Journal of
Water & Climate Change

 Journal of Water and Climate Change Vol 14 No 2, 442 doi: 10.2166/wcc.2023.315

Assessment of change in forests land, carbon stock and carbon emissions of KPK, Pakistan for past three decades using geospatial techniques

Muhammad Arif Goheer[a], Laraib Fatima[b], Humera Farah[b], Sher Shah Hassan [a,*] and Nazir Abbas[c]

[a] Global Change Impact Studies Centre, Ministry of Climate Change, Islamabad, Pakistan
[b] Department of Earth & Environmental Sciences, Bahria University, Islamabad, Pakistan
[c] Directorate of Agricultural Engineering, Tarnab, KPK, Pakistan
*Corresponding author. E-mail: shershah538@gmail.com

SSH, 0000-0002-9330-4120

ABSTRACT

Reducing emissions from deforestation and forest degradation is a mechanism to cut down GHG emissions and protect the threatened forest ecosystems. Pakistan is suffering from high forest degradation and deforestation rates, but recent plantations under BTTAP have created a significant impact. This study was designed to identify the LULC changes, forest sequestration and emissions from forest degradation in the forest hub districts (Malakand, Mardan, Lower Dir and Upper Dir) of KPK, Pakistan using Landsat imageries. LULC changes were analyzed from 1990 to 2020. In addition, the amount of carbon sequestration and emissions from forest degradation were also calculated. Results of the analysis showed forest area reduction from 1990 to 2009, followed by a sharp increase in the next decade (2010–2020) by 56%. Around 836 km^2 of land was found to be covered with forests during BTTAP. The net change was a 32% increase in forest land over three decades. The study offers important information which environment managers and decision-makers can utilize to encourage the plantation of trees and save existing forests in the country to combat climate change.

Key words: carbon sequestration, climate change, emission from deforestation, GIS & RS, LULC, supervised classification

HIGHLIGHTS

- Forest area reduced from 1990 to 2009, and a sharp increase was seen in the next decade (between 2009 and 2020) by 56%.
- Almost 836 km^2 of land was found to be covered with forests.
- The net change was recorded as a 32% increase in forest land in the study area over three decades.
- From 1990 to 2000, 1.3 tons of carbon stock was degraded. From 2000 to 2009, 3.4 tons of carbon stock degraded.

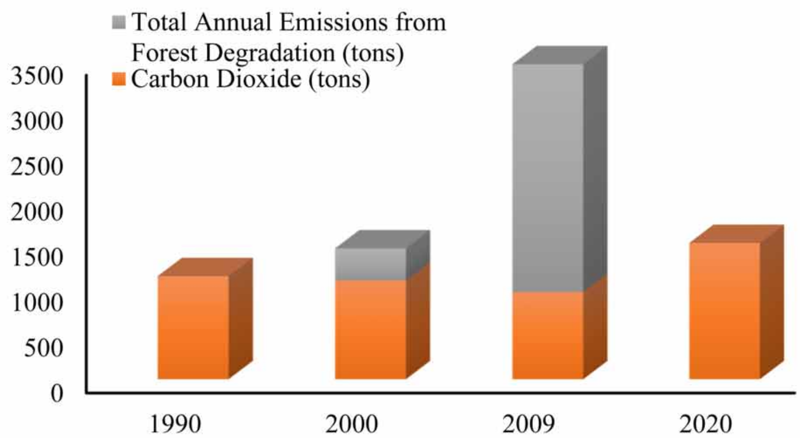
GRAPHICAL ABSTRACT

This study was designed to identified the LULC changes, forest sequestration and emission from forest degradation in forest hub districts (Malakand, Mardan, Lower Dir and Upper Dir) of KPK, Pakistan using Landsat imageries. LULC changes was analyzed from 1990 to 2020. Results of the analysis shows that forest area were increased by 32% (see table). The figure below summarizes total carbon sequestration (tons) potential and emissions due to deforestation over the time period in the study area.

Net change in classes over the years (1990 - 2020)

Category	Change (km^2)	% Change
Forest land	565.55	32.17
Agricultural land	-937.75	-44.45
Water Bodies	-28.83	-63.89
Settlement	1493.77	86.95
Others	-1092.48	-47.33

Note: -ive sign shows decreasing trend



Carbon Stock Assessment and total annual emissions from forest degradation

INTRODUCTION

Global environmental problems have become more obvious since the industrial era, deforestation being one of them (Iqbal & Khan 2014). Among the countries affected by climate change, Pakistan is at the higher end of the list, and deforestation is one of the deeper problems it is facing right now (Hussain *et al.* 2019). Fortunately, the plantation of forests plays a considerable part in measures related to climate change mitigation (Hussain *et al.* 2019). Activities that allow carbon dioxide (CO_2) in the atmosphere lead to the destruction of forests. New forests, however, help in mitigating detrimental impacts created by the change in climate, by eliminating CO_2 from the atmosphere (Khan *et al.* 2021).

Globally, forests cover up 31% of the terrestrial area as of this time (UN Global Forest Goals Report 2021). The percentage of Pakistan's forest area is unclear. Only some countries have consistent data from proper assessments over time. The UN's Food and Agriculture Organisation (FAO) estimates Pakistan's forests cover 2.2% of the total land. On the other side, Pakistan Forest Institute figures it to be 5.1%. 14.10% of the KPK is covered with forests, which is almost 40% of all forests in Pakistan (Kahlon & Talal 2020).

To expand and maintain their forest area, countries created strategies and plans, often with calculated targets, detailed objectives, processes, and resources. Recently Pakistan started Billion Tree Tsunami Project, which aimed for an increase in the forest area to 6% by 2020 and then to 10% by 2030 (Kahlon & Talal 2020). KP forest department revealed the Billion Tree Tsunami Afforestation Project or BTTAP in 2014, which followed the guidelines of Forest Ordinance 2002 and KP Forest Policy. It was planned in accordance with the Green Growth initiative in Khyber Pakhtunkhwa (KPK) Province to promote the forest sector. It concluded in November 2017 (Kamal *et al.* 2019).

Environmentalists and naturalists have given extensive attention to the changing aspects of land use and many environmental problems such as flooding, salinity, water quantity and quality degradation, land degradation and its direct effect on surroundings such as local climate, forest cover loss, reducing agricultural stretches, increasing built-up and increasing impermeable surfaces, etc. (Fahad *et al.* 2020, 2022). Land-use and land-cover (LULC) change is a significant motivator of global change (Butt *et al.* 2015). Specifically, changes in tropical areas are of major concern due to the widespread and quick changes in the distribution and attributes of forests (Iqbal & Khan 2014). Through in-depth research into environmental changes, researchers are seeing that LULC change due to human activities play a major role in the evolution of global warming (Hossen *et al.* 2019). It is safe to say that LULC is a product of the social and economic activities of humans and their environment (Chang *et al.* 2018).

Several anthropogenic activities like tropical deforestation, land misuse, biomass burning, soil erosion, agricultural practices and industrial development release a huge amount of CO_2 into the atmosphere which results in increased temperature which melts glaciers and causes flooding (Fahad *et al.* 2020). Among these, forests play a critical role as a sink for carbon emissions. Between 1990 and 2010, the total global forest carbon stock fell from 668 gigatons (Gt) in 1990 to 662 Gt in 2010. This was due to the decline in the forest area. In 2020, it remained at 662 Gt (UN Global Forest Goals Report 2021).

LULC related to deforestation and land degradation releases CO_2 and other greenhouse gases which turned out to be an urgent matter in the scientific community (Hossen *et al.* 2019). In a study that focused on mapping deforestation trends in Western Himalayas, Pakistan, extensive deforestation was revealed in the area from 1990 to 2010. Nearly 170,684 ha (1,706.84 km^2) of the forest had been lost, or roughly 0.38% of forest land was degraded every year (Qamer *et al.* 2016). Another study took place in Margallah Hills National Park. It is a protected area of Islamabad. The results showed a decrease in forested land in 2017, compared to that in 1990. Also, land-use change released substantial carbon into the atmosphere. This implied that land-use change considerably modifies carbon dynamics in the long run (Mannan *et al.* 2018).

LULC changes were observed in Azad Jammu and Kashmir, Pakistan from 1998 to 2009 (Iqbal & Khan 2014). Forest cover, which covered 23.60% (175.50 km^2) area in 1998 had declined to 20.90% (155.50 km^2) in 2009. In one study by Ali *et al.* (2017), a decline was seen in forest cover from 1992 to 2011 in Swat Valley, Pakistan. Total annual deforestation was 1,268 ha from 2001 to 2008 in the valley. The total percent drop in carbon stocks because of deforestation was recorded to be 17.25. Dynamics of LULC change were studied by Hassan *et al.* (2016) in Islamabad, Pakistan from 1992 to 2012. While the other classes (agricultural land, settlement, water bodies) witnessed an increase, the forest area was reduced to a great extent.

Anthropogenic activities have distinct carbon footprints that are measured as total emissions of GHGs resulting from an activity. A study by Fahad *et al.* (2020) suggested that in order to meet the global climate targets, quantification of the net global warming potential of agricultural practices requires precise estimates of local, regional and global carbon budgets. They conducted a case study for observing the development of a deep soil carbon profile resulting from a 10-year wheat–cotton and wheat–maize rotation on semi-arid lands. Results showed that by implementing no tillage along with mulch application, lower carbon losses from soil can mitigate the risks associated with global warming. Therefore, it is necessary to reconsider agricultural practices and soil erosion after a land-use change when calculating global carbon footprints (Fahad *et al.* 2021a, 2021b).

Changes in LULC affect carbon stocks at different intensities, therefore, the valuation of carbon stocks can assist in decision-making, mainly in the context of ecosystem services in areas of interest (Fernandes *et al.* 2021). Therefore, this study aimed to assess the LULC change patterns over the past three decades (1990–2020) to better understand the merits or demerits of the project, and to help policymakers, environmental planners and administrators with future projects of the same nature. Moreover, a carbon stock assessment was also done to help determine the impact of local tree plantation drives. The main objectives of the study were: (i) to identify the forest cover change dynamics in selected districts of KPK over a defined temporal scale, and (ii) to assess changes in carbon stock and emission from deforestation using the mathematical algorithm as a result of LULC changes.

MATERIALS AND METHODS

Study area

KPK is located in the northwest of Pakistan (34.00°N 71.32°E). About one-third of Pakistan's forests are in this province. According to FAO (2017), 760,000 ha of land in KPK is covered with coniferous forests. This makes the region significant for carbon sequestration. The districts selected for this study were Malakand, Mardan, Lower Dir and Upper Dir having areas of 952, 1,632, 1,582 and 3,699 km^2, respectively (Figure 1).

The climate in the province fluctuates in accordance with altitude. The mountainous regions experience cold winters and cool summers. A broad range of temperatures has been experienced in the province. Precipitation usually occurs from January to April. It is variable but averages roughly 16 inches annually (Raziq *et al.* 2016).

Satellite data acquisition and pre-processing

Satellite imagery provided by Landsat (4-5 & 8) for AOI was secured from the USGS website for the last three decades. The quality of the image especially for those with limited or low cloud cover was the deciding factor for the selection of Landsat satellite images dates. The best imagery found was of September for the years 1990, 2000, 2009 and 2020 (Table 1).

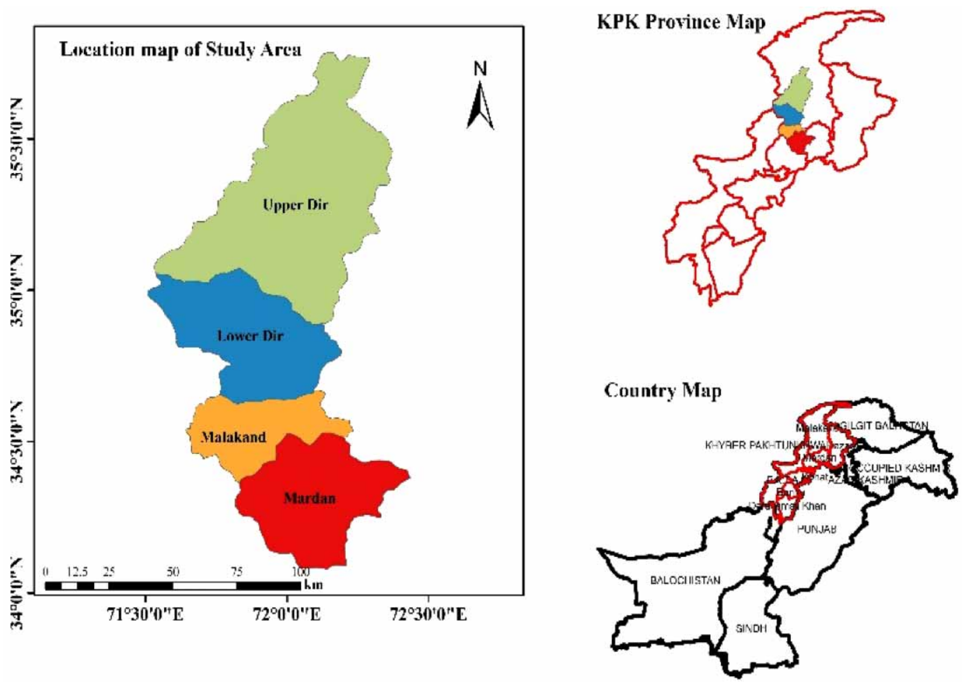


Figure 1 | Geographical location of the study area (Mardan, Malakand, Lower Dir and Upper Dir).

Table 1 | Satellite data specifications

Data	Date of acquisition	Resolution (m)	Row/Path	Source
Landsat 4-5 TM imagery	September 1990	30	151, 35; 151, 36	USGS
	September 2000	30		
	September 2009	30		
Landsat 8 OLI imagery	September 2020	30	151, 35; 151, 36	USGS

Imageries from satellites may often be distorted geometrically due to differences in acquisition systems and certain movements. Distortions such as geometric and radiometric ones were corrected before processing. All the bands were stacked in ERDAS Imagine software to get the composite image. As the study area was covered by two or more tiles. Mosaic was done to merge images or tiles to create a single image. The study area was extracted from the mosaiced images of 1990, 2000, 2009 and 2020 in ArcMap.

Image classification

Maximum likelihood supervised classification was performed over an area of interest (AOI) on images for the years 1990, 2000, 2009 and 2020 in ArcMap. LULC was classified into five classes (Table 2). The LULC classes included forest area, an agricultural area, settlement, water bodies and others.

More than 150 training samples/signature files were compiled for each land cover type (Forest area, Agricultural area, Water bodies, Settlement and Others). For guidance, these training areas were identified and visualized in high-resolution images on Google Earth.

Accuracy assessment and area calculation

An accuracy assessment of the images was carried out to determine the quality of information originating from the data. It was carried out using by taking Reference points based on ground truth data taken from Google Earth and visual analysis. To assess the accuracy of the classification, every LULC map was compared to corresponding reference data. The ground truth data obtained as a result was used to verify the classification accuracy.

A comparison of reference data and classification results was carried out statistically using error matrices. For each classified image (1990, 2000, 2009, 2020), the overall, producer's and user's accuracies were obtained.

The attribute tables of each class for all classified images were used to calculate the area of different land cover over the AOI. This was done in ArcMap. The analysis was helpful to identify various changes occurring in different classes of land use like an increase in urban built-up area or forest-covered area, etc. that took place over the time span of the study.

Carbon stock assessment

Carbon stock assessment was done by using emission factors from the Forest reference emission level of KPK obtained from Pakistan Forest Institute, Peshawar (Ali *et al.* 2020). There are different methods used for calculating carbon sequestration on different scales, globally (Sun & Liu 2020). The formulas and constant values used in this study were taken from a study by Ali *et al.* (2017) and Khan *et al.* (2021), based on those reported by the Intergovernmental Panel on Climate Change's Greenhouse Gas Inventory Guidelines Reference Manual which are also standardized by UNFCCC.

Carbon stocks for the years 1990, 2000, 2009 and 2020 were calculated using IPCC conversion factors. To calculate the total wood volume, the forest area obtained from the classification process was used. The wood volume (Equation (1)) was converted to dry matter biomass (DMB) (Equation (2)) by multiplying with a constant of 0.43. For carbon stock (Equation (3)), wood volume was multiplied by Basic wood density (0.5, since forests in the study area, are generally classified as conifers), Biomass expansion factor (1.3) and Conversion factor (0.47). For calculating total CO_2 (Equation (4)), Carbon stock

Table 2 | Classes delineated based on supervised classification

Sr. #	Class name	Description
1.	Forest area	Mixed forest lands
2.	Agricultural area	Crop fields and lands for grazing
3.	Water bodies	Rivers, open water, lakes, ponds and reservoirs
4.	Settlement	Residential areas, commercial properties, industrial setups, transportation, roads and other infrastructure
5.	Others	Land areas of exposed soil and barren area influenced by human impact

was multiplied by a constant of 3.66 (Ali *et al.* 2017). Above-ground biomass was focused on in this study.

$$\text{Total wood volume } (m^3) \quad V = \text{TFC} \times 1.454 \times 0.396 \tag{1}$$

$$\text{Total dry matter biomass (DMB)(tons)} \quad \text{DMB} = \text{wood volume} \times 0.43 \tag{2}$$

$$\text{Carbon Stock (tons per km}^2) \quad C_{\text{stock}} = \text{Volume} \times \text{BWD} \times \text{BEF} \times \text{CF} \tag{3}$$

$$\text{Carbon dioxide (tons)} \quad CO_2 \text{ equivalent} = C_{\text{stock}} \times 3.6667 \tag{4}$$

where TFC is the total forest cover; V is the volume of timber; BWD is the basic wood density (0.5 for conifers); BEF is the biomass expansion factor (1.3 for conifers); CF is the conversion factor (0.47).

Emissions from forest degradation

The total carbon value loss was assessed from 1990 to 2009. Change in carbon was determined by Equation (5) and the rate of carbon loss (annual) was determined by Equation (6). Similarly, the emission factor for forest degradation (Equation (7)) and total annual emissions from forest degradation was calculated (Equation (8)) (PFI 2021).

$$\Delta C = \text{TFC}_{t_2} - \text{TFC}_{t_1} \tag{5}$$

$$\text{Annual carbon Stock degradation ACSD (tons)} = \frac{\text{TFC}_{t_2} - \text{TEC}_{t_1}}{(t_1 - t_2)} \tag{6}$$

$$\text{Emission factor for forest degradation (tons)} = \text{ACSD} \times 3.66 \tag{7}$$

$$\text{Total annual emission from forest degradation (tons)} = \text{forest area degraded} \times \text{mission factor} \tag{8}$$

where ΔC is the carbon loss or gain; TFC_{t2} is the total forest carbon at time t_2; TFC_{t1} is the total forest carbon at time t_1.

RESULTS AND DISCUSSION

LULC change statistics

According to the 1990 image classification results (Figure 2(a)), the forest area in terms of km^2 was 1,758, Agricultural land was 2,109, Water bodies 45, Settlement 1,718 and Others 2,308 (Figure 3). In 2000, the classification result (Figure 2(b)) shows that the forest area in terms of km^2 was 1,684, agricultural land was 1,936, water bodies 27, settlement 2,275 and others 2,015. An increase can be seen in the settlement in 2000 as compared to 1990. Forest area, on the other hand, has decreased (Figure 3).

Next in 2009 image classification results (Figure 2(c)), the forest area and agricultural land decreased to 1,486 and 1,846 km^2, respectively. The settlement has kept on increasing in 2009, i.e. 2,731 km^2 as compared to 2000. Similarly, in 2020 (Figure 2(d)), an increase in forest area was noticed, i.e. 2,323 km^2 compared with 1990 and 2009. This is due to afforestation made by the KPK government under the project Billion Tree Tsunami. The details of the area for each class are shown in Figure 3. It can be seen clearly in Figure 3, forest area continued to decline from 1990 to 2009. Afterward, a sharp increase is seen in the graph in the forest class. Agricultural land continues to decrease over the study period. While the settlement shows a huge increase with each passing decade.

LULC changes were observed in Azad Jammu and Kashmir, Pakistan from 1998 to 2009. Forest cover, which covered 23.60% (175.50 km^2) area in 1998 had declined to 20.90% (155.50 km^2) in 2009 (Iqbal & Khan 2014). Ali *et al.* (2017) conducted a study on LULC changes in Swat Valley, Pakistan. They observed a declining trend in forest cover from 1992 to 2011. Total annual deforestation was 1,268 ha from 2001 to 2008 in the valley. The total percent drop in carbon stocks because of deforestation was recorded to be 17.25.

Dynamics of LULC change were studied by Hassan *et al.* (2016) in Islamabad, Pakistan from 1992 to 2012. While the other classes (agricultural land, settlement, water bodies) saw an increase, forest area was reduced to a great extent.

Net change in each class

The LULC transition statistics of each class for 1990–2000, 2000–2009 and 2009–2020 are shown in Table 3 and discussed below.

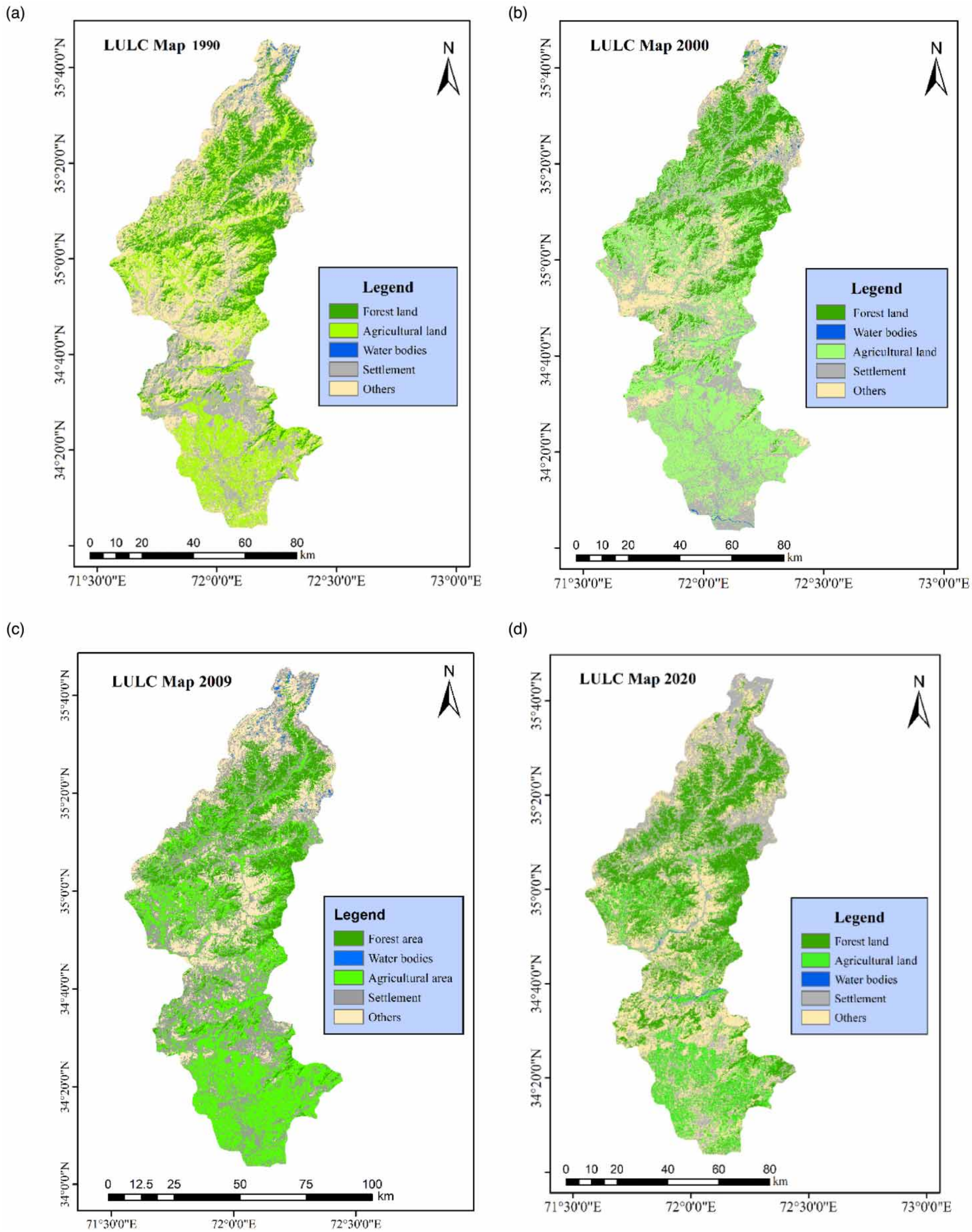


Figure 2 | LULC Map (a) 1990, (b) 2000, (c) 2009 and (d) 2020 of selected districts.

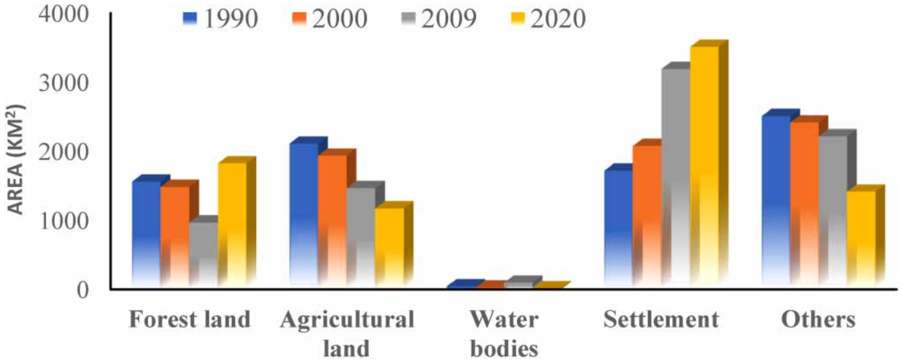


Figure 3 | Comparison of LULC change in the study area over 30 years (1990, 2000, 2009, 2020).

Table 3 | Decade wise area change in classes over the years (1990, 2000, 2009, 2020) calculated in percentage

Category	Years	Change (km^2)	% Change
Forest land	1990–2000	−74.02	−4.21
	2000–2009	−197.37	−11.72
	2009–2020	836.94	56.29
	Net change	565.55	32.17
Agricultural land	1990–2000	−173.46	−8.22
	2000–2009	−89.70	−4.63
	2009–2020	−674.59	−36.53
	Net change	−937.75	−44.45
Water bodies	1990–2000	−17.48	−38.72
	2000–2009	7.81	28.24
	2009–2020	−19.17	−54.05
	Net change	−28.83	−63.89
Settlement	1990–2000	557.84	32.47
	2000–2009	455.55	20.02
	2009–2020	480.38	17.59
	Net change	1,493.77	86.95
Others	1990–2000	−292.88	−12.69
	2000–2009	−176.29	−8.75
	2009–2020	−623.31	−33.89
	Net change	−1,092.48	−47.33

Note: −ive sign shows decreasing trend.

Forest land

Between 1990 and 2000, forest area reduced by 4% relative to the start of the study time span (1990) which was approximately 74 km^2. By 2009, this decline continued, and it was seen that the forest area reduced by 11%, compared to what was seen in 2000 (Table 3).

Forest areas increased tremendously between 2009 and 2020 by 56%. This may be due to new plantations as a result of BTTP in the study area. Around 836 km^2 of land was found to be covered with forests. The net change in forest area was recorded as a 32% increase.

Agricultural land

Agricultural land decreased in the first decade by 8%, losing about 173 km^2 of land to increasing settlement. From 2000 to 2009, another 4% decrease was seen as 89 km^2 of land was lost as an agricultural area. The greatest decrease was seen from 2009 to 2020, whereby 674 km^2 was converted into other classes. Overall, a 44% decrease was seen in this class over three decades.

Water bodies

Being a category largely influenced by changing seasons, a 38% decrease was seen in water bodies from 1990 to 2000, followed by a 28% increase from 2000 to 2009. A decrease of 54% was seen from 2009 to 2020. This may be due to less rainfall and increased temperatures in the last decade. A net decrease of 63% in the water bodies was recorded over three decades for this class.

Settlement

The settlement category saw the most expansion over the study period. From 1990 to 2000, 32% (557 km^2) of land was converted into a settlement. Another 20% increase was seen from 2000 to 2009 as 455 km^2 of land changed into developed areas. It increased again from 2009 to 2020 by 17%. Overall, an 86% increase was recorded for this class. Most of the agricultural class and other classes were converted into a settlement over three decades.

Others

From 1990 to 2000, this class decreased by 12%. Another 8% was decreased from 2000 to 2009. Another sharp decrease was seen from 2009 to 2020 by 33%. This decline was probably due to an increase in Settlement and forested land. Overall, the net decrease seen in three decades was 47%.

Accuracy assessment

Using the formulae discussed before, various parameters to evaluate the accuracy of the classification process of all images were computed and tabulated (Table 4). Overall accuracy ranged from 76.8 to 83.5%. The user's accuracy ranged from 81.5 to 88.9% while the producer's accuracy ranged from 72.2 to 80.6%. Figure 4 shows the reference point collected from Google Earth for accuracy assessment.

Table 4 | User accuracy, producer's accuracy and overall accuracy of image classification

Year	User accuracy (%)	Producer's accuracy (%)	Overall accuracy (%)
1990	83.79	77.59	80.42
2000	81.59	76.32	79.64
2009	85.68	72.27	76.83
2020	88.91	80.62	83.50

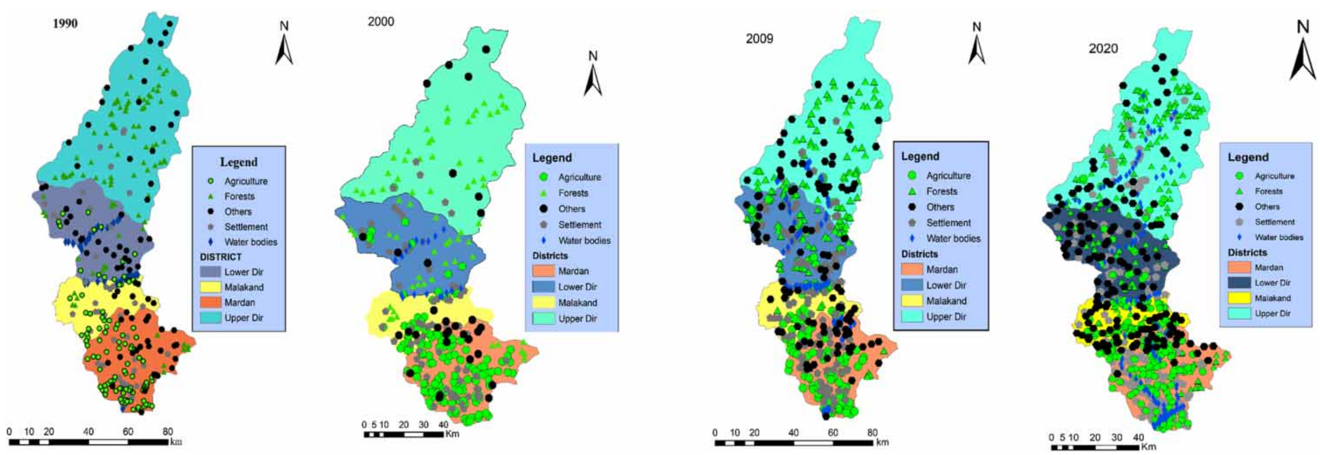


Figure 4 | Accuracy assessment by selecting reference points on AOI using Google Earth.

Carbon stock analysis

In 1990, the forest area calculated was 1,758 km^2. Total wood volume was 1,012 m^3. Total DMB was calculated as 435 tons. Carbon stock for 1990 was recorded to be 309 tons per km^2 and its CO_2 equivalent was 1,134 tons. Forest cover decreased in 2000 (1,684 km^2), hereby decreasing wood volume, which was 969 m^3. DMB was calculated to be 416 tons. The carbon stock was 296 tons per km^2. This also resulted in decreased CO_2 equivalent which was 1,086 tons.

In 2009, forest cover decreased further, standing at 1,486 km^2. The total wood volume was 856 m^3. Total DMB was 368 tons. Carbon stock for the year was calculated to be 261 tons per km^2. The CO_2 equivalent was 958 tons. This implied that land-use change considerably modifies carbon dynamics in the long run (Mannan *et al.* 2018).

Forest cover increased substantially in 2020, with 2,323 km^2 area covered with forests. Wood volume was calculated as 1,338 m^3. Total DMB increased as well, which was 575 tons. Carbon stock increased greatly (408 tons per km^2), resulting in increased CO_2 equivalent, which was 1,498 tons. Table 5 shows the carbon stock assessment for the selected years. In a similar study that focused on mapping deforestation trends in Western Himalayas, Pakistan, extensive deforestation was revealed in the area from 1990 to 2010. Nearly 170,684 ha (1,706.84 km^2) of the forest had been lost, or roughly 0.38% of forest land was degraded every year (Qamer *et al.* 2016).

Annual emissions from forest degradation

Table 6 shows the results for annual emissions from forest degradation. From 1990 to 2000, 1.3 tons of carbon stock was degraded. From 2000 to 2009, 3.4 tons of carbon stock degraded. The negative sign here (Table 6) implies a decrease in carbon stock. From 2009 to 2020, carbon stock increased, which has already been explained above. Between 1990 and 2000, the forest area degraded was 74 km^2, and the resulting annual emissions due to forest degradation were 352 tons. This further increased from 2000 to 2009, when degraded forest area increased to 197 km^2, and the annual emissions due to forest degradation were calculated to be 2,507 tons. From 2009 to 2020, an increase in carbon stocks was identified in the study area. This was probably due to increased plantations in the region.

Uncertainty in the analysis

In some cases, spectral signatures were confused with bare soil (Others) due to mixed pixels. This caused an underestimation of built-up area at some points and created a slight overestimation in the Settlement class at various sites. As rural settlements are not clustered at one point and are mostly found scattered in hilly areas, so it was much more difficult to separate the

Table 5 | Carbon stock assessment for the years 1990, 2000, 2009 and 2020

Year	Forest Area (km^2)	Total wood volume (m^3)	Total dry matter biomass (DMB) (tons)	Carbon stock (tons per km^2)	Carbon dioxide (tons)
1990	1,758.24	1,012.37	435.32	309.28	1,134.03
2000	1,684.22	969.75	416.99	296.26	1,086.29
2009	1,486.85	856.11	368.13	261.54	958.99
2020	2323.79	1,338.00	575.34	408.76	1,498.80

Table 6 | Total annual emissions from forest degradation

Year	Carbon stock	Annual carbon stock degradation (ACSD) (tons)	Emission factor for forest degradation (tons)	Forest area degraded (km^2)	Total annual emissions from forest degradation (tons)
1990	309.28				
1990–2000	296.26	−1.30	4.77	74.02	352.75
2000–2009	261.54	−3.47	12.71	197.37	2,507.90
2009–2020	408.76	14.72			

scattered residential areas from bare soil because of serious spectral mixing. Google Earth was used as a reference in such cases. Large urban settlements concentrated at one point such as Mardan city and some rural residential areas in plain valleys were easier to classify.

CONCLUSIONS

The analysis by using supervised classification in 1990, 2000, 2009 and 2020 suggested that the study area included different topographies (Forest land, Agricultural land, Water bodies, Settlement and Others) which changed over time. Image classification of LULC was carried out by making use of Ground truth points and satellite data for the AOI. The forest area declined by 4% during the period from 1990 to 2000 and 11.7% from 2000 to 2009; however, it increased considerably from 2009 to 2020 by 56%. An increase in the forest cover also resulted in an increased carbon stock from 2009 to 2020. There was a significant change in forest land, agricultural land and settlement due to higher human impact and BTTAP, in the case of an increase in forest land. The results indicated that the tree plantations have proven to be significant in promoting an increase in the carbon stock. If this pattern of new tree plantation continues, along with the protection of existing forests, it may ultimately help combat climate change in the future.

When medium-level spatial resolution data such as provided by Landsat is used, mixed pixels can be a frequent challenge that arises particularly for urban areas that are a diverse mixture of features mainly comprising of vegetation, trees, water, etc. Better quality images, if available, can result in a better classification process.

The findings of this analysis act as a base for studies in forest LULC change in the region and will help policymakers to improve policies to efficiently manage the land resources, i.e. reserving more land for forests and discouraging deforestation all over the country.

The study provides proof that the BTT plantation drive has been successful in increasing carbon stocks to an extent. Further plantations need to be done in the country to combat climate change and achieve carbon sequestration, as forests are the main source our country can currently rely on for this purpose. Management practices and precautionary measures should be taken to minimize the disastrous effects of human activities on forests and soil structure. Land misuse should be minimized, and restoration processes must be carried out for better crop production and to avoid/minimize forest degradation and soil erosion (Fahad *et al.* 2020).

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Ali, S., Ali, W., Khan, S., Khan, A., Rahman, Z. U. & Iqbal, A. 2017 Forest cover change and carbon stock assessment in Swat valley using remote sensing and geographical information systems. *Pure and Applied Biology (PAB)* **6** (3), 850–856.

Ali, A., Ashraf, M. I., Gulzar, S. & Akmal, M. 2020 Estimation of forest carbon stocks in temperate and subtropical mountain systems of Pakistan: implications for REDD+ and climate change mitigation. *Environmental Monitoring and Assessment* **192** (3), 1–13.

AR-AMS000X, C.E.B., Simplified baseline and monitoring methodologies for small-scale afforestation and reforestation project activities under the CDM implemented on settlements. (UNFCCC).

Butt, A., Shabbir, R., Ahmad, S. S., Aziz, N., Nawaz, M. & Shah, M. T. A. 2015 Land cover classification and change detection analysis of Rawal watershed using remote sensing data. *Journal of Biodiversity and Environmental Science* **6** (1), 236–248.

Chang, Y., Hou, K., Li, X., Zhang, Y. & Chen, P. 2018 Review of land use and land cover change research progress. In *IOP Conference Series: Earth and Environmental Science*. (Vol. 113, No. 1, p. 012087).

Fahad, S., Hasanuzzaman, M., Alam, M., Ullah, H., Saeed, M., Ali Khan, I. & Adnan, M. 2020 *Environment, Climate, Plant and Vegetation Growth*. Springer Nature Switzerland AG.

Fahad, S., Sönmez, O., Turan, V., Adnan, M., Saud, S., Wu, C. & Wang, D. 2021a *Sustainable Soil and Land Management and Climate Change*, 1st edn. Footprints of climate variability on plant diversity. CRC Press, Boca Raton.

Fahad, S., Sönmez, O., Saud, S., Wang, D., Wu, C., Adnan, M. & Arif, M. (eds) 2021b *Engineering Tolerance in Crop Plants Against Abiotic Stress, 1st edn. Footprints of Climate Variability on Plant Diversity*. CRC Press, Boca Raton, CA.

Fahad, S., Adnan, M., Saud, S. & Nie, L. 2022 *Climate Change and Ecosystems: Challenges to Sustainable Development*, 1st edn. Footprints of climate variability on plant diversity. CRC Press, Boca Raton.

FAO Global Forest Resources Assessment (FRA) 2017 Available from: https://www.fao.org/forest-resources-assessment/en/. Accessed 9 January 2022.

Fernandes, M. M., de Moura Fernandes, M. R., Garcia, J. R., Matricardi, E. A. T., de Souza Lima, A. H., de Araújo Filho, R. N., Gomes Filho, R. R., Piscoya, V. C., Piscoya, T. O. F. & Cunha Filho, M. 2021 Land use and land cover changes and carbon stock valuation in the São Francisco river basin, Brazil. *Environmental Challenges* **5**, 100247.

Hassan, Z., Shabbir, R., Ahmad, S. S., Malik, A. H., Aziz, N., Butt, A. & Erum, S. 2016 Dynamics of land use and land cover change (LULCC) using geospatial techniques: a case study of Islamabad Pakistan. *SpringerPlus* **5** (1), 1–11.

Hossen, S., Hossain, M. K. & Uddin, M. F. 2019 Land cover and land use change detection by using remote sensing and GIS in Himchari National Park (HNP), Cox's Bazar, Bangladesh. *Journal of Science, Technology and Environment Informatics* **7** (02), 544–554.

Hussain, S., Mubeen, M., Ahmad, A., Akram, W., Hammad, H. M., Ali, M., Masood, N., Amin, A., Farid, H. U., Sultana, S. R. & Fahad, S. 2019 Using GIS tools to detect the land use/land cover changes during forty years in Lodhran district of Pakistan. *Environmental Science and Pollution Research* **27**, 1–17.

Iqbal, M. F. & Khan, I. A. 2014 Spatiotemporal land use land cover change analysis and erosion risk mapping of Azad Jammu and Kashmir, Pakistan. *The Egyptian Journal of Remote Sensing and Space Science* **17** (2), 209–229.

Kahlon, T. M. & Talal, S. A. 2020 Climate security of Pakistan: dissecting the carbon dilemma. *Margalla Papers* **1**, 96–109.

Kamal, A., Yingjie, M. & Ali, A. 2019 Significance of billion tree tsunami afforestation project and legal developments in forest sector of Pakistan. *International Journal of Law and Society* **1**, 157.

Khan, I. A., Khan, W. R., Ali, A. & Nazre, M. 2021 Assessment of above-ground biomass in Pakistan forest ecosystem's carbon pool: a review. *Forests* **12** (5), 586.

Mannan, A., Feng, Z., Ahmad, A., Liu, J., Saeed, S. & Mukete, B. 2018 Carbon dynamic shifts with land use change in Margallah Hills National Park, Islamabad (Pakistan) from 1990 to 2017. *Applied Ecology and Environmental Research* **16** (3), 3197–3214.

PFI (Pakistan Forest Institute) 2021 *Forest Reference Emission Level of Khyber Pakhtunkhwa, Pakistan*. Forest Institute Peshawar.

Qamer, F. M., Shehzad, K., Abbas, S., Murthy, M. S. R., Xi, C., Gilani, H. & Bajracharya, B. 2016 Mapping deforestation and forest degradation patterns in western Himalaya, Pakistan. *Remote Sensing* **8** (5), 385.

Raziq, A., Xu, A., Li, Y. & Zhao, Q. 2016 Monitoring of land use/land cover changes and urban sprawl in Peshawar City in Khyber Pakhtunkhwa: an application of geo-information techniques using of multi-temporal satellite data. *Journal of Remote Sensing and GIS* **5**, 174.

Sun, W. & Liu, X. 2020 Review on carbon storage estimation of forest ecosystem and applications in China. *Forest Ecosystems* **7** (1), 1–14.

UN Global Forest Goals Report. 2021. Available from: www.un.org. (accessed 11 January 2022).

First received 24 August 2022; accepted in revised form 11 January 2023. Available online 27 January 2023