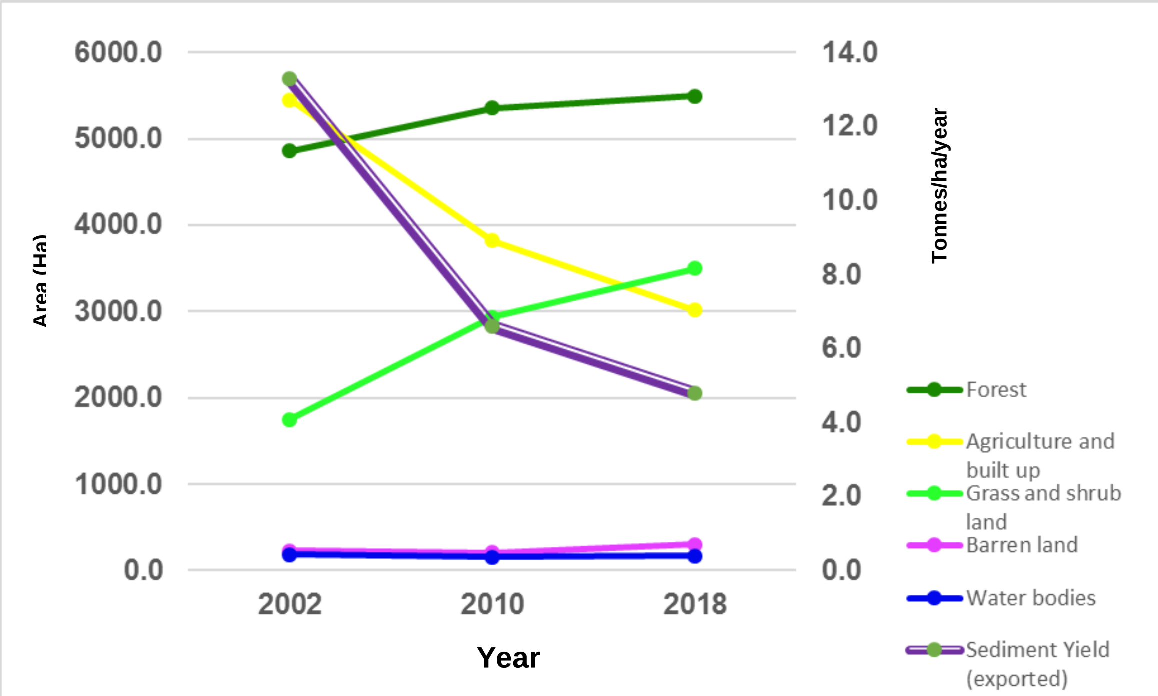


Figure 4. 5 Land Use Land Cover and Sediment Yield in Kulekhani Watershed

Regarding the sediment retention, the Simbhanjyang was found the highest contributor for sediment retention (3691 t/ha/yr) followed by Palung (3677 t/ha/yr), Chitlang (3547 t/ha/yr), Salmakulekhani (3217 t/ha/yr), Khaiti (3136 t/ha/yr), Andheri (3085 t/ha/yr) and others (between 2023 to 3056 t/ha/yr). Similarly, the Palung was found the highest contributing sub-watershed for potential soil erosion (175 t/ha/yr) followed by Sankhmool (159 t/ha/yr), Andheri (140 t/ha/yr), Salmakulekhani (111 t/ha/yr) and others (between 57 to 99 t/ha/yr) for the study period from 2002 to 2018.

4.7.3. Scenario of Sensitive Sub-watershed with respect to Sedimentation Level

According to suggestions provided by Bouguerra et al. (2019, p. 4179) and Welde (2016, pp. 37–38), the sub-watersheds were primarily ranked on the basis of annual sediment yield rate exported by them by sorting in descending order to assign the sensitivity rank for the sub-watersheds. According to Borrelli et al. (2015, p. 8), the sub-watersheds having sedimentation rate from 1 to 5 (t/ha/yr) belong the moderate soil erosion risk and the greater than 5 (t/ha/yr) considered to be in high soil erosion risk in terms of sedimentation occurrence. Hence, the 90% of the sub-watersheds (rank 1 to 9 in table

4.18) belong to the high erosion risk remaining one sub-watershed (Khaiti Khola). However, the Palung sub-watershed was found as the most sensitive in terms of sediment producers to the reservoir (13.98 t/ha/yr) followed by other three major sensitive sub-watersheds Andheri (13.62 t/ha/yr), Simbhanjyang (12.14 t/ha/yr) and Shankhmool (9.50 t/ha/yr) where their erosion risks are very much close to each other.

As the sediment yield is known as the function of runoff and other processes occurring in the watershed (Welde, 2016, pp. 35–37), the sub-watersheds namely Palung, Andheri, Simbhanjyang and Shankhmool determined as most sensitive that was not only due to a single factor of having greater ratios of agriculture and built up land but also due to a combined effects of rainfall erosivity index (R factor) , soil erodibility (K) factor including steep slope of the sites within the watershed. Among the four sub-watersheds, Andheri, Shankhmool and Palung seem to occur within relatively moderate to high rainfall (R factor) values. Likely, the Simbhanjyang was found to occur within moderate rainfall (R factor) values (Table 3.7, Map 1.1 and Map 3.2). Similarly, the Palung has been almost occurred within the higher soil erodibility (K) factor values and, the remaining sub-watersheds belong to have lower to high values of K factor (Map 1.1 and Map 3.4). The greater area (72.2%) of the watershed has been found within the steep slope greater than 26.8% (Appendix-3) or 21% of the total area belongs to greater than 30^0 slope (Table 1.1 and Map 1.3). This result is also evidenced by the previous studies as the Palung Khola is known as main stream of the Kulekhani watershed; Where the discharge increases from June to September during the rainy season (Dhakal, 2011, p. 28) and extensive over use of agriculture land and forest has also been evidenced by the previous studies (Sthapit, 1996, p. 17). Comparatively, the two sub-watersheds of the groups second; namely Khaiti, and Chitlang having lowest sediment exporting values; were found to have relatively reverse characteristics with respect to rainfall erosivity index (R factor), soil erodibility (K) factor, forest cover as well as agriculture and built up land cover within the watershed (Table 4.3,Table 4.18, Map 3.2 and Map 3.4).

4.7.4. Scenario of Relationship between Sediment yield Predicted and Observed in the Reservoir

The correlation between sediment yield measured in the Kulekhani reservoir and predicted by the model showed significant relationship with low positive value having correlation coefficient r = 0.31579. However, the predicted value for the drainage basin has been usually significantly found greater than the measured sediment yield (Atkinson, 1995, p. 273; Vanoni, 1975), the predicted value of sediment yield for 2018 was found comparatively less than the measured. This might be due to the other factors' influence like landslides, streambank erosion or gully erosion occurrences that is not covered by the result of this InVEST model as its limitations. As the previous researcher Pokharel & Thapa, (2018) was found stated that the slope in range 30^{o} – 65^{o} had undergone failure in the past years and further the chance of failure was very high in the slope lying in the range of 40^{o} – 60^{o} in the Kulekhani watershed.

4.8. Calibration and Validation of the Model

According to the suggestions provided by Welde (2016, pp. 35–38) and Vigiak et al. (2012, p. 85), after selecting the sensitive input parameters, the InVEST SDR_{max} model was calibrated for threshold flow accumulation and parameter K_b. The model was calibrated by changing the parameter sequentially for obtaining optimum agreement between observed and simulated sediment yield values. The optimum value for threshold flow accumulation was obtained as 2100 from starting value 1000. Likely, the optimum value for K_b was selected as 1.5 instead of its provided default value as 2.

Comparison of sedimentation rate measured in the reservoir with the obtained predicted sedimentation rate by the model is a means of validation of the obtained result (NCP, 2017, p. 144). According to Hamel et al. (2017, pp. 7–8), available predicted data on sedimentation yield and understanding of the local sediment budget for a given watershed is key to improved confidence in model result. The result of the comparison showed the data on sedimentation yield measured in the reservoir for 2002, 2010 and 2018 relatively closed to each other in quantity with similar decreasing trend in their respective year. However, the data of 2010 was found relatively far from each other compared to that of 2002 and 2018. The correlation between sediment yield measured in the Kulekhani reservoir and predicted by the model showed significant relationship with low positive value having correlation coefficient r = 0.31579. This shows that the result of the InVEST SDR_{max} model has been found in right direction within its limitations.

Chapter-5: Conclusion and Recommendations

5.1 Conclusion

The result on LULC classification of the Kulekhani watershed showed that the forest cover class has been found increased continuously during 2002, 2010 and 2018. Similarly, the grass and shrub land cover was found increased continuously within these three time respectively. In the contrast, the agriculture and built up area was found decreased within these period in parallel of the above two cover classes correspondingly. Unlikely, the others two land cover classes barren land water bodies have been found decreased first in 2010 but increased in 2018 with low amount.

Out of total ten, the two groups of the sub-watersheds were found clearly visible with respect to hold the comparative size of forest cover and agriculture and built up area. In the first, 50% of the sub-watersheds namely Salma Kulekhani, Chitlang, Simbhanjyang, Gharti and Khaiti were found to have the higher forest land cover area than agriculture and built up land cover within the LULC of those sub-watersheds. On the contrast, the second 50% of the sub-watersheds namely Bisinkhel, Palung, Chuiliprang, Andheri and Shankhmool were found to have lower forest cover than the agriculture and built up within all the sub-watersheds.

The result on LULC change showed that the forest land cover was continuously increased at the rate of 10.2% from 2002 to 2010 and 2.6% from 2010 to 2018 to achieve overall increment as 13% from 2002 to 2018. Similarly, the grass and shrub land was found increased at the rate of 68% from 2002 to 2010 and 19% from 2010 to 2018 to achieve overall increment rate 99.9% from 2002 to 2018. On contrast, the agriculture and built up area was found continuously decreased at the rate of -30% from 2002 to 2010 and -21.1% from 2010 to 2018 to lose overall -44.7% from 2002 to 2018. Unlikely, the barren land cover was found decreased at the rate of -10.2% from 2002 to 2010 and again increased by 46.2% to overall gain 31.3% from 2002 to 2018. Likely, the water bodies was found decreased at the rate of -14.2% from 2002 to 2010 and gained by 8% from 2010 to 2018 to overall lose by -7.3% from 2002 to 2018. During the study period the all land use land cover classes were found converted from each other annually.

The result showed that the annual sedimentation rate of the Kulekhani watershed was found continuously decreasing at the rate of 13.3 (t/ha/yr), 6.6 (t/ha/yr) and 4.8 (t/ha/yr) in the year 2002, 2010 and 2018 respectively. Similarly, the potential soil loss predicted by RUSLE was also found in decreasing at the rate of 157.0 (t/ha/yr), 100.0 (t/ha/yr) and 83.7 (t/ha/yr) in the three temporal analyzing year. On contrast, the sediment retention capacity of the watershed was found increasing at the rate of 3058.5 (t/ha/yr), 3065.2 (t/ha/yr) and 3067.0 (t/ha/yr) for those three year 2002, 2010 and 2018 respectively.

The sub-watersheds namely Palung, Andheri, Simbhanjyang and Shankhmool determined as most sensitive were not only due to a single factor of having greater value of agriculture and built up land area but also due to a combined effects of rainfall erosivity index (R) , soil erodibility factor (K) including steep slope of the sites within the watershed. Comparatively, the three sub-watersheds of the groups second namely Khaiti, Chitlang and Chuliprang having relatively lowest sediment exporting values were found to have relatively reverse characteristics with respect to rainfall erosivity index (R factor), soil erodibility (K) factor, forest cover as well as agriculture and built up land cover within the watershed.

The InVEST SDR_{max} model was found appropriate to provide the sediment yield closed to the sedimentation rate and trend of the reservoir within the three timeline 2002, 2010 and 2018 having total life span of 16 years of the Kulekhani watershed for this study. Furthermore, the correlation coefficient (r = 0.31579) between sediment yield measured in the Kulekhani reservoir and predicted by the model shows that the result of the InVEST SDR_{max} model has been found in right direction within its limitations.

5.2 Recommendations

Based on the above finding and discussions, the following recommendations might be appropriated to be addressed in future improvement:

- The sub-watersheds namely Palung, Andheri, Simbhanjyang and Shankhmool were found to be most sensitive with respect to sedimentation yield contributing to the reservoir. Therefore, the first priority of the conservation measures should require the attention of managers on these above four sub-watersheds compared to the others within the Kulekhani watershed.

References

Adam, A. H. M., A.M.H, E., & Abdelrahim . M, S. (2013). *Accuracy Assessment of Land Use & Land Cover Classification (LU/LC) “Case study of Shomadi area-Renk County-Upper Nile state, South Sudan”. 3*(5), 6, Accessed date: 2020-04–30.

Ahmad, A., & Quegan, S. (2016). Haze Removal Concept in Remote Sensing. *Applied Mathematical Sciences*, *10*, 845–859. https://doi.org/10.12988/ams.2016.6128, Accessed date: 2020-04-29 11:00:54

Amatya, U. B. (2004). *Rainstorm Induced Erosion and Sediment Deposition: A Case Study of Kulekhani Watershed* [A Thesis Submitted To The Department of Civil Engineering for the Partial Fulfilment of the Requirements for the Degree of Master of Science in Water Resource Engineering (Hydraulic Engineering)]. Tribhuvan University, Nepal, Accessed date: 2020-02-01.

Anderson, J. R. (1977). Land Use and Land Cover Changes—A Framework for Monitoring. *J. Res. US Geology Survey*, *5*, 143–152, Accessed date: 5/6/2020.

Andualem, T. G., Belay, G., & Guadie, A. (2018). Land Use Change Detection Using Remote Sensing Technology. *Journal of Earth Science & Climatic Change*, *9*(10). https://doi.org/10.4172/2157-7617.1000496, Accessed date: 2020-03-31 18:32:00

Aryal, K., Thapa, P. S., Tamang, P., & Bhattarai, D. (2019). Effect of Integrated Watershed Management on Vegetation Cover, Soil Organic Carbon and Soil Fertility in Mid-Hills of Nepal. *Agriculture and Forestry Journal*, *3*. http://ojs.univ-tlemcen.dz/index.php/AFJ/. Accessed date: 4/3/2020

ASF. (2009). *ALOS Palsar Earth Data Sets (Online)* [ASF, Data Search]. Earth Data. https://search.asf.alaska.edu/#/? Atkinson, E. (1995). Methods for Assessing Sediment Delivery in River Systems. *Hydrological Sciences Journal*, *40*(2), 273–280, Accessed date: 3/29/2020.

Ban, J. K., Yu, I., & Jeong, S. (2016). Estimation of Soil Erosion Using RUSLE Model and GIS Techniques for Conservation Planning from Kulekhani Reservoir Catchment, Nepal. *Journal of Korean Society of Hazard Mitigation*, *16*(3), 323–330. https://doi.org/10.9798/KOSHAM.2016.16.3.323, Accessed date: 2020-02-17 16:37:36

Bharatkar, P. S., & Patel, R. (2013). *Approach to Accuracy Assessment tor RS Image Classification Techniques*. *4*(12), 8, Accessed date: 4/30/2020.

Bhatt, B. C., & Nakamura, K. (2005). Characteristics of Monsoon Rainfall around the Himalayas Revealed by TRMM Precipitation Radar. *Monthly Weather Review*, *133*(1), 149–165. https://doi.org/10.1175/MWR-2846.1

Biswas, A. K. (1990). Watershed Management. *Water Resources Development*, *6*, Accessed date: 4/21/2020. https://thirdworldcentre.org/wp-content/uploads/2015/05/Watershed-Management.pdf

Biswas, S. S., & Pani, P. (2015). Estimation of Soil Erosion Using RUSLE and GIS Techniques: A Case Study of Barakar River Basin, Jharkhand, India. *Modeling*

Earth Systems and Environment, *1*(4), 42. https://doi.org/10.1007/s40808-015-0040-3, Accessed date: 2020-04-27 11:47:39

Bodaly, R. A., Beaty, K. G., Hendzel, L. H., Majewski, A. R., Paterson, M. J., Rolfhus, K. R., Penn, A. F., Louis, V. L. S., Hall, B. D., & Matthews, C. J. (2004). *Peer reviewed: Experimenting with hydroelectric reservoirs*. ACS Publications.

Bodart, C., Eva, H., Beuchle, R., Raši, R., Simonetti, D., Stibig, H.-J., Brink, A., Lindquist, E., & Achard, F. (2011). Pre-Processing of a Sample of Multi-Scene and Multi-Date Landsat Imagery Used to Monitor Forest Cover Changes Over the Tropics. *ISPRS Journal of Photogrammetry and Remote Sensing*, *66*(5), 555–563, Accessed date: 4/28/2020.

Bogdan, S.-M., Pătru-Stupariu, I., & Zaharia, L. (2016). The Assessment of Regulatory Ecosystem Services: The Case of the Sediment Retention Service in a Mountain Landscape in the Southern Romanian Carpathians. *Procedia Environmental Sciences*, *32*, 12–27. https://doi.org/10.1016/j.proenv.2016.03.008, Accessed date: 2020-04-03 11:00:21

Bokan, L. T. (2015). *Simulation of Sediment Yield Using SWAT Model: A case of Kulekhani Watershed*. 124, Accessed date: 4/19/2020.

Borrelli, P., Märker, M., & Schütt, B. (2015). Modelling Post-Tree-Harvesting Soil Erosion and Sediment Deposition Potential in the Turano River Basin (italian Central Apennine): Modelling Post-Tree-Harvesting Soil Erosion and Sediment Deposition. *Land Degradation & Development*, *26*(4), 356–366. https://doi.org/10.1002/ldr.2214, Accessed date: 2020-02-20 21:09:46

Botero, B. A., Parra, J. C., & Otálvaro, M. (2019). *Effect of Population Dynamics and Land Use on the Contribution of Sediments to Reservoirs for Hydropower Generation*. 35–46. https://doi.org/10.2495/WS190041, Accessed date: 2020-03-31 18:42:42

Bouguerra, H., Bouanani, A., Khanchoul, K., Derdous, O., & Tachi, S. E. (2017). Mapping Erosion Prone Areas in the Bouhamdane Watershed (algeria) Using the Revised Universal Soil Loss Equation Through Gis. *Journal of Water and Land Development*, *32*(1), 13–23, Accessed date: 2020-04-08 20:47:44. https://doi.org/10.1515/jwld-2017-0002

Bouguerra, S., Jebari, S., & Tarhouni, J. (2019). An Analysis of Sediment Production and Control in Rmel River Basin Using InVEST Sediment Retention Model. *Journal of New Sciences, Agriculture and Biotechnology*, *66(4)*, Accessed date: 4/3/2020. www.jnsciences.org

Brauman, K. A., Daily, G. C., Duarte, T. K., & Mooney, H. A. (2007). The Nature and Value of Ecosystem Services: An Overview Highlighting Hydrologic Services. *Annual Review of Environment and Resources*, *32*(1), 67–98. https://doi.org/10.1146/annurev.energy.32.031306.102758, Accessed date: 2020-05-06 23:07:19

Cammeraat, E. L. (2004). Scale Dependent Thresholds in Hydrological and Erosion Response of a Semi-Arid Catchment in Southeast Spain. *Agriculture, Ecosystems & Environment*, *104*(2), 317–332, Accessed date: 2/26/2020.

Carletta, J. (1996). Assessing Agreement on Classification Tasks: The Kappa Statistic. *Computational Linguistics*, *22*(2), 249–254, Accessed date: 5/1/2020.

Chadli, K. (2016). Estimation of Soil Loss Using RUSLE Model for Sebou Watershed (Morocco). *Modeling Earth Systems and Environment*, *2*(2), 51. https://doi.org/10.1007/s40808-016-0105-y, Accessed date: 2020-04-26 10:30:49

Cohen, E., McNulty, S., Sun, G., & Wingard, M. (2011). *Watershed Workshop: Universal Soil Loss Equation and InVEST*. 35, Accessed date: 5/8/2020.

Cohen, J. (1960). A Coefficient of Agreement for Nominal Scales. *New York, NY 10003*, *Educ. Psycho!, Meat. 20*, Accessed date: 4/30/2020. http://www.garfield.library.upenn.edu/classics1986/A1986AXF2600001.pdf

Congalton, R. G. (1988). A Comparison of Sampling Schemes Used in Generating Error Matrices for Assessing the Accuracy of Maps Generated from Remotely Sensed Data. *Photogrammetric Engineering*, 8, Accessed date: 4/30/2020.

Congalton, R. G. (1991). A Review of Assessing the Accuracy of Classifications of Remotely Sensed Data. *Remote Sensing of Environment*, *37*(1), 35–46, Accessed date: 4/29/2020.

Cook, M. R., Moss, N. E., Rogers, A. L., & McKinney, M. (2014). *Analysis of Sediment Loading Rates and Water Quality for the Bon Secour River Watershed, Baldwin County, Alabama*. *Geological Survey of Alabama*, 39, Accessed date: 5/12/2020.

David, W. P. (1988). *Soil and Water Conservation Planning: Policy Issues and Recommendations* (p. Accessed date: 5/3/2020). Philippine Institute for Development Studies.

Dhakal, M. (2011). *Climate Change Impacts on Reservoir based Hydropower Generation in Nepal: A case study of Kulekhani Hydropower Plant*. 69, Accessed date: 2/17/2020.

Dhar, O. N., Rakhecha, P. R., Lighthill, J., & Pearce, R. P. (1981). *Monsoon Dynamics: The Effect of Elevation on Monsoon rainfall Distribution in the Central Himalaya (Online)* (1st ed.). Cambridge University Press. https://doi.org/10.1017/CBO9780511897580

Dhital, M. R., Manandhar, S., Hino, T., & Daisuke, S. (2014). *Sediment Accumulation in the Kulekhani Reservoir Due to the 1993 Debris Flows and Landslides*. https://www.researchgate.net/publication/272792958, Accessed date: 2020-04-03

DHM, N. (2015). *Draft Report: Study of Climate and Climatic Variation over Nepal*. 41.

Dijkshoorn, J. A., & Huting, J. R. M. (2009). *Soil and Terrain Database for Nepal (1.1 Million)*. ISRIC-World Soil Information. https://www.isric.org/sites/default/files/isric_report_2009_01.pdf, Accessed date: 3/31/2020

DSCWM, N. (2015). *Soil Conservation and Watershed Management Programs/Activities*. Department of Soil Conservation and Watershed Management Forestry Complex Babarmahal, Kathmandu, Accessed date: 2020-04-20.

Dumitriu, D., Rădoane, M., & Rădoane, N. (2017). Sediment Sources and Delivery. In M. Radoane & A. Vespremeanu-Stroe (Eds.), *Landform Dynamics and Evolution in Romania* (pp. 629–654, Accessed date: 2020-02-25 20:46:30). Springer International Publishing. https://doi.org/10.1007/978-3-319-32589-7_27

Duru, U. (2016). Integrated Approach of GIS and USLE for Erosion Risk Analysis in the Sapanca Lake Watershed. *The International Journal Of Engineering And Science (IJES)*, *5*(8), 37–43, Acessed date: 5/3/2020. http://www.theijes.com/papers/v5-i8/Version%202/G0508023747.pdf

Erencin, Z., Shresta, D. P., & Krol, I. B. (2000). C-Factor Mapping Using Remote Sensing and GIS. *A Case Study of Lom Sak/Lom Kao, Thailand. Geographisches Institut Der Justus-Liebig-Universität Giessen and Intern Inst. for Aerospace Survey and Earth Sci.(ITC), Enschede, The Netherlands*, Accessed date: 5/25/2020.

ESRI. (2018, January). Interpolation in the Presence of Barriers. *Analytics*. https://www.esri.com/arcgis-blog/products/analytics/analytics/interpolation-in-the-presence-of-barriers/

FAO. (2016). Land Cover Classification System Software version 3. *Food and Agriculture Organization of the United Nations / Rome, 2016*, 40. http://www.fao.org/3/a-i5232e.pdf

Foody, G. M. (2002). Status of Land Cover Classification Accuracy Assessment. *Remote Sensing of Environment*, *80*(1), 185–201, Accessed date: 4/2/2020.

Ghimire, S., Dhungana, N., & Upadhaya, S. (2019a). Impacts of Climate Change on Water Availability and Reservoir Based Hydropower. *Journal of Forest and Natural Resource Management*, *1*(1), 52–68, Accessed date: 4/18/2020.

Ghimire, S., Dhungana, N., & Upadhaya, S. (2019b). Impacts of Climate Change on Water Availability and Reservoir Based Hydropower. *Journal of Forest and Natural Resource Management*, *1*(1), 52–68. https://doi.org/10.3126/jfnrm.v1i1.22653

Goodman, J. (2011). *The Watershed Book: A Citizen's Guide to Healthy Streams and Clean Water*. Cuyahoga River Community Planning Organization, Accessed date: 4/20/2020.

Hamel, P., Chaplin-Kramer, R., Sim, S., & Mueller, C. (2015). A New Approach to Modeling the Sediment Retention Service (InVEST 3.0): Case Study of the Cape Fear Catchment, North Carolina, USA (Online). *Science of The Total Environment*, *524–525*, 166–177. https://doi.org/10.1016/j.scitotenv.2015.04.027, Accessed date: 2020-04-03 13:16:12

Hamel, P., Falinski, K., Sharp, R., Auerbach, D. A., Sánchez-Canales, M., & Dennedy-Frank, P. J. (2017). Sediment Delivery Modeling in Practice: Comparing the Effects of Watershed Characteristics and Data Resolution Across Hydroclimatic Regions. *Science of The Total Environment*, *580*, 1381–1388. https://doi.org/10.1016/j.scitotenv.2016.12.103, Accessed date: 2020-05-12 11:20:04

IPCC (Ed.). (2003). *Good Practice Guidance for Land Use, Land-Use Change and Forestry /the Intergovernmental Panel on Climate Change. Ed. By Jim Penman*. http://www.ipcc-nggip.iges.or.jp. Accessed date: 4/29/2020

Isaaks, E. H., & Srivastava, R. M. (1989). An Introduction to Applied Geostatistics. *Oxford University Press, New York*, 557, Accessed date: 2020-06–05.

Jo, A., Ryu, J., Chung, H., Choi, Y., & Jeon, S. (2018). Applicability of Various Interpolation Approaches for High Resolution Spatial Mapping of Climate Data in Korea. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLII–3*, 703–710. https://doi.org/10.5194/isprs-archives-XLII-3-703-2018, Accessed date: 2020-06-08 22:52:37

Karydas, C. G., Sekuloska, T., & Silleos, G. N. (2009). Quantification and Site-Specification of the Support Practice Factor When Mapping Soil Erosion Risk Associated with Olive Plantations in the Mediterranean Island of Crete. *Environmental Monitoring and Assessment*, *149*(1–4), 19–28, Accessed date: 5/4/2020.

Kilic, P. A., & Soni, B. (2014). Watershed and Stream Network Delineation from DEMs. *University of Nebraska-Lincoln*, 80, Accessed date: 5/5/2020.

Kim, C. (2016). Land Use Classification and Land Use Change Analysis Using Satellite Images in Lombok Island, Indonesia. *Forest Science and Technology*, *12*(4), 183–191. https://doi.org/10.1080/21580103.2016.1147498, Accessed date: 2020-04-01 21:13:15

Kim, H. S. (2006). *Soil Erosion Modeling Using RUSLE and GIS on the Imha Watershed, South Korea* [Thesis, Colorado State University Fort Collins, Colorado]. https://www.engr.colostate.edu/~pierre/ce_old/resume/Theses%20and%20Dissertations/KIMHYOENSIK-Thesis.pdf, Accessed date: 5/3/2020

Koirala, P., Thakuri, S., Joshi, S., & Chauhan, R. (2019). Estimation of Soil Erosion in Nepal Using a RUSLE Modeling and Geospatial Tool. *Geosciences*, *9*(4), 147. https://doi.org/10.3390/geosciences9040147

Krippendorff, K. (2004). *Content Analysis: An Introduction to Its Methodology* (2nd ed). Sage, Accessed date: 2020-05-01.

Kunz, M., & Kottmeier, C. (2006). Orographic Enhancement of Precipitation over Low Mountain Ranges. Part II: Simulations of Heavy Precipitation Events over Southwest Germany. *Journal of Applied Meteorology and Climatology*, *45*(8), 1041–1055. https://doi.org/10.1175/JAM2390.1

Kuok, K. K. K., Mah, D. Y. S., & Chiu, P. C. (2013). Evaluation of C and P Factors in Universal Soil Loss Equation on Trapping Sediment: Case Study of Santubong River. *Journal of Water Resource and Protection, 2013, 5, 1149-1154*, *5*. https://doi.org/10.4236/jwarp.2013.512121, Accessed date: 4/27/2020

Laraque, A., Ronchail, J., Cochonneau, G., Pombosa, R., & Guyot, J. L. (2007). Heterogeneous Distribution of Rainfall and Discharge Regimes in the Ecuadorian Amazon Basin. *Journal of Hydrometeorology*, *8*(6), 1364–1381. https://doi.org/10.1175/2007JHM784.1

LF, Y., Gs, Y., & Qf, Z. (2016). Soil Erosion Assessment of the Poyang Lake Basin, China: Using USLE, GIS and Remote Sensing. *Journal of Remote Sensing & GIS*, *5*(3). https://doi.org/10.4172/2469-4134.1000168, Accessed date: 2020-04-27 09:50:07

Li, J., & Heap, A. D. (2008). *A Review of Spatial Interpolation Methods for Environmental Scientists*.

Li, L., Wang, Y., & Liu, C. (2014). Effects of Land Use Changes on Soil Erosion in a Fast Developing Area. *International Journal of Environmental Science and Technology*, *11*(6), 1549–1562, Accessed date: 4/26/2020.

Liang, Y., Liu, L., & Huang, J. (2017). Integrating the SD-CLUE-S and InVEST Models into Assessment of Oasis Carbon Storage in Northwestern China. *PLOS ONE*, *12*(2), e0172494. https://doi.org/10.1371/journal.pone.0172494, Accessed date: 2020-02-17 16:38:03

López-Serrano, P., Corral-Rivas, J., Díaz-Varela, R., Álvarez-González, J., & López-Sánchez, C. (2016). Evaluation of Radiometric and Atmospheric Correction Algorithms for Aboveground Forest Biomass Estimation Using Landsat 5 TM Data. *Remote Sensing*, *8*(5), 369. https://doi.org/10.3390/rs8050369, Accessed date: 2020-04-29 10:37:09

Lu, D., Mausel, P., Batistella, M., & Moran, E. (2004). Comparison of Land-Cover Classification Methods in the Brazilian Amazon Basin. *Photogrammetric Engineering & Remote Sensing*, *70*(6), 723–731. https://doi.org/10.14358/PERS.70.6.723

Lüke, A., & Hack, J. (2017). Modelling Hydrological Ecosystem Services: A state of the art model comparison. *Hydrology and Earth System Sciences Discussions*, 1–29. https://doi.org/10.5194/hess-2017-436, Accessed date: 2020-04-03 13:27:15

Lüke, A., & Hack, J. (2018). Comparing the Applicability of Commonly Used Hydrological Ecosystem Services Models for Integrated Decision-Support. *Sustainability*, *10*(2), 346. https://doi.org/10.3390/su10020346, Accessed date: 2020-04-03 14:15:27

Ly, S., Charles, C., & Degré, A. (2013). Different methods for spatial interpolation of rainfall data for operational hydrology and hydrological modeling at watershed scale. A review. *Biotechnol. Agron. Soc. Environ.*, 15, Accesed date: 2020-06–05.

Mielniczuk, U. B., Mielniczuk, J., Obroślak, R., & Przystupa, W. (2019). A Comparison of Some Interpolation Techniques for Determining Spatial Distribution of Nitrogen Compounds in Groundwater. *International Journal of Environmental Research*, *13*(4), 679–687. https://doi.org/10.1007/s41742-019-00208-6

Morgan, R. P. C. (2005). *Soil Erosion and Conservation* (3rd ed). Blackwell Pub, Accessed date: 2/25/2020.

NCP, S. (2017). *User Guide for Sediment Retention, Sediment Delivery Ratio (Online)*. https://naturalcapitalproject.stanford.edu/software/invest, Accessed date: 2019-03-28

NEA, N. (2003). *Kulekhani Reservoir Sedimentation Study Report, 2003*. Project Development Department, Enginnering Service. Ratnapark, Kthamandu.

NEA, N. (2011a). *Nepal Electricity Authority, Annual Report, 2011.*

NEA, N. (2011b). *Kulekhani Reservoir Sedimentation Study Report, 2011*. Project Development Department, Enginnering Service. Ratnapark, Kthamandu.

NEA, N. (2018). *Kulekhani Reservoir Sedimentation Study Report, 2018*. Nepal Electricity Authority Engineering Service,Survey Department.

NEA, N. (2019). *Nepal Electricity Authority, Annual Report, 2019.*

Nilsson, S. (1998). A Review of Assessing the Accuracy of Classifications of Remotely Sensed Data and of Methods Including Remote Sensing Data in Forest Inventory. *International I n s t i Tute for Applied Systems Analysis, A-2361 Laxenburg ,Aust r Ia*, *INTERIM REPORT IR-98-081*, Accessed date: 4/30/2020.

Nyakatawa, E. Z., Reddy, K. C., & Lemunyon, J. L. (2001). Predicting Soil Erosion in Conservation Tillage of Cotton Production Systems Using the Revised Universal Soil Loss Equation (RUSLE). *Soil and Tillage Research*, *57*(4), 213–224, Accessed date: 4/13/2020.

OER, S. (n.d.). Streams and Rivers (Online). *Physical Geography, Earth's Fresh Water*. Retrieved June 20, 2020, from https://courses.lumenlearning.com/suny-earthscience/chapter/water-erosion/

Panagos, P., Borrelli, P., Meusburger, K., Alewell, C., Lugato, E., & Montanarella, L. (2015). Estimating the Soil Erosion Cover-Management Factor at the European Scale. *Land Use Policy*, *48*, 38–50. https://doi.org/10.1016/j.landusepol.2015.05.021, Accessed date: 2020-04-12 23:09:57

Panagos, P., Borrelli, P., Meusburger, K., van der Zanden, E. H., Poesen, J., & Alewell, C. (2015). Modelling the Effect of Support Practices (P-Factor) on the Reduction of Soil Erosion by Water at European Scale. *Environmental Science & Policy*, *51*, 23–34. https://doi.org/10.1016/j.envsci.2015.03.012, Accessed date: 4/12/2020

Pandit, B. H., Wagley, M. P., Neupane, R. P., & Adhikary, B. R. (2007). Watershed Management and Livelihoods: Lessons from Nepal. *Journal of Forest and Livelihood 6(2) September, 2007*, Accessed date: 4/20/2020.

Parveen, R., & Kumar, U. (2012). Integrated Approach of Universal Soil Loss Equation (USLE) and Geographical Information System (GIS) for Soil Loss Risk Assessment in Upper South Koel Basin, Jharkhand. *Journal of Geographic Information System*, *04*(06), 588–596. https://doi.org/10.4236/jgis.2012.46061, Accessed date: 2020-03-31 21:19:00

Phillips, D. L., Dolph, J., & Marks, D. (1992). A comparison of geostatistical procedures for spatial analysis of precipitation in mountainous terrain. *Agricultural and Forest Meteorology*, *58*(1–2), 119–141, Accessed date; 6/5/2020. https://scholar.google.com/scholar?

Pimple, U., Sitthi, A., Simonetti, D., Pungkul, S., Leadprathom, K., & Chidthaisong, A. (2017). Topographic Correction of Landsat TM-5 and Landsat OLI-8 Imagery to Improve the Performance of Forest Classification in the Mountainous Terrain of Northeast Thailand. *Sustainability*, *9*(2), 258. https://doi.org/10.3390/su9020258, Accessed date: 2020-04-01 22:03:57

Pokharel, B., & Thapa, P. B. (2018). Assessment of Rock Slope Stability in Kulekhani Watershed, Central Nepal. *Nepal Geological Society, 2018, 35*, 5, Accessed date: 4/19/2020.

Pontius, R. G. (2000). Quantification Error Versus Location Error in Comparison of Categorical Maps. *PHOTOGRAMMETRIC ENGINEERING*, *66, no, 8*, 1011–1016, Accessed date: 4/30/2020.

Poudel, K. (2020). Watershed Management in Nepal: Challenges and Constraints. *Proceedings of the Asian Regional Workshop on Watershed Management*, 10. https://www.google.com/search?, Accessed date: 3/31/2020

Pradhan, A. M. S., Dawadi, A., & Kim, Y. T. (2012). Use of Different Bivariate Statistical Landslide Susceptibility Methods: A Case Study of Khulekhani Watershed, Nepal. *Journal of Nepal Geological Society*, *44*, 1–12, Accessed date: 4/18/2020.

Prakasam, .C. (2010). Land Use and Land Cover Change Detection Through Remote Sensing Approach: A Case Study of Kodaikanal Taluk, Tamil Nadu. *INTERNATIONAL JOURNAL OF GEOMATICS AND GEOSCIENCES*, *1 No 2*. http://www.ipublishing.co.in/jggsvol1no12010/EIJGGS1015.pdf, Accessed Date: 5/6/2020

Rajalakshmi, K., Murugan, D., T.I., M., T, G. K., & C.S., D. (2013). *Supervised Methods for Land Use Classification*. *1*(7), 11.

Randle, T., Kimbrel, S., Collins, K., Boyd, P., Jonas, M., Vermeeren, R., Eidson, D., & Cooper, D. (2017). *Frequently Asked Questions about Reservoir Sedimentation and Sustainability*. 34, Accessed date: 5/12/2020.

Renard, K. G., USA, & USA (Eds.). (1997). *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE)* (Vol. 703). National Technical Information Service, 5285; Port Roya Road, Springfield, VA 22161, Accessed date: 2020-04-08.

Renard, Kenneth G., Foster, G. R., Weesies, G. A., & Porter, J. P. (1991). RUSLE: Revised Universal Soil Loss Equation. *Journal of Soil and Water Conservation*, *46*(1), 30–33, Accessed date: 2020-04–13.

Robinson, A. R. (1977). *Relationship between soil erosion and sediment delivery.*

Rosenfield, G. H. (1986). A Coefficient of Agreement as a Measure of Thematic Classification Accuracy. *Photogrammetric Engineering*, 5, Accessed date: 4/30/2020.

Sangroula, D. P. (2007). Sediment Management for Sustainability of Storage Projects in Himalayas-A case study of the Kulekhani Reservoir in Nepal. *International Conference on Small Hydropower-Hydro Sri Lanka*, *22*, 24, Accessed date: 4/18/2020.

Schilling, K. E., Jha, M. K., Zhang, Y.-K., Gassman, P. W., & Wolter, C. F. (2008). Impact of Land Use and Land Cover Change on the Water Balance of a Large Agricultural Watershed: Historical Effects and Future Directions: Impact of Lulc Change on Water Balance. *Water Resources Research*, *44*(7). https://doi.org/10.1029/2007WR006644, Accessed date: 2020-05-06 12:06:49

Shahi, D. B. (2015). *A Resorvoir Sedimentation and Conservation of River Environment: Sediment Replenisnment Method*. https://doi.org/10.13140/RG.2.2.20107.69920, Accessed date: 2020-04-19 12:02:28

Sharma, K. D. (1998). The hydrological indicators of desertification. *Journal of Arid Environments*, *39*(2), 121–132.

Shrestha, H. S. (2012). *Sedimentation and Sediment Handling in Himalayan Reservoirs*. 236, Accessed date: 2/17/2020.

Shrestha, S. B. (2016). *Soil Erosion and Payment for Sediment Retention in Kulekhani Watershed*. 127, Accessed date: 4/19/2020.

Shrestha, S., Khatiwada, M., Babel, M. S., & Parajuli, K. (2014). Impact of Climate Change on River Flow and Hydropower Production in Kulekhani Hydropower Project of Nepal. *Environmental Processes*, *1*(3), 231–250. https://doi.org/10.1007/s40710-014-0020-z, Accessed date: 2020-04-23 22:07:10

Smith, M. J. D., Goodchild, M. F., & Longley, P. (2007). *Geospatial Analysis: A Comprehensive Guide to Principles, Techniques and Software Tools*. Matodor, Accessed date: 6/7/2020. https://books.google.com.np/books?

Song, C., Woodcock, C. E., Seto, K. C., Lenney, M. P., & Macomber, S. A. (2001). Classification and Change Detection Using Landsat TM Data: When and How to Correct Atmospheric Effects? *Remote Sensing of Environment*, *75*(2), 230–244, Accessed date: 4/1/2020.

Srichaichana, J., Trisurat, Y., & Ongsomwang, S. (2019). Land Use and Land Cover Scenarios for Optimum Water Yield and Sediment Retention Ecosystem Services in Klong U-Tapao Watershed, Songkhla, Thailand. *Sustainability*, *11*(10), 2895. https://doi.org/10.3390/su11102895, Accessed date: 2020-04-03 14:15:53

Sthapit, A. B., Gautam, H., & Joshi, P. R. (2009). *Statistical Methods* (5th Edition). Buddha Academic Publishers and Distributors Pvt.Ltd., Kathmandu , Nepal.

Sthapit, K. M. (1996). *Sedimentation Monitoring of Kulekhani Reservoir*. ICIMOD, Nepal, Accessed date; 4/18/2020.

Stöcklin, J., & Bhattarai, K. D. (1977). *Geology of the Kathmandu Area and Central Mahabharat Range, Nepal Himalaya. Report of Department of Mines and Geology/UNDP(unpublished)*. Accessed date; 4/15/2020.

Stone, R. P., & Hilborn, D. (2012). *Universal Soil Loss Equation, USLE.* Ministry of Agriculture, Food & Rural Affairs, Agriculture & Rural, Accessed date: 3/28/2020.

Suryakant, Er. S. S. (2017). *Modelling of Soil Erosion and Water Harvesting Potential for Improved Carbon Sequestration in Urmodi Basin* [College of Agricultural Engineering and Technology]. https://pdfs.semanticscholar.org/048e/3ca26cc6b812c668d52da28276a306f1fcef.pdf?, Accessed date: 3/28/2020

Upadhyaya, S. K. (2005). *Payment for Environmental Service: Sharing Hydropower Bnefits with Upland Communities*. RUPES Kulekhani, Working Paper1, Winrock International , Nepal.

USGS. (2018). *U.S. Geological Survey: Science for a Changing World (Online)*. USGS, Earth Explorer. https://earthexplorer.usgs.gov/

USGS. (2020). *Common Landsat Band RGB Composites (Online)*. https://www.usgs.gov/media/images/common-landsat-band-rgb-composites

Usman, M., Liedl, R., Shahid, M. A., & Abbas, A. (2015). Land Use/Land Cover Classification and Its Change Detection Using Multi-Temporal MODIS NDVI Data. *Journal of Geographical Sciences*, *25*(12), 479–506, Accessed date: 4/2/2020.

Vanmaercke, M., Poesen, J., Maetens, W., de Vente, J., & Verstraeten, G. (2011). Sediment Yield as a Desertification Risk Indicator. *Science of The Total Environment*, *409*(9), 1715–1725. https://doi.org/10.1016/j.scitotenv.2011.01.034, Accessed date: 2020-02-25 20:44:53

Vanoni, V. A. (Ed.). (1975). *Sedimentation Engineering*. The Society. https://ascelibrary.org/doi/book/10.1061/9780784408230, Accessed date: 5/7/2020

Verstraeten, G., Prosser, I. P., & Fogarty, P. (2007). Predicting the Spatial Patterns of Hillslope Sediment Delivery to River Channels in the Murrumbidgee Catchment, Australia. *Journal of Hydrology*, *334*(3–4), 440–454, Accessed date: 5/4/2020.

Vigerstol, K. L., & Aukema, J. E. (2011). A Comparison of Tools for Modeling Freshwater Ecosystem Services. *Journal of Environmental Management*, *92*(10), 403–409, Accessed date: 5/1/2020.

Vigiak, O., Borselli, L., Newham, L. T. H., McInnes, J., & Roberts, A. M. (2012). Comparison of Conceptual Landscape Metrics to Define Hillslope-Scale Sediment Delivery Ratio. *Geomorphology*, *138*(1), 74–88. https://doi.org/0.1016/j.geomorph.2011.08.026, Accessed date: 3/28/2020

Vopravil, J., Janeček, M., & Tippl, M. (2007). Revised Soil Erodibility K-Factor for Soils in the Czech Republic. *Soil and Water Research*, *2*(1), 1–9, Accessed date: 4/1/2020.

Wang, H.-W., Kondolf, M., Tullos, D., & Kuo, W.-C. (2018). Sediment Management in Taiwan's Reservoirs and Barriers to Implementation. *Water*, *10*(8), 1034, Accessed date: 2/26/2020.

Wang, L. T., & DeLiberty, T. L. (2005). *Landsat Atmospheric Correction: The Good, the Bad, and the Ugly (Online)*. 15. https://proceedings.esri.com/library/userconf/proc05/papers/pap1560.pdf, Accessed date: 2020-04-28

Webster, R., & Oliver, M. A. (2007). *Geostatistics for environmental scientists*. John Wiley & Sons. Accessed date: 2020-06-05.

Welde, K. (2016). Identification and Prioritization of Subwatersheds for Land and Water Management in Tekeze Dam Watershed, Northern Ethiopia. *International Soil and Water Conservation Research*, *4*(1), 30–38. https://doi.org/10.1016/j.iswcr.2016.02.006, Accessed date: 2020-05-12 17:19:13

Wischmeier, W. H., & Smith, D. D. (1965). *Predicting Rainfall-Erosion Losses from Cropland East of the Rocky Mountains: Guide for Selection of Practices for Soil and Water Conservation (Online)*. US Department of Agriculture, Accessed date: 5/7/2020.

Wischmeier, W. H., & Smith, D. D. (1978). *Predicting rainfall erosion losses: A guide to conservation planning*. Department of Agriculture, Science and Education Administration.

Yogacharya, K. S. (2008). A Review on Status of Sediment Studies in Nepal. *Journal of Hydrology and Meteorology*, *5*(Hydro Engineering Service, Kathmandu, Nepal), Accessed date; 4/3/2020.

Zuazo, V. H. D., & Pleguezuelo, C. R. R. (2008). Soil-Erosion and Runoff Prevention by Plant Covers. A Review. *Agronomy for Sustainable Development*, *28*(1), 65–86. https://doi.org/10.1051/agro:2007062, Accessed date: 2020-02-25 20:43:05

Appendix-1 Crop management (C-factor) as reference from literature review

Land Use Types	C-factor	Source
Arable land		
Grain maize corn	0.38	(Panagos et al., 2015, p. 40)
Rice	0.15	
Pulse (Legumes)	0.32	
Potato	0.34	
Common wheat	0.20	
Oil seed	0.28	
Non-arable land		
Permanent crops i.e.		
Fruit trees and plantation	0.2188	
Pasture	0.0903	
Heterogeneous agriculture i.e.		
Land principally used for agriculture with significant area of natural vegetation	0.1232	
Agro-forestry area	0.0881	
Forest i.e.		
Broad leaved forest	0.0013	
Coniferous forest	0.0011	
Mixed forest	0.0011	
Shrub/herbaceous vegetation i.e.		
Natural grass land	0.0435	
Traditional wood land shrub	0.0219	
Open space with little or no vegetation	0.2652	
Bare rock	0	
Glacier and snow	0	
Water bodies, Lakes	0	
Irrigated crop land	0.088	(LF et al., 2016, p. 4)
Rainfed crop land	0.31	
Broad leaved deciduous forest	0.003	
Needle leaved forest	0.017	
Shrub land	0.069	
Grass land	0.05	
Sparse vegetation	0.18	
Artificial surface	0.01	
Bare area	1.00	
Water bodies	0	
Dense forest	0.001	(Erencin et al., 2000, p. 15)
Open forest	0.001	
Shrub and bush vegetation	0.01	
Low cover vegetation (Fallow)	0.20	
Bare soil	1	
Residential areas and home gardens	0.14	
Forest	0.03	(Koirala et al., 2019, p. 7)
Shrub land	0.03	
Grass land	0.01	
Agriculture land	0.21	

Land Use Types	C-factor	Source
Arable land		
Barren land	0.45	
Water bodies	0.00	
Snow and glacier	0.00	
Built up	0.00	
Mosaic of crops, pasture and natural zone	0.394	(Botero et al., 2019, p. 38)
Open forest	0.002	
Grass land, pasture and herbaceous vegetation	0.11	
Dense forest	0.002	
urban settlements	0	
Forest with undergrowth	0.002	(Kuok et al., 2013, p. 1152)
Forest with no undergrowth	0.003	
Mixed forest	0.002	
New shifting agriculture	0.20	
Old shifting agriculture	0.05	
Settlement/clear land	0.25	
Cultivated grass	0.007	
Percentage of areas covered by canopy of trees and undergrowth i.e.		(Kim, 2006, p. 50)
100 – 75	0.001 – 0.001	
70 – 45	0.002 – 0.004	
40 - 20	0.003 – 0.009	
Forest	0.005	(Duru, 2016, p. 43)
Urban	0.20	
Orchard	0.05	
Irrigated farming	0.28	
Dry farming	0.07	
Range land	0.09	
Barren land	0.35	
Marsh land	0.00	
Agriculture land	0.28	(Biswas & Pani, 2015, p. 6)
Waste land	0.18	
Settlement/built up area	1.00	
Reservoir	0.00	
Rivers	0.00	
Vegetation cover	0.006	
Rainfed crop land	0.07	(Chadli, 2016, p. 6)
Grass land / shrub land (20 – 50%)	0.1	
Broad leaved deciduous forest (>40%)	0.001	
Coniferous forest (>40%)	0.001	
Mixed forest (>15%)	0.001	
Urban area (>15%) vegetation	0	
Bare area	0	
Water bodies	0	

Appendix-2 Support practice (P- factor) as reference from literature review

Slope (%)	Terracing		Contouring	Stripping crop	Source
	Bench	Broad base			
(1 - 2)	0.10	0.12	0.60	0.30	(David, 1988, p. 60)
(3 - 8)	0.10	0.10	0.50	0.15	
(9 - 12)	0.10	0.12	0.60	0.30	
(13 - 16)	0.10	0.14	0.70	0.35	
(17 - 20)	0.12	0.16	0.80	0.40	
(21 - 25)	0.12	0.18	0.90	0.45	
(>25)	0.14	0.20	0.95	0.50	
(9 - 12)			0.60		(Panagos et al., 2015, p. 26; Morgan, 2005, p. 123)
(13 - 16)			0.70		
(17 - 20)			0.80		
(21 - 25)			0.90		
(>25)			0.95		
(1 - 2)			0.60	0.30	(Wischmeier & Smith, 1965, p. 37)
(3 - 8)			0.50	0.25	
(9 - 12)			0.60	0.30	
(13 - 16)			0.70	0.35	
(17 - 20)			0.80	0.40	
(21 - 25)			0.90	0.45	
0.0 - 7.0		0.10	0.55	0.27	(Kim, 2006, p. 52)
7.0 - 11.3		0.12	0.60	0.30	
11.3 - 17.6		0.16	0.80	0.40	
17.6 - 26.8		0.18	0.90	0.45	
>26.80		0.20	1.00	0.50	
Slope (%)	Land use types			P-Values	Source
0 - 330	Water bodies			0	(LF et al., 2016, p. 4)
	Irrigated cropland				
0 - 330				0.05	
0 - 5				0.11	
(5 - 10)				0.12	
(10 - 20)				0.14	
	Arable lands				
20 -30				0.19	
30 - 50				0.25	
>50				0.33	

Slope (%)	Terracing		Contouring	Stripping crop	Source
	Bench	Broad base			
0 - 330	Forest land			0.80	
0 - 330	Others			1.00	
	Level bench terrace			0.14	(Morgan, 2005, p. 123)
	reverse slope bench terrace			0.05	
	Outwards slopping bench terrace			0.35	
	Level retention bench terrace			0.01	
	Tied ridging			0.10 - 0.20	
	Water bodies			0.00	(L. Li et al., 2014, p. 1552)
	Waste lands and built up			1.00	
	Orchard land			0.20	
	Crop land			0.35	
	Forest land			0.50	
	Tillage Practice				(David, 1988, p. 60)
	Conventional tillage			1.00	
	Zoned tillage			0.25	
	Mulch tillage			0.26	
	Minimum tillage			0.52	

Appendix-3 Sub-wtershed Wise Area by Slope (Percent)

Sub-watersheds		Slope Category in Percent					Total area
ID	Name	0 - 7	7 - 11.3	11.3 - 17.6	17.6 - 26.8	>26.8	
1	Andheri Khola	49.6	74.9	120	168.9	898.7	**1312**
2	Bisinkhel Khola	31.3	54.2	105.3	145.4	646.4	**982.6**
3	Chitlang Khola	39.2	73.4	151.1	239.4	1799.6	**2302.6**
4	Chuliprang Khola	68	86.1	127.6	194	1052.2	**1527.9**
5	Gharti Khola	32.4	35.9	74.3	110.8	643.7	**897.1**
6	Khaiti Khola	13.1	20.5	47.6	88.4	491.9	**661.5**
7	Palung Khola	21	39.2	105.6	220.6	965.2	**1351.6**
8	Salma Kulekhani Khola	111	17	34.6	71.1	659.4	**893.1**
9	Sankhmool Khola	57.5	50.6	56.1	78.2	779.4	**1021.7**
10	Simbhanjyang Khola	22.7	46	129.8	257.3	1060.9	**1516.8**
11	**Total Area_ha**	**445.8**	**497.8**	**951.9**	**1574.2**	**8997.3**	**12467**
12	**Total Area_%**	**3.6**	**4**	**7.6**	**12.6**	**72.2**	**100**