

Spatiotemporal Analysis of Forest Fire Occurrence and NDVI Based Vegetation Recovery in the Terai Arc Landscape (Tal), Nepal

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Abstract: Forest fires are recurrent seasonal disturbances in Nepal's lowland forests and strongly influence vegetation condition and recovery. This study assesses fire occurrence and NDVI-based vegetation recovery across the Terai Arc Landscape (TAL) from 2014–2023 using satellite data. Burned area was analysed for protected areas (PAs) and non-protected areas (NPAs), while MODIS NDVI time series were used to evaluate vegetation response and post-fire recovery. Results show strong spatial and temporal variability in fire activity, with April as the dominant fire month and forest-rich protected areas experiencing extensive burning. Annual burned area and mean NDVI showed a strong inverse relationship ($r = -0.87$). Single-fire trajectories showed marked NDVI declines during fire years followed by gradual recovery, but recovery rates differed substantially among protected areas. Banke and Bardiya showed comparatively faster recovery, whereas Chitwan and Shuklaphanta required longer periods. The findings demonstrate that burned-area extent alone does not explain vegetation recovery and highlight the value of integrated fire and NDVI monitoring for forest management.

Keywords: NDV, Forest fire, Terai arc landscape, Vegetation recovery, MODIS.

This study integrates burned-area mapping and NDVI time series to quantify fire patterns, vegetation dynamics and recovery. Objectives were to assess spatial and temporal fire occurrence, characterize NDVI variability, evaluate fire-related vegetation response, and derive T50, T80 and T90 recovery times.

Methodology

Forest areas were identified using the National Land Cover Monitoring System. MODIS MCD64A1 BurnDate and MOD13A1 NDVI (500 m) data were processed in Google Earth Engine to analyze burned areas, vegetation conditions, and fire recurrence from 2014–2023. Protected and non-protected areas were compared. Recovery analysis focused on isolated fire events in 2016, 2018, 2019, 2020, and 2021, excluding pixels burned within two preceding and three following years. Vegetation recovery was assessed using pre-fire NDVI, with T50, T80, and T90 indicating recovery to 50%, 80%, and 90% of baseline greenness.

Results and discussion

Fire occurrence was highly recurrent across the TAL. Most burned pixels experienced one to two events, while localized clusters experienced three to six or ≥ 7 burns, indicating persistent fire pressure. Forest coverage exceeded 94% in Banke and Bardiya, compared with 90.89% in Chitwan, 84.96% in Parsa and 79.96% in Shuklaphanta; KCA had only 5.84% forest cover. Banke reached 84.4% burned area in 2016 and Bardiya 67.2%; Chitwan generally remained below 15%. KCA recorded no detected fire during 2014–2023.

Fire activity was strongly seasonal. Average burned area rose from 301.29 km² in March to 1,033.84 km² in April, then fell to 170.87 km² in May and 43.36 km² in June, with negligible burning during July–December. Annual burned area was highest in 2016 (1,536.74 km²), followed by 2021 (1,218.83 km²) and 2019 (1,198.22 km²); 2015, 2018 and 2020 were comparatively low-fire years

Introduction

The TAL is a fire-prone subtropical landscape where seasonal dryness, fuel continuity, vegetation structure and human activities control fire occurrence. Existing studies have largely emphasized fire incidence and susceptibility, while long-term links between fire history and vegetation recovery remain less constrained, particularly where repeated fires mask individual-event responses.

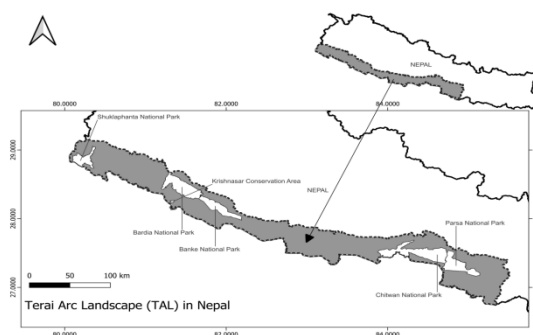


Figure 1. Study area and protected-area units within the Nepalese TAL.).

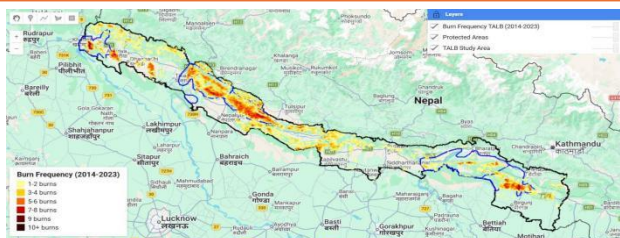


Figure 2. Recurrent fire frequency across the TAL, 2014–2023.

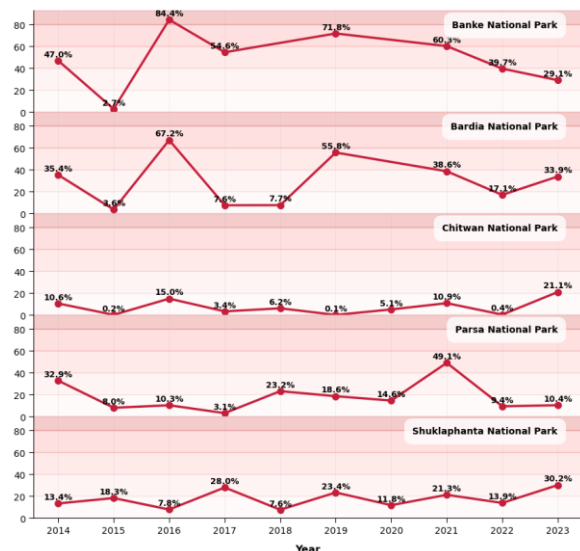


Figure 5. Annual burned-area percentage within individual protected areas, 2014–2023.

The protected-area comparison indicates that management status alone does not determine fire impact. Higher burned-area proportions in Banke and Bardiya are consistent with extensive, connected forest and grassland fuel beds, whereas fragmented landscapes outside protected areas can limit fire spread through roads, settlements and agricultural clearings. The absence of detected fire in KCA further suggests that fuel availability and forest continuity are important controls on landscape fire occurrence.

NDVI showed pronounced seasonality: median NDVI declined to 0.53 in April and increased during the monsoon, reaching about 0.87 in September. The annual series showed a modest positive long-term trend despite interannual variability. Annual burned area and mean NDVI had a strong inverse association (Pearson $r = -0.87$), indicating lower vegetation greenness in years with greater fire extent.

Post-fire trajectories showed rapid declines followed by gradual recovery. Banke National Park after the 2016 fire reached T50, T80 and T90 in approximately 1.3, 2.1 and 2.4 years. Mean recovery in Banke was 1.37, 2.20 and 2.47 years for T50, T80 and T90, respectively; Bardiya and Parsa had T90 values of about 2.75 and 2.77 years. Chitwan and Shuklaphanta exceeded 3.6 years for T90, while the non-protected area required approximately 2.01, 3.22 and 3.62 years for T50, T80 and T90. Thus, recovery time was not directly proportional to burned-area extent and likely reflected vegetation structure, moisture availability and landscape conditions.

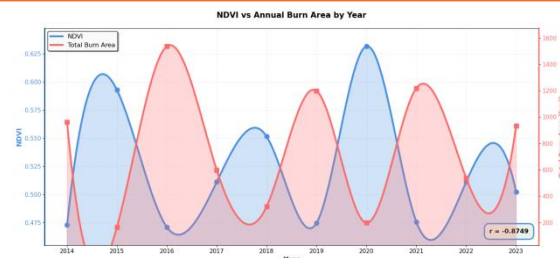


Figure 6. NDVI distribution and recovery trajectory for Banke National Park following the 2016 fire event.

The recovery metrics. The fire year showed a clear shift toward lower NDVI relative to the 2015 baseline, followed by progressive convergence toward the pre-fire distribution. The fitted recovery trajectory had a positive slope of 0.0082 with $R^2 = 0.498$, while the recovery thresholds indicated approximately 1.3 years for T50, 2.1 years for T80 and 2.4 years for T90. The relatively rapid recovery in Banke is consistent with the thesis interpretation that fire-adapted grassland and mixed forest–grassland systems can regenerate rapidly following seasonal burning. In contrast, longer recovery in Chitwan and Shuklaphanta may reflect differences in canopy structure, vegetation composition and moisture availability.

Conclusion

The TAL experiences peak forest fires in April, with burned areas varying annually. Forest-rich protected areas experienced greater burning, while KCA recorded none. The negative burned-area–NDVI relationship indicates vegetation stress, although positive NDVI trends suggest recovery. Recovery periods varied across areas, highlighting the importance of integrated fire and vegetation monitoring for effective forest management and restoration.

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