Assessment of Landcover Change of Kathmandu District, Nepal

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KEYWORDS

Landcover, Google Earth Engine, Remote Sensing, Urban Planning

ABSTRACT

It is necessary to understand land cover changes for managing and monitoring natural resources and development, especially urban planning. Remote sensing and geographical information systems (GIS) are proven tools for assessing land use and land cover changes, which helps planners advance sustainability. Google Earth Engine is used in this study to detect land cover changes in one of the rapidly growing cities in Nepal. It was discovered that from 2013 to 2019, 0.26% of the total area was increased by forests, 3.28% by settlement, 0.015% by wetland, and 1.21% by otherland. The overall accuracy and kappa coefficient of the landcover change study for 2013 are 80% and 0.74, and the overall accuracy and kappa coefficient of the study of landcover change for 2019 are 83.33% and 0.78. The status of the landcover change in Kathmandu district before and after the earthquake showed that forest covers the highest area, followed by cropland, and then settlement in both years 2013 and 2019. Forest, settlement, wetland, and other land have increased by 0.26%, 4.54%, 0.015%, and 1.21%, respectively. However, cropland and grassland have been decreased by 3.28% and 0.22% respectively.

1. BACKGROUND

Land is a delineable area of the earth's terrestrial surface, encompassing all attributes of the biosphere immediately above or below this surface, including those of the near surface, climate, soil, and terrain forms; the surface hydrology (including shallow lakes, rivers, marshes, and swamps); the near-surface sedimentary layers and associated groundwater reserve; the plant and animal populations; the human settlement pattern; and the physical results of past and present human activity (terracing, water storage or drainage structures, roads, buildings, etc.) (FAO, 1995).

Because all aspects of sustainability were meant to be captured, nine land use functions were considered, each of which was either societal, economical, or environmental. The societal land use functions are the provision of work, human health, recreation, and culture. The economic landuse functions are residential and land-independent production, land-based production, and transport. The environmental landuse functions are provision of abiotic resources, support and provision of biotic resources, and maintenance of ecosystem processes (Perez-Soba *et al.* 2008).

Although the terms "land cover" and "land use" are often used interchangeably, their actual meanings are quite distinct. Land cover refers to the surface cover on the ground, such as vegetation, urban infrastructure, water, bare soil, etc. Identification, delineation, and mapping of land cover are important for monitoring studies, resource management, and planning activities. Identification of land cover establishes the baseline from which monitoring activities can be performed. Land use represents economic and cultural activities, for example, recreation, wildlife habitat, agriculture, residential, etc. Land use applications involve both baseline mapping and subsequent monitoring, since timely information is required to know what current quantity of land is in what type of use and to identify land use changes from year to year. This knowledge will help to develop strategies to balance conservation, conflicting uses, and developmental pressures. (Ravisankar, 2017).

Land-use and land-cover change are two of the main driving forces behind global environmental change. They have a high influence on a variety of environmental and landscape attributes, including water quality, land and air resources, ecosystem function, and the climatic system itself through greenhouse gas changes and surface albedo effects (Lambin *et al.* 2000).

Green space coverage has substantial importance for the quality of life as it has a significant impact on ecosystem functions, local microclimate, air quality, recreation, and aesthetic perceptions (Vatseva et al. 2016). Green spaces and other nature-based solutions provide innovative approaches to increasing the quality of urban settings, enhancing local resilience, and promoting sustainable lifestyles while at the same time improving the health and well-being of urban residents. Well-planned and managed urban green spaces ensure adequate opportunities for exposure to nature. Urban biodiversity is maintained and protected. Similarly, environmental hazards such as air pollution or noise are reduced. Various extreme weather impacts, such as heat waves, extreme rainfall, or flooding, are mitigated (WHO, 2017).

Urban expansion has increased the exploitation of natural resources, changing land use and land cover patterns. Understanding land use and land cover changes has become a necessity in managing and monitoring natural resources and development, especially urban planning.

In this regard, remote sensing and geographical information systems are proven tools for assessing land use and land cover changes that help planners advance sustainability (Lee et al. 2018). Geographic Information Systems (GIS) and remote sensing are powerful means for mapping and analyzing green space coverage at various spatial and temporal scales. It is a cost-effective and precise alternative to studying landscape dynamics. The transformation of Earth observation data into useful information is necessary for green space planning and decision-making. This can be done with the availability of high-resolution remote sensing images and multi-source geospatial data. Due to improvements in satellite image quality and availability, it has been easier to perform image analysis at a much larger scale than in the past. Thus, remote sensing and GIS have greater scope for the conception of dynamic models of physical environmental processes (Jensen, 2005).

According to the preliminary results of the National Census 2078, the population of Nepal stands at 29,192,480, which is 2,697,976 more than the population of 26,494,504 ten years ago (2068). Nepal's population has grown by 10.18%. The annual growth rate for the last ten years is 0.93%, compared to 1.35% in the previous census. As per UN-HABITAT (2013), the last quarter of the 20th century saw a fast expansion of Kathmandu Valley, reflecting the trend of urban growth dominant in the Himalayan region and elsewhere in South Asia (UN-HABITAT, 2013).

The study conducted by Maharjan (2018) using Landsat images for the years 2006, 2013, and 2017 identified that forest areas have been in relatively stable condition and that aggressive urban growth has somewhat slowed down in the last 5 years. However, mostly agricultural lands were converted into settlement areas, and other areas increased by about 68.15% from 2006 to 2017. Also, due to the 2015 earthquake, co-seismic surface deformation was reported along with its effects on the natural environment, such as landslides and liquefaction (Maharjan, 2018).

Thus, the study will compare how landcover change has occurred with the increasing population in 2013 and 2019, and will also explore the status of landcover change before and after earthquakes by using a globally reliable and fast remote sensing method, i.e., Google Earth Engine, which gives robust results. It will help urban planners and researchers make assessments of landscape development and change for continuous monitoring, well-planned development, and management of natural resources.

2. METHODOLOGY

2.1. Study area

The map of study area is shown in figure 1.

Figure 1: Map of study area

Kathmandu district is taken as the study area in this research. Kathmandu is one of the 77 districts of Nepal and covers an area of 433.61 km2. It is located in the Kathmandu Valley, Bagmati Province, of Nepal, a landlocked country in South Asia. The total number of people in the district is 2041578 (as per the census of 2021). Kathmandu Metropolitan City is the headquarters of this district, which is also the capital of Nepal. It is one of the three districts located in the Kathmandu Valley. It is located from 27°27′E to 27°49′E longitude and from 85°10′N to 85°32′N latitude. The district is surrounded by Bhaktapur and Kavrepalanchok in the east, Dhading and Nuwakot in the west, Nuwakot and Sindhupalchok in the north, and Lalitpur and Makwanpur in the south (http://ddcktm.gov.np/). The altitude of the district ranges from 1,262 m to 2,732 m above sea level. The temperature fluctuates between 32 °C in summer (June–July) and -2°C in winter (December–January) in the urban center. The district includes 11 municipalities, which are Budhanilkantha, Chandragiri, Dakshinkali, Gokarneshwar, Kageshwar Manohara, Kathmandu, Kirtipur, Nagarjun, Shankharapur, Tarakeshwar, and Tokha.

The main reason to choose Kathmandu as the study area is that it is the most developed area among other cities and towns in Nepal. A huge number of people have migrated from rural to urban areas, and the rapid increase in population has resulted in challenging problems such as crowding and landuse conflicts (e.g., competitive demands for land use have an adverse effect on neighboring landuses) and problems in urban planning and management (Bakrania, 2015). This case study analyzes the land cover of Kathmandu district using remote sensing Landsat data for the years 2013 and 2019.

For this study, Google Earth Engine (GEE) scripts followed by Forest Research and Training Centre in the study of National Land Cover Monitoring System was customized as per requirements. The methods for this study is described in figure 2 as follows:

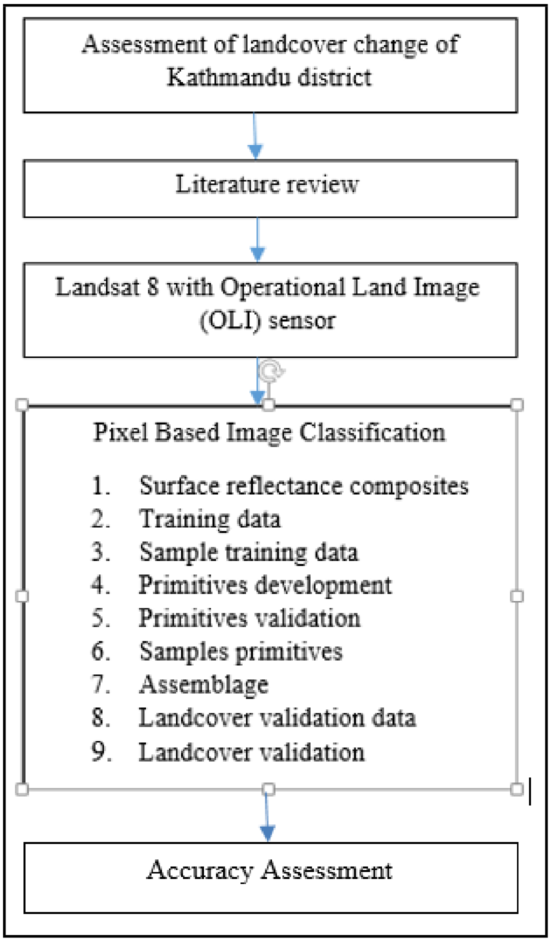

Figure 2: Methodology flowchart

2.2. Pixel based image classification

Landsat 8 with Operational Land Imager (OLI) sensor was acquired through the commonly used high power planetary-scale raster analysis utilities of Google Earth Engine (GEE) (Sidhu et al., 2018) and further landcover mapping and classification work was carried out in QGIS 3.24.1. The detail of satellite data is given in table 1.

Table 1: Characteristics of landsat image

Satellite	Sensor	Path-Row	Date	Resolution (m)	Band
Landsat 8	Operational Land Imager (OLI)	141-41	2013 and 2019	30	1 to 8

2.2.1. Surface reflectance composites

It involves image pre-processing such as shadow and cloud masking Bidirectional Reflectance Distribution Function (BRDF) and topographic correction. For composites preparation, Landsat 8 was used. After this, image composites were created which consists of all the information that is required to capture the information in the study area throughout the year. Composites image for 2013 and 2019 of Kathmandu district was created. These data were hosted in the Earth Engine data archive and have approximately 30 meters ground resolution, multiple bands spanning visible to thermal wavelengths, and approximately 16-day revisit time.

2.2.2. Training data

The training data points of Forest, Cropland, Wetland, Grassland and Settlements were generated. Rest of the land was taken as other land. Top level landcover categories in the good practice guidance of International Panel on Climate Change (IPCC) were followed (IPCC, 2003). Total 519 points i.e., 160 points for forest, 5 points for grassland, 2 points for wetland, 150 points for cropland and 192 points for settlement for 2013 were selected with high certainty.

510 points i.e., 158 points for forest, 20 points for grassland, 12 points for wetland, 165 points for cropland and 155 points for settlement for 2019 were collected from the 0.4*2 km grid spread over the entire district with the help of high-resolution satellite imagery. This kind of high-resolution earth observation data allows us to select location with extended coverage. It involves identification of typology for the specific country on the basis of which reference data were being collected.

2.2.3. Sample training data

The data which were used to perform classification called covariates. However, these data were added to our reference points so that the classifier can use these to train the model. Covariate dataset were extracted on the pixel where reference points (which are actually our "known" points) so that they can be used to train a classifier which is actually predicting class of other pixels (which are actually our unknown points).

2.2.4. Primitive development

The sampled reference points were used to create primitive layers. For this, random forest classifier was used. Since the classification is the probability of a certain biophysical feature existing within that pixel, classification was performed using only two classes i.e. 1. Class that specifies that said a certain feature exists 2. Class that specifies that said feature doesn't exist. For instance, for tree cover primitive generation, points were set that symbolize tree cover as a class 1 and other points such as settlement, river etc. as class 0.

2.2.5. Primitive validation

For the validation of the primitives, stratified random samples i.e. 13 points for forests, 16 points for cropland, 4 points for grassland, 6 points for wetland and 11 points for settlement for 2013 were generated to validate the developed primitive. Similarly, 13 points for forests, 17 points for cropland, 4 points for grassland, 8 points for wetland and 11 points for settlement for 2019 were generated to validate the developed primitives.

2.2.6. Sample primitives

Quality check of primitives using validation points was done by plotting probability distribution of points throughout a certain primitive over 2013 and 2019. This gives the distribution of probabilities throughout the points that are supposed to be of same class vs. those that are supposed to be of different class.

2.2.7. Assemblage

A decision tree was prepared with the help of assembler based on user specified thresholds which can be tuned based on visual assessment as well as primitive assessment plots. The order of primitives in the list denotes the order in which primitives are placed in the decision tree with the first primitive placed on the top and so forth which means that if a pixel has high probability on two primitives (according to specified threshold) the final class will be based on the primitive that is higher up on the decision tree.

2.2.8. Landcover validation data

Primitive of each landcover class was formed and landcover class map of 2013 and 2019 was produced. Land cover of 2013 was validated with the help of stratified sample points. 8 points for forest, 8 points for cropland, 1 point for grassland, 2 points for wetland and 6 points for settlement were collected in GEE. Similarly, 8 points for forest, 9 points for cropland, 1 point for grassland, 2 points for wetland and 6 points for settlement were collected in GEE for the validation of landcover of 2019.

2.2.9. Landcover validation

After having a set of landcover map, its quality was checked for which the accuracy assessment of the map was done. For this, a set of data separated for validation purposes was used which are not used to train the model. Analyzed data was presented in maps and bar diagrams through statistical calculation showing LULC changes area wise in 2013 and 2019 and interpretation was done accordingly.

2.4. Accuracy Assessment

The overall accuracy and overall kappa coefficient of the classification was assessed. The overall accuracy of the classified image compares how each of the pixels is classified versus the definite land cover conditions obtained from their comparing ground truth (Rwanga and Ndambuki, 2017). Kappa coefficient is a degree of how the classification results compare to values assigned by chance. So, higher the kappa coefficient, higher the accuracy of the classification is (Ukrainski, 2019). Further, producer's accuracy and user's accuracy will be assessed. Producer's accuracy is the accuracy of the map from the point of view of the map maker (the producer).The user's accuracy is the accuracy of the map from the point of view of a map user, not the map maker.

Besides, the satellite images for image classification and image base analysis, other primary and secondary data were also collected. Secondary data were collected from various published journals, articles, reports, books, websites, thesis, officials' records etc.

2.5 Data analysis

Collected information and data was presented and interpreted with the help of bar diagrams using MS Excel 2013.

3. RESULT AND DISCUSSION

3.1. Status of landcover of Kathmandu district of 2013 and 2019

The study provided an empirical and explicit land cover map of 2013 and 2019, depicting the land cover change of Kathmandu district in Nepal (Figures 3 and 4).

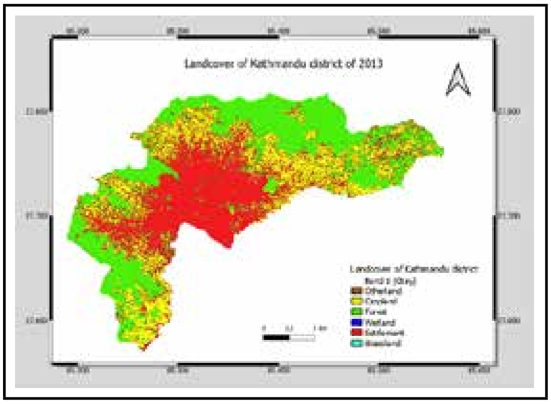

Figure 3: Landcover map of 2013

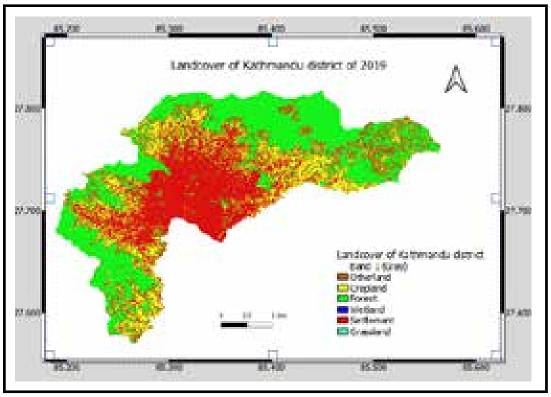

Figure 4: Landcover map of 2019

The study revealed that the major portion of landcover in both years 2013 and 2019 was covered by forest, cropland and settlement. The largest area is covered by forest. Cropland occupies the next largest area after forest, followed by settlement. The remaining areas are covered by otherland, grassland and wetland. The status of landcover change in Kathmandu district between 2013 and 2019 are illustrated in Table 2 and Figure 5.

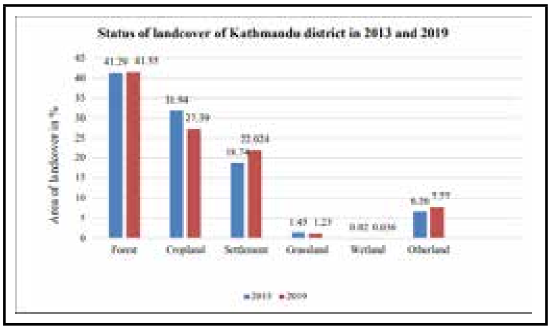

Figure 5: Status of landcover of Kathmandu district of 2013 and 2019

In 2013, the forest covered 170.987 km², or 41.29% of the entire area of Kathmandu district. Following the forest, cropland takes up the second largest land area at 132.27 km², accounting for 32.94 % of the total area. Settlement covers 77.61 km² i.e. 18.74% of the total area. Otherland and grassland cover 27.172 km² and 6.012 km² of land, accounting for 6.56 % and 1.45 % of the district's total area, respectively. Only 0.089 km² i.e. 0.02% wetland are available.

Whereas, in 2019, forest occupied 172.065 km², which is 41.55 % of the total area of the Kathmandu district. The cropland occupies 113.45 km², corresponding to 27.39 % of the total area. After that, settlement occupies 91.21 km² (i.e., 22.02 % of the total area). Otherland and grassland cover 32.167 km² and 5.098 km² of land, representing 7.77% % and 1.23% of the district's total area, respectively. With respect to wetland, this analysis only covers 0.152km² which corresponds to 0.04%. Grasslands are the most difficult land cover to recognize in photographs (Zhao *et. al.*, 2017).

Table 2: Status of landcover of Kathmandu district in 2013 and 2019

Landcover class	Area in 2013 (Sq. Km.)	Area in 2019 (Sq. Km.)
Forest	170.987	172.065
Cropland	132.27	113.449
Settlement	77.61	91.209
Grassland	6.012	5.098
Wetland	0.0894	0.152
Other land	27.172	32.167
Total	414.14	414.14

Table 3: Status of landcover change of Kathmandu district in 2013 and 2019

Landcover class	Change in area (Sq. km.) (2013-2019)	Change in area (%)
Forest	1.078	2.73
Crop land	-18.821	-47.68
Settlement	13.599	34.45
Grassland	-0.914	-2.32
Wetland	0.062	0.16
Other land	4.995	12.66

The landcover change analysis showed landcover changes based on the respective initial year 2013 as a reference. The result indicates that forests, otherland, wetland, and settlements have increased, whereas cropland and grassland have decreased. Forest, wetland, settlement, and other land have been expanded by 0.19 km2, 0.015 km2, 16.39 km2, and 5.19 km2, respectively. Cropland and grassland, on the other hand, have shrunk to an area of 20.92 km2 and 0.914 km2, respectively. The status of landcover change in Kathmandu district between 2013 and 2019 is shown in Table 3. The study of the landcover change matrix of 2013 and 2019, i.e., after the earthquake, shows the conversion of each landcover as follows (Table 4)

Table 4: Landcover change matrix of Kathmandu district of 2013 and 2019

Landcover class		2013						
		Other land	Crop land	Forest	Wetland	Settlement	Grass land	Total
		(Area in Sq. Km.)						
2019	Other land	22.01	9.01	0.31	0.01	0.81	0.02	**32.17**
	Cropland	3.05	109.29	1.08	0	0.03	0.003	**113.45**
	Forest	1.51	1.45	168.25	0.00	0.01	0.85	172.07
	Wetland	0.02	0.05	0.002	0.08	0	0	0.15
	Settlement	0.58	12.46	1.32	0	76.76	0.089	91.21
	Grassland	0.002	0.01	0.025	0.00	0.01	5.05	5.10
	Total	27.17	132.27	170.98	0.09	77.61	6.01	414.14

(Note: This study used the mapped area of 414.14 km² applying WGS 84 map projection.)

The forest cover has been increased by 0.26 %. The major land cover conversion into the forest is from otherland (0.36 %) and cropland (0.35%). Likewise, 0.21% of grassland, 0.001% of settlement and 0.00009% of wetland area are converted into forest. However, forest cover is converted into otherland (0.075%), cropland (0.261%), wetland (0.0005%), settlement (0.32%) and grassland (0.006%). Thus, area of total forest gain and total forest loss of Kathmandu district is 3.82 km² and 2.74 km² respectively. According to ward level analysis of landcover conversion of Kathmandu district, major forest gain areas are Sheshnarayan-9, Jitpurphedi-5, Sundarijal-1 and Saukhel -9 and major loss areas are Kabhresthali-3, Sangla-8, and Bhimdhunga-2.

The cropland area has decreased by 4.54%. The land cover conversion into the crop is from otherland (0.74%), forest (0.26%), settlement (0.006%), and grassland (0.0007%). However, cropland is converted into otherland (2.18%), forest (0.35%), wetland (0.012%), settlement (3.008%), and grassland (0.002%). Thus, the area of total cropland gain and total cropland loss in Kathmandu district is 4.16 km2 and 22.98 km2, respectively. Major cropland gain areas are Lapsiphedi-9, 3, Sundarijal-5, and Nanglebnhare-6, and major cropland loss areas are Matatirtha-9, Kirtipur-17, and Dahachowk-3.

The area of settlement has been increased by 3.28%. The landcover conversion into the settlement is from otherland (0.14%), cropland (3.008%), forest (0.32%), and grassland (0.02%). However, settlement is converted into otherland (0.196%), cropland (0.006%), forest (0.001%), and grassland (0.002%). Thus, the area of total settlement area gain and total settlement area loss is 14.45 km2 and 0.85 km2, respectively. Major settlement gain areas are Tokha Chandeshwari-5, Kirtipur-14, and Matatirtha-2, and major settlement loss areas are Gothatar-6, Balambu-4, and Kirtipur-6.

The rapid increase in built-up area confirms past reports by the United Nations Department of Economic and Social Affairs and subsequently by other researchers (Khanal *et al.,* 2019; Ishtiaque et al., 2017; and Poudel et al., 2016), who asserted that urbanization is the main cause for the conversion of agricultural and forest lands into built-up areas in Kathmandu valley. The increase in urban growth has been increased in adjacent areas of the cities and built-up areas along the main roads by creating new cores. Khanal et al. (2019) reported that the rate of urbanization in Kathmandu increased rapidly after the civil war ended in 2006.

The area of grassland has decreased by 0.22%. The landcover conversion into grassland is from otherland (0.0005%), cropland (0.002%), forest (0.006%), wetland (0.0005%), and settlement (0.002%). However, grassland is converted into otherland (0.005%), cropland (0.0007%), forest (0.21%), and settlement (0.021%). Thus, the area of total grassland gain and total grassland loss is 0.048 km2 and 0.962 km2, respectively. Major grassland gain areas are Kathmandu-31, 35, and 9, and major grassland loss areas are Kathmandu-35, Dakshinkali-6, and Chhaimale-9.

The area of wetland has been increased by 0.02%. The landcover conversion into the wetland is from otherland (0.005%), cropland (0.012%), and forest (0.0005%). However, wetland is converted into otherland (0.002%), forest (0.0009%), and grassland (0.0005%). Thus, the area of total wetland gain and loss is 0.072 km2 and 0.009 km2, respectively. Major wetland gain areas are Dakshinkali-6, Kathmandu-1, and Chalnakhel-9, and major wetland loss areas are Kirtipur-15, Kathmandu-1, and Gongabu-1.

The area of otherland has increased by 1.21%. The landcover conversion into otherland is from cropland (2.18%), forest (0.07%), wetland (0.002%), settlement (0.19%), and grassland (0.005%). However, other land is converted into cropland (0.74%), forest (0.36%), wetland (0.005%), settlement (0.14%), and grassland (0.0005%). Thus, the area of total otherland gain and total otherland loss is 10.16 km2 and 5.16 km2, respectively. Major other land gain areas are Matatirtha-9, Kirtipur-17, and Dahachok-3, and major other land loss areas are Lapsiphedi-1, Sundarijal-1, and Nanglebhare-1.

Landcover changes are regarded as a main source of environmental changes such as soil degradation, greenhouse gas emissions, climate change, and biodiversity loss. Therefore, land cover change can be considered an important issue in the present context. Among various landcovers, forests are vital to addressing these kinds of global concerns.

The error matrix generated from the accuracy assessment of 2013 and 2019 landcover is presented in tables 5 and 6, respectively. The overall accuracy of the classification and the overall kappa statistic achieved were 80% and 0.74, respectively, for 2013, whereas the overall accuracy of the classification and kappa statistic achieved 83.33% and 0.78, respectively, for 2019. In 2013, the user's accuracy of wetland, settlement, and grassland was 100%, 100%, 80%, and 100%, respectively, whereas the producer's accuracy of wetland, settlement, and grassland was 100%, 100%, 80%, and 100%, respectively. Similarly, in 2019, the user's accuracy of wetland, settlement, and grassland is 100%, 100%, 80%, and 100%, respectively, whereas the producer's accuracy of wetland, settlement, and grassland is 100%, 100%, 83.33%, and 100%, respectively.

During the study, a few sample points in the case of grassland and wetland were taken in comparison to other classes. Even though those sample points were few in number, they were taken with high certainty. However, the data that falls under cropland was not fully covered while collecting data, as some areas of cropland were left accounting for bare soil, due to which the areas of other land automatically rose in both years. The NLCMS study conducted by FRTC in 2022 shows that there is no bare soil in Kathmandu district. The result of this study regarding cropland area is less (-31.26 km2 in 2013 and 56.93 km2 in 2013) than the result of FRTC, which indicates that some landcover parts that fall under the category of cropland were left while collecting data. Due to this, those left areas were automatically added to other land as bare soil, due to which cropland has the lowest user's accuracy obtained, i.e., 62.5% in 2013 and 55.56% in 2019. However, forest, wetland, and grassland have the highest accuracy obtained, followed by settlement in both 2013 and 2019.

Table 5: Accuracy assessment of landcover of 2013

	Other land	Crop land	Forest	Wetland	Settlement	Grass land	Total	User's (%)
Otherland	0	0	0	0	0	0	0	0
Cropland	2	5	0	0	1	0	8	62.5
Forest	0	0	8	0	0	0	8	100
Wetland	0	0	0	2	0	0	2	100
Settlement	1	0	0	0	4	0	5	80
Grassland	0	0	0	0	0	1	1	100
Column Total	3	5	8	2	5	1	24	
Producer's accuracy (%)	0	100	100	100	80	100		

Table 6: Accuracy assessment of landcover of 2019

	Otherland	Cropland	Forest	Wetland	Settlement	Grassland	Total	User's (%)
Otherland	0	0	0	0	0	0	0	0
Cropland	3	5	0	0	1	0	9	55.56
Forest	0	0	8	0	0	0	8	100
Wetland	0	0	0	2	0	0	2	100
Settlement	1	0	0	0	5	0	6	80
Grassland	0	0	0	0	0	1	1	100
Column Total	4	5	8	2	6	1	26	
Producer's accuracy (%)	0	100	100	100	83.33	100		

4. CONCLUSION

Land cover is a critical factor in the environmental study of Nepal. This analysis states the current status of forests and other different land cover classes in 2013 and 2019. Based on the results derived from this assessment, the calculated results for forests, settlements, wetlands, and grassland are reliable. However, further studies are necessary to generate more reliable results in terms of cropland and other land.

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