

## SPATIO-TEMPORAL VARIATION AND CLIMATE CHANGE IMPACT ON REGENERATION OF CHIR PINE IN SUBTROPICAL PINE FORESTS IN PAKISTAN

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### Abstract

Sub-tropical Chir pine forests are one of the most important forest ecosystems. Unfortunately, our forests are depleting at alarming rate. To address this problem, this study was designed. The study area was District Rawalpindi, including Murree, Kahuta and Kotli Sattian, the study was conducted to find out regeneration of Chir pine in district Rawalpindi through Spatio-temporal changes. The temporal changes were detected between 1999-2024 (2004-2009, 2009-2014, 2014-2019 and 2019-2024) by using satellites namely MODIS, Land Sat 8 and Sentinel 2 respectively. The trend in Chir pine cover during 1999-2004 was moderate, dense Chir pine cover was highest covering an area of 396 km<sup>2</sup>. This positive trend was due to less deforestation. In 2004-2009 a slight decrease in dense Chir pine cover was observed, the reason for negative trend was deforestation or land use changes, in between 2009-2014 a dense Chir pine area remained largely stable due to local conservation efforts or natural growth in certain areas and less Chir pine area increased from previous years, 2014-2019 highest value of dense Chir pine cover was recorded as 634 km<sup>2</sup>. This shift reflects ecological restoration projects or changes in local land management practices, in years 2019-2024 dense Chir pine forests showing decrease in some pockets due to fire, and moderate dense Chir pine increased.

**Key words:** Chir pine; Spatio-temporal; Landsat; Sentinel; Climate change

### Introduction

Forests and trees are vital for the terrestrial ecosystem, providing air purifiers, oxygen storage, carbon storage, and natural water cycle management. Trees and forests are vital for the terrestrial ecosystem. They support the survival of numerous animals, including humans. Forests contribute significantly to ecosystem recovery. *Pinus roxburghii*, has high conservation importance in temperate forests due to its ecological and economic value (Ahmed *et al.*, 2023; Ali *et al.*, 2022) including timber, wood for fuel, resin, glue and herbicides (Chandran *et al.*, 2011; Fule *et al.*, 2021). They are also used for bark, brooms, thatch, and leaf litter for livestock bedding. Chir pine branches are transported home for rituals and ceremonies and their thick, fire-resistant bark protects the cambium from frequent surface fires (Gupta *et al.*, 2009; Kumar & Pandey, 2022; Bargali *et al.*, 2022; Hussain *et al.*, 2024) Young pine trees develop buds from near the ground due to fire damage, demonstrating their resilience. (Ansari *et al.*, 2022).

*Pinus roxburghii* (Chir pine) is a longleaf Indian pine and it belongs to the family Pinaceae. It stands out amongst the most critical conifers in Himalayan area, which adjusts the life of different groups of the district Rawalpindi. A substantial Chir pine tree is 21 to 33 m tall and the normal measurement is 0.6 m. The crown is adjusted or round about fit as a fiddle. The needles are in threes which are 20 to 30 cm long and the stem is straight or erect (Kumar & Pandey, 2022; Saha *et al.*, 2022; Ansari *et al.*, 2022).

The Chir pine forest range in the temperate zone, including Murree, Kahuta and Kotli Sattian, faces various spatio-temporal problems due to tourism and urbanization. Spatio-temporal changes refers to the variations or patterns that occur over both space (geographical areas) and time. Spatial Changes are variations observed in different locations or regions. For example, differences in vegetation types across various altitudes or regions, variations in land use patterns across cities, or the distribution of species in different habitats (Malik *et al.*, 2023; Muhammad *et al.*, 2024) Temporal Changes refer to variations that occur over time. Examples include seasonal changes in weather patterns, yearly fluctuations in agricultural yields, long-term trends in temperature due to Climate Change, or historical changes in population dynamics, when spatial and temporal aspects are combined, it involves studying how something changes over both space and time. For example tracking the spread of a disease in different regions over several months or years; monitoring deforestation rates in a particular forest over decades; Observing urban expansion in cities over a century and analyzing changes in wildlife migration patterns across different seasons and locations (Ansari *et al.*, 2022).

In Uttaranchal slopes, during recent years, point-by-point biological investigations have been completed on the Chir pine forests (Tiwari, 1994; Zobel *et al.*, 2001). The pitch of *Pinus roxburghii* was used to heal breaks on either side of eyes to reduce swelling in India (Sharma *et al.*, 2022). Therefore, with the exception of few, there is in

depth an absence of the indigenous regeneration of *Pinus roxburghii* (Shiva, 2023).

Regeneration assumes critical part being developed, which shows composition, structure, stand dissemination and future product of the woods territory. It is the procedure of Forest working through which woods and trees get by after some time. (Hussain *et al.*, 2024). Working of three noteworthy segments is viewed as an effective recovery of tree species:

- i. The capacity to start new seedlings
- ii. The capacity of seedlings and saplings to survive
- iii. The capacity of seedlings and saplings to develop

For the support of forests cover, recovery status of forest species is the most imperative. Recovery status can be shown by figuring the age, size and structure of individual types of that timberland stand. Vegetation in the mountainous ranges is influenced by different factors in which elevation, aspect, slope and soil proosity are dominant that they adjust the administrations of dampness and introduction to sun. Similarly, the contrasts between the microclimate, angle and height enormously influences the vegetation inside the forest area. It has been seen that the pine forests have serious anthropogenic unsettling influences. The types of disturbances influences were fundamentally included deforestation, animal grazing, cutting, surface consuming and litter expulsion. These unsettling influences are affecting the biological community soundness and furthermore impeding the procedure of progression (Joshi *et al.*, 2024; Konsam *et al.*, 2017). Both characteristic and anthropogenic exercises cause unsettling influence and are considered when the reaction of vegetation is not normal and human exercises. Different species that are happening in Chir pine woodlands normally neglects to recover. Hereby, it is

important that the recuperation of tree species in opening can be variable, yet in warm calm forests. It has been suggested that the recovery strategy for these tree species is not an unchangeable property, yet rather can be an alterable one in association with the closeness or non-attendance of various species, for instance, key predominant species.

## Material and Methods

**Description of the study area:** The study area was comprised of Murree, Kahuta, and Kotli Sattian tehsils of Rawalpindi District, Punjab, Pakistan. Elevation ranges from approximately 500 m to over 2,200m above sea level. The region experiences a subtropical Climate, with higher precipitation of 1200 mm and cooler temperatures at upper elevations (Fig. 1). Chir pine (*Pinus roxburghii*) forms the dominant forest type, often associated with *Quercus incana* in mixed stands (Ali *et al.*, 2022).

**Methods:** Spatio-temporal changes were analyzed at five-year intervals (1999–2004, 2004–2009, 2009–2014, 2014–2019, and 2019–2024). MODIS (Tian *et al.*, 2023) MOD13Q1 (250 m resolution) was used for early periods, Landsat-8 OLI (30 m) for 2014, and Sentinel-2 MSI (10 m) for 2019 and 2024 (Zarzeluo *et al.*, 2025). All datasets were projected to WGS 1984 UTM Zone 43N.

NDVI was calculated in Google Earth Engine using standard formulations. Chir pine density classes were defined using NDVI thresholds (Bhavsar *et al.*, 2017) adapted from published studies on subtropical conifer forests:

- Less vegetation: NDVI < 0.30
- Moderately dense Chir pine: NDVI 0.30–0.50
- Dense Chir pine: NDVI > 0.50

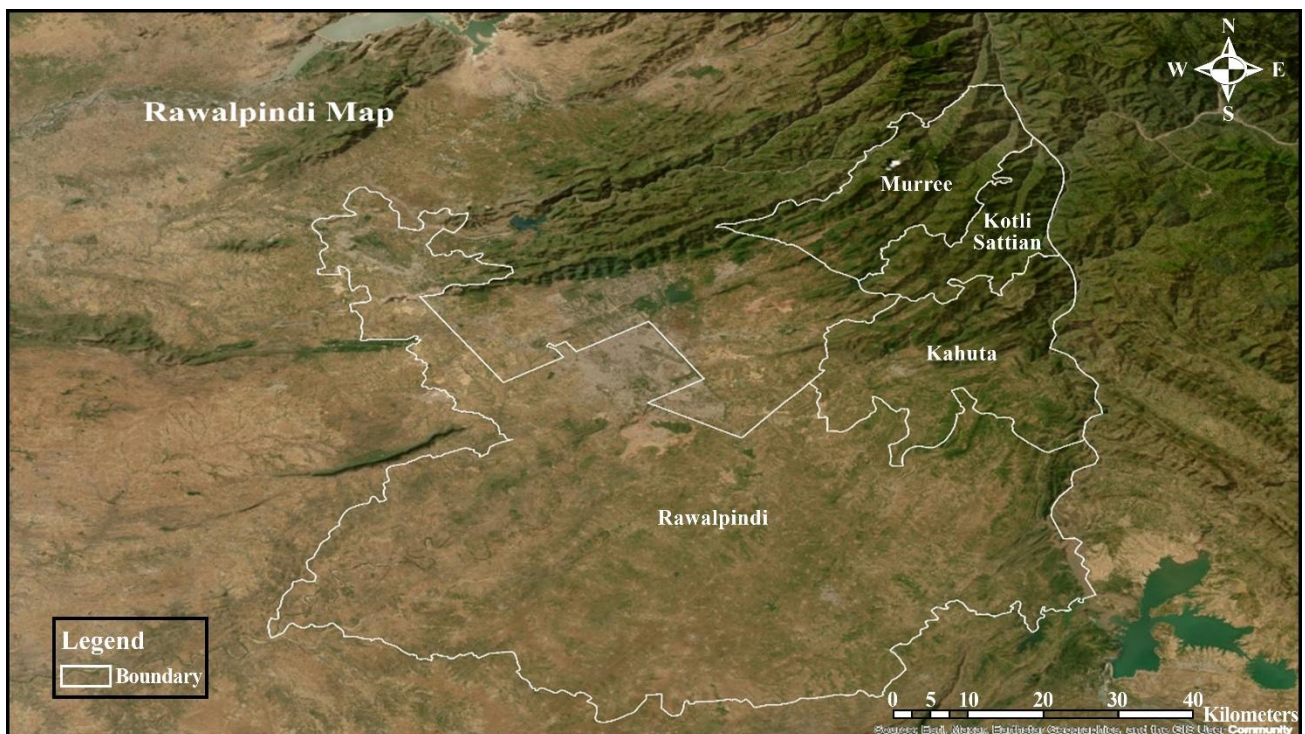


Fig. 1. Locality Map of study area and spatial distribution of samples across study sites.

These thresholds were applied consistently across all time periods to enable comparative analysis.

Due to differences in spatial resolution among sensors, the analysis focused on landscape-scale area statistics rather than pixel-level comparison. NDVI rasters (Saleem *et al.*, 2025) were clipped to the study boundary, reclassified, and converted to polygons in ArcMap. The area for each vegetation class was calculated in square kilometers.

Changes in Chir pine density classes were assessed by comparing area statistics across time periods. Forest dynamics were categorized as afforestation (increase), deforestation (decrease), unchanged vegetation, and unchanged non-vegetation

**Results**

Between 1999 and 2004, dense Chir pine cover was highest at 396 km<sup>2</sup>, indicating a positive trend due to reduced deforestation (Fig. 2). From 2004 to 2009, dense Chir pine was 342 km<sup>2</sup>, decreased by 54 km<sup>2</sup>, the reason for the negative trend reflecting deforestation and land use changes (Fig. 3). During 2009–2014, dense Chir pine cover remained to some extent stable 376 km<sup>2</sup> (Fig. 4), though areas with less dense cover increased, including local conservation efforts or natural growth in certain areas. Between 2014 and 2019, the highest dense Chir pine cover

was recorded at 399 km<sup>2</sup> (Fig. 5). This shift may reflect ecological restoration projects or changes in local land management practices, attributed to conservation and restoration efforts. From 2019 to 2024, dense Chir pine decreased in some pockets, mainly due to fire, while moderately dense Chir pine increased, indicating ongoing fragmentation (Fig. 6). The accompanying change detection map quantifies the changes in forest cover across the four categories:

Overall change detection indicated afforestation over approximately 172 km<sup>2</sup> and deforestation over 282 km<sup>2</sup> during the 25-year period, highlighting the spatial heterogeneity of regeneration processes across the landscape (Fig. 7).

**Accuracy considerations and limitations:** A formal pixel-level accuracy assessment using historical ground-truth data was not feasible due to the unavailability of consistent reference datasets across the full 25-year period. Therefore, the analysis emphasizes area-based temporal trends rather than classification accuracy at individual pixel scale. Similar approaches have been adopted in long-term regional forest monitoring studies where historical validation data are limited. This limitation is acknowledged, and results should be interpreted as indicative of broad regeneration patterns rather than precise stand-level estimates.

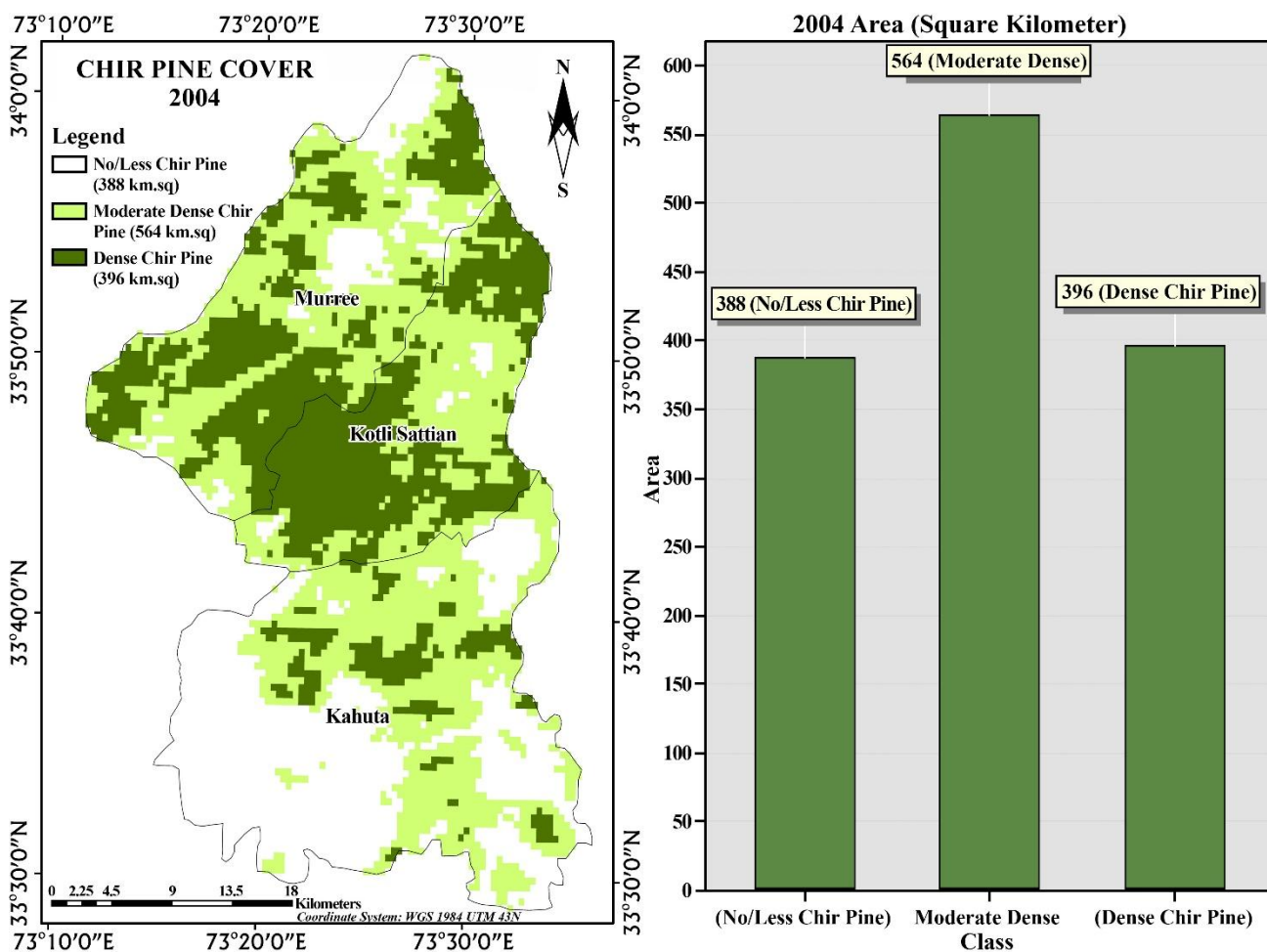


Fig. 2. Change detection in Chir pine cover between 1999-2004.

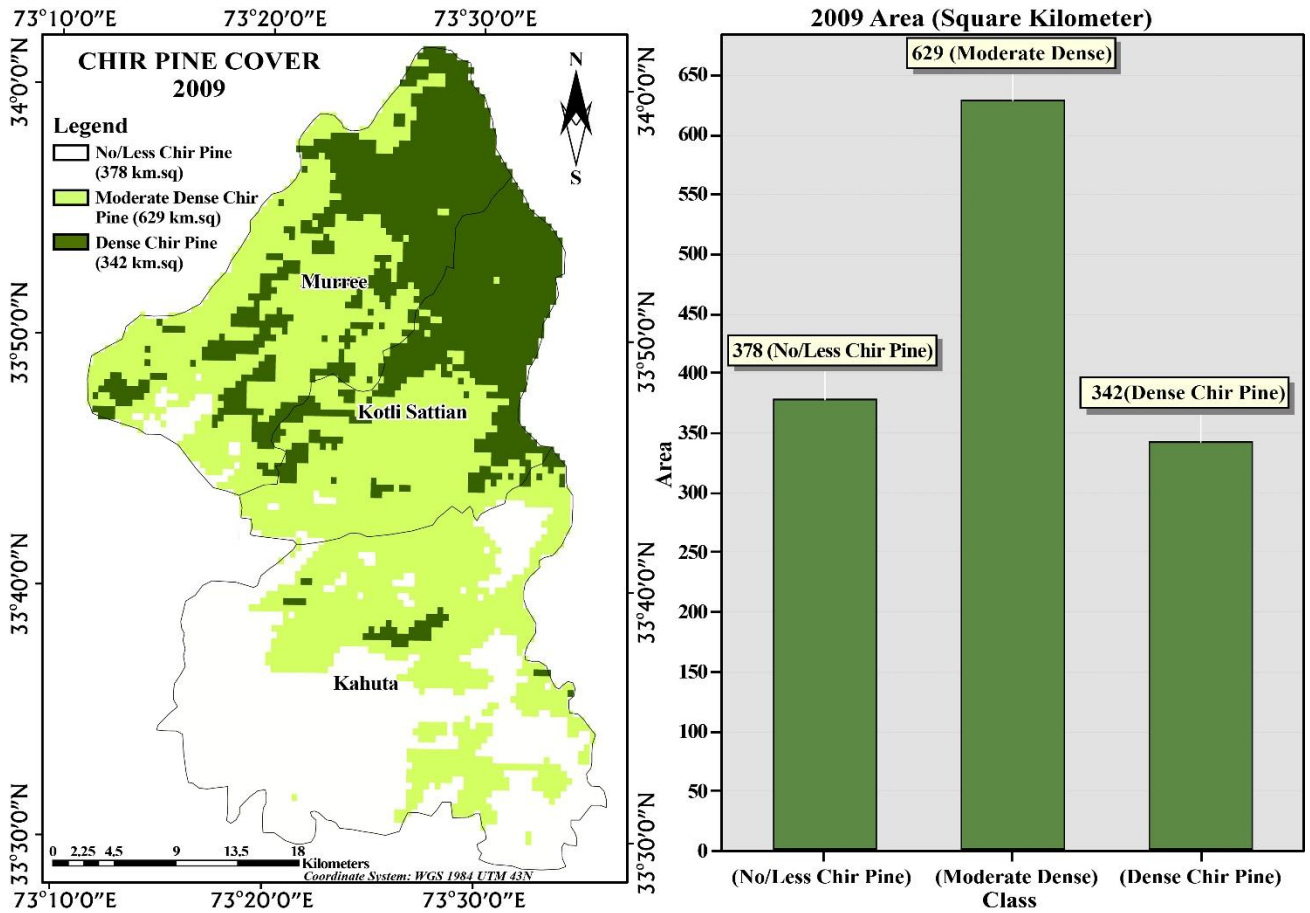


Fig. 3. Change detection in Chir pine cover between 2004-2009.

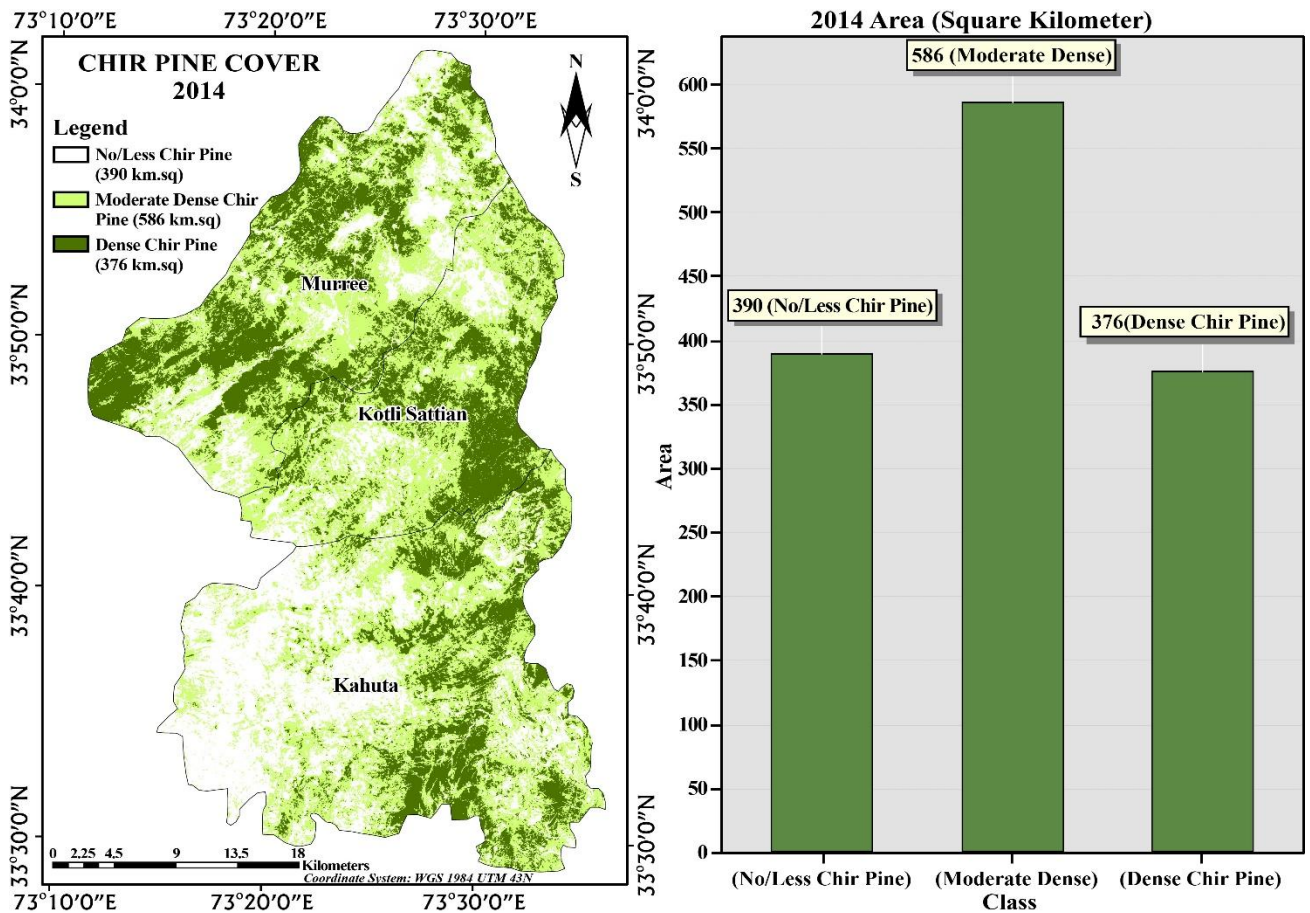


Fig. 4. Change detection in Chir pine cover between 2009-2014.

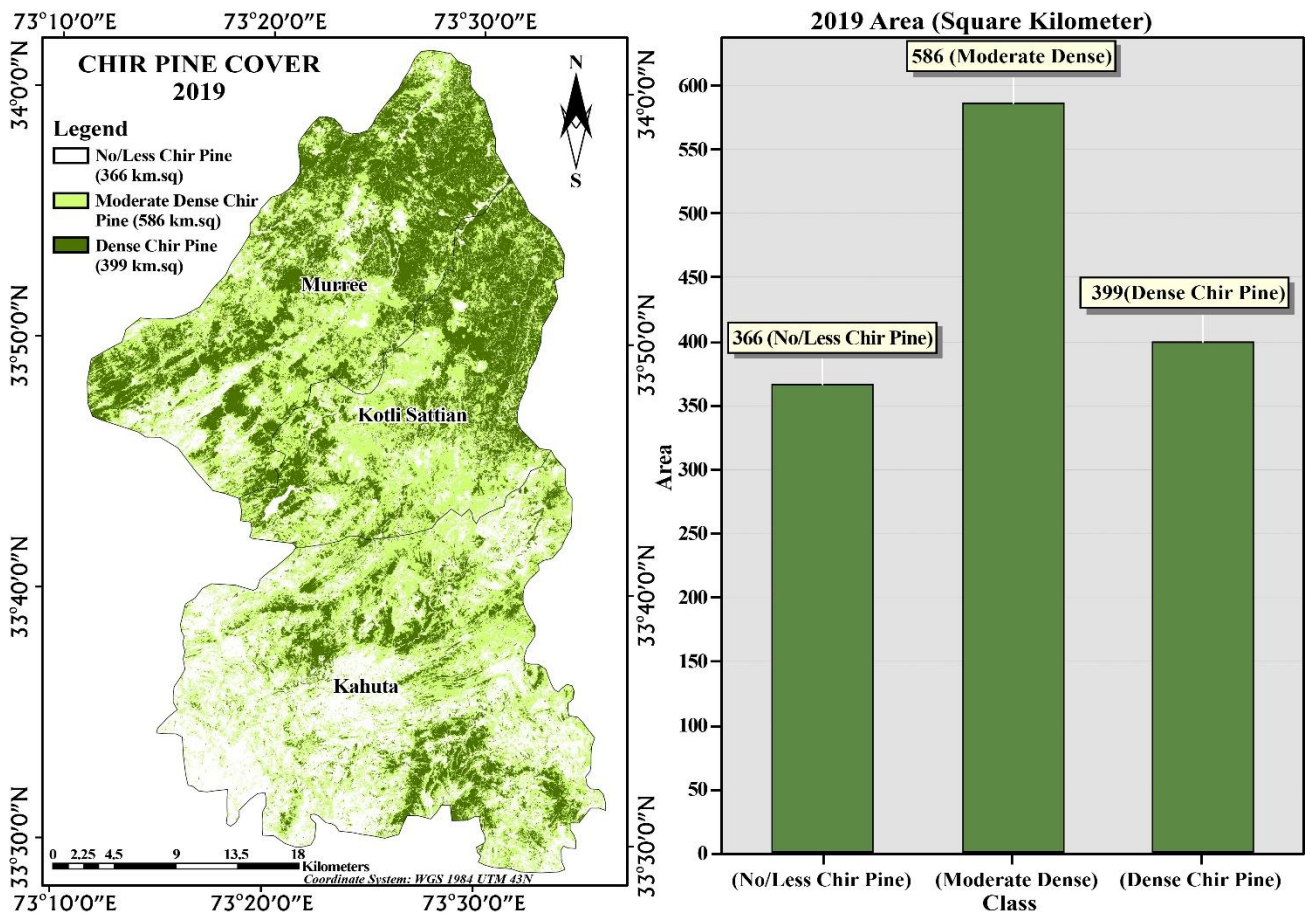


Fig. 5. Change detection in Chir pine cover between 2014-2019.

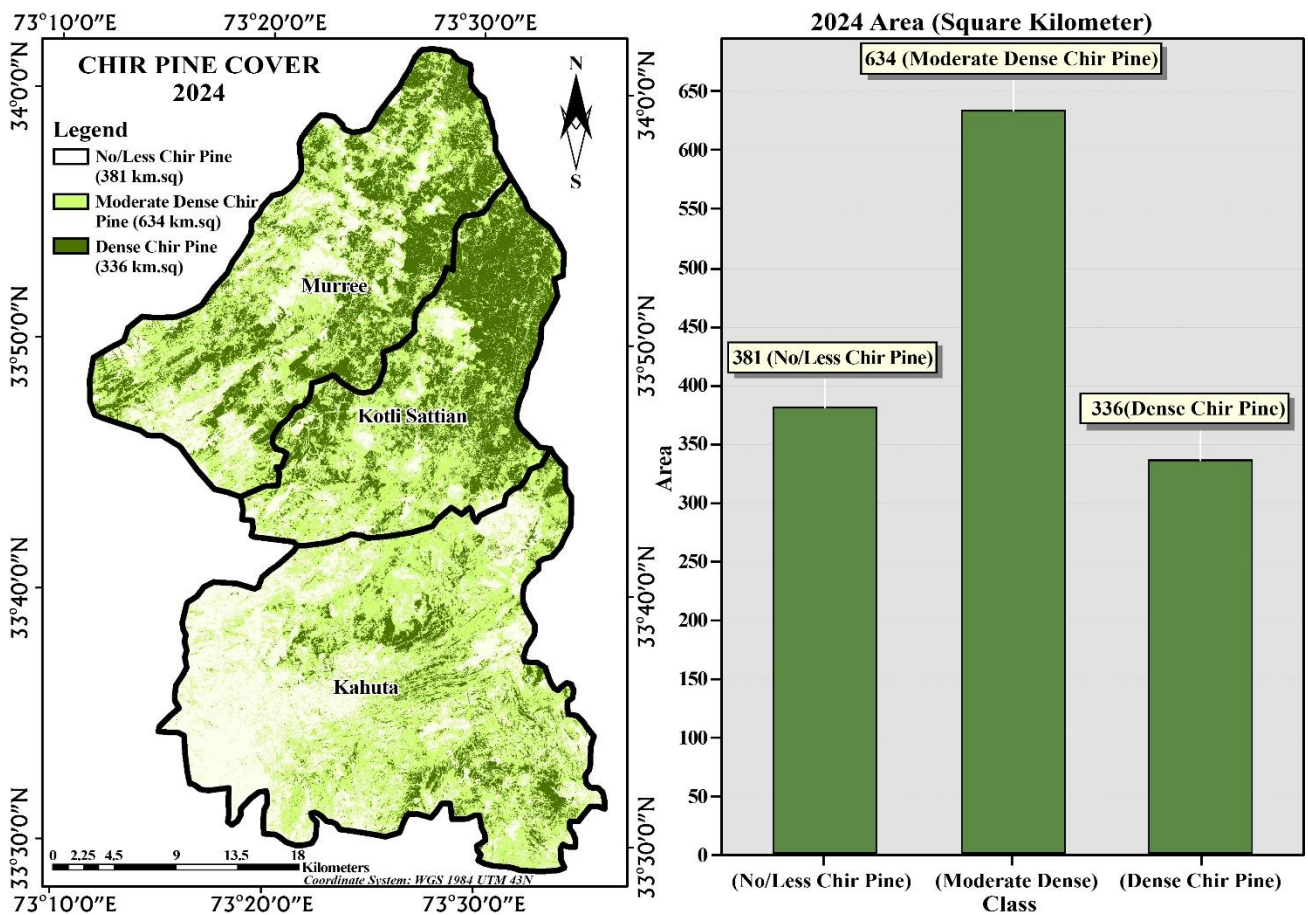


Fig. 6. Change detection in Chir pine cover between 2019-2024.

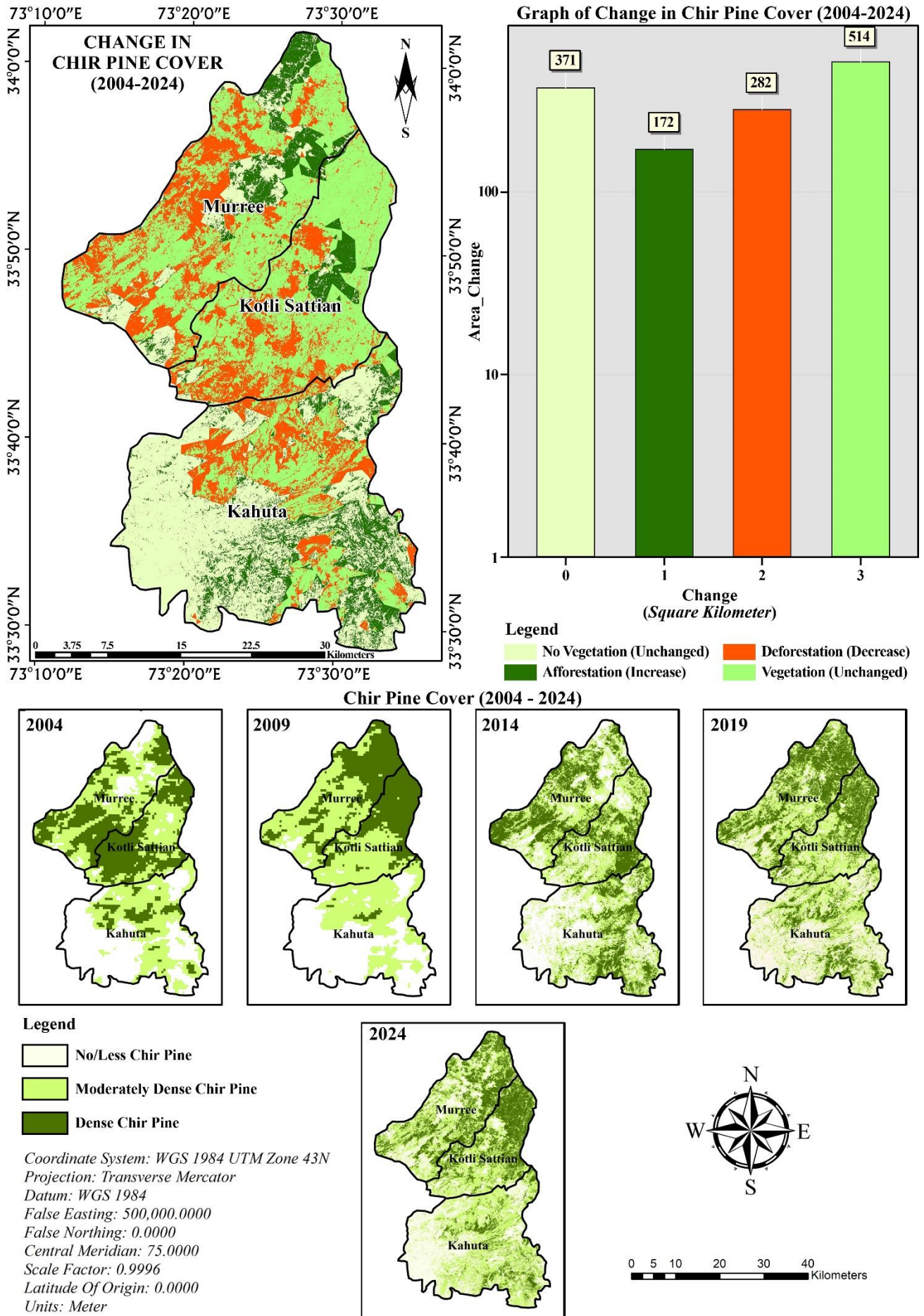


Fig. 7. Combined Map, Change detection in Chir pine cover for past 25 years.

## Discussion

The observed regeneration trends reflect the combined influence of anthropogenic pressure, disturbance regimes, and forest management practices. Periods of decline correspond with land-use change and fire incidence, while recovery phases suggest natural regeneration under reduced disturbance.

The increase in dense Chir pine cover between 2014 and 2019 aligns with regional reports of improved forest protection and reduced illegal harvesting. However, the subsequent decline after 2019 emphasizes the vulnerability of Chir pine forests to recurrent fire events and increasing fragmentation. Similar Spatio-temporal fluctuations have been reported in other Himalayan pine ecosystems, where regeneration success is strongly linked to disturbance intensity and management interventions.

Interpretation of long-term landscape-level trends (Saleem *et al.*, 2025; Rai *et al.*, 2020). This approach is particularly useful in data-scarce regions where historical ground validation is limited (Dangwal *et al.*, 2022; Dangwa & Tajinder; Dyola *et al.*, 2020). The subtropical Chir Pine Forests and managed under Punjab Shelter wood system. In this system whole forest is divided into four periodic blocks. In periodic block I, II, III AND IV, trees are with age of 1-25, 26-50, 51-75 and from 76-100 years. Sharma *et al.*, (2023) Rotation age of Chir pine is 100 years. Natural regeneration (through mother trees) is important for sustainable management with no or low cost. Artificial regeneration is generally carried out in the area deprived of mother trees, or after hazards like fire, floods or heavy erosion of soil. Sustainable management of these natural forests depends on regeneration. Dangwal *et al.*, 2022) Afforestation in these forests is too difficult/expensive and mortality rate is more as compare to artificial regeneration activities. In case of natural regeneration mortality rate is low due to the local seed well adopted to the local climate. However, fire incidents affect the regeneration. Occasionally Fire is also helpful in regeneration as the seeds come in contact to soil after burning of hay and leaves from ground surface (Hengesbaugh, 2021) I personally experienced that Where ever some earth work is being carried out for artificial regeneration, natural regeneration do come there and survival rate is more than seed sown for artificial regeneration. If we want these forests for future then we have to think and plan about regeneration. If there will be more regeneration, then less siltation in our reservoirs and water quality will be enhanced because these forests are important watershed for Mangla and Simli dams (Attri *et al.*, 2017).

Effect of spatio temporal changes on regeneration of chir pine was determined during last 25 years, the temporal classes were 1999-2004, 2004-2009, 2009-2014, 2014-2019 and 2019-2024. The satellites used were MODIS, Landsat 8 and Sentinel-2. During 1999-2004, moderate dense Chir pine cover was highest covering an area of 396 km<sup>2</sup>. This positive trend was due to less deforestation or less land use changes. The time between 2004-2009, a slight decrease in dense Chir pine cover was observed, the reason for negative trend was deforestation or land use change. During 2009-2014, dense Chir pine area remained largely stable including local conservation efforts or natural growth in certain areas. Less Chir pine area, an increase from previous years (Sharma *et al.*, 2023).

The time between 2014-2019, highest value of dense Chir pine cover was recorded as 634 km<sup>2</sup>. This shift may reflect ecological restoration projects or changes in local land management practices. Ecosystem services rendered by Chir pine forests were measured through questionnaire survey. These forests provide fuel wood, timber, fuel wood for matem, springs (water) and ecotourism. The last part was rehabilitation of Chir pine regeneration through Plant Growth Promoting Rhizobacteria. The isolated bacteria were applied on seedlings of chie pine and significant difference was observed in seedling height.

2019-2024 dense Chir Pine forests showing a decrease in some pockets, while overall forest fragmentation persists and Moderate Dense Chir Pine has escalated.

In between 1999-2004, Moderate Dense Chir Pine cover was highest followed by Dense Chir Pine Cover encompassing an area of 396 km<sup>2</sup>.

The 2009-2014 Landsat data revealed a more accurate picture of forest density. Although the area of less dense forest continued to expand, the dense Chir Pine areas remained largely stable, indicating local conservation efforts or natural regrowth in certain areas.

The 2014-2019 Sentinel-2 data demonstrated a slight recovery in dense Chir Pine areas (Highest Value recorded), alongside ongoing fragmentation in moderately dense forests. This shift may reflect ecological restoration projects or changes in local land management practices.

**Management and Policy Implications:** The findings of this study have direct relevance for forest management in Rawalpindi District and similar subtropical pine ecosystems. Periods of improved regeneration highlight the effectiveness of reduced disturbance and protection measures, while recent declines underscore the need for strengthened fire management and controlled grazing. The results demonstrate that freely available satellite data can support cost-effective, long-term monitoring of Chir pine regeneration, enabling forest departments to identify vulnerable areas, prioritize restoration efforts, and evaluate management outcomes over time.

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**Conflict of Interest:** There is no conflict of interest among authors.

**Author's Contribution:** Sajjad Haider Zaidi performed original research, Lubna Ansari did supervision, Aamir Saleem and Umer Habib provided technical expertise. Saud Aslam, Ambreen Bhatti and Kashif Hussain helped in field data collection.

## References

- Ahmed, S., M. Awais, M.M. Sadiq, A. Umar, L. Dufosse, M.T. Khan and R.M. Mahmoud. 2023. *Ganoderma multistipitatum* sp. nov. from Chir pine tree (*Pinus roxburghii* Sarg.) in Pakistan. *J. King Saud Uni. Sci.*, 35(3): 102554.
- Ali, S., S.M. Khan, Z. Siddiq, Z. Ahmad, K.S. Ahmad, A. Abdullah and E.F. Abd\_Allah. 2022. Carbon sequestration potential of reserve forests present in the protected Margalla Hills National Park. *J. King Saud Univ. Sci.*, 34(4): 101978.

- Ansari, L., W. Ahmad., A. Saleem., M. Imran., K. Malik., I. Hussain and M. Munir. 2022. Forest cover change and climate variation in subtropical Chir pine forests of murree through GIS. *Forests*, 13(10): 1576-1586.
- Attri, V., D.P. Sharma and R. Dhiman. 2017. Floristic diversity and natural regeneration status of chir pine (*Pinus roxburghii* sarg.) forest: a case study of Rajgarh forest division of Himachal Pradesh. *Bull. Environ. Pharm. Life Sci.*, 6 (3): 1-6.
- Ayer, S. 2023. Study of phytosociological parameters and carbon stock between two community forest of different ecological regions of Udaypur District of Nepal. *J. Multidiscip. Res. Adv.*, 1(2): 32-44.
- Bargali, H., L.P.P. Calderon, R.C. Sundriyal and D. Bhatt. 2022. Impact of forest fire frequency on floristic diversity in the forests of Uttarakhand, western Himalaya. *Trees For People*, 9: 100300.
- Bhavsar, D., A. Kumar and A. Roy. 2017. Applicability of NDVI temporal data base for western Himalaya forest mapping using fuzzy based PCM classifier. *Int. J. Environ.*, 25(44): 131-141.
- Chandran, M., A.R. Sinha and R.B.S. Rawat. 2011. Replacing controlled burning practice by alternate methods of reducing fuel load in the Himalayan Long leaf Pine (*Pinus roxburghii* Sarg.) forests. In: *5th International Wildland Fire Conference*, South Africa.
- Dangwal, B., S.K Rana, V.S. Negi and I.D. Bhatt. 2022. Forest restoration enhances plant diversity and carbon stock in the sub-tropical forests of western Himalaya. *Trees, Forests and People*, 7(3): 100201.
- Dangwal, L.R. and S. Tajinder. 2012. Comparative vegetational analysis and *Pinus roxburghii* Sarg. regeneration in relation to their disturbances in some Chir pine forest of block Nowshera, district Rajouri, J and K, India. *ISCA J. Biol. Sci.*, 1(1): 47-54.
- Dyola, N., D.R. Bhujju, D.K. Kharal, S. Aryal, N.P. Gaire and L. Hitler. 2020. Growth pattern of *Pinus roxburghii* under different regimes of invasive species in Panchase, Nepal Himalayas. *Pak. J. Bot.*, 52(1): 261-270.
- Fule, P.Z., S.C. Garkoti and R.L. Semwal. 2021. Frequent burning in chir pine forests, Uttarakhand, India. *Fire Ecol.*, 17(1): 1-11.
- Glenny, W., J.B. Runyon and L.A. Burkle. 2022. A review of management actions on insect pollinators on public lands in the United States. *Biodiv. Conser.*, 31(8): 1995-2016.
- Gupta, B., R. Mehta and V.K. Mishra. 2009. Fire ecology of ground vegetation in *Pinus roxburghii* Sargent plantations in North-West Himalaya—floristic composition and species diversity. *Casp. J. Environ. Sci.*, 7(2): 71-78.
- Hengesbaugh, M. 2001. *Creatures of habitat: the changing nature of wildlife and wild places in Utah and the Intermountain West*. Utah State University Press.
- Hussain, A., H. Ullah, M. Zubair, N. Alam, L. Ansari, U. Habiba and S. Alam. 2019. Impact of environmental variables and anthropogenic activities on the regeneration of Chir Pine (*Pinus roxburghii*) Forests in District Swat, Pakistan. *Fresenius Environ. Bull.*, 28(11A): 8736-8744.
- Hussain, A., M. I. Ashraf, S. Hussain, M. Atif and B.A. Khan. 2024. Impacts of wildfire on soil characteristics in subtropical Chir Pine forests of Murree, Pakistan. *Int. J. Appl. Exp. Biol.*, 3(1): 61-67.
- Joshi, V. C., V. S. Negi., R. C. Sundriyal and D. Arya. 2024. Temporal changes in species richness, composition and diversity of the forest stands over 36-year period, Western Himalaya, India. *Trees, Forests and People*, 16(4): 100572.
- Konsam, B., S.S. Phartyal, M. Kumar and N.P. Todaria. 2017. Life after fire for understory plant community in subtropical Chir pine forest of Garhwal Himalaya. *Ind. Forest.*, 143(8): 759-766.
- Kumar, A., R. Pandey and S. Singh. 2022. Seed dispersal mechanisms and regeneration dynamics of *Pinus roxburghii* in forest ecosystems. *J. Ecol. Forest.*, 144(9): 766-778.
- Kumar, M., H. Singh, J.A. Bhat and G.S. Rajwar. 2013. Altitudinal variation in species composition and soil properties of Banj Oak and Chir Pine dominated forests. *J. For. Environ. Sci.*, 29(1): 29-37.
- Kumar, R. and R. Pandey. 2022. Analyzing the impact of burning on vegetation in Himalayan chir pine (*Pinus roxburghii* Sarg.) forests, India. *Appl. Ecol. Environ. Res.*, 20(2): 113-127.
- Malik, S.U., M.I. Ashraf and M.A. Goheer. 2023. Spatio-temporal dynamics of greenhouse gas emissions from soil in forest ecosystems of Pakistan. *Pak. J. Bot.*, 55(4): 1449-1458.
- Muhammad, S., A. Ali., K. Mehmood., H. Ahmad., M. Hayat., M.T. Khan and S. Fahad. 2024. Temporal variations in burn severity among various vegetation layers in subtropical *Pinus roxburghii* (Chir Pine) forest of Hindu Kush mountain range. *Trees, Forests and People*, 18: 100664.
- Rai, P.B., R.R. Sears, D. Dukpa, S. Phuntsho, Y. Artati and H. Baral. 2020. Participatory assessment of ecosystem services from community-managed planted forests in Bhutan. *Forests*, 11(10): 1062.
- Saha, S., B. Bera, P.K. Shit, S. Bhattacharjee, D. Sengupta, N. Sengupta and P.P. Adhikary. 2023. Recurrent forest fires, emission of atmospheric pollutants (GHGs) and degradation of tropical dry deciduous forest ecosystem services. *Total Environ. Res. Themes.*, 7: 100057.
- Saleem, M.F., H. Akhter and M.A. Khan. 2025. Assessment of forest fire vulnerability in Chir pine forest of Pallandri, Azad Jammu and Kashmir (AJK) Pakistan. *Global Forests*, 12(15): 230-242.
- Sharma, U., R. Kaushal and Y.P. Sharma. 2022. Effect of forest fires on soil carbon dynamics in different land uses under NW Himalayas. *Ind. J. Ecol.*, 49(6): 2322-2329.
- Shiva, K. 2023. Temporal variations in subtropical *Pinus roxburghii* (Chir Pine) forest of Hindu Kush mountain range. *Trees, Forests and People*, 23: 100664.
- Singh, J.A. Bhat and G.S. Rajwar. 2023. Species composition in Chir Pine dominated forests. *J. For. Environ. Sci.*, 30(3): 37-48.
- Tian, X., C. Tang, X. Wu, J. Wang, F. Zhao and D. Liu. The global spatial-temporal distribution and EOF analysis of AOD based on MODIS data during 2003–2021. *J. Atmos. Environ.*, 302(9): 676-691.
- Tiwari, G. 1994. Assessment of Spatio-temporal changes in Chir pine in Uttranchal. *Int. J. Appl. Earth Obser. Geoinform.*, 130(7): 272-281.
- Zarzeluo, C., A. Lopez, M. Bermudez, M. Ortega and I. Caballero. 2025. Monitoring intertidal ecosystems: Assessing spatio-temporal variability with Sentinel-2 and Landsat 8. *Int. J. Appl. Earth observation and Geoinformation.*, 142(8): 104-120.
- Zobel, W., R. Lopez, M. Cablerro and N. Rajwar. 2001. Altitudinal variation in species composition of Chir Pine dominated forests. *J. For. Environ. Sci.*, 27(3): 114-129.