SPATIOTEMPORAL CHANGE DETECTION IN FOREST COVER DYNAMICS ALONG LANDSLIDE SUSCEPTIBLE REGION OF KARAKORAM HIGHWAY, PAKISTAN

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ABSTRACT:

Forest Cover dynamics and its understanding is essential for a country’s social, environmental, and political engagements. This research provides a methodical approach for the assessment of forest cover along Karakoram Highway. It has great ecological and economic significance because it’s a part of China-Pakistan Economic Corridor. Landsat 4, 5 TM, Landsat 7 ETM and Landsat 8 OLI imagery for the years 1990, 2000, 2010 and 2016 respectively were subjected to supervised classification in ArcMap 10.5 to identify forest change. The study area was categorized into five major land use land cover classes i.e., Forest, vegetation, urban, open land and snow cover. Results from post classification forest cover change maps illustrated notable decrease of almost 26 % forest cover over the time period of 26 years. The accuracy assessment revealed the kappa coefficients 083, 0.78, 0.77 and 0.85, respectively. Major reason for this change is an observed replacement of native forest cover with urban areas (12.5%) and vegetation (18.6%) However, there is no significant change in the reserved forests along the study area that contributes only 2.97% of the total forest cover. The extensive forest degradation and risk prone topography of the region has increased the environmental risk of landslides. Hence, effective policies and forest management is needed to protect not only the environmental and aesthetic benefits of the forest cover but also to manage the disaster risks. Apart from the forest assessment, this research gives an insight of land cover dynamics, along with causes and consequences, thereby showing the forest degradation hotspots.

1. INTRODUCTION

Forests are important for sustenance of life on Earth. Forests offer numerous goods and services that comprise of fuelwood, timber, food and fodder. They are vital for the conservation of ecosystem, maintenance of water quality, prevention and reduction of natural hazards such as floods, erosion, landslides, avalanches, and drought and hence in regulating the climate on the regional level. A wide range of socioeconomic benefits are also provided by the forests. These include forest products, employment and areas that hold cultural value (FAO, 2005).

Lately, forests are gaining rising recognition as they play a vital role as carbon sinks and combating the increased levels of carbon is critical in the mitigation of climate change (FAO, 2010). However, there is a constant decline in global forest cover change. Total area of 4128 million ha was covered by forests in the 1990 and by the end of 2015 this has decreased and is recorded to 3999 million ha. There’s a worldwide decline in forest cover from 31.6% to 30.6% (FAO, 2016).

The land cover dynamics are a product of synergistic composition of anthropogenic activities and the natural or climatic effects. The change detection analysis is critical in assessing complex interactions between natural phenomenon and anthropogenic actions for effective resource management and policy making (Seif and Mokarram, 2012). The interactions are governed and understood by comparing multi-temporal remotely sensed data and historic knowledge or the ground truth data and consequently determining the land cover change quantitatively and cartographically (Seif and Mokarram 2012; Zoran, 2006).

Numerous researches have been undertaken globally to detect changes in forestation (Duveiller, 2007; Dwomoh, 2009; Souza et al., 2013, Gilani et al., 2015; Sajjad et al., 2015; Qamer et al., 2016; Khalid et al., 2016; Kundu, 2017). The main cause of forest depletion is extensive urbanization and agricultural incentives (Souza et al., 2013; Gilani et al., 2015; Sajjad et al., 2015). In developing countries, however, forests are also being degraded due to illegal logging and timber mafia (Khalid et al., 2016; Qamer et al., 2016).

Geomatics and geospatial techniques have largely been applied to monitor the change detection in forest cover dynamics. The geospatial techniques incorporate the remote sensing data as cost effective, time saving and accurate input with the GIS environment for effective data analysis and updating (Kachawala, 1985; Chilar, 2009; Gilani et al., 2015). Various GIS techniques comprising of Object based image classification, pixel based imaged classification (supervised, unsupervised and hybrid) and various geostatistical models have been performed to
study the change detection of land cover dynamics around the globe (Gilani et al., 2015; Qamer et al., 2016).

According to the international standards, the estimated area for a country to be covered with forests should be 25%.
Unfortunately, Pakistan falls too short of this standard and has only about 4.8% of its land covered with forests. Hence, the current study aims to focus on the Karakoram Highway since the region is blessed with some of the great forest reserves and due to its steep topography, the area has increased risk of landslides. Due to mudflow and large boulders, each year the

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highway is blocked and all kinds of transportation is restricted. Therefore, it is a strong motivation to assess the forest degradation owing to its high environmental and ecological significance. Moreover, the general shift towards urbanization provides a strong incentive to monitor the forest cover dynamics.

The current study aims to monitor the change in forest cover along the study area over the past 2.5 decades. However, the specific objectives of this study are:
1) to identify the forest cover dynamics from 1990 to 2016.
2) to assess the capability of geospatial techniques for change detection analysis on wide spatiotemporal scale.
3) to determine the forest cover change to other land use land cover classes over defined temporal scale.

2. MATERIALS AND METHODS

2.1. Study Area

The study area includes the Karakoram Highway (N-35) originating from Hasanabdal till the Sazin and Chilas region (Figure 2). The Karakoram Highway (KKH) is among the highest international highways. It is at an altitude of 4,693 m or 15,397 ft. The total length of KKH is about 1300 km and it stretches approximately 700kms from Islamabad through Karakoram Mountains into China. Along the path, there are some of the great mountain ranges like Pamirs, Himalayas and Karakorams. Majority of the highway is dominated by huge barren mountains. Indus River runs through KKH for over 200 km. The Karakoram Highway along with Indus River divides the mountain range of Himalayas and Karakoram Range and winds along the foot of Nanga Parbat. Moreover, the fact that this highway runs along the region with high topographic relief and is prone to soil erosion makes it susceptible to landslides. The highway is termed as China Pakistan Economic Corridor (CPEC) that is the framework of regional connectivity. KKH is not only intended to benefit Pakistan and China but it will also be beneficial to the neighbouring countries; Afghanistan, Iran, India and the Central Asian Republic regions. It is a step towards economic regionalization in this globalized world. Therefore, its economic and ecological significance provides a good rationale to detect and explore the forest cover dynamics of this region. It lies between the latitude from 33^{o} and 35^{o} (N) and longitude from 72^{o} and 73^{o} (E). Majority of the highway is dominated by huge barren mountains. Indus River runs through KKH for over 200 km. The summers are mild and winters are intense with snow. The annual precipitation ranges from 150mm to 2000mm. The max annual mean temperature ranges from 16^{o} to 25^{o} C and min annual mean temperature varies from -3^{o} to -14^{o} C (PMD).

2.1.1. Dataset

For the current study, the 30-m satellite images (with less than 10% cloud cover) for the years 1990, 2000, 2010 and 2016 were acquired from Landsat 4-5 MSS, Landsat 7 ETM and Landsat 8 OLI. The images of summer season (June through September) were downloaded from the USGS earth explorer website.

Data	**Year**	**Resolution**
Landsat 4-5 MSS	1990	30m
Landsat 7 ETM+	2000	30m
Landsat 8 OLI	2010	30m
Landsat 8 OLI	2016	30m

Table 1 Data acquisition of remotely sensed imagery

2.2. Methodology

The detailed methodology is illustrated in the Figure 1. The main steps involved include the image pre-processing, extraction of the study area, supervised classification and generation of the forest cover maps.

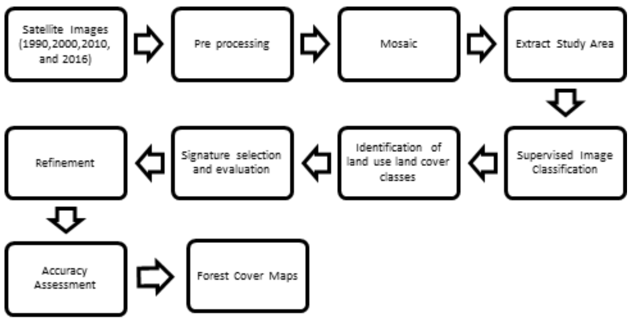

Figure 1 Methodology flow chart for mapping forest cover dynamics

2.2.1. Image Pre-Processing and Extraction of Study Area: The usage of multi-temporal satellite imagery for extensive area mapping raise several challenges that includes noise, geometric correction errors, and illumination errors (Homer et al., 2004). The image pre-processing was performed using radiometric correction tool in ERDAS IMAGINE 2014. This helps in enhancing the details of the image, thus improving the chances of better analysis. A mosaic of the satellite images was generated and later, a buffer of 10 km around the Karakoram Highway (originating from Hasanabdal to Sazin and Chilas) was made to extract the study area.

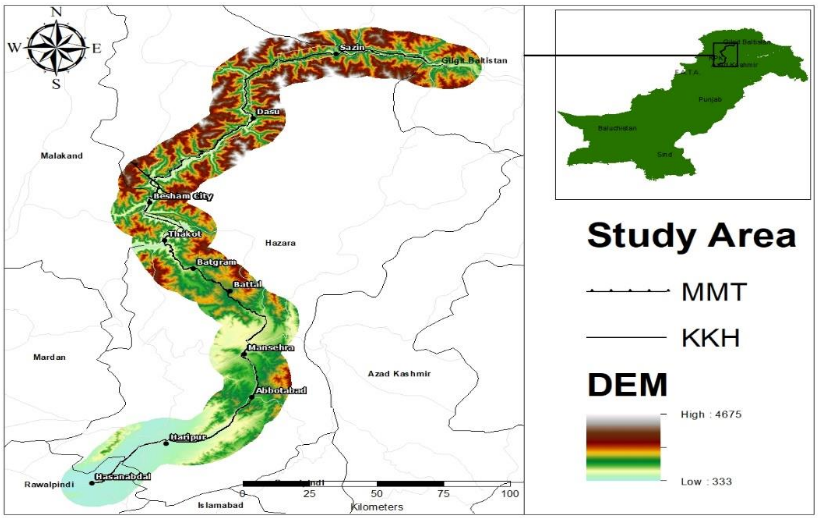

Figure 2 Study area map

2.2.2. Supervised Image Classification: The approach of supervised image classification requires the analyst to select adequate training samples that are representative of the research area (Jensen 1987). The training samples are identified on the basis of ground truth data and visual interpretation of the satellite imagery. The supervised classification is based on the pixels or the digital number values of the region of interest. 100 pixel-based signatures were selected for each land use land cover class and stored in the respective signature file. The Land use land cover classes identified for the current study are expressed in the Table 2. Maximum Likelihood Classifier Algorithm was used because of its better performance that considers heterogeneity of land cover in the study area, vector mean of the signatures, and the calculation of probability of the specific signature for the individual land use land cover class (Jensen, 1987). Maximum Likelihood Algorithm is also beneficial for it reduces the anomalies in classification that may come up due to the similar spectral responses of the objects in the area (Yaun et al., 2005). Thus, the entire study area was categorized and delineated into broad land cover classes of forests, vegetation, urban, open land and snow. The signatures and histograms were reviewed and refined, thereby producing level 1 classification output.

LULC Classes	**Description**
Urban	Consists of settlements and urban structures including roads and houses
Vegetation	Includes the urban vegetative land cover like recreational parks, green belts and also agricultural fields
Open Land	Barren mountains and areas with no vegetation
Forests	Area densely covered with trees and the reserved forests
Water	Water bodies including Indus River and streams.
Snow	Fresh snow

Table 2 Description of LULC classes

2.2.3. Accuracy Assessment: The quality of the classified images of 1990, 2000, 2010 and 2016 was performed by accuracy assessment in ArcMap 10.5. Accuracy assessment is estimated by ratio of sums of diagonal values and total number of assessed pixels/values and the resultant is the correctly classified pixels given in percentage (Campbell and Wyne., 2011). This process involves the comparison of classified data with the reference data for that particular training site (Jensen, 2007). An error matrix is considered as a standard method for representing output and judging the performance of accuracy assessment (Story and Congalton, 1986; Rees, 1999). For current study, a total of 500 random stratified sampling points were used and Google Earth Imagery was considered as the reference data to assess the accuracy. Later, the comparison between the classified data and reference data yielded the results in form of error matrix. For the assessment of individual land cover class, Kappa coefficient was calculated using the following formula (Eq. 1).

$$K = [P(A) - P(E)] / [1 - P(E)] \qquad \text{(I)}$$

where, $P(A)$ = total number of events with accurate value of K
$P(E)$ = Expected level of accuracy of K

2.2.4. Change Detection and Post-Classification Comparison: To improve the classification accuracy, post classification comparison was performed and the classes with mixed pixels were re-examined (Harris and Ventura, 1995; Lu and Weng, 2005). The post classification comparison was carried out in ArcGIS 10.5 using overlay change detection for the selected years.

The percentage change in forest cover was calculated using the following formula (Eq. II).

$$\text{Percentage Change in Forest Cover} = [(b-a)/c] * 100 \qquad \text{(II)}$$

where, a= forested area in old year
b = forest area in current year
c= total area

For identifying the shift in each class, pixel by pixel cross tabulation matrix was made. Thus, thematic maps were generated representing the shift from one land use land cover class to other class.

3. RESULTS AND DISCUSSIONS

3.1. Classification and Forest Cover Change Maps

Forest cover maps and results from error matrix and kappa coefficients were generated for the years 1990, 2000, 2010 and 2016 (Figure. 3). The overall accuracies for the years 1990, 2000, 2010 and 2016 are given in the table 3. The percentage change in each class of land cover is summarized in Figure 4.

Year	*Overall Accuracy*	*Kappa Coefficient*
1990	88%	0.83
2000	85%	0.78
2010	83%	0.77
2016	89%	0.85

Table 3 Accuracy assessment of classified images

The results showed drastic decrease in forest cover and a subsequent increase in the urban area (10%) and vegetative cover (38%). The forested area covered 46% of the total region in the 1990 which was significantly decreased to only 20% in 2016. This results revealed that around 26% of forested area have been degraded in the past 2.5 decades.

The area is densely populated with conifers and pine forests. Forest types along Karakoram Highway includes the Sub Tropical Pine Forest, Himalayan moist temperate forest, Himalayan dry temperate forest and sub alpine forests. The forest species dominant in the region consists of Chir pine (Pinus roxburghii) at an elevation of 900m to 1700m. The main conifer species in the ranking of higher altitude include Cedrus deodara (Deodar, diar), Picea smithiana, Pinus wallichiana and Abies pindrow (Partal) (Siddique, 1997). Currently, there's no significant decrease in the reserved forests that covers 2.9% of the total forest cover. If the deforestation trend continued in unsustainable pattern, the forest species in this area are likely to go endangered.

The drivers of deforestation include the timber mafia, consumption of fuel wood for domestic purposes and trend towards urbanisation. Considering the continuous consumption for fuel wood, it is estimated that by the year 2027 the forests of Malakand and Hazara may cease to exist. About 21% of total demand is being covered by range lands, agricultural and plantation supplies. There is approximately 8.8 million m^3 uncovered demand/supply gap by 2027 which is expected to continue growing up to 13.6 million m^3 by 2050 (Joachim, 2000). However, the mountainous region of Pakistan has not experienced any major forest loss due to environmental and natural factors like climate, water, epidemic or landslides etc.

With the on-going deforestation and destruction to the forest ecosystem, there is a threat to biodiversity and it may affect the ecosystem services including aesthetic and recreational facility, carbon sequestration and soil conservation. The removal of vegetative cover from the steep slopes makes them vulnerable to soil erosion and other natural hazards like landslides (Hamilton, 2008). The Himalayan region is of greater concern in this regard since the damage to this region will not only adversely affect this region but also the neighbouring plains of Indus basin via hydrological cycle. This may result in triggering the phenomenon of soil erosion, silting, floods and desertification. The floods are a more frequent and severe incident in the past 2.5 decades as compared to last 65 years because of high rate of surface runoff and soil erosion in the region (Tejwani, 1987). As per Pakistan Water Strategy, Pakistan is required to increase the water storage of 18 million acre-feet (MAF) by 2050, out of which 30% is to be replace the storage loss due to silting (Qamer et al., 2016).

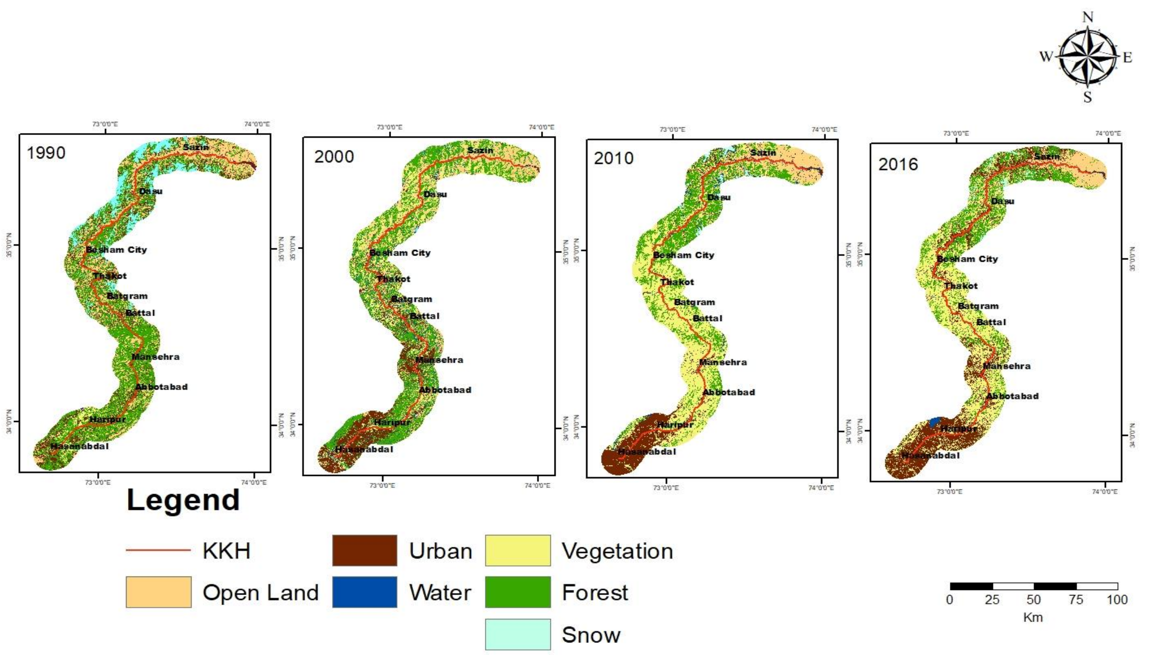

Figure 3 Forest cover dynamics from 1990 to 2016

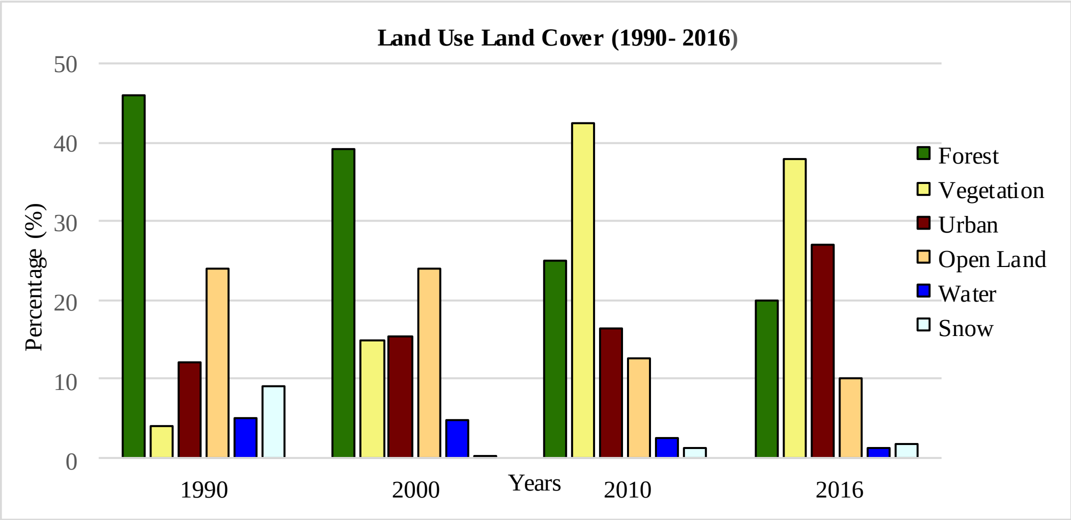

Figure 4 Spatiotemporal change of each LULC class from 1990 to 2016

	Area (Percentage)
Forest to Vegetation	18.6
Forest Unchanged	12.5
Forest to Urban	12.1
Urban to Vegetation	10.3
Urban Unchanged	6.9
Urban to Open Land	6.7
Snow to Vegetation	5.8
Snow to Urban	5.3
Water to Vegetation	3.5
Snow to Forest	3.1
Water to Forest	2.4
Vegetation to Urban	2.1
Urban to Forest	1.8
Forest to Open Land	1.8
Water to Snow	1.1
Snow to Open Land	1.1
Water to Open Land	0.9
Water to Urban	0.8
Vegetation Unchanged	0.4
Forest to Snow	0.2

Table 4 LULC dynamics area (%) from 1990 to 2016

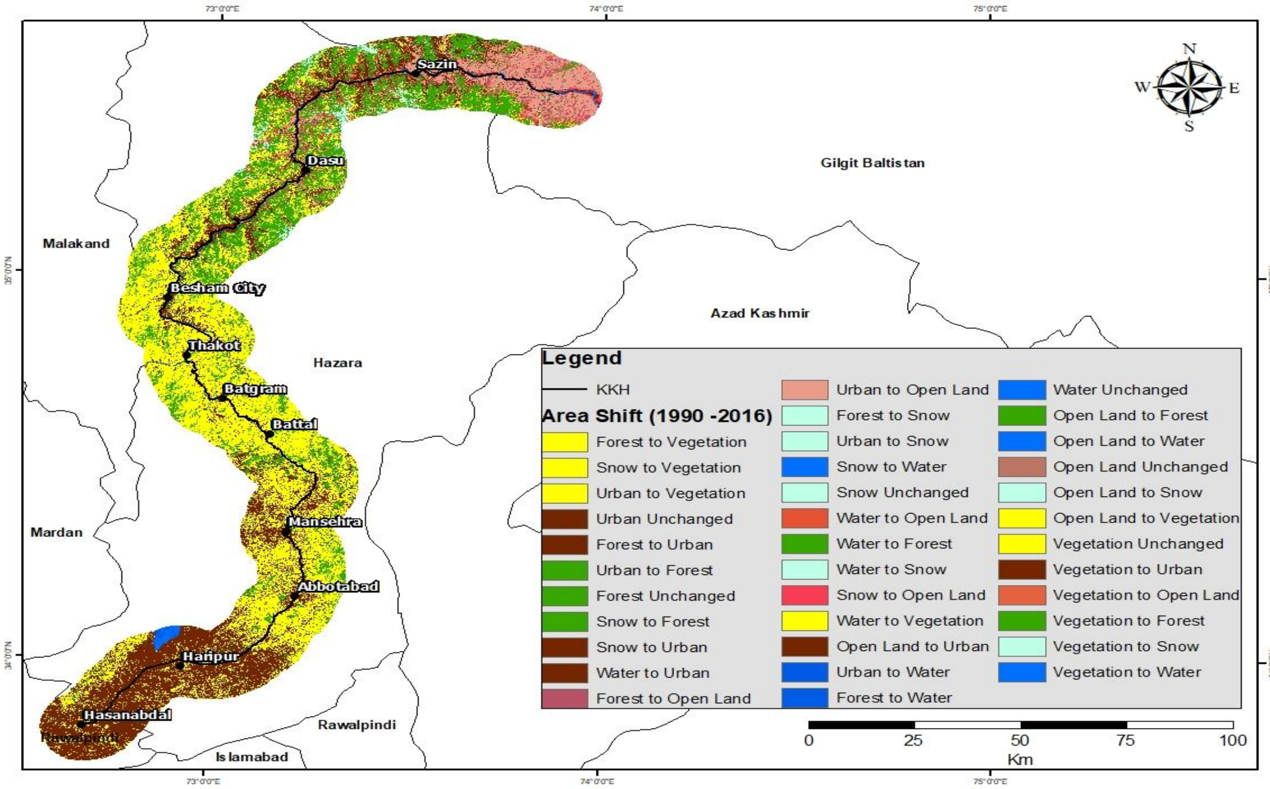

Figure 5 Forest Cover Shift (1990 to 2016)

3.2. Area Shift

The cross-tabulation results for 1990-2016 showed 20.2% of area remained undisturbed that includes all the land cover classes and the significant shift from each LULC is illustrated in Table 4. Forest class showed that most of the forest clearing occurred for agricultural and vegetation purpose. Almost 18.6% of forest was degraded and changed into agricultural land. The area also showed a substantial shift from forest to urbanization. Almost 12% of forest cover has been converted into urban area in the past 2.5 decades (Figure 5). Thus, there is a huge shift of forest towards extensive vegetation and urbanization.

The time series land cover mapping for the years 1990, 2000, 2010 and 2016 showed that extensive deforestation occurring in the research area. Within the KP region, covering Abbottabad to Besham City, showed highest degradation because of area shift towards urbanization and agricultural vegetation. The primary causes of forest degradation in the region includes area shift towards pastures and parklands and supply and demand of wood. The area showed drastic increase in the aesthetic greenery and agricultural vegetation. This type of vegetation is also subjected to high grazing. Wood consumption for domestic purposes and village carpentry also contributes in the forest degradation in the study area (Siddique, 1997). Numerous reports relate deforestation with its connection to timber mafia and competitor groups for financial benefits and clearing by security forces for strategic reasons (Fischer et al., 2010; Ali et al., 2006).

Due to institutional neglect of the forest management department, forests in the northern Pakistan are facing constant decline. Hence, the need of the hour is to implement efficient forest management techniques (Pellegrini, 2007). The historical analysis incorporated with the satellite imagery accentuate the importance of resource rights of forest conservation. There is also a major disconnection between de jure and de facto forest resource rights that resulted in extensive deforestation. Therefore, the concerned authorities need to clearly identify the forest resources rights, formulate community management systems and legal framework that monitors, records and reports each acts and violations transparently (Khan, 2009). Moreover, an extensive study explaining the drivers of deforestation may also help in rectifying the damage done by deforestation.

As far as the limitations of the research are concerned, the steep terrain entailed some challenges in the interpretation of the analysis and its conversion in the shadowed regions. Considering the slow growth of the forest areas and lower detectability, the forest gains are apparently lesser than the losses.

CONCLUSIONS

This research delivers forest degradation and deforestation statistics along 10-km of Karakoram Highway initiating from Hasanabdal to Sazin and Chilas over a period of 25 years. The study utilized a consistent dataset and methodology. The results showed significant increase in deforestation trend. There has been 26% decrease in forest cover from 1990 to 2016. However, the reserved forests along the area remain undisturbed. The results showed that geospatial techniques are effective in monitoring and counteracting the spatiotemporal changes in the land use land cover. The accuracy assessment results were reassuring and hopeful for the adopted approach of supervised classification. The area shift map illustrated that the forest cover has majorly changed (18.6%) into vegetation cover that primarily encompass the agricultural land. The results showed a substantial shift of 12% towards urbanization. The deforestation in the area can be attributed to violation of environmental laws, poor forest management and non-conductance of proper Environmental Impact Assessment. The forest degradation hotspots recognised in this study encourages further research to study the underlying deforestation drivers. The quantitative research on underlying factors causing the degradation using spatiotemporal analysis can promote effective and inclusive forest management strategies. Furthermore, this subject would garner more consideration in future research.

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