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FOREST FIRE RISK ASSESSMENT AND MITIGATION IN SUB TROPICAL CHIR PINE FOREST OF MURREE

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ABSTRACT
Forest fires engulf massive portions of forests, wildlife sanctuaries, and nearby communities all over the world. Improvements in forest fire risk assessment and effectively mapping fire-prone zones play a crucial role in minimizing the adverse consequences of wildfires and enabling strategic conservation of forest ecosystems. This holds particular significance in areas with limited historical fire data. This research aims to analyze the factors contributing to wildfire occurrences in the subtropical chir pine forest of Murree and to develop effective mitigation measures. By employing a comprehensive approach that incorporates spatial analysis, climatic variables, vegetation characteristics, and historical fire data, the research seeks to provide insights into the underlying causes of forest fires. The findings contribute to the development of targeted strategies for reducing fire risks, enhancing forest resilience, and preserving the ecological integrity of the Murree chir pine forest.

Keywords:*Chir pine, Forest, Forest fire, Mitigation, Murree*

INTRODUCTION
Fire, has been complexly linked with human being since the dawn of civilization. The impact of fires ignited by human agency undoubtedly traces its origins back to the entrance of the first humans in the subcontinent. The gravity of this issue has escalated considerably due to the rapidly increasing human and livestock populations, coupled with the resulting surge in the need for forest resources from both individuals and communities (Bahuguna & Upadhyay, 2002).

Wildfires create substantial disturbances in forest habitats, primarily driven by extreme summer temperatures and limited moisture availability. Another leading factor contributing to the outbreak of fires is the complete dryness of biomass accumulated on the forest floor. Unfortunately, with the impact of global warming, this situation is expect to worsen in the future, further exacerbating the issue and becoming a significant driver of global warming (Giorgi, 2006; Turco, Llasat, von Hardenberg, & Provenzale, 2017).

Across the globe, wildfires are a natural phenomenon and an integral part of forest habitats, their impacts varying depending on the specific fire regime in each region (Bento-Gonçalves, Vieira, Úbeda, & Martin, 2012).

Annually, a staggering 340 million hectares of vegetated land surface around the world fall victim to devastating forest fire, accounting for 3.5% of global disasters and incurring a staggering $68 million USD in damages. Tropical forests, spanning between 150 up to 250 million hectares, are especially vulnerable to these conflagrations. The Mediterranean region annually witnesses the scorching of 0.7 to 1 million hectares of vegetation. Shockingly, 90-95% of these forest fires stem from human activities, arising from a complex interplay of factors including suboptimal practices, limited access to alternative firefighting methods, unfortunate accidents, Inadequate comprehension of fire hazards, machinery mishaps, negligence, and carelessness (FAO, 2021; SOTWP, 2017).

Forest fire are frequently observed in Pakistan. As evidenced by a survey conducted by the Pakistan Forest Institute in 2000, approximately 1.27 percent of the total area, which amounts to 49,986 hectares has been adversely affected by such fires within the expansive 3.950 million hectares of forested land. Among the areas facing substantial jeopardy is the Margalla Hills forest in Islamabad, Pakistan, where wildfires pose a considerable threat. Over a period spanning from May 2005 to July 2018, a distressing 25,812 hectares of the Margalla Hills forest succumbed to the ravaging flames. Consequently, preserving forest resources within the Margalla, Islamabad region stands as a pivotal contemporary challenge (Tariq et al., 2020).

During the past two years, the province of Khyber Pakhtunkhwa has witnessed the reporting of nearly 90 forest fires, which collectively led to the destruction of over 100,000 trees (Earth Enable, 2019).

Fire bears a dual nature concerning its environmental impacts. Often associated with harmful consequences, it inflicts damage and devastation upon wildlife and natural ecosystems. Paradoxically, it can also prove beneficial to our flora and fauna. For instance, the thermal effects of fire on the soil lead to the rupture of seed coverings, promoting germination. Moreover, the heat triggers the opening of woody seed pods in the canopy, facilitating the dispersal of seeds onto the enriched ash deposit below. Thick understory vegetation is cleared through the fire's action, thereby reducing competition among seedlings. This, in turn, fosters new growth, providing sustenance for a diverse array of creatures. However, the aftermath of fire can be detrimental, especially in vulnerable ecosystems like rainforests, where recovery may take centuries. Individual plants or animals may perish or suffer injury in the fire's wake. Furthermore, fire can instigate erosion, leading to sedimentation in creeks and wetlands (NSW, 2021).

Extensive research has been conducted on the influence of wildfires on wood production, tree regeneration, and animal composition (Mataix-Solera, Cerdà, Arcenegui, Jordán & Zavala, 2011). While fires are a natural ecological element, human activities in the area, including grazing and tourism, have escalated the frequency of these disturbances over the past five decades. Wildfires have significant effects on soil properties, encompassing physical, chemical, and biological alterations (Rey, Vasquez, Marco & Prieto, 2013)

When a forest fire ignites suddenly, analyzing its behavior becomes challenging due to the difficulties in gathering the necessary simulation parameters. Utilizing models, maps, and databases within a geospatial information system (GIS) enables the simulation of fire scenarios and the collection and analysis of data from forests at the greatest risk of fire outbreaks. These approaches can help mitigate the risk of forest fires and potential Natechs, such as the strategic placement of lookout towers and patrols in high-risk zones and the development of land use plans based on risk assessments. Additionally, it is possible to integrate data on fire hazard levels and forest accessibility with facility distribution in high-risk regions. Alternatively, satellite imagery and remote sensing (RS) analysis can be widely employed to detect and monitor fire behavior for operational purposes. These technologies not only offer increased efficiency and precision compared to traditional survey methods but also contribute to time and resource savings, ultimately safeguarding human lives (Minas, Hearne & Handmer, 2012).

Planning efforts and fire risk reduction may benefit from new information provided by considering the spatial analysis scale for fire occurrence (Yang et al., 2007). Strategies and tactics for preventing fires rely on knowledge regarding the spatial arrangement of fire incidents (Tian et al., 2013). Therefore, GIS-based wildfire risk assessment could be a feasible option for sites where the above methods are not applicable. This methodology has been applied to create forest fire hazard zoning maps that connect the environmental factors of a region with the possibility of forest fires, allowing for the identification of risk potential in various ecosystems. However, prior studies of GIS-based forest fires have paid minute attention to the integration of natural forest geographies as a measure to evaluate forest fire hazards & map risk zones. In addition, more evidence is required to enhance our concept of the spatial and temporal variation in forest fire risk. The key objective of this research is to develop a better conceptual framework for fire hazard mapping and to explore the spatio-temporal fluctuations in forest fire hazards associated with changes in the landscape (Shinneman et al., 2012; Helfenstein & Kienast, 2014; Hernandez-Leal et al., 2006).

One way to estimate the risk of forest fires is to use Canadian Fire Weather Index (FWI) System, which is a tool for applied forestry. However, FWI does not consider how different types of forest cover affect fire risk, and it depends on weather data that are interpolated from point sources. A possible solution to this problem is to use satellite remote sensing data, which can cover large areas and collect data from remote locations without harming the environment. Remote sensing methods can also provide a more efficient and timely way to evaluate the danger of wildfires, as they can measure variables that influence fire ignition, examples include the moisture and temperature levels of both living and deceased vegetation. By using optical and thermal infrared sensors, remote sensing methods can estimate the live (FMC) and the (LST). These estimates can be combine with the (NDVI) to calculate the ratio NDVI/LST, which has a clear relationship with live FMC (Chuvieco, Deshayes & Stach, 1999).

Many studies have explored different fire risk indices based on remote sensing data. However, these indices do not consider the heat energy of the fuels before they ignite, and they rely on reflectance data from remote sensors. We used data from the (ASTER) (Dasgupta, Qu, & Hao, 2006). The direct effect of households on fire spread at the landscape level is not considered by any existing model. Previous studies have shown that simple models of landscape dynamics can successfully reproduce the main features of complex landscape patterns. In this study, we use a simple model of fire spread to examine if a small number of houses can significantly influence fire propagation at the landscape level, depending on whether they are resistant to fire or not. We only considered homogeneous landscapes and fire spread as a simple percolation phenomenon, with fixed densities and flammabilities of houses. Other factors that influence actual fire spread, such as wind, topography, fuel variability, firebrands, and weather, are not included in this study. Therefore, more detailed fire models are needed to apply the current theoretical results in practice. Our model simulates the landscape as a two-dimensional grid of 48 _ 48 cells. A random fraction d of cells are houses, while the rest are vegetation cells. Fire starts in a randomly selected cell and moves to adjacent cells. Cells can only burn once and the edges of the grid are nonflammable cells. Fire spreads from a burning vegetation cell to any of its eight unburned neighboring cells as a random event with probability (Keane et al., 2004)

Evaluating the risk of forest fires is a crucial part of managing and conserving forests. It is important to understand the elements that influence fire risk, including vegetation types, landscape features, climate, and human actions, to create effective strategies for reducing this risk. In the chir pine forests of Murree, these factors interplay in intricate ways, requiring a thorough risk assessment approach. Recent progress in remote sensing along with geographic information systems (GIS) has introduced innovative implements for assessing fire risk and observing forest conditions, providing forest managers and policymakers with essential information (Chuvieco et al., 2014).

Effective strategies to mitigate forest fires need to be comprehensive, focusing on both preventing fires and lessening their effects. In Murree, this includes creating firebreaks, conducting controlled burns, and involving the local community in fire prevention and response. Key elements of a thorough fire mitigation plan are educational and awareness initiatives, better infrastructure, and early warning systems. Combining traditional knowledge with modern technology can improve the success of these strategies (Mutlu et al., 2020).

Climate change significantly affects the dynamics of forest fires, impacting their frequency and intensity. In subtropical areas such as Murree, shifts in weather patterns, extended dry periods, and rising temperatures are expected to heighten fire risks. Consequently, assessments and mitigation efforts must take the long-term effects of climate change into account. Adaptive management strategies that use climate models and forecasts can aid in creating resilient forest management practices capable of enduring future climatic changes (Flannigan et al., 2009).

The main objectives of this research synopsis describe the problem of forest fires in the northern region of Pakistan, where sub-tropical forests and chir pine trees are found. The dry sub-tropical climate makes the forests prone to fire, which affects both the trees and the people nearby. The research synopsis also mentions that Pakistan needs more fire management plans and research to understand and reduce the fire risk.

PROBLEM STATEMENT

Sub-tropical forests are found in the northern region of Pakistan, which face a significant risk of forest fires due to the prevailing dry sub-tropical climate. These fires pose a considerable threat to the growth and survival of chir pine trees and also cause harm to nearby human communities. Unfortunately, Pakistan's lack of active fire management plans and limited scientific research at national levels delays our understanding of forest fire risk assessment and mitigation. Addressing these issues is crucial to better protect these vulnerable ecosystems and the people living in their vicinity.

OBJECTIVES

This research has following objectives.

1.To evaluate the factors contributing to forest fire vulnerability in sub-tropical chir pine forest of Murree.

2.To detect fire prone areas in chir pine forest of Murree through GIS modeling.

REVIEW OF LITERATURE

Weibin Youa et al. (2017) reported that this research work delves into the significance of enhancing forest fire risk assessment and the creation of fire risk zone maps to mitigate the adverse consequences of wildfires and strategize for safeguarding forested regions. The study introduces a developed theoretical framework for evaluating and creating a fire risk map through the use of fire return interval departure (FRID), which depends on four crucial factors: topography, anthropogenic activities, environment factors, and forest physiognomies. Within this context, the study specifically identified 12 variables in accordance with the outlined conceptual framework to construct a composite forest resource inventory (FRI) for quantifying probable fire hazards and delineating risk zones within the work system design (WSD), situated in the northwestern region of China. The findings revealed that the primary fire risk areas within the work system design (WSD) predominantly fell within the low to moderate risk categories, constituting 76.7% of the total work system design (WSD) area in 1997 and increasing to 79.2% in 2009. Three-dimensional variability in forest resource inventory (FRI) exhibited anisotropic physiognomies that evolved over time, with the years 1997 to 2009 witnessing an escalating the impact of both autocorrelation and stochastic elements. Notably, these factors played nearly equal roles in influencing forest fire dynamics within the work system design (WSD). Additionally, the study utilized a fire risk map to evaluate the susceptibility of cultural legacy assets within the work system design (WSD), most of which were situated in areas with a limited to moderate level of risk, consequently facing a low risk of potential fire-related damage.

Mohsen Naderpoura et al. (2019) stated that, forest wildfires present a significant peril to forests, communities, and industrial facilities on a global scale. Furthermore, these fires have the potential to trigger technological mishaps, commonly referred to as natural hazards triggering technological accidents (Natechs). One of the widely recognized approaches for predicting forest fires and evaluating the risk of Natechs resulting from forest fires involves utilizing spatial parameters in fire modeling. This investigation constitutes a comprehensive examination of GIS-based methodologies for modeling forest fire and their associated Natechs, which have been adopted worldwide. The research methodically scrutinizes the techniques employed in the assessment of forest fire susceptibility, hazard levels, and overall risk, categorizing them into four overarching groups: (a) Models based on statistics and data analysis; (b) Models utilizing machine learning

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techniques; (c) Models employing multi-criteria decision-making approaches; and (d) Models that combine different methods into ensembles. The findings of this study can aid decision-makers in the selection of the most suitable methodologies tailored to definite forest circumstances. The outcomes reveal that data-determined methods are the most commonly employed techniques, whereas ensemble approaches demonstrate superior accuracy.

The study by Aqil Tariq et al. (2021) examined this study employed machine learning techniques and integrated socio-economic and environmental data to analyze the spatial and temporal trends in forest fire incidents within the Margalla Hills region in Islamabad, Pakistan. The primary drivers behind forest fires in this area were found to be human activities and socio-economic factors that influenced their occurrence. The research considered a range of environmental factors, including altitude, precipitation, forest type, terrain, and humidity index, in addition to socio-economic variables such as population density, distance from roads, and proximity to urban areas. These variables were utilized to gain insights into how human behavior influenced the risk of fire outbreaks.

To forecast the likelihood and spatial distribution of forest fires in the Margalla Hills, the study applied two distinct machine learning methods: maximum entropy modelling (Maxent) and random forest (RF). The evaluation of these models was conducted using the receiver operating characteristic (ROC) curve and the corresponding area under the receiver operating characteristic (ROC) curve area under the ROC curve (AUC). The research also conducted an analysis of the fire history spanning from 1990 upto 2021, aiming to establish the relationship between fire probability and changes in socio-economic and environmental factors. Notably, the AUC values for fire probability using the Maxent model were 0.532, 0.569, and 0.518 for the 1990s, 2000s, and 2010s, respectively. In contrast, the AUC values for the random forest model were 0.782, 0.825, and 0.789 for the same time periods, indicating a higher level of accuracy. The study revealed that fires predominantly occurred in urban areas and were closely linked to accessibility and human activities/behavior. Consequently, the random forest models demonstrated superior validation AUC values. These findings hold the potential to inform the development of preventive strategies aimed at reducing the risk of forest fires by considering both socio-economic and environmental factors.

Wittenberg, van der Wal, Keesstra and Tessler (2020) reported that in November 2016, the District of Haifa in Northern Israel’s urban dry streams (wadis) was engulfed in flames. However, the fire was not the only threat to the urban areas. The precipitation that followed could have resulted in urban flooding, which would have exacerbated the damage caused by the fire. In order to restore the burnt areas and prevent future occurrences, a substantial rehabilitation initiative was launched several months after the fire. The rehabilitation plan for urban forests was devised and executed in consideration of the topographical layout of the burned region and the anticipated soil erosion.

Among all the sites examined, the control site (burned and left unmanaged) exhibited the highest levels of soil water level, organic substance, and electrical conductivity. Nevertheless, the presence of ash cover posed challenges in predicting precipitation responses. According to the findings, these disparities in hydraulic conductivity (K) between the ash and soil layers resulted in precipitation infiltrating primarily through the ash layers, leading to soil erosion as water flowed along the ash-soil interface. Most of the salvaged sites exhibited erosion indicators, with only downstream areas being shielded by log barriers. Afforestation was identified as a means of promoting soil homogenization, although the resulting vegetation cover was expected to be less dense and stable compared to natural reforestation.

Miguel E. Castillo Soto (2012) proposed a new method to assess regions prone to forest fires, a methodology was developed that integrates three geographical factors: the geographical distribution of fire incidents, the road network, and regions characterized by an urban-wildland interface. This research selected a specific area in central Chile, situated at latitude 33S, as a case study and applied fuzzy logic to analyze these variables. Through this approach, the study pinpointed irregular areas that captured the cumulative impacts of these criteria.

In practical terms, the spatial outcomes of this model were indicative of the size and configuration of areas with a higher incidence of forest fires and associated losses. This fusion of variables resulted in a notable increase in the overlap of critical regions, ranging from 66.02% to 252.09%, particularly in areas with heightened fire severity. The collective influence of these criteria enabled the creation of geographical information layers that can be further integrated with other territorial variables to formulate a comprehensive fire protection model.

Neuendorf (2020) recommended fires are a strategy to minimize fuel loads in response to the rise of wildfires in the US and globally. After a fire, the total organic matter shows noticeable changes in its appearance; however, the fire also produces hydrophobic substances due to the partial burning of organic matter, which can change the soil's ability to absorb substances. This study aims to examine how soil profiles collected from the field after different stages of prescribed burning are affected.

Keeley (2009) stated that forest fire regimes, which include factors like frequency, intensity, and spatial distribution, are shaped by both natural conditions and human activities. In the subtropical chir pine forests of Murree, comprehending these fire regimes is vital for crafting effective fire management strategies. Analyzing historical fire data can reveal patterns that are essential for assessing risks and developing mitigation measures.

Flannigan, Stocks, & Wotton (2000) describe that Climate plays a crucial role in forest fire risk by changing temperature, precipitation, and wind patterns. Studies indicate that climate change is raising the probability of fires by creating hotter and drier conditions. This issue is especially pertinent in subtropical areas like Murree, where adaptive fire management strategies are necessary to address these evolving conditions.

Ansari, et al. (2022) concluded that forests are crucial natural resources, providing essential benefits such as carbon storage, oxygen production, soil protection, and water cycle regulation. However, despite these important services, forests are being destroyed at an alarming rate. In Murree, Pakistan, recent changes in forest cover have exacerbated various climatic issues. There has been a noticeable lack of research on how changes in forest cover affect climate variations in Murree, underscoring the need to address this gap. Additionally, monitoring the causes of deforestation is vital for developing effective mitigation strategies. This study aims to evaluate changes in forest land in Murree subtropical Chir pine forests from the past two decades (2001–2021) and correlate these changes with climatic parameters, including lowest and extreme temperatures and rainfall, during this period. The finding also seeks to categorize the primary drivers of logging in the area. Using a supervised classification technique (Maximum Likelihood Classification) with GIS, five different land-use land-cover (LULC) categories were delineated and ordered. The accuracy of these classifications was assessed using KAPPA analysis. Climatic statistics were interpolated using empirical Bayesian kriging (EBK) and correlated with forest cover changes explicitly. A questionnaire and SPSS analysis were employed to identify the drivers of deforestation. The results revealed an 8.26% decrease in forest area in Murree from 2001 to 2021. The main drivers of deforestation were identified as fuelwood collection (54%), agricultural growth (22%), timber production (16%), and urban development (8%). During this period, the normal extreme temperature increased by 0.26°C, the average minimum temperature by 1.71°C, and rainfall decreased yearly by 139.8 mm, suggesting that the decline in forest cover has contributed to rising temperatures and decreasing rainfall in Murree.

Agee & Skinner (2005) explain the flammability of various vegetation types significantly influences fire behavior. In chir pine forests, the buildup of resinous needles and other debris can result in severe fires. Proper management of this vegetation is essential for lowering fire risk and improving forest resilience.

Fernandes & Botelho (2003) elaborate that managing fuel loads through techniques such as controlled burns and mechanical thinning is crucial for decreasing fire severity. In Murree's chir pine forests, these practices can help lessen the threat of large, destructive fires. Successful fuel load management involves meticulous planning and implementation to ensure that fire risk reduction is balanced with maintaining ecological health.

Chuvieco & Kasischke (2007) examine the use of remote sensing (RS) in addition to geographic information systems (GIS) has transformed forest fire management, allowing for the monitoring of fire-prone regions, evaluating vegetation health, and tracking ongoing fires. These technologies greatly improve fire risk assessment and mitigation efforts in the chir pine forests of Murree.

PENG Guang-xiong et al. (2007) reveal new the fire susceptibility index (FSI) serves as a tool for assessing the risk of forest fires by leveraging the fundamental concept of the heat energy present prior to ignition. FSI calculations necessitate data inputs related to fuel temperature and fuel moisture content (FMC), which can be derived from remote sensing information. In the context of peninsular Malaysia, FSIs were computed for a span of nine days leading up to the fire incidents in 2004 and 2005 and subsequently validated using fire occurrence data. The findings indicate that FSI values tend to rise as the day of the fire event approaches, implying that FSI can effectively gauge fire risk. Moreover, FSI can be applied to compare fire risk levels across various ecological regions and time periods, while also offering the adaptability to be tailored to specific vegetation types or ecological regions to enhance its predictive accuracy.

Alan et al. (2010) studied the effects of fuel reduction treatments near or far from residential buildings in Oregon, US, for forest health and restoration. We simulated 10,000 wildfires with extreme conditions and considered the burn likelihood and flame length for each cell in the area. We also estimated the wildfire risk for 170 buldings and the expected death of large trees. We found that treatments far from buildings reduced the wildfire loss of large trees by 70% and also lowered the burn probability and flame length around buildings. These results show the benefits of fuel treatments in the wildlands that are often ignore in previous research.

Materials and Methods

Study Area

The Murree hills of Pakistan covers approximately 80,000 hectares. The latitude and longitude of the given study area varies from 33° 47′ 15″ to 33° 54′ 47″ N and 73° 16′ 54″ to 73° 29′ 18″ E. The altitudes vary between 939 and 1873 meters above sea level, giving rise to three distinct forest types: a moist temperate forest at the highest points, a sub-tropical Chir pine forest in the middle, and a sub-tropical Broad-leaved forest at the lower foothills. Within the study area, the mean annual precipitation spans ranging 500 to 1200 mm, accompanied by temperature fluctuations between 5°C during cold winter and 40°C in sizzling summer.

Physiography

Murree Hills, located in northeastern Punjab, Pakistan, form a significant part of the Murree District's landscape, known for its scenic beauty and lush forests. The region's unique physiographic features, including varied altitudes, steep slopes, and rugged terrain, significantly influence the local climate, biodiversity, and human activities. The hills, part of the outer Himalayas, stretch from 600 to over 2,300 meters above sea level, creating diverse microclimates and habitats. This complex topography, along with substantial monsoon rainfall and a subtropical highland climate, supports a rich variety of flora and fauna, including Chir Pine, Blue Pine, and Deodar forests.

The geological composition encompasses shales, sandstones, limestone, and marls as predominant sedimentary rocks. The soil itself holds a loamy texture, consisting of diverse proportions of sand, silt, and clay. Situated in the native domain of the Chir forest, the research site is subject to management through the shelterwood Silvicultural system.

Hydrologically, the Murree Hills are characterized by numerous streams and rivers, fed by rainfall and snowmelt, which are vital for the region's water supply and agriculture. Human settlements, primarily small villages and towns, dot the landscape, with Murree town serving as the main urban center and a popular tourist destination. While tourism boosts the local economy, it also brings environmental challenges such as deforestation, soil erosion, and water pollution. The diverse vegetation and land use, primarily forest-based with limited terrace farming, provide essential ecosystem services like soil stabilization,

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water regulation, and carbon sequestration

Climate

Murree Hills experience a subtropical highland climate, significantly cooler and wetter than the surrounding plains. The climate varies with altitude, with higher elevations experiencing colder temperatures and more precipitation. The area receives substantial rainfall, especially during the monsoon season (July to September), which supports dense forest cover and diverse flora and fauna. Winters (November to February) are cold, with snowfall common at higher elevations, while summers (May to August) are mild and pleasant.

Vegetation and land use

The dominant tree species prevailing in the region is Pinus roxburghii, commonly referred to as chir Pine. Other notable companion trees in the area encompass Pinus wallichiana (kail), Quercus incana (rhin), and Pyrus pashia. In the understory vegetation, a diverse range of plant species can be found, including Myrsinea africana (khukhal), Adhatoda vasica (Bahekar), Berberis lycium spp. (sumblu), Carissa spinarum (granda), Dodonaea viscosa (sanatha), cannabis sativa and Capparis decidua (karir).

These forests provide critical ecosystem services such as soil stabilization, water regulation, and carbon sequestration. Land use in the region is primarily forest-based, with limited agricultural activities due to the steep terrain. Terrace farming is practiced in some areas, growing crops like maize, wheat, and vegetables.

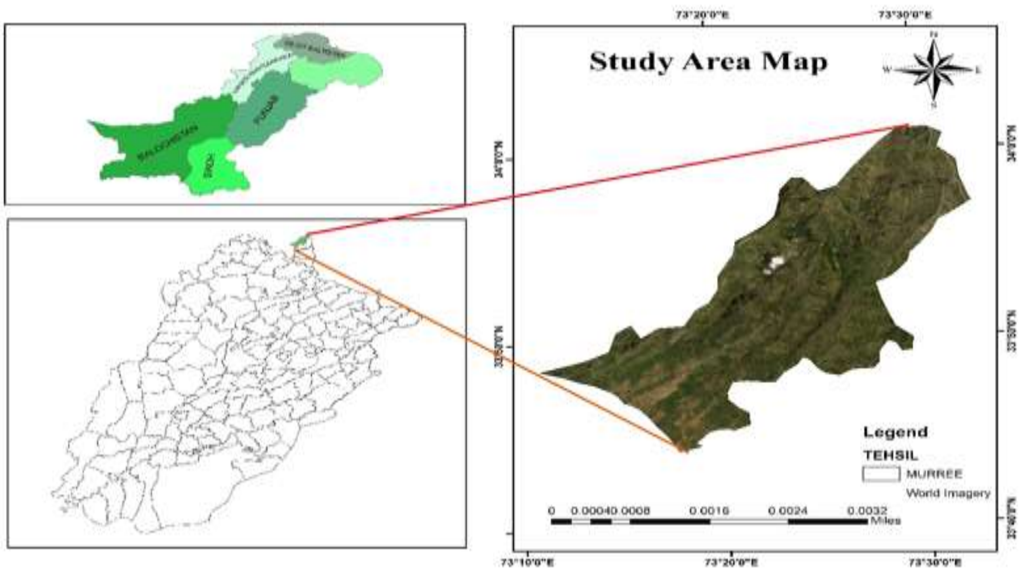

Figure 1: Map of the study area in province of Punjab.

METHODOLOGY

To fulfill the objectives of this research two different methods were applied, one social survey method which was based on questionnaire. The data was gathered using a social survey method. Participants were chosen using a purposive sampling strategy, specifically from villages that were either severely affected by fire seasons or located near high-risk fire zones and the second one through GIS modelling.

Preparation of an interview schedule

To collect data, a questionnaire was developed as the research instrument, containing a total of 33 questions. These questions included both structured and unstructured formats. Prior to the main data collection, the questionnaire was pre-tested with five individuals from the target study area. The pre-test revealed that eight of the questions were challenging to answer due to their technical nature.

The Murree Forest Division office was visited, and relevant staff members were interviewed regarding forest fire incidents and the actions taken by forest department officials. Interviews were conducted with one forest officer, two forest guards, and two rangers to understand how information about forest fires is gathered. Fire records were obtained from the Murree sub-division office. From the recorded incidents, one affected village was chosen for data collection. Visits were made to these sites, and 40 inhabitants were interviewed to assess their willingness to help the forest department in fire control, identify potential causes of forest fires, and understand the impact of these fires on chir pine regeneration.

Contact with respondent

With the assistance of local forest guards, each participant was identified and interviewed to gather their opinions on forest fires. Interviews were conducted at their homes, in the fields while they were plowing, in the hills while they were cutting grass for their animals, and while they were herding livestock. The purpose of the study was clearly explained to each participant. While most were willing to participate, a few were hesitant, especially when questions related to their income were asked, fearing taxation. Some participants were anxious and wanted to know the study's implications and potential benefits for them. The nature of the research was clarified to them, although some remained suspicious of the study's motives. Nonetheless, the researcher successfully gained their trust and established a satisfactory report.

Data collection

The respondent's answers were documented using a questionnaire during an interview. The necessary information was noted on the questionnaire while the interviewee was present. Additionally, field observations were noted in a diary.

Other information

Data on fire incidence from the past five years, along with other pertinent details such as preventive measures, detection systems, control measures, firefighting equipment, skilled manpower, and past management systems, were gathered from the office of the Divisional Forest Officer in Murree.

Analysis of data

The study aims to identify the regions within the Chir Pine (Pinus roxburghii) forests of Murree that are most susceptible to fires and to understand the factors contributing to forest fires. The analysis was conducted using SPSS basic statistical methods, specifically averages and percentages. The findings were then organized and displayed in tables.

DETECTING FIRE PRONE AREAS THROUGH GIS MODELLING

To following the objective "detecting fire prone areas in chir pine forest of Murree" which is based on fire risk modelling through GIS, the following steps and procedure were applied

GIS and Fire risk modelling

GIS (Geographic Information Systems) and fire risk modeling are essential tools for assessing and managing forest fire risks. GIS allows for the spatial analysis of various factors contributing to fire vulnerability, such as topography, vegetation types, and historical fire occurrences. By integrating these data layers, fire risk modeling can identify high-risk areas and predict potential fire behavior under different conditions. This information is crucial for developing targeted mitigation strategies, optimizing resource allocation, and improving emergency response plans. In the context of the sub-tropical chir pine forests of Murree, GIS-based fire risk modeling helps in pinpointing fire-prone zones, thereby enabling proactive measures to prevent and control forest fires.

Data acquisition

Satellite imagery

Sentinel-2B (10m resolution) was acquired for land use and land cover (LULC) analysis. The high-resolution imagery from Sentinel-2B is suitable for detailed mapping and classification of different land cover types, providing crucial information for understanding the distribution and condition of vegetation and other surface features. Landsat (30m resolution) were acquired for the extraction of the Normalized Difference Vegetation Index (NDVI). This data helps in assessing vegetation health and density, which are key indicators of areas susceptible to wildfires.

Elevation data
SRTM DEM (30m resolution) was obtained from the United States Geological Survey (USGS) database, the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) provides detailed topographical features such as slope and aspect. These features are critical for understanding terrain influences on fire behavior and risk.

Point elevation data
This data was collected using the Point Tool in Google Earth Pro, additional elevation data points were gathered to enhance spatial analysis. This supplementary data helps improve the accuracy of topographical assessments by providing more detailed elevation information for specific locations.

Data preprocessing
Sentinel-2B imagery
Atmospheric Correction were done for atmospheric interference to enhance image clarity. In cloud masking identifies and removes cloud-covered pixels to prevent data distortion. While in image mosaicking a combination of multiple images were done to create a seamless representation of the study area.

LULC Classification
Performed using supervised classification techniques, resulting in distinct classes representing various land cover types, providing a detailed understanding of land use patterns and vegetation distribution.

Landsat imagery
NDVI Calculation was conducted using the following formula:
NDVI= $\frac{NIR+RED}{NIR-RED}$
The NDVI values were used to assess vegetation health, with higher values indicating denser and healthier vegetation, which is crucial for identifying potential wildfire-prone areas.

Slope and aspect derivation
Slope measures the steepness or incline of the terrain, essential for understanding potential fire spread dynamics. Aspect indicates the direction the slope faces, affecting sunlight exposure, vegetation type, and moisture levels, which influence fire risk.

Kriging for elevation data
The point elevation data collected from Google Earth Pro was interpolated using the Kriging method in ArcGIS 10.8. This geostatistical technique creates a continuous elevation surface, providing a more accurate and detailed representation of the terrain's elevation, enhancing spatial analysis and modeling accuracy.

Weighted overlay analysis
Layer preparation
The following layers were prepared for weighted overlay analysis:

LULC Map: Represents different land cover types and their associated fire risk.
Slope Map: Indicates the terrain's inclination, influencing the rate at which fire can spread.
Aspect Map: Determines the direction of the slope, which affects vegetation type and dryness.

NDVI Map: Shows vegetation density, critical for understanding fuel availability.

Weight assignment
Each layer was assigned a weight based on its influence on fire risk:
LULC: 40%
Slope: 25%
Aspect: 20%
NDVI: 15%
The weights were determined through expert consultation and literature review to reflect the relative importance of each factor in fire risk assessment.

Overlay and risk mapping
The weighted overlay analysis was performed in ArcGIS 10.8, combining all the layers with their respective weights. This process resulted in a composite map that highlights areas with varying levels of fire risk, providing a visual representation of potential wildfire hotspots based on the integrated analysis of multiple factors.

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FIRE RISK MAP DEVELOPMENT

The final Fire Risk Map categorizes the study area into different risk levels such as low, moderate, high, and very high. This classification provides a clear and comprehensive understanding of fire risk distribution across the region.

The weighted overlay analysis results, which combined LULC, slope, aspect, and NDVI layers with their respective weights, were used as the foundation for developing the fire risk map.

Risk Level Classification

Using the composite map from the weighted overlay analysis, thresholds were established to categorize different risk levels. These thresholds were defined based on statistical analysis and expert consultation to ensure they accurately reflect varying degrees of fire risk.

Validation

The initial fire risk map was validated against historical fire incidence data to ensure its accuracy and reliability. This step involved comparing the predicted high-risk areas with actual past fire occurrences to assess the map's predictive capability.

Refinement

Based on validation results, necessary refinements were made to improve the map's accuracy. This could include adjusting weightings, redefining risk thresholds, or incorporating additional data if needed.

Map Production

The validated and refined fire risk map was produced using ArcGIS 10.8, ensuring high-quality visual representation. The map clearly delineates areas of varying fire risk, aiding in easy interpretation and practical application.

Application of the Fire Risk Map

The final Fire Risk Map serves as a critical tool for identifying vulnerable areas and prioritizing mitigation efforts. It helps in decision-making for resource allocation, emergency planning, and implementation of fire prevention and mitigation strategies.

RESULTS AND DISCUSSION

Socio-economics charcteristics

Gender Distribution of Respondent

The data presented in the table 1 illustrates a stark gender distribution, with all 50 occurrences being male and zero female, resulting in a 100% frequency for males and 0% for females.

Table 1: Gender of Respondent

Gender	Frequency	Percent
Male	50	100.0
Female	0	0.0

Age of the Respondent

The data given below in table 2 indicates a varied age demographic, with individuals falling into distinct age groups. Among the respondents, 14% are aged 25 or younger, while 16% fall within the age range of 26 to 36. A significant portion, constituting 50%, lies within the age bracket of 37 to 47. Furthermore, 20% of respondents are aged 47 and above.

Table 1: Age of Respondent

Age	Frequency	Percent
25 and less	7	14
26-36	8	16
37-47	25	50
47 and above	10	20
Total	50	100.0

Marital Status of the Respondent

The table 3 presents the marital status distribution of the respondents within the studied population, highlighting the proportion of individuals classified as married versus unmarried. It reveals that the majority of respondents, constituting 76%, are married, while the remaining 24% are unmarried.

Table 2: Marital status of respondents

Marital status of respondents	Frequency	Percent
Married	38	76.0
Unmarried	12	24.0
Total	50	100.0

Household Structure of Respondent

This table 4 reveals that a substantial majority, comprising 74% of respondents, reside in joint family setups, while the remaining 26% live in separate households.

Table 3: Family type of respondent

Family type of respondent	Frequency	Percent
Joint	37	74
Separate	13	26
Total	50	100.0

Occupation of Respondent

The occupation distribution of respondents reveals that 64% are engaged in business, 14% are students, and 22% hold government positions as shown in table.

Table 4: Occupation of Respondent

Occupation of respondent	Frequency	Percent
Business	32	64.0
Student	7	14.0
Govt. job	11	22.0
Total	50	100.0

Literacy Rate of Respondent

The table 6 show education distribution of respondents demonstrates that 32% are illiterate, 22% have completed primary education, 18% have attained SSC (Secondary School Certificate), 12% have completed HSSC (Higher Secondary School Certificate), and 16% have graduated from college or university.

Table 5: Education of respondent

Education of respondent	Frequency	Percent
Illiterate	16	32.0
Primary	11	22.0
SSC	9	18.0
HSSC	6	12.0
Graduation	8	16.0
Total	50	100.0

Key Environmental Effects

The primary environmental impact of forest fire breakdown indicates that 52% of respondents identify air pollution as the main concern, followed by 26% expressing concerns over decreased soil fertility, and 22% highlighting the issue of stunted growth.

Table 6: Primary environmental impact of forest fire

Primary environmental impact	Frequency	Percent
Air pollution	26	52.0
Decreases soil fertility	13	26.0
Stunt growth	11	22.0
Total	50	100.0

Wildlife Response To Forest Fire Events

The analysis of the effect of forest fires on wildlife reveals that 26% of respondents perceive no impact, while 12% note a decrease in food sources. However, the majority, comprising 62% of respondents, express concerns over the displacement and habitat loss experienced by wildlife due to forest fires.

Table 7: Effect of forest fire on wildlife

Effect of forest fire on wildlife	Frequency	Percent
No impact	13	26.0
Decreased food sources	6	12.0
Displacement and habitat loss	31	62.0
Total	50	100.0

Social And Economic Impact Of Forest Fires On Communities

The assessment of impact of forest fire on the local community reveals that 18% of respondents report no social impact, while 34% observe improved community bonding. However, a significant portion, constituting 40% of respondents, express concerns over displacement, health issues, and economic loss. Additionally, 8% of respondents indicate other impacts on the local community.

Table 8: impact of forest fire on local community

Impact on local community	Frequency	Percentage
No social impact	9	18.0
Improved community bonding	17	34.0
Displacement, health issues and economic loss	20	40.0
Others	4	8.0
Total	50	100.0

Climatic Factors

The analysis of climatic factors highlights that 14% of respondents perceive high humidity, while the majority, comprising 64%, indicates experiencing dry and hot conditions. Additionally, 16% report encountering low temperatures, while 6% note abundant rainfall as a significant climatic factor.

Table 9: Climatic Factors A Major Cause of Forest Fire

Climatic factors	Frequency	Percentage
High humidity	7	14.0
Dry and hot conditions	32	64.0
Low temperature	8	16.0

Abundant rainfall	3	6.0
Total	50	100.0

Role Of Topography

The role of topography in influencing fire dynamics is evident, with 20% of respondents noting that flat terrain reduces fire risk, while 74% highlight the influence of hilly and rugged terrain on fire behavior. Only 6% of respondents believe that topography has no impact on fire vulnerability.

Table 10: Topography Influencing Fire Dynamics

Role of topography	Frequency	Percentage
Flat terrain reduces fire risk	10	20.0
Hilly and rugged terrain can influence fire behavior	37	74.0
Topography has no impact on fire vulnerability	3	6.0
Total	50	100.0

Vegetation types and their contribution to forest fires

The results in the below table12 illustrates that among respondents, 62% attribute forest fires to coniferous chir pine vegetation, while 24% identify Abies pindrow as a contributing factor. Additionally, 8% mention moss, and 6% specify succulent vegetation as leading to forest fires.

Table 11: Type of vegetation lead to forest fire

Type of vegetation lead to forest fire	Frequency	Percentage
Coniferous chir pine	31	62.0
Moss	4	8.0
Succulent	3	6.0
Abies pindrow	12	24.0
Total	50	100.0

Historical Drivers Of Forest Fire Occurrence

The table 13 indicates that 76% of respondents believe historical factors contribute to forest fires, while the remaining 24% do not perceive historical factors as significant contributors.

Table 12: Historical Factor Contribute To Forest Fire

Historical factor contribute to forest fire	Frequency	Percentage
Yes	38	76.0
No	12	24.0
Total	50	100.0

Anthropogenic Influences On Wildfires

The data in table 14 reveals that 86% of respondents acknowledge human activity as a contributing factor to forest fire vulnerability, while 14% do not perceive human activity as significant in this regard.

Syphard et al. (2017) investigate the influence of human activities on the likelihood of wildfires in the northeastern United States. Their study reveals that areas with higher human footprints, such as urban developments and road networks, are more prone to wildfires. The findings underscore the need for integrated land-use planning and fire management strategies that account for human presence and activities to effectively reduce wildfire risk. The research highlights the significant impact of anthropogenic factors on wildfire occurrence and emphasizes the importance of addressing these factors in wildfire mitigation efforts.

Table 13: Human A Contributing Factor To Forest Fire

Response	Frequency	Percentage
Yes	43	86.0
No	7	14.0
Total	50	100.0

Effect Of Water Availability On Forest Fires

The table 15 indicates that 66% of respondents recognize the influence of water availability on forest fires, while 34% do not perceive it as a significant factor.

Table 14: Influence of Water Availability on Forest Fires

Response	Frequency	Percentage
Yes	33	66.0
No	17	34.0
Total	50	100.0

Role Of Community In Reducing Fire Risk

The data suggests that 22% of respondents believe community involvement has no impact on fire risk, while another 22% suggest that communities can aid in reducing fire risk by hosting controlled burns. A majority of 60% emphasize the importance of reporting suspicious activities and promoting fire safety awareness within communities. Additionally, 6% mention other roles communities can play in mitigating fire risk.

Cohen (2000) explores the critical role of home ignitability in preventing disasters in the wildland-urban interface. The study emphasizes that reducing the vulnerability of homes to ignition from wildfires is more effective than traditional fire suppression methods. By focusing on the materials and design of buildings, as well as the immediate surroundings, communities can significantly mitigate fire risk. Cohen's findings highlight the importance of proactive measures in enhancing fire safety and reducing the likelihood of catastrophic fire events.

Table 15: Role of community in reducing fire risk

Role of community in reducing fire risk	Frequency	Percentage
Community involvement has no impact on fire risk	11	22.0
Communities can help by hosting controlled burns	11	22.0
Reporting suspicious activities and promoting fire safety awareness	25	60.0
Others	3	6.0
Total	50	100.0

Contribution Of Controlled Burns

The table 17 reveals that 62% of respondents recognize the contribution of controlled burns in reducing fire risk, while 38% do not perceive controlled burns as effective in mitigating fire risk. Fernandes and Botelho (2003) reviews the effectiveness of prescribed burns in reducing fire hazards and supports the view that controlled burns can significantly contribute to fire risk reduction. Boer et al. (2009) provides evidence on the long-term effectiveness of controlled burns in reducing the incidence and extent of wildfires, supporting the majority of respondents who recognize the benefits of controlled burns.

Table 16: Contribution of Controlled Burns in Reducing Fire Risk

Response	Frequency	Percentage
Yes	31	62.0
No	19	38.0
Total	50	100.0

Measures To Reduce Fire Risk

The data in the table 18 indicates that 10% of respondents suggest increasing logging activities as a measure to reduce the risk of fire, while 18% advocate for controlled burns. A significant majority of 70% emphasize the importance of improved firefighting equipment in mitigating fire risk. Additionally, only 2% mention implementing fire breaks as a measure to reduce the risk of fire.

Fernandes and Botelho (2003) reviews the effectiveness of prescribed burns in reducing fire hazards, which aligns with the 18% of respondents advocating for controlled burns.

Agee and Skinner (2005) discuss various methods for reducing forest fire risks, including the importance of improved firefighting equipment and the role of logging activities in managing fuel loads.

Table 17: The table illustrates measures to reduce the risk of fire

Measures to reduce the risk of fire	Frequency	Percentage
Increase logging activities	5	10.0
Controlled burn	9	18.0
Improved firefighting equipment	35	70.0
Implementing fire breaks	1	2.0
Total	50	100.0

Method Of Controlling Forest Fire

The table 19 illustrates the methods for controlling forest fires, with 6% of respondents suggesting animal grazing, 44% recommending the use of water buckets, and a majority of 50% advocating for the implementation of fire breaks. These findings underscore the diverse strategies employed in forest fire management efforts.

(Davies & Boyd, 2019) Discusses how grazing can be an effective tool in reducing wildfire risks in certain ecosystems by reducing fuel loads.

(Fernandes & Botelho, 2003) reviews the effectiveness of various fire management techniques, including the use of water for fire suppression and the creation of fire breaks to control the spread of wildfires.

Table 18: The table illustrates methods for controlling forest fires

Methods	Frequency	Percentage
Animal grazing	3	6.0
Water buckets	22	44.0
Fire breaks	25	50.0
Total	50	100.0

Composite Map Description

The map presents a composite map of Tehsil Murree, likely utilizing Sentinel-2B satellite imagery. The map showcases the geographical boundaries of the region, incorporating a color-coded legend to interpret the spectral bands

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employed. The provided composite map of Tehsil Murree, generated from Sentinel-2B satellite data, offers a valuable spatial overview of the region. The map employs a standard RGB color composition (Red, Green, Blue) using spectral bands 1, 2, and 3, respectively. A legend accompanying the map aids in deciphering the color variations representing different land cover types or features within the Tehsil. The scale of the map is approximately 1:20,000, providing a detailed perspective of the area. The map's orientation is indicated by a north arrow, aiding in spatial referencing.

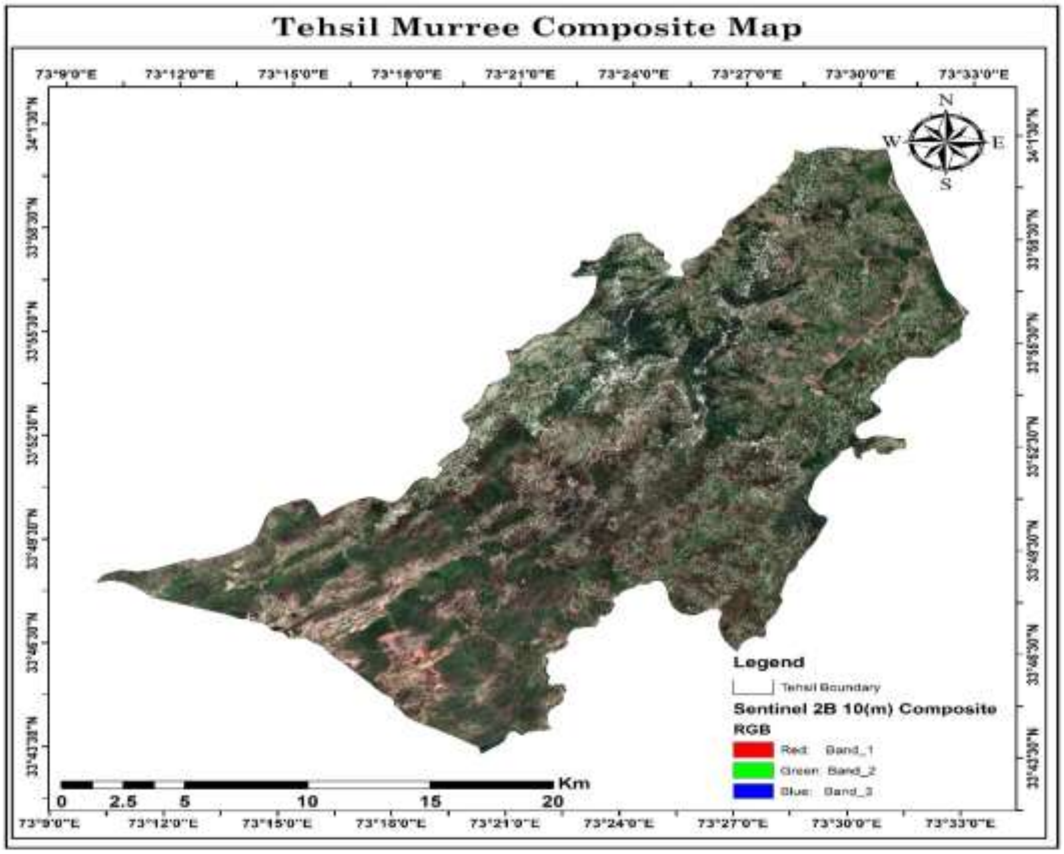

Figure 2: Characteristics of Tehsil Murree Composite Map (2024)

Aspect

The figure 3 presents an aspect map of Tehsil Murree, likely derived from elevation data. The map displays the directional orientation of slopes within the region, categorized into eight distinct aspect classes. The provided aspect map of Tehsil Murree offers a valuable depiction of the directional orientation of slopes within the region. Derived from elevation data, the map categorizes slopes into eight distinct aspect classes, represented by a diverse color scheme. A legend accompanying the map aids in deciphering the color variations corresponding to the different slope directions. The scale of the map is approximately 1:100,000, providing a broad overview of the area. The map's orientation is indicated by a north arrow, aiding in spatial referencing

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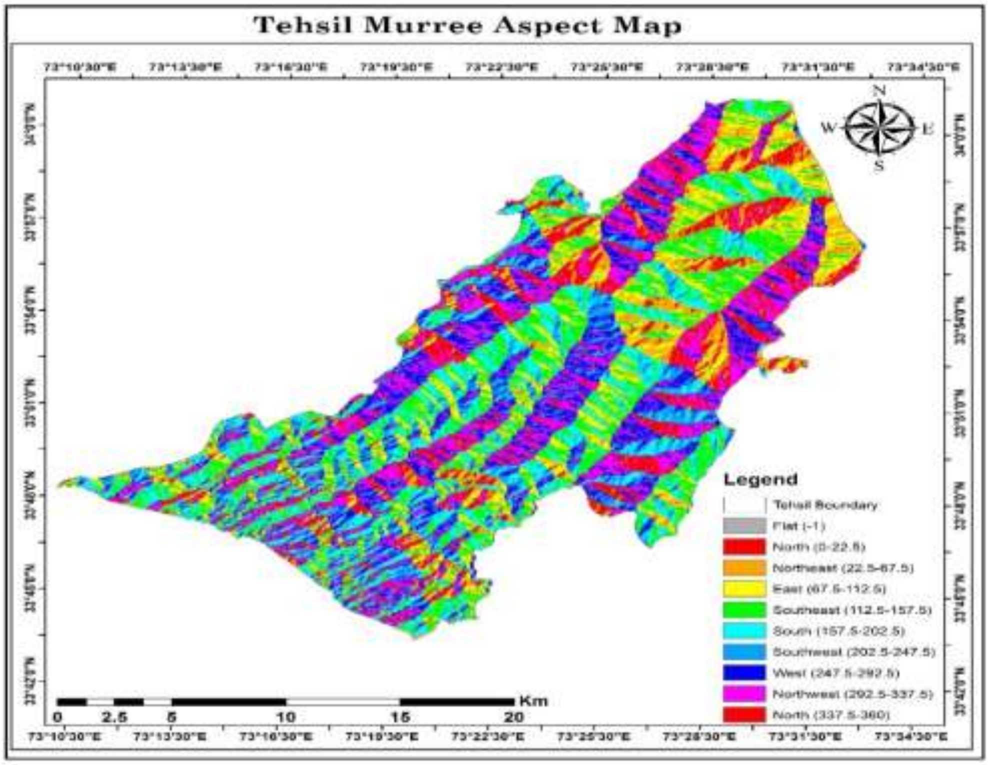

Figure 3: Tehsil Murree Aspect Map

Slope

The provided figure 4 is a slope map of Tehsil Murree, displaying the inclination or steepness of the terrain across the region. The map utilizes a color gradient to represent different slope classes, ranging from gentle to steep slopes. The Tehsil Murree Slope Map offers a visual representation of the topographic variability within the study area. Employing a color-coded scheme, the map effectively delineates areas of varying slope gradients. The legend accompanying the map provides a key to interpreting the slope classes represented by the different colors. The map incorporates standard geographic features such as a north arrow and a scale bar, facilitating spatial orientation and distance estimation.

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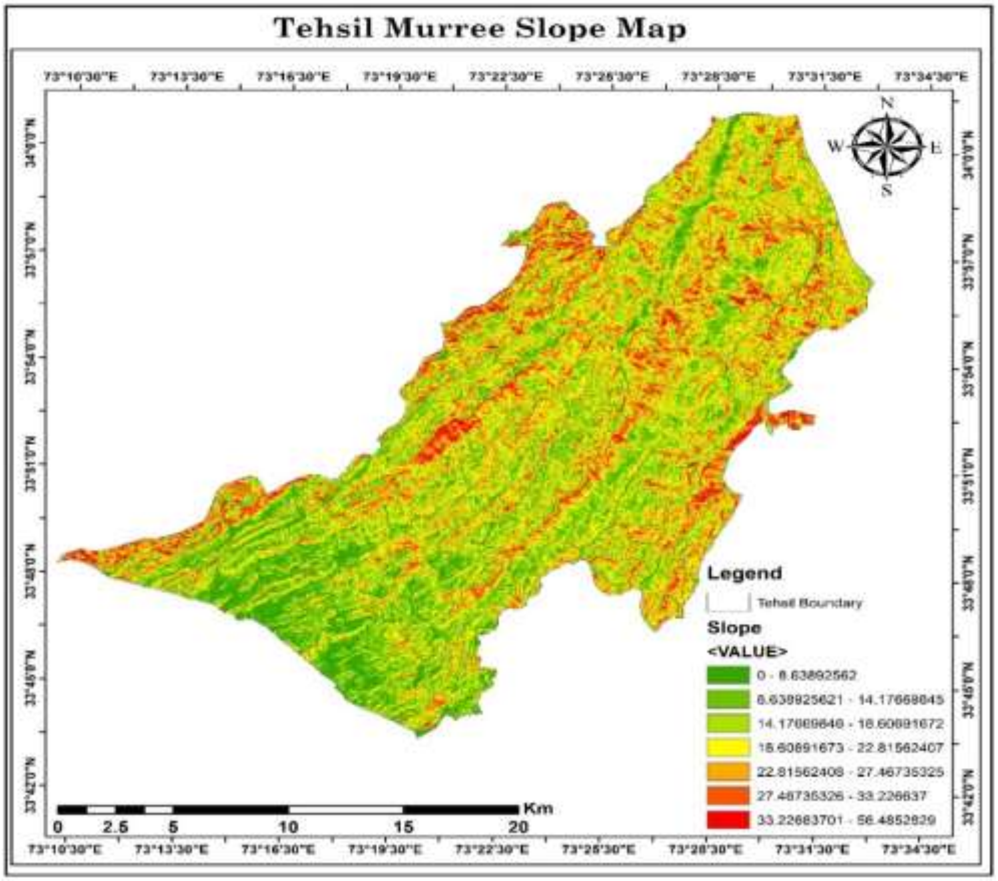

Figure 4: Tehsil Murree Slope Map

Topography

The provided map is a topographic map of Tehsil Murree, illustrating the elevation variations across the region. It employs contour lines to depict the shape and configuration of the terrain, with a color gradient enhancing the visualization of elevation changes. The Tehsil Murree Topographic Map presents a detailed portrayal of the region's topography, utilizing contour lines and a color scheme to effectively communicate elevation data. The map showcases the intricate pattern of ridges, valleys, and peaks that characterize the landscape. The color gradient complements the contour lines, providing a visual hierarchy that emphasizes areas of higher elevation. The inclusion of a legend, scale bar, and north arrow enhances the map's readability and spatial orientation.

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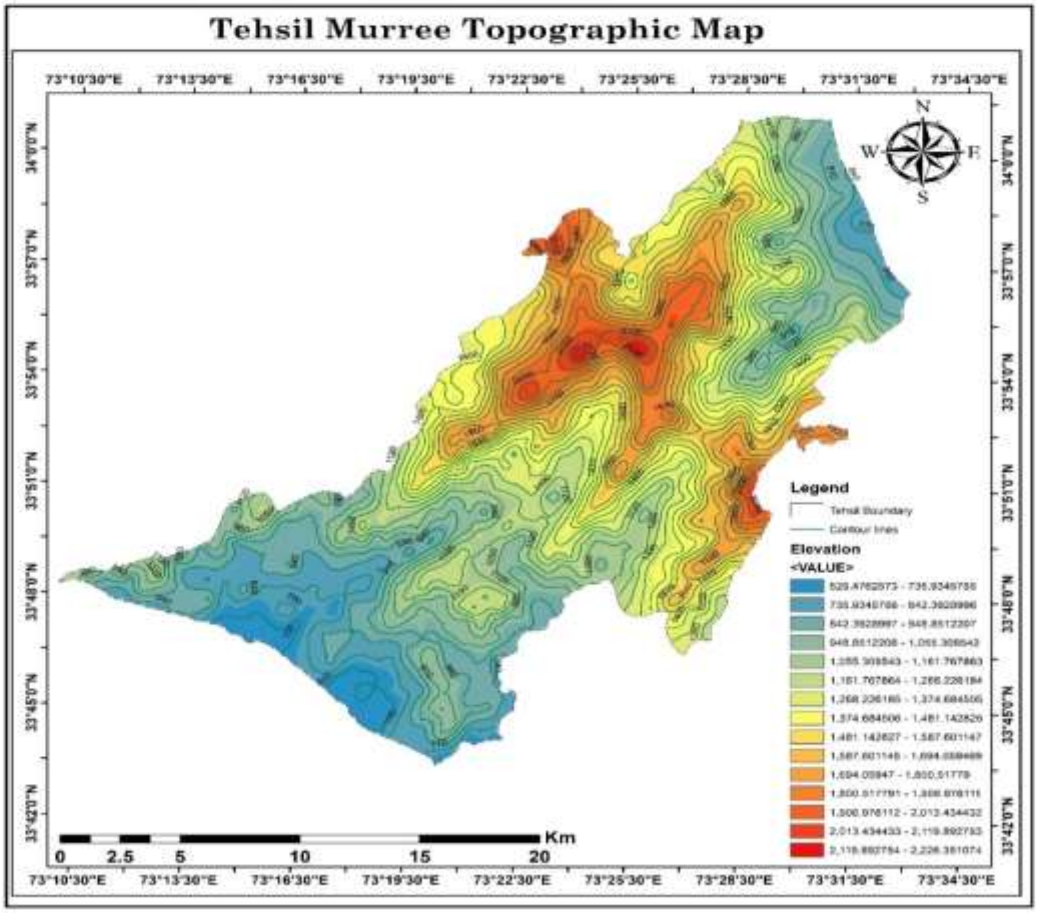

Figure 5: Tehsil Murree Topographic Map

Fire Risk Map of Tehsil Murree

The provided map is titled Wild Fire Risk Area Map (By Percentage) and appears to depict the wildfire risk levels across Tehsil Murree. The "Wild Fire Risk Area Map (By Percentage)" presents a spatial representation of the potential wildfire risk within Tehsil Murree. The map employs a color-coded scheme to classify areas based on their estimated fire risk levels, ranging from very low to high. The legend accompanying the map provides a key to interpreting the color variations corresponding to the different risk categories. The map incorporates standard geographic features such as a north arrow, scale bar, and grid coordinates, facilitating spatial orientation and distance estimation.

The map utilizes a base map with a grid coordinate system (latitude and longitude) and a scale bar, indicating distances in kilometers. The map displays varying shades of color to delineate areas with different wildfire risk levels. These colors likely correspond to the percentages mentioned in the legend. The legend explains the color-coded system used to represent different wildfire risk levels:

High Risk (7%)
Low Risk (34%)
Moderate Risk (60%)
Very Low Risk (0%)

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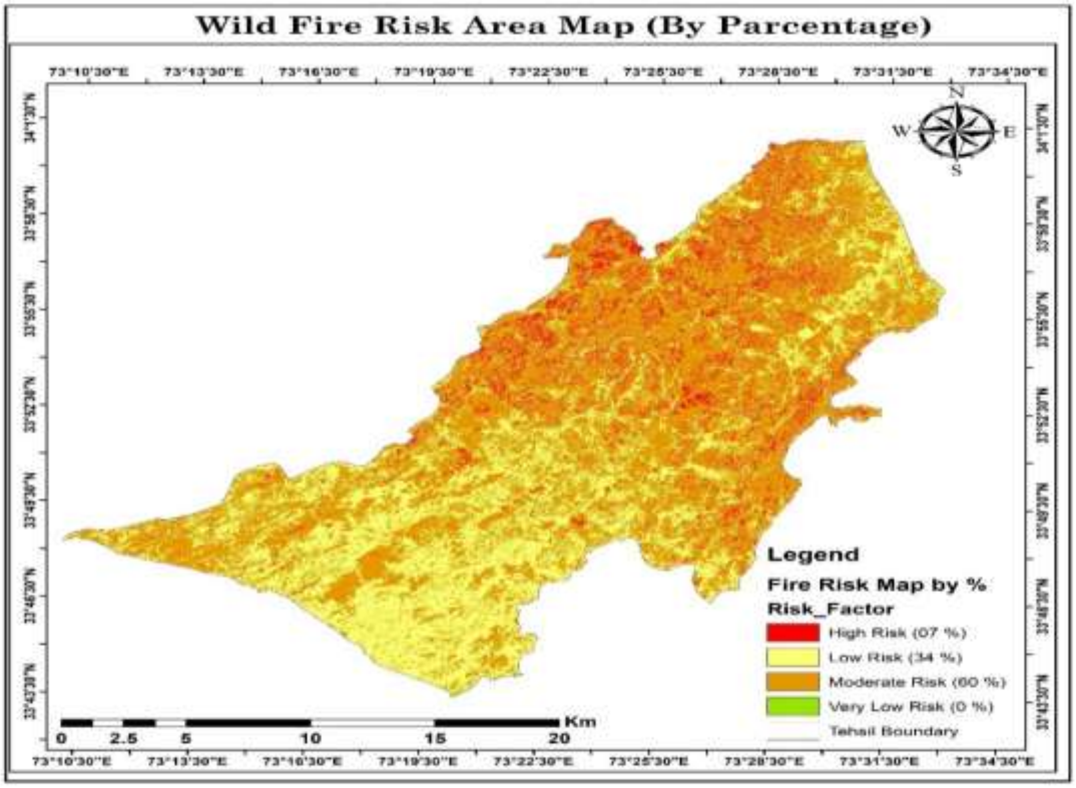

Figure 6: Wild Fire Risk Area Map (By Percentage)

NDVI Map for Tehsil Murree

The NDVI (Normalized Difference Vegetation Index) map of Tehsil Murree presents a spatial representation of vegetation greenness and vigor within the specified region. The map employs a color gradient ranging from red (low NDVI values, indicating sparse or less vigorous vegetation) to green and yellow (high NDVI values, signifying dense and healthy vegetation).

The map reveals a heterogeneous distribution of vegetation across Tehsil Murree. Areas exhibiting higher NDVI values (green and yellow tones) are concentrated in the specific locations, e.g., central and eastern regions, suggesting a greater abundance and health of vegetation in these zones. Conversely, regions with lower NDVI values (reddish hues) are observed in [specific locations, e.g., western and southern areas], indicating sparser vegetation cover or potentially degraded land conditions. The legend indicates that NDVI values in Tehsil Murree span from a low of -0.109 to a high of 0.511256. This range suggests a considerable variation in vegetation density and health across the region. The map outlines the district boundary, allowing for an assessment of vegetation patterns within the administrative unit of Tehsil Murree.

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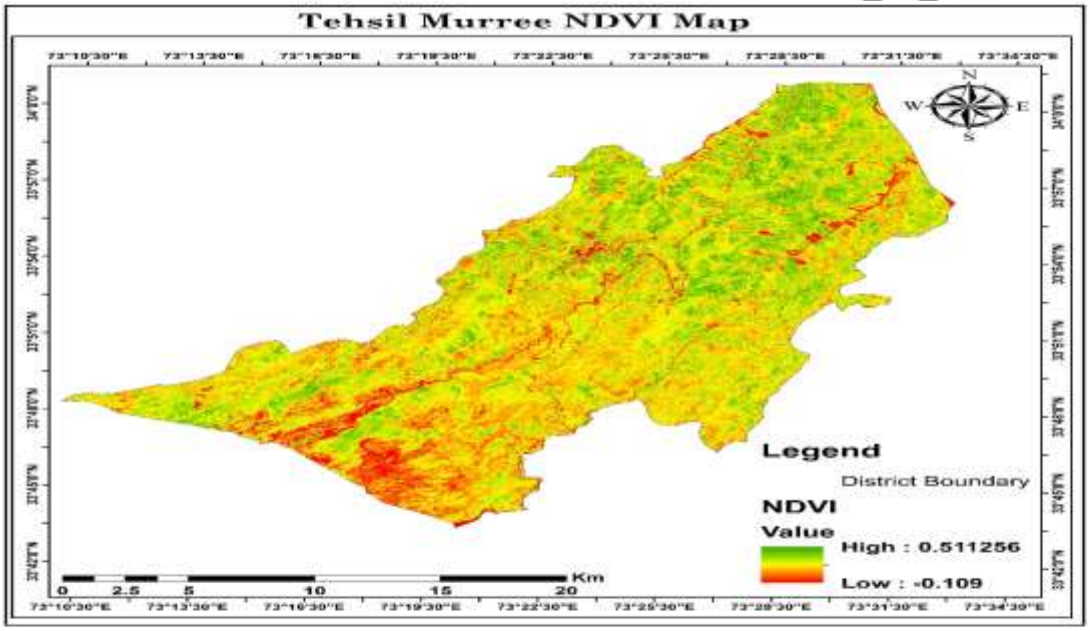

Figure 7: Tehsil Murree NDVI map

POTENTIAL INTERPRETATIONS

Land Cover: The NDVI map 7 provided insights into the distribution of different land cover types within Tehsil Murree. Areas with high NDVI values may correspond to forests, agricultural fields, or grasslands, while lower values could indicate barren lands, built-up areas, or water bodies.

Environmental Factors: Variations in NDVI can be influenced by several environmental factors, including elevation, slope, aspect, soil type, precipitation, and temperature. Further analysis would be required to determine the specific factors driving the observed NDVI patterns.

Temporal Changes: The NDVI map represents vegetation conditions at a specific point in time. To assess vegetation dynamics and trends, it would be valuable to compare this map with NDVI data from different time periods. A valuable insight, into the spatial distribution of vegetation within the region were gained by analyzing and interpretation of NDVI map of tehsil Murree, contributing to a deeper understanding of your research topic.

LAND USE AND LAND COVER OF TEHSIL MURREE

This map depicts land use and land cover of Tehsil Murree. It utilizes a color-coded legend to classify different land cover types within the region. The map distinguishes between several land cover categories, including Dense Forest, Sparse Forest, Vegetation (Sparse), Urban/Built-up Area, Barren Land, and Roads. Dense Forest appears to dominate the central and eastern regions of Tehsil Murree, while Sparse Forest is prevalent in the western and southern areas. Urban/Built-up areas are concentrated in [specific locations, if visible], and Barren Land is scattered throughout the region. The map includes a scale bar (in kilometers) and a north arrow, aiding in spatial orientation and distance estimation. The Tehsil boundary is outlined, providing a clear demarcation of the study area.

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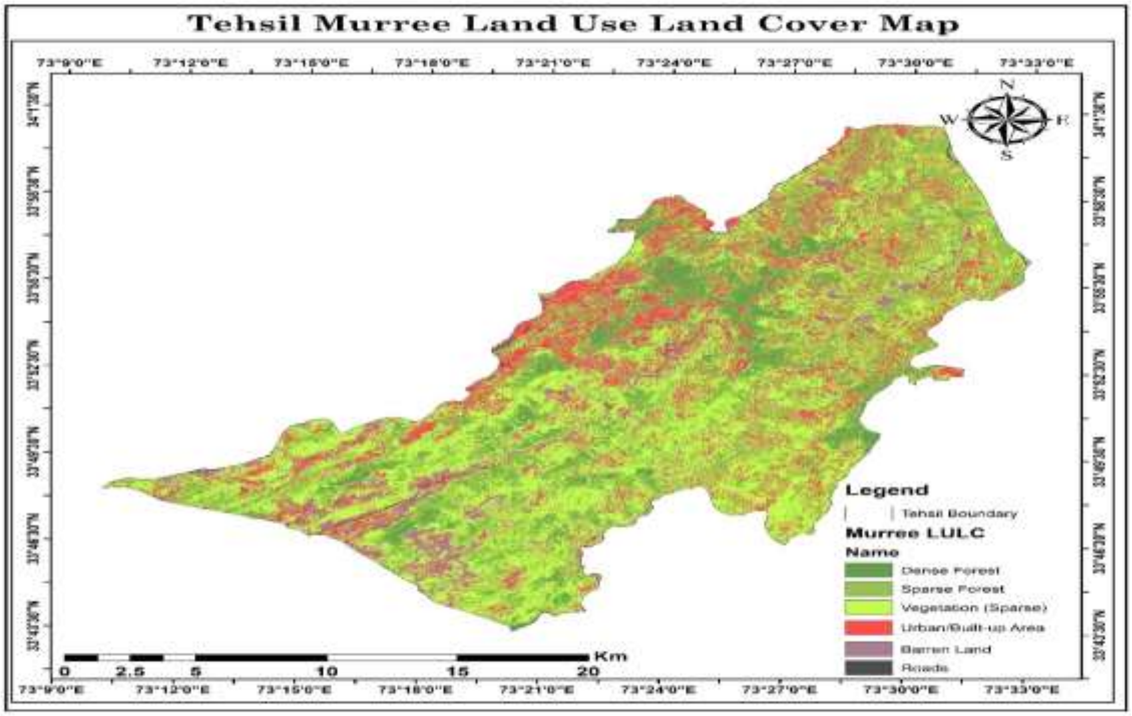

Figure 8: land use land cover map of tehsil Murree

Potential Interpretations

Land Use Dynamics: The map offers insights into the spatial distribution of different land use types within Tehsil Murree. The predominance of forest cover suggests the area's ecological significance.

Environmental Implications: The presence of Barren Land and Sparse Vegetation areas might indicate potential environmental concerns such as deforestation or land degradation.

Data Limitations: The map's accuracy and resolution depend on the underlying data and classification methodology. Further investigation into data sources and classification criteria would be necessary for a comprehensive analysis. By analyzing and interpreting the map, a valuable insight was gained into the land use and land cover patterns of tehsil Murree.

Puri et al. (2011) assessed forest fire risk in Northeast India using geospatial tools. In this research, the construction of a forest fire risk map for Manipur was achieved through a comprehensive modeling approach utilizing various spatial datasets, including LULC, vegetation types, slope, aspect, and Euclidean distances to towns and roads. By applying a weighted sum approach and ISODATA clustering technique, the study effectively categorized the forest fire risk into five distinct levels, from very low to very high. This methodology provides a detailed spatial analysis of fire risk, highlighting areas most susceptible to fires based on multiple factors. The use of spectral profiles for classification and the detailed risk distribution table enhance the map's applicability for fire management and prevention strategies in the region.

Summary

This study highlights the multifaceted nature of forest fire risk assessment and mitigation in the sub-tropical chir pine forest of Murree. It underscores the importance of understanding local demographics, environmental impacts, and community involvement. effective mitigation strategies require a combination of improved firefighting resources, community education, and proactive measures like controlled burns and fire breaks. The social survey revealed all 50 respondents were male, with ages ranging from under 25 to over 47. Most respondents (76%) were married and lived in joint families (74%). Occupations included business (64%), students

(14%), and government positions (22%). Key environmental concerns were air pollution (52%) and decreased soil fertility (26%). Wildlife impacts included displacement (62%), while community impacts were displacement, health issues, and economic loss (40%). Most respondents experienced dry and hot conditions (64%). Topography significantly impacted fire behavior, with 74% noting hilly terrain increased fire risk. chir pine vegetation was a major fire contributor (62%), and human activity was acknowledged by 86% as a factor. Community involvement in fire safety was emphasized by 60%, and controlled burns were seen as effective by 62%. Key mitigation strategies included improved firefighting equipment (70%) and fire breaks (50%). Water availability was recognized by 66% as influencing fire risk. Wildfire risk area map (by percentage) for tehsil Murree represents wildfire risk zones across the region using a color-coded scheme. The map classifies areas into four risk levels—high, moderate, low, and very low—based on estimated fire risk percentages. It provides a clear spatial overview with standard geographic elements such as a north arrow, scale bar, and grid coordinates for orientation and distance measurement. According to the map, 60% of the area is classified as moderate risk, 34% as low risk, 7% as high risk, and 0% as very low risk. The legend details the percentage ranges associated with each risk level, aiding in risk assessment and management planning. The NDVI map for Tehsil Murree highlights various land cover types, with high NDVI values indicating vegetation such as forests and grasslands, while lower values suggest barren or built-up areas. Environmental factors like elevation, slope, and precipitation influence NDVI variations. The map provides a snapshot of vegetation conditions at a specific time, and comparing it with NDVI data from other periods could reveal trends and changes. This analysis offers valuable insights into the spatial distribution of vegetation in the region.

CONCLUSION

- An overwhelming 86% of respondents recognize human activity as a major factor in forest fire vulnerability.
- A majority of respondents (62%) acknowledge the effectiveness of controlled burns in reducing fire risk.
- Fire breaks and water buckets are the most effective fire management techniques, with 50% and 44% frequency of use respectively.
- The majority of respondents (62%) associate forest fires primarily with coniferous chir pine vegetation, with smaller percentages attributing the risk to Abies pindrow, moss, and succulent vegetation.
- Vegetation (Sparse) covers the largest area (41%), followed by Dense Forest (17%) and Sparse Forest (15%), indicating potential forest fire risks in Murree region.
- Fire risk map for tehsil Murree indicates a high fire risk (70%) across a significant portion of the area, with lower risks (21% and 9%) present in other zones.
- The GIS results analysis show that type of vegetation affects the fire vulnerability.
- Terrain features, including slope and topography, significantly influence fire behavior.

Recommendation

1. Legislation should establish comprehensive rules and regulations, including prohibitions, the authority of forest officers, and the legal responsibilities of citizens, to mitigate forest fire risks.
2. Implement early warning mechanisms such as watchtowers and electronic detection systems to facilitate rapid responses and accurate location tracking of forest fires.
3. Regularly conduct controlled burns within forested areas to manage vegetation and reduce the likelihood of uncontrolled fires.
4. Legislation should impose severe penalties on individuals who intentionally start fires in forest areas to deter such illegal activities.
5. Install fencing around forested regions to protect against illegal logging and overgrazing, which can exacerbate fire hazards.
6. Improve communication with local communities and increase their awareness about fire prevention and control, leveraging their involvement to manage fire risks effectively.
7. Provide fire control training to both forest staff and local residents to enhance their capability in

managing and preventing forest fires.

8. Ensure that forest officers regularly visit high-risk areas and actively engage with local communities to support and promote fire control measures.

9. Enhance accessibility and communication infrastructure in areas prone to forest fires to support efficient response and management.

10. Focus on the development and training of personnel in both proactive and reactive measures for effective forest fire control.

11. Equip forest personnel with protective gear, including gloves, long boots, and fire-resistant clothing, to ensure their safety during fire management activities.

12. Prior to potential forest fires, remove flammable materials such as pine needles and leaves from fire lines to minimize fire hazards.

Given the limited responses to the questionnaire, the data provided is preliminary. It is advised that the Murree Forest Sub Division gather comprehensive information on forest fires for the development of a national report and strategy on forest fire management

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