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Land Use and Cover Change Detection in Shankharapur Municipality, Kathmandu Using Spectral Indices

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Abstract

The surging increase of the urban population has been accompanied by a sharp increase in urban built-up areas. The growth of population contributing to rapid expansion of built-up area in recent decades has caused a substantial Land Use Land Cover (LULC) change across Nepal and in particular Kathmandu Valley (KV). In this study, a Normalized Difference Vegetative Index (NDVI) and Normalized Difference Built-up Index (NDBI) was applied to three Landsat imagery collected over time (2002, 2013, and 2022) and one Sentinel-2 imagery that provided recent and historical LULC conditions for, Shankharapur municipality that lies in the eastern part of Kathmandu. The three-land use land cover categories were identified and mapped from the value of NDBI and NDBI. We found that over a period of 20 years (from 2002 to 2022), the Shankharapur municipality has lost 14.64% and 25.97% of its forests and sparse vegetation, and increase in the settlement/open land by 5.48% and 226.73% as indicated by NDVI and NDBI for Landsat imagery respectively. The increase in settlement/open land can be summed to the augmented activities like constructing new building and increase forest and land defragmentation including construction of road and land planning to fulfill the demand of influx of people after the earthquake of 2015. The results of NDVI and NDBI from Sentinel-2 imagery also support the increase in settlement/open land and decrease in forest and sparse vegetation. Also, agriculture cover increased by 4.25 sq.km between 2002 to 2013 and increased by 4.85 sq.km. from 2013 to 2022 as indicated by NDVI derived from Landsat imagery. However, the significant amounts of losses of forest and sparse vegetation during 20 years have been absorbed by the expanding urbanized areas and agriculture land as more land is subjected to the built-up and land planning along with the wood-logging as a result of aftermath of the earthquake, 2015, where population has increased by 19.4 % in the span of 10 years from 2011 to 2021 and is never retreating in terms of changing land cover. Therefore, such trends if unchecked can result in loss of biodiversity and ecosystem services associated with deteriorating conditions for human well-being.

Keywords: *Land Use Land Cover, NDBI, NDVI, Satellite Imagery*

Introduction

Although urban areas make up only a small fraction of the total global land area, they host more than 54% of its population, furthermore, the urban population is expected to rise by over 2 billion by 2050 (UN, 2014). The surging increase of the urban population has been accompanied by a sharp increase in urban built-up areas (Zheng et al., 2021). Synoptically, this rapid urbanization has led to the depletion of resources and multiple environmental problems and disasters, exacerbated the problems of water scarcity, air pollution, and urban heat-island effects, and imposed strong pressure on global and regional sustainability (Tang & Ma, 2018; Xian et al., 2019; Zheng et al., 2021). Urban built-up areas expansion have far-reaching impacts on human society and living environments all over the world (Zheng et al., 2021).

According to Preliminary census report of 2021 (CBS, 2021), has revealed the urban population to be 66.08 percent and rural population of 33.92 percent. Adjusting the population after the Federal restructure from rural to urban area, the population of the urban area was 63.19 percent and rural population was 36.81 percent during census 2011. Hence, comparing population between 2011 and 2021 shows that urban population has increased by 2.89 percent. The growth of population contributing to rapid expansion of built-up area in recent decades have caused a substantial LULC change across

Nepal and in particular Kathmandu Valley (KV). Rapid urbanization—coupled with lack of proper planning and high rural-urban migration—is the key driver of these changes. With 3.94% urban growth rate between 2010 and 2014, the KV is going through significant transformation of its landscapes in recent years making it important to understand the dynamics of LULC change processes, including their interactions with local and regional environmental change (Ishtiaque et al., 2017). In addition, predictions of land use and land cover change trends for 2030 shows a worsening trend with forest, agriculture and water bodies to decrease by an additional 14.43%, 6.67% and 25.83%, respectively. The highest gain in 2030 is predicted for urbanized areas at 18.55% (Wang et al., 2020).

Understanding and monitoring the dynamics of land use and land cover changes, their intensity, direction, drivers, and impacts provide useful information for sustainable development planning (Lu et al., 2004) and therefore remains an important goal in the field of land cover change science. Remote sensing in combination with GIS technology has been proven to provide scientifically credible results and policy recommendations that have assisted decision-makers and planners to advance sustainable development especially in fast growing urban settings (Appeaning Addo, 2010). As a result, remote sensing and GIS have become popular tools for better understanding of spatiotemporal and spectral characteristics of land use and land cover changes at local and global scales (Wang et al., 2020; Weng, 2001). Change detection, the process of identifying differences in the state of a feature or phenomenon by observing it at different times (Singh, 1989) is useful in many applications related to land use and land cover (LULC) changes, such as shifting cultivation and landscape changes, urban landscape pattern change, deforestation, quarrying activities and landscape and habitat fragmentation and other cumulative changes (Abd El-Kawy et al., 2011).

Despite rapid growth in population and expansion of urban area, only a few LULC change studies have been conducted on Kathmandu Valley to date and considering the expansion of urban built-up areas as a result of increased population and simultaneous diminution in other land use land cover especially that occurred after the post-civil war and massive earthquake that occurred in 2015 (Ishtiaque et al., 2017), an assessment would be crucial in conceptualizing and interpreting the changing LULC patterns in the area. Thus, the objective of this study is to examine the LULC dynamics in the period of 2002-2022 using Landsat imageries using Normalized Difference Vegetation Index and Normalized Difference Built-up Index tools in ArcGIS Pro.

Materials and Methods

Study Area

Shankharapur municipality lies at the eastern part of the Kathmandu district and is the smallest municipality in the terms of population. According to Census 2021, the total population of Shankharapur municipality is 30414 of which 15188 are male and 15226 are female (CBS, 2021). The municipality is situated at an altitude ranging from 1,100 meters to 2,400 meters above sea level and covers an area of 60.21 sq.km. Shankharapur municipality is located at $27^o42'56.68"$N-$27^o47'32.11"$N latitude to $85^o25'42.41"$E-$85^o33'56.36"$E longitude.

Shankharapur municipality being the area that lies within the Kathmandu district, it is expected to experience the same climate as that of Kathmandu. The Kathmandu district has a sub-tropical climate (below 2000 m) and temperate climate (above 2000 m) and is influenced by south Asian monsoon (UNDESA, 2014). The annual average precipitation is about 1407 mm with monsoon period that lasts from June to September accounting for more than 80% of its annual precipitation. The annual average temperature in the valley is around 18.1^oC, with some mountain tops remaining under seasonal snow (Ishtiaque et al., 2017). The main vegetation type of the district is mixed conifer and broadleaved forests at lower elevations, slowly transitioning to conifers to shrub land and occasional snow at higher elevations (Wang et al., 2020).

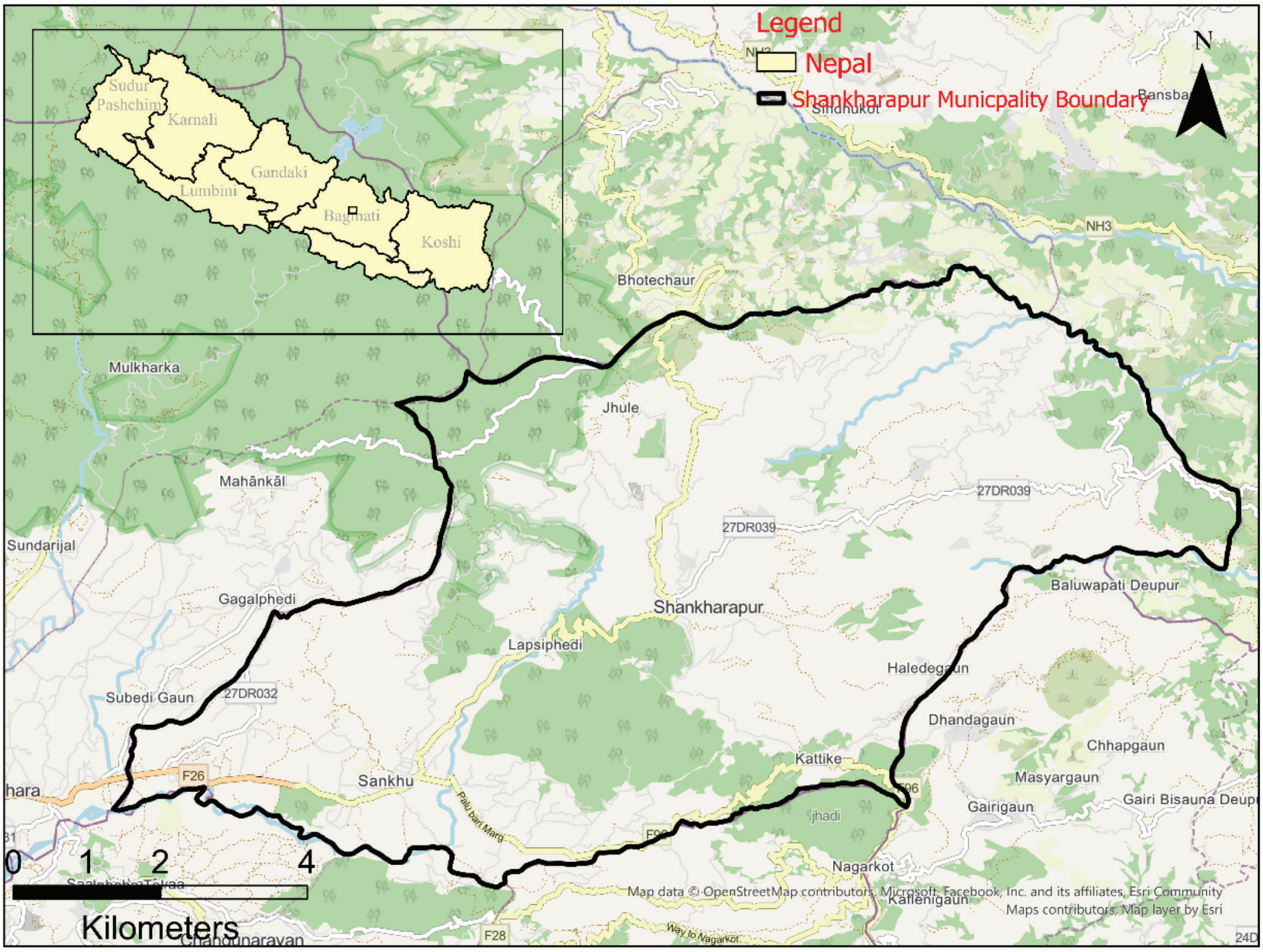

Figure 1: Location of Study Area: Shankharapur Municipality

Data acquisitions and Use

Landsat 9-OLI-2 and Landsat 8-OLI captures the images in 11 different band, Landsat 07 ETM+ captures the images in eight different band. All three images from the Landsat captures all the images with the spatial resolution of 30m except Panchromatic band which has spatial resolution of 15 m. Whereas, Sentinel-2 consists of twelve different bands with spatial resolution of 10 m, 20 m and 60m. The details of the bands of the images acquired from the different satellite are presented in Table 1 below.

The satellite imagery required for the study is acquired from two different open source. Earth explorer from USGS is used to download the Landsat 9 (March), Landsat 8 (November) and Landsat 7 (February) image from the year March, 2022, November, 2013 and February, 2002 respectively. Similarly, Copernicus open hub is used for downloading the Sentinel-2 imagery for the year December, 2022. The imagery obtained and processed have the cloud cover less than 10%. Imagery of Landsat 9 and Sentinel-2 image is used to compare the difference in NDVI and NDBI of the study area due to the difference in spatial resolution of the image.

Image Processing

Pre-Processing is the initial step of processing which is carried out to correct for any distortions due to the characteristics of the image systems and imaging conditions (Raut et al., 2020). However, the image obtained from the source do not require preprocessing as all the Landsat image downloaded are Level-2 Science Product which are preprocessed data products that have undergone several processing steps to correct for various atmospheric and instrumental effects. In addition, the Sentinel-2 image was Level-2a product which

Table 1: Bands with their resolution and wavelength of different satellite imagery

Bands	Landsat 7 Enhanced Thematic Mapper Plus (ETM+)		Landsat 9 and 8 Operational Land Imagery (OLI) and Thermal Infrared Sensor (TIR)		Sentinel-2 S2B Level 2a		
	Image Source: https://earthexplorer.usgs.gov				Image Source: https://scihub.copernicus.eu		
	Band Name (Resolution in Meter)	**Wavelength (micrometer)**	**Band Name (Resolution in Meter)**	**Wavelength (micrometer)**	**Band Name (Resolution in Meter)**	**Central Wavelength (nm)**	**Bandwidth (nm)**
1	Blue (30m)	0.45-0.52	Ultra-Blue (30m)	0.435-0.451	Coastal/Aerosol (60m)	442.3	45
2	Green (30m)	0.52-0.60	Blue (30m)	0.452-0.512	Blue (10m)	492.1	98
3	Red (30m)	0.63-0.69	Green (30m)	0.533-0.590	Green (10m)	559	46
4	NIR (30m)	0.77-0.90	Red (30m)	0.636-0.673	Red (10m)	665	39
5	SWIR 1 (30m)	1.55-1.75	NIR (30m)	0.851-0.879	Vegetation Red Edge (20m)	703.8	20
6	Thermal (60m)	10.40-12.50	Short-Wave Infrared SWIR-1 (30m)	1.566-1.651	Vegetation Red Edge (20m)	739.1	18
7	SWIR 2 (30m)	2.09-235	SWIR-2 (30m)	2.107-2.294	Vegetation Red Edge (20m)	779.7	28
8	Panchromatic (15m)	0.52-0.90	Panchromatic (15m)	0.503-0.676	NIR (10m)	833	133
8a	-	-	-	-	Vegetation Red Edge (20m)	864	32
9	NA	-	Cirrus (30m)	1.363-1.384	Water Vapour (60m)	943.2	27
10	NA	-	Thermal Infrared -TIR1 (100m)	10.60-11.19	SWIR-Cirrus (60m)	1376.9	76
11	-	-	TIR2 (100m)	11.50-12.51	SWIR (20m)	1610.4	141
12	-	-	-	-	SWIR (20m)	2185.7	238

has been subjected to radiometric corrections, geometric refinement and atmospheric corrections.

The individual bands for different years downloaded was stacked (Band 3, 4, and 5 for Landsat 7, Band 4, 5 and 6 for Landsat 8 and 9 and Band 4, 8 and 11 for Sentinel-2) to get final composite layer which was carried out in ArcGIS Pro. Then, the composite bands imageries were subjected to the clip by the administrative study area of Shankharapur municipality. For each composite imagery Normalized Difference Vegetative Index and Normalized Difference Built-up Index were calculated. The indices thus obtained are minuscule validated by the google image of respective years to compute the threshold value for differentiating the LULC types. Then, the land use/land cover was classified by dividing the value of indices into Forest/Sparse Vegetation, Agriculture land and Settlement/Open area including plotting land/ Water bodies and Sandy Areas and then reclassify in ArcGIS Pro. Water bodies and sandy areas are also included in Settlement since only Salinadi river which flows through the middle of the Shankharapur municipality which indices value are very narrow and are unpresentable in the map.

Land Cover Classification and Change Analysis

Normalized Difference Vegetative Index (NDVI) and Normalized Difference Built-up Index (NDBI) are used to determine the change in the vegetation and built-up area for the past 20 years in the Shankharapur municipality.

NDVI is widely used vegetative indices technique to determine the distribution of vegetation based on the characteristic reflectance patterns of green vegetation. The NDVI value varies from -1 to 1. Higher the value of NDVI reûects high Near Infrared (NIR), means dense greenery and lower value represents the area with no greenery. NDVI was calculated by the following formula;

NDVI = (NIR – RED) / (NIR + RED)

Therefore, For Landsat 7 data, NDVI = (Band 4 – Band 3)/ (Band 4 + Band 3)

For Landsat 8 and 9 data, NDVI = (Band 5 – Band 4) / (Band 5 + Band 4)

For Sentinel-2 data, NDVI = (Band 8 – Band 4) / (Band 8 + Band 4)

NDBI is used to determine the distribution of the built-up area based on the characteristic reflectance patterns of built-up area. NDBI value also ranges between -1 to 1. Normalize Diûerence Built-up Index value lies between -1 to +1. Negative value of NDBI represent water bodies whereas higher value represents dense build-up areas. NDBI value for vegetation is low with higher value representing the built-up areas. NDBI is calculated by the following formula;

NDBI = (SWIR-NIR) / (SWIR+NIR)

For Landsat 7 data, NDBI = (Band 5 – Band 4) / (Band 5 + Band 4),
For Landsat 8 and 9 data, NDBI = (Band 6 – Band 5) / (Band 6 + Band 5),
For Sentinel-2 data, NDBI = (Band 11– Band 8) / (Band 11 + Band 8)

For calculating the NDVI and NDBI Landsat 7 imagery was used for the year 2002, Landsat 8 imagery was used for the year 2013 and Landsat 9 imagery was used for the year 2022. Similarly, Sentinel-2 imagery was also used to calculate NDVI/ NDBI for the year 2022 to compare the results of Landsat 9 as spatial resolution of Sentinel-2 is high to that of Landsat (10m to 30m). Based on the value of the indices of NDVI and NDBI land use/ land cover was classified for the year 2002, 2013 and 2022. NDVI and NDBI for the different years was compared and change detection of land cover in area was calculated.

Results and Discussion

Results of the NDVI an NDBI for the year 2002, 2013 and 2022 are presented in the Table 2. The results for the land use land cover types are classified in three different types as: Forest and Sparse Vegetation, Agricultural Land and Settlement/Open Land which also includes plotting land, water bodies and sandy areas.

Analysis of Land Use and Land Cover Classes for 2002

The results of the analysis of the 2002 image (Figure 2) have shown the agricultural land dominated the landscape with 35.21 sq.km indicated by both NDVI and NDBI. Similarly forest and sparse vegetation acquired 23.56 sq.km and 21.55 sq.km whereas, the least covered land cover types is settlement including open land and water bodies/sandy area as analyzed from NDVI and NDBI respectively. Both, NDVI and NDBI indicates that the settlement area is confined to the south-west and less dense and sparse vegetation in the north-east part of the municipality. Agriculture cover is widely spread and majority of land is conquered in every part of the municipality as major population of the municipality is dependent in agricultural production for the income generation activities during year 2002.

Table 2: Composite table of area statistics of Shankharapur municipality of 2002, 2013 and 2022 for Landsat Imagery

Land Use Land Cover Types	Normalized Difference Vegetative Index (Area in Sq. Km.)				Normalized Difference Built-Up Index (Area in Sq꞉ Km.)			
	2002	2013	2022	Area Change (20 Years)	2002	2013	2022	Area Change (20 Years)
Settlement/Open Land	1.01	1.44	3.30	3.80	2.5	3.44	4.08	1.58
Agriculture	39.46	35.21	40.06	1.00	34.57	35.21	38.99	4.42
Forest and Sparse Vegetation	19.74	23.56	16.85	-4.80	23.14	21.55	17.13	-6.01

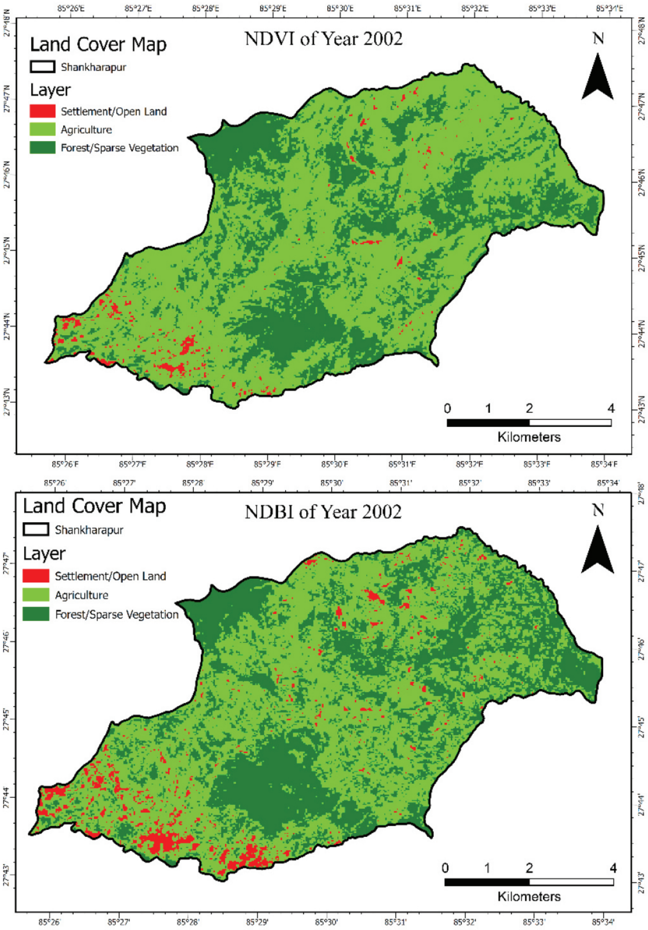

Figure 2: NDVI and NDBI of the Year 2002 derived from Landsat 07 Imagery

Analysis of Land Use and Land Cover Classes for 2013

Compared to 2002 results, findings from the year 2013 shows an increase in the cover of forest area and decrease in agriculture area followed by a slight increase in settlement cover as shown in Figure 3. In 2013, NDVI indicated that settlement/built up areas and open land is 1.44 sq.km, agriculture covers 35.21 sq.km. and forest and sparse vegetation covers 23.56 sq/km. Whereas, NDBI of same year indicated the settlement/built up areas and open land covers 3.44 sq.km, agriculture covers 35.21 sq.km. and forest and sparse vegetation covers 21.55 sq/km. Both of the indices show same area covered by the agriculture land but NDBI show significant increase in settlement area as NDBI, measures the amount and density of built-up areas by using SWIR and NIR reflectance. Comparing between NDVI between 2002 and 2013 the forest and settlement and open land has been increased in the northern and north-east part of the municipality and reducing agriculture cover indicating more people abandoning agricultural land and the shifting their income generation activities from farming and conversion of agriculture to sparse vegetation. One of the study also showed that after the 1990s, there has been a slight decrease in the rate of land area conversion to agricultural land, especially around Kathmandu (Paudel et al., 2018). However, in contrast NDBI show slight increase in agriculture and decrease in vegetation probably due to the difference in surface reflectance calculating the indices.

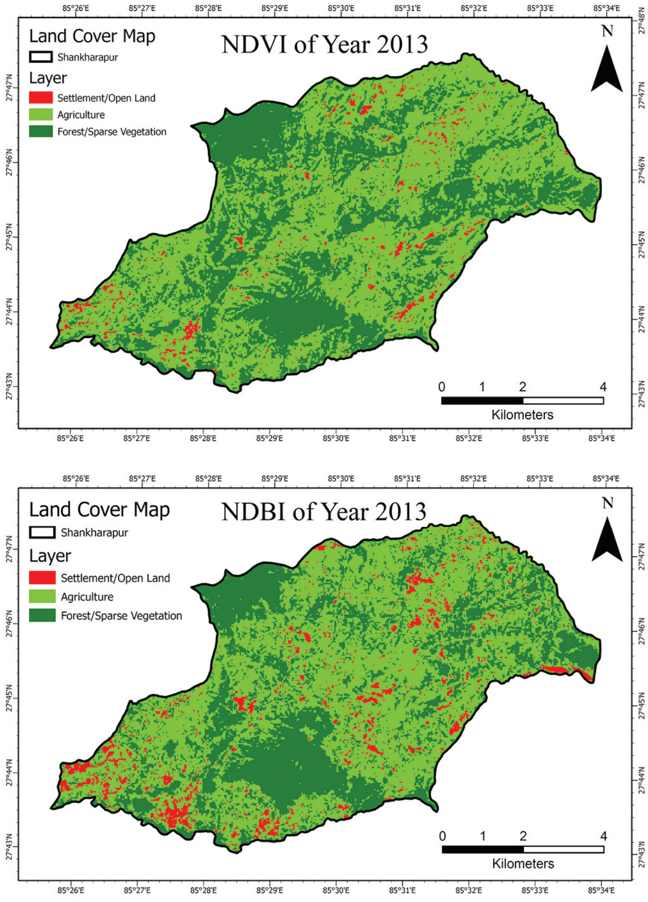

Figure 3: NDVI and NDBI of the Year 2013 derived from Landsat 08 Imagery

Analysis of Land Use and Land Cover Classes for 2022

NDVI from Landsat imagery for the year 2022 have indicated the settlement/open land, agriculture, forest and sparse vegetation cover to be 3.3021 sq.km., 40.06 sq.km. and 16.85sq.km. and from Sentinel-2 imagery to be 1.95 sq.km, 38.72 sq.km. and 19.52

sq.km. respectively. Similarly, NDBI from Landsat imagery for the same year shows settlement/open land, agriculture, forest and sparse vegetation cover to be 4.08 sq.km., 38.99 sq.km. and 17.13 sq.km. and from Sentinel-2 imagery to be 2.29 sq.km., 39.70sq. km. and 17.70 sq.km. respectively. The difference of the land cover area represented by Landsat and Sentinel imagery is due to the differences in band widths, spatial resolutions, and data processing, different sensors can deliver notably different NDVI behaviors, particularly between spaceborne and airborne sensors (Huang et al., 2021). Whereas, Both NDVI and NDBI showed the increase in settlement area in the surrounding land area in south-west and north-east part of the municipality in the area with easily accessible by road. Comparing the NDVI and NDBI from Sentinel-2 imagery for the year 2022 showed settlement/open land to be 1.95sq.km and 2.79 sq.km, agriculture cover 38.72 sq.km. and 39.70 sq.km. and forest and sparse vegetation to be 19.52 and 17.70 respectively.

Land Cover Change Analysis

The land use and land cover from 2002 to 2022 calculated from Normalized Difference Vegetative Inex (NDVI) and Normalized Difference Built-up Index (NDBI) showed important trends in land use transition from one class to another. The distribution of transition between land use classes detailed coverage of area transition (sq.km. and %) from one to other classes were presented in Table 2, 3 and 4. NDVI has represented the area of a total change of 226.73% (3.80 sq.km) in Settlement/Open Land between 2002-2022 in whereas, Forest and Sparse Vegetation represented 32.79% in 2002, increase to 39.13% in 2013 and then again decrease to 27.99% in 2022 with total decrease of 14.64% (4.80 sq.km) between 2002-2022. However, NDBI showed a slight decrease in forest and sparse vegetation of 1.59 sq.km (2.64%) between 2002-2013.

Concerning with results of NDVI, the increase in forest and vegetation and reduced agriculture area

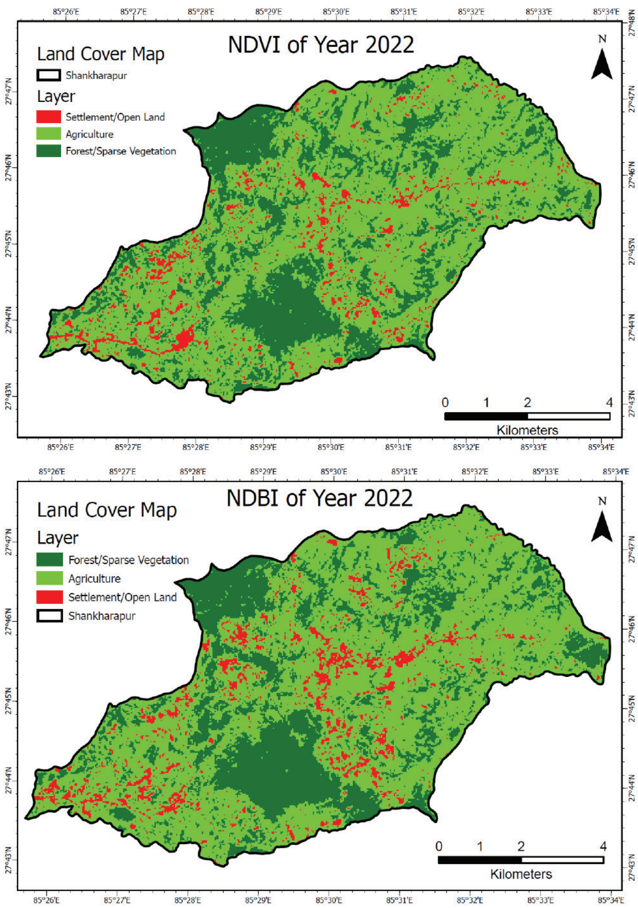

Figure 4: NDVI and NDBI of the Year 2022 derived from Landsat 09 Imagery

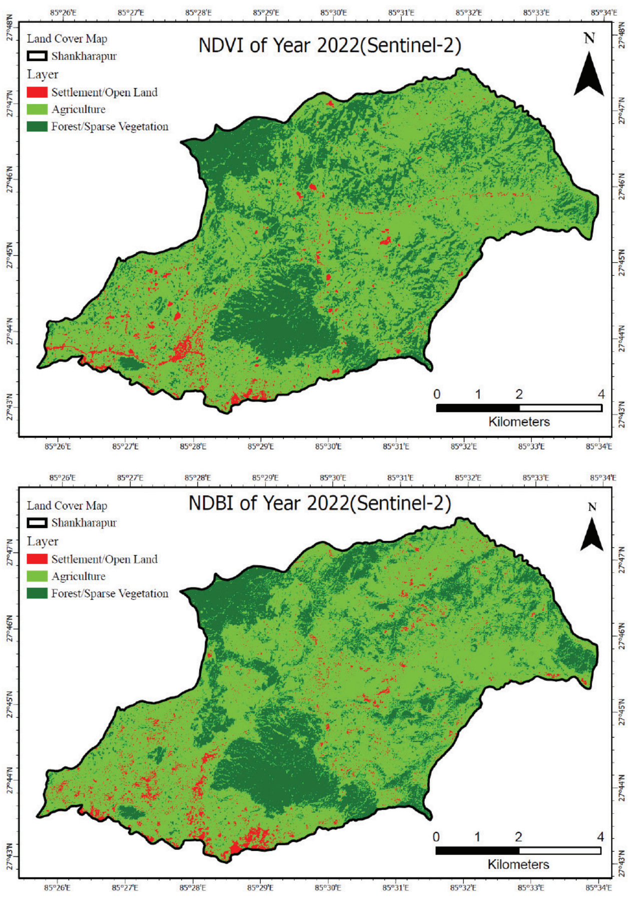

Figure 5: NDVI and NDBI of the Year 2022 derived from Sentinel-2 Imagery

Table 3: Composite table of NDVI area statistics (%) of Shankharapur municipality of 2002, 2013 and 2022

Land Cover Types (NDVI)	2002 Area (%)	2013 Area (%)	2022 Area (%)	Change %	Change %/Year
Settlement/Open Land	1.68	2.39	5.48	226.73	11.34
Agriculture	65.54	58.48	66.53	1.52	0.08
Forest and Sparse Vegetation	32.79	39.13	27.99	-14.64	-0.73

Table 4: Composite table of NDBI area statistics (%) of Shankharapur municipality of 2002, 2013 and 2022

Land Cover Types (NDBI)	2002 Area (%)	2013 Area (%)	2022 Area (%)	Change %	Change %/Year
Settlement	4.15	5.71	6.78	63.20	3.16
Agriculture	57.42	58.48	64.76	12.79	0.64
Forest and Sparse Vegetation	38.43	35.79	28.45	-25.97	-1.30

can be attributed to the abandoned agricultural practices due to the shortage of labor resulting in less agriculture practices in the area between 2002 and 2012. This is supported by influx of remittance in Nepal as the economically independent age groups has moved to the foreign employment for better income opportunities as credited to remittance inflow which was NPR 47.22 billion in FY 2000/01 which is more than quintupled to NPR 253.55 billion in 2010/11 (NPC, 2020). In addition, the settlement/open land as indicated by NDVI increased by 226.73% with 11.34% change every year for the period of 20 years and 63.20% increased with 3.16% increase every year for the similar period as represented by NDBI. Both of the indices regarding the settlement area showed the tremendous increase in the land use class. This increase sums up the augmented activities like constructing new building and increase land defragmentation and land planning to fulfill the quest of building the new home and people inflowing in Kathmandu valley after the earthquake of 2015, increased remittances by 20.9 percent in 2015 versus 3.2 per cent in 2014 (IOM, 2019). Also, the decreased forest land between 2002 and 2012 can be linked to a number of activities or events can lead to forest fragmentation including road construction, logging, conversion to agriculture, wildfires, and human conflict over a forest patches (Uddin et al., 2015). Between 2002-2010 NDBI indicated a slight increase in the agricultural land in similarity with the spatiotemporal distribution of agricultural land in Nepal revealing an increasing trend between 1910 and 2010 and this expanded rate of increase in agricultural land has varied between different eco, physiographic, and altitudinal regions of the country, significantly driven by population changes and policies over the period of this investigation (Paudel et al., 2018). During the period between 2013-2022, both NDVI and NDBI indicated the increase in agriculture and decrease in forest and sparse vegetation cover comprehend the increased logging of private forest to supply the increased demand of wood for the construction of new house affected by the earthquake. The findings are similar with another study which shows the built-up area of Kathmandu Valley has increased from 38 sq. km in 1990 to 119 sq. km in 2012 over the period of 22 years, with a 211% increase (Timsina, 2020). Similarly, a recent study conducted by (Ishtiaque et al., 2017) shows that Kathmandu Valley's urban area is expanded up to 412% in last three decades. In addition, another study over a period of 20 years (from 1990 to 2010), the Kathmandu district has lost 9.28% of its forests, 9.80% of its agricultural land and 77% of its water bodies and these losses have been absorbed by the expanding urbanized areas, which has gained 52.47% of land (Wang et al., 2020).

Conclusion

This study used GIS and remote sensing techniques to detect and predict land use and land cover changes in the Shankharapur municipality over a 20-year period by using NDVI and NDBI. The observations in the Shankharapur municipality exhibits the magnitude and extent of threats and challenges of changing landscapes, land cover and land use from increased migration with unplanned urbanization trends occurring at south-west, north-east at major road locations.

Quantitative evidence from this study indicates that the Shankharapur has undergone significant land use and land cover changes since 2002. Forest and agricultural lands dominated the land use and land cover of the municipality, however there is an increase in settlement and open land area between 20 years period from 2002 to 2022. This dramatic increase in the settlement is due to rapid increase in urbanization which remains a key driver of land use and land cover changes and is taking over agricultural and forest lands. Other factor attributing to the urbanization in the area includes the rapid increase in the remittance in the area, shifting agriculture-based income to foreign employment, and natural hazard like earthquake etc. This small town in the eastern part of Kathmandu Valley which population has increased by 19.4 % in the span of 10 years from 2011 to 2021 and is never retreating in terms of changing land cover. Such trends if unchecked can result in loss of biodiversity and ecosystem services associated with deteriorating conditions for human well-being, thereby increasing the vulnerability of humans and ecosystem to small changes in the system including climate (Wang et al., 2020).

Thus, the rate of these land conversions has advanced after the rapid urbanization post-civil war since 2006, and natural hazard i.e., earthquake in the year 2015 coupled with lack of stringent government policies regarding land planning and conversions and weak monitoring in the face of corruption (Wang et al., 2020).

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