Eurasian Journal of Soil Science 2023, 12(2), 190 - 204

Eurasian Journal of Soil Science

Journal homepage : http://ejss.fesss.org

Assessment of land use land cover dynamics and its impact on springs water in Ritung Khola Sub-Watershed, Myagdi district, Nepal

Sachin Timilsina [a,*], Saurav Shrestha [b], Shankar Tripathi [c], Rajeev Bhattarai [d], Shambhu Kumar Mishra [e], Raju Raj Regmi [a], Diwakar Paudel [e], Mahamad Sayab Miya [a]

[a] Tribhuvan University, Institute of Forestry, Pokhara Campus, Pokhara 33700, Nepal
[b] University of New Haven, 300 Boston Post Road, West Haven CT 06516, USA
[c] Tribhuvan University, Institute of Forestry, Hetauda Campus, Hetauda 44100, Nepal
[d] School of Forest Resources, College of Natural Sci., Forestry and Agriculture, University of Maine, Orono, ME 04469, USA
[e] Soil and Watershed Management Office, Parbat 33400, Gandaki Province, Nepal

Article Info
Received : 10.09.2022
Accepted : 20.01.2023
Available online : 30.01.2023

Author(s)
S.Timilsina *
S.Shrestha
S.Tripathi
R.Bhattarai
S.K.Mishra
R.R.Regmi
D.Paudel
M.S.Miya

* Corresponding author

Abstract

Land Use Land Cover (LULC) Change has emerged as a significant environmental issue and a worry for the sustainable use of natural resources. This study was performed to determine the rate in change of land cover and its significant impact on springs water in the Ritung Khola sub-watershed of Myagdi district, Nepal, between 2010 and 2020. This study analyzes LULC dynamics and it's impact on springs water using satellite imageries (Landsat 5 TM and Landsat 8 OLI/TIRS) and focus group discussions with the inhabitants. We used Supervised Maximum Likelihood Classification algorithm to classify attributes of the LULC changes. The results demonstrated a significant change in LULC during those ten years (2010-2020). The area covered by agricultural land and human settlements significantly increased by 313.54% and 367.14%, respectively. On the contrary, barren land, water bodies and forest cover have been reduced by 37.52%, 13.16% and 5.26%, respectively. The number of active springs followed decreasing trend as many of them were completely displaced or dried due to erosions and frequent landslides. The findings from this study are expected to facilitate the planning process adopted to prevent springs under the threat of extension and mitigate the water scarcity problem.

Keywords: Landsat, land cover, land use, springs, watershed, water bodies.

© 2023 Federation of Eurasian Soil Science Societies. All rights reserved

Introduction

Land cover is defined as the physical and biological cover of the land surface, whereas land use means activities on physical things (such as agriculture, forest, building, and water) that tend to change the land surface phenomena (Mueller and Zeller, 2002; Foley et al., 2005). The unprecedented pace and magnitude of the anthropogenic activities on the land surface alter the Land Use and Land Cover (LULC) pattern, which is an absolute must to consider (Lambin et al., 2001; Zhang et al., 2015). LULC change is an endlessly changing phenomenon undergoing on the Earth (Reid et al., 2000).

In Nepal, several factors, including population growth, uneven economic development, and urban-centric economic growth, contributed to LULC dynamics (Rimal et al., 2018; Rimal et al., 2018b). These dynamics cause the environment to deteriorate and opened doors for major environmental dangers such as biodiversity loss, modifications to radioactive forcing and hydrological regimes, climate change, and contamination of other natural ecosystems (Niyogi et al., 2009; Liu et al., 2014; Porfiriev, 2015, Liping et al., 2018). Over the

: https://doi.org/10.18393/ejss.1244373
: http://ejss.fesss.org/10.18393/ejss.1244373
Publisher : Federation of Eurasian Soil Science Societies
e-ISSN : 2147-4249

past few years, the forest area, water resources, and barren land have been changing and are likely to continue to change in the future (Dinka and Chaka, 2019).

Over the past few decades, remote sensing (RS) and Geographic Information System (GIS) become the prominent approaches for the understanding of spatiotemporal characteristics, and extraction of valuable information by classifying the spectral characteristics of land cover features for Natural Resource Management (NRM) (Jensen, 2005; Lillesand et al., 2015; Panigrahi et al., 2017). These techniques are useful for the management and improvement of the watershed by integrating and analyzing spatiotemporal data to study LULC changes at different levels (Attri et al., 2015). The image pixel was used as the basic unit of analysis in the 1980s and 1990s classification procedures, with each pixel being assigned to a certain land cover class. With progress, different classification techniques considering pixel as a basic analysis unit were developed, such as supervised (artificial neural network, decision tree, random forests, support vector machine, maximum likelihood classification), unsupervised (K-means and ISODATA), and hybrid classification (semi-supervised and mixing of supervised and unsupervised) techniques (Zhang et al., 2005; Alajlan et al., 2012).

The complex interactions between groundwater, surface water, and the aquatic-terrestrial ecotone are what make springs special and diverse (Von Fumetti et al., 2017). They are formed due to fractures, faults, and a rock contact form where groundwater emanates to the surface (Ibeneme et al., 2013). Globally, springs are considered 'natural laboratories' due to their peculiarity i.e. water reaches the surface through fracture of porous layer (Odum, 1971). They are extremely important to Nepal's rural areas, where about 80% of the country's 13 million residents who live in hills and mountains depend on them for drinking water (Tambe et al., 2012; Sharma et al., 2016; Bhat et al., 2020). The hydrology of the slope in Nepal's middle mountain has been disrupted by anthropogenic factors like as land cover changes, catchment degradation, and the construction of rural road networks (Ghimire et al., 2019). These activities result in the drying of springs and a reduction in the permanent flow of water from the springs during the dry season (ICIMOD, 2015; Chapagain et al., 2019; Ghimire et al., 2019). Although the springs play a significant role in water security, they haven't received adequate attention by protective legislation which in turn is leading to the threat of their drying up and the destruction of their natural habitat (Barguin and Scarsbrook, 2008; Cantonati et al., 2012).

LULC changes also have notable impacts on the quality and quantity of several forms of water such as groundwater, surface runoff, and the dissemination of non-point source (NPS) pollutants over a range of spatiotemporal scales (Weng, 2001; Frumkin, 2002; Li and Wang, 2009). The springs in the Ritung Khola sub-watershed are facing several threats and are on the verge of disappearance. Furthermore, the evaluation of LULC dynamics in this sub-watershed with the combined tools of RS, GIS, and the social study has not been practiced in this sub-watershed until the date. This sub-watershed is one of those notable examples where no information available regarding LULC changes, even though it mixes with the Myagdi River (perennial river originated from Mt. Dhaulagiri).

This study was carried out with a general goal to understand the dynamics of LULC between 2010 and 2020 and their impact on springs water availability. In addition, the specific objectives of our study were

i. to assess the effectiveness of historical Landsat images for detecting LULC changes over the ten years (2010-2020),
ii. integrating the remote sensing techniques with local people's perception regarding the changes, and
iii. creating a detailed LULC change map of the Ritung-Khola sub-watershed area at a spatial resolution of 30 m.

The long-term study of the change in the land cover and its linkages with the underground water availability bolsters the efficient use and preservation strategies of these water sources in most of the hilly landscapes. Temporal information of land coverage and its conservation is an asset for the sustainable development of a community. There have been several related studies on land cover changes previously; however, researchers have failed to analyze the linkage between LULC and Ground water resources. Ritung Khola sub-watershed is a representative sub-watershed for the entire Hindu Kush Himalayan (HKH) region and the associated community. Entire HKHs region is facing water resources depletion over few decades due to different environmental and climatic changes. In this context, this study emphasizes the importance of temporal change in land phenomena and its impact on springs resources.

Material and Methods

Study area

This study was performed in the Ritung Khola sub-watershed area (83^{0}18'0" E to 83^{0}24'0"E and 28^{0}21'0"N to 28^{0}27'0"N) of the Malika Rural Municipality, Myagdi district, Gandaki Province, Nepal (Figure 1). The sub-watershed encompasses a 71.44 km² area. The outlet of this sub-watershed drains into the Myagdi River through the Ritung River (Ritung Khola), which is also a tributary of the Kali Gandaki River. The two main branches of the Ritung River are the Dajung River and the Ruma River (Khahare Khola). The altitude of the study area ranges from 1,076 m (confluence of Myagdi River and Ritung River) to 3,470 m (Sarbara danda) (Figure 1). There exist three types of climatic conditions in this sub-watershed: subtropical, temperate, and subalpine. This sub-watershed is more facing towards the north east rather than south west. This sub-watershed is more prone to soil erosion bearing the land capability class III and class IV within most of the sub-watershed (LRMP, 1986). Indian dammer (*Shorea robusta*), chestnut (*Castanopsis indica*), Indian or Nepalese alder (*Alnus nepalensis*), pine (*Pinus* sp.), and Chinese guger tree (*Schima wallichii*) are the major tree species found in this area. The land use pattern of this study area was found well managed to the date as majority of the settlements are around the cultivable land, mostly along with spurs and saddles. However, the migration of people from uplands towards the low land for facilities and other benefits is resulting in the unsustainability of the land-use system. The settlement area covers about 30% of the total area of the watershed. Therefore, to disseminate the information for the management of land-use system and conservation of springs in the sub-watershed, selection of this area for our study was vital.

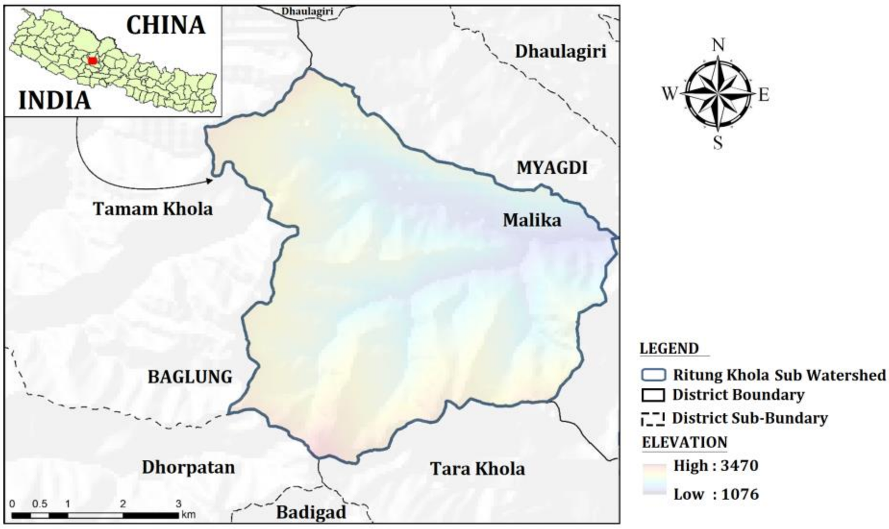


Figure 1. Study area map showing Ritung Khola Sub-watershed area

Data collection

Field data

Primary data like information from Focus Group Discussions (FGDs) were used to identify springs conservation activities, use status and perception, GPS point for training sample and accuracy assessment. Secondary data like Landsat images were used for image classification and to determine LULC change, and other literature to acquire knowledge about methods and analysis techniques. Fieldwork was started with a reconnaissance survey which was conducted in April 2021 to obtain a general understanding of the LULC status of the study area. During this survey, ground information was acquired to define the nature of ground covers such as forests, agriculture, water bodies, barren land, and settlements. A reconnaissance survey was followed by the primary data collection. The field data were collected from random locations and 338 GPS points for 2020 image classification were obtained covering all the LULC classes during fieldwork in April 2021. The history of each types of land use was acquired from the local people by the means of FGDs. FGDs were also utilized to collect other additional data from the respondents to determine the impacts of each LULC class on the springs water of the study area.

Satellite data acquisition

The watershed boundary was delineated using the Shutter Radar Topography Map (SRTM), Digital Elevation Model (DEM), and atmospherically corrected Landsat data which were downloaded from USGS Earth Explorer (https://earthexplorer.usgs.gov/). Landsat data included surface reflectance bands in Landsat 5 Thematic Mapper (TM) and Landsat 8 Operational Land Imager (OLI) images (Table 1).

Table 1. Characteristics of the satellite images used in this study

Satellite	Sensor	Spatial resolution (m)	Path/Row	Date of acquisition
Landsat 5	TM	30	142/40	2010/12/03
Landsat 8	OLI/TIRS	30	142/40	2020/11/12

LULC classification

The steps involve in supervised image classification were:

Defining training sites

A total of 338 training points (agriculture 60, settlements 51, water bodies 74, barren land 71, and forest 82) for image classification for 2020 image were identified, and for 2010, 492 training points (agriculture 145, settlements 55, water bodies 61, barren land 87, and forest 144) were taken.

Image classification

The supervised classification technique was carried out to classify the pre-processed Landsat images from the individual dates. Maximum Likelihood Classification (MLC), one of many supervised classifiers, was regarded as a widely used method for categorizing the pre-processed satellite image (Lillesand et al., 2015; Yang et al., 2015). It automatically classifies pixels in an image into a target class (Vahtmae et al., 2012). The LULC classification scheme is shown in (Table 2). Images that have the same spectral signature such as natural and plantation forests, riverine forests, and dry evergreen forests were included in the class forest because of the difficulty in differentiating one from the other.

Table 2. Characteristics of the LULC classes used in the study.

Class name	Description
Forest	Trees forming closed or nearly closed canopies; natural, plantation, and degraded forest, shrubs, and herbs.
Agriculture	Crop and fallow lands.
Barren land	Exposed soil, barren area, exposed rocks, and permanently abandoned land.
Water bodies	Rivers, open water, streams, ponds, and reservoirs.
Settlement	Residential, commercial, industrial, urban, and rural settlements.

Focus Group Discussions (FGDs)

Three Focus Group Discussions (FGDs) involving a total of 31 participants were conducted to better understand the dynamics of LULC and its effect on springs water. Each group consisted of 12, 9 and 10 members from the three selected localities in the study area (Phulbaari, Aadhibara, and Okharbot), respectively. The age of participants involving in discussion ranged from 30 to 75 years. A local motivator with strong understanding of the surrounding areas helped to identify the participants. The trained facilitator of each focus group led the participants through a set of pre-planned questions. The drivers of spring water depletion due to LULC change in this study area were identified, classified, and ranked after identifying the main issue of spring depletion based on the outcomes of consultation with the respondents. Scores for identified causes and drivers were assigned using pairwise ranking (Bekele et al., 2018). The discussion questions were open-ended and designed mainly to identify the impact of LULC changes on spring water according to the perceptions of the locals. In each group meeting, questions related to the impacts of LULC on springs water, conservation measures of springs, and government, Non-governmental Organizations (NGOs), International non-governmental organizations (INGOs), and Community-based Organizations (CBOs) support for the springs' conservation were asked. Each meeting lasted for approximately an hour, and the text contains the responses. Data from field observations of LULC change and spring water were also gathered by the research team and used in group discussions, problem explanations, and result interpretations.

Data analysis

Accuracy assessment for LULC classification models

We assessed the accuracy of our LULC classification models using the simple random sampling method (Li et al., 2021). The random points were adopted to validate the classification accuracy of LULC data in Google Earth Pro. For the referenced or sample database, this study used Google Earth Pro and ground verification points from different places lie in this sub-watershed. A total of 338 training samples were used to classify an image of 2020 and those samples were checked in Google Earth Pro for validation or accuracy assessment. A historical Google Earth image was used as reference data for the accuracy assessment of the 2010 image. The distance between random points was assigned a minimum of 30m and a maximum of 50m distance apart. A total of 338 and 492 training samples were collected based on the visual abundance to prepare the LULC map of 2020 and 2010 respectively. For the validation, 97 and 153 points were used for the years 2020 and 2010 respectively, where more validation points were used for the year 2010 to ensure better classification based on old imageries. After that, the created ground truth points were superimposed on the LULC map, and the value was extracted. The KAPPA test, which is based on a confusion matrix after the classification, was used to compare the referenced data and the classified image statistically. Lastly, the accuracy of the classified images was calculated based on the calculation of users, producers, and overall accuracy. Formulae for overall accuracy, user's accuracy, and producer's accuracy which are used for accuracy assessment are:

$$\text{Overall accuracy (\%)} = \frac{\text{Total number of correctly classified pixels (Diagonal)}}{\text{Total number of referenced pixels}} \quad (1) \quad \text{(Bharatkar and Patel, 2013)}$$

$$\text{User's accuracy (\%)} = \frac{\text{No. of correctly classified pixels in each category} * 100}{\text{Classified total pixels in that category (Row total)}} \quad (2) \quad \text{(Bharatkar and Patel, 2013)}$$

$$\text{Producer's accuracy (\%)} = \frac{\text{No. of correctly classified pixels in each category} * 100}{\text{classified total pixels in that category (Column total)}} \quad (3) \quad \text{(Bharatkar and Patel, 2013)}$$

Another method of accuracy assessment is KAPPA which still makes use of the error matrix (Congalton, 2001). Its value ranges from 0 to 1 where 0.80 signify a strong agreement, 0.40-0.80 denote a moderate agreement, and below 0.40 characterize a poor agreement (Congalton, 1996). This study follows the equation (4) given by (Foody, 2002; Rwanga and Ndambuki, 2017) for KAPPA statistics calculation in accuracy assessment.

$$\text{KAPPA (K)} = \frac{N \sum_{i=1}^{r} x_{ij} - \sum_{i=1}^{r}(x_{i} * x_{+i})}{N^2 - \sum_{i=1}^{r}(x_{i+} * x_{+i})} \quad (4)$$

Change detection

The rate of change ha/year and percentage share of each class during the studied periods were calculated using the formula given by (Shiferaw and Singh, 2011).

$$\Delta A(\%) = \frac{(At2 - At1) * 100}{At1} \quad (5)$$

where, Δ A (%) = percentage change in the area of LULC class type between initial time At_1 and final period At_2, At_1 = area of LULC class at an initial time, At_2= area of LULC class at the final time.

Results

LULC status of Ritung Khola sub-watershed in 2010

A total of five LULC classes namely, Forest, Agriculture, Water bodies, Settlements, and Barren land were used for the classification purposes (Table 2). Forest constituted the highest area (5963.56 ha, 83.48%) from the study site, followed by the Barren land (948.60 ha, 13.28%). Agriculture land, Water bodies, and Settlements covered an area of 205.66 ha (2.88%), 18.93 ha (0.27%), and 7.36 ha (0.09%) respectively (Table 3, Figure 2a).

Table 3. Area and percentage coverage of LULC of Ritung Khola sub-watershed in 2010

Year: 2010		
Land classes	Area (ha)	Area coverage (%)
Forest	5963.56	83.48
Agriculture	205.66	2.88
Water Bodies	18.93	0.27
Settlements	7.36	0.09
Barren Land	948.60	13.28
Total	7144.12	100

LULC status of Ritung Khola sub-watershed in 2020

Various changes were observed for the same land cover classes in a 10-years interval. The post-classification of the Landsat image of 2020 showed forest covering an area of 5650.10 ha (79.09%) of the total study area. Agriculture land had occupied an area of 851.94 ha (11.92%) of the study area. The barren land, settlement, and water body had covered an area of 592.89 ha (8.30%), 32.7 ha (0.46%), and 16.49 ha (0.23%) respectively (Table 4, Figure 2b).

Table 4. Area and percentage coverage of LULC of Ritung Khola sub-watershed in 2020

Year: 2020		
Land classes	Area (ha)	Area coverage (%)
Forest	5650.10	79.09
Agriculture	851.94	11.92
Water Bodies	16.49	0.23
Settlements	32.70	0.46
Barren Land	592.89	8.30
Total	7144.12	100

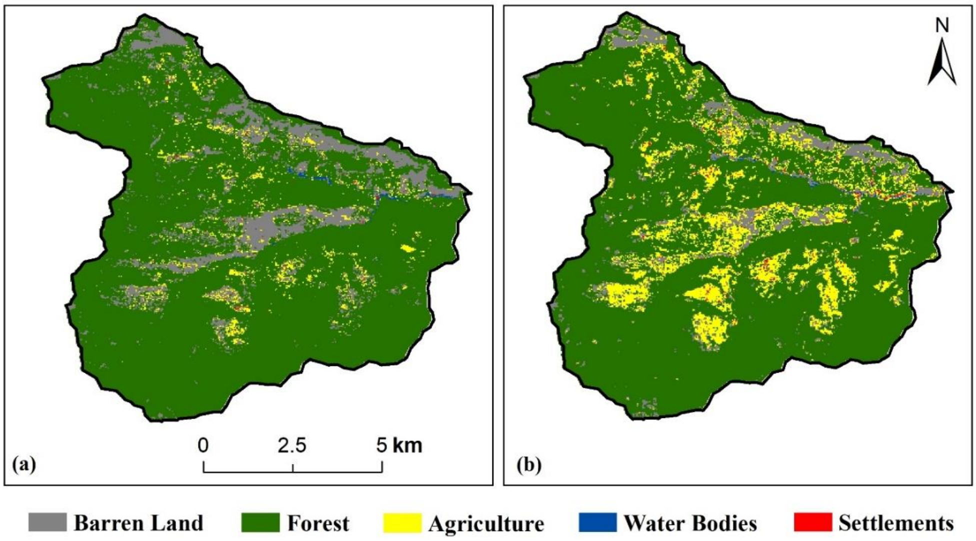


Figure 2. (a) Land Use Land Cover Map of Ritung Khola Sub-watershed- 2010 (b) Land Use Land Cover Map of Ritung Khola Sub-watershed- 2020

Accuracy assessment of LULC classification

The overall accuracy and Kappa coefficient of the classified images were 86.4%, and 0.81 for 2010 and 85%, 0.82 for the 2010 respectively.

Land use and land cover class change trends between 2010 and 2020

The change in area of LULC types during the period (2010-2020) in the Ritung Khola sub-watershed are demonstrated in (Table 5). During 10 years, the area covered by Settlements class in this sub-watershed surged by more than 300%, i.e., 0.09% to 0.46% representing a 25.7 ha increases in area. The agriculture class also increased by 313.54%, i.e., 2.88% to 11.92% (645.9 ha increase in the area). The barren land decreased from 13.28% to 8.30% (decrease in the area of 356.1 ha). Between 2010 and 2020, there has also been a reduction in the area occupied by water bodies. The percentage decrease in the class of water bodies was 13.16% that is 0.27% from 2010 to 0.23% in 2020 with a decrease in the area of 2.5 ha. The classification result showed that the forest land decreased over the last 10 years by 5.26% i.e., 83.48% from 2010 to 79.09% in 2020 with a decrease in the area of 314 ha.

Table 5. Composite table of area statistics (ha and %) of Ritung Khola sub-watershed in 2010 and 2020

S.N.	Land Cover Classes	Total change in status between 2010-2020	
		Area (ha)	Coverage (%) change between 2010 and 2020
1.	Forest	-314	-5.26
2.	Agriculture	645.9	313.54
3.	Water Bodies	-2.5	-13.16
4.	Settlements	25.7	367.14
5.	Barren Land	-356.1	-37.52

Land use land cover change transition matrix from 2010-2020

A total of 1358.443 ha of land area were transitioned from one class to another class in this study period. During the time interval, major changes could be observed in the class agriculture i.e., 646.28 ha. Considering the 205.657 ha area that was agricultural area in 2010, 114.868 ha were still agricultural land, but approximately 90.789 ha of agricultural land was converted to other land cover classes (65.545 ha to forest, 0.805 ha to water bodies, 4.874 ha to settlements, and 9.565 ha to barren land). Similarly, barren land area experienced a conversion of 608.398 ha (252.225 ha to forest, 343.709 ha to agriculture, 2.104 ha to water bodies, and 10.36 ha to settlements) but it retained 340.207 ha in 2020 as barren land. Furthermore, the forest land retained 5327.144 ha of it in 2020 with an overall transition of 636.42 ha (387.118 ha to agriculture, 10.575 ha to water bodies, 16.473 ha to settlements, and 222.254 ha to barren land). In addition, the area of the settlements changed by 6.904 ha (2.161 ha to forest, 3.555 ha to agriculture, 0.005 ha to water bodies, and 1.183 ha to barren land). The least change was observed in water bodies as out of 18.934 ha area in 2010, 3.002 ha was still water bodies in 2020, but about 15.932 ha of water bodies area was converted to other classes (3.029 ha to forest, 2.687 ha to agriculture, 0.531 ha to settlements, and 9.685 ha to barren land) (Table 6). The water bodies were mainly replaced by barren land followed by forests and agricultural land. The modifications that took place in each class are listed in (Table 7).

Table 6. The cross-tabulation matrix of land cover classes between 2010 and 2020 (Area in ha)

Land Use Land Cover Classes		2020					
		Forest	Agriculture	Water Bodies	Settlements	Barren Land	Total (2010)
2010	Forest	5327.144	387.118	10.575	16.473	222.254	5963.564
	Agriculture	65.545	114.868	0.805	4.874	19.565	205.657
	Water Bodies	3.029	2.687	3.002	0.531	9.685	18.934
	Settlements	2.161	3.555	0.005	0.459	1.183	7.363
	Barren Land	252.225	343.709	2.104	10.36	340.207	948.605
	Total (2020)	5650.104	851.937	16.491	32.697	592.894	7144.12

Table 7. Summary of land cover conversion between 2010 and 2020

Land cover classes	Total land area converted (ha)
Forest	636.42
Agriculture	90.789
Water Bodies	15.932
Settlements	6.904
Barren Land	608.398
Total	1358.443

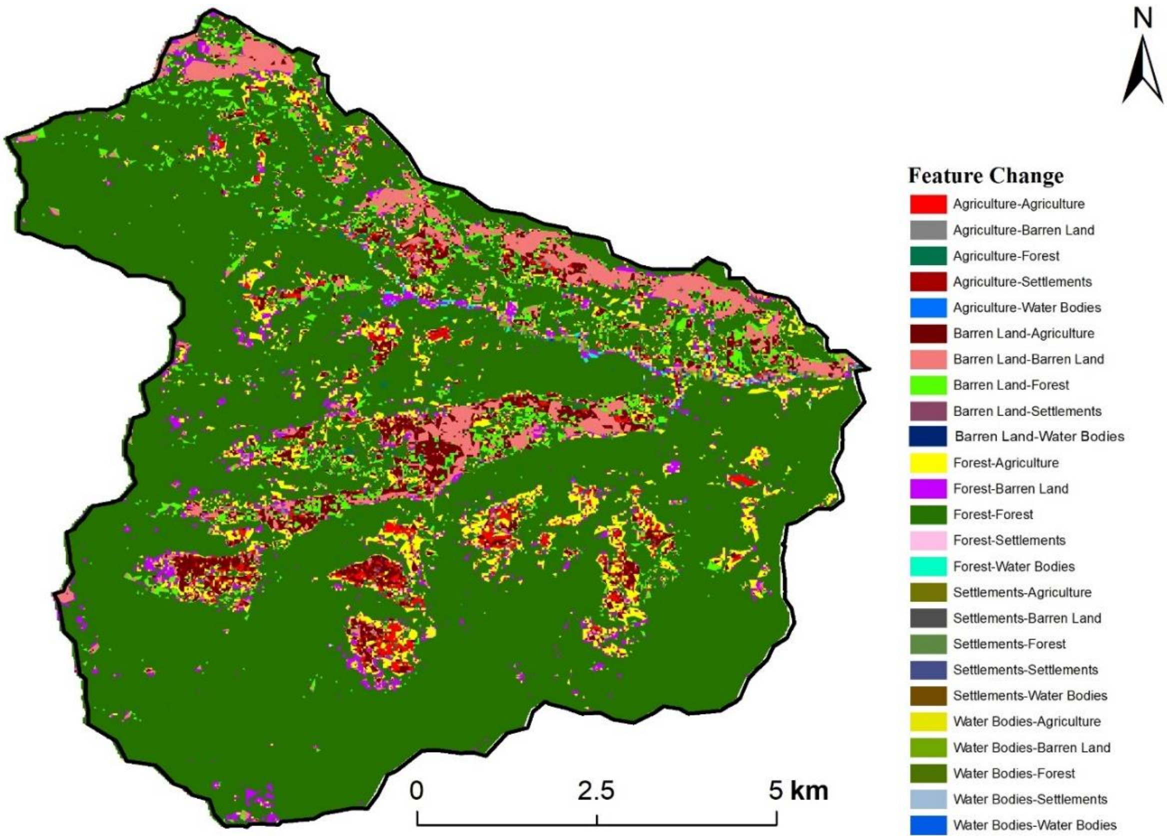


Figure 3. LULC class changes between 2010 and 2020

Impacts of LULC dynamics in springs in Ritung Khola sub-watershed

Among three FGDs, the discussion carried out in Malika Rural Municipality-04, Phulbari, Myagdi with local participants revealed that there were around four springs in the "Datreni'' area in 2010 but now, hardly 1-2 springs are seen in this area. There were no activities or programs from the government bodies, NGOs, INGOs, and CBOs for the conservation of springs in that area. However, the application of bio-engineering techniques (plantation of *Bambusa* sp., *Bauhinia variegata*, and *Ficus semicordata*) is currently implemented by the locals to protect the land from erosion and landslide which somehow conserves the displacement of existing springs.

Another discussion was carried out in Malika Rural Municipality-03, Aadhibara, Myagdi which indicated that the constructions of roads (five roads in Niskot currently under construction), agricultural land transformation into barren land, Bilbang landslide, and decrease in forest cover by 3-4% in the last 10 years are the key factors for decreased springs in this area. There were six springs in 2010 but tentatively around 2 springs are currently functional. Similarly, the discussion carried out in Malika Rural Municipality-04, Okharbot, Myagdi, disclosed that the construction of roads is the major parameter to lessen springs. Recently, there are around 25 springs, but only one is used by them. The spring name "Dadagaun Mul" was used by the people of Okharbot for irrigation, drinking, and several household purposes. There exists another spring "Tamakhani Mul" but the people don't use water from this spring. The water from 'Dipli Khola' is used by the people for drinking purposes. Dhordore kholso and Asare kholso consist number of springs in past but nowadays its availability is in decreasing trend. The surface runoff that occurs from the Okharbot in a sloppy land brings a landslide that has direct impacts on the nearby village 'Jukepani Tole' in the lower area. But recently, engineering techniques have been implemented using gabions to control the landslide and help protect the life and settlements of the "Jukepani Tole". We observed four springs where water level has decreased year by year (Figure 4).

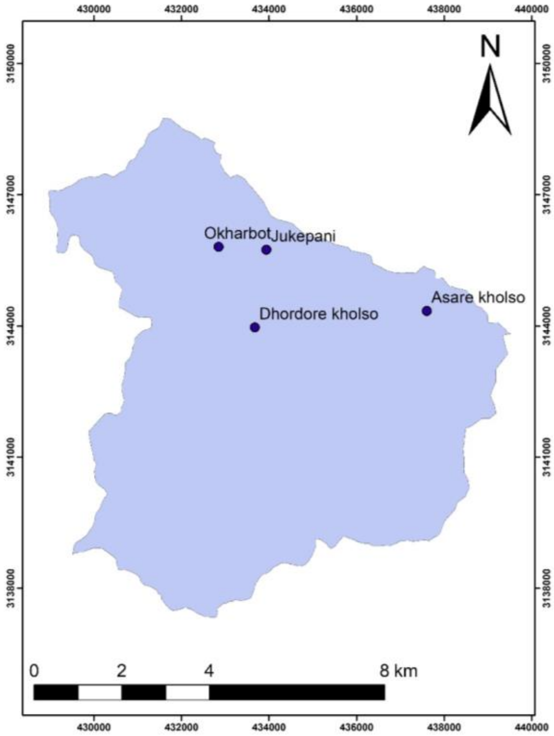


Figure 4. Springs which were active but has decreased water availability

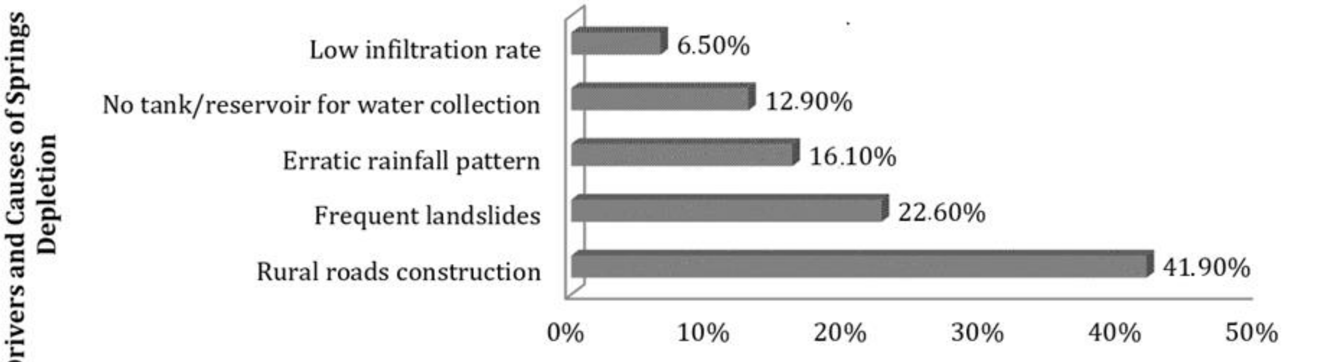
After finalizing the discussion in three selected areas, the main reasons behind the depletion of springs were ranked according to the perceptions of the local people. Rural roads construction was ranked first (41.9%) according to the FGDs (Table 8). Then the frequent landslide was ranked second (22.58%), due to the haphazard road construction. Erratic rainfall pattern ranked third (16.13%), no tank/reservoir for water collection ranked fourth (12.9%), and finally, low infiltration rate ranked fifth (6.45%), and this is solely due to the following reason (Table 8, Figure 5). The priority-based ranking table of causes and drivers of springs depletion is shown in Table 8.

Table 8. Priority ranking table of causes and drivers of springs depletion

S.N.	Drivers of Springs depletion	Score	Rank
1.	Frequent landslides	7	2
2.	Low infiltration rate	2	5
3.	Rural roads construction	13	1
4.	No tank/reservoir for water collection	4	4
5.	Erratic rainfall pattern	5	3

The main drivers or causes of springs depletion revealed and ranked during the discussions due to LULC change are presented in (Figure 5).

In a nutshell, the group discussion carried out in three areas of this sub-watershed comparatively summarized that the springs are in decreasing trend due to several drivers which are aforementioned. They further elaborated on the impacts perceived by springs as a result of these drivers in this sub-watershed, which is clearly shown in (Figure 6).



	Rural roads construction	Frequent landslides	Erratic rainfall pattern	No tank/reservoir for water collection	Low infiltration rate
Score (%)	41.90%	22.60%	16.10%	12.90%	6.50%

Figure 5. Rank of main drivers and causes for springs depletion by local people

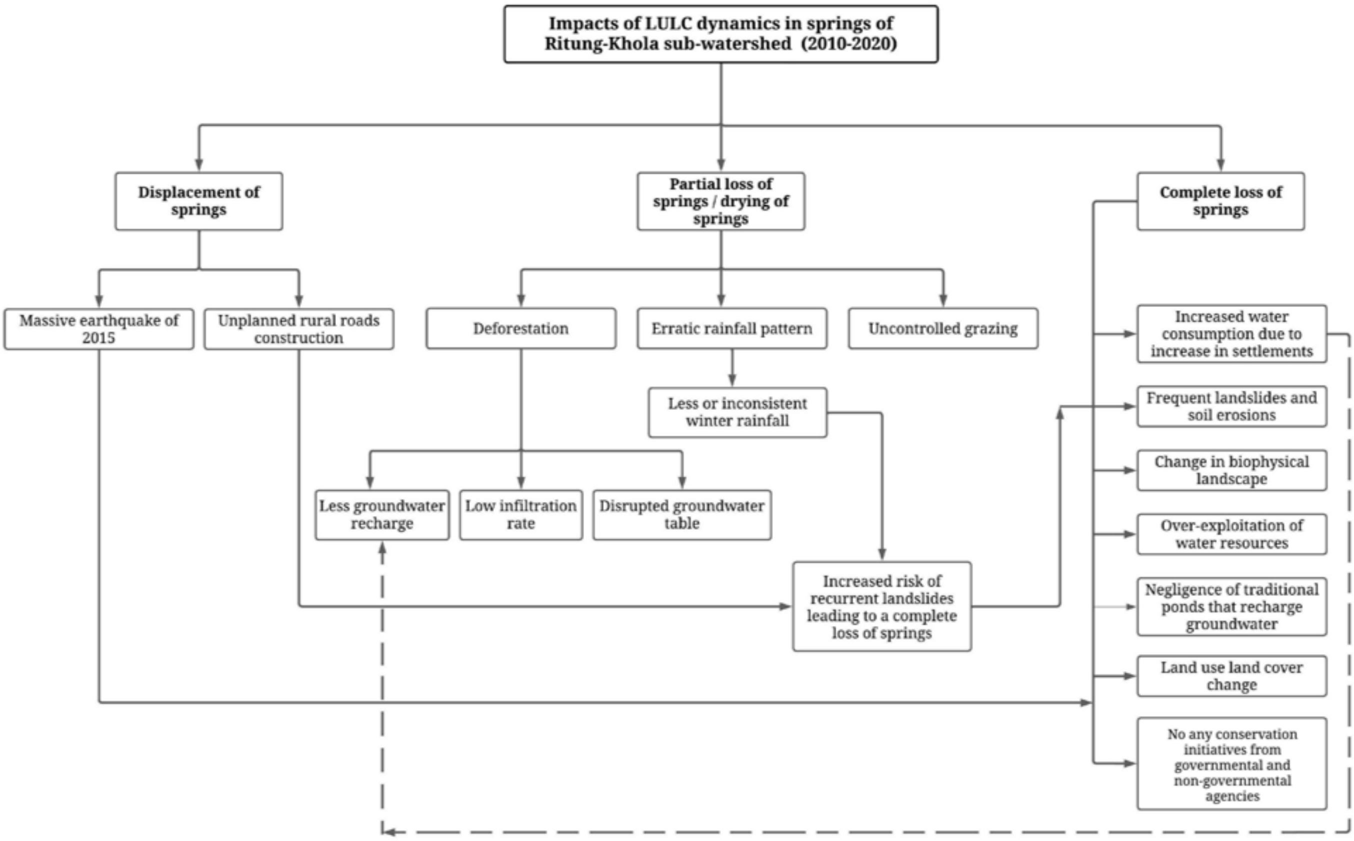


Figure 6. Flow chart showing the impact of LULC changes in springs as per the responses from the locals.

Discussion

Land Use Land Cover status of Ritung Khola Sub-watershed

Detecting changes and classifying LULC have been made easier by integrating GIS and RS data (Lo and Yeung, 2007; Dengiz, 2018). The multi-temporal Landsat series of imageries were used for the LULC classification in our study as performed in several other research (Yuan et al., 2005; Lu and Weng, 2005). However, there are several limitations of this method during image classification (Rogan and Chen, 2004) as it could have challenges with the heterogeneity of the environment which was problem during our study as well (Herold et al., 2002; Baghdadi and Zribi, 2016). The sporadic and unplanned patches in this sub-watershed area also pose a challenge for accuracy (Abdullah et al., 2019; Cai et al., 2019). Despite the fact that RS techniques have significant drawbacks, they have a number of advantages over conventional methods in terms of repeating coverage, inexpensive data capture, and extensive coverage (Xie et al., 2008; Kadhim et al., 2016). MLC algorithm was used for the LULC classification and determine their changes over the time and space (Norovsuren et al., 2019; Tripathi et al., 2020; Rakhmonov et al., 2021; Regasa et al., 2021).

Initially, land use classification map for 2010 showed that agriculture land is distributed between the dense forest area and the banks of rivers (Figure 2a). Most of the agriculture lands were fallow as the population was low. The reverse was found in the year 2020 when fallow lands were used up for agriculture and settlements substantially increased (Figure 2b). The analysis of the LULC from 2010 and 2020 reveals that this sub-watershed shows a magnificent transition from one land cover to another (Table 6). The increasing trend in LULC change directs the influence of population change and economic development in the sub-watershed (Attri et al., 2015). The change map also demonstrates that the agricultural land and settlements are in increasing trend whereas, forest, barren land, and water bodies are in the decreasing trend during these 10 years (Figure 3). The reason for declining forest cover might be due to the expansion of rural roads network, dependency of locals on forests for fuelwoods, cattle grazing, and deforestation (Thapa and Weber, 1995; Tiwari, 2000). The discussion conducted in Aadhibara reveals that forest cover decreased by 3-4% over the past 10 years. The results show that most of the forest area has been converted to agricultural land (Kandel et al., 2010). A study of Soussan et al. (1995) showed a comparable result with our study stating that rural road networks and infrastructure development has resulted in the clearing of forest cover in the hills of Nepal. Chaudhary et al. (2016) also found infrastructural development as a main cause of forest cover removal in Nepal. However, there is a little bit of depth in our result on how barren land and forest land both get decreased (Table 5). Barren land can decrease due to several efforts such as afforestation programs or could be replaced by agricultural land which is evident in our study (Table 6). The positive side is the lowest percentage change in forest cover (5.26%) as compared to other land classes where the decrease is attributed to some artificial interventions and construction of roads and foot trails in this sub-watershed.

A significant portion of forest-land was converted to other LULC categories, primarily to barren land, and agricultural land (Baral et al., 2018). According to the FGDs, most of the forest area has been cleared by encroachment for agriculture or construction purposes i.e., barren land for the construction of settlements. There is no introduction of a community forest program for the conservation of forest resources, which is also the main reason for the decline in forest cover which is contrary with the finding of Choudhary and Pathak (2016). Agricultural land has gone up from 2.88% (205.66 ha) in 2010 to 11.92% (851.94 ha) in 2020 with a significant increase in the area (645.9 ha), i.e., more than threefold increase in coverage (Table 5). Encroachments of other land covers including uncultivated areas of forest land results in agricultural expansion (Bufebo and Elias, 2021). Previously, the people residing in this sub-watershed mainly grew crops on steep slopes but nowadays, production and expansion of cropland extend to the peripheral land (around settlements and roads too) due to increase in population (Choudhary and Pathak, 2016). The use of different modern agricultural technologies and easy availability of labor (both men and women) are the factors in increasing agricultural land (Maharjan et al., 2020). Agricultural land was also increased at the expense of barren land and forests (Dhakal, 2010; Chalise and Kumar, 2020). The majority of people in FGDs was farmers and engaged in farming activities to run their livelihood. Paudel et al. (2016) mentioned that the farmland has increased by 13% around the nation over the recent 50 years which signifies the finding of this study. The main tenets of expanding agricultural land throughout the nation after the 1990s are the long-term plan and policies (Pesticide Act 199, Agriculture Perspective Plan 1995/96, and Land use policy 2012) and the development of infrastructure across the nation (MoAD, 2015). CBS (2019) indicated that 93.7% of agricultural land in 2011 was obtained from land-use statistics for Nepal. Similarly, barren land has decreased from 13.28% (948.60 ha) to 8.30% (592.89 ha) during this period. Most of the barren land is converted into agricultural land which is the main reason for increasing agricultural land and decreasing barren land (Koirala, 2010). Some researchers (Adhikari et al., 2018; Chalise and Kumar, 2020) summarized that there was a decrease in percentage of barren land from 1995 to 2015 and 1993 to 2013 in Sarada, Rapti, and Thuli Bheri river basins, and Phewa Watershed Pokhara, Nepal respectively. The decrease in the barren land area is due to the awareness and sustainable forest management programs from different governmental and non-governmental agencies (Tripathi et al., 2020). The concept of bio-engineering for erosion and landslide control has also aided in decreasing the barren land area (Dhital et al., 2013).

Another major increase was observed in the area of the settlement from 0.09% (7.36 ha) to 0.46% (32.70 ha) with a total of 25.7 ha area added (Table 5). Construction of new housing design, farmhouses, schools, and some recreational amenities results in an increment in settlements (Ishtiaque et al., 2017). In addition to these changes, there is a tendency to build new footpaths, roads, and other buildings to improve accessibility and internal movement in the region. Durban, the city of Malika Rural Municipality lies near the outlet of this sub-watershed which is dense and well equipped with different facilities. This results in increasing settlements around the peripheral areas. Rimal et al. (2018) portrays urban centers as the major factor for the increment in settlements in the Kaski district of Nepal. Easy road access to local villages has also fostered the expansion of settlements (Rimal et al., 2015; Adhikari et al., 2018). Additionally, the conversion of forest area into settlements and highways is a result of rapid urbanization (Wang et al., 2020).

The water bodies are minimally decreased during 10 years. The water bodies decreased from 0.27% (18.93 ha) to 0.23% (16.49 ha) with a decrease in the area of 2.5 ha (Table 5). The majority of water springs and streams got displaced or vanished from this area which decreased the area of water bodies (Figure 4). The area coverage of this watershed is more prone to soil erosion and frequent landslides during June-July which causes sedimentation in Ritung Khola, and Ruma Khola via different streams and other water sources that decrease the concentration of water level and purity of natural water. Encroachment of land along rivers by agricultural land is another major cause of declining water bodies (Agaton et al., 2016). Adhikari et al. (2018) study also highlighted that sedimentation and encroachment were the main disturbance to decline the area of water resources in the Phewa watershed, Kaski, Nepal. However, there is the least change in water bodies compared to other classes due to the availability of the same level of water in Ritung Khola and other streams that merged into it.

Impacts of LULC dynamics in springs in Ritung Khola sub-watershed

Further analysis on the impact of LULC changes in springs was performed by FGDs in three selected areas of this sub-watershed. Most of the respondents mentioned that the springs are dried and completely vanished due to the construction of rural roads in different places (Parajuli et al., 2019). Villagers have relied on springs to meet their basic requirements since time immemorial (Ghimire et al., 2019). According to the villagers, “There used to be large number of springs near each house in the past 10 years”. However, in recent years, the villagers have faced water scarcity due to a less number of springs which cannot provide sufficient water to perform daily activities. The study carried out by Sharma et al. (2016) demonstrated a similar result of springs decline in the Mid-hills of Nepal. Also, due to the 2015 earthquake, some springs of this area might have been displaced and completely vanished (Sharma et al., 2016; Chapagain et al., 2019). According to Talchabhadel et al. (2018), the monsoon dominates the rainfall pattern in Nepal, with the four months from June to September receiving about 80% of the country's yearly rainfall. The gap in rainfall pattern also is also a reason for springs' water declination (Miller et al., 2012). The fragile land results in erosion and landslides in different places, which was responsible for the displacement, and drying of the existing springs (Sharma et al., 2016). Chinnasamy and Prathapar (2016) mentioned identical reasons for loss of springs due to spatial variation in geology. The locals predicted that the remaining water springs would be completely lost after 10-15 years if the same trend continues without any conservation practices. The transition matrix (2010-2020) also highlights the decreasing trend of water bodies which indicates that springs are also some sorts of disappearing water resources (Table 6). There is less rainfall during the dry season which lowers the groundwater table that has a direct impact on springs (Gurung and Bhandari, 2009). The decrease in settlement areas by 50% in the last 10 years due to the floods and landslides occurred from Ruma Khola is also a key factor in decline of springs. One-fourth of forest cover decreased due to an increase in settlements over the past 10 years which lead to decrease in the springs from another way. Currently, the conservation status of springs is good from the local people’s perception because the Soil and Watershed Management office, Parbat provides construction aids like gabion and retaining walls which prevents the displacement of spring’s water in a sloppy area, controlling erosion and landslides. The improvement of water reservoirs/rainwater harvesting is necessary for the conservation of different water resources in this area (Adhikari et al., 2021). However, this ought to be the case in the majority of locations as about 80% of Nepal's 13 million inhabitants who live in hills and mountains rely on springs as their main source of water; as a result, they must be conserved by enlisting various conservation programs at all levels, from local to national (Sharma et al., 2016).

The other reason for decline in the springs area was the ongoing construction of rural roads in this area without considering proper conservation techniques (Sharma et al., 2016; Adhikari et al., 2021). The locals themselves create design without consulting the engineer’s team to assess the soil and site geography for roads construction. The ongoing construction of five roads in the Niskot area also hinders the sustainable conservation of the springs and has greater impacts on them. The springs are displaced from their current location due to the recurrent landslides occurred due to road construction (Chapagain et al., 2019). The Bilbang landslide has a severe impact on springs leading to partial loss of springs. The severe landslide pattern also has an impact on the complete loss of springs (Figure 6). Landslides displace the sources of springs and deposit sediments in different river falls in this sub-watershed (for example, Ruma Khola) (Chapagain et al., 2019). The primary source of water for crops and springs in this region is rainfall. However, due to the gap or erratic rainfall patterns, large numbers of springs are drying up rapidly leading to partial loss of springs in this area (Figure 6) (Chaudhary et al., 2011; Tambe et al., 2012; Chapagain et al., 2019; Adhikari et al., 2021). The inconsistent rainfall pattern (high and low) creates a chance of soil erosion and landslides. The decrease in forest cover has parallel links to a decrease in vegetation that ultimately creates a low infiltration rate (Sharma et al., 2016). The roads construction also creates compactness in the soil that eventually decreases the infiltration capacity (Yang and Zhang, 2011). Due to this, the groundwater level and groundwater recharge decrease, which also has an impact on the complete loss of springs (Figure 6). In addition, Government Organizations (GOs), NGOs, INGOs, and CBOs haven't given the conservation priorities for the springs conservation, which has severe impacts on the complete loss of springs (Sharma et al., 2016). There is no provision for rainwater harvesting and tank for water collection during scarcity (Figure 6) (Sharma et al., 2016; Adhikari et al., 2021). People also harvest snow and use the melt water for livestock and irrigation in the highlands of Nepal (Panthi et al., 2019).

Conclusion

LULC practices in the study area have changed dramatically over the past 10 years based on the data acquired through the use of GIS and RS technologies to meet the specific research objectives. Landsat 5 and Landsat 8 satellite with TM and OLI/TIRS sensors were respectively used to classify images. After the classification, the study shows that area of agricultural land, and settlements were increased whereas, forest, water bodies, and barren land had decreased. The discussion of FGDs reveals the significant decrease in springs' number is due to erosion, landslides, road construction, and lack of support from NGOs, INGOs, and CBOs for the sustainable conservation of springs. Forest coverage has decreased from 2010 to 2020; therefore, tree planting should be promoted by the local communities with the help of government offices and non-governmental offices. The water resources are on decreasing trend so; land encroachment near water bodies should be reduced to lessen the depletion of water resources in this sub-watershed. Based on scientific studies, watershed level springs rejuvenation projects should be started by incorporating local people, government organizations, and other stakeholders in order to combat depression and displaced springs. Activities to revive springs, monitoring of water resources, and Integrated Watershed Management (IWM) programs are highly recommended for the conservation of springs' water. The supervised image classification shows decent accuracy for all the classified features. There are some limitations despite having the satisfactory classification result. The research was carried out within a short period using Landsat images of moderate spatial resolution, which could be improved using newer satellite data with finer spatial resolution. In addition, ground truth data were collected based on the 2010 land-use classification types due to the unavailability of latest LULC map. Furthermore, this study might help land-use planners and academicians to formulate the necessary policies for the sustainability of sub-watersheds, whereby conserving the vulnerable springs to reduce water scarcity in local communities.

Acknowledgements

This paper is a part of a research project by the first author (Mr. Sachin Timilsina). We are indebted to Tribhuvan University, Institute of Forestry (IoF), Pokhara Campus, Soil and Watershed Management Office, Parbat, Kushma and Malika Rural Municipality for providing the platform to conduct this research. The authors would like to thank Mr. Bibek Tamang, Er. Ramchandra Timilsina, Er. Bikash Thapa, Er. Rabin Lamichhane, and Mr. Shishir Paudel for their support during the study period. We would like to thank all helping hands during this manuscript preparation. Also, the authors were grateful to the editors and anonymous reviewers for their constructive comments and suggestion to improve the quality of this manuscript.

References

Abdullah, A.Y.M., Masrur, A., Adnan, M.S.G., Baky, M.A.A., Hassan, Q.K., Dewan, A., 2019. Spatio-temporal patterns of land use/land cover change in the heterogeneous coastal region of Bangladesh between 1990 and 2017. *Remote Sensing* 11(7): 790.

Adhikari, N., Pant, R.R., Rimal, B., Rai, R., 2018. Land use and land cover change in Western Nepal: A case from Phewa Watershed-Pokhara, Nepal. *Himalayan Scientific Journal* 9: 33-42.

Adhikari, S., Gurung, A., Chauhan, R., Rijal, D., Dongol, B.S., Aryal, D., Talchabhadel, R., 2021. Status of springs in mountain watershed of western Nepal. *Water Policy* 23(1): 142-156.

Agaton, M., Setiawan, Y., Effendi, H., 2016. Land use/land cover change detection in an urban watershed: a case study of upper Citarum Watershed, West Java Province, Indonesia. *Procedia Environmental Sciences* 33: 654-660.

Alajlan, N., Bazi, Y., Melgani, F., Yager, R.R., 2012. Fusion of supervised and unsupervised learning for improved classification of hyperspectral images. *Information Sciences* 217: 39-55.

Attri, P., Chaudhry, S., Sharma, S., 2015. Remote sensing & GIS-based approaches for LULC change detection–a review. *International Journal of Current Engineering and Technology* 5: 3126–3137.

Baghdadi, N., Zribi, M., 2016. Land surface remote sensing in urban and coastal areas. London: ISTE Press Ltd.

Baral, P., Wen, Y., Urriola, N.N., 2018. Forest cover changes and trajectories in a typical middle mountain watershed of western Nepal. *Land* 7(2): 72.

Barquín, J., Scarsbrook, M., 2008. Management and conservation strategies for coldwater springs. *Aquatic Conservation: Marine and Freshwater Ecosystems* 18(5): 580-591.

Bekele, D., Alamirew, T., Kebede, A., Zeleke, G., Melesse, A.M., 2019. Land use and land cover dynamics in the Keleta watershed, Awash River basin, Ethiopia. *Environmental Hazards* 18(3): 246-265.

Bharatkar, P.S., Patel, R., 2013. Approach to accuracy assessment tor RS image classification techniques. *International Journal of Scientific & Engineering Research* 4(12): 79–86.

Bhat, S.U., Mushtaq, S., Qayoom, U., Sabha, I., 2020. Water quality scenario of Kashmir Himalayan Springs—A case study of Baramulla District, Kashmir Valley. *Water, Air, & Soil Pollution* 231(9): 1-17.

Bufebo, B., Elias, E., 2021. Land use/land cover change and its driving forces in Shenkolla watershed, south Central Ethiopia. *The Scientific World Journal* Article ID 9470918.

Cai, G., Ren, H., Yang, L., Zhang, N., Du, M., Wu, C., 2019. Detailed urban land use land cover classification at the metropolitan scale using a three-layer classification scheme. *Sensors* 19(14): 3120.

Cantonati, M., Füreder, L., Gerecke, R., Jüttner, I., Cox, E.J., 2012. Crenic habitats, hotspots for freshwater biodiversity conservation: toward an understanding of their ecology. *Freshwater Science* 31(2): 463-480.

CBS, 2019. Environmental Statistics of Nepal. National Planning Commission, Secretariat Central Bureau of Statistics. Government of Nepal, Kathmandu, Nepal.

Chalise, D., Kumar, L., 2020. Land use change affects water erosion in the Nepal Himalayas. *PLoS ONE* 15(4): e0231692.

Chapagain, P.S., Ghimire, M., Shrestha., S. 2019. Status of natural springs in the Melamchi region of the Nepal Himalayas in the context of climate change. *Environment, Development and Sustainability* 21(1): 263-280.

Chaudhary, P., Rai, S., Wangdi, S., Mao, A., Rehman, N., Chettri, S., Bawa, K. S., 2011. Consistency of local perceptions of climate change in the Kangchenjunga Himalaya landscape. *Current Science* 101(4): 504-513.

Chinnasamy, P., Prathapar, S.A., 2016. Methods to investigate the hydrology of the Himalayan springs: a review. International Water Management Institute (IWMI). IWMI Working Paper 169, Colombo, Sri Lanka. 28p.

Choudhary, R., Pathak, D., 2016. Land use/land cover change detection through temporal imageries and its implications in water induced disaster in Triyuga watershed, east Nepal. *Journal of Nepal Geological Society* 51: 49-54.

Congalton, R.G., 1996. Accuracy assessment: a critical component of land cover mapping. In: Gap Analysis: A Landscape Approach to Biodiversity Planning. Scott, J.M., Tear, T.H., Davis, F. (Eds.). American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland, USA. pp. 119–131.

Congalton, R.G., 2001. Accuracy assessment and validation of remotely sensed and other spatial information. *International Journal of Wildland Fire* 10(4): 321-328.

Dengiz, O., 2018. Potential impact of land use change on land productivity dynamics with focus on land degradation in a sub-humid terrestrial ecosystem. *Theoretical and Applied Climatology* 133(1): 73-88.

Dhakal, K.R., 2010. Land use change in Khageri watershed, Chitwan. *The Third Pole: Journal of Geography Education* 8: 51-56.

Dhital, Y.P., Kayastha, R.B., Shi, J., 2013. Soil bioengineering application and practices in Nepal. *Environmental Management* 51(2): 354-364.

Dinka, M.O., Chaka, D.D., 2019. Analysis of land use/land cover change in Adei watershed, Central Highlands of Ethiopia. *Journal of Water and Land Development* 41: 146–153.

Foley, J.A., DeFries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K., Helkowski, J.H., Holloway, T., Howard, E.A., Kucharik, C.J., Monfreda, C., Patz, J.A., Prentice, I.C., Ramankutty, N., Snyder, P.K., 2005. Global consequences of land use. *Science* 309(5734): 570–574.

Foody, G.M., 2002. Status of land cover classification accuracy assessment. *Remote Sensing of Environment* 80(1): 185-201.

Frumkin, H., 2002. Urban sprawl and public health. *Public Health Reports* 117: 201–217.

Ghimire, M., Chapagain, P.S., Shrestha, S., 2019. Mapping of groundwater spring potential zone using geospatial techniques in the Central Nepal Himalayas: a case example of Melamchi–Larke area. *Journal of Earth System Science* 128: 26.

Gurung, G.B., Bhandari, D., 2009. Integrated approach to climate change adaptation. *Journal of Forest and Livelihood* 8(1): 91-99.

Herold, M., Scepan, J., Clarke, K.C., 2002. The use of remote sensing and landscape metrics to describe structures and changes in urban land uses. *Environment and Planning A: Economy and Space* 34(8): 1443-1458.

Ibeneme, S.I., Ukiwe, L.N., Essien, A.G., Nwagbara, J.O., Nweze, C.A., Chinemelu, E.S. Ivonye, C.A., 2013. Assessment of the chemical characteristics of a spring water source at Ife-Owutu, Ezinihite-Mbaise, Southeastern Nigeria. *American Journal of Engineering Research (AJER)* 2(10): 282-290.

ICIMOD, 2015. Reviving the drying springs reinforcing social development and economic growth in the Midhills of Nepal. International Centre for Integrated Mountain Development, Lalitpur, Nepal, pp. 1–6.

Ishtiaque, A., Shrestha, M., Chhetri, N., 2017. Rapid urban growth in the Kathmandu Valley, Nepal: Monitoring land use land cover dynamics of a himalayan city with landsat imageries. *Environments* 4(4): 72.
Jensen, J.R., 2005. *Introductory Digital Image Processing: A Remote Sensing Perspective*. 3rd Prentice Hall, Upper Saddle River, New Jersey.
Kadhim, N., Mourshed, M., Bray, M., 2016. Advances in remote sensing applications for urban sustainability. *Euro-Mediterranean Journal for Environmental Integration* 1: 7.
Kandel, C.M., Caetano, M., Cabral, P., 2010. Forest cover monitoring of Bara district (Nepal) using remote sensing and geographic information systems. *Banko Janakari* 20(1): 30-36.
Koirala, S., 2010. Land use/ land cover change and its impact on soil erosion process in Begnas Tal Rupa Tal watershed using geospatial tools, Kaski district, Nepal. Master of Science in Geospatial Technologies, University of NOVA, Lisbon. 62p. Available at [Access date: 10.09.2022]: https://run.unl.pt/bitstream/10362/2732/4/TGEO0030.pdf
Lambin, E.F., Turner, B.L., Geist, H.J., Agbola, S.B., Angelsen, A., Bruce, J.W., Coomes, O.T., Dirzo, R., Fischer, G., Folke, C., George, P.S., Homewood, K., Imbernon, J., Leemans, R., Li, X., Morgan, E.F., Mortimore, M., Ramakrishnan, P.S., Xu, J., 2001. The causes of land-use and land-cover change: moving beyond the myths. *Global Environmental Change* 11(4): 261–269.
Li, C., Ma, Z., Wang, L., Yu, W., Tan, D., Gao, B., Feng, Q., Guo, H., Zhao, Y., 2021. Improving the accuracy of land cover mapping by distributing training samples. *Remote Sensing* 13(22): 4594.
Li, Y., Wang, C., 2009. Impacts of urbanization on surface runoff of the Dardenne Creek watershed, St. Charles County, Missouri. *Physical Geography* 30(6): 556-573.
Lillesand, T.M., Kiefer, R.W., Chipman, J.W., 2015. Remote Sensing and Image Interpretation, 7th Ed. Wiley, 750p.
Liping, C., Yujun, S., Saeed, S., 2018. Monitoring and predicting land use and land cover changes using remote sensing and GIS techniques - A case study of a hilly area, Jiangle, China. *PLoS ONE* 13(7): e0200493.
Liu, Y., Huang, X., Yang, H., Zhong, T., 2014. Environmental effects of land-use/cover change caused by urbanization and policies in Southwest China Karst area–A case study of Guiyang. *Habitat International* 44: 339-348.
Lo, C.P., Yeung, A.K., 2007. Concepta and Techniques of Geographic Information Systems. Pearson Prentice Hall. 732p.
LRMP, 1986. Land Utilization Report. Land Resource Mapping Project, Kenting Earth Science Canada and Department of Topography, Government of Nepal, Kathmandu, Nepal. p 112.
Lu, D., Weng, Q., 2005. Urban classification using full spectral information of Landsat ETM+ imagery in Marion County, Indiana. *Photogrammetric Engineering & Remote Sensing* 71(11): 1275-1284.
Maharjan, A., Kochhar, I., Chitale, V.S., Hussain, A., Gioli, G., 2020. Understanding rural outmigration and agricultural land use change in the Gandaki Basin, Nepal. *Applied Geography* 124: 102278.
Miller, J.D., Immerzeel, W.W., Rees, G., 2012. Climate change impacts on glacier hydrology and river discharge in the Hindu Kush–Himalayas. *Mountain Research and Development* 32(4): 461-467.
MoAD, Agriculture Development Strategy (ADS), 2015. Government of Nepal, Ministry of Agricultural Development, Singhdurbar: Kathmandu, Nepal.
Muller, D., Zeller, M., 2002. Land use dynamics in the central highlands of Vietnam: a spatial model combining village survey data with satellite imagery interpretation. *Agricultural Economics* 27(3): 333-354.
Niyogi D., Mahmood R., Adegoke, J.O., 2009. Land Use/Land-Cover Change and Its Impacts on Weather and Climate. *Boundary Layer Meterology* 133: 297–298.
Norovsuren, B., Tseveen, B., Batomunkuev, V., Renchin, T., Natsagdorj, E., Yangiv, A., Mart, Z., 2019. Land cover classification using maximum likelihood method (2000 and 2019) at Khandgait valley in Mongolia. IOP Conference Series: Earth and Environmental Science, 381: 012054.
Odum, H.T., 1971. Fundamentals of ecology. Saunders. Philadelphia, USA. 574p.
Panigrahi, S., Verma, K., Tripathi, P., 2017. Data mining algorithms for land cover change detection: a review. *Sādhanā* 42(12): 2081-2097.
Panthi, J., Khatiwada, K.R., Shrestha, M.L., Dahal, P., 2019. Water poverty in the context of climate change: a case study from Karnali river basin in Nepal Himalaya. *International Journal of River Basin Management* 17(2): 243–250.
Parajuli, K., Joshi, J., Gautam, J., 2019. Major Springs and Their Status in Mid-Hills of Nepal: A Case Study of Samdi Micro-Watershed of Dhandkhola Watershed, Tanahun. Proceeding Research Seminar on Climate Change, Clean Energy. 8 March 2019, Hetauda, Makwanpur, Nepal. pp. 10-15.
Paudel, B., Zhang, Y.L., Li, S.C., Liu, L.S., Wu, X., Khanal, N.R., 2016. Review of studies on land use and land cover change in Nepal. *Journal of Mountain Science* 13(4): 643-660.
Porfiriev, B., 2015. Climate change as a major slow-onset hazard to development: An integrated approach to bridge the policy gap. *Environmental Hazards* 14(2): 187-191.
Rakhmonov, S., Umurzakov, U., Rakhmonov, K., Bozarov, I., Karamatov, O., 2021. Land use and land cover change in Khorezm, Uzbekistan. Annual International Scientific Conference on Geoinformatics – GI 2021: "Supporting sustainable development by GIST" E3S Web of Conferences 227: 01002.
Regasa, M.S., Nones, M., Adeba, D., 2021. A review on land use and land cover change in Ethiopian basins. *Land* 10(6): 585.
Reid, R.S., Kruska, R.L., Muthui, N., Taye, A., Wotton, S., Wilson, C.J., Mulatu, W., 2000. Land-use and land-cover dynamics in response to changes in climatic, biological and socio-political forces: the case of southwestern Ethiopia. *Landscape Ecology* 15(4): 339-355.

Rimal, B., Baral, H., Stork, N.E., Paudyal, K., Rijal, S., 2015. Growing city and rapid land use transition: Assessing multiple hazards and risks in the Pokhara Valley, Nepal. *Land* 4(4): 957-978.

Rimal, B., Zhang, L., Keshtkar, H., Haack, B.N., Rijal, S., Zhang, P., 2018. Land use/land cover dynamics and modeling of urban land expansion by the integration of cellular automata and markov chain. *ISPRS International Journal of Geo-Information* 7(4): 154.

Rimal, B., Zhang, L., Keshtkar, H., Sun, X., Rijal, S., 2018. Quantifying the spatiotemporal pattern of urban expansion and hazard and risk area identification in the Kaski District of Nepal. *Land* 7(1): 37.

Rogan, J., Chen, D., 2004. Remote sensing technology for mapping and monitoring land-cover and land-use change. *Progress in Planning* 61: 301-325.

Rwanga, S.S., Ndambuki, J.M., 2017. Accuracy assessment of land use/land cover classification using remote sensing and GIS. *International Journal of Geosciences* 8(04): 611.

Sharma, B., Nepal, S., Gyawali, D., Pokharel, G.S., Wahid, S., Mukherji, A., Acharya, S., Shrestha, A.B., 2016. Springs, storage towers, and water conservation in the midhills of Nepal. International Centre for Integrated Mountain Development. ICIMOD Working Paper 2016/3, Kathmandu, Nepal. 45p.

Shiferaw, A., Singh, K.L., 2011. Evaluating the land use and land cover dynamics in Borena Woreda of South Wollo Highlands, Ethiopia. *Ethiopian Journal of Business and Economics* 2(1): 69–104.

Soussan, J., Shrestha, B.K., Uprety, L.P., 1995. The social dynamics of deforestation: a case study from Nepal. Taylor & Francis. 170p.

Talchabhadel, R., Karki, R., Thapa, B.R., Maharjan, M., Parajuli, B., 2018. Spatio-temporal variability of extreme precipitation in Nepal. *International Journal of Climatology* 38(11): 4296-4313.

Tambe, S., Kharel, G., Arrawatia, M.L., Kulkarni, H., Mahamuni, K., Ganeriwala, A.K., 2012. Reviving dying springs: climate change adaptation experiments from the Sikkim Himalaya. *Mountain Research and Development* 32(1): 62-72.

Thapa, G.B., Weber, K.E., 1995. Status and management of watersheds in the Upper Pokhara Valley, Nepal. *Environmental Management* 19(4): 497-513.

Tiwari, P.C., 2000. Land-use changes in Himalaya and their impact on the plains ecosystem: need for sustainable land use. *Land Use Policy* 17(2): 101-111.

Tripathi, S., Subedi, R., Adhikari, H., 2020. Forest cover change pattern after the intervention of community forestry management system in the mid-hill of Nepal: A case study. *Remote Sensing* 12(17): 2756.

Vahtmäe, E., Kutser, T., Kotta, J., Pärnoja, M., Möller, T., Lennuk, L., 2012. Mapping Baltic Sea shallow water environments with airborne remote sensing. *Oceanology* 52(6): 803-809.

von Fumetti, S., Bieri-Wigger, F., Nagel, P., 2017. Temperature variability and its influence on macroinvertebrate assemblages of alpine springs. *Ecohydrology* 10(7): e1878.

Wang, S.W., Gebru, B.M., Lamchin, M., Kayastha, R.B., Lee, W.K., 2020. Land use and land cover change detection and prediction in the Kathmandu district of Nepal using remote sensing and GIS. *Sustainability* 12(9): 3925.

Weng, Q., 2001. A remote sensing? GIS evaluation of urban expansion and its impact on surface temperature in the Zhujiang Delta, China. *International Journal of Remote Sensing* 22(10): 1999-2014.

Xie, Y., Sha, Z., Yu, M., 2008. Remote sensing imagery in vegetation mapping: a review. *Journal of Plant Ecology* 1(1): 9-23.

Yang, J.L., Zhang, G.L., 2011. Water infiltration in urban soils and its effects on the quantity and quality of runoff. *Journal of Soils and Sediments* 11(5): 751-761.

Yang, W., Yin, X., Xia, G.S., 2015. Learning high-level features for satellite image classification with limited labeled samples. *IEEE Transactions on Geoscience and Remote Sensing* 53(8): 4472-4482.

Yuan, F., Sawaya, K.E., Loeffelholz, B.C., Bauer, M.E., 2005. Land cover classification and change analysis of the Twin Cities (Minnesota) Metropolitan Area by multitemporal Landsat remote sensing. *Remote Sensing of Environment* 98(2-3): 317-328.

Zhang, C., Chen, Y., Lu, D., 2015. Mapping the land-cover distribution in arid and semiarid urban landscapes with Landsat Thematic Mapper imagery. *International Journal of Remote Sensing* 36(17): 4483-4500.

Zhang, G., Cao, Z., Gu, Y., 2005. A hybrid classifier based on rough set theory and support vector machines. In: Fuzzy Systems and Knowledge Discovery. FSKD 2005. Lecture Notes in Computer Science, vol 3613. Wang, L., Jin, Y. (Eds.). Springer, Berlin, Heidelberg. pp. 1287-1296.