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Landscape Metrics and NDVI Analysis to analyze Urban Growth and Green Space loss: Insights from Murree Tehsil (2000-2020)

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Abstract

Investigating changes in vegetation is crucial for understanding interactions between land and atmosphere, and their consequent effects on climate. The variations in Land Use Land Cover hold profound implications for environmental conditions and landscape characteristics. In this study, we focus on detecting transformations in green spaces and analyzing the landscape patterns within Murree Tehsil, which is an area driven by rapidly increasing urbanization trends and eco-tourism attractions in Pakistan. We employed multi-temporal Landsat imagery, including TM and OLI-TRIS from the years 2000, 2010, and 2020, and detected changes in the green space and calculated various landscape metrics. Our findings show concerning trends, as the dense vegetation that accounted for 62.44% in 2000 decreased to a mere 56.31% by 2020. In contrast, sparse vegetation and settlements, which represented 22.06% and 2.02% in 2000, surged to 30.13% and 6.73%, respectively, by 2020. The landscape metrics also revealed decreasing trends until 2010 and a slight increase in 2020 due to afforestation efforts. The dynamic transformation of Murree's landscape underscores a multifaceted process that is fundamentally reshaping the local ecosystem. Considering these changes, it becomes important to assess and estimate such changes with precision. Such understanding would have a direct relevance for effective planning and the sustainable utilization of our natural resources.

***Keywords*: Green space; Vegetation change; Landscape metric analysis; Fragmentation; Urban growth**

1. Introduction

Land Use and Land Cover (LULC) is crucial for understanding the interconnectedness between various transformations on the Earth's surface, such as urbanization and deforestation, along with associated phenomena (Bhandari et al., 2012; Sertel et al., 2018). Urbanization is the most dominant and complex process since the mid-20th century (Zhang et al., 2013). For monitoring and mapping purposes for LULC change, remote sensing has become beneficial in recent times (Malik et al., 2020). LULC maps find extensive application across diverse research domains focused on changing the Earth's processes due to human interactions. These maps also serve as instrumental tools for investigating landscape patterns. Landscape metrics are specialized tools developed to quantify the geospatial characteristics of map patterns. Landscape metrics have wide usage, with a number of researchers acknowledging their relationship to change in LULC, distribution of biological diversity, ecological processes, and ecosystem services (Duarte et al., 2018; Jiang et al., 2006). LULC plays an important role in the interaction between the ground and the atmosphere, influencing local, regional, and global climates (Bilal et al., 2021). Analysis of landscape patterns scrutinizes the structure of landscape elements and their spatial distribution, representing them via graphs, characters, or landscape indices (Liding et al., 2008). The combination of all class types and patches in the given area is a landscape-level assessment. Various Landscape metrics as Largest Patch Index (LPI), Patch Density (PD), Percentage of Landscape (PLAND), and Landscape Shape Index (LSI) (explanation given in the methods), are applicable at class, patch, and landscape scales (Sertel et al., 2018).

Over the past few decades, rapid economic and population growth have led to a significant increase in LULC induced by urbanization. This trend is widespread in the developing nations, especially in the central parts of the cities. So, it is crucial to investigate these changes and their environmental impacts (Baqa et al., 2022). Sustainable urban environments are created by green spaces within cities. The continuous ongoing process of urbanization is a worldwide challenge, altering the development of infrastructure, often at the expense of agricultural areas and urban green areas, which leads to an increase in impermeable surfaces, reduced rainfall, and increased temperature (Khattak et al., 2015). Globally, this unregulated urban expansion triggers landscape degradation, loss of open landscapes, disturbance in agricultural and forested areas, loss of biodiversity, and drought. These factors pose serious threats to the overall physical environmental quality (Arshad et al., 2022; Waseem and Khayyam, 2019).

The urbanization process in Islamabad has been linked to a decline in vegetative cover, which, in turn, is associated with a rise in Land Surface Temperature (LST), as reported in a study by Waseem and Khayyam (2019). Dilawar et al. (2021) Investigated the relationship between Urban Thermal Environment (UTE) and LULC changes in Faisalabad. The study findings revealed a reduction in vegetative areas, primarily attributed to urban expansion. This was identified as a contributing factor to the increased LST, and poor ecological conditions were reported in urban buffers. Arshad et al. (2022) delve into investigating the effect of surface urban heat islands due to LULC changes. High LST in Lahore, Pakistan, was discovered by green spaces in old city areas and transition zones.

On a large scale, the significant variations in LULC patterns due to population growth, industrialization, and unregulated infrastructure expansion are particularly notable in developing countries, including Pakistan. Murree Tehsil is widely regarded as Pakistan's top tourist destination, but unfortunately, the area's natural beauty is being rapidly harmed by the increased population. The quality of towns depends on how the city's green areas are designed, managed, and guarded. Green spaces must be considered a prime concern for the central institutions (du Toit et al., 2018). Those who manage green spaces well. The present research is meant to study the spatial and temporal Land Use models of the Murree Tehsil. This paper aims to examine the change in green spaces by using LULC, NDVI, and landscape-level metrics that would help in overcoming the environmental problems and promoting sustainable development.

2. Materials and Methods

2.1 Study Area

Murree Tehsil, a popular tourist destination and hill station in Pakistan, is one of the major tehsils within Rawalpindi District with a total area of 434.0 km². It lies at 33º54′30″ North Latitude and 73º23′25.08″ East longitude (Fig. 1).

It is situated along the Kohala Highway, 30km north of Islamabad. The area encompasses habitats of temperate coniferous forest as well as temperate broadleaf and mixed forest ecoregions. Its average elevation stands at 2,291 meters above the mean sea level. It is famous for dense forests at high elevations that include Diar (*Cedrus deodara),* Blue Pine (*Pinus wallichiana*), Horse Chestnut (*Aesculus spp.*), and Oak (*Quercus spp.*) as the main tree species and Indian Leopard, Leopard Cat, and Rhesus Macaque as famous wildlife species (Ashraf et al., 2014). These forests not only supply timber, firewood, and several other benefits to local communities but also function as a watershed.

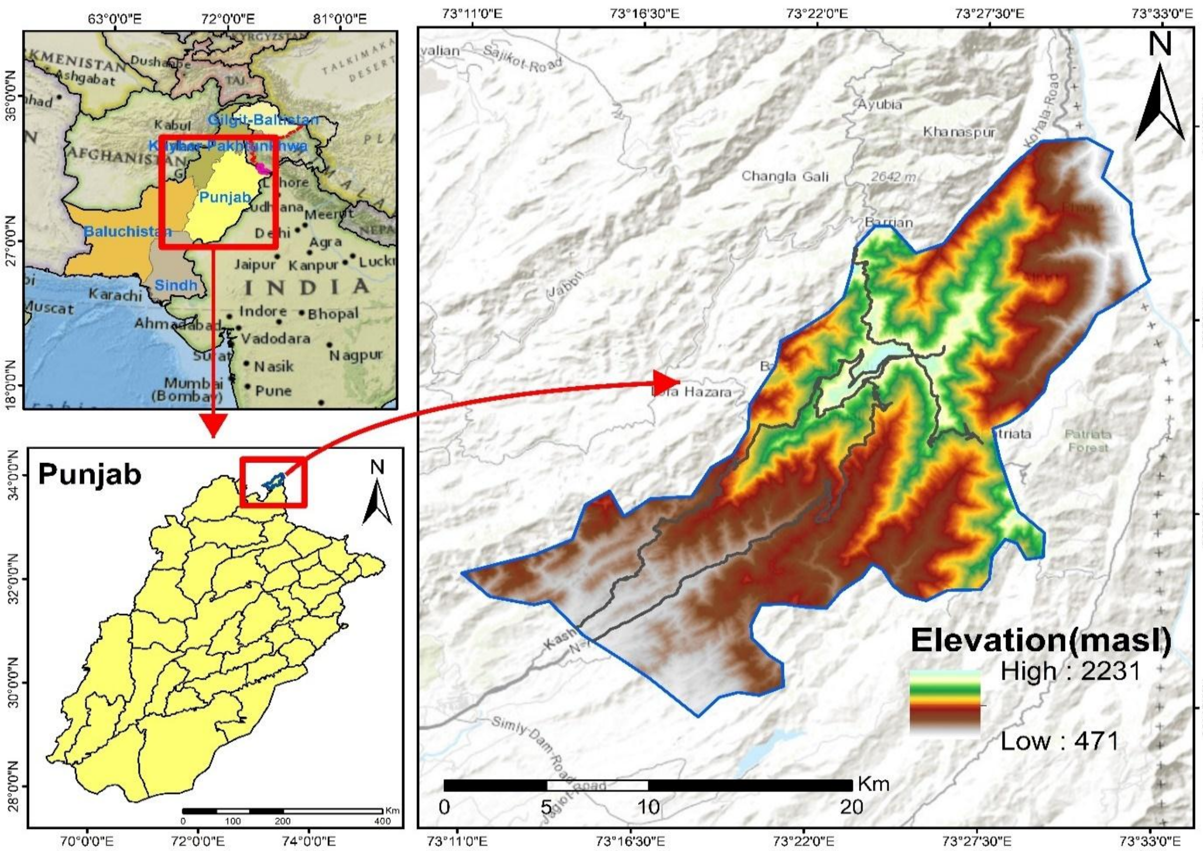


Fig. 1. Topography and geographical location of Muree Tehsil.

2.2 Data Acquisition and Analysis

The research utilizes cloud-free remote sensing images obtained from Landsat 5 Thematic Mapper (TM) and Landsat 8 Operational Land Imager and Thermal Infrared Sensor (OLI-TRIS), acquired through the U.S. Geological Survey (Table 1). LULC maps for the years 2000, 2010, and 2020 were generated using the supervised maximum likelihood classifier in ERDAS IMAGINE 2014.

Accuracy Assessment was also carried out for each LULC map. This involves comparing the classification with Region of Interest (ROI) or ground-truth data to evaluate its performance, reflecting real-world conditions. Sufficient samples from each class must be collected when comparing the results with reference or ground truth data. A stratified random sampling method was employed for each of the LULC maps to gather the diverse classes within the area. It involved generating more than 100 random points and relied on a combination of visual interpretation and ground truth data. The overall accuracy (Eq. 1) obtained from ground truth data measures how accurately each class pixel is classified compared to the actual land cover on the ground. The Producer's accuracy estimates the error of omission which indicates how accurately real-world Land Cover types are classified (Eq. 3). The User's accuracy is measured from the users' perspective and signifies the likelihood of a classified pixel aligning well with the Land Cover type in associated real-world location (Eq. 2). The kappa coefficient (Eq. 4) and error matrix are established to evaluate the image classification accuracy. These accuracies are calculated as:

$$The\ overall\ accuracy = \frac{No.of\ correct\ points}{total\ number\ of\ points} \quad (1)$$

$$User\ accuracy = \frac{Number\ of\ correctly\ classified\ pixels\ in\ each\ category}{Total\ number\ of\ classified\ pixels\ in\ that\ category\ (row\ total)} \times 100 \quad (2)$$

$$Producer\ Accuracy = \frac{Number\ of\ correctly\ classified\ pixels\ in\ each\ category}{Total\ number\ of\ classified\ pixels\ in\ that\ category\ (column\ total)} \times 100 \quad (3)$$

$$Kappa\ Coefficient\ (T) = \frac{\text{(Total Sample} \times \text{Total Corrected Sample) - } \sum \text{(Column total} \times \text{Row total)}}{\text{Total Sample2 - } \sum \text{(Column total} \times \text{Row total)}} \quad (4)$$

Table 1: Satellite images used in the study.

Satellite Type	Tile ID	Sensor	No. of Bands	Observation Date
Landsat 5	LT51500362000286RSA00, LT51500372000286RSA00	TM	7	12th October, 2000
Landsat 5	LT51500362010169KHC00, LT51500372010169KHC00	TM	7	18th June, 2010
Landsat 8	LC81500362020277LGN00	OLI-TRIS	11	3rd October, 2020

Green space change analysis was calculated for the entire study area using Normalized Difference Vegetation Index (NDVI) in both ERDAS 2014 and ArcGIS 10.3. The NDVI is a straightforward numerical indicator that serves to analyze the remote sensing measurements and determine the presence of live green vegetation in the given target (Bhandari et al., 2012). The calculation of NDVI is expressed as:

$$NDVI = \frac{(NIR-RED)}{(NIR+RED)} \quad (5)$$

Where RED is visible red reflectance (600-700 nm), and NIR is near-infrared reflectance (750-1300 nm).

In the Grid format, the classification resulted images were converted to calculate landscape metrics in FRAGSTATS 3.3. Four landscape metrics (Percentage of Landscape (PLAND), Patch Density (PD), Largest Patch Index (LPI), and Landscape Shape Index (LSI)) were used to measure the urban green space's spatial patterns. A patch was the basic spatial unit to calculate spatial patterns and statistical measurements (Neel et al., 2004). A patch represents homogeneous sections (non-linear area) of Land Cover that provide structural information (Turner and Gardner, 2015).

PLAND, a global index, represents the relative abundance of each land use type, and it was calculated as:

$$\text{PLAND} = \frac{\sum_{j=1}^{n} a_{ij}}{A}(100) = P_i \quad (6)$$

Where P_i is the landscape proportion occupied by the patch type (class) i; a_{ij} Is the area (m²) patch ij.

Patch density quantifies the spatial distribution and organization of patches in a landscape and gives information about the frequency and size distribution of these patches within a given area. Higher PD values indicate smaller and more numerous patches, while lower values indicate larger and fewer patches with more contiguous land cover. It is an important metric because it helps to understand the fragmentation and distribution of land cover classes in a landscape, which has ecological and environmental implications. The PD measures the number of patches per unit area and can be calculated as:

$$\text{PD}=\frac{n_i}{A}\times 10^6 \qquad (7)$$

Where n_i is the number in the landscape of patch type (class) i. A is the total landscape area.

The Largest Patch Index calculates the proportion of the landscape's overall area occupied by the largest patch. When LPI approaches 0, it denotes that the largest patches of land become increasingly smaller. On the other hand, when it reaches 100, it means that the entire landscape consists of a single patch. LPI, which represents the dominance of landscape areas, can be calculated as:

$$\text{LPI} = \frac{\max\limits_{j-1} a_{ij}}{A}(100) \qquad (8)$$

Where i = 1, j = 1, m or m′ patch types (classes) a_{ij}= area (m^2) of patch ij, a_{ij}= area (m^2) of patch ij within the specified neighborhood of the patch ij.

Landscape shape index indicates the shape of a landscape patch divergence from the circle, which is considered ideal. Due to its standardization, it has a direct interpretation in landscape complexity. LSI is calculated as:

$$\text{LSI} = \frac{.25\, E^*}{\sqrt{A}} \qquad (9)$$

E^* denotes the overall length (in meters) of the landscape edge (the total length involving the corresponding class). LSI equals 0.25 (adjustment for raster format) times is the sum of the entire landscape boundary, and A is the total landscape area (Zhou and Wang, 2011).

3. Results

3.1 Land Use Land Cover Pattern

The classification pattern employed to classify the LULC includes dense vegetation, sparse vegetation, urban settlements, water, and barren land. The results showed greater variations in urban settlements. As shown in Table 2, the urban settlements calculated in the year 2000 were 7.73 km^2 (2.02%), which increased to 14.31 km^2 (7.74%) in 2010 and, in the year 2020, the urban settlements further increased to 25.75 km^2 (6.73%) at the expense of vegetation and barren lands. The dense vegetation in the study area has been in a declining trend throughout the time, with an annual rate of change of -9.81% from the year 2000 to 2020, and in the same period (2000-2020), the sparse vegetation increased by 36.85%. The barren land covered about 46.28 km^2 (12.10%) in 2000, 50.06 km^2 (13.08%), and 24.89 km^2 (6.51%) in 2020. Water areas have decreased by -77.02 % at the same time. Figure 2 also displays the variations in several Land Use Land Cover classes (in km^2 and percentages) during the 2000-2020 period.

The accuracy assessment for the year 2000 (Table 3a), the dense and sparse vegetation were slightly under-classified, while the urban settlements were accurately classified. In the year 2010, the sparse vegetation was correctly classified, but the dense vegetation and urban settlements were slightly under-classified (Table 3b). In the year 2020, the dense vegetation was again slightly under-classified, but the urban settlements and sparse vegetation were slightly over-classified (Table 3c). The overall assessment demonstrates that the supervised classification methodology performed well, reaching an overall accuracy of 81.33%, 90.3% and 91.11% and Kappa statistics were 0.75, 0.87, and 0.88, respectively, for 2000, 2010, and 2020 (Table 3).

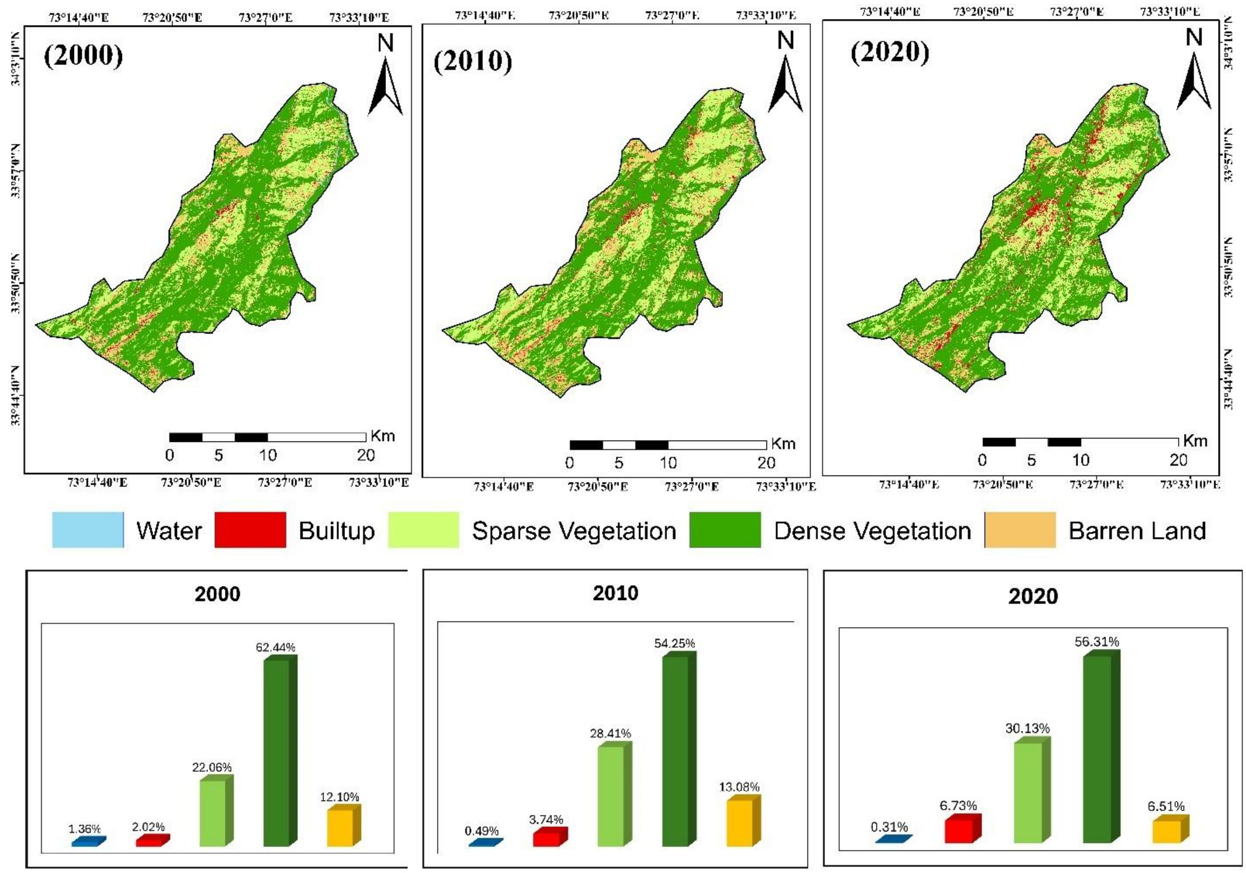


Fig. 2. Supervised classification maps for the year 2000, 2010, and 2020.

Table 2: Comparison of areas of different land uses from 2000-2020.

Land Use Class	**Year**			**Yearly Percent Change in Land Use**		
	2000	**2010**	**2020**	**2000-2010**	**2010-2020**	**2000-2020**
	Km² and (%)	**Km² and (%)**	**Km² and (%)**	**Km² and (%)**	**Km² and (%)**	**Km² and (%)**
Water	5.23 (1.36)	1.90 (0.49)	1.18 (0.31)	-3.33(-63.97)	-0.72(-36.73)	-4.05(-77.20)
Urban Settlement	7.73 (2.02)	14.31 (3.74)	25.75 (6.73)	6.58(85.14)	11.44(79.94)	18.02(233.16)
Sparse Vegetation	84.38 (22.06)	108.68 (28.41)	115.23 (30.13)	24.3(28.78)	6.55(6.05)	30.85(36.58)
Dense Vegetation	238.82 (62.44)	207.49 (54.25)	215.38 (56.31)	-31.33(13.11)	7.89(3.79)	-23.44(-9.81)
Barren Land	46.28 (12.10)	50.06 (13.08)	24.89 (6.51)	3.78(8.09)	-25.17(-50.22)	-21.39(-46.19)

Table 3 (a): Accuracy Assessment of Classified Imagery of 2000.

	Reference Data					**Classified Total**	**Producer's Accuracy**
Classified Data	**Water**	**Urban Settlements**	**Sparse Vegetation**	**Dense Vegetation**	**Barren land**		
Water	6	1	0	1	0	6	100%
Urban	0	7	0	1	1	9	77%
Sparse Vegetation	0	0	19	2	1	25	76%
Dense Vegetation	0	0	2	19	0	23	82%
Barren land	0	1	4	0	10	12	83%
						75	
Reference Total	8	9	22	21	15	**Overall Accuracy = 81.33%**	
User's Accuracy	75%	77%	86%	90%	66%	**Overall, Kappa Statistics 0.75**	

Table 3 (b): Accuracy Assessment of Classified Imagery of 2010.

	Reference Data					Classified Total	Producer's Accuracy
Classified Data	**Water**	**Urban Settlements**	**Sparse Vegetation**	**Dense Vegetation**	**Barren land**		
Water	7	0	0	0	1	7	100%
Urban	0	12	0	0	2	13	92.31%
Sparse Vegetation	0	0	22	2	0	24	91.60%
Dense Vegetation	0	0	0	21	0	23	91.30%
Barren land	0	1	2	0	13	16	81.20%
						83	
Reference Total	8	14	24	21	16	**Overall Accuracy = 90.3%**	
User's Accuracy	87.50%	85.70%	91.60%	100%	81.20%	**Overall, Kappa Statistics 0.87**	

Table 3 (c): Accuracy Assessment of Classified Imagery of 2020.

	Reference Data					Classified Total	Producer's Accuracy
Classified Data	**Water**	**Urban Settlements**	**Sparse Vegetation**	**Dense Vegetation**	**Barren land**		
Water	7	0	0	0	0	7	100%
Urban	0	14	0	0	4	14	100%
Sparse Vegetation	0	0	22	3	0	23	95.60%
Dense Vegetation	0	0	1	29	0	32	90.60%
Barren land	0	0	0	0	10	14	71.40%
						90	
Reference Total	7	18	25	30	10	**Overall Accuracy = 91.11%**	
User's Accuracy	100%	77%	88%	96%	100%	**Overall, Kappa Statistics 0.88**	

3.2 Green Space Intensity Analysis

In the present study, three images (2000, 2010, and 2020) have been categorized based on the normalized difference vegetation index (NDVI). The Normalized Difference Vegetation Index (NDVI) is the index used to determine the relationship between growth rate and spectral variation. This can be used to examine the change in vegetation as well as the increase in dense vegetation. The maps of NDVI have been produced from the satellite image of Murree Tehsil (Fig. 3). The threshold values of NDVI vary from -1 to +1, where +1 indicates healthy vegetation, while the values near -1 indicate barren land. These values used in satellite imagery are contingent on the sensitivity of the near-infrared (NIR) band of a specific sensor.

Figure 3 illustrates the NDVI maps showing vegetation distribution across three different time periods. NDVI values range from -0.3 to 0.6, where the values between -0.3 to 0.1 indicate non-vegetative areas such as snow or water, the range from 0.1 to 0.3 indicates sparsely vegetated or barren land, and the values from 0.3 to 0.6 represent moderately to densely vegetated areas. This study categorized NDVI values into two classes, i.e., high and low values. Both high and low NDVI values indicate high and low vegetation density, respectively. The highest NDVI value was found in the upper part of the study area. The lower values determine the rivers and wetland regions of the study area. The value of 0.3 was not taken into consideration as it represents non-green features. The values near 0 represent rocks or deserts where there is no vegetation. The values in this study range from 0.66 to 0.56 in 2000 and 2020, respectively, in determining the greenness of Murree Tehsil (Table 4). These high values represent healthy and dense vegetation areas with lush, thriving plant life. Scattered patches exhibited higher NDVI values, suggesting a notable change in Land Use. The decrease in NDVI value in the respective time indicates a shift primarily attributed to the loss of forested areas, resulting in agricultural expansion and human encroachment.

Table 4: Classification of NDVI

NDVI		
Year	**Minimum**	**Maximum**
2000	-0.34	0.66
2010	-0.26	0.67
2020	-0.20	0.56

3.3 Landscape Metrics Analysis

In this step, the results were presented, analyzed, and interpreted by employing statistical and graphical approaches. Landscape metrics such as LPI, PLAND, PD, and LSI metrics (Table 5) are suitable to assess the landscape structure by using satellite-based LULC maps.

The largest patch index, for examination of landscape composition, in the respective time contains the highest value of dense vegetation, while the other classes, such as sparse vegetation, water, barren land, and urban settlements, were low in value, as shown in Figure 4 (d). In contrast, the LPI of dense vegetation declined to 49.6 % in 2020, which was affected by expansion in urban settlements and deforestation (Table 5). The PLAND of urbanization has shown the highest upward trend due to developmental processes like industrial development, transportation, and commercial and human activities. The 30.08% PLAND value in 2020 for urban settlements shows its dominance in patch size (Table 5). This increased value of PLAND shows the greater influence of urbanization on classes that show a decline in the percentage of landscape (Fig. 4a). In landscape metrics, the value of PD shows the present condition of all the Land Use types.

The variation in values of PD, like sparse vegetation, urban settlements, dense water, and barren land, had different values compared to each other, indicating that their fragmentation has taken place due to anthropogenic and developmental activities.

Table 5: Landscape Metrics at Class Level from 2000-2020 in Murree

Landscape Metrics	Year	Water	Urban Settlements	Sparse Vegetation	Dense Vegetation	Barren Land
PLAND*	2000	1.47	2.19	22.10	61.83	12.42
	2010	0.51	4.11	28.37	53.68	13.34
	2020	0.32	7.09	30.09	55.76	6.75
PD**	2000	5.19	8.43	11.30	4.20	15.84
	2010	1.44	17.84	11.01	4.87	15.18
	2020	0.76	16.30	14.73	6.04	13.34
LPI***	2000	0.33	0.13	2.77	53.50	0.36
	2010	0.21	0.15	2.52	44.72	0.61
	2020	0.21	0.47	4.90	49.63	0.32
LSI****	2000	49.16	60.85	91.57	51.67	99.81
	2010	24.68	92.52	89.37	58.87	95.76
	2020	15.69	91.55	109.19	66.05	82.76

**PLAND: Percentage of Landscape (percent);*
***PD: Patch Density (number per 100 hectares);*
****LPI: Largest Patch Index (percent);*
*****LSI: Landscape Shape Index (no unit)*

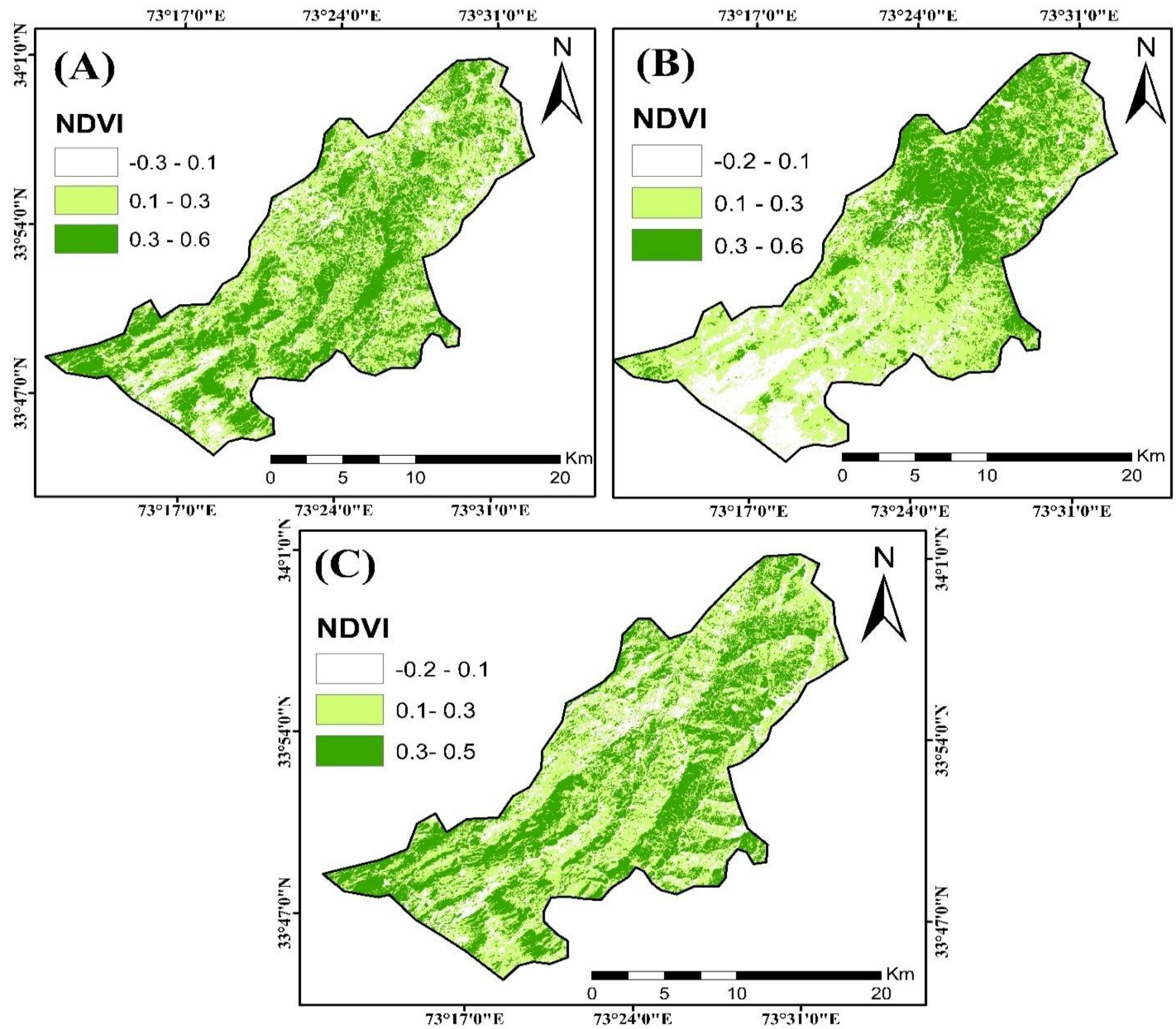


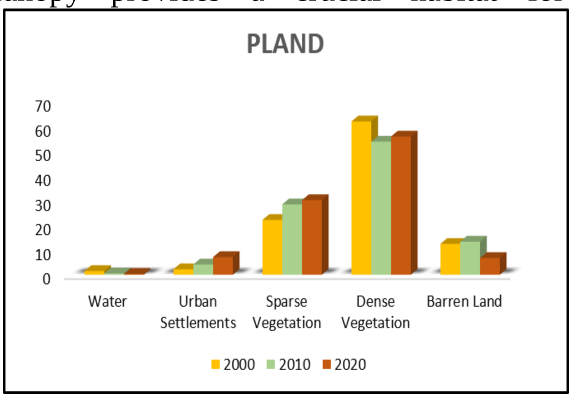
Fig. 3. Green space change analysis through NDVI for A) 2000, B) 2010, and C) 2020.

The PD of barren land has also shown the same trend; the value went to 13.3 from 15.8 (Table 5). The next index we took into analysis involved highlighting the landscape shape, which is the Landscape Shape Index (LSI). LSI's highest value has been determined in sparse, urban settlements and barren land, while the decline trend is seen in water and barren land. Sparse vegetation increased from 91 to 109 during the two time periods, whereas urban settlement increased to 91.5 from 60.8 (Fig. 4b).

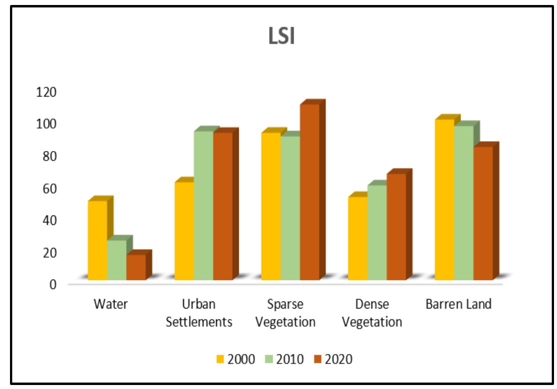
4. Discussion

Forest cover has been declining at an alarming rate in the recent past in recent years (Kausar et al., 2016a). Murree Tehsil is not only a tourist spot, but it is also famous for its high reserve of tree species (Ansari et al., 2022). Many anthropogenic activities, such as forest cutting for fuel wood and timber mafia, are held responsible around the Islamabad Murree Express Way for the extinction of species. The clearing of the forest also influences the tourists who visit the area to enjoy the beauty of nature (Jamal et al., 2018). In this research, we employed LULC, NDVI, and Landscape metric analysis to examine green space change patterns and the reasons behind them.

Dense vegetation has reduced from 62.44% in 2000 and further to 56.31% by 2020 with an annual percent change of -9.81%. This decrease could be best explained by the growth of sparse vegetation, forest fire, population growth (urban expansion), illegal logging, and unsustainable natural resource management practiced in the study area. The forest serves as a vital component of green carbon, storing and sequestering carbon dioxide from the atmosphere. The tree canopy provides a crucial habitat for grasslands and animals that are vulnerable to temperature fluctuations. The growth of urbanization has harmed forest cover, which has led to soil erosion, rapid runoff, loss of soil fertility, and a decline of biodiversity (Mujahid Hussain et al., 2017).



(a)



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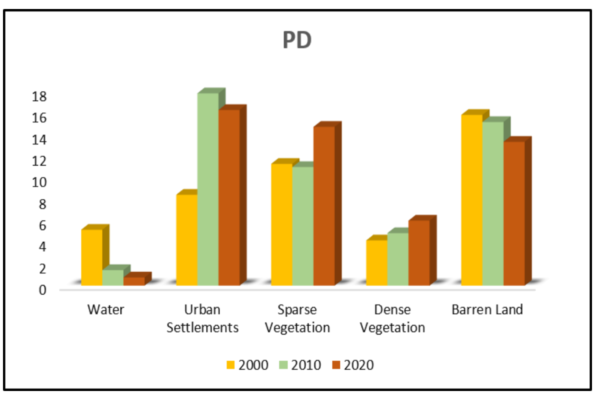

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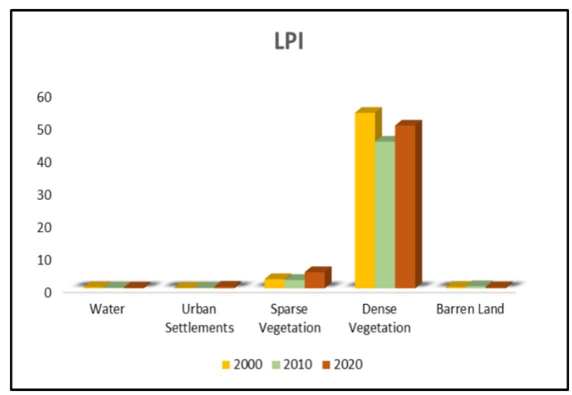

(d)

Fig. 4. Graph showing Land Metric Analysis of (a) Percentage of Landscape (PLAND), (b) Landscape Shape Index, (c) Patch Density, (d) Largest Patch Index (LPI).

The greenhouse effect is responsible for the temperature rise (Aftab and Hickey, 2010). With the establishment of the New Murree project, the 4.8% meager forest cover of the total area further declined because of rapid growth in population and urbanization. NESPAK reported that, in the project area, there were approximately 146,000 trees. The plan accounted for erasing 5 to 8 percent of these trees (approximately 11,680). This had a tremendous effect on dense vegetation (Mujahid Hussain et al., 2017). Sparse vegetation covered a total area of 22.06% in 2000, 28.41% in 2010, and 30.13% in 2020 (Table 2), but the annual change shows an increase in sparse vegetation by 36.5%. Generally, there has been an alarming increase in sparse vegetation throughout study periods, and if this trend continues, it will have negative consequences on the green cover of the area.

Image analysis revealed an increasing trend in urban settlements, that is, 2.02% to 6.73% from 2000 to 2020. The area covered by dense vegetation and sparse vegetation is in a degraded state, which has resulted in the growth of urban expansion. However, urban settlements saw a decrease in the area from 41,043.43 hectares to 37,198.97 hectares in the year 2005. During the year 2005

Earthquake, 40% of the settlements were destroyed and triggered land sliding as well (IUCN) (Kausar et al., 2016b). In 2010, a rapid increase in the area covered by settlements was 3.74% and a declining trend is observed in the coverage of the forest Land Cover class. The development of infrastructure also contributed to the growth of urban settlements. Barren land covered a total area of 12.10% in 2000, and later it decreased to 6.51% in 2020. The annual decreasing rate was -46.19% (Table 2). Landslides can also result from construction activities, particularly when structures disrupt the stability of the slope's base, altering the natural stress distribution and causing environmental strain (Mujahid Hussain et al., 2017). The road construction and other structures stress the infiltration area, which results in reduced aquifer recharge. The magnitude of water body changes from the period 2000-2020 is a declining trend with an annual decreasing rate of -77.20%. The decline in water bodies during the study period is due to the seasonal changes with fluctuations in water level. The Land Use transformation of this water into other LULC classes can contribute to a decline in water. But the groundwater is the main source in Murree tehsil (Virk et al., 2020), on which 85% of households are dependent. The deforestation due to the new Murree project affected the surface runoff from snowmelts and rainfall. The key challenges that are affecting the availability of water at both domestic and city levels are climate change, urban sprawl, inadequate governance, and demographic changes (Virk et al., 2020). The difference in spatial patterns of vegetated and non-vegetated areas is related to the urban plans of the city. In the 2000 datasets, it was observed that over half of the area was vegetated.

The accuracy assessment (Table 3) of these images shows that dense vegetation is slightly under-classified because some of the dense vegetation is classified as sparse vegetation, which is understandable, and the reason could be the low resolution of the Landsat images. These classifications could be enhanced using high-resolution images. The classified images for the years 2010 and 2020 exhibit an overall accuracy and kappa exceeding 90% and 0.80, respectively. Conversely, for the year 2000, while still commendable, the metrics are slightly lower at 81.33% for overall accuracy and 0.75 for kappa.

The green space shrinkage is related to the manner of development in this area, which is evident from the decline in NDVI (High NDVI demonstrates vegetation, and low NDVI represents building materials). The vivacity of environmental parameters, i.e., NDVI analysis, resulted in observing the status of dense forests that will further help the decision-makers and policies in the urban and district planning sectors. The analysis highlights that urbanization in Murree Tehsil coincides with a deteriorating green status and can be a risk to the environment.

The different landscape metrics sets have been integrated into the LULC study to determine the spatial patterns of change. Our research engaged four landscape metrics to observe landscape topographies of dominance, fragmentation, and shape. The results revealed that these metrics indicated the deviations in the spatial patterns of urban green space. The decreasing PLAND and the increasing PD for sparse vegetation from 2000 to 2020 revealed its fragmentation, which is directly affected by geography and human activities. Fragmentation is the breaking up of the larger areas of land type into smaller sections. The increasing value of PD indicates that landscape fragmentation was at a higher pace during the years (Aftab and Hickey, 2010). On the other hand, a decrease in PLAND (for water, dense vegetation, and barren land) and PD (for water and barren land) suggests that their area has shrunk in size but possibly not fragmented. Class area and percentage of landscape (PLAND) are metrics of landscape composition, particularly how much of the land is made up of a certain patch type. This is a significant characteristic of ecological application. The greater difference observed in the PLAND index is in urbanization and barren land during the two decades, from 2000 to 2020, which means the area of barren land was consumed to increase the infrastructure of city development. A slight increase in the LPI was also observed in 2020, and one of the reasons could be the afforestation of blank areas in the state forests of Murree hills. The landscape transformation analysis and landscape metric analysis revealed that spatial configuration over time and landscape composition lead to environmental destruction. Moreover, it is essential to consider the autocorrelation in some of the landscape metrics examined (Table 5). For the shape representation of LULC classes, LSI is suitable to define the status of development and direction of growth classes. Though it does not demonstrate the rise or decline of urban settlements in a proper manner, it still indicates selected features of the urban areas in terms of their mutual relationship between the urban area and environment (Gyenizse et al., 2014). PLAND is linked with LPI, which recommends that large patches describe a great percentage of the landscape, which reflects the dominance of the landscape. The direct relation between LPI and LSI shows that growth in patch size leads to an increase in LSI. This is because of the patch size-dependent problem of the landscape shape index. Generally, there is a similar metric output of urban settlements and sparse vegetation, which indicates the direct relation to the extent of human intervention and developmental processes due to the rise in population (Aftab and Hickey, 2010).

This study underlines the need for stronger institutional capacity in the Murree District Government to manage natural resources more efficiently. Immediate actions must include restricting forest loss, regulating urban expansion, and basing development decisions on rigorous geological and environmental assessments. There is an urgent need for tourism management, particularly for addressing waste generation and habitat degradation.

Although this study provides valuable insights into vegetation and land cover changes in Murree Tehsil, it is limited by the lack of ground-level socioeconomic and ecological data. The analysis mainly depended on multi-temporal Landsat imagery and landscape metrics, which, while effective at capturing spatial patterns, do not fully reveal the underlying causes of land use change. Including field surveys, census data, and tourism records would have made the findings more comprehensive. However, such integration was limited by several factors: (i) the absence of consistent, long-term ground datasets covering the entire study period (2000–2020), and (ii) resource and time limitations that restricted data collection efforts. As a result, the study focuses on spatial trends in vegetation decline and urban growth rather than their complete socioeconomic and ecological causes. Future research should address these gaps by combining remote sensing with ground-based data to develop a more thorough and policy-relevant understanding of environmental changes in the region.

5. Conclusion

The findings of the study provide insights into the research question of whether the changes in green spaces from 2000 to 2020 are primarily attributed to urban sprawl. This analysis utilizes LULC patterns, NDVI analysis, and landscape metrics. The expansion of urbanization in the study area not only poses environmental threats but also triggers social and economic consequences. To cope with the population's needs, the green spaces in the study area should be preserved and increased. Green spaces are an essential component of the built environment, as these spaces improve health and societal well-being and mitigate the effects of climate change. The consequences of the study highlight the fact that urban planning plays a crucial role in shaping our understanding of the importance of vegetative cover. The detection in forest land was in a declining trend during the entire study duration. Most of the original vegetation has been destroyed because of human activities. Growing tourism and other activities, such as urbanization in Murree

Tehsil, cause a serious threat to biodiversity as well. The study results are very important for government and non-governmental organizations, and the public to respond quickly and address the problem. Local and regional authorities are responsible for the promotion and conservation of green space in Murree Tehsil. Effective management and strategic planning are imperative to address the challenges associated with changes in green spaces, ultimately fostering sustainable development.

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Author's Contribution

Samra Waheed proposed the main concept and contributed to the manuscript's write-up and analysis. Qudsia Nadeem was involved in data acquisition and processing and analysis. Maryam Mazhar was responsible for data interpretation and manuscript organization. Aneeza Islam assisted in the preparation of illustrations and figures and contributed to data validation and final formatting of the manuscript. Maria Ali was responsible for the examination of relevant literature and proofreading the manuscript. Iftikhar Ali carried out the review and editing; improvement of discussion and conclusion. Muhammad Jamal ud din Qureshi carried out the technical review and ensured the overall quality of the manuscript before submission and Syed Adnan assisted in proofreading, compliance check and submission of manuscript.

Consent to Participate and Publish

All authors declare to participate in and publish the manuscript.

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The authors declare no competing interests.

Availability of data and material

The data is freely available and can also be provided upon request.

References

Aftab, E., & Hickey, G. M. (2010). Forest administration challenges in Pakistan: The case of the Patriata reserved forest and the "New Murree" development. *International Forestry Review*, *12*(1), 97–105. https://doi.org/10.1505/ifor.12.1.97

Ansari, L., Ahmad, W., Saleem, A., Imran, M., Malik, K., Hussain, I., Tariq, H., & Munir, M. (2022). Forest Cover Change and Climate Variation in Subtropical Chir Pine Forests of Murree through GIS. *Forests*, *13*(10). https://doi.org/10.3390/f13101576

Arshad, S., Ahmad, S. R., Abbas, S., Asharf, A., Siddiqui, N. A., & Islam, Z. ul. (2022). Quantifying the contribution of diminishing green spaces and urban sprawl to the urban heat island effect in a rapidly urbanizing metropolitan city of Pakistan. *Land Use Policy*, *113*(November 2021), 105874. https://doi.org/10.1016/j.landusepol.2021.105874

Ashraf, I., Saeed, U., Shahzad, N., Gill, J. I., Parvez, S., & Raja, A. (2014). *Delineating Legal Forest Boundaries to Combat Illegal Forest Encroachments: A Case Study in Murree Forest Division, Pakistan*. https://api.semanticscholar.org/CorpusID:126687155

Baqa, M. F., Lu, L., Chen, F., Nawaz-Ul-huda, S., Pan, L., Tariq, A., Qureshi, S., Li, B., & Li, Q. (2022). Characterizing Spatiotemporal Variations in the Urban Thermal Environment Related to Land Cover Changes in Karachi, Pakistan, from 2000 to 2020. *Remote Sensing*, *14*(9). https://doi.org/10.3390/rs14092164

Bhandari, A. K., Kumar, A., & Singh, G. K. (2012). Feature Extraction using Normalized Difference Vegetation Index (NDVI): A Case Study of Jabalpur City. *Procedia Technology, 6,* 612–621. https://doi.org/10.1016/j.protcy.2012.10.074

Bilal, H., Siwar, C., Mokhtar, M. B., Kanniah, K. D., Govindan, R., & Ansari, T. A. (2021). Assessment of land use and land cover changes in association with hydrometeorological parameters in the Upper Indus Basin. *Journal of Himalayan Earth Sciences*, 1-13. http://ojs.uop.edu.pk/jhes/article/view/1664

Dilawar, A., Chen, B., Trisurat, Y., Tuankrua, V., Arshad, A., Hussain, Y., Measho, S., Guo, L., Kayiranga, A., Zhang, H., Wang, F., & Sun, S. (2021). Spatiotemporal shifts in thermal climate in response to urban cover changes: a case analysis of major cities in Punjab, Pakistan. *Geomatics, Natural Hazards and Risk*, *12*(1), 763–793. https://doi.org/10.1080/19475705.2021.1890235

du Toit, M. J., Cilliers, S. S., Dallimer, M., Goddard, M., Guenat, S., & Cornelius, S. F. (2018). Urban green infrastructure and ecosystem services in sub-Saharan Africa. *Landscape and Urban Planning*, *180*(November 2017), 249–261. https://doi.org/10.1016/j.landurbplan.2018.06.001

Duarte, G. T., Santos, P. M., Cornelissen, T. G., Ribeiro, M. C., & Paglia, A. P. (2018). The effects of landscape patterns on ecosystem services: meta-analyses of landscape services. *Landscape Ecology*, *33*(8), 1247–1257. https://doi.org/10.1007/s10980-018-0673-5

Gyenizse, P., Bognár, Z., Czigány, S., & Elekes, T. (2014). Landscape shape index as a potential indicator of urban development in Hungary. *Acta Geographica Debrecina Landscape & Environment Series*, *8*(2), 78–88.

Jamal, T., Naseer, S., Hassan, S. S., Batool, H., Mahmood, R., Naz, A., Butt, A., Tanver, U., Kaukab, I. S., Alvi, S., Ahmad, J., Akhtar, A., Javed, A., & Ali, A. (2018). Appraisal of Deforestation in Murree through Open Source Satellite Imagery. *Advances in Remote Sensing*, *07*(02), 61–70. https://doi.org/10.4236/ars.2018.72005

Jiang, Z., Huete, A. R., Chen, J., Chen, Y., Li, J., Yan, G., & Zhang, X. (2006). Analysis of NDVI and scaled difference vegetation index retrievals of vegetation fraction. *Remote Sensing of Environment*, *101*(3), 366–378. https://doi.org/10.1016/j.rse.2006.01.003

Kausar, R., Baig, S., & Riaz, I. (2016a). Spatio-temporal land use/land cover analysis of Murree using remote sensing and GIS. *Asian Journal of Agriculture and Rural Development*, *6*(3), 50–58. https://doi.org/10.18488/journal.1005/2016.6.3/1005.3.50.58

Kausar, R., Baig, S., & Riaz, I. (2016b). Spatio-temporal land use/land cover analysis of Murree using remote sensing and GIS. *Asian Journal of Agriculture and Rural Development*, *6*(3), 50–58. https://doi.org/10.18488/journal.1005/2016.6.3/1005.3.50.58

Khattak, M. S., & Ali, S. (2015). Assessment of temperature and rainfall trends in Punjab province of Pakistan for the period 1961-2014. Journal of Himalayan Earth Sciences, 42-61. http://ojs.uop.edu.pk/jhes/article/view/1944

Liding, C., Yang, L., Yihe, L., Xiaoming, F., & Bojie, F. (2008). Pattern analysis in landscape ecology: progress, challenges, and outlook. *Acta Ecologica Sinica*, *28*(11), 5521–5531. https://doi.org/10.1016/s1872-2032(09)60011-1

Malik, S. M., Arshad, S., Alam, K., & Bilal, O. (2020). Monitoring urban growth and land use changes using GIS and remote sensing: A case study of Tehsil Burewala. Journal of Himalayan Earth Sciences, 140-1582. http://ojs.uop.edu.pk/jhes/article/view/1819

Mujahid Hussain, S., Waheed, A., & Naeem Asghar, M. (2017). Emerging Challenges in Land Use Regulation System: a Case Study of Murree, Pakistan. *Journal of Research in Architecture and Planning*, *22*, 16–25. https://doi.org/10.53700/jrap2212017_2

Neel, M. C., McGarigal, K., & Cushman, S. A. (2004). Behavior of class-level landscape metrics across gradients of class aggregation and area. *Landscape Ecology*, *19*(4), 435–455. https://doi.org/10.1023/B:LAND.0000030521.19856.cb

Sertel, E., Topaloğlu, R. H., Şallı, B., Algan, I. Y., & Aksu, G. A. (2018). Comparison of landscape metrics for three different level land cover/land use maps. *ISPRS International Journal of Geo-Information*, *7*(10). https://doi.org/10.3390/ijgi7100408

Turner, M. G., & Gardner, R. H. (2015). *Landscape Ecology in Theory and Practice Pattern and Process Second Edition*.

Virk, Z. T., Khalid, B., Hussain, A., Ahmad, B., Dogar, S. S., Raza, N., & Iqbal, B. (2020). Water availability, consumption and sufficiency in Himalayan towns: A case of Murree and Havellian towns from Indus River Basin, Pakistan. *Water Policy*, *22*, 46–64. https://doi.org/10.2166/wp.2019.012

Waseem, S., & Khayyam, U. (2019). Loss of vegetative cover and increased land surface temperature: A case study of Islamabad, Pakistan. *Journal of Cleaner Production*, *234*, 972–983. https://doi.org/10.1016/j.jclepro.2019.06.228

Zhang, C., Wu, J., Grimm, N. B., McHale, M., & Buyantuyev, A. (2013). A hierarchical patch mosaic ecosystem model for urban landscapes: Model development and evaluation. *Ecological Modelling*, *250*, 81–100. https://doi.org/10.1016/j.ecolmodel.2012.09.020

Zhou, X., & Wang, Y. C. (2011). Spatial-temporal dynamics of urban green space in response to rapid urbanization and greening policies. *Landscape and Urban Planning*, *100*(3), 268–277. https://doi.org/10.1016/jlandurbplan.2010.12.013