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Title: Role of Reforestation in Reducing Landslide Risk in Galyat, Pakistan: A Remote Sensing and GIS-Based Temporal Analysis (2011–2025)

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Role of Reforestation in Reducing Landslide Risk in Galyat, Pakistan: A Remote Sensing and GIS-Based Temporal Analysis (2011–2025)

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Abstract

Landslides are among the most common natural hazards in mountainous regions, often resulting in loss of life, damage to infrastructure, and destruction of agricultural land. Forest cover plays an important role in slope stabilization, soil erosion control, and landslide-risk reduction; however, empirical evidence regarding this relationship in specific mountainous landscapes remains limited. This study investigates the relationship between vegetation change and landslide occurrence in the Galyat region of Pakistan from 2011 to 2025. Remote sensing and Geographic Information System (GIS) techniques were used to derive the Normalized Difference Vegetation Index (NDVI) from Landsat 5, 8, and 9 imagery for 2011, 2017, and 2025. These data were compared with a landslide inventory digitised from high-resolution Google Earth Pro imagery for the corresponding years. Mean NDVI decreased from 0.355 in 2011 to 0.181 in 2017 before increasing slightly to 0.197 in 2025. Landslide frequency decreased from 125 events in 2011 to 52 in 2017 and then increased to 76 in 2025. In contrast, total landslide-affected area increased from 55.78 ha in 2011 to 93.26 ha in 2017 and 98.38 ha in 2025. These contrasting trends indicate that vegetation condition alone does not explain changes in landslide activity in Galyat. Reforestation should therefore be considered alongside rainfall, slope characteristics, geology, and land-use change within an integrated landslide-risk reduction strategy. The study also demonstrates the usefulness of remote sensing and GIS for monitoring vegetation and landslide dynamics in data-scarce mountainous regions.

Keywords: Reforestation; Landslide risk; NDVI; Remote sensing; GIS

1. Introduction

Landslides are among the most widespread and damaging natural hazards in mountainous regions, where they can cause loss of life, destruction of infrastructure, degradation of agricultural land, and disruption of local communities. Their occurrence is controlled by the interaction of several environmental and anthropogenic factors, including rainfall intensity,

slope gradient, geological conditions, soil characteristics, vegetation cover, drainage, road construction, and land-use change (Glade et al., 2005; Quevedo et al., 2023). Mountainous areas with steep slopes, fragile geological formations, and intense seasonal rainfall are particularly susceptible to slope failure. Changes in vegetation and land cover can further modify these conditions and influence the stability of slopes.

Forest vegetation plays an important role in maintaining slope stability. Tree roots reinforce the soil and can increase its resistance to failure, while vegetation cover protects the soil surface from erosion. Forest canopies intercept rainfall and reduce direct raindrop impact, while vegetation can also influence infiltration and surface runoff. Consequently, removal or degradation of forest cover may reduce soil cohesion, expose the ground surface to erosion, and increase slope instability. Reforestation is therefore widely recognised as a nature-based approach that may contribute to landslide-risk reduction while simultaneously supporting biodiversity conservation, watershed protection, carbon sequestration, and ecosystem restoration (Sidle & Bogaard, 2016).

However, the relationship between forests and landslides is complex. Increased vegetation cover does not necessarily result in an immediate or uniform reduction in landslide susceptibility. The effectiveness of forest vegetation depends on factors such as forest type, age, species composition, root development, slope conditions, and forest management. Newly planted forests may initially provide limited slope reinforcement because their root systems require time to develop. Similarly, recently harvested or disturbed forest areas may temporarily become more susceptible to erosion and slope failure due to exposed soil and reduced root reinforcement (Griffiths et al., 2020; Canavesi & Alvalá, 2012; Zhang et al., 2022). Therefore, vegetation should be considered as one of several interacting factors influencing landslide occurrence.

Previous research from different geographical regions demonstrates this complexity. Griffiths et al. (2020), in their study of Tasman, New Zealand, reported substantially greater shallow-landslide occurrence on pasture slopes than under mature forest cover. Mature natural and plantation forests provided considerable protection, whereas young plantations offered less protection until their root systems became sufficiently established. Similarly, Canavesi and Alvalá (2012), studying reforested areas in São Paulo, Brazil, found that preserved forests and mature Eucalyptus plantations were generally associated with lower landslide susceptibility, while newly planted or recently harvested areas were more vulnerable because

of exposed soil and limited vegetation development. Research from China has also demonstrated that forest type, origin, age, and tree species can influence landslide susceptibility, indicating that the protective role of forests varies considerably among vegetation conditions (Zhang et al., 2022).

Not all increases in forest cover, however, necessarily reduce environmental hazards. Salbitano et al. (2021), examining long-term forest changes in Cinque Terre National Park, Italy, showed that forest expansion following the abandonment of agricultural terraces was associated with changing hydrogeological and fire risks. Their findings demonstrate that vegetation expansion must be interpreted in relation to land management, terrain, and previous land use rather than being considered independently. Quevedo et al. (2023) similarly concluded that land use and land cover represent important conditioning factors in landslide susceptibility, but their effects interact with rainfall, topography, geology, soil properties, and human activities. Collectively, these studies suggest that reforestation may contribute to slope stability, but its influence cannot be evaluated independently from other landslide-controlling factors.

Pakistan provides an important setting for examining this relationship because large areas of its northern mountainous regions experience both forest degradation and landslide hazards. In response to environmental degradation, Pakistan has implemented major forest-restoration initiatives. The Billion Tree Tsunami Afforestation Project was launched in Khyber Pakhtunkhwa in 2014 under the provincial Green Growth Initiative and focused on restoring degraded forests, increasing tree cover, conserving biodiversity, and improving ecosystem services. This initiative was followed by the Ten Billion Tree Tsunami Programme, launched nationally in 2018 to expand afforestation, regeneration, ecosystem restoration, climate-change adaptation, and disaster-risk reduction activities across Pakistan (Government of Khyber Pakhtunkhwa, 2018; Ministry of Climate Change, 2018).

The Galyat region of Abbottabad District, Khyber Pakhtunkhwa, provides a particularly relevant case for examining vegetation and landslide dynamics. Located within the western Himalayas, Galyat is characterised by steep mountainous terrain, high rainfall, fragile geological conditions, and extensive forest cover. At the same time, forest degradation, infrastructure development, urban expansion, overgrazing, and other forms of human disturbance have affected parts of the landscape. These environmental and anthropogenic conditions contribute to landslide susceptibility and make effective slope and forest

management important for the region. Previous research has examined slope-failure potential in Galyat, but empirical temporal evidence specifically comparing vegetation change with landslide occurrence remains limited (Ahmed & Akram, 2018).

Remote sensing and Geographic Information System (GIS) techniques provide an effective means of investigating such changes across large and difficult-to-access mountainous landscapes. Satellite-derived vegetation indices, particularly the Normalized Difference Vegetation Index (NDVI), allow vegetation condition and greenness to be assessed across different time periods. When combined with spatial landslide inventories, these data can be used to compare temporal patterns in vegetation and landslide activity. Such an approach is particularly valuable in areas where long-term field observations and detailed environmental datasets are limited.

Against this background, the present study investigates the role of reforestation in reducing landslide risk in Galyat by examining changes in vegetation condition and landslide occurrence between 2011 and 2025. Landsat-derived NDVI is used as an indicator of vegetation condition, while landslide occurrences are assessed using a GIS-based inventory developed from Google Earth Pro imagery. The main objective of the study is to analyse the role of reforestation in reducing landslide risk in the Galyat region from 2011 to 2025. Specifically, the study addresses how landslide frequency and affected area changed during the study period, how vegetation cover changed based on NDVI analysis, and what relationship exists between changes in vegetation cover and landslide occurrence. By addressing these questions, the study seeks to contribute evidence relevant to forest management, environmental planning, and integrated landslide-risk reduction in the mountainous regions of Pakistan.

2. Study Area

The Galyat region is located in Abbottabad District, Khyber Pakhtunkhwa, Pakistan, within the western Himalayas. The study area extends approximately between 34.1°–34.3° N latitude and 73.2°–73.4° E longitude, with elevations ranging from about 1,500 m in the valleys to more than 3,000 m above sea level. Major peaks include Mukshpuri (3,024 m) and Miranjani (2,992 m). The region is characterised by rugged mountainous terrain, steep slopes, and narrow valleys, which contribute to its susceptibility to slope instability and landslide occurrence (Ahmed & Akram, 2018).

The region experiences a humid subtropical highland climate, with heavy monsoon rainfall occurring mainly from July to September and snowfall during the winter months from December to February. Average annual rainfall exceeds 1,500 mm. The combination of intense seasonal rainfall, steep slopes, and fragile geological formations creates favourable conditions for landslide occurrence, particularly where natural vegetation has been removed or slopes have been disturbed.

Galyat supports extensive forest ecosystems dominated by chir pine (*Pinus roxburghii*), blue pine (*Pinus wallichiana*), oak (*Quercus incana*), and deodar (*Cedrus deodara*). These forests contribute to soil conservation, groundwater recharge, biodiversity conservation, and slope stabilisation. However, forest degradation and fragmentation associated with illegal logging, overgrazing, infrastructure development, and urban expansion have affected parts of the region. Reforestation and forest-conservation initiatives have therefore become important components of environmental management in Galyat (Food and Agriculture Organization of the United Nations, 2020; Khyber Pakhtunkhwa Forest Department, 2021).

The regional economy is predominantly rural and depends on agriculture, livestock, forestry, tourism, and small-scale commercial activities. Tourism is particularly important in hill stations such as Nathiagali, Ayubia, and Dunga Gali. The interaction between mountainous terrain, forest resources, expanding infrastructure, tourism-related development, and human activities makes Galyat an appropriate study area for examining temporal relationships between vegetation condition and landslide occurrence.

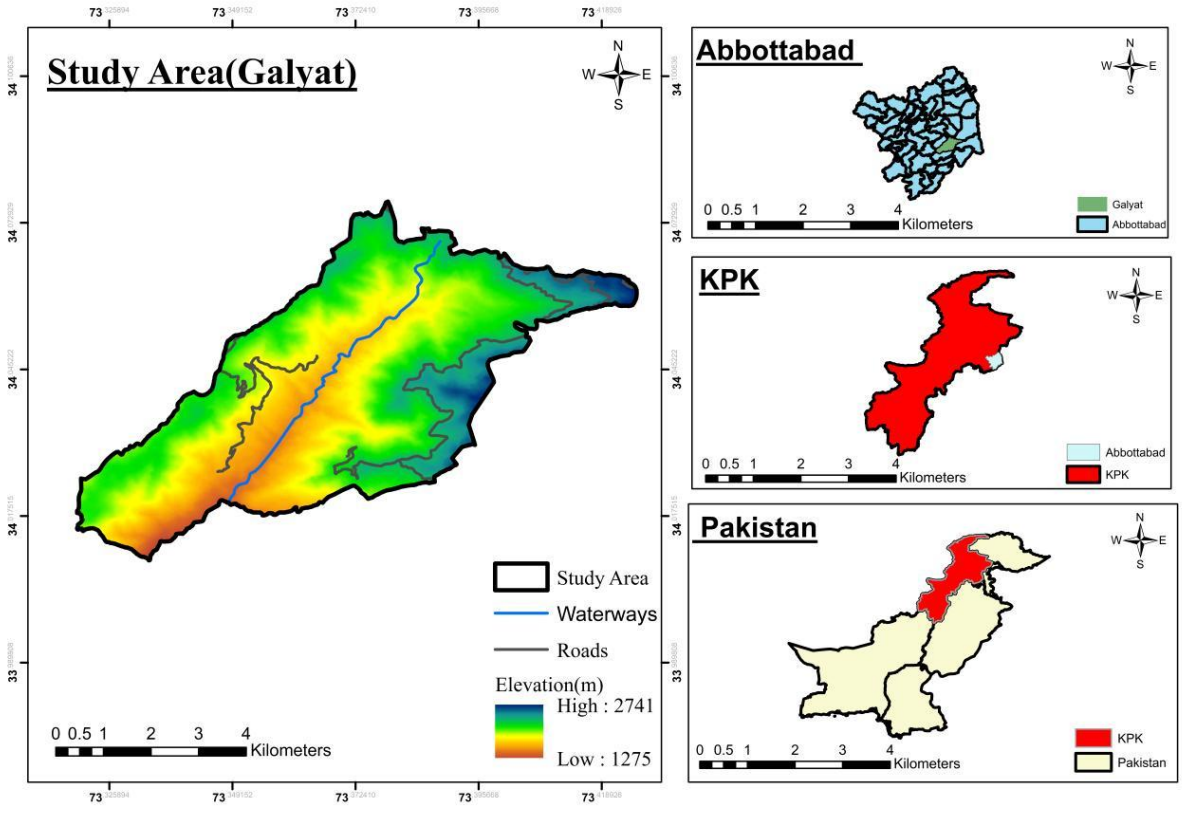


Figure 1. Location of the Galyat study area, Abbottabad District, Khyber Pakhtunkhwa, Pakistan.

3. Materials and Methods

3.1 Data sources

This study used secondary geospatial data to examine temporal changes in vegetation condition and landslide activity in the Galyat region for the years 2011, 2017, and 2025. Satellite imagery was obtained from the United States Geological Survey (USGS) EarthExplorer archive and used to assess vegetation condition through the Normalized Difference Vegetation Index (NDVI). Landsat 5 Thematic Mapper (TM) imagery acquired in September 2011, Landsat 8 Operational Land Imager (OLI) imagery acquired in September 2017, and Landsat 9 Operational Land Imager-2 (OLI-2) imagery acquired in November 2025 were used in the analysis. The relevant multispectral bands have a spatial resolution of 30 m.

NDVI was calculated using the red and near-infrared (NIR) spectral bands according to:

NDVI = (NIR − Red) / (NIR + Red)

For Landsat 5 TM, Band 4 was used as the NIR band and Band 3 as the red band. For Landsat 8 OLI and Landsat 9 OLI-2, Band 5 was used as the NIR band and Band 4 as the red band. These combinations were used to generate NDVI layers representing vegetation condition for each selected year. Historical landslide occurrences for 2011, 2017, and 2025 were obtained using Google Earth Pro. Landslides identified for each selected year were digitised as polygons and imported into ArcGIS for spatial and temporal analysis. The landslide inventory was used to determine changes in landslide frequency and affected area and to compare these changes with vegetation conditions represented by the corresponding NDVI layers.

3.2 Data analysis

All spatial and temporal analyses were performed using ArcGIS 10.8. Landslide polygons for 2011, 2017, and 2025 were digitised and standardised, and each polygon was assigned a year attribute. The datasets for the three observation years were subsequently merged into a single temporal layer to facilitate spatial and temporal comparison.

Summary statistics were calculated for each observation year, including the sum, mean, minimum, maximum, and range of landslide area. The Zonal Statistics as Table tool in ArcGIS 10.8 was used to generate statistical summaries, while the Calculate Geometry tool was used to calculate the area of individual landslide polygons and determine the total landslide-affected area for each year. Landslide frequency was determined from the number of mapped landslide polygons recorded for 2011, 2017, and 2025.

The NDVI raster layers generated for 2011, 2017, and 2025 were analysed to assess temporal changes in vegetation condition. Mean NDVI values were calculated for each observation year and used as indicators of overall vegetation greenness within the study area. The landslide polygons were then overlaid on the corresponding NDVI raster layers to examine the spatial distribution of landslides in relation to vegetation condition.

Temporal changes in mean NDVI, landslide frequency, and total landslide-affected area were compared across 2011, 2017, and 2025. Graphical representations were prepared to illustrate changes in vegetation condition and landslide activity over the study period. The combined spatial and temporal analysis was used to identify patterns between vegetation change and

landslide occurrence and to assess these patterns in relation to the potential role of reforestation in reducing landslide risk.

4. Results

4.1 Vegetation cover change (2011–2025)

The NDVI analysis revealed considerable temporal variation in vegetation condition across the Galyat region between 2011 and 2025. Mean NDVI decreased from 0.3549 in 2011 to 0.1810 in 2017, representing a substantial decline in vegetation greenness during the first observation period. Between 2017 and 2025, mean NDVI increased slightly from 0.1810 to 0.1965, indicating a modest recovery in vegetation condition. However, the mean NDVI recorded in 2025 remained considerably below the 2011 value.

The spatial NDVI maps also showed variation in vegetation condition across the study area. In 2011, areas with relatively high NDVI values represented denser and healthier vegetation, whereas lower values indicated sparse vegetation, exposed land, or other non-vegetated surfaces. The 2017 NDVI map showed an overall reduction in vegetation greenness compared with 2011. By 2025, vegetation condition showed some improvement relative to 2017, although the overall level had not returned to that observed in 2011. These temporal changes are illustrated by the NDVI maps and mean NDVI trend for the three observation years.

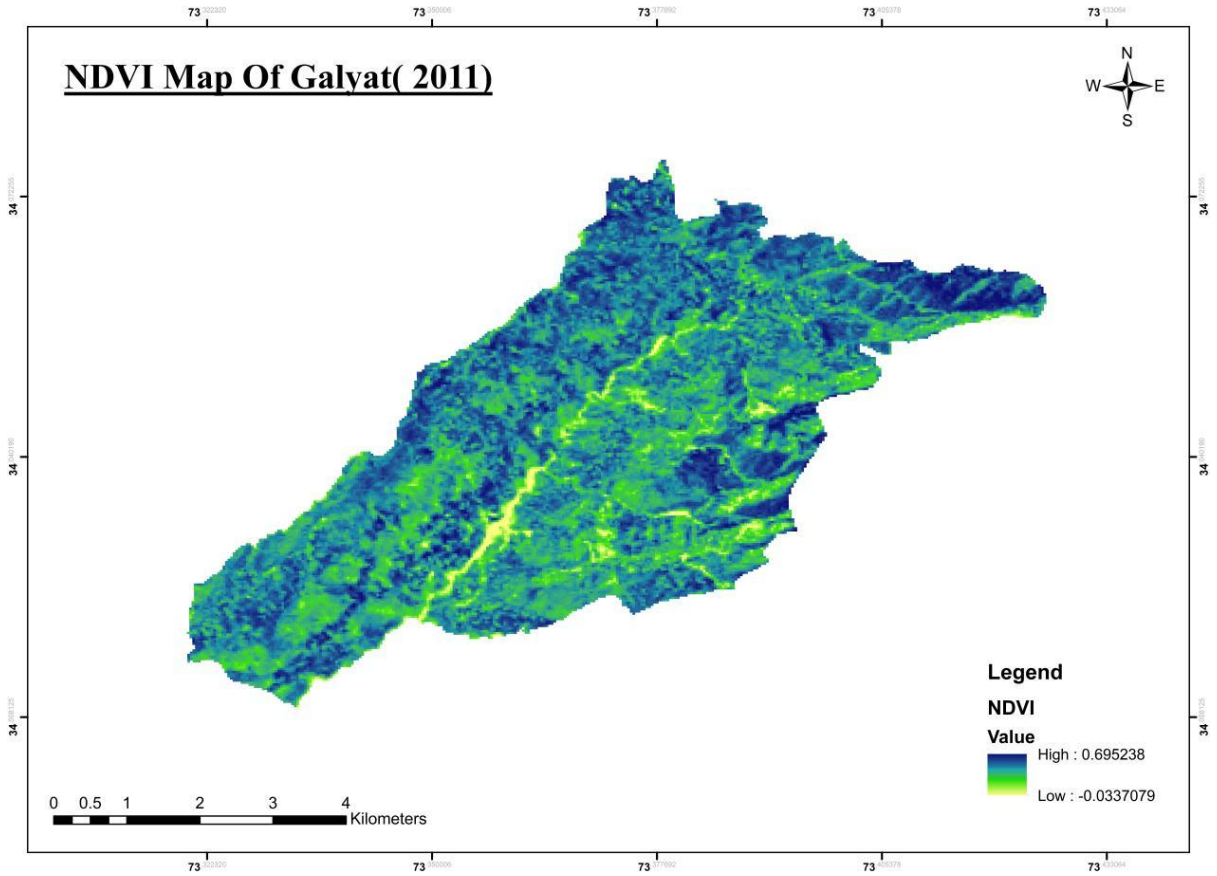


Figure 2. Spatial distribution of the (NDVI) in the Galyat region, Pakistan, in 2011 (Source :DIVA GIS,2026)

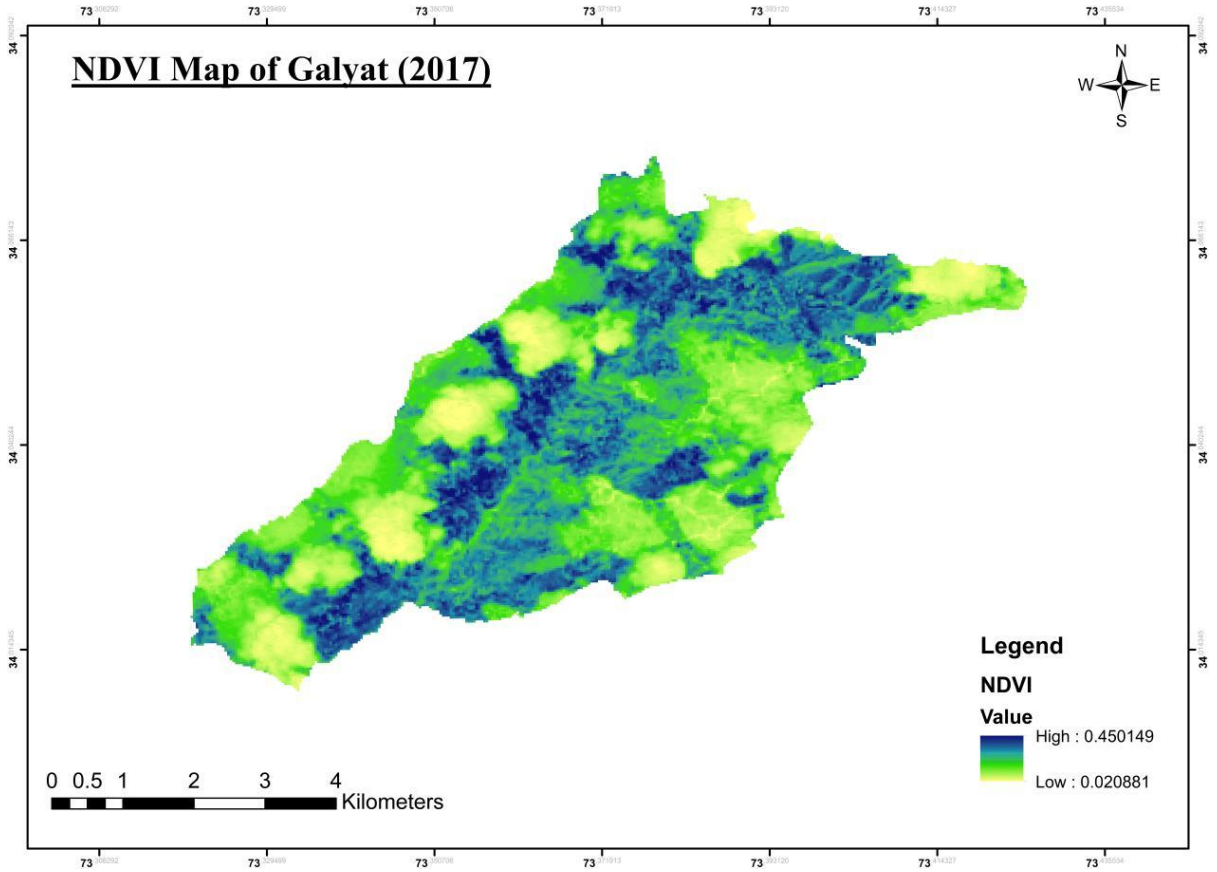


Figure 3. Spatial distribution of the NDVI in the Galyat region, Pakistan, in 2017 (Source :DIVA GIS,2026)

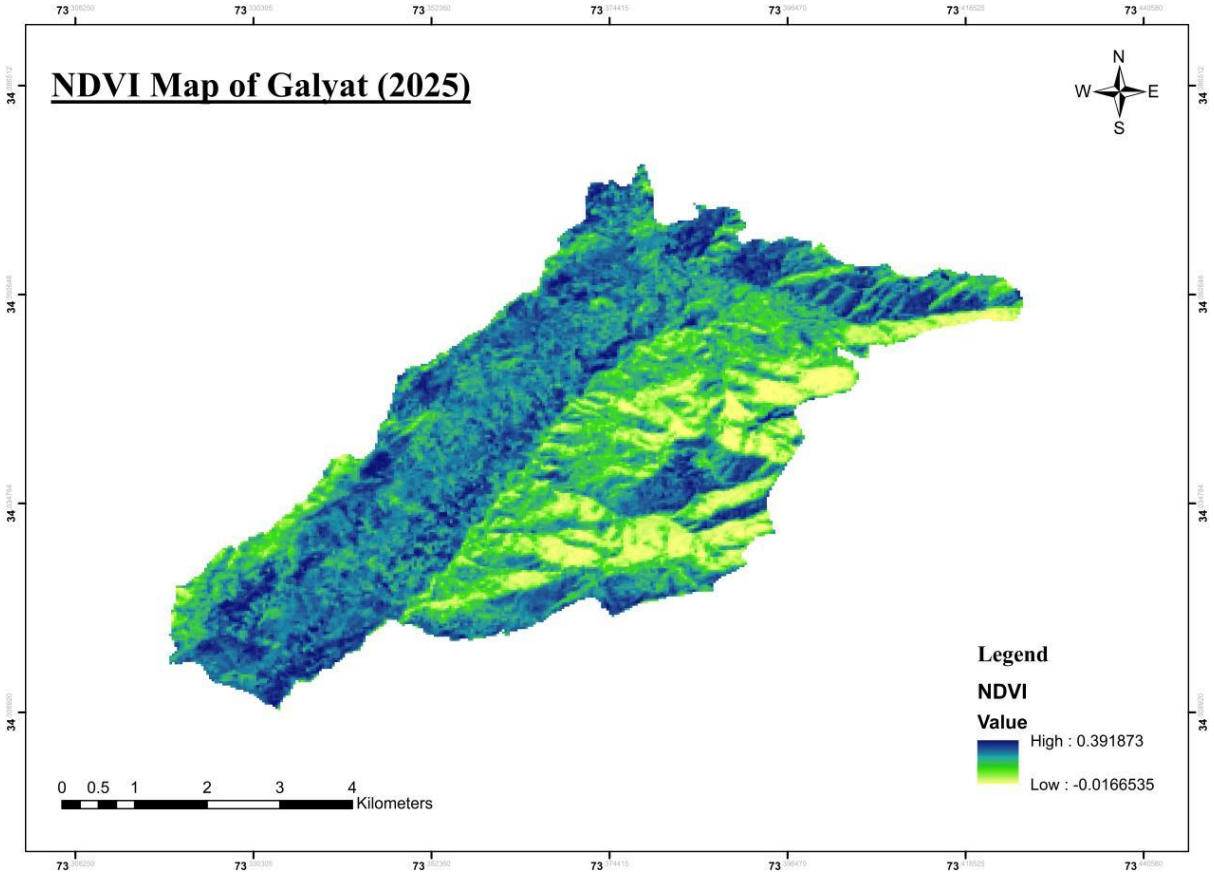
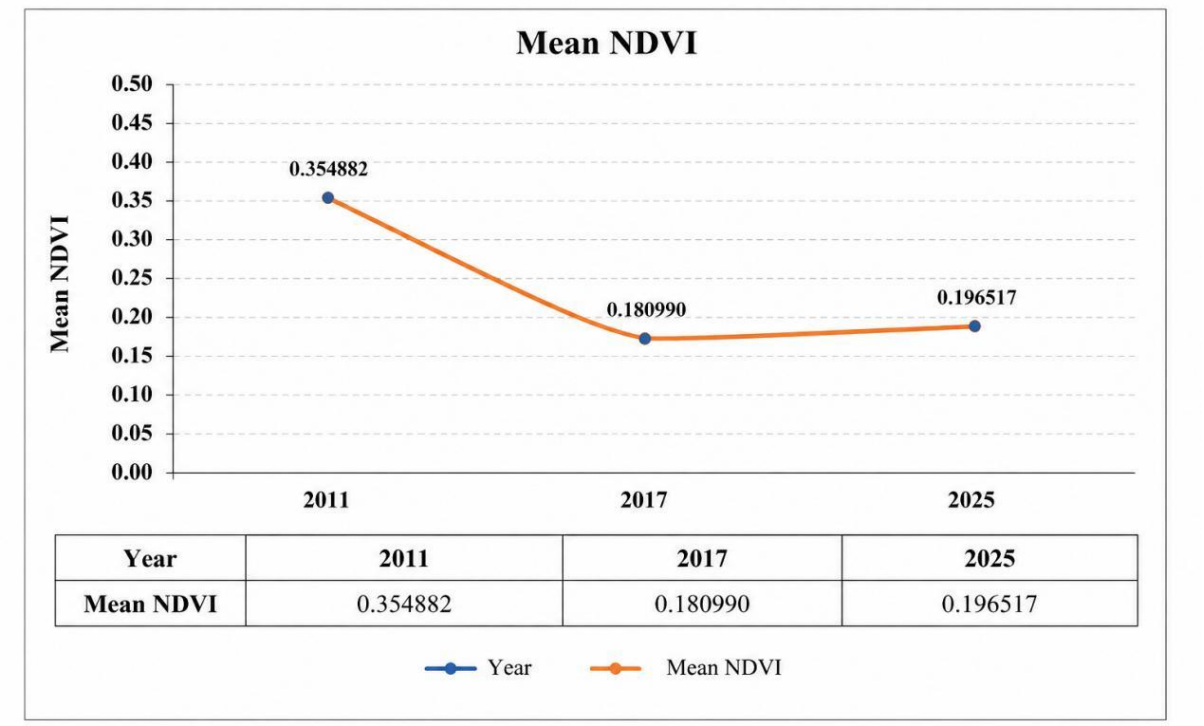


Figure 4. Spatial distribution of the NDVI in the Galyat region, Pakistan, in 2025 (Source :DIVA GIS,2026)



Year	2011	2017	2025
Mean NDVI	0.354882	0.180990	0.196517

Figure 5:Temporal trends of NDVI in Galyat,2011-2025 (Source: Author,2026)

4.2 Landslide trends (2011–2025)

Landslide frequency and affected area showed different temporal patterns across the three observation years. In 2011, 125 landslides were recorded, affecting a total area of 557,837.64 m² (55.78 ha). By 2017, landslide frequency had decreased substantially to 52 events; however, the total affected area increased to 932,606.50 m² (93.26 ha). The mean mapped landslide area also increased from 4,462.70 m² in 2011 to 17,934.74 m² in 2017, indicating that fewer but larger landslides were mapped in 2017.

In 2025, landslide frequency increased to 76 events, while the total affected area increased further to 983,774.39 m² (98.38 ha). The mean landslide area was 12,944.40 m², lower than in 2017 but substantially higher than in 2011. Overall, landslide frequency decreased between 2011 and 2017 and then partially increased by 2025, whereas total landslide-affected area increased continuously across the three observation years.

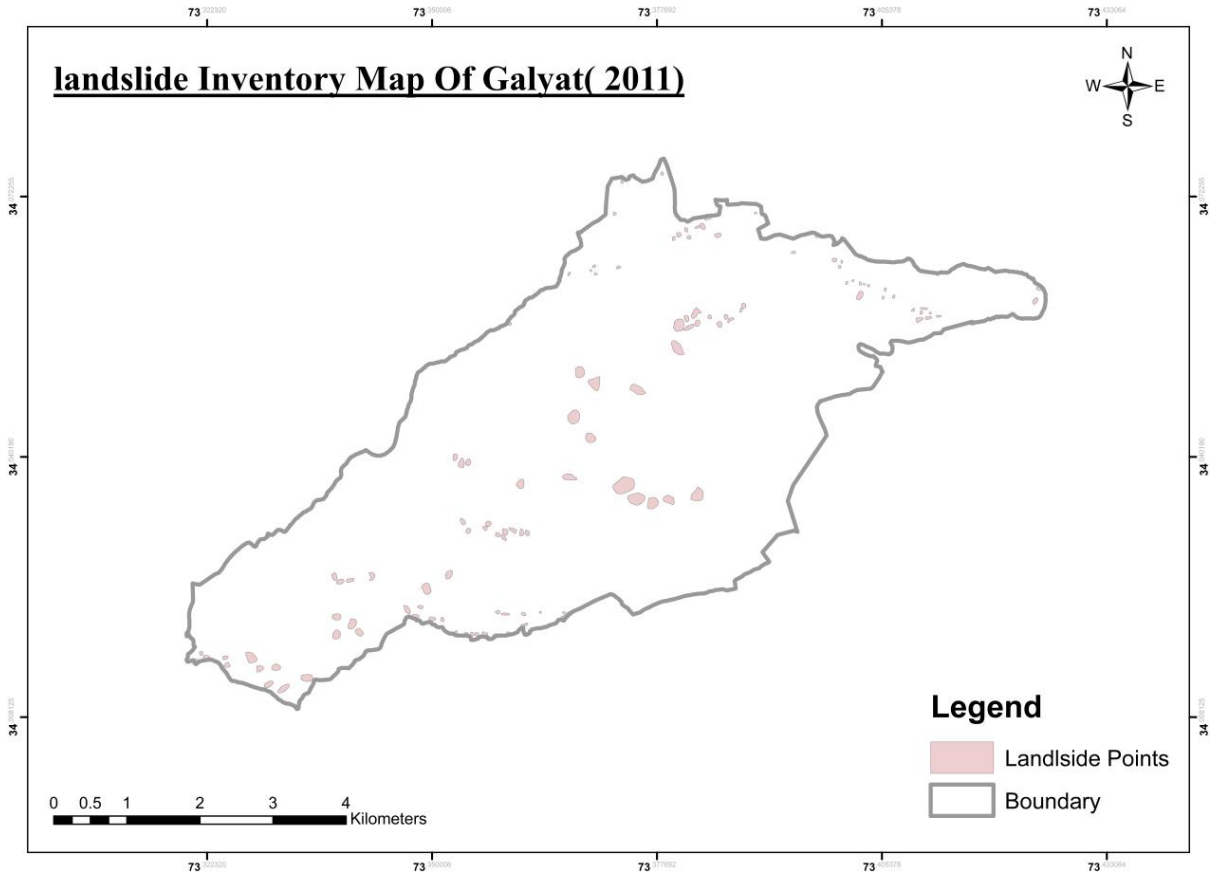


Figure 6 Landslide Inventory Map(2011) (Source :DIVA GIS,2026)

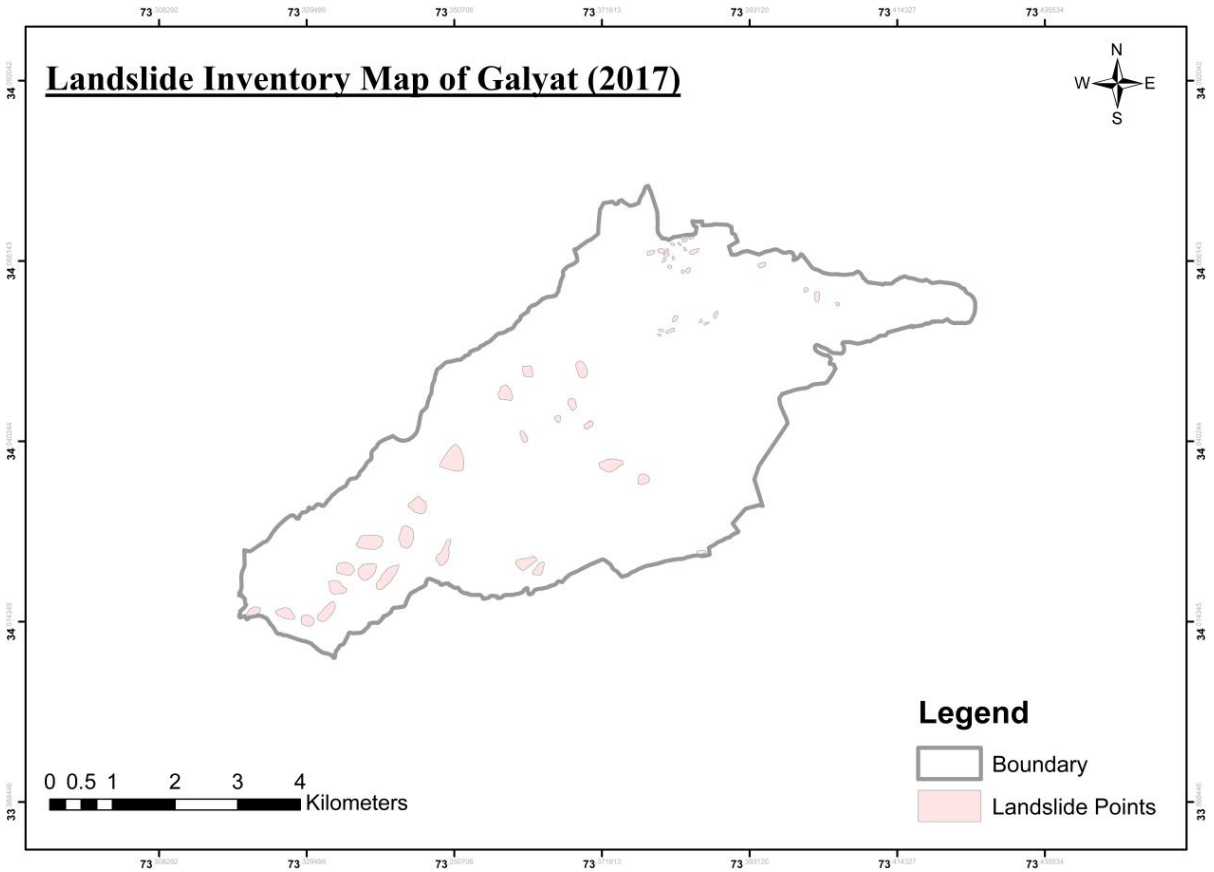


Figure 7 Landslide Inventory Map(2017) (Source :DIVA GIS,2026)

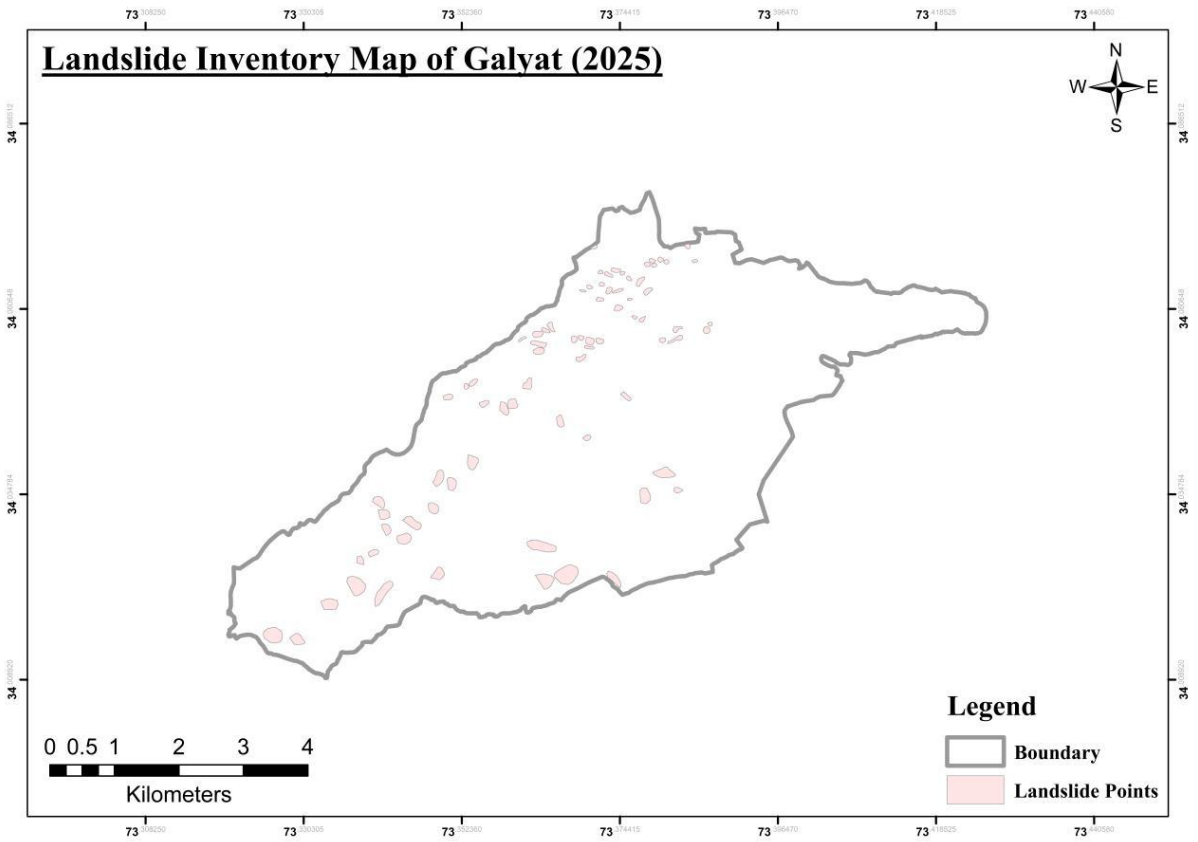


Figure 8: Landslide Inventory Map (2025) (Source :DIVA GIS,2026)

Table 1. Year-wise statistical summary of landslide area in Galyat (2011–2025).

Year	Landslide Frequency	Total Affected Area (m²)	Mean Landslide Area (m²)	Minimum Landslide Area (m²)	Maximum Landslide Area (m²)	Range of Landslide Area (m²)
2011	125	557,837.64	4,462.70	354.89	41,168.43	40,813.54
2017	52	932,606.50	17,934.74	1,377.23	91,621.73	90,244.49
2025	76	983,774.39	12,944.40	1,787.45	65,050.44	63,262.99

Table 2. Landslide frequency and affected area in Galyat (2011–2025).

Year	Landslide Count	Landslide Area (m²)	Landslide Area (ha)
2011	125	557,837.64	55.78
2017	52	932,606.50	93.26
2025	76	983,774.39	98.38

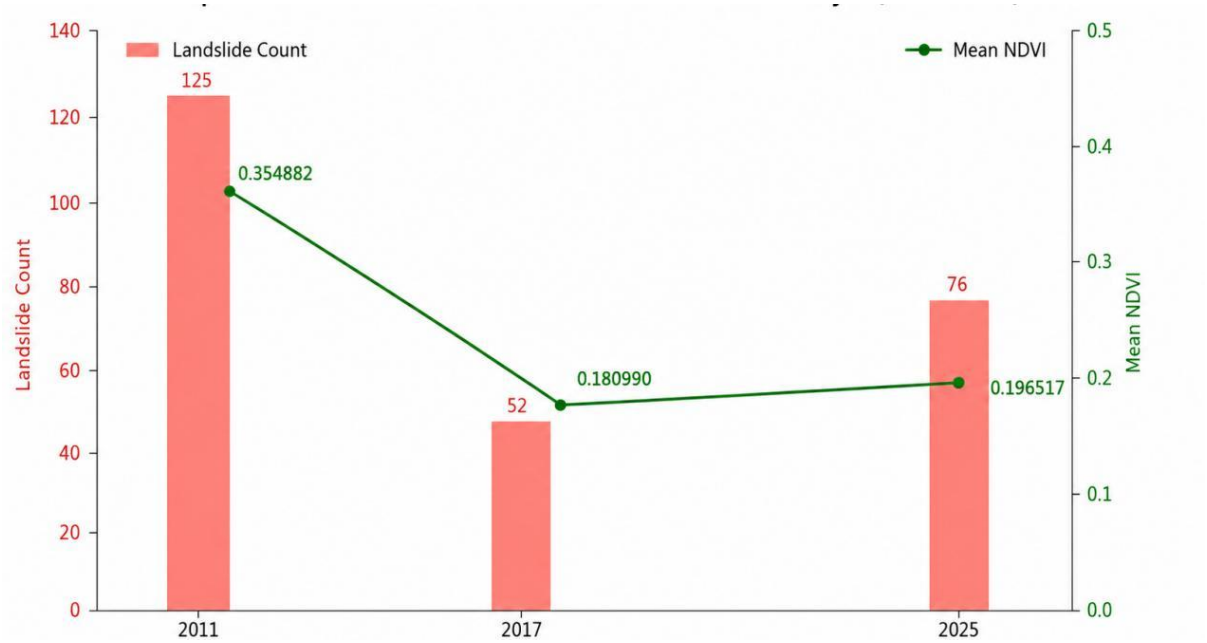
4.3 Relationship between NDVI and landslide activity

When mean NDVI and landslide frequency are considered jointly (Table 3), both decreased between 2011 and 2017 and both increased between 2017 and 2025. However, total landslide-affected area followed a different pattern, increasing from 55.78 ha in 2011 to 93.26 ha in 2017 and 98.38 ha in 2025. Therefore, the temporal relationship between vegetation condition and landslide activity differs depending on whether activity is represented by landslide count or affected area. The highest mean NDVI occurred in 2011, which also had the highest landslide count but the lowest total affected area among the three observation years.

Table 3. Mean NDVI and landslide frequency in Galyat (2011–2025).

Year	Mean NDVI	Landslide Count
2011	0.3549	125
2017	0.1810	52
2025	0.1965	76

These results do not show a simple or consistent relationship between vegetation condition and landslide activity during the study period. Landslide count broadly followed the direction of NDVI change, whereas total affected area increased across all three observation years. The potential reasons for these contrasting patterns, including rainfall, geology, slope characteristics, land-use change, and differences in landslide size, are considered in the Discussion.



5. Discussion

This study examined temporal changes in vegetation condition and landslide activity in the Galyat region between 2011 and 2025 to assess the potential role of reforestation in landslide-risk reduction. Mean NDVI declined from 0.3549 in 2011 to 0.1810 in 2017 and subsequently increased slightly to 0.1965 in 2025. Landslide frequency decreased from 125 events in 2011 to 52 events in 2017 before increasing to 76 events in 2025. In contrast, total landslide-affected area increased from 55.78 ha in 2011 to 93.26 ha in 2017 and 98.38 ha in 2025. The mean landslide area was also much larger in 2017 and 2025 than in 2011. These contrasting patterns show that landslide frequency and landslide-affected area did not respond in the same way over time and that a simple inverse relationship between vegetation greenness and landslide activity was not evident during the study period.

This finding does not necessarily imply that reforestation has no role in reducing landslide risk. Forest vegetation can contribute to slope stability through several physical and hydrological mechanisms. Tree roots can reinforce soil and increase resistance to slope failure, while vegetation cover can reduce surface erosion, intercept rainfall, and influence runoff and infiltration processes (Sidle & Bogaard, 2016). These mechanisms provide a strong theoretical basis for considering reforestation as a nature-based approach to slope

management. However, the effectiveness of vegetation in stabilising slopes depends on forest characteristics and the environmental setting in which vegetation occurs. Consequently, vegetation condition should not be interpreted as an independent control on landslide activity.

The results from Galyat can be compared with findings from other mountainous environments. Griffiths et al. (2020) reported that mature forest cover in New Zealand was associated with substantially lower shallow-landslide occurrence than pasture during major rainfall events. However, they also demonstrated that recently established plantations provided less protection until root systems developed sufficiently. Similarly, Canavesi and Alvalá (2012) found that preserved forests and mature Eucalyptus plantations in Brazil were generally associated with lower landslide susceptibility, whereas newly planted or recently harvested areas were more vulnerable because of exposed soil and less-developed vegetation. Zhang et al. (2022) further demonstrated that forest type, origin, age, and tree species influenced landslide susceptibility in China. Together, these studies indicate that the presence or greenness of vegetation alone cannot fully represent the slope-stabilising function of a forest.

The findings of the present study are therefore particularly important when interpreting NDVI. NDVI provides an effective remote-sensing indicator of vegetation greenness and is useful for monitoring broad temporal changes in vegetation condition. However, it does not directly measure root strength, forest age, tree density, species composition, canopy structure, or below-ground biomass. Two locations with similar NDVI values may therefore have substantially different capacities to reinforce a slope. A recently regenerated area may exhibit increasing vegetation greenness while still lacking the mature root systems required to provide substantial mechanical reinforcement. This limitation is particularly relevant when attempting to assess the effects of reforestation programmes using NDVI alone.

Rainfall represents another potentially important explanation for the observed temporal pattern. Galyat experiences heavy monsoon rainfall, and intense precipitation can trigger slope failure by increasing soil moisture and pore-water pressure and reducing slope stability. Rainfall conditions for 2011, 2017, and 2025 were not quantitatively incorporated into the present analysis. Consequently, differences in rainfall intensity, duration, or antecedent moisture conditions among the observation years may have contributed to differences in landslide frequency and affected area. The high landslide activity recorded in 2011 despite

the highest mean NDVI illustrates why vegetation condition alone cannot be assumed to determine landslide occurrence.

Topographic, geological, and anthropogenic factors may also have influenced the observed pattern. Galyat is characterised by steep slopes, rugged terrain, and geological conditions that contribute to natural slope instability. In addition, road construction, infrastructure development, urban expansion, forest disturbance, and other land-use changes can modify drainage patterns and slope geometry. Quevedo et al. (2023) emphasised that vegetation and land cover should be considered together with rainfall, slope, geology, soil characteristics, and human disturbance when assessing landslide susceptibility. The findings from Galyat are consistent with this multi-factor interpretation because changes in vegetation greenness did not correspond independently with reductions in landslide activity.

The temporal pattern observed between 2017 and 2025 is nevertheless noteworthy in the context of forest-restoration activities in Pakistan. Mean NDVI increased from 0.1810 to 0.1965 during this period, indicating partial vegetation recovery. This period overlaps with the implementation of the Billion Tree Tsunami Afforestation Project in Khyber Pakhtunkhwa and the subsequent Ten Billion Tree Tsunami Programme at the national level. Large-scale restoration research in Pakistan has also reported vegetation recovery in mountain regions (Abbas et al., 2023). However, the present analysis cannot determine whether the observed increase in NDVI was directly caused by these programmes. The increase could reflect reforestation, natural regeneration, other land-cover changes, or a combination of these processes. Therefore, the observed NDVI recovery should be interpreted as being temporally consistent with vegetation restoration rather than as direct evidence of a causal effect of the afforestation programmes.

Forest management may be equally important as increases in vegetation cover. Salbitano et al. (2021) demonstrated that forest expansion following abandonment of agricultural terraces in Italy did not uniformly reduce environmental hazards. Instead, unmanaged landscape change contributed to new hydrogeological and fire vulnerabilities. This finding reinforces the view that reforestation should involve appropriate species selection, long-term forest management, protection of developing stands, and consideration of local terrain and drainage conditions rather than simply increasing vegetation cover.

Several limitations of the present study should therefore be recognised. First, the analysis was based on only three observation years, 2011, 2017, and 2025. These temporal snapshots cannot represent annual variability in either vegetation condition or landslide occurrence. Second, the Landsat imagery used for 2011 and 2017 was acquired in September, whereas the 2025 imagery was acquired in November. Because NDVI is influenced by seasonal vegetation conditions, this difference in acquisition timing may have affected direct comparison of NDVI values among the three years. Third, the 30 m spatial resolution of Landsat imagery limits the identification of fine-scale vegetation characteristics and cannot distinguish important slope-stabilising properties such as forest age, root density, and species composition. Fourth, the landslide inventory was developed through interpretation and digitisation of Google Earth Pro imagery and was not independently validated through field observations. Small, obscured, or rapidly revegetated landslides may therefore have been missed, while uncertainty may exist in the delineation of some landslide boundaries.

Finally, rainfall, slope gradient, geology, soil properties, drainage conditions, road networks, and detailed land-use change were not incorporated quantitatively into the analysis. This limits the ability of the present study to isolate the specific contribution of reforestation from other landslide-conditioning factors. Future research should therefore combine multi-year NDVI and land-cover datasets with rainfall records, digital elevation models, slope and geological information, road and drainage data, and detailed records of plantation locations and establishment dates. Field verification of landslide inventories and the use of higher-resolution satellite imagery would further strengthen the analysis.

Overall, the findings indicate that reforestation remains relevant to landslide-risk reduction in Galyat, but its contribution should be understood within a broader system of interacting environmental and human controls. The absence of a simple inverse temporal relationship between NDVI and landslide activity does not invalidate the slope-stabilising functions of vegetation. Rather, it demonstrates that vegetation greenness alone is insufficient to explain temporal variation in landslide occurrence. Reforestation should therefore be integrated with drainage management, appropriate land-use planning, slope stabilisation, forest conservation, and monitoring of vulnerable areas as part of a comprehensive landslide-risk reduction strategy for Galyat.

6. Conclusion

This study examined the potential role of reforestation in reducing landslide risk in the Galyat region of Pakistan by analysing temporal changes in vegetation condition and landslide activity between 2011 and 2025. Remote sensing and GIS techniques were used to compare Landsat-derived NDVI with landslide frequency and affected area for three observation years: 2011, 2017, and 2025. The analysis demonstrated considerable temporal variation in both vegetation condition and landslide occurrence.

Mean NDVI decreased from 0.3549 in 2011 to 0.1810 in 2017, followed by a modest recovery to 0.1965 in 2025. Landslide frequency decreased from 125 events in 2011 to 52 events in 2017 before increasing to 76 events in 2025. In contrast, total landslide-affected area increased from 55.78 ha in 2011 to 93.26 ha in 2017 and 98.38 ha in 2025. These results show that changes in landslide frequency and affected area followed different temporal patterns, with fewer but larger mapped landslides in 2017 compared with 2011 and a further increase in total affected area by 2025.

The results did not reveal a consistent inverse temporal relationship between vegetation condition and landslide activity. Therefore, changes in landslide occurrence in Galyat cannot be explained by vegetation condition or reforestation alone. Landslide activity is likely to reflect interactions among multiple environmental and anthropogenic factors, including rainfall, slope characteristics, geology, soil conditions, drainage, land-use change, road construction, and human disturbance. Nevertheless, reforestation and forest conservation remain important components of landslide-risk management because vegetation can contribute to soil reinforcement, erosion control, and improved slope stability.

The findings highlight the value of integrating reforestation with other risk-reduction measures, including appropriate land-use planning, drainage management, slope stabilisation, forest conservation, and monitoring of landslide-prone areas. Remote sensing and GIS provide practical tools for monitoring vegetation change and landslide activity in mountainous and data-scarce environments. Future studies should incorporate additional observation years, rainfall records, detailed land-cover classification, slope and geological information, higher-resolution imagery, field validation, and spatial records of reforestation activities to better quantify the specific contribution of reforestation to landslide-risk reduction in Galyat.

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