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ASSESSING FOREST DYNAMICS OF AYUBIA NATIONAL PARK: LINKING CLIMATIC VARIABILITY AND LAND USE LAND COVER CHANGE USING GEOSPATIAL TECHNIQUES

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Abstract
The dynamics of forests are essential to comprehend the resilience of the ecosystem to climate change and human anthropogenic demands. This study assessed the forest cover changes in Ayubia National Park (ANP), Pakistan, over a 30-year period (1994–2024), using Landsat satellite imagery and geospatial techniques. To verify accuracy and image classification under supervision they were classified at four time points (1994, 2004, 2014, 2024), and were supported by climatic data (temperature and precipitation).The Results indicate that the forest cover expanded by 318 ha (13.04%), grassland, and barren lands decreased by 136 ha (29.25) and 182 ha (38.89) respectively, that is, between 1994 and 2024, implying a successful natural regeneration and conservation initiative like Billion Tree Afforestation Project. Despite a rise in mean annual temperature (+1.11 °C) and a reduction in mean annual precipitation (−18.67 mm), Over the study period, forest expansion persisted, highlighting the resilience of temperate ecosystems. The integration of remote sensing and climate data underscores the role of climate- smart forestry and sustainable land use planning in ensuring biodiversity conservation and ecosystem stability in Pakistan's protected areas.

INTRODUCTION

Climate change and transformation in land use are two of the most urgent forces that are recreating world forest ecologies. The forests have been found to be reservoirs of carbon, which are important in biodiversity; they occupy approximately a third of all land on the earth, 31 percent; moreover, they are exposed to deforestation, degradation, and climatic pressure (FAO, 2020) yet one out of every three forests has been lost since the end of the ice age more than 10,000 years ago. It has been destroyed to provide fuelwood, agriculture, and livestock rearing on two billion hectares or two times the size of the United States. (Ritchie, 2021). Between 2001 and 2024 Pakistan is estimated to have lost 9.5 thousand hectares of tree cover, which was 1.0% of the 2000 tree cover area, and 2.8 Mt of CO_2 emissions. . This does not account for gains in tree cover over the same period. (Global Forest Watch, n.d.)Ayubia National Park (ANP) is an ecologically important protected area that is found in the wet temperate forests of the Western Himalayas, which has hydrological, biodiversity, and storage of carbon. It is, however, vulnerable to the anthropogenic pressure, climatic variations and changing land use patterns.On 5 June 2015, the Government of Khyber Pakthunkhwa in cooperation with IUCN (International Union to save nature) initiated its own Billion-tree campaign as part of the international Bonn Challenge. (IUCN, 2015). It had the aim of raising the total provincial forest cover by 17% to 22% percent. (Kharl & Xie, 2017). The BTAP (Billion Tree Afforestation Project) was completed in three phases: phase I (2014-15), phase II (2015-16) and phase III (2016-17). (Ullah et al., 2024). The Changes in Forest Cover around this time line are prominent in this research using Geospatial techniques. Advances in Geographic Information Systems (GIS) and remote sensing have enabled detailed, long-term monitoring of forest dynamics. Within this context, this study investigated forest dynamics of ANP from 1994 to 2024, linking it with land use/land cover (LULC) change and climatic variability, using Landsat imagery and geospatial techniques. The results offer information about the strength of the Himalayan temperate ecosystems and how they can be managed in the conditions of climate change.

Objectives

I. To quantify and visualize forest cover changes in Ayubia National Park for the years 1994, 2004, 2014, and 2024.

II. To assess how climate variability (temperature and precipitation trends) has influenced forest dynamics.

III. To explore how land use/land cover change have contributed to forest cover dynamics.

Study Area

Ayubia National Park (ANP) is situated in Abbottabad District, Khyber Pakhtunkhwa, Pakistan, covering 3,312 hectares of the Western Himalayan eco-region. The park lies between 34°1.8'– 34°3.8' N latitude and 73°22.8'–73°27.1' E longitude, with elevations ranging from 2,300 to 3,000 meters. ANP harbors diverse coniferous and broad-leaved species, including *Pinus wallichiana*, *Abies pindrow*, and *Quercus dilatata*, and supports important fauna such as leopards, rhesus monkeys, and numerous avian species. Its climatic temperature is humid temperate with the yearly mean maximum temperature of 19.2 o C and 1,412 mm (Junaid et al., 2010).

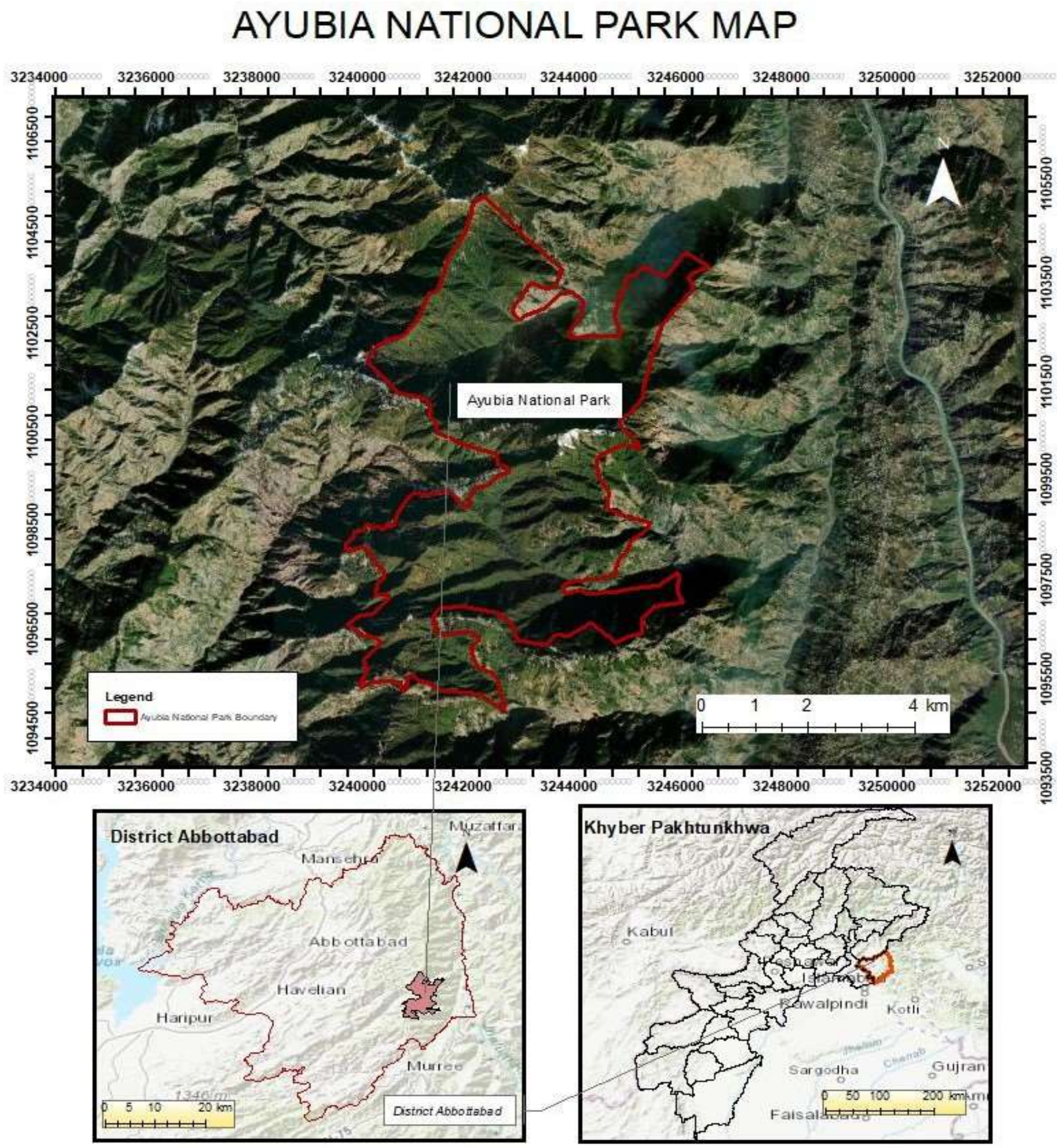

Figure 1 : Study Area Map

Materials and Methods

Landsat satellite imagery (TM, ETM+, and OLI) for the years 1994, 2004, 2014, and 2024 was obtained from the United States Geological Survey (USGS) archives, selected with minimal cloud cover (0–10%) to ensure data reliability. Image preprocessing, including atmospheric and geometric corrections, was carried out prior to analysis. Supervised classification was conducted using the Maximum Likelihood Classification (MLC) algorithm, which is widely recognized for its robustness in LULC studies. (Lemma et al., 2021. Three major land cover categories, forest, grassland, and barren land, were delineated based on spectral signatures derived from training samples The classification Accuracy was determined using a confusion matrix method and the overall accuracy and the Kappa coefficient was calculated based on 130 random points assessed using Google Earth Pro. The

KNMI (Royal Netherlands Meteorological Institute) was used to find climatic variables, namely, temperature and precipitation. Climate Explorer and Climate Engine websites were employed to determine long-term variability across the same three-decades.

Forest dynamics were further quantified using the Annual Rate of Change (ARC) formula to capture both net change and temporal trends. Statistical analyses, including Spearman correlation and Chi-square tests, were performed using IBM SPSS Statistics 26.

Integrating satellite-based LULC analysis with climate data provided a comprehensive framework to evaluate the combined influence of land use practices and climate variability on forest cover dynamics in Ayubia National Park.

Results and Discussion

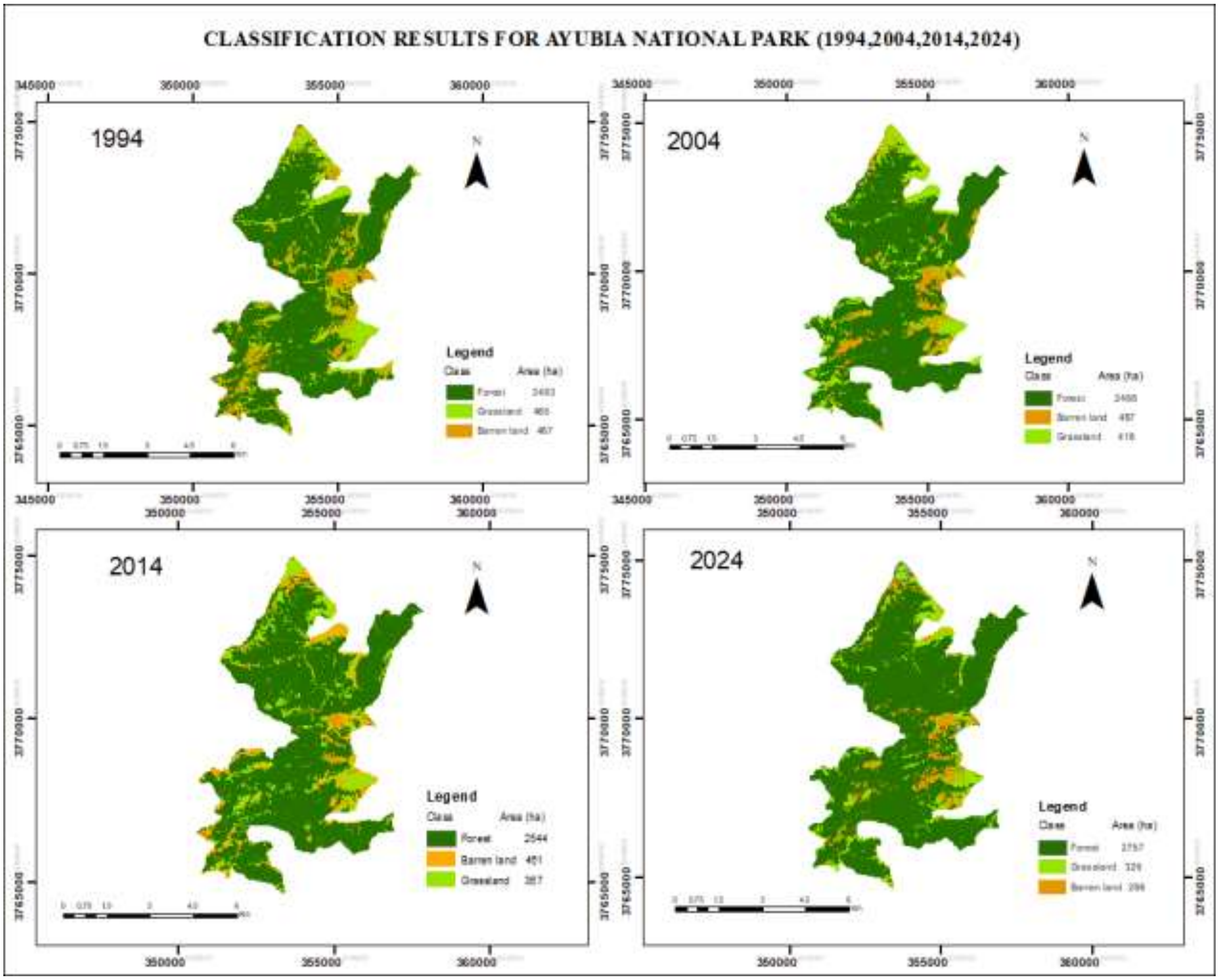

Figure 2 : Classification Results for Ayubia National Park (1994, 2004, 2014, 2024)

FOREST COVER DYNAMICS OF AYUBIA NATIONAL PARK (1994-2024)

Table 1: Table showing Forest Change Dynamics of Ayubia National Park (1994-2024)

Period	Forest Cover Change (ha)	Forest Cover Change (%)	Forest ARC (%/yr)	Non-Forest Change (ha)	Non-Forest Change (%)	Non-Forest ARC (%/yr)
1994-2004	49.07	2.01	0.2	-49.07	-5.26	-0.53
2004-2014	56	2.25	0.23	-56	-6.33	-0.63
2014-2024	213	8.37	0.84	-213	-25.72	-2.57
1994-2024	318.07	13.04	0.43	-318.07	-34.09	-1.136

The results of the classification obtained in figure 2 and table 1 indicated that there was an incremental difference in the forest cover at the period the study was carried out. Forest covered 2,438 ha (72.3%), and increased to 2,757 ha (81.8%), representing a net increase of 318 ha (+13.04%). The Annual Rate of Change (ARC) rose from +5.0 ha/year (1994–2004) to +21.3 ha/year (2014–2024), indicating an accelerated pace of forest recovery in the last decade. The classification achieved an Overall Accuracy ranging from 86% to 90%, with Kappa coefficients between 0.77 and 0.85, indicating strong agreement and reliability of the classified maps. A

Spearman rank correlation confirmed that this increase was statistically significant ($\rho=1.0$, $p<0.001$), providing strong evidence of a consistent upward trend in forest cover over the 30- year period. These findings demonstrate substantial forest recovery, probably by regeneration and massive interventions consisting of the Billion Tree Afforestation Project (BTAP).

FOREST COVER DYNAMICS LINKED WITH LULC CHANGE (1994-2024)

Table 2: Table Showing Forest Change Dynamics Linked with LULC Change (1994-2024)

Time Period	LULC class	Total Area (ha)		Net Change in Area (1994-2004)	
		1994	2004	Change in Hectares	Percentage Change
1994-2004	Forest	2438.93	2488	49.07	2.012
	Grassland	465.39	416.5	-48.89	-10.505
	Barren Land	467.8	467.5	-0.3	-0.064
	LULC class	Total Area (ha)		Net Change in Area (1994-2004)	
		2004	2014	Change in Hectares	Percentage Change
2004-2014	Forest	2488	2544	56	2.25
	Grassland	416.5	367	-49.5	-11.88
	Barren Land	467.5	461	-6.5	-1.39
	LULC class	Total Area (ha)		Net Change in Area (1994-2004)	
		2014	2024	Change in Hectares	Percentage Change
2014-2024	Forest	2544	2757	213	8.37
	Grassland	367	329	-38	-10.35
	Barren Land	461	286	-175	-37.96
	LULC class	Total Area (ha)		Net Change in Area (1994-2004)	
		1994	2024	Change in Hectares	Percentage Change
1994-2024	Forest	2438.93	2757	318.07	13.04
	Grassland	465.39	329	-136.39	-29.31
	Barren Land	467.8	286	-181.8	-38.86

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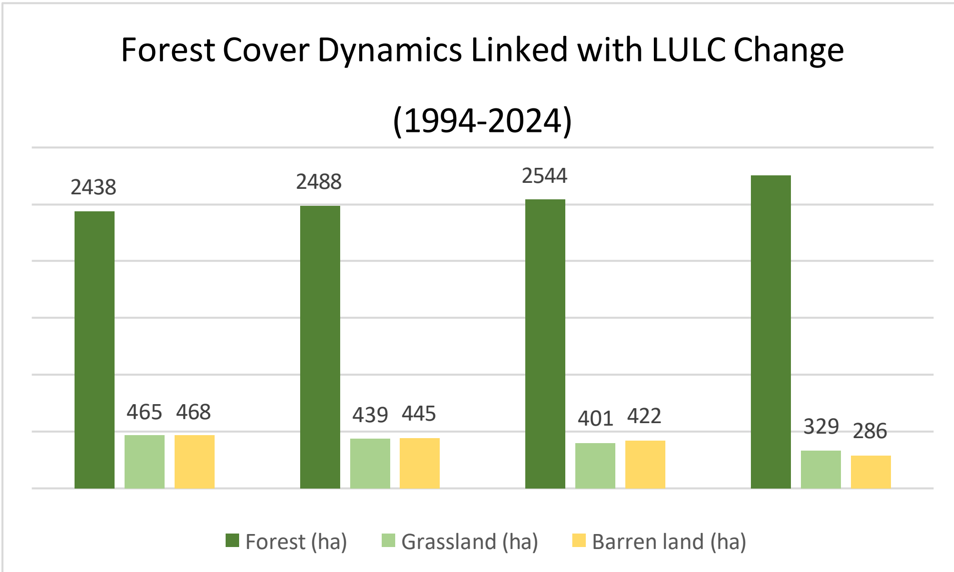

Figure 3: Graph Showing Forest Cover Dynamics Linked with LULC Change (1994-2024)

There was a significant change in land cover composition. Table 2, figure 3, indicates that Grassland went down to 329 ha (9.8%) and 468 ha (13.9%) respectively; Barren land went down to 13.89 -286 ha). These shifts in LULC composition were statistically significant as demonstrated by a Chi-square test (98.2, p<0.0001), which proved that the amount of forest increase was coupled with significant losses of other land classes.

FOREST COVER DYNAMICS LINKED WITH CLIMATIC VARIABILITY (TEMPERATURE AND PRECIPITATION), 1994–2024

Table 3: Table Showing Forest Change Dynamics Linked with Climatic Variability (Temperature And Precipitation (1994-2024))

Time Period	Forest Area (ha)		Forest Cover		Temperature				Precipitation			
			Change				Change				Change	
1994-2004	1994	2004	Hectares	Percent	1994	2004	Celsius (°C)	Percent	1994	2004	mm	Percent
	2438.93	2488	49.07	2.01	16.83	16.87	0.04	0.25	96.75	74.42	-22.33	-23.08
	Forest Dynamics		Forest Cover		Temperature				Precipitation			
			Change				Change				Change	
2004-2014	2004	2014	Hectares	Percent	2004	2014	Celsius (°C)	Percent	2004	2014	mm	Percent
	2488	2544	56	2.25	16.87	17.36	0.49	2.91	74.42	89.58	15.16	20.37
	Forest Dynamics		Forest Cover		Temperature				Precipitation			
			Change				Change				Change	
2014-2024	2014	2024	Hectares	Percent	2014	2024	Celsius (°C)	Percent	2014	2024	mm	Percent
	2544	2757	213	8.37	17.36	17.94	0.57	3.31	89.58	78.08	-11.50	-12.84
	Forest Dynamics		Forest Cover		Temperature				Precipitation			
			Change				Change				Change	
1994-2024	1994	2024	Hectares	Percent	1994	2024	Celsius (°C)	Percent	1994	2024	mm	Percent
	2438.93	2757	318.07	13.04	16.83	17.94	1.11	6.59	96.75	78.08	-18.67	-19.30

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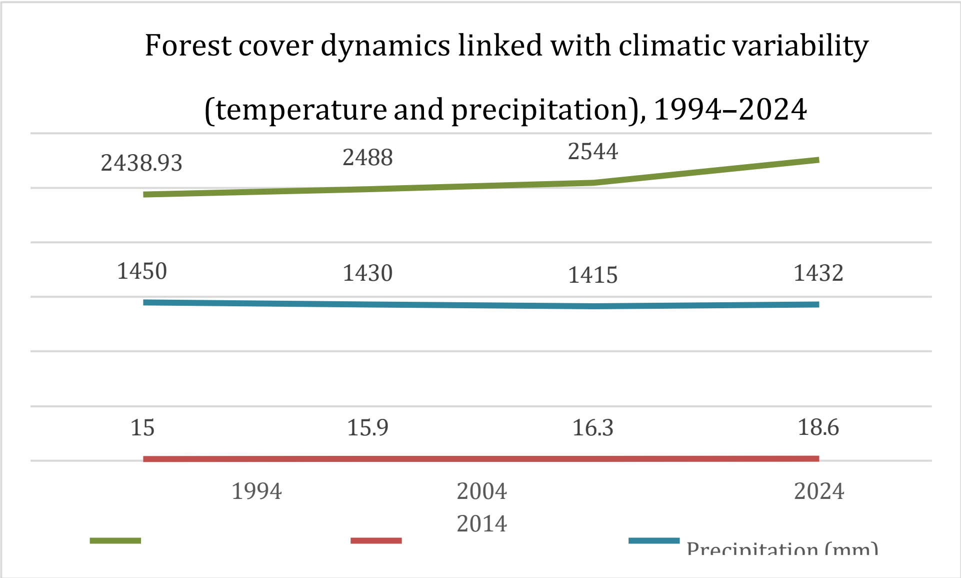

Figure 4: Graph Showing Forest cover dynamics linked with climatic variability (temperature and precipitation), 1994– 2024

Climatic analysis showed an increase in mean annual temperature by +1.11 °C and a decline in mean annual precipitation by 18.67 mm over three decades. Despite these changes, forest cover expanded, suggesting resilience of moist temperate ecosystems under moderate climate stress. However, the reduction in grassland and barren land points to significant land cover transformation, reinforcing the need for continuous monitoring. The results align with regional studies reporting similar LULC-driven dynamics in the Western Himalayas. (Aftab et al., 2024; Ansari et al., 2022)

Correlation analysis between forest cover and climatic variables indicated that there was positive correlation with mean annual temperature (r=0.90, p=0.095) but because of the few observations, the relationship was not statistically significant. On the contrary, there was a weak negative relationship between forest cover and precipitation (r=−0.29, p=0.71). These results indicate that the increase of forests in Ayubia National Park could be more consistent with gradual warming rather than the fluctuation of cloudy precipitations, but it is necessary to be careful about the interpretation of these findings.

This paper underlines the importance of geospatial surveillance in the trapping of finer-scale processes and the importance of conservation management and climate-sensitive forestry management practices regarding forest resilience within a fortified region.

Conclusion

This study demonstrates that Ayubia National Park has experienced a consistent increase in forest cover (+318 ha) over three decades, despite rising temperatures and declining rainfall.

The findings underscore the resilience of temperate Himalayan ecosystems and the positive impact of conservation initiatives such as BTAP. Integrating geospatial monitoring with climate-smart forestry is essential for ensuring long-term ecosystem stability, biodiversity conservation, and sustainable land management in Pakistan's protected areas.

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