Czech University of Life Sciences

Faculty of Forestry and Wood Sciences

Department of Silviculture

Effect of Harvesting Systems on the Undergrowth in Himalayan Moist Temperate Forests of Pakistan

Study Program: Silviculture

Supervisor: prof. Ing. Vilém Podrázský, CSc.

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Ph.D. THESIS ASSIGNMENT

Ing. Javed Iqbal

Forestry Engineering
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Thesis title

Effect of Harvesting Systems on the Undergrowth in Himalayan Moist Temperate Forests of Pakistan

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Objectives of thesis

At baseline, the research project will examine the current levels of understory and vegetation composition of the Forest in the moist temperate forest by using GIS and RS techniques to minimize the duration of the research work. Other activities may also include the growth under different Harvesting System that include the group selection system, Signal tree selection system and clear felling.
The research question will be refined after the literature review and baseline study;
(1) What types of effects on undergrowth under different harvesting system?
(2) Effects of harvesting system on edaphic condition of the site?
(3) Growth rate comparison in the different aspect and topographic condition?
(4) Identify potential for more fuelwood producing and palatable species in the area to fulfill the demand of the local community and nomadic grazers? and
(5) Proposal of the new concept of forestry treatments instead of traditional forestry

Methodology

It is envisaged the research will include a practical research element to investigate questions raised in the study, primarily targeted at current situation of the vegetation and ground in moist temperate forest. To achieve these goals it will be defined questionnaire based on literature review and local demands. Use of the questionnaires is based on a standard format to obtain mainly qualitative responses from community, complemented by interviews and focus groups. Sampling intensity for the research is 2.5% of the total area. The study area will be categorized into different harvesting system areas, within that it is future divided on the basis of research objectives (Cluster Sampling).Total no. of plots in the research area are 75 with sample plot size of 0.1 ha circular in shape (radius 17.84 m). Before investigating the above question it is obligatory to search for these questions (1) to investigate the site and site index for the growth rate and potential of the area, and (2) to find undergrowth characteristics under different harvesting system. Analysis and evaluative methods may include: Standard statistical packages (SPSS) will be used to examine any cross-tabulation, or associations, or grouping which emerges (e.g. through factor analysis). The data will be collected in the month of June to August during 2015. Three regions and three silvicultural system areas will be measured: single tree selection system, group selection system, clear-felling. The species, height and diameter structure will be analyses as well as the changes in time. For the qualitative data, a qualitative data analysis software package will be used to assist coding, and derivation of themes, from the interview and field data.

The proposed extent of the thesis

min. 70 stran odborného textu

Keywords

forest regeneration, himalayan forest, anthropic effects, silvicultural system

Recommended information sources

Arlidge, C., 1995. Wood supply and woodland caribou on the Nakina/Geraldton forests and the Lac Seul forest. Ontario Ministry of Natural Resources, Thunder Bay, Ontario, Canada. NWST Technical Report TR-97.

Hart, S.A., Chen H.Y.H.: Fire, logging, and overstory affect understory abundance, diversity and composition in boreal forest, Ecol. Monogr., 78 (2008), pp. 123–140

- Julee J. Boan, Brian E. McLaren, Jay R. Malcolm, Influence of post-harvest silviculture on understory vegetation: Implications for forage in a multi-ungulate system, Forest Ecology and Management Volume 262, Issue 9, 1 November 2011, Pages 1704–1712

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Prague on 28. 06. 2021

I hereby confirm that this Ph.D. research thesis “Effect of Harvesting systems on the Undergrowth in Himalayan Moist Temperate Forests of Pakistan” was conducted and elaborated independently with the keen interest and consultation of my supervisor. The quoted literature review was used in this study to produced quality research in the field of silviculture based on actual data with a future recommendation.

I agree with publishing this Ph.D. research thesis according to Czech law n. 111/1998 Sb. about the universities in its current valid wording. This agreement is independent of the result of the defense.

June 2021, Prague

ABSTRACT

Modern forestry operations are focused towards sustainable management in the temperate ecosystem and promote multi-species support and indigenous species preference for natural process in forest stand. The present study is focused on identifying management activities and status of the forest for conservation, protection and production level. Moreover, the stand structure diversity was also examined, focused on the undergrowth, regeneration activities and survival rate. The research question are; what types of effects on undergrowth under different harvesting system? Effects of harvesting system on edaphic condition of the site? Growth rate comparison in the different aspect and topographic condition? Identify potential for more fuelwood producing and palatable species in the area to fulfil the demand of the local community and nomadic grazers? and Proposal of the new concept of forestry treatments instead of traditional forestry?

Western Himalayan moist temperate forest of Pakistan represents the largest productive and commercial forest of the country/region, with great floristic complexity and high biodiversity. The research area is located (North 35.931010dd, East 75.465168dd, South 33.225403dd and West 72.125281). The research area is divided into three zones: (1) Khyber Pakhtunkhwa (13S-633P), (2) Azad Jammu and Kashmir (2S-13P) and Punjab (3S-27P). The data collection at plots and site selection also focus on; tracks, silvicultural system harvesting plots, and individual sites for random data collection. Mature forest crop stand plot size is 0.1 ha (1000 m^2 or 17.84 m radius), whereas the regeneration plot size is 0.01 ha (100 m^2 or 5.64 m radius).

Major research covered; Forest management and disturbance included; past and present silvicultural systems and tending operation, followed with forest disturbance and degradation. Second area of research based on vegetation dynamic and stand structure in relation to silvicultural system. this research area covered; Impact of silvicultural system on natural regeneration, followed by; floristic complexity in relation to Silvicultural operations, and Forest stand structure in relation to silvicultural system. Third aspect covered with Climate change and silvicultural system; which include; climate change and Silvicultural practices. The fourth aspect covered edaphic and social aspect and their role in silvicultural activities. This include; Forest soil horizon characteristics along with altitudinal variation, Potential of silvicultural systems concerning soil carbon pools, Socio-economic status of a local community practicing silvicultural operation, Phytogeography and distribution, and Land-Use classification.

Detail study need to be conduct in the study region, present study show a high significant on the stand structure and stand composition from the different climactic factors. Especially unexpected rainfall pattern which highly affect the silvicultural practices in the region. Silvicultural practices need to be formulating according to the climatic factors so that less damage or negative impact will observed in the forest stand. Temperature doesn’t have any impact on the management activities due to less correlation. Silvicultural operations and management practices need to observe to reduced the damages and protect and conserve their mountainous forest for future generation.

Keywords: Harvesting system, Undergrowth, Himalayan, Moist Temperate, Stand structure, Disturbance, Climate Change.

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1. INTRODUCTION

Sustainable forest management is a complex task in temperate regions (Lindenmayer , Franklin 1997) and it is topical especially under low cover density, complex biodiversity, and hard ground relief with different land-uses (Ellum 2009; Stevens et al., 2017). To enhance the productive abilities of the forest ecosystem it needs to determine the growth process in the particular ecological/silvicultural systems (Assmann 1970), for sustainable management. Such, forest growth and ecological processes in managed forests are depending on harvesting methods or silvicultural systems (Short , Radford 2008; Bataineh et al., 2013; Vacek 2016). The ecological functions and running processes are related to biodiversity (Felton et al., 2016), and biodiversity of temperate forests in different regions is indicated by the forest stand species, spatial and age structure which leads towards the management adaptation of these forests (Laginha Pinto Correia et al., 2017). Modern forestry operations are focused towards sustainable management in the temperate ecosystem and promote multi-species support and indigenous species preference for natural process in forest stand (Kuiters et al., 1996). Temperate forest stands are managed under proper silvicultural practices like; regeneration cuts, weeding, cleaning, thinning, tending, improvement felling, pruning and climber cutting prescribed by the management plans of the forest units/estates in most regions of the world considered as productive forest (Khattak 1964; Champion et al., 1965b; Habich et al., 2001).

Forest management practices and silvicultural operations determine the stand structure and productivity of forest stand (Rogers , Station 1996; Larocque 2016). Harvesting or silvicultural systems are the main focus on the regeneration abilities of the forest stand (Troup 1952; Champion et al., 1965b), through which we define the forest function and management system. There are many harvesting systems in different regions of the world whereas; clear-felling and selection system mainly represent practices in a productive forest for the sustainable management (Shegelman et al., 2015; Kumar et al., 2016; Yao et al., 2016). Long term harvesting impacts are highly influenced the soil organic carbon (Clarke et al., 2015), change in biodiversity and species communities (Ellum 2009), stand structural diversity and forest growth (Baret et al., 2017). Silvicultural treatment in the temperate region needs to carried out in a less affected manner to protect typical flora, fauna, micro and macro-organisms (Kuiters et al., 1996). Clear-felling is less focused to prevent disturbance in the productive commercial forest (Mannerkoski et al., 2005). Present studies were focused on two different harvesting system; Clear-Felling (Wedge and Strip) and Selection System (Group selection and Single-tree selection system) (Lughmani 1961; Shah 1967). Wedge, strip and group selection system were tested during 80's by the Swiss-German foresters on one-hectare plots, to estimate the growth and regeneration rate, but in 1991-92 government ban the green harvesting in Pakistan and the research study was not followed by any forester and researcher. Clear-felling is less focused to prevent forest disturbance in protective and commercial forests (Kuiters et al., 1996).

Species abundance, diversity and richness showed status and health conditions of undergrowth in forest ecosystems (Causton 2012; Gris et al., 2014). These undergrowth layers provide niche to birds community (Camprodon , Brotons 2006), termites, herbivores and early fire (Traoré et al., 2015), with potential to affect the soil nutrient cycles (De Boer , Kester 1996). Undergrowth also helps as a bio-monitoring tool in the analysis of pine stand in temperate regions for deposition of nutrients and acids from the atmosphere (van Dobben et al., 1999). Un-cleaned areas from nutrients and acids deposition allow variation in snow temperatures which are significantly higher than cleaned areas (Hansson 2006). The response of beech forest in the mountain forest regions is conservative to the undergrowth in the spruce stand while considering the succession (Vacek et al., 2017). The under-growth is highly affected by a nonfunctional management plan in the region, where the forest department avid to perform the silvicultural operation in the region due to the green felling ban (Sadozai 2003). The stand structures and compositions which were ignored by the management official also severely characterized the undergrowth (Fischer et al., 2010; Kato-Noguchi et al., 2017). Temperate forest ecosystem and the structure of the stand are unique then the other ecological regions in the world, undergrowth in these forest changes the architecture and habitat for micro and macro-organisms (Barnes et al., 1997; Barbour 1999).

Climate change impact studies and biomass estimation also result to evaluate the forest stand for sustainable management under the different project (Amjad et al., 2014). Mountain forest has great input to the watershed, water storage and source for the down country. Due to high gradient, these mountains also have great threat during flood season, and washed away many human settlements and represented great lost to the natural resources. Scientific and technical evaluation and studies need to be conducted for future planning and policy-making as the region (Himalayan part of Pakistan) is highly vulnerable due to industrialization from northern (China) and eastern (India) sites. In present, billion tree tsunami project for afforestation and conservation of forest resources were executed in Khyber Pakhtunkhwa province (2014), which were spread throughout the country in 2018 by the name of Plant for Pakistan a five year project. This project was initiated to cover the forest area by afforestation, reforestation, and declaration of protected areas. This results to enhance the forest area very significantly acted throughout the region, especial in moist temperate forest this project was highly rated.

Outdoor recreation is the key eco-commercial service of these mountainous forests in the region of interest. Flora and fauna are highly diversified in its nature, great importance for protection and scientific management is required for forest resources conservation and sustainability. Silvicultural systems and tending operations are important management tools for the optimization and utilization of forest resources. Millions of local and foreign tourist visited the beauty of these mountain forest, with beautiful lakes, lash green and full of flowers meadows and pastures, dense forest tracks, waterfalls, wildlife habitat for beautiful birds and mammals. The regions are also famous for fish hunting in the cold waters of Himalayas. These recreational activities also negatively contribute towards the land-use, water management, pollutions control etc. Infrastructure also change the original landscape of the region, sedimentation is increased with the passage of time, this sedimentation results to rise the bed level of country water reservoir (dams) Tarbela, Mangla and Warsak.

Regeneration gaps lead forest ecosystem to deterioration and degradation of forest stand structure (Barnes et al., 1997). To investigate the life cycle of forest stands, regeneration process and factors influencing the process needs to be identified (Guo et al., 2003). Heterogeneity of forest stands with species composition influenced rate of regeneration (Chen et al., 2007). To maintain the ecosystem of forests, regeneration process needs to be properly managed by means of artificial and natural regeneration (Kent , Coker 1992). In the naturally regenerated forest ecosystem plants may die or recruit to the understorey, after the competition surviving they became a part of overstorey (Barnes et al., 1997). Regeneration aspects which were found in woody vegetations are; vegetative, viable seed bank, dormant and persistent seed bank, the fire-induced opening of cones, widely wind-dispersed seeds, locally dispersed seeds and persistent juveniles (Grime 1988; Barnes et al., 1997). Seed production in forest crop influenced the rate of growth (diameter & height) which effect the timber production (Morris 1951; Tappeiner 1969).

The present study is focused on identifying management activities and status of the forest for conservation, protection and production level. Moreover, the stand structure diversity was also examined, focused on the undergrowth, regeneration activities and survival rate. The studies about the aim of the study were given in the next chapters.

1.1 Aim of the Reserach

At baseline, the dissertation project was examining the current levels of understory and vegetation composition of the forest in the moist temperate forest by using GIS and RS techniques to minimize the duration of the research work. Other activities may also include the growth under different harvesting system that include the group selection system, signal tree selection system and clear felling.

The research question:

(1) What types of effects on undergrowth under different harvesting system?

(2) Effects of harvesting system on edaphic condition of the site?

(3) Growth rate comparison in the different aspect and topographic condition?

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2. REVIEW of LITERATURE

2.1. Temperate Forest;

The temperate forest is one of the important biomes for the production of high-quality timber as well as a hotspot for biodiversity and livelihood (Liu et al., 2020; Du et al., 2021). Temperate forests are located between arctic and the tropical region as it is warmer than poles and colder then tropics according to climatic characteristics (Tyrrell et al., 2012). Temperate zone is among the five latitudinal band zones of the world, temperate forest cover about 120 – 260 millions of ha, and 30 millions ha to spread on temperate mountain forest, temperate continental, and temperate oceanic forests respectively (Blondeel et al., 2021; Yuan et al., 2021). Ecological classification also has vital importance by putting sino-japanese and iso-iranian-toranian vegetation types in south-east Asia (FAO 2010). These forests are located in Euro-Asia, North-America, South-America, East-Asia which is identified in figure 2.1 by green colour. The growth in these forests is mostly comprised with trees especially tall ones with a height of about 100 m, majority of the flora is evolved under a particular environmental condition, niche, and adaptation to the regional climate (FAO 2001; Kuennecke 2008). This biome is a potential dominant zono-biome of the temperate zone in the northern hemisphere. Central European beech forests and oak forests formed a climax type of ecosystem in the lowlands and lower hills in Central Europe. The name of the biome is derived from the characteristic feature of edificators, which is a formation of leaf apparatus at the beginning of vegetation period and fall of leaves at the beginning of the dormancy period, i.e. in the winter months (Odriozola et al., 2020; Qin et al., 2020). So the determinants are deciduous broad-leaves with admixed adapted conifers (Schlanser et al., 2020).

A number of synonymous labels are used, e.g. temperate deciduous forests or only deciduous forests in the context of Central European vegetation. They occur in three important areas in the world. First, a major part of Europe except most of Scandinavia, north-eastern Russia, and the Mediterranean; the second area is east of North America between the Atlantic and 95° E, and between 30° and 45° N; and finally, in East Asia in the east of China, Manchuria, Korea and the northern part of Japan between 35° and 50° N (Freemark , Boutin 1995; Fatur , Kreft 2020; Li et al., 2020). However, the climate is always characterized by 4–6 warm months and an average July temperature of around 20 °C. Depending on the distance from the ocean, continentality is reflected in the amount of rainfall and especially winter temperatures. The average annual temperature is around 10 °C (5–10 °C) and the annual precipitation is between 500–1,500 mm (Stoks et al., 2017; Renoz et al., 2019). Maximum precipitation comes in summer. Microclimatic values are then strongly influenced by the stand and its character and annual foliage dynamics (Newman , Hart 2006). A typical stand microclimate is formed, which, with its light, weather, and moisture conditions, is significantly different from that of a forest-free site. (Rockström , Gordon 2001; Faber-Langendoen et al., 2020)

Deciduous broad-leaved forests are found in plains and foothills up to 1,000 m above sea level (Schulze 2018). In the south of Europe, their contact zono-biome is the Mediterranean sclerophyllous forest, in the east it is the steppe, and in the north, the border with boreal coniferous forests – taiga. In North America, this zone is adjacent to the Gulf of Mexico in the south, prairies in the west, and taiga in the north. Finally, in East Asia, the neighbouring biomes are represented by subtropical and tropical forests (S), steppes (SE), deserts (E), and taiga (N). The soil is formed by weathering of all types of rocks and young sediments of fluvial and aeolian origin (Santini et al., 2019).

Two soil types are typical: cambisols and luvisols (brown forest soils and illimerized soils) (Martins , Angers 2015). A number of other names have been used in former classifications (brown earth for both types, illimeric podzols, etc.) (Mayer et al., 2020). In cambisols, the pedogenetic browning process prevails (brownification, brunification, alteration), where oxidation and hydration of primary minerals release iron in the form of amorphous divalent iron oxides, which later transform into the form of goethite and lepidocrocite (Liu et al., 2019). At the same time, secondary clay minerals are formed. In depletion (illimerization), we register mechanical transfer (by percolating water) of clay particles from upper horizons to deeper layers, which are thus relatively enriched (Motiejūnaitė et al., 2019). Thus, a luvic (argillic) diagnostic horizon is created, in which the soil particles are covered with colloid coatings. The soil of this zone is characterized by significant annual dynamics of temperature and humidity. This is related to fluctuations in pedochemical and pedobiological characteristics (pH, the content of available nutrients, bases, the activity of soil fauna and microorganisms, etc.) (Cheng et al., 2019).

These tall trees are dominated by coniferous, evergreen, and broadleaves species. Major species are; *Acer, Pistacia, Alnus, Betula, Fagus, Quercus, Juglans, Robinia, Prosopis, Magnolia*, *Morus, Fraxinus, Olea, Platanus, Prunus, Salix, Populus, Ailianthus,* etc. broadleaves species. The coniferous species are; *Picea spp., Larix spp., Pinus spp., Abies spp., Thuja spp., Juniperus spp., Cedrus spp.,* etc. The MAT is varying due to vide spread in the globe warmer temperate reached up-to 20°C, whereas, the colder temperate MAT is 8°C. The world's highest mountain peaks were also found in the ranges of these temperate forests (the peaks are not in the ecologically temperate forest due to saver cold and no vegetation) (Kaila 1981; Bukhari et al., 2012; Chakrabarti 2016b).

Since the Neolithic, the deciduous forest zone in Europe and Asia has been exposed to a very strong civilization impact. Large areas were ploughed up and the remaining forest areas are subject to the most intense silviculture. Anthropic influences manifest in strict adherence to spatial-temporal order, change in species composition, and multi-purpose use of forests. Very few primaeval deciduous forests remain in existence, even in North and South America, where colonisation began about two centuries ago. Climatic and productive conditions have facilitated intensive urbanization and economic exploitation in these, until recently, virgin regions (Bani et al., 2018).

2.1.1 Temperate forests in Euroasia; cover a large area in Europe compared to the rest of the temperate region, these forests were greatly affected by Pleistocene Ice Age. These forests were also affected by the movement of the continental sheet in the northern hemisphere. Downward of these forests, the conditions are covered with a Mediterranean climate, and on the northward toward pole is boreal forest shown in figure 2.2. These forests have the lowest diversity due to migration of vegetation prevented by the Alps, whereas many species were extinct in the region due to the ice age. Major species of the region which is widespread geographically is European beech which is suitable according to the climate, Scots pine, and Norway spruce are becoming widespread due to plantation. One of the largest European temperate forests which cover about 1,878 km^2 between Belarus and Poland is one of the world heritage site (Bialowieza primeval forest).

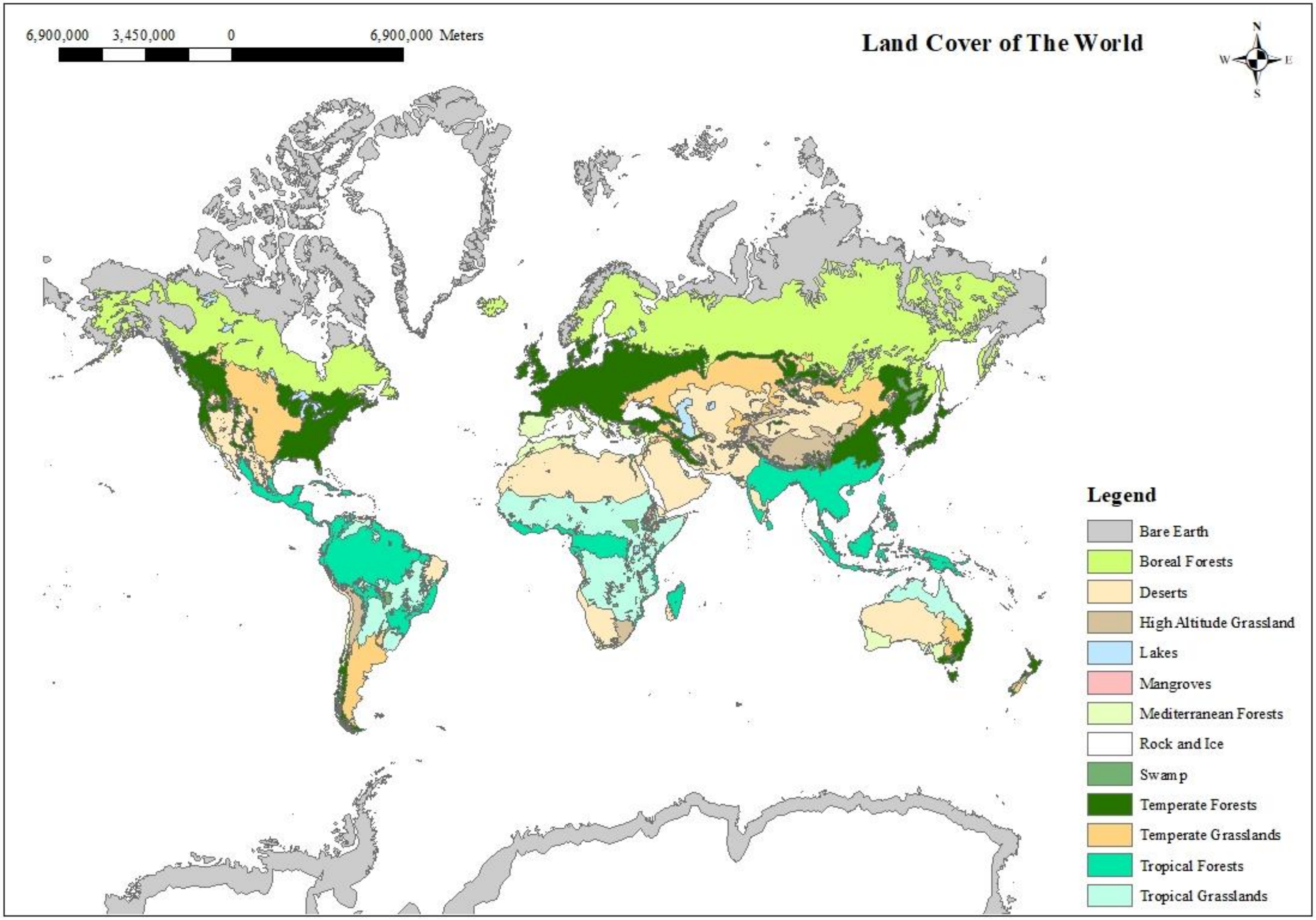


Figure 2.1: Temperate forest biome distribution. (*Map by Javed Iqbal*) ArcGIS Desktop 10.7.1

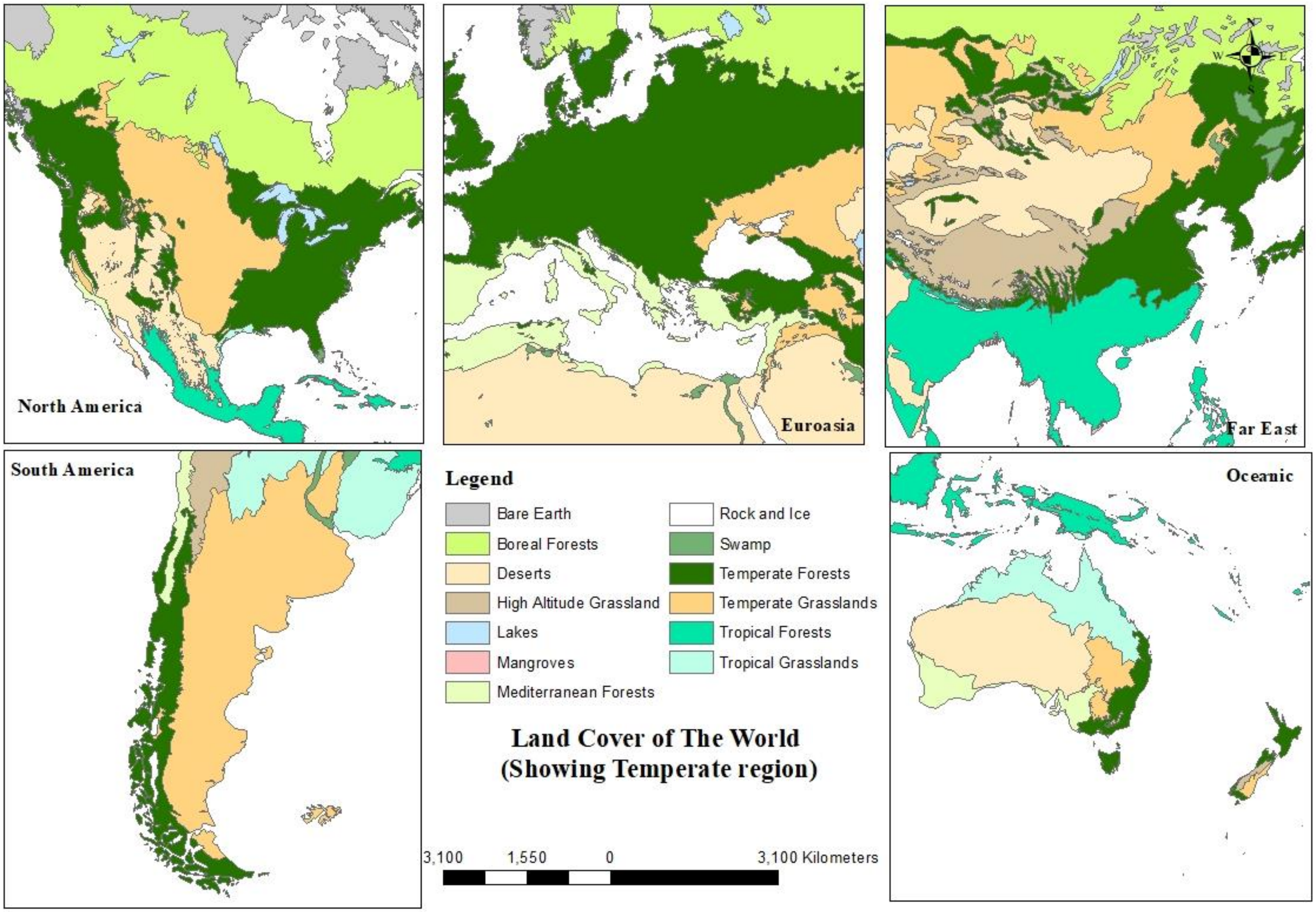


Figure 2.2: Temperate forest biome distribution. (*Map by Javed Iqbal*) ArcGIS Desktop 10.7.1

2.1.2 *Temperate forests in N America;* is distributed in east and west region divided by the temperate grassland in the middle. These forests are also surrounded by the water from the Atlantic oceans on the east and Pacific on the west, whereas the north is limited with boreal forest and in the south region, deserts are found. The United States of America and Canada's geographical regions were covered by these forests. The clear demarcation is shown in figure 2.2. These forests are quite young compared to the other temperate region of the world. The North American temperate forest is different than other temperate forest regions of the world by species composition covered mostly with coniferous species. This continent is typically represented by maple-beech forests, which are the original dominant climax in the humid northern and eastern parts of the continent. Significant species include *Fagus grandifolia*, *Acer saccharum* (typical K-strategists), followed by e.g. *Betula lutea*, *Tilia americana*, *Quercus borealis*, *Q. alba*, *Q. bicolor*, *Liriodendron tulipifera,* and others. Drier and warmer southern regions were, in natural conditions, dominated by oak-chestnut forests – *Castanea dentata*, *Quercus montana*, *Q. coccinea*, *Q. borealis*, *Q. alba*, *Carya ovata*, and others. In the western region, oak-hickory forests dominated, predominantly composed of various oak species (at least 10 – e.g. *Q. borealis*, *Q. velutina*, *Q. alba*, *Q. macrocarpa*) and five hickory species (esp. *Carya ovata*, *C. alba*, *C. illinoensis* – pecan) (Carlson et al., 2012; Carroll et al., 2012; Henke et al., 2012)

2.1.3 *Temperate forests in S America – Patagonia;* This region is restricted to southern South America shown in Figure 2.2. These forests cover Columbia and Chile also join Argentinian borders in the west. Limited in the east with temperate grassland and in the north part of the Mediterranean forest. These mountains and forests are widely exposed to the winds from the Pacific, the windward aspect of these forests show high precipitation. Deciduous southern beech forests are found in these ranges after the Mediterranean forest. *Caricaceae* family species are most common in the south and central American forest and the genus *Nothofagus* is dominant here (Carlson et al., 2012; Carroll et al., 2012; Henke et al., 2012)

2.1.4 *Temperate forests in Far East or east Asia;* region is untouched by the glaciation and one of the large biomes in the temperate ecotone. Due to the stability in these biomes, the plants (phytocoenoses, plant communities) are preserved older than any other. These forests highlight the human impact and intensive use for agriculture and fuelwood consumption in the region. Figure 2.2 shows the distribution widely in the Asian region (China, Japan, Korea, sub-continent, and Iranian region). There are some identical forests in China only the humidity level can differentiate the region from the rest of the temperate forest. Some of these forests include also in one of the highest peaks mountains ranges of the world in the sub-continent region. These forests are mostly covered with conifers species different than the rest of the world forest which are dominant or partially dominated by the broadleaved species. East Asian deciduous forests are characterized by extraordinarily rich biodiversity. The genera correspond to the areas mentioned above, but dozens and hundreds of other species developed there. Particularly luxuriant forests are composed of beech (*Fagus crenata*), followed by Manchurian ash (*Fraxinus mandshurica*) and Erman's birch (*Betula ermanii*). The present study is also conducted in the region in far-east or East-Asia, the western Himalayan moist temperate forest of Pakistan.

2.1.5 *Oceanic Temperate forest;* due to limited geographical areas in the Oceanic region, these forests are found in south-east Australia and New Zealand. The precipitation varies from 600 mm to 2000 mm from low elevation to the high elevation region in Australia. Whereas, in New Zealand the annual precipitation ranger from 1800 to

4000 mm. These forests are mostly situated near the coastal areas, the forest is dominated by *Nothofahus cunninghammii, Lagorostrobos franklinii, Phyllocladus aspleniifolius, Anadopetalum biglandulosum, Elaeocarpus holopetalus Eucalyptus spp.*, etc. Broadleaved species made these forests more productive and diversified, but the coastal atmosphere diversified the species stand structure. The location is shown in figure 2.2.

2.2 Temperate forests in the Czech Republic;

The Czech Republic is located in Central Europe adjacent to the alpine region in the Euroasia temperate forest. Ecologically the forests fall in the temperate forest with broadleaved and coniferous species, covering an area of 33% (2.6 Million ha). Central European beech forests and oak forests formed a climax type of ecosystem in the lowlands and lower hills in the Czech Republic (Thorn et al., 2017). Deciduous broad-leaved forests are also marked by the occurrence of particular conifers, especially the genera and species with lower competitiveness (pine, yew, silver fir). Trees of this zono-biome can reach a substantial height of 30–40 m. In the mixed forest zone, they can be even taller, in favourable conditions, for example, the tallest known spruce in the Boubín old-growth forest has 59.5 m and a similar height was found in spruce and fir trees in Šumava and Beskydy Mts (Remeš 2018). However, the tallest measured individual in the Czech Republic is a Douglas-fir with a height of over 64 m and age of only about 140 years, growing in a valley position near the town of Železný Brod. In the conditions of the Czech Republic with a considerably simplified species composition (the result of glacial and geography conditions of Europe), a distinctive altitudinal zonation occurs, which is also reflected in the distinction of altitudinal vegetation levels – oak, beech-oak, oak-beech, beech, fir-beech, and spruce-beech – with predominant winter oak (*Quercus petraea*), European beech (*Fagus sylvatica*), silver fir (*Abies alba*) and the first geographical occurrence of Norway spruce (*Picea abies*). Other woody plant species (i.e. several tens, including shrubs) usually form only an admixture, indicating other habitat characteristics (elm, maple – nutrient-rich, ash – moisture-rich, etc.) Similarly, the growth of spruce outside natural spruce forests is made possible by the particularities of individual habitats, e.g. inversion of vegetation zones in deep valleys (e.g. the Sázava river valley) (Huth et al., 2017). The specificities of individual localities are also reflected in the composition of ground vegetation, which forms the basis for a practical distinction and classification of forest communities for the needs of forest typology (Schulze 2018). The characteristic synusia of the ground vegetation is the pre-spring and spring aspect, constituted mainly by geophytes (Bončina et al., 2019).

2.3 Moist temperate forest of Pakistan;

The presented dissertation is focused on the Himalayan region. The geological, geographical, political, and ecological distribution has generated variation in the Himalayan ranges. The Himalayan range covers Bhutan, Nepal, India, and Pakistan from political geography, Figure 2.3 and 2.4 show temperate region in the country and also the ecological zonation in the entire country, location coordinates cover 33.262143dd, 35.829804dd, and 72.128056dd, and 75.3594dd (South, North, West, and East ends, respectively). The altitude of these forests ranges from 1200 to 3600 m with respect to aspects, topography, temperature, and the direction towards Iranian or Japanese vegetation characteristics (Khan 1958). The temperature in the region is varying: winter minimum temperature is -10℃ and maximum temperature is 14℃, during the summer the minimum temperature is about 5℃ and Maximum is 22℃ (Ives 2006; Munawar et al., 2015). Physical geography covers high mountain ranges and peaks like mountain Mount Everest and also Plateau plains (Kaila 1981; Blaikie , Muldavin 2004). Map suitable Geological distribution is covered by Sub-Himalaya, Lesser Himalaya, Higher Himalayan Crystallines, Tethyan Himalaya, and Indus-Tsangpo suture zone (Shah , Moon 2004; Chakrabarti 2016a). Ecologically the vegetation zones are alpine pasture, sub-alpine pasture, temperate forest both dry and moist, sub-tropical pine forest, and scrub forests of *Acacia* and *Olea*. Moist Temperate forest of Pakistan cover and area of 572508 ha in Azad Jammu and Kashmir, Khyber Pakhtunkhwa, Punjab, (Gilgit-Baltistan and part of Balochistan province), they covered dry temperate region (Hussain 1984; Bukhari et al., 2012).

Detailed information about the species composition in the temperate forests are; *Acer caesium* Wall. ex Brandis, *Acer pictum* auct., *Pistacia integerrima* J. L. Stewart, *Hedera nepalensis* K. Koch, *Berberis lycium* Royle in Trans., *Alnus nitida (Spach)* Endl.Gen., *Betula utilis* D.Don, *Sarcococca saligna* (D.Don) Muell.-Arg. *Lonicera webbiana* Wall., *Viburnum grandiflorum* Wall. ex DC., *Viburnum nervosum* D. Don, *Cornus macrophylla* Wall., *Corylus colurna* L., *Diospyros lotus* L., *Rhododendron arboreum* Sm., *Euphorbia wallichii* Hook. f., *Quercus dilatata* Royle, *Quercus glauca* Thunb., *Quercus ilex* L., *Quercus incana* Roxb., *Quercus semecarpifolia* Smith in Rees, *Ribes himalense* Decne., *Parrotia persica* (DC.) C.A.Mey., *Aesculus indica* Wall., *Juglans regia* L., *Plectranthus barbatus* Andrews, *Ficus palmata* Forssk., *Olea glandulifera* Wall., *Paeonia emodi* Wall., *Indigofera heterantha* Wall., *Abies pindrow* Royle, *Cedrus deodara* Roxb., *Picea smithiana* Wall., *Pinus roxburghii* Sar. Himalayan moist temperate scrub, Pohu Scrub (*Parrotia persica*), Himalayan temperate parkland, and Himalayan temperate pastures (Champion et al., 1965a; Champion et al., 1965b; Council et al., 2002; Bank 2015). *Pinus wallichiana* A.B. Jackson, *Actaea spicata* L., *Anemone obtusiloba* D. Don, *Clematis montana* Buch.-Ham., *Rhamnus virgata* Roxb., *Cotoneaster humilis* Dunn, *Fragaria nubicola* (Hook.f.) Lindl., *Prunus cornuta* Wall. ex Royle, *Prunus cornuta* Wall., *Prunus padas* L., *Pyrus pashia* Buch.-Ham., *Rosa macrophylla* Lindl., *Rosa moschata* Herrm., *Rosa webbiana* Wall., *Rubus armeniacus* Focke.,

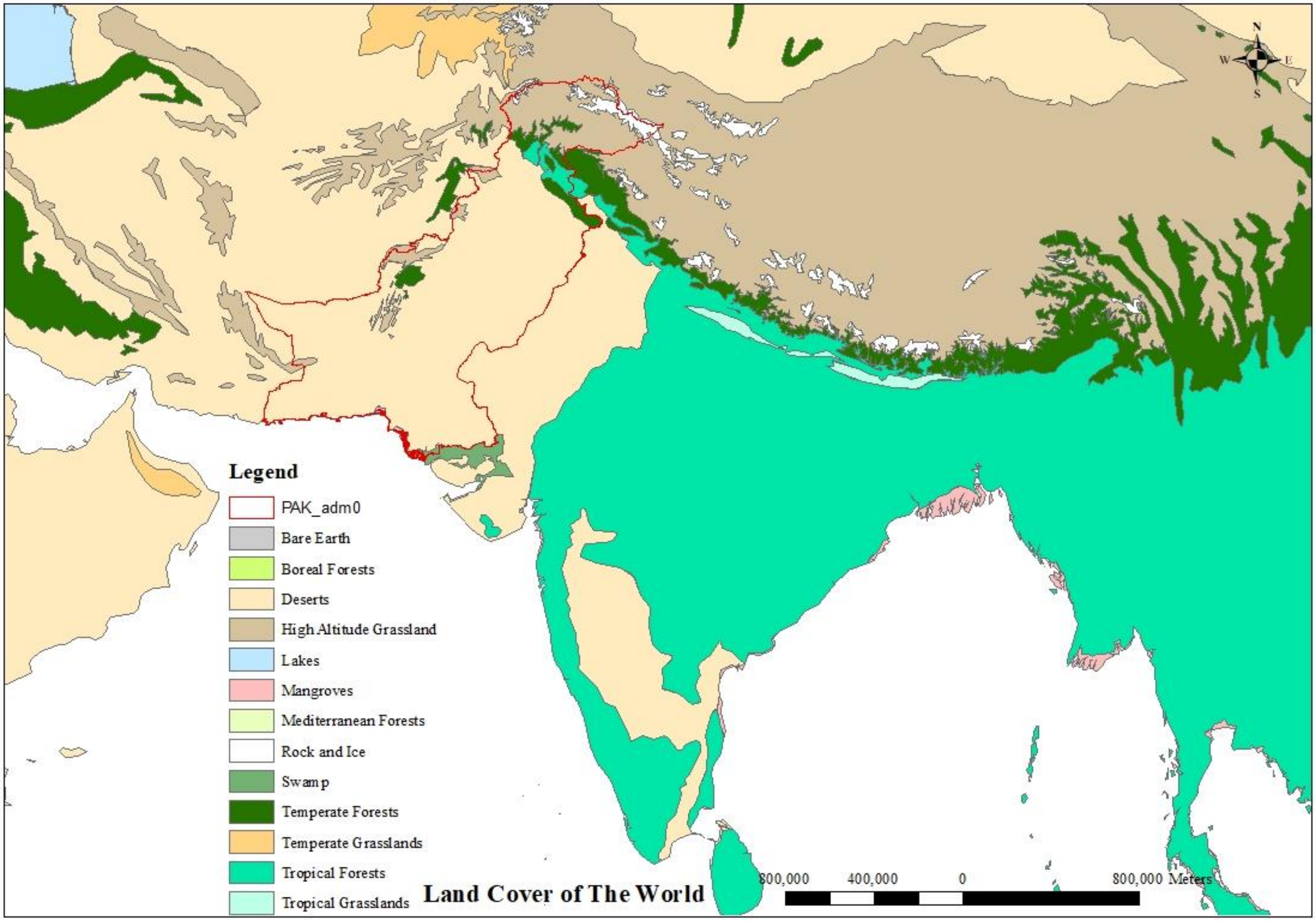


Figure 2.3: Temperate forest biome distribution in South-Asia. (*Map by Javed Iqbal*) ArcGIS Desktop 10.7.1

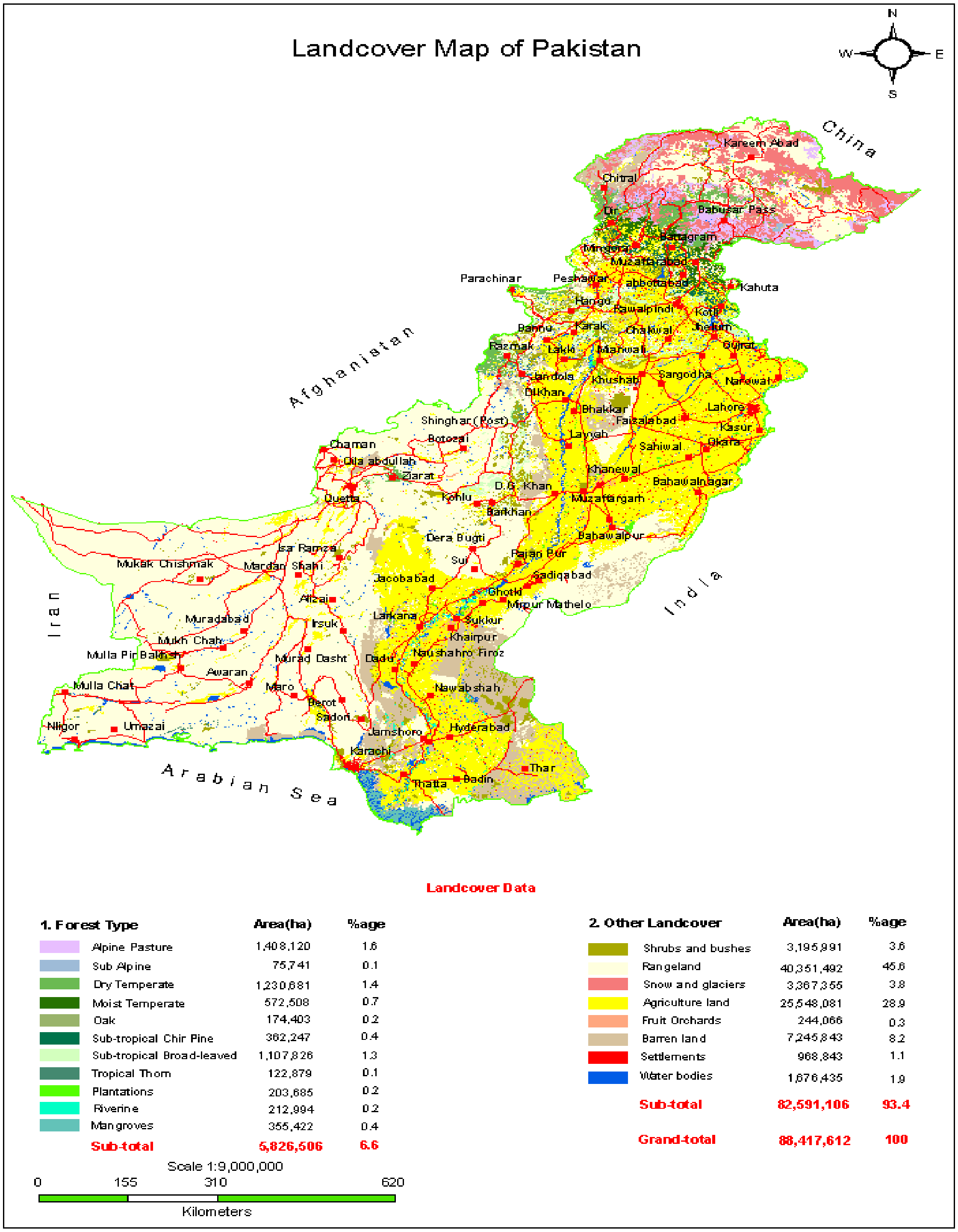


Figure 2.4 Land-use classification of Pakistan along with the area (ha)

Sorbus aucuparia L., *Populus alba* L., *Populus ciliata* Wall., *Salix flabellaris* Andersson in Kung., *Taxus baccata* L., *Ulmus wallichiana* Planch., and *Viola kashmiriana* W. Becker,. The Taxonomic family of these species are widespread in the region but due to the limited study and covered only moist temperate region of Himalayan only 30 families were recorded i.e.; *Aceraceae, Anacardiaceae, Araliaceae, Berberidaceae, Betulaceae, Buxaceae, Caprifoliaceae, Cornaceae, Corylaceae, Ebenaceae, Ericaceae, Euphorbiaceae, Fagaceae, Grossulariaceae, Hamamelidaceae, Hippocastanaceae, Juglandaceae, Labiatae, Moraceae, Oleaceae, Paeoniaceae, Papilionaceae, Pinaceae, Ranunculaceae, Rhamnaceae, Rosaceae, Salicaceae, Taxaceae, Ulmaceae,* and *Violaceae*, (Champion et al., 1965a; eFloras 2008).

Ecologically the moist temperate forest is divided into three regions: Lower Western Himalayan Temperate forests which includes; Low-level blue pine forest (*Pinus wallichiana*), Moist deodar forest (*Cedrus deodara*), Western mixed coniferous forest, Ban oak forest (*Quercus incana*), and Moru oak forest (*Quercus dilatata*). The second region is ; Upper West Himalayan fir and mixed broadleaved forest which includes; Upper West Himalayan fir and mixed broadleaved forest, and Kharsu oak forest (*Quercus semecarpifolia*). Whereas, the third region covers; Edaphic, seral, and Degraded type of Himalayan moist temperate forests which include; Moist temperate deciduous forest, *Populus-Salix flabellaris* Forest, *Alder* forest, Riverain blue pine forest, High-level blue forest, Secondary blue pine forest (*Pinus wallichiana*),

2.4. Harvesting system and sustainable management

Productive and protective functions of the mountainous forest ecosystem are severely degraded by different disturbance factors (Gunn et al., 2019). Energy and fuelwood consumption, which contributes to forest degradation, is often higher in the mountainous regions as compared to the settled areas (lowlands) (Sulaiman et al., 2017). Forest management and anthropogenic activities also enhance soil properties transition and increase forest litter which provides a favourable source to the degradation and transformation process (Zhu et al., 2019). The intensity of the forest degradation process is linked to the decision making and policy formulation from the government, landowners, and companies (Morales-Barquero et al., 2015). Unmanaged grazing system results in the trampling and compaction effects (Sulieman 2018) which deteriorate fragile pastures and grasslands in the mountains (Mack et al., 2013; Bormann et al., 2015). Recent climate change phenomena enhanced forest degradation in mountain regions, temperate forest, and riverside forest (Munawar et al., 2015; Ahmad et al., 2018; Gunn et al., 2019).

Forest is highly diversified by nature as one end of the country touched the deep waters of the Indian Ocean and on the other end touches one of the highest mountain ranges of the world the Karakorum, and Himalayans. These diversifications give four different ecological zonations that are Tropical, Sub-Tropical, Temperate, and Alpine. These ecological zones are divided based on temperature into nine classes. Whereas, the ecologist divided the ecological zones which are based on lowland and highland classification. The country is also a habitat of the migratory bird species from the cold areas (Siberian regions) to the warm waters by using the water bodies. Conservation sites such as National Park, Natural Park, Game Reserve, Game sanctuary, Wilderness areas, Protected forest, Reserved forest, Communal Lands, and also other classified sites and areas. After the British rules the government started to protect and conserved the forest and other natural resources by using the Forest act 1927, and Forest act 1936 for communal lands. Forest policies of 1955, 1962, 1975, 1980, 1988, 1991, 2001, and 2015, these policies have the main aim to protect the forest and other natural resources like wildlife, range management, etc.

Mass afforestation activities were also designed and implemented during the past 50 years of these policies, i.e. in arid areas and in highly fuelwood consumption areas afforestation activities were during the early years of independence highly implemented which were later on converted to environmental, and conservation approach. One of the largest man-made forests (Changa Managa Irrigated Plantation) was established in 1865 by the British rules to supply fuelwood for steam engines throughout the country. There are several other plantations by the name of Khundya, Chichawatni, Dapher, and others. These irrigated plantation cover species e.g. *Dalberghia sissoo, Acacia nilotica*, *Eucalyptus camaldulensis*, *Morus alba*, *Populus alba*, and other wood pricing species which are not dominant in the plantation. Presently, there was a project by the Government of Pakistan by the title of Clean and Green Pakistan to plant a Trillion trees in the country.

2.5. Ecological and environmental impact of silvicultural systems

Ecologically and biologically Pakistan is one of the richest countries, including high mountains of Himalayan, Karakorum, and Hindu Kush and deep Indian ocean with high diversity (Hussain 1984). Forest ecosystems are one of the major parts of the natural richness. Production is one of the key elements of forest resources and their services play role especially in the coniferous forests (Müller et al., 2019). These forests are the major source of palatable plant species (Khan 1985), they also provide fuel-wood and medicinal plants to the local community (Sher , Al-Yemeni 2011). Due to the heavy exploitation, intensive utilization, and recreational activities (Rashid et al., 2011) in these valuable ecological niches, the fauna and floristic community become near to extinct (Al-Yemeni , Sher 2010; Sher , Al-Yemeni 2011). Special management is demanded, for wildlife biodiversity maintenance in many cases (Moser et al., 2002).

To get maximum benefits without destroying these forests, foresters need sustainable management rules and integrated plans. Harvesting or silvicultural system is the scientifically based method to utilize these forests properly and sustainably. This concept was mentioned originally by Hans Carl von Carlowicz (von Carlowitz 1713) and it is used systematically in forestry since 1713. Silvicultural systems are the "set of silvicultural operations by which forest crops are tended, harvested, and replaced by new crops – this constitutes a Silvicultural Systems" (Troup 1952) for standard definition (Association 1953; Champion et al., 1965b). The availability of environmental resources to establish and create new individuals and survivors are provided by the silvicultural treatments and tending operations (Harper et al., 1965; Lewandowski et al., 2015). According to studies during, plant compositions, differences were significantly shifted through the years (four-decade), the sites were degraded due to reduction (35 %) in species richness, forbs and grasses ratio was increased due to an increase in acidity and change of the soil chemical composition (McGovern et al., 2011) in North American temperate forests and also in the tropical region. The distribution of natural regeneration, its amount, and types are also determined by the interaction of a wide range of overstorey and understorey vegetation with climatic and edaphic factors (Bataineh et al., 2013). The soils have undergone large changes in the past years due to environmental pressure (McGovern et al., 2013), which affects the species composition, structure, and diversity of the forest stands. That ultimately influenced the choice of silvicultural systems and tending operations in the mountainous forest with scattered vegetation.

Natural regeneration of the high mountains in Pakistan is the only source of growing stock. Almost every forest species are regenerated through seeds except some broad leave species (Yadava et al., 2017). Suitable ground and site conditions are required for the germination and establishment of seedlings. Site conditions like topography, aspect, slope, moisture availability, the thickness of humus, light exposure, and grazing activities are playing a vital role in the germination process. Forest stand structure and density also affect natural regeneration by allowing required light, water, and space availability of enough seed for the germination (Rocha et al., 2016; Splawinski et al., 2016). Soil depth, and decomposing humus with more nutrients prone to be ideal space for regeneration. The temperature in the mountainous regions fluctuates during the day (high) and particularly at the night time (low) (Chakrabarti 2016a). Natural regeneration is threatened by many natural and anthropogenic factors. Natural factors that influenced natural regeneration are; heavy wind, erosion, heavy rainfall, animals (squirrels), natural fire, wind-thrown, and torrents (Tinya et al., 2019). Whereas, grazing practices, tree harvesting activities, roads, and trails represent the most important anthropogenic factors which affect the regeneration process in high mountains (dos Santos et al., 2019; Maltoni et al., 2019; Rezende , Vieira 2019).

Natural regeneration is highly diversified due to crop stage requirements, composition, structure, and density. Seedlings are sensitive to many environmental factors compared to older individuals; species composition is also taken into consideration. Early colonizer species (pioneer, preparatory species) require high favorability for establishment in newly and freshly deposited exposed sites. The chemical and structural diversity of soil is also influencing the process of crop establishment. Hydrological components and groundwater availability are somehow affecting the germination process, which was later dependent on species adaptability to the habitat and environmental factors. Plant community also influenced the seed dispersal; seed ripening, seed germination ground, seedling, sapling stage problems (exposition to light, water, and nutrients) protection from biotic and anthropogenic factors (birds, animals, humans, and other anthropogenic factors). Heavily grazed sites are always deteriorated and highly exposed to natural disasters and vulnerability.

Most of the forests have mixed species composition and also variation in structure in the mountain region (Pignataro et al., 2017; Dănescu et al., 2018). Shade tolerant and light-demanding species are common during the early stage of their development/secondary succession. Good seed years also influenced the rate of regeneration and density in mountain forests. Climatic factors such as snow and heavy rainfall also affect the favourable site for regeneration. Secondary succession in the temperate forest region is enhanced by disturbance activities and events. Recently, the 2005 earthquake also provided ground to succession activities. The temperate forest also developed a stand development model after the gap phase and post-disturbance. These forests have the most evident of three models i.e. Stand Development Model (Oliver 1980) and the model focused on population is Population Model (Peet , Christensen 1980) and Beechwood Model (Watt 1947) is mostly found in these regions.

The moist temperate forest is covered with diversified composition and structure of forest crop, from mosses to higher plants in the region as shown in Figure 4.1 in the next section of this chapter. Dynamics of natural forest development and secondary succession in forests is varying with species *Pinus wallichiana* A.B. Jackson is highly shade tolerant and mostly found with *Picea smithiana* Wall. and *Abies pindrow* Royle. *Cedrus deodara* Roxb. is also dominated by *Abies pindrow* Royle in between 1800-2400m a.s.l., whereas they can be found naturally from 1500-2800m altitude. Good seed years vary with species, therefore the uneven-aged structure is more suitable for sustainable management. According to the past practice in the temperate forests a shelter-wood system was adopted by classifying dried and moist regions. On dried site 10-14m spacing or 51-75 trees/ha seed barer was left to provide sufficient seed supply to the site, whereas on moist site 9m spacing were observed or 123 mother trees stood as seed factory (Champion et al., 1965b). Supplementary artificial regeneration practices were also observed if there is a bad seed season or any other natural hazards were observed in the areas (de Carvalho et al., 2017).

Forests are continuously expending (changes to distribution, mortality, drought, and growth) due to potential climate change (Lindner et al., 2014) and uncertainty in climatic factors (Yao et al., 2016). Silvicultural practices tend toward the improvement of the forest crop (Short , Radford 2008), by providing species selection and reducing the canopy as well as the intensity of damages. The ecosystem is also very vulnerable to climate change; forests are directly focused on the species tolerance level (Ojima et al. 1991).

Coniferous forests are high forests regenerated naturally, most of the species are light-demanding and some of them shade-tolerant. To regenerate the stand. the forest crop seed bearer were left in the stand i.e. 12-18 tree per hectare for *Pinus roxberghii*, whereas, in deodar forest have 50-60 tree per hectare with a mid-elevation range from dry to moist region. Lower elevation forests were burnt periodically due to the abundance of grass species which also affect the germination and dormancy of seeds. To obtain a good result of natural and artificial regeneration, protection enclosures were observed. During the planting activities, forest managers need to close the areas for grazing, seed collection, fuelwood collection, grass cutting, etc., and other human activities for the best results. Good seed season provides good results of germination.

Mountains are an important source of natural forests, which need to be conserved for the future, to protect the environment from degradation (FAO 2010). Forest ecological studies and research are highly important for the adaptation of organisms to their environment (Landi , Angiolini 2008) in the mountains. These mountain forests are classified according to the floristic complexities and vegetation distribution. There is a high diversity within the regional vegetation distribution and also among the vegetation communities (Brummitt 2005). Whereas, vegetation distribution was mainly limited by the availability of favorable habitat (Guo et al., 2003). Micro-topographic, edaphic and abiotic factors with climatic conditions are also limiting the distribution of vegetation at the local level (Svensson , Callaghan 1988; Marquez et al., 1997). The floristic complexity plays an important role in biodiversity and also in the distribution of vegetation (Marques et al., 2011). Diversity is characterized by the floristic complexity, which is always differentiated by the minority of genera in one region (Brummitt 2005). Biodiversity play vital role in REDD+ under the Convention on Climate Change by United Nations Framework, information about the species distribution and types is needed for the estimation and analysis (Aye et al., 2014).

2.6. Social and economic aspect of silvicultural practices

Silvicultural systems are the scientifically based management tool for the sustainable production, conservation, and protection of natural resources most importantly in the high mountains. As a forest management tool or management plan is defined by (Troup 1952; Champion et al., 1965b) "*A set of silvicultural operations by which forest crops are tended, harvested, and replaced by new crops constitutes a silvicultural system*" as mentioned above. The most important factors from the present global situation are the social-economic factors. During the last few decades, anthropogenic activities cause serious damages to natural resources. Natural resource deterioration rate increases with local demand and less importance given to management practices. Forests and their environment which includes; environmental factors (temperature precipitation soil geology and interspecies interaction) animals and humans are highly diversified and complex. Therefore, the factors which can be easily improved, control, and modified need special attention.

Sustainable development Goals (SDGs) cover around seventeen different targets, some of the targets are about Clean Water and Sanitation (6), Climate Action (13), Life Below water (14), and Life on Land (15) have concerned with Forest resources directly or indirectly. Especially Climate action is closely related to forest resources. The target and indictors of climate action are; Climate-related hazards, strengthen the resilience, natural disasters which are indicated by deaths, a missing person, local government implementation clearly show the plus or minus of the target. Second, the integrated climate change policy measure is taken in the country which is indicated by different reports throughout the country in different aspects of production. Third, to improve awareness and institutional strengthening in the country (Nations 2018; Nations 2020). The silvicultural system also contributes directly or indirectly to developed new models, mapping, integrated plans, restoration activities, and help in national forest policy. Therefore, highly recommended studies need to be conducted in the research area of this dissertation.

People are dependent on natural resources for their livelihood in the mountain region of the Himalayas, Hindukush, and Karakuram. The silvicultural system indirectly benefitted the local people during harvesting, tree selection, and afforestation activities (Bragg et al., 2020). Moreover, the aesthetic beauty of the landscape also provides a healthy environment for the inhabitants (Staton et al., 2019). Application of silvicultural systems provides ground to fuelwood, medicinal plants, mushroom culture, and protection to the micro and macro flora and fauna of the region (Finkeldey , Ziehe 2004; Taeroe et al., 2019). The communities in the mountain region are highly dependent on the natural resources, they are also a part of the management activities in the study area (Skulska et al., 2020). Due to forest research and developmental project the status of these people and their socio-economic condition uplift in the past few decades (Shigaeva , Darr 2020).

2.7. Short description of particular silvicultural systems, use in the Czech Republic, and in Pakistan.

Variation in the ecological zones affects the silvicultural treatments and other management activities. This ecological variation covers temperature, species composition, stand structure, topographical variation, and management policy. *"Silvicultural systems differ from each other in the method of regeneration, natural (from seed or coppice) or artificial, the type of crop produced (whether even-aged or uneven-aged) the timing of the fellings in the rotation, and the spatial distribution of the felled and unfelled areas*"(Champion et al., 1965b). Silvicultural systems that are practiced in Pakistan after independence (1947) are; *high forest systems* and *coppiced systems.* The details of these systems are shown in the following flowchart given on the next page;

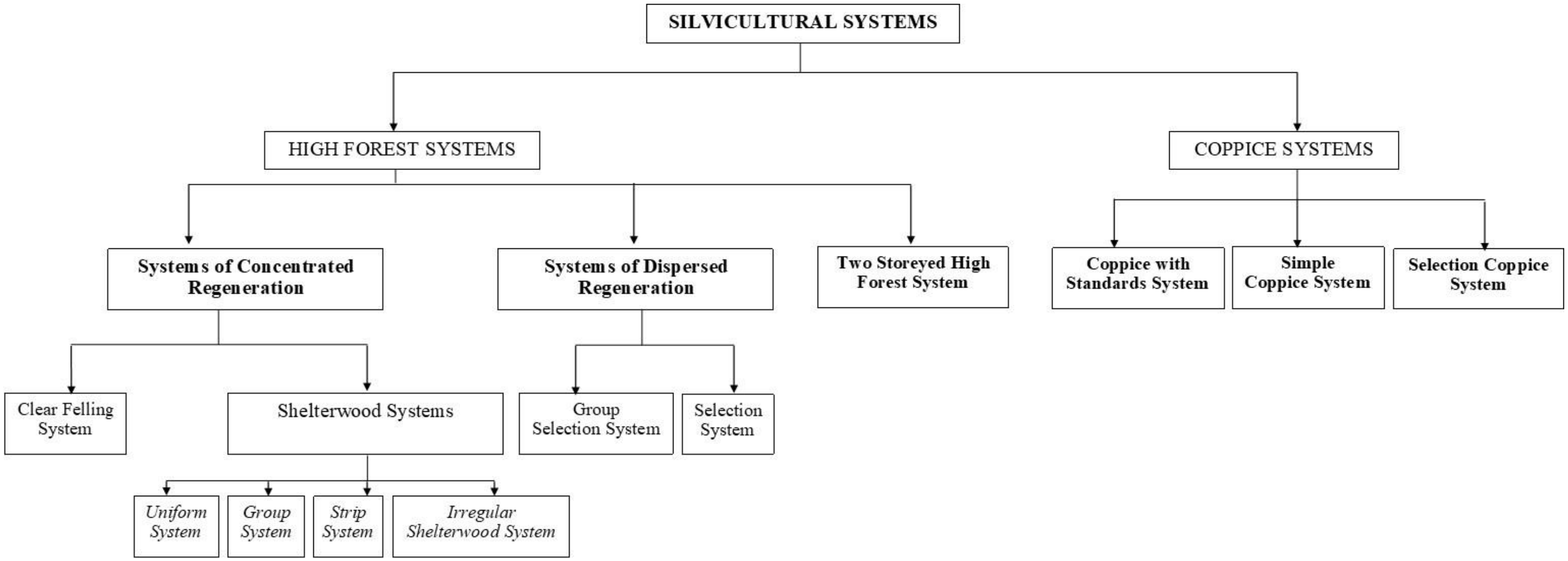
The regeneration is dispersed in the mountain region of Pakistan, these forests are considered and fall into the High Forest system. Selection system and group selection systems were practiced in the past, presently only single-tree selection systems were observed and it also applied only for the dead, dying, or diseased tree along with wind thrown, snow damaged (top broken or half-broken). In the coniferous forest of Pakistan modified selection system is applied, due to the topographic difficulty (steepness), aspect, grazing hotspot, and poor crops. The exploitable size trees i.e. 60-72 cm d.b.h. were harvested after the regeneration was established. The over-mature trees are left in-case the regeneration is not enough to stock the area (Yusuf 1955; Lughmani 1961; Khattak 1964; Champion et al., 1965b; Shah 1967; Sadozai 2003).

As mentioned above flowchart for silvicultural systems in Pakistan is based on the regeneration method and ability of the forest stand. The forest stand is classified into the high forest and coppice forest stands. Further, these systems are classified according to the density of the forest stand concentrated and dispersed vegetation. The silvicultural system applied in the region (Himalayan mountains) are;

Clear felling system – this system is no longer applicable in any part of natural forest in Pakistan except in the riverine forest in inundated regions during the pre-flooding seasons. Mostly *Populus, Acacia, Tamarix* species were highly desired to harvest in these regions (not applicable in the study region).

Shelterwood system – subtropical chir pine forests were managed through irregular shelterwood system; such forest is highly light demander in nature compared to other forest stands. During the practice, the forest is divided into annual coupe where mother trees were left for seed production. These trees help the natural regeneration during the regeneration period which is 25 years in these forest stand; numbers of seed bearer are dependent on the availability of mother trees 60 – 75 tree/ha (applicable in the study region).

Selection system – this system is highly demanded due to the low density of forest stand, disperse vegetation in the country forest. The tree was selected on the basis of 3D’s by the forest manager in a protected and reserved forest stand (applicable in the study region).



Flowchart; Silvicultural system practiced in Pakistan (Champion et al., 1965b)

Group selection system – due to the high level of damages from the selection system to early regeneration and sapling in the stand. Group selection systems were applied in various regions of the mountain forest. The selection site may not exceed 2 ha, such practices were exercised in the moist temperate forest of *Cedrus* and Pines (applicable in the study region).

Two-storeyed high forest – irrigated plantation is managed under such a silvicultural system. *Dalbergia* and *Morus* species were managed in such a manner. *Morus alba* is shad-barrier species that survives under *Dalbergia* species is a tall and fast-growing species (not applicable in the study region).

Coppice system – all foothill forest, scrub forest, tropical dry deciduous forest are in many cases managed under such a silvicultural system (not applicable in the study region).

The silviculture system in the Czech Republic are oriented on reproduction of productive and stable forest stands, regular thinning operation are practiced in the region.

Clear-cut system – the forest is regenerated mainly on the totally felled area and artificial regeneration by planting is prevailing. Such a system is also best suitable for the dense forest crop especially with coppicing ability, high regeneration density, and shrub vegetation or low height trees. This system is still dominant in the country due to tradition and technological advantages. The risk factor in such a silvicultural system is very low due to full area clearing, which may cause disturbance to other adjacent forest stands. There are legislative limits: 1 ha size (in determining cases as flood-plain forests, pine sites, and long mountain slopes – 2 ha), further the width must not exceed 2 stand heights. The new stand is fully exposed to the opened field conditions, convenient for species like pine, larch, oak, spruce (Vacek 2016; Bragg et al., 2020).

Border cut (strip) system – this system applies to one of the species composition which is best suitable for semi shad area regeneration. The felled area is a long strip following old stand border, not exceeding one stand height in width, good for semi-shade tolerant species, regeneration is usually combined, using ecological conditions of outer and interior stand borders.

Shelter system – the regeneration is usually natural under released stand canopy, convenient for shade-tolerant species like European beech, silver fir, and partly Norway spruce (Raymond , Bédard 2017; Kooch et al., 2020).

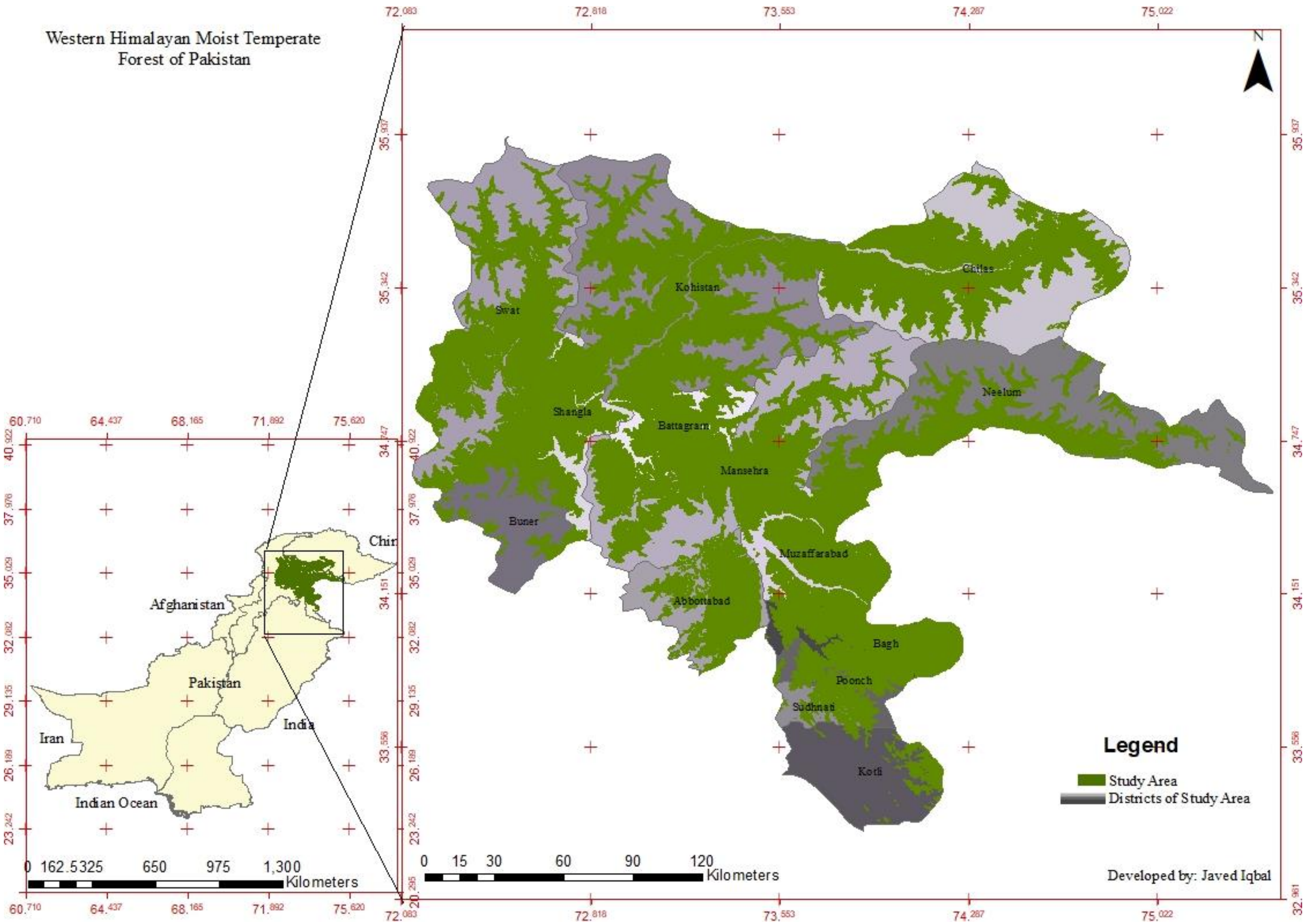
Selection system – the selection of individual trees, which were marked by the professional according to the selected criteria for the felling of trees. This tree selection may vary with; market demand, dead, dying, top broken, damaged, infected, and mature. A high level of skills is required for the felling of the forest tree due to the high risk to the adjacent crop.

Close-to-nature silviculture (CNS) – For all systems, good practices and optimization methods are available. The transfer in other ecological conditions should always respect the regional conditions. The forest management system is replaced by close-to-nature silviculture, the management system based on closed vegetation regeneration, and even-aged coniferous species composition (O'Hara , I. Valappil 1999). These even-aged species composition comprised by monoculture. In the central European forest, close-to-nature silviculture was first practiced during the 19^{th} century (second half). These management activities started from small-scale which later on upgraded to large-scale management and regeneration practices. This concept is used for sustainability which can be adapted for climate change (Remeš 2018). The long-term experience for CNS is understood widely for selective management activities. In the 20^{th}-century selection system for the selective forest and CNS for irregular shelterwood method. Czech lands (Opočno manor farm) were first experienced with CNS in 1924 for a period of 30 years. The transformation of monoculture forest stands to a mixed forest stand, where the management activities were observed from a clear system to a selective forest system. This practice was conducted into two stages; species composition was changed to give strength to the forest stand include forest soil recovery. In the second stage, they create a mixed stand by using the change in the horizontal canopy which gradually changes to the vertical and spatial canopy. The attribute consider in CNS are; stand diameter structure, height structure, DBH frequency distribution, stand spatial structure, and tree species composition (Buongiorno et al., 1994; Lähde et al., 1999; Schütz 1999).

3. MATERIAL AND METHODS

3.1 Field of study – Western Himalaya moist temperate forest:

Western Himalayan moist temperate forest of Pakistan represents the largest productive and commercial forest of the country/region (Champion et al., 1965a), with great floristic complexity and high biodiversity (Abbasi et al., 2012; Dar , Sundarapandian 2016). On the contrary, they are occupying highly sensitive and fragile geological structures referring to the youngest mountain ranges (Chakrabarti 2016b). A total of 572 thousand ha (0.7%) of the country area are covered by moist temperate forest (Bukhari et al., 2012); these forests were classified based on lower and upper west Himalayas with addition to degraded forest cover (Champion et al., 1965a). The forest covered the northern part of the country (Khyber Pakhtunkhwa, Punjab, Azad Jammu & Kashmir (Pakistan) and tribal areas) with significance to recreation and watershed values. The region is dominated by coniferous species (*Pinus wallichiana* A.B. Jackson, *Cedrus deodara* Roxb., *Pinus roxburghii* Sargent, *Abies pindrow* Royle, and *Picea smithiana* Wall.) with co-dominance of broadleaved species (*Quercus dilatata* Royle, *Populus ciliata* Wall.), which are also associated with conifers (Amjad et al., 2014; Mandal , Joshi 2014). Altitudinal variation varies from 1200 - 3300 m a.s.l. (Hussain 1984). Sub-tropical Chir-pine forests prevail on lower elevations and Subalpine/alpine pastures on the upper levels, whereas the western and northern territory is surrounded by dry temperate forests (Champion et al., 1965a; Mujtaba Shah et al., 2014). Site locations were shown in figure 3.1 by using ArcGIS 10.5.1 academic version. The research area is located (North 35.931010dd, East 75.465168dd, South 33.225403dd and West 72.125281) annex-1.



Figure; 3.1 Area of the Study Westrn Himalyan Moist temperate forest of Pakistan

The forest is classified according to the species composition into the Coniferous Mountain Forest with a mixture of broadleaved forests. These forests were commercially used for the production of timber before the green harvesting ban in 1992. Most of the areas are heavily grazed by the local and nomadic grazers. The details of the species composition are given in annex-II.

3.2 Description of the area of research:

The research area is covered with high mountains ranging between 1200m to 3500m elevation. Details were already given in table 3.1 subtitles, whereas Map 3.1 also shows further site situation. The research area is remote and some sites are hard to access. The meteorological data are also provided in Table 3.2. The geological consideration of the study area is significant due to geomorphological characteristics. The geological characteristics are determined by metamorphic and granitic rocks in nature which are divided into; Hazara granitic complex, Nanga Parbat granitic complex (Naran-Nanga Parbat-Haramosh section), and Hazara-Mansehra-Swat-Besham Domain.

The legal status of the forest is varying with the region and province forest law and local communities. The forest in the study area is classified legally as; Protected forest (all acts are permitted until and unless prohibited by the forest law), Reserved forest (all acts are prohibited until and unless permitted by the forest law), Guzara Forest (private forest land covered with forest vegetation managed by the forest department), and State forest (these forests are only found in Azad Jammu and Kashmir state).

These forests are historically used for the production of timber, whereas nowadays only dead, dying, and diseased trees were harvested (DDD trees). The rest of the activities in these forests are recreational forests and areas for grazing of domestic animals both by the locals and nomadic people crossing the country. Present land-uses of the area are; Forest, Agriculture, National park, Agro-silvopastoral system, Recreation zones, Residential sites, and Pastoral meadows. Land use types are described and characterized in Table 3.1.

Table 3.1: Land use type characteristics in the study area

S.No	Land-Use Classification	Activities
1	Forest	Watershed, wildlife protection and biodiversity, national parks, timber harvesting, rangeland conservation, non-timber forest products, and fisheries.
2	Agriculture	Cereal crops (maize and rice), vegetables, horticulture, apiculture, poultry forms, and tea cultivation.
3	Residential area	Only residential constructions and buildings (no industrial zones are available), and roads

The research area ecologically falls in the moist temperate region of the Himalayan ranges. Climatic data from the different metrological stations are recorded.

Table: 3.2: Climatic characteristics of sites representing the study area: Source; Pakistan Metrological department website, climate-data.org. www.pmd.gov.pk (other online weather data were also used for cross-check)

Balakot	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Avg. Mean Annual**
Avg. Temperature (°C)	10	11.7	15.9	19.7	21.9	23.5	23.5	23.4	22.1	19.5	14.6	10.9	18.05833333
Min. Temperature (°C)	3.1	4.2	8.1	12.3	15.9	19	19.9	19.6	18.1	14	7.6	3.3	12.09166667
Max. Temperature (°C)	17	19.2	23.7	27.1	27.9	28	27.1	27.2	26.2	25	21.7	18.5	24.05
Precipitation / Rainfall (mm)	16	20	33	53	116	246	363	318	198	68	7	12	120.8333333
Naran													
Avg. Temperature (°C)	7.25	8.15	11.9	18.15	21.3	25.9	26.9	24.4	23.35	19.3	13.5	9.15	17.4375
Min. Temperature (°C)	3.1	3.9	6.4	12.9	15.7	19.2	22.6	20.4	19.8	14.3	8.8	4.4	12.625
Max. Temperature (°C)	11.4	12.4	17.4	23.4	26.9	32.6	31.2	28.4	26.9	24.3	18.2	13.9	22.25
Precipitation / Rainfall (mm)	279.6	329	220	172.4	82.1	74.1	426.4	431.6	147.2	64.3	120.4	55.3	200.2
Kalam													
Avg. Temperature (°C)	1.5	2.8	7.6	13	17.3	23	24.1	23.4	19.8	15.1	9.5	4	13.425
Min. Temperature (°C)	-2.2	-1.3	3	7.9	11.6	16.6	17.8	17.5	13.7	9	4.1	0	8.141666667
Max. Temperature (°C)	5.3	6.9	12.3	18.2	23.1	29.5	30.5	29.4	26	21.2	15	8.1	18.79166667
Precipitation / Rainfall (mm)	49	66	88	93	64	32	66	66	41	28	15	31	53.25
Changla Gali													
Avg. Temperature (°C)	0.1	0.6	5.1	10.6	14.7	18.6	17.8	17.2	15.3	12	7.3	2.9	10.18333333
Min. Temperature (°C)	-3.1	-2.8	1.6	6.6	10.1	13.9	13.9	13.6	11	7.4	3	-0.8	6.2
Max. Temperature (°C)	3.4	4.1	8.7	14.6	19.3	23.3	21.7	20.8	19.6	16.6	11.7	6.6	14.2
Precipitation / Rainfall (mm)	102	108	134	117	87	95	258	264	116	53	29	44	117.25
Shogran													
Avg. Temperature (°C)	0.8	1.5	6.1	11.3	15.6	20.1	20.1	19.4	17	13.1	8.3	3.3	11.38333333

Min. Temperature (°C)	-2.6	-2.2	2.1	6.9	10.4	14.5	15.1	14.8	11.8	7.8	3.4	-0.5	6.791666667
Max. Temperature (°C)	4.2	5.3	10.2	15.8	20.8	25.7	25.2	24.1	22.3	18.5	13.3	7.1	16.04166667
Precipitation / Rainfall (mm)	73	89	113	110	80	62	151	153	74	43	23	37	84
Kaghan													
Avg. Temperature (°C)	1.8	2.8	7.4	12.6	16.6	21.3	21.5	20.8	18.3	14.3	9.4	4.2	12.58333333
Min. Temperature (°C)	-1.7	-1.1	3.1	7.9	11.1	15.4	16.1	15.9	12.7	8.5	4.1	0.1	7.675
Max. Temperature (°C)	5.4	6.8	11.7	17.3	22.2	27.3	27	25.8	23.9	20.1	14.7	8.3	17.54166667
Precipitation / Rainfall (mm)	65	83	107	104	75	52	126	124	62	40	21	34	74.41666667
Nathia Gali													
Avg. Temperature (°C)	0.8	1.3	5.9	11.2	15.3	19.2	18.3	17.6	15.8	12.6	7.9	3.5	10.78333333
Min. Temperature (°C)	-2.4	-2.2	2.2	7.1	10.6	14.4	14.3	14	11.4	7.9	3.5	-0.2	6.716666667
Max. Temperature (°C)	4.1	4.8	9.6	15.3	20	24	22.3	21.3	20.2	17.3	12.4	7.3	14.88333333
Precipitation / Rainfall (mm)	102	109	134	116	86	95	261	266	117	53	28	45	117.6666667
Auybia													
Avg. Temperature (°C)	1.5	1.9	6.4	11.7	15.8	19.5	18.5	17.8	16.1	13	8.3	4	11.20833333
Min. Temperature (°C)	-1.8	-1.6	2.7	7.6	11.1	14.8	14.6	14.3	11.8	8.3	3.9	0.2	7.158333333
Max. Temperature (°C)	4.9	5.4	10.2	15.9	20.5	24.3	22.5	21.4	20.5	17.7	12.8	7.9	15.33333333
Precipitation / Rainfall (mm)	104	110	135	115	84	99	274	279	121	53	29	45	120.6666667
Murree													
Avg. Temperature (°C)	3.2	3.7	8.3	13.5	17.4	21	19.4	18.6	17.2	14.4	9.8	5.7	12.68333333
Min. Temperature (°C)	-0.3	0	4.4	9.1	12.6	16.3	15.7	15.3	13.1	9.7	5.2	1.6	8.558333333
Max. Temperature (°C)	6.7	7.5	12.2	17.9	22.2	25.8	23.2	22	21.4	19.1	14.4	9.8	16.85
Precipitation / Rainfall (mm)	102	106	131	104	76	99	286	290	124	51	27	44	120
Jikha Gali													
Avg. Temperature (°C)	3.6	4.1	8.8	13.9	17.8	21.6	20	19.1	17.7	14.8	10.2	5.9	13.125
Min. Temperature (°C)	0	0.3	4.7	9.4	12.9	16.7	16.2	15.7	13.4	9.9	5.4	1.7	8.858333333
Max. Temperature (°C)	7.2	8	12.9	18.4	22.8	26.5	23.9	22.6	22.1	19.7	15	10.2	17.44166667

Precipitation / Rainfall (mm)	93	97	122	98	71	87	248	249	110	47	25	41	107.3333333
Muzzafrabad													
Avg. Temperature (°C)													
Min. Temperature (°C)	9.2	11.4	15.9	20.7	25.3	30	28.7	27.4	25.8	21.3	15.6	10.9	20.18333333
Max. Temperature (°C)	3.1	5.2	9.4	14.1	18.3	22.9	23.1	22.1	19.3	13.5	7.8	4	13.56666667
Precipitation / Rainfall (mm)	15.3	17.6	22.4	27.3	32.3	37.1	34.4	32.8	32.3	29.1	23.4	17.8	26.81666667
	94	121	138	108	70	93	304	283	114	42	32	58	121.4166667

3.3. Plot selection and establishing:

Plot establishment and number; The research area is divided into three zones: (1) Khyber Pakhtunkhwa, (2) Azad Jammu and Kashmir and (3) Punjab (Table 3.3). Khyber Pakhtunkhwa is further classified (13 sites and 633 plots) into: single tree selection system (150 plots), group selection system (148 plots), Shorgan Track (23 plots), Malkandi (17 plots), Kamal Ban (19 plots), Naran Track (9 plots), Naran (16), Galies Track (70), Shangla Lilawni (35), Shangla Yakh Tangye (41), Kalam (40), Kund (62), and Chatar Plan (33). Punjab is classified into (3 sites and 27 plots) i.e. Patriata (11), Burban (6), and Murree (10). Azad Jammu and Kashmir are classified into two sites Muzaffrabad (7), and Loon bagla (6) details of the plots are given in Annex-I. The data collection at plots and site selection also focus on; tracks, silvicultural system harvesting plots, and individual sites for random data collection.

Plot size; due to the heterogeneity of forest stand and research area, research plots vary with the size and dimensions. Mature forest crop stand plot size is 0.1 ha (1000 m^2 or 17.84 m radius), whereas the regeneration plot size is 0.01 ha (100 m^2 or 5.64 m radius). Site quality is categorized according to Class I, II, III, and IV from the management plan of the compartments. The ecological zones were defined from the species as; mixed-coniferous (MC), mixed-coniferous-pine (MC-P), mixed-coniferous-cedrus (MC-C), pine (P), cedrus (C), cedrus-pine (CP), pine-cedrus (PC). The silvicultural system in the study practice are; single tree selection system (STSS), group selection system (GSS), strip clear-cut (SCC), irregular shelterwood system (ISWS) and shelterwood system (SWS).

Table: 3.3 Details of research site classification with the number of plots

No	Zones	Sites	Altitude range (m)	Ecological zone	Site quality / Age (years)	Silvicultural system	Number of Plots
1	Khyber Pakhtunkhwa	Single Tree Selection System	2122.3 - 2191.9	MC	I / 14 – 74	STSS	150
		Group Selection System	2119.1 – 2163.7	MC	I / (28 – 58)	GSS	148
		Shorgran Track	2041.1 – 2912.3	MC-P	I / (12 – 160)	STSS	23
		Malkandi	1534.2 – 2435.3	MC-C	I / (12 – 130)	STSS	17
		Kamal Ban	1824.8 – 2360.6	MC-C	I / (10 – 143)	STSS	19
		Naran Track	2392.4 – 2710.3	MC-P	II / (22 – 85)	STSS	09
		Naran	2519.3 – 2696.2	P	II / (20 – 90)	STSS	16
		Galies Track	2148.8 – 2604.6	MC-C	I / (10 – 125)	STSS	70
		Shangla Lilawni	2152.2 - 2679	MC	I / (12 – 104)	STSS	35
		Shangla Yakh Tangye	2055.3 – 2474.8	MC	I / (12 – 98)	STSS	41
		Kalam	2030.2 – 2176.6	C	II / (65 – 101)	GSS	40
		Kund	1934.9 – 2509.7	MC-P	II / (25 – 75)	SCC	62
		Chatar Plan	1254.4 – 1902	P	I / (30 – 75)	STSS	33
2	Punjab	Patriata	1535.7 – 2023.2	CP	II / (55 – 90)	ISWS	11
		Burban	1913 – 2010	CP	I / (25 – 90)	SWS	06
		Murree	1891.4 – 2043.5	PC	I / (25 – 104)	SWS	10
3	Azad Jammu and Kashmir	Muzaffrabad	2088.6 – 2376	P	II / (18 – 72)	STSS	07
		Loon Bagla	1472.2 –1906.9	P	II / (25 – 85)	STSS	06

Experimental design; two types of experimental designs were used due to high variation in data sets and nature. Randomized Complete Block Design (Vegetation analysis, stand structure for the whole region and socio-economic data), and Cluster Sampling (site classification, stand structure for harvesting system, and biodiversity analysis). The study cover area of 572 thousand ha, the altitudinal difference is 2000 m which makes the site more heterogenic (Bukhari et al., 2012; Dar , Sundarapandian 2016). The forest type is in between subtropical and subalpine regions from low to high elevation whereas dry temperate forests are also found on the same elevation towards north and western directions (Champion et al., 1965a).

3.4 Measurement at the plots: measured characteristics, tools, numbers of measurement

Devices, Tools, and Material; several tools, devices, and the material was used for the collection and evaluation of the data which are; *height measurements;* Haglöf Vertex IV, Bitterlich relascope, measuring tape and rod for regeneration., *diameter measurement;* Bitterlich relascope, diameter tape, caliper and measuring tape., *crown height;* Haglöf Vertex IV., *bole height;* Haglöf Vertex IV, *soil profile;* measuring tape, pit excavation tool, soil sample collection bags, soil Auger, probe and spade., *plot measurement*; measuring tap, Bitterlich relascope, GPS (Garmin eTrex 10), compass and compartment area map., *coordinates and altitude;* GPS., *ground vegetation;* 1 meter quadrate (100 grids shows 1 % of the area), seizers, paper bags., *increment and age;* increment borer and plantation records. For recording of data, tools were used: notebook, pencil smartphone, camera (still and videos). *social data;* pre-tested and well-designed questionnaire was used for the collection and data record from the community, tourists, nomads (grazers), and also forest department professionals. (Mueller-Dombois , Ellenberg 1925; Habich et al., 2001; Palmer et al., 2005; Sweden 2007; Causton 2012; Prodan 2013). In addition to that soil samples and socio-economic data were also collected for more investigation and impact of different forestry practices (Ives 2006). Soil sample includes; depth of the soil, identification of soil horizon, calculated (pH, soil aggregates, soil density, soil organic matter, and soil moisture) in the laboratory (Carter , Gregorich 2007). Socio-economic data were collected on pretested and well organize questionnaire.

Soil samples were taken in each plot, where data were collected for stand structure and vegetation analysis. Besides that data were also collected from different land-uses (agriculture, pasture, forest, orchards, and barren land). For socio-economic data villages and individuals were interviewed in the forest and near to the forest area, people who are closely dependent on the forest were also interviewed outside the target zone to verify the information. Information was also recorded along the roadside for natural hazards. The hotspot and sensitive site especially visited for data collection regarding impact and intensity. Meteorological data were received from the metrological department in every district also from the online website on the same day. Mortality data were recorded in every hundred-meter elevation.

Evaluation of components; During the study forest species are mostly considered for data collection are; tree diameter, tree height, crown height, straight tree bole length, species identification for diversity calculation, site slope measurements, coordinates reading, tree age and increment, adjacent (tree distancing), soil profile measurements (depth and horizons), ground vegetation consider as undergrowth (frequency, biomass, and cover), social data were also collected as; income, literacy rate, forest dependency, forest products collection, etc. The components that derived from the preliminary data are; alpha and beta diversity, importance value index, stand structure (horizontal and vertical layers), basal area, density, volume calculation, biomass calculation, canopy structure, soil properties, and analysis, and also demarcation by using Geographic Information System and Remote Sensing. (Mueller-

Dombios , Ellenberg 1925; Khattak 1964; Zeide 1985; Rubin et al., 2006; Van Laar , Akça 2007; Bonham 2013)

3.5 Statistical analysis and methods

The research studies focus on stand structure complexities and undergrowth analysis under silvicultural practices and harvesting system in the mountainous region. Multivariate, qualitative, and quantitative studies were analyzed, and based on questionnaires and field protocol (Lindhagen 1996; Urban 2006).

Statistical analysis was made through software packages i.e. PAST (PAleontological STatistics) version 2.17d, Statistica, Sigmaplot, and MS excel. Research article related to Management practices were assesed with average (arithmetic mean, and induvial which is frequency), Disturbance also evaluate with relative frequency. For the assessment of stand structure individual frequency and mean value was calculated. The non-linear regression was fitted to the data and the variance of the data was calculated by analysis of variance (ANOVA). The formulas for evaluation of the components are;

$$\text{Density}=\frac{\text{Total Number of individual}}{\text{Total number of sample plot}} \qquad \text{(Eq.1)}$$

$$\text{Shannon Index (H)}= -\sum_{i=1}^{s} p_i \ln p_i \qquad \text{(Eq. 2)}$$

$$\text{Simpson Index (D)}=\frac{1}{\sum_{i=1}^{s} p_i^2} \qquad \text{(Eq. 3)}$$

$$\text{Equitability } (E_H)=\frac{H}{H_{max}} \qquad \text{(Eq. 4)}$$

$$\text{Evenness}=\frac{e^H}{S} \qquad \text{(Eq. 5)}$$

$$\text{Fisher's alpha… } S=a^* \ln\left(1+\frac{n}{a}\right) \qquad \text{(Eq. 6)}$$

$$\text{Relative frequency} = \frac{Number\ of\ individuals\ in\ each\ sample\ site}{total\ number\ of\ population} \qquad \text{(Eq.7)}$$

The statistical analysis of the data represented through graphical representation, with bar charts, linear graph, scatter plot representation, and pie chart for the land use representation. (Mueller-Dombois , Ellenberg 1925; Hammer et al., 2001; Schulz et al., 2009; Wildi 2011; Šmilauer , Lepš 2014)

3.6 Problems and issue during data collection:

The research areas have great diversity in every aspect i.e. topography, climate, social, language, administrative, and cultural which is not possible to cover under the same planning and strategy. Therefore, the number of a problem were faced during the data collection which limits the information and record from the field. The problems and issues are;

1. Limited growth seasons to study the undergrowth and other floristic analysis.
2. Restriction on the border region with India which also limits the information and topography of the region doesn't allow the researcher to cover the vast site to include in the sampling.
3. In the socio-economic data, some of the villages and sampling sites were excluded due to bias data information.
4. Diameter and increment of the trees were also difficult to measure due to the starch wood collection which damaged the butt log.
5. Tree heights were also difficult to record due to slope and crown density.

4. RESULTS AND DISCUSSION

The outcomes of this research study comprised of conference publication, research articles, and unpublished data analysis were shown in this chapter. The contribution also investigates the derived and secondary data related to the Himalayan mountain forest of Pakistan from primary data which were collected from the region. The results is divided on management, vegetation composition and stand structure, disturbance, soil and social aspect of the research area.

4.1 Forest Management and disturbance

4.1.1 Past and present silvicultural systems and tending operations in Himalayan moist temperate forests of Pakistan

The results of the research parameter shows relationship between silvicultural systems and other management operation both in past and present. Past and present silvicultural or harvesting systems; Due to the limited forest resources and less intense vegetation cover in Himalayan moist temperate forests, the silvicultural (harvesting) systems have very limited application. In the past (1947–1992) these forests were harvested under proper silvicultural system, i.e. selection system (this system is applied due to low vegetation cover, steep terrain and also due to recreational activities in the area). In the 1980s one-hectare plot were harvested for research purposes under group selection system, and one-hectare plot were clear felled under clear felling system. Besides that, strip clear-felling were also observed in Kund forest in the 1980s. Since 1993 until present, green felling were banned, only 3D (dead, dying and diseased), wind fallen, top/half broken and snow damaged trees are harvested under prescribed selection system.

The period before 1992 shows clear indication in Figure. 4.1, of scientific and management activities in the study area (average of percentage is about 1.9 % in clear felling area, whereas an average of 88.6 % activities was found in the selection system). After 1992 there is a clear indication of less management activities in the study area shown in Figure. 4.2, (no evidence of clear felling system were found, whereas selection system was partially working after 1999 by the government and average 14.56 % activities were active). The comparison between the periods is also illustrated on Figure. 4.3, which graphically represents the activities before and after 1992.

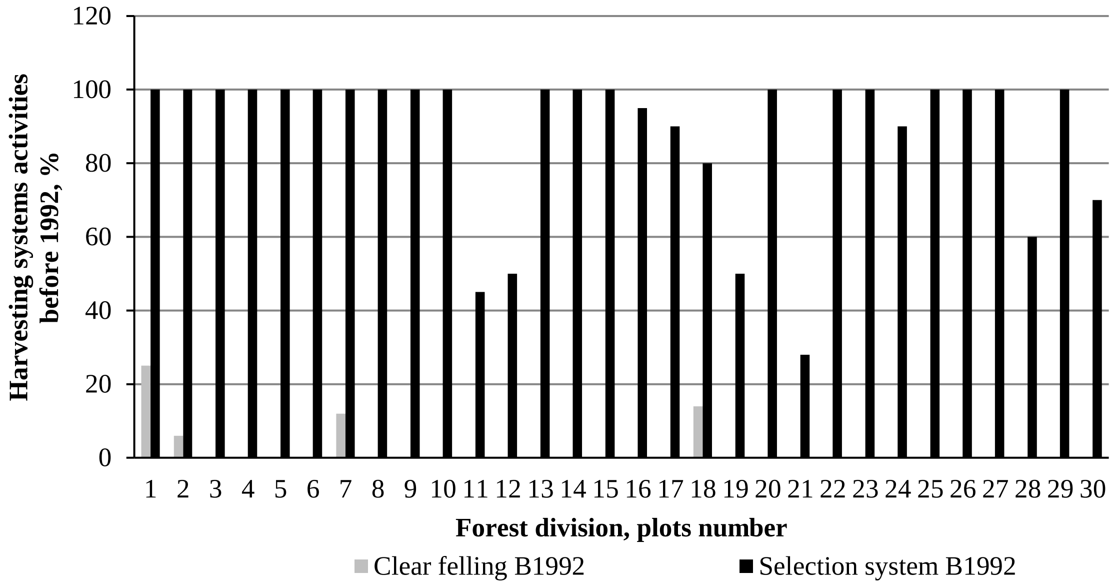


Figure. 4.1: Silvicultural system (Harvesting system) – past.

Note: X-axis – Forest division as plots (administrative zones for forest management), Y-axis – harvesting system share of activities, %.

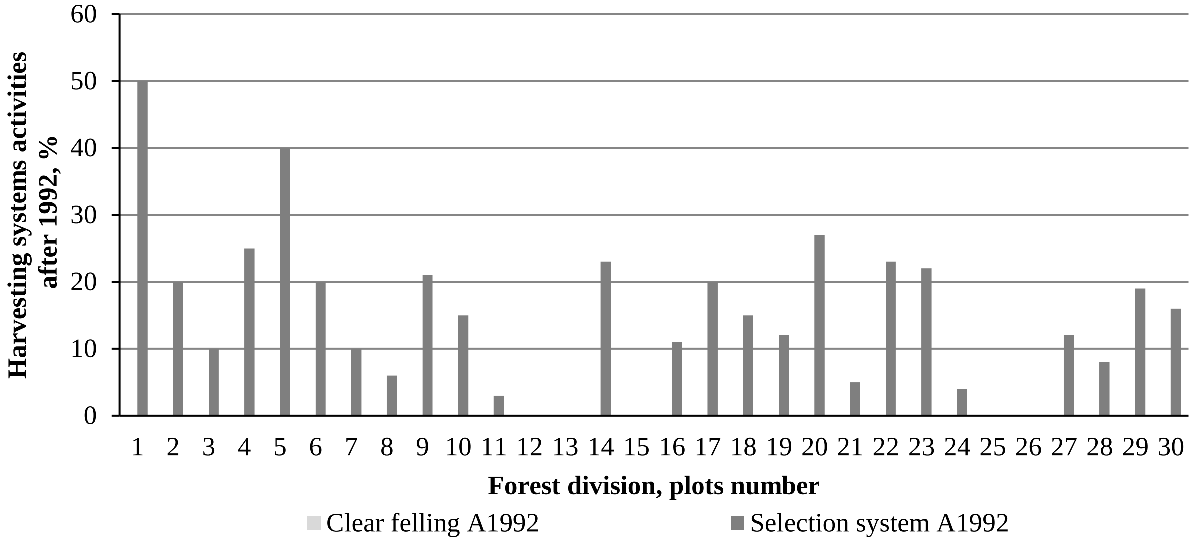


Figure. 4.2: Silvicultural system (harvesting system) – present.

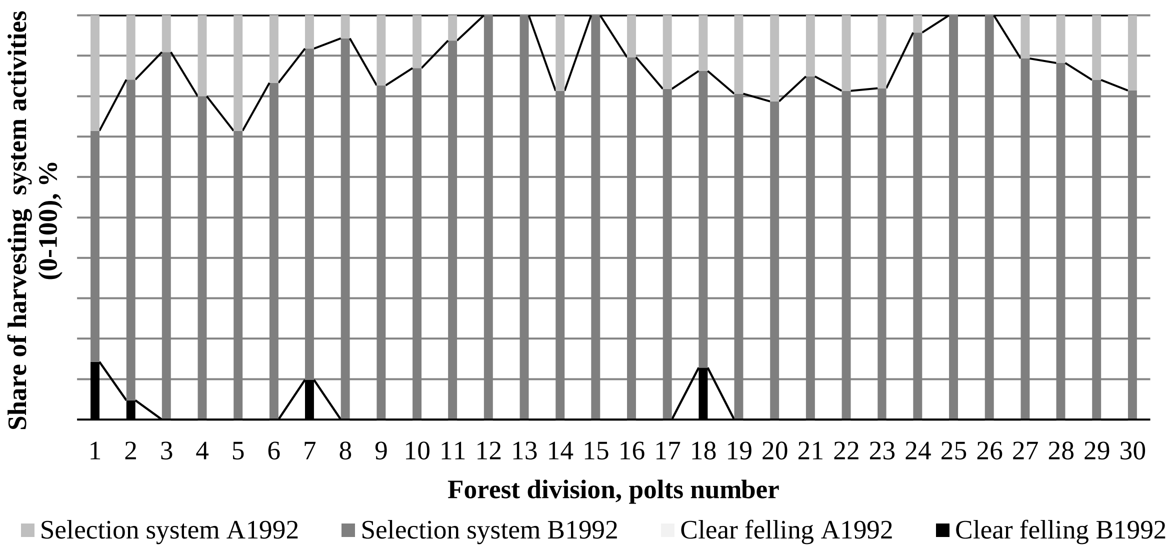


Figure. 4.3: Combined representation of harvesting data in the research area.

Note: X-axis shows forest division as research plots as administrative zones, Y-axis shows the share of harvesting activities in the region before and after green felling ban.

Silviculture or tending operations; Silviculture or tending operation tends toward the improvement of the forest crop (Short , Radford 2008) by providing species selection and reducing the canopy, as well as the intensity of damages. The tending operation may be defined as ‘any treatment or tending designed to enhance growth, quality, vigour, and composition of the stand after establishment or regeneration and prior to final harvest’ (Helms 1998). According to the species composition, the operations were carried out in the forest area. Weeding is not compulsory because weeds are very rare in the area and mostly highly nutritional and palatable plant species were found due to favourable growth condition. Cleaning was done just before the plantation or afforestation activities. Due to the low density and cover in the study area, thinning operation is very limited except for some special treatment. Pruning was also done during summer and before winter for fuel-wood collection and also for seed collection (Yusuf 1955; Lughmani 1961; Shah 1967).

Combine representation of tending operation before 1992, whereas the activities after green felling ban were discounted in the research area. Weeding (WD) activities were about 21.1 % on average, cleaning (C) activities are higher in number but they are not clearly categorized by the department (88.6 % average), thinning (T) and improvement felling (IF) were found 16.1 % and 1.43 % average, respectively shown in Figure.4.4.

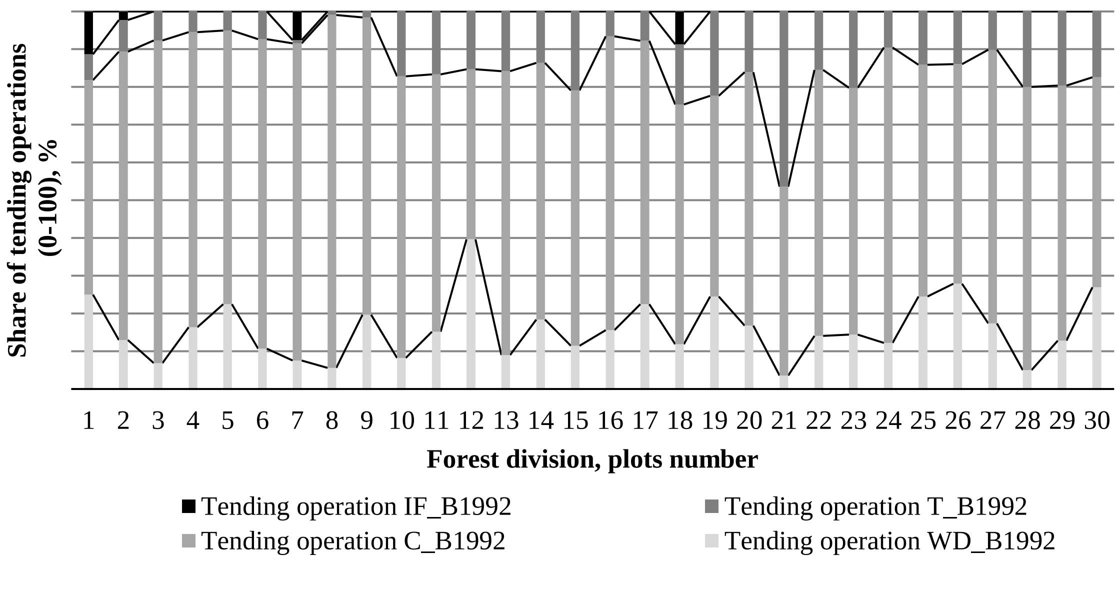


Figure. 4.4: Tending operations or silviculture practices in the research area.

4.1.2 Forest disturbance & degradation in western Himalayan moist temperate forest of Pakistan

Mountain forests are very fragile and sensitive to natural disturbances due to the topography, flammable material, situation, and location of the forest stand. The sources are divided into climatic, Geo, biotic, and Anthropogenic, which are highly active in the study area since the last two decades. Due to the productive function of the moist temperate forest, Forest disturbance is highly sensitive to management activities, climate change, and anthropogenic activities. Intensity or severities of disturbance were classified according to the relative frequency between the minimum and maximum (0–0.1635) on a different elevation in the study area. Data were analyzed and classified as in the Table 4.1.

Table 4.1: General event summary description (Source: Field Data).

Major source	**Sources type**	**Min–Max (RF)**	**Avg. RFrequency**
Climate	Natural Fire	0–0.1489	0.045464
	Wind Damages	0.0241–0.0964	0.045441
	Snow Damages	0–0.0748	0.04545
Geo	Landslide	0.0098–0.0882	0.045436
	Rockfall	0–0.1042	0.045455
Biotic	Grazing	0–0.0849	0.04545
	Insect & Disease	0.0122–0.0976	0.045473
Anthropogenic	Logging	0–0.1635	0.045445
	Shifting Cultivation	0–0.1414	0.04545
	Counter Fire	0–0.0901	0.045468
Total		0.0315–0.0686	0.045445

Climatic sources; Natural vegetation in the mountains region is highly resistant to climatic disturbances, such as: fire, wind, and snow damages, due to the adaptability, but they are also highly sensitive in case of uncertainty and intensity of events (Bartels et al., 2016; Yu et al., 2016).

Natural fire; These events are not so common in moist temperate forests. Fire is the main contributor to ecological stability in the mountain region but is extremely dangerous with intensity and geographical situation. Animals, Rockfall, and high temperature ignite flammable material, which is the main source of fire in these regions. The results show that there are high treats in the lower as well as the upper elevations of mountainous forests (38.29% and 55.31%). Lower elevation or transition zone are affected due to high temperature and availability of flammable material, i.e., *Pinus roxberghii*, and grasses. The pre-upper regions are also threatened by lightning and low density of the stand, but these regions are less affected by such disturbance as compared to the lowland forests. The data show that most of the fire events occur on a high elevation 2,800–3,300 m (55.31%) or on a low elevation from 1,200 to 1,900 m (38.29%) due to natural lightning/thunders and availability of flammable material with species composition, such as *Pinus roxberghii*, whereas in the mid-range elevation, (2,000–2,700m) fire is not very common (6.38%) due to high moist condition, the complexity of species composition, and low flammable material amount (Figure. 4.5).

Wind disturbance; It affects the stand structure, enhance fire intensity, and composition of the stand on a very large scale in fragile mountain regions (Quine and Gardiner, 2007). The data showed that altitude does not a matter for wind disturbance, as the patches which were recorded are influenced by the terrain (ridges, mound, or peaks) and soil water; (31.32%, 34.93%, and 33.73% Lower, mid, and high altitude, respectively).

Snow damages; High numbers of snow damages were recorded on mid-level altitude (48.59%) because of stand competition, diameter, height ratio, and also due to the gradient which increases the velocity, whereas on low and high elevations (18.69% and 32.71%), there is less competition for growth, gentle gradient, and normal distribution of diameter height ratio.

Floods; Floods are one of the common natural disasters in the mountainous region, which enhances the landslides, erosion, and cutting of river banks. The floods damage the river banks where the sites are sensitive to erosion, landslides, and cutting. After-effects of the floods have a good impact in lowlands or on the river bed to provide a favorable condition for the succession process. There is no such quantitative data were recorded for floods due to limited time and resources.

Geo-sources; Himalayan mountains are the youngest mountainous range of the world (Shah and Moon, 2004), which make them hotspot for different geological activities as follows:

Landslide; Landslide is very common in the Himalayan Mountains due to the fragile ecosystem and less stabilized geological structure. Low landslides were found on a high elevation (6.86%) due to the stable geological formation and loess soil depth. Maximum landslides were recorded in low and mid-elevation (42.15% and 50.98%) due to steepness, moisture availability, less developed soil, and ground instability.

Rockfall; Rockfall is dangerous and cause a high level of casualties of human life and animals and also damage the forest stand. Rockfall events were recorded on barren areas with a steep slope, and also on high elevations, altitudinal variation doesn't influence rockfall events showed in Figure 4.6. (Low 43.75%, mid 50%, and high 6.25%)

Avalanches; Avalanches are not so common in the mountains range of the research. But still, there are numbers of evidence were found in the valleys which identified the events and damages from avalanches. No such data were collected due to limited time and resources.

Earthquake; Earthquake damages the forest land and also certain geo-structures in the mountain. Most of the earthquake disturbances enhanced other disturbance processes, such as the rockfall, landslip, and landslide. Earthquake 2005, was the massive disaster in South-Asia, damaged thousand of ha., of forest land. Those destabilized areas need to re-vegetated, the earthquake also contributes to the disturbance.

Biotic sources; Life plays a vital role in changing the ecological structure. Mountain forests are heavily influenced by biotic factors.

Grazing; This factor has a high importance in mountainous forests with high floristic composition. These animals also play an important role in land improvement and soil degradation. Disturbance due to animals' movement and heavy grazing provides ground to the new plants but also destroys the growth of plant species. Disturbance due to grazing activities in the mountain is very high both on low (42.45%) and high (43.39%) elevation, because of nomadic and local graziers. Mid-range elevation covers about 14.15% of the grazing disturbance.

Insects and disease; They enhanced the disturbance in a diverse floristic condition in a mountainous forest. Insect and disease damages were affected by climatic change in recent years. Results showed that there is a high influence of insect and disease damage on the mid-elevation (57.31%), due to old growth, lighting/fire (High Altitude 23.17%), snow and wind damages provide favorable habitat, whereas damaged trees act as host to the insects which caused diseases.

Anthropogenic factors; Humans utilized the forests from early days of life, but from last few decades, they managed these forests on a sustainable basis, for maximum utilization of natural resources. From the past few centuries, industrialization and structural development have destroyed these forest resources. Deforestation of the forest also contribute to the disturbance phenomena; such events are: logging operation, land clearing for agriculture, or other uses and fire activities that burn the grasses for grazing purposes (McGovern et al., 2011).

Logging; Logging operations are key to maximizing the production of forest stand and replacing the forest with new plants. Data shows that there is more than 33% disturbance due to logging activities (legal or illegal). High Logging activities found on low altitude (56.73%), high altitude also contributes 26.92%.

Land clearing/shifting cultivation; It is very common and clearly visible, locals clear the forest land for agriculture or pastoral activities. Forests land clearings are prominent on the high (28.28%) and low (68.68%) elevation due to access to the residential area or close to the sub-alpine pasture. The only disturbance which is dangerous for the forest stands cover and protection of valuable species.

Counter fire/human activities; They are the beneficial cultural operation for the regeneration as well as for the harvesting of fodder crop for livestock on a lower elevation (48.64%). Such disturbances are highly productive for forest stand cover and composition. High Altitude is also affected by the counter fire 36.03% but the area of disturbance is less than 100 sq.m.

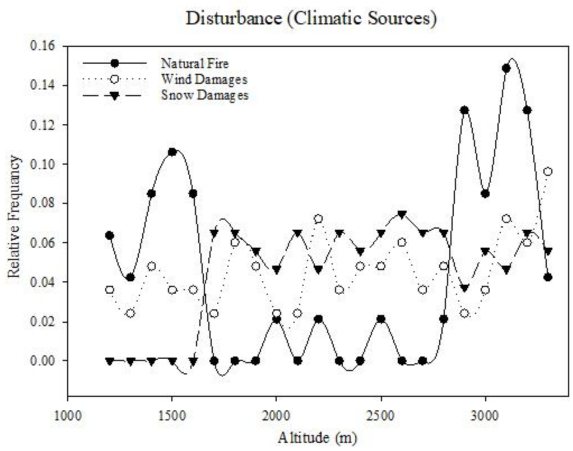


Figure 4.5. Low snow damages were recorded on low elevation as compared to mid and high altitude. Natural fire is low on mild altitude compared to low and high altitude. Wind damages are almost same in region.

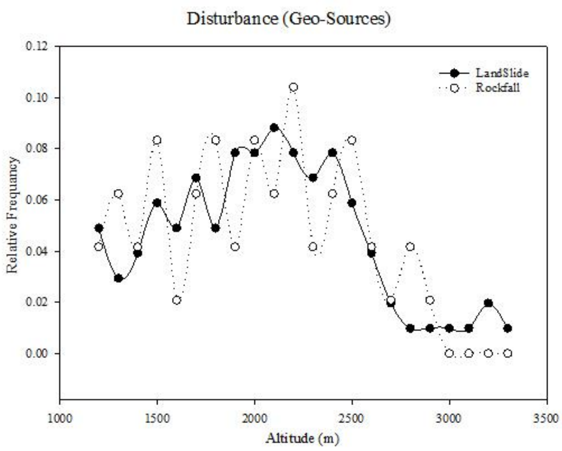


Figure 4.6. Only two type of Disturbance were found during data collection in Geo-Source. The data (relative frequency) show low events on higher altitude that is more than 2,700 m, as compared to mid and low altitude (2,700 m).

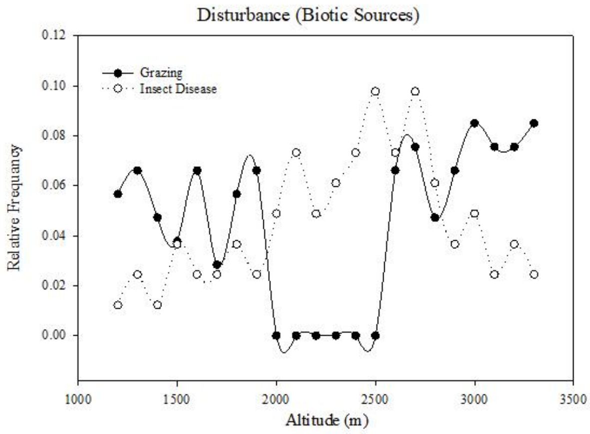


Figure 4.7. Insect- and Disease-infected trees were found throughout the region, high in the upper mid range of altitude. Grazing activities were only found on low and high altitude range.

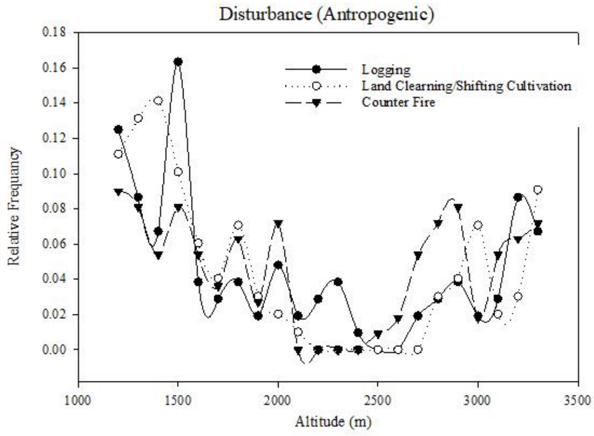


Figure 4.8. Human activities are very active in region, whereas the high activities on lower altitude and also on the high altitude.

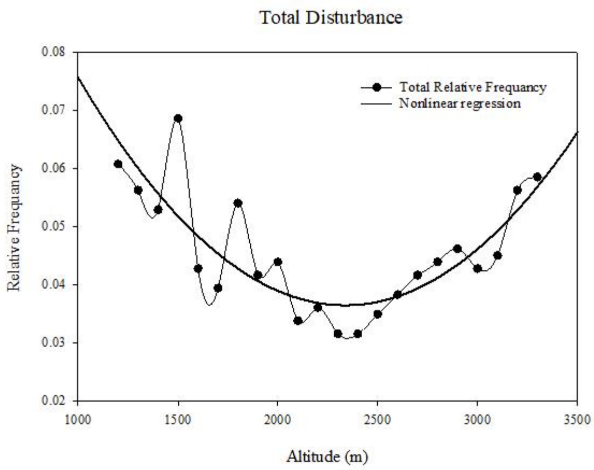


Figure 4.9. Equation: Polynomial, Quadratic $f = y0 + a*x + b*x^2$. Low impact of disturbance on mid range altitude due to less accessible and expose. Normality test and significance level ($p = 0.6751$).

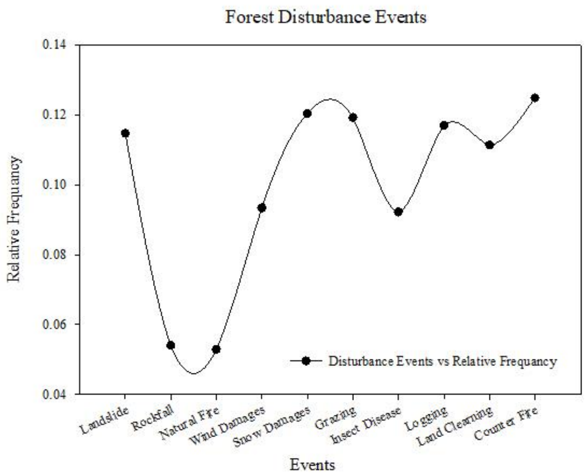


Figure 4.10. Graphical representation show low occurrence of Rockfall Natural Fire compare to the rest of disturbance event.

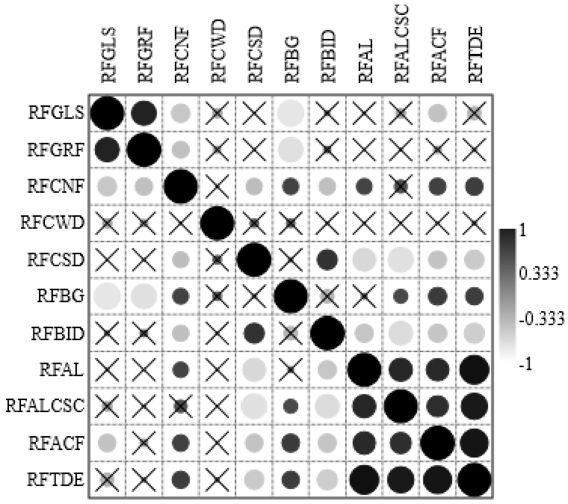


Figure 4.11. Correlation among the events, where crossed show $p > 0.05$ significance level.

4.2 Vegetation dynamic and stand structure in relation to silvicultural system

4.2.1 Impact of silvicultural system on natural regeneration in Western Himalayan Moist Temperate forests of Pakistan

The research site was divided based on the silvicultural system (group selection system and single-tree selection system) 148 plots and 150 plots accordingly. The group selection system was examined on-site which were clear-felled under a project in the 1980s of 2 ha. The study also highlights, future predictions for the conservation, which are highly sensitive and a hot-spot for wildlife and climate change phenomena. Silvicultural practices such as (silvicultural system, cleaning, weeding, thinning operations) are regularly practiced which can reduce the negative impact on these productive forests.

Regeneration diversity; During the data collection, vegetation diversity was also examined, where only the species which were found in the sample plot and the surrounding area were also listed in annex-1. Regeneration diversity in the study site is focused on main forest crop, which includes *Pinus wallichiana* (PW), *Cedrus deodara* (CD), *Picea smithiana* (PS), *Abies pindrow* (AP), *Quercus dilatata* (QD), *Aesculus indica* (AI), *Alnus nitida* (AN), *Pinus* *roxburghii* (PR), *Robina pseudoacacia* (RP), *Ailanthus altissima* (AA) and some other species which are rarely found in the regeneration plots. A number of taxa found in both the silvicultural system (Group selection system and Single-tree selection system) are 10, with individual repetition of (17 and 15 respectively) calculated and analysed by diversity indices.

The details of the silvicultural systems are below;

Group selection system; The group selection system that examines the KamalBan forest of the Kaghan forest division. Four major species were found along with other species that were rear in the sample plot. The density of the main forest species per meter square was (±10.58PW, ±5.03CD, ±2.16PS, and ±0.99AP) detail were given in (Table 4.2);

Table 4.2. Quadrate measurement; (calculate variation among the species and also between the two silvicultural systems)

	Group selection system			Single-tree selection system		
Species	Density / m^2	Total number of seedlings /ha	Relative Frequency (%)	Density / m^2	Total number of seedling / ha	Relative Frequency (%)
Pinus wallichiana	10.584	105844.156	56.401	9.279	92792.208	53.581
Cedrus deodara	5.032	50324.675	26.817	5.240	52402.597	30.259
Picea smithiana	2.162	21623.377	11.522	1.266	12662.338	7.312
Abies pindrow	0.987	9870.130	5.260	0.636	6363.636	3.675
Quercus dilatata	-	-	-	0.273	2727.273	1.575
Aesculus indica	-	-	-	0.221	2207.792	1.275
Alnus nitida	-	-	-	0.065	649.351	0.375

Pinus roxburghii	-	-	-	0.019	194.805	0.112
Robina pseudoacacia	-	-	-	0.188	1883.117	1.087
Ailanthus altissima	-	-	-	0.130	1298.701	0.750

through quadrate measurement in the study area. Quadrate measurements show a high level of influence in the group selection system compared to the single tree selection system with the number of seedlings/ha. A number of taxa and species was high in the single-tree selection system to the group selection system. Therefore, both of the systems are highly rich in density and diversity. Diversity indices were also shown diversity in (Table 4.3);

Table 4.3. Diversity indices; (The diversity were calculated, and examine the data, by Simpson and Shannon index)

	Group selection system			Single-tree selection system		
		Lower	Upper		Lower	Upper
Taxa_S	4	3	4	10	3	6
Individuals	17	17	17	15	15	15
Dominance_D	0.4061	0.247	0.5083	0.3859	0.2034	0.4968
Simpson_1-D	0.5939	0.4917	0.753	0.6141	0.5032	0.7966
Shannon_H	1.08	0.7036	1.252	1.244	0.6682	1.413
Evenness_e^H/S	0.736	0.5594	0.8861	0.347	0.5775	0.9051
Brillouin	0.6035	0.4882	0.9436	0.5554	0.4168	0.9752

Menhinick	0.9234	0.6925	0.9234	2.403	0.7209	1.442
Margalef	1.059	0.7059	1.059	3.323	0.7385	1.846
Equitability_J	0.7789	0.581	0.9095	0.5403	0.6082	0.9093
Fisher_alpha	1.557	1.057	1.649	9.867	1.128	3.706
Berger-Parker	0.5329	0.373	0.6927	0.5197	0.3465	0.6929
Chao-1	4	3	5	10	3	9

the dominance of (0.41) both on the upper and lower level of dominance. The Simpson and Shannon diversity were also calculated, (±0.59 and ±1.1 respectively) whereas the maximum values are ±1.39 in the group selection system. The equitability and evenness are high also the data record (±0.78 and ±0.74 respectively), which shows the excellent mixed crop for sustainable forest management practices. Statistical summary of the data is also shown in (Table 4.4);

Table 4.4. Summary statistics; (Comparison between two different systems)

	Group selection system	Single-tree selection system
N	4	10
Min	0.987013	0.0194805
Max	10.58442	9.279221
Sum	18.76623	17.31818
Mean	4.691558	1.731818
Std. error	2.140144	0.9761641

Variance	18.32087	9.528964
Stand. dev	4.280288	3.086902
Median	3.597403	0.2467532
25 prcntil	1.280844	0.1136364
75 prcntil	9.196429	2.25974
Skewness	1.170253	2.113901
Kurtosis	0.7522905	3.919991
Geom. mean	3.265304	0.3857658
Coeff. var	91.23382	178.2463

a std.error of ±2.14 and variance of ±18.32 along with the stand.dev of ±4.28, this data has shown significant value (≤0.05) in the data. Diversity t-test variance is ±0.029 as compared to the statistical summary which is ±18.32, which shows in (Table 4.5);

Table 4.5. Diversity t-test; (Additional analysis for mature comparison and evaluation of the data)

Shannon index			
Group selection system		Singal tree selection system	
H:	1.0798	H:	1.2441
Variance:	0.029714	Variance:	0.077317
t:	-0.50215		
df:	29.206		
p(same):	0.61932		

Simpson index			
D:	0.40607	D:	0.38595
Variance:	0.0085853	Variance:	0.0088374
t:	0.15245		
df:	35.977		
p(same):	0.87969		

with less difference on diversity level for the Shannon index. Whereas the Simpson index for diversity t-tests variance is highly significant that is ±0.01. The equal variance test for group selection system values on (p=0.05) is 5.08, whereas the f values for the system are 1.92 shown in (Table 4.6);

Table: 4.6. F test; (Comparison with table 7 for the authenticity of the results)

Tests for equal variances			
Group selection system		Single-tree selection system	
N:	4	N:	10
Variance:	18.321	Variance:	9.529
F :	1.9227	p (same var.):	0.39295
Critical F value (p=0.05):	5.0781		
Monte Carlo permutation:	p (same var.):	0.7531	
Exact permutation:	p (same var.):	0.76324	

Two sample t-test was also examined to analyse the values in both the silvicultural systems. This shows the critical values of 2.18 under p=0.05, as the t value is 1.46 under the unequal variation of t-test 1.26.

Single-tree selection system; The single-tree selection system was observed in the Malkandi forest with help and suggested by the forest department for data collection in comparison to the KamalBan forest with a group selection system. The total area of the research site for data collection is two ha., with 10 major species and surrounded by *Populus ciliate* which was rare for data inventory and did not include in the data. Density per meter square of the major species was (±9.28PW, ±5.24CD, ±1.27PS, ±0.64AP, ±0.27QD, ±0.22AI, ±0.07AN, ±0.019PR, ±0.19RP, ±0.13AA) further detail is in (Table 4.2). For the diversity indices, statistical packages have used the results are shown in Table 4.3, mean dominance of (0.39) with a lower level of 0.20 and upper level of 0.50 of dominance. Table 4.3 also shows ±0.61 and ±1.24 Simpson and Shannon diversity respectively, whereas the maximum value ±2.30 for the Single-tree selection system. Summary statistics of the research data shows that single tree selection system with the standard error of ±0.98 and the stand. dev. of 3.09. The two-sample tests (t-test) shows in Table 4.7;

Table 4.7. Two sample test (t-test); (Variance and confidence level were examined in the table)

Tests for equal means			
Group selection system		Single-tree selection system	
N:	4	N:	10
Mean:	4.6916	Mean:	1.7318
95% conf.:	(-2.1193 11.502)	95% conf.:	(-0.47641 3.94)
Variance:	18.321	Variance:	9.529
Difference between means:		2.9597	
95% conf. interval (parametric):		(-1.4544 7.3739)	

95% conf. interval (bootstrap): (-1.2455 6.7591)

t :	1.4609	p (same mean):	0.16972	Critical t value (p=0.05):	2.1788
Uneq. var. t :	1.2583	p (same mean):	0.27207		
Monte Carlo permutation:	p (same mean):	0.1635			
Exact permutation:	p (same mean):	0.16484			

The single-tree selection system shows variance ±9.53, p- values of 0.05. The single-tree selection system gives high variation in species composition, but the number of individuals in this silvicultural system is low.

From the regeneration diversity, it was a clear indication that the forest stand is highly diversified, diversification leads the forest for the maximum productivity (yield productivity) (Rosenzweig and L 1995; Suratman 2012; Barlow et al. 2016; Felton et al. 2016). *Pinus wallichiana* and *Cedrus deodara* are abundantly available in the region which has high market value both for locals and urban markets.

The number of taxa is highly important in the diversity of the forest stands, the group selection system and single-tree selection system has the same number, whereas the species variation is large in GSS compared to STSS. This relation of the silvicultural system and management activities has strong relation between the ecology and the management, as the silvicultural system contributes to the health with management treatment and practices (Ames et al. 2015; de Sousa et al. 2015; Egnell and Ulvcrona 2015). The diversity in both of the research sites shows excellent diversity due to the functions of these forests like these forests are managed for the production of timber and also acts as a protective role of the watershed area. *Cedrus deodara* is the main timber productive species in the mountainous regions, whereas species like *Pinus wallichiana* consider as firewood in the high altitude region (Maltoni et al. 2019). *Quercus* species are both in the low and high altitude is one of the main and easy access tree species for the firewood with high calorific value.

Forest regeneration is also under competition with other undergrowth, which causes a high threat to future regeneration (Vopravil et al. 2014; Novák et al. 2015). But, due to the favourable condition for the growth and soil health also in a very good condition on a moderate slope area, which can help the regeneration (Marques et al. 2010). Regeneration diversity has great importance, for future conservation, climate change, forest degradation, and deforestation activities (Sulaiman et al. 2017). Group selection is more compact visibly as compared to the single tree selection system, whereas a single-tree selection system is more diversified in species composition, stand structure, moisture availability, less humus most of the little is decomposed (Achat et al. 2015).

The regeneration highly influenced by the first regeneration felling which retained seedbearers which need to be 10 – 14 m apart in deodar regeneration sites (Champion et al. 1965). Fir and spruce regeneration sites are treated with shelterwood system where these species are highly associated with broadleaved species (Champion et al. 1965; Vauhkonen and Pukkala 2016). These two species has different growth requirements in the early stage of there life. Weed growth are also highly significant for the interception and disturbance during the growth season of these natural regeneration areas (Yamashita et al. 2016). Due to unfavorable growth condition, bad seed years, competition due to weeds and or other unwanted plant species, lead foresters to treat the regeneration with artificial supplementation if its necessary (Tappeiner 1969).

4.2.2 Floristic complexity in relation to Silvicultural operations of Himalayan Moist Temperate Forests of Pakistan.

The article is under consideration for analysis, due to large extend of the data. The floristic complexity were also highlighted in first article of vegetation dynamics, as the data of this article not only focused on group selection system and single tree selection. The vegetation dynamics focused on all three layers of the vegetation (trees, shrubs, and ground vegetation).

Some of the high altitude vegetation analysis is present here, these results has no direct relation to the dissertation.

Floristic details are also given in annex-I along with the altitude throughout the region of research. Moreover the subalpine region results shows significant impact from grazing system on vegetation composition. The results shows 84 species (families 44), vegetation cover (48.57% max), on gentle slope, whereas, near to the water bodies 119%. Species like *Euphorbia*, *Rumex*, and *Medicago* are found abundantly. 48.57% forbs, 5.55% grasses, 37.72% herbs, and 7.67% shrubs, whereas 20% trees were recorded. Species composition with height contribution is; *Plantago* with minimum and maximum 11.29% and 50.98% respectively. Maximum and minimum vegetation density i.e. 88.45(000) ha^{-1}, and 2.30(000) ha^{-1} respectively found on PL. GS has a density of 21.9(000) ha^{-1}, NWB density was 11.33(000) ha^{-1}. IVI *Poa, Aristida, Ranunculus, Ephedra, Indigofera,* and *Juniper* has greater values. The results defined that these pastures need extensive scientific studies for the sustainable management, of livestock production, in high altitude mountains. Forest stand composition shows along the altitudinal variation, variation is limited to certain species.

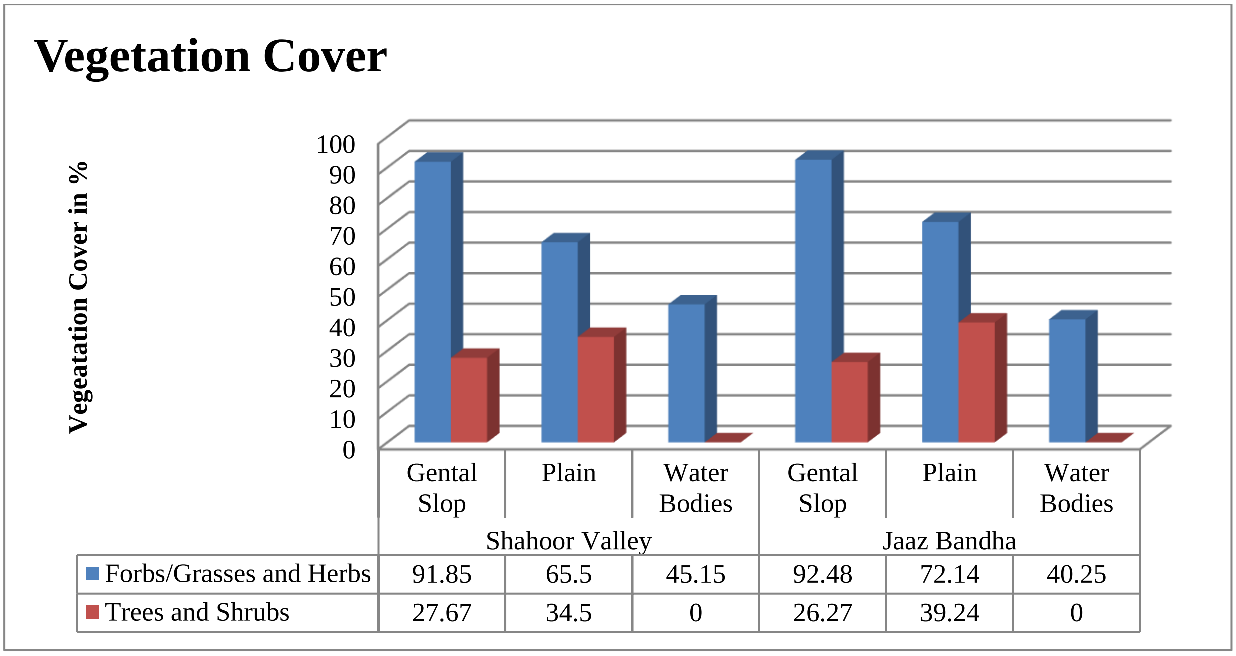


Figure: 4.12. Vegetation cover % found in the study area with different landscape

4.2.3 Forest stand structure in relation to silvicultural system in the western Himalayan moist temperate forest of Pakistan.

Forest stand structures are also disturbed due to silvicultural system in the region. Impact of group selection system and single tree selection system is clearly present in Figure 4.13 and 4.14. *Group Selection System (GSS);* was examined in 1980s under a project for integrated land use management system. This silvicultural system is widely used in rich temperate regions of the globe for the sustainable management. Research study examines the relation between the silvicultural system and forest stand structure. The detail information and data are present as follow;

Horizontal & Vertical distribution; Nature of GSS is limited in diversification both ecologically and environmentally, on the other hand genotypical characteristics may varies according to the species. Vertical and horizontal distribution is classify into stand density and crown position.

Diameter; the diameter classes classify the presence of stand structure in group selection system limited to lower classes ≤ 36 cm, whereas in upper classes moist of the species are only limited to 38, 44, 56, 70, 78, and 84 diameter class as shown in Figure. 4.13. The surrounding stand structure are quite different in nature, where number of individuals are limited but the diversity of stand is high. The predicted values shows slight change in the projection of data the maximum ±110.4 diameter values for 128 cm with height 63 m.

Height; the height data in the sample plot shows high variation at confidence level of mean at 95% i.e. ± 3.71. The mean height of the forest stand is 8.20 with minimum and maximum value of 0 and 44 respectively. High standard deviation of 13.44 with skewness of 1.48. the stand species are limited to due to harvesting system application compared to other silvicultural systems.

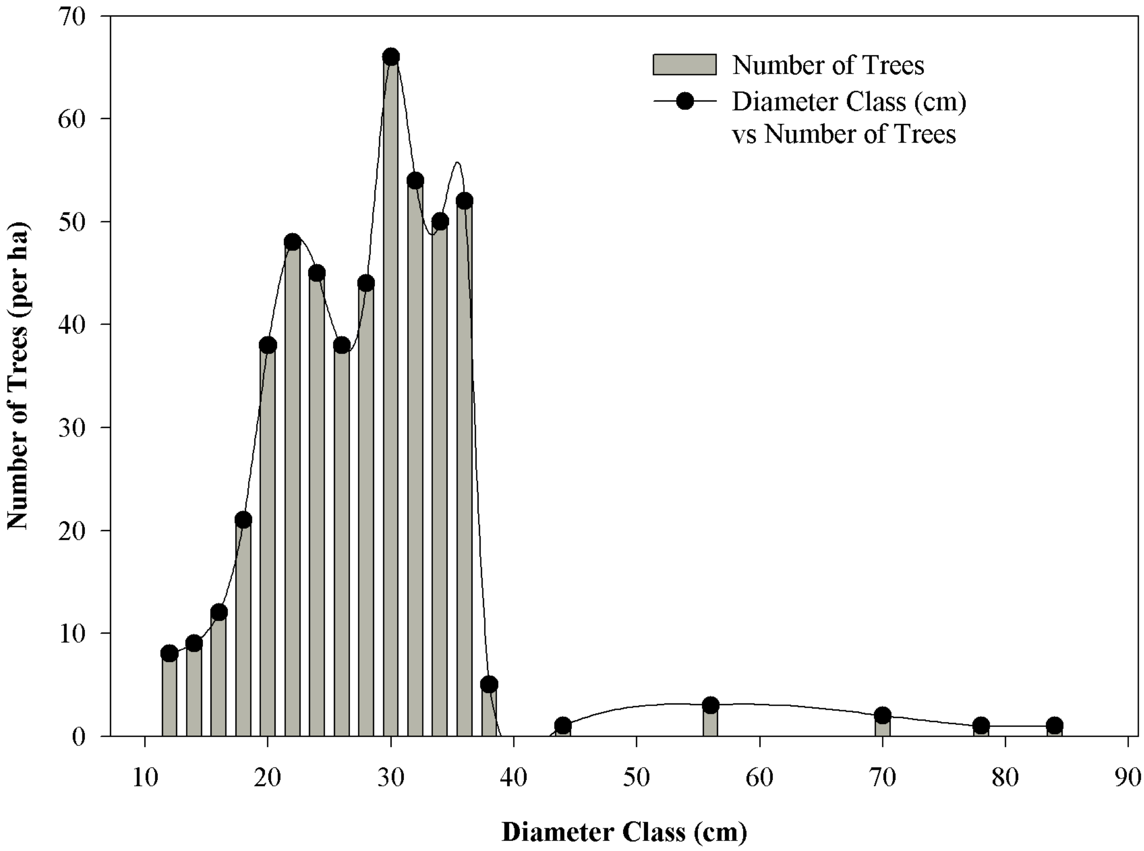


Figure: 4.13. Density per ha group selection system clear visibility that the number of trees are high in number (no understorey vegetation)

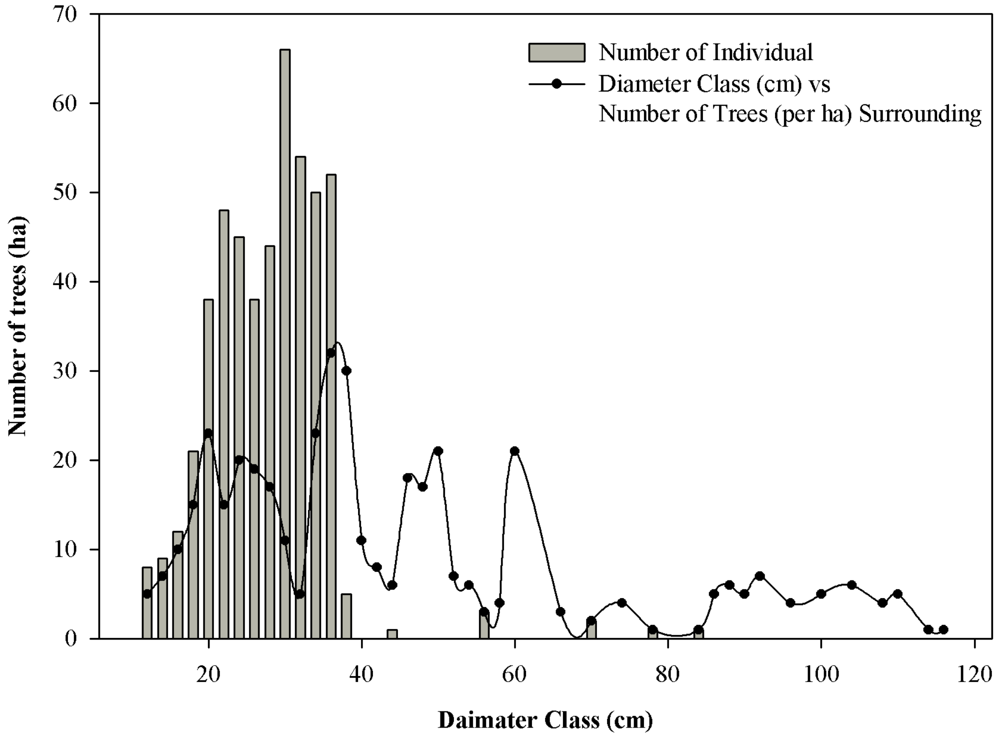


Figure 4.14: comparison between group selection system and surrounding areas (no understorey vegetation)

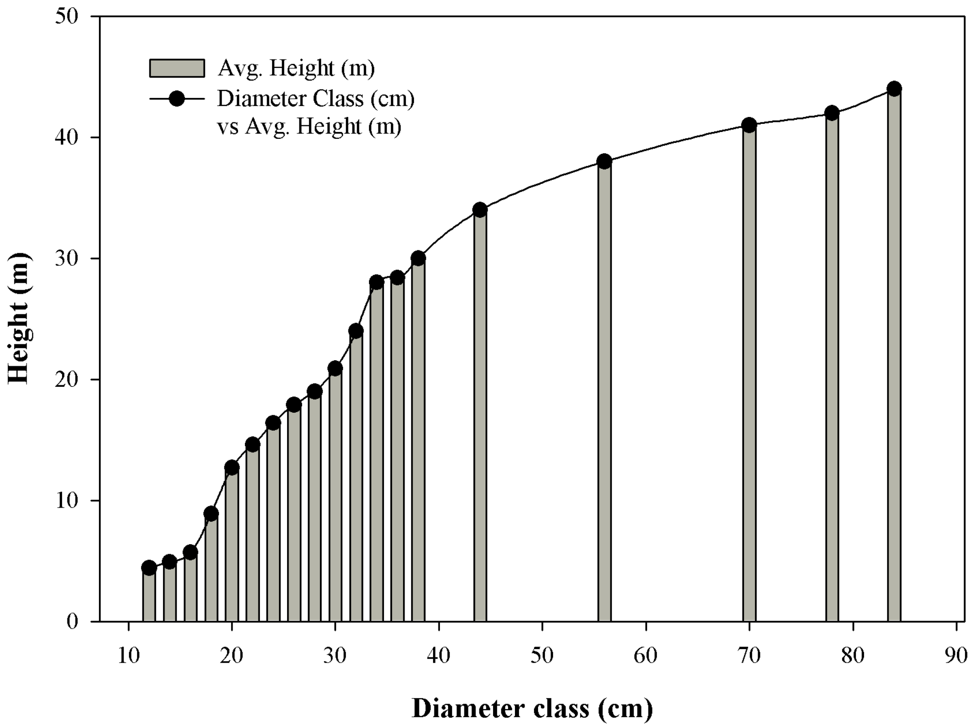


Figure: 4.15: Diameter height model

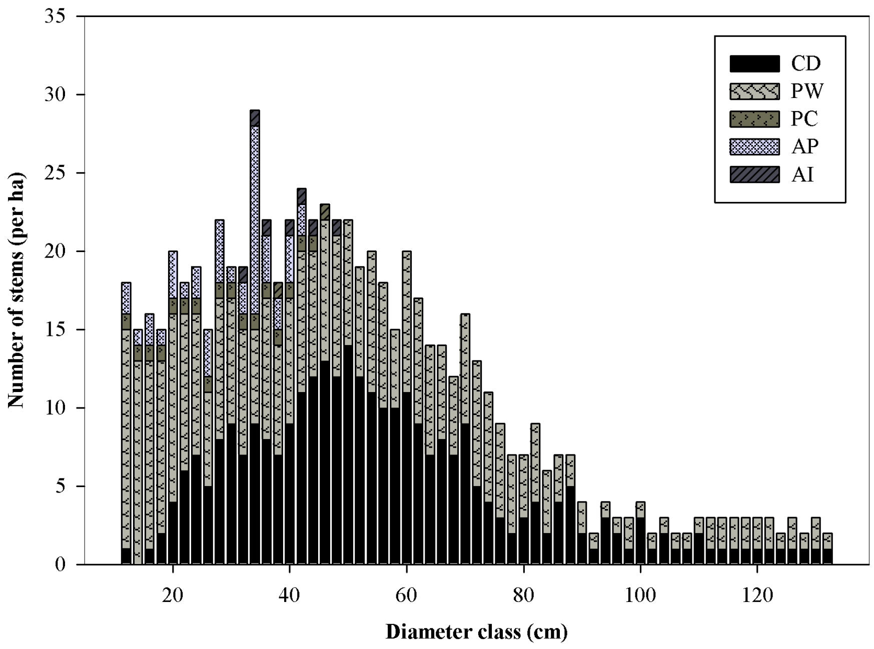


Figure: 4.16. Number of stems and species diversity in stand structure

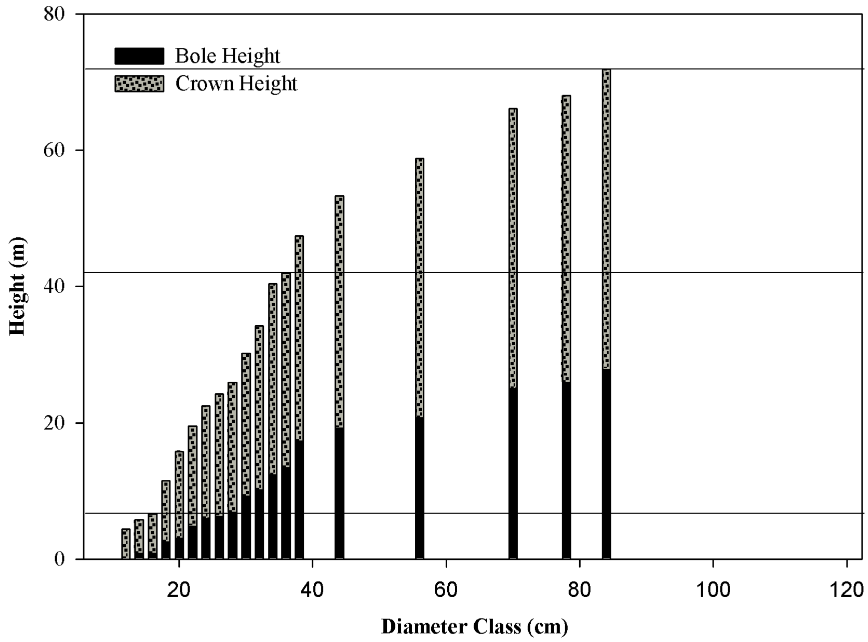


Figure: 4.17. Vertical distribution (three crown layers were identified emergent; Upper canopy; Lower canopy)

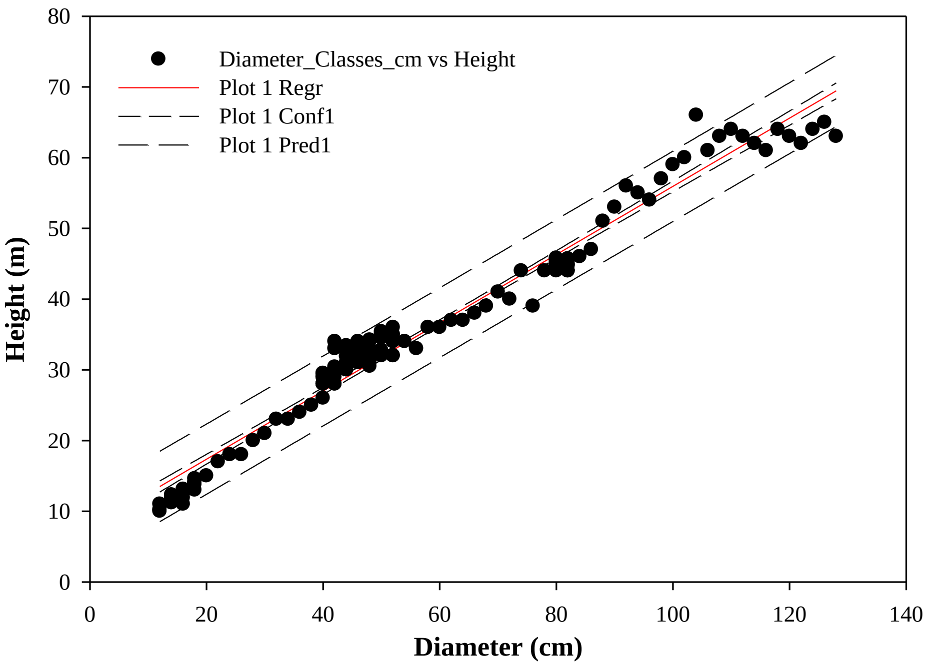


Figure: 4.18. Height vs Diameter Relation (Confidence, predication for Diameter vs Height and Regression)

Forest Stand diversity along the altitudinal variation; the species list in the stand structure focused on trees detail were shown in annex-III.

4.3 Climate change and silvicultural system

4.3.1 Climate Change and Their Impact on Silvicultural Practices in Western Himalayan Moist Temperate Forest of Pakistan (Conference abstract)

Western Himalayan Moist Temperate forest of Pakistan has great bio-diversity and one of the productive ecological zones for timber production. In the past twenty-five years, these mountainous forest were not managed under proper silvicultural system due to ban on green harvesting and other cultural and tending operation in 1991-93, only 3D's (Dead, Dying and Diseased) trees removal were allowed from 1999. Present study is the part of Doctoral research to find effects of harvesting system on environmental, social and economic issues in the region. In this regard climate and Management of forests are considered for evaluation.

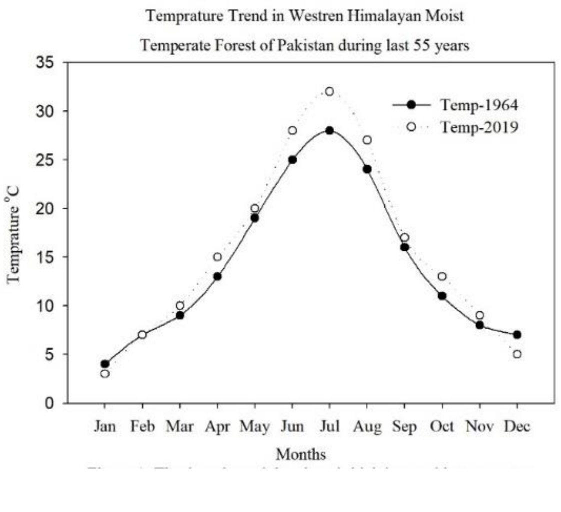
Climate change issues were also highlighted during past few decades. They have great influence on these forests with increase in temperature, uncertainty of precipitation, wind and storm pressure. Temperature fluctuation is about 2°C to 5°C varies with valleys, ridges, depression and peaks in the study area. That's affects the natural regeneration and other plant growth activities, also enhanced the disturbance which leads to the vulnerability of forests. Bio-diversity of the region were also shift from its natural zone, growth and time of establishment for plants were also decreases and faster with short time 10 to 15 days. Growth altitude differences were up to ±150 meter, which change the ecological zonation and requirements of the plants for nourishment. Wind throne, snow damaged were also increased 15 to 20 % according to the local records from forest management plan. Silvicultural operations and management practices need to observe to reduced the damages and protect, conserve the mountainous forest for future generation.

4.3.2 Climate change and silvicultural practices in western Himalayan moist temperate forest of Pakistan

Climate change phenomenon affects the mountain regions of the world which causes flooding, insect attack, migration, and treat to the flora and fauna. A total of 16 days were considered as maximum working days; avg. 11 days per month were feasible to work. Thinning operations did not practice in the natural forest after the green harvesting ban in 1992-1993. Only wind highly affects the working hours as compared to snow. Rainfall is also reduced the working speed. The existent climatic phenomena completely changes the operations pattern in the region. Which will adversely affect the vegetation composition and stand structure.

Temperature pattern; The climate of the study area mostly covers and surrounded by subtropical and alpine pasture with snow peaks in many parts of the track. Just like other parts of the world, these mountains are also affected by, change in temperature both during the summer and winter season. Due to which the growing season was limited or fast in many areas. In Figure 4.20; the summer season shows an increase of 4 to 3 °C during the day time, these are the maximum increase. Whereas during the winter season decrease in the temperature range from 2 to 1 °C.

Disturbance; Disturbance are also highly influenced by climate change in the mountains. Landslide events are high in number, as compared to the rest of the factors of disturbance as shown in Figure 4.21; A low number of insect attacks and lightning events were recorded, wind damages are high than snow damages. Figure 4.19; The data showed that there is high increased in temperature during (Jun-Jul), on other hand there is also decrease in temperature during Dec-Jan), which shows the uncertainty in temperature during the year. Figure 4.20; Due to unstable geological structure are more in number as compared to the other disturbance in the region. Low insect and disease attack also show stability in the stand structure.



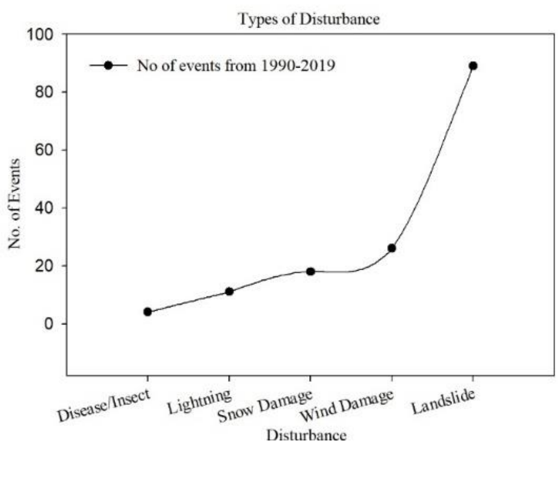


Figure 4.19 – 4.20.; Trend of temperature (55 years) and disturbance in the region from 1990 – 2019.

Silvicultural Practices Relation with climatic factors due to climate change; Climatic factors interacting with each and formed a different pattern of weather which influenced the management practices. The temperature has a less positive and negative impact on the silvicultural practices, harvesting was highly affected by an increase or decrease in temperature. Rainfall, wind and snow damage the forest stand which influenced the stand structure and affects silvicultural practices. Among these climatic factors, rainfall has serious damages to the activities in the mountain forest, because of the high intensity of rainfall due to the monsoon region.

Temperature (T) - silviculture operations; Temperature fluctuation is about 2°C to 5°C varies with valleys, ridges, depression and the peak of these mountains. That affects the natural regeneration and other plant growth activities and enhanced the disturbance which leads to the vulnerability of the mountain forest. Bio-diversity of the region also shifted from its natural zone, growth and time for the establishment of plants were also decrease and faster with a shorter period of 10 to 15 days. Growth; altitude differences were up to ±150 m, which change the ecological zonation and requirements of the plants for nourishment. Wind throne, snow damaged were also increased 15 to 20% according to the local records from the forest management plan. The p-value is 3.89 on a 95% confidence level. Mean of active days for the management practices are; 11.14W, 14.33C, 16A, 16R, 7.4NR, 11.25IF, 11.58CC and 11.25P. The temperature is plotted with the reference to silvicultural operation. Minimum avg; working days were 7.4 and a maximum of 13.7. shows a clear indication that temperature did not severely affect the management activities in the region due to the moderate temperature range. The summer season is barely affected where the avg; working days reduced to 7.4.

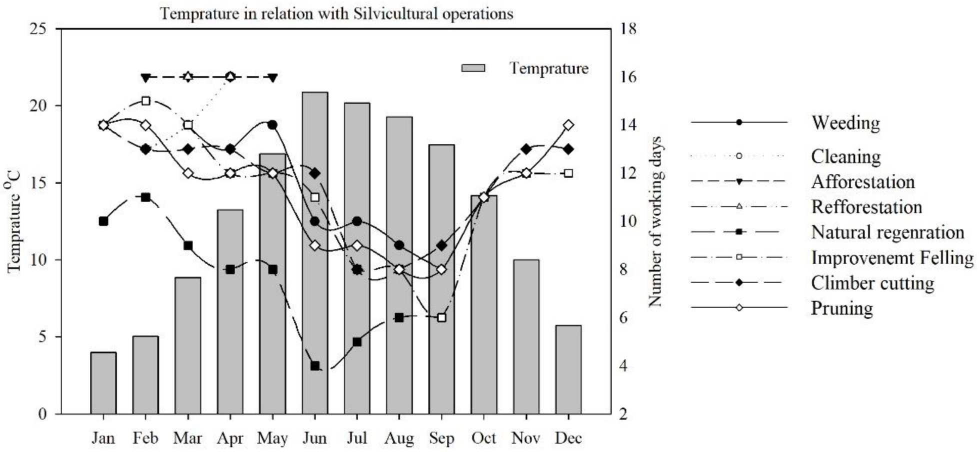


Figure 4.21: Representation of temperature with respect to silvicultural activities (days)

Wind (WD) - silviculture operations; The mountain terrain and high ground relief there very small variation in the wind speed throughout the year. The main factors for that were the river and high mountains. The speed of the wind affects the operational activities in the forest stand very greatly. The avg; speed throughout the years is 11.5 km/h, minimum, and maximum avg; wind speed is 10.8, and 12.5 respectively. Due to such speed, the activities in the region were seriously affected, specifically IF, CC, and PP has shown in the Figure 4.23; The p-value is 0.305 on 95% confidence level. The mean of active days for the management practices are; 9.14W, 8.33C, 9A, 12R, 7.44NR, 9.91IF, 6.91CC and 6.91P. The wind is plotted with the reference to silvicultural operation. Minimum avg; working days were 6, and a maximum of 9.5. shows a clear indication that wind was highly affecting the management activities in the region due to moderate high wind speed throughout the year and the range of the pattern is also wide due to high mountains. The early summer season and early winter were barely affected where the avg; working days raised to 9.5.

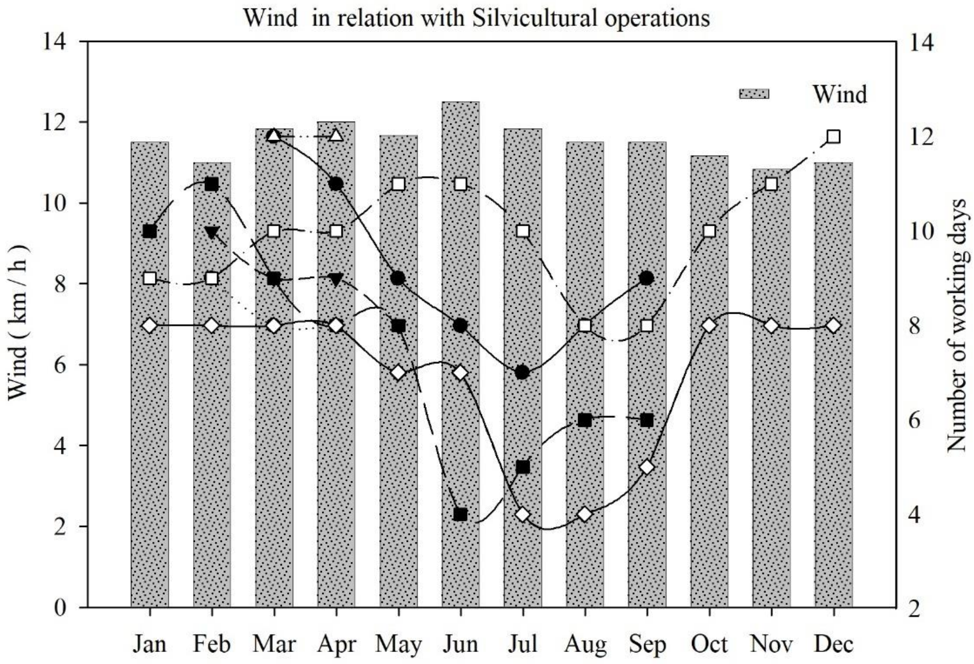


Figure 4.22: Representation of Wind with respect to silvicultural activities (days)

Snowfall (SF) – silviculture operations; The region is suitable for the heavy snowfall during the winter season. Snowfall acts as the temperature in the region and very little impact on management activities. Most of the activities were performed during the summer season or early summer, which is not a heavy snowfall season. The avg; snowfall throughout the year is 1.5 cm minimum and maximum snowfall is 1 and 4.7 respectively. There was a difficulty on the steep terrain for the worker. The p-value is 1.632 on a 95% confidence level. Mean of active days for the management practices are; 10.71W, 13C, 13.75A, 14.5R, 6.22NR, 11.41IF, 11.33CC and 10.83P. The snowfall is plotted with the reference to silvicultural operation in the Figure 5.23; the average data were also shown in the Table 5; minimum avg; working days were 7.4 and maximum 13. shows a clear indication that snowfall does not severely affect the management activities in the region. As limited months were affected due to snowfall only during winter.

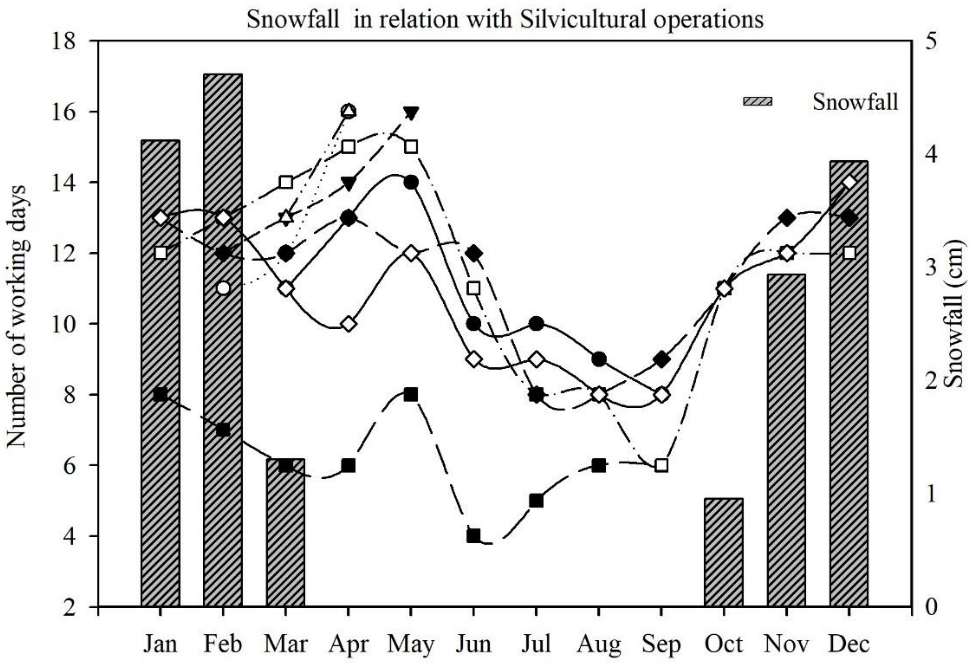


Figure 4.23: Representation of snowfall with respect to silvicultural activities (days)

Rainfall (RF) - silviculture operations; Climatic and ecological research sites fall in the temperate region, which received more rainfall and snowfall in the region both microclimatic or macroclimatic factors responsible for the environmental condition. Rainfall varies only on a short scale whereas, the overall rainfall situation is almost very high. The results show that the summer is season has high precipitation in the area compared to the winter season. The p-value is 46.56 on a 95% confidence level. The mean of active days for the management practices are; 9W, 3C, 13A, 16R, 5NR, 12IF, 2.6CC and 10.8P. The rainfall is plotted with the reference to silvicultural operation. The average data were also shown in the Table 4.8; minimum avg; working days were 4.8 and a maximum of 11.7. shows a clear indication that rainfall severely affected the management activities in the region due to microclimatic and macroclimatic conditions. The summer season highly affected avg; working days reduced to 4.8.

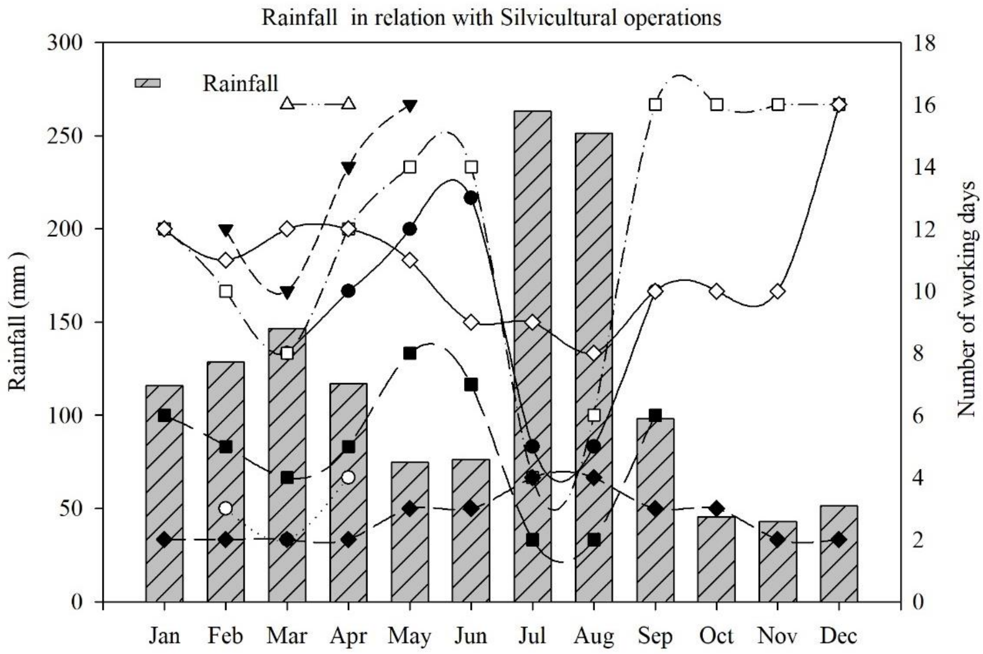


Figure 4.24: Representation of rainfall with respect to silvicultural activities (days)

Table 4.8; Avg; working days under silvicultural operation is the region in relation to climate change

Months	Temperature	Snowfall	Wind	Rainfall	*Avg; Activities during the month*
Jan	13.0	11.5	8.8	8.0	10.3
Feb	13.7	11.3	9.2	7.2	10.3
Mar	13.5	11.6	9.5	7.8	10.6
Apr	13.3	12.9	9.3	9.4	11.2
May	12.3	12.6	8.3	10.7	11.0
Jun	9.2	9.2	7.4	9.2	8.8
Jul	8.0	8.0	6.0	4.8	6.7
Aug	7.8	7.8	6.0	5.0	6.7

Sep	7.4	7.4	6.6	9.0	7.6
Oct	11.0	11.0	8.7	9.7	10.1
Nov	12.3	12.3	9.0	9.3	10.8
Dec	13.0	13.0	9.3	11.3	11.7
Min	7.4	7.4	6.0	4.8	6.7
Max	13.7	13.0	9.5	11.3	11.7

Temperature – snowfall – silvicultural operations; Temperature and snowfall in the region has less impact on silvicultural operations. The region is not highly affected by the temperature due to the topographic factor and ecological components (Ives 2006). The results indicate that the temperature fluctuation in the study area is very small scale. Microclimatic factors also influenced the working potential in the area (Yadava et al., 2017). Variation in the silvicultural operation throughout the years was related to the temperature and snowfall in the region (Iqbal 2019b). Due to no extreme positive and negative relationships, there is no such indication of effect to the working days or hours during the season. In certain cases, there is no such relationship between the activities and climatic factors, as more importance is given to the month of activities (Iqbal 2019a). Snowfall has rarely affected the activities in the mountainous area due to slack season and no silvicultural operation except climber cutting and pruning were observed during the study. These activities were hardly affected by the snowfall, but during heavy snowfall time, the movement of the worker or locals are limited (Lagergren , Jönsson 2017).

Wind – rainfall – silvicultural operations; As shown in Figures 4.21 and 4.23 that wind and rainfall adversely affect the working hours and frequency of fieldman availability in the study area. Due to the microclimatic weather phenomena, local precipitation is quite often in the region (Ives 2006). Which affects the activities in the forest area. Sudden rainfall also enhanced the frequency of local torrents and flooding the valleys. Due to the steep slope, the life-threatening situation is always alarming in the whole region (Lagergren , Jönsson 2017). Due to the regular rainfall risk of landslide, river bank – cuts and stone throne satiation was also observed (Iqbal 2019a). This satiation limited the activities of forest fieldmen, local community, forest officers, and mobility of the mechanical machinery. The wind is directly related to rainfall or vice versa, the intensity and speed of the wind increase the windfall and damages the tall trees on the steep slopes, ridges and also on the peak/top of the mountain (Yadava et al., 2017). The wind mostly reduced the working ability of the fieldman in the forest area, improvement felling, pruning and climber cutting is extremely life risked in the partially open forest (Lagergren , Jönsson 2017). Whereas in a dense forest there is a 40 to 50 % impact on the working ability.

4.4 Edaphic and social aspects and their role in silvicultural activities

4.4.1 Forest soil horizon characteristics along with altitudinal variation under a silvicultural system in the Himalayan moist temperate forest of Pakistan.

The results from the data analysis were discussed in detail based on soil horizon along with altitudinal variation, slope and aspect were also discusses and results were shown in Figure. 4.25 and 4.26. Forest stand composition and density of the crop is also calculated and recorded which was related to the soil profile.

Soil horizon along with altitudinal variation; The soil horizons show a significant change in depth along with the attitude on high elevation from (3000 m). The soil classes (O, A, B) were show similarities in depth from 1200 – 2900 m a.s.l. Whereas, (C) class has a high variation from 1700 m which further continues up to 3600 m. soil horizon class (O) avg; depth on 1200 m was 10 cm which gradually decreases up to 1800 m altitude. The factors responsible for the decrease in depth are low forest (0.01 %) stand density and collection of dead tree material by the local community (Adams et al. 2019). The upper horizon continues to increase (8 cm) in depth up to 2400 m altitude, the ground conditions show low access, high density (0.9 %), and moderate understory vegetation (Dvorak and Novak 1994). The organic layer was last recorded at 3000 m a.s.l, beyond this elevation there is very low tree vegetation were found, the slope is also high in these zones (only 20% onward was found for data collection).

Second horizon (A) was continuously found in the region, there is very low variation in depth along with the altitude from (3.29 to 5 cm) up to 3100 m, beyond this elevation the depth decrease rapidly. The main factor responsible for low variation was (O) horizon, good quality of forest stand and other vegetation (Carter, 2007).

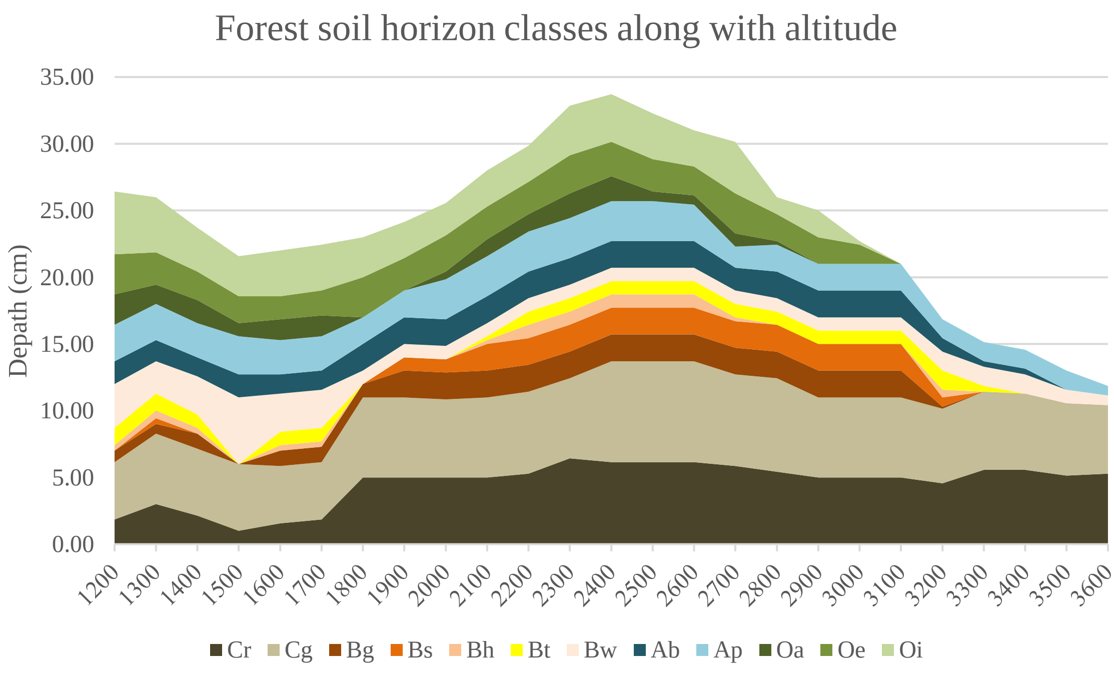


Figure: 4.25. A detailed description and graphical presentation of altitudinal variation (m) concerning forest soil depth (cm)

Third horizon (B) was found an entire range. Detail (B) was only available in the middle ranges started from 2100 – 3100 m a.s.l. The factors responsible are; stand density, diversity, parent rock material, and (O, A) horizon (Adams *et al.*, 2019). (C) horizon is entirely found in the region due to the regular event of earthquake and weathering process in the area (Liu, 2007).

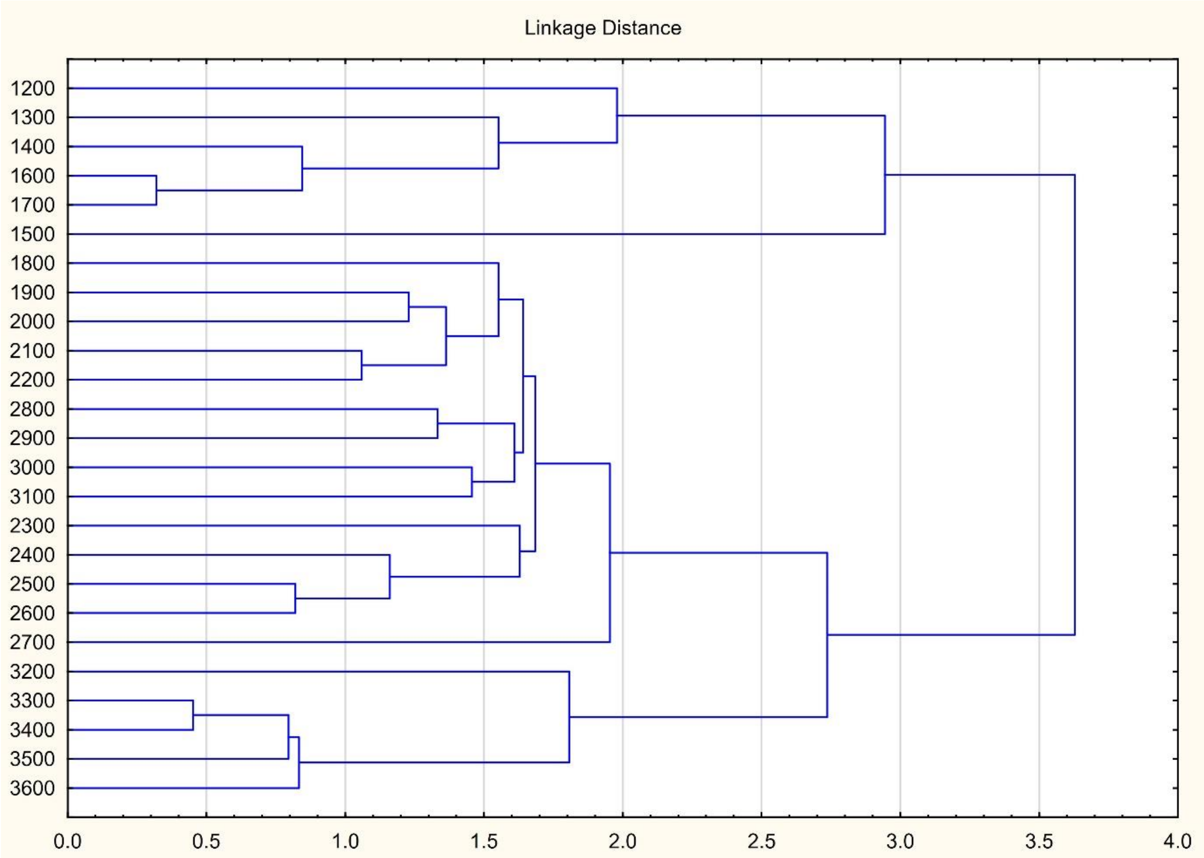


Figure: 4.26: Tree diagram for 25 variables (elevation zones) single linkage-euclidean distances.

Soil horizon aspects and slope; Aspect is directly related to vegetation cover, vegetation cover play important role in the forest soil profile (Hopmans *et al.*, 2005). The studies show no significant impact on aspects related to soil depth. Slope plays a vital role in the soil depth which was identified in the data by 5 – 60 % with a good depth of 25 – 31 cm the slope shows the stability on the surface and also shows the easy access to different forest activities

(Martins, 2015). Whereas the high slope more than 60 % has low depth ranges from 16 – 22 cm, which causes low stability to the surface and increases the runoff (Sauer *et al.,* 2005).

Soil horizon and vegetation composition with stand density; Forest stand composition and stand density were found between 0.01 – 0.9 % in the region from high altitude to mid and low altitude respectively. The lowest forest density was found on higher elevation from 0.01 from 2800 m a.s.l. and above and also on high slope region. high altitude has low vegetation cover and density due to severe climatic conditions and a short growing season (Nussbaum *et al.,* 2016).

4.5. Other Results from the data; research article

"Potential of silvicultural systems concerning soil carbon pools in Himalayan Moist Temperate Forest of Pakistan". Soil carbon was calculated in different areas of the study along with two silvicultural systems (group selection system and single-tree selection system). Due to the limitation of the data further analysis need to be made to deeply evaluate the results.

Social data were also examined, research article with the title; "Socio-economic status of a local community practicing silvicultural operation in Himalayan Moist Temperate Forest of Pakistan" will be evaluated very soon.

Landscape ecology and phytogeography; the title can be analysis with help of a Geographic information system. Potential research articles are; "Phytogeography and distribution of Himalayan Moist Temperate Forests of Pakistan". Second one; "Land-Use classification in the western Himalayan moist temperate forest of Pakistan; climate change and management activities".

5. CONCLUSION

The discussion for conclusion is based on the available literature and past history of silvicultural operation in the mountainous region. Mountain forests show many problems worldwide (Borůvka et al., 2005). Due to the high recreational (tourism), conservation (wildlife), commercial (timber, medicinal plants and livestock), protection (watershed) and historical/geological (Himalayas) values of the Himalayan moist temperate forests, sustainable management of the forest must be focused for the future development of the area, as well as of the rest of the country (Champion et al., 1965a). For the sustainable development of these mountainous forests, developmental indicators must be defined before aim towards strategic and operational activities (Golusin , Ivanović 2009). The socio-economic condition and livelihood of communities living in or adjacent to these forests are completely dependent on these forests (de Sousa et al., 2015). These forests have high potential as a watershed for the water reservoirs (Tarbela and Mangla) and also a source of fresh water to all reservoirs of Pakistan. Study areas are highly productive for the fodder collection, livestock grazing and high value of medicinal plants, which are affected by the lack of research (Abbasi et al., 2012). Present and past harvesting system and management systems in the area are only focused on trees (main crop), very little importance was given to the understorey vegetation or undergrowth.

Organizationally, as well as technically, timber harvesting or silvicultural systems are complex systems due to the advancement in the technology (Shegelman et al., 2015). These systems exposed the area for many environmental, biological and social factors, research study related to the impact of harvesting system on the undergrowth, site index and site quality, growth of the regeneration, composition, yield production, tree growth, diversity, and economic consideration must be taken into account for the sustainable management of the area (Chaudhary et al., 2016). These areas are very sensitive to erosion, to reduce the rate of erosion or its control, vegetation cover plays a vital role for the protection and conservation of these watersheds (Bataineh et al., 2013).

Tending operations also plays an important role in the growth and establishment of forest stands (Short , Radford 2008; Novák et al., 2015). Impacts of these operations affect the growth of the main crop, regeneration establishment, growth, space to the undergrowth, biomass production, and soil potential for the growth and also for supply fuel-wood. Tending operations will also help the livelihood and socio-economic conditions of the local communities. Studies aimed in the future will also provide a good understanding of the management of these forests, to reduce the high flood risk, land destabilization, sustainable eco-tourism, and ecological diversity. The integrated management plan for the optimum production and contribution to climate change, mitigation/adaptation, and carbon sequestration is also required for future management and development of forest resources (Kumar et al., 2016).

These mountain forests have great importance; social, scientifically and economically. There is a need for detail studies regarding ecologically disturbance and develop a productive model for the stability and improvement of these forest resources. This study provides baseline information for the advance research by using geo-informatics, ecological, social and economic model. From the results, it's clear that these forests are still in better condition, but if those events regularly occur and found, may lead to the deterioration and degradation of these diverse mountain forests. Data conclusion was focused on the stability of mountain forests for long term planning. Anthropogenic activities need to be restricted and increase afforestation activities to increase the forest-covered area.

Stand Structure of both group selection system and single-tree selection were different due to the silvicultural system. Group selection is more compact visibly as compared to the single tree selection system, whereas a single-tree selection system is more diversified in species composition, stand structure, moisture availability, less humus most of the little is decomposed. Compared to group selection system litter is partially decomposed due to low moisture less exposure to sunlight. Diameter, height data were also collected but due to out of focus to the present study it wasn't included here. Whereas visibly there is homogeneity in diameters and height of the main stand crop. Only partial differences were observed on the edges due to low competition in the group selection system compared to the single-tree selection system.

Forest stands are highly diversified in the single-tree selection system, along with the undergrowth but a number of an individual is high in the group selection system. Single-tree stand composition gives high value to watershed and also plays a vital role in livestock management, wildlife conservation and source of Fuelwood. Due to the nature of these mountain areas the stand composition is very important. The present study also highlights the future prediction for the conservation of these forests, which are highly sensitive and a hotspot for wildlife and climate change phenomena. The carbon sequestration ability of these mountain forests has great importance after calculating the regeneration growth and rate of success.

These valuable forests need critical care and proper silvicultural, scientific and economic management practices need to be addressed for the policy of mountain forest. The mountain forest are highly threatened throughout the globe. Silvicultural practices such as (silvicultural system, cleaning, weeding, thinning operations) are regular practices that can reduce the negative impact on these productive forests.

The high-altitude forest with a single-tree selection system has a significant impact on the soil horizon due to high floristic diversity and good vegetation density. Where the surface is not fully exposed to the precipitation and other biotic factors. The single-tree selection system is quite effective for soil conservation and water harvesting techniques. Long term policy and proper management plan in the mountains area prolong the life of the dames and water reservoirs of the country. Integrated land-use management systems with the application of silvicultural operation in the hotspot area will be highly significant for the future generation and climate change control in the high altitude. Diversified soil profile also enhanced the microbial activities in the forest, improve forest soil health and sources to the soil carbon reservoir. The study will help the forest manager, ecologist, and soil conservationist for the preparation of a sustainable management plan.

Detail study need to be conduct in the study region, present study show a high significant on the stand structure and stand composition from the different climactic factors. Especially unexpected rainfall pattern which highly affect the silvicultural practices in the region. Silvicultural practices need to be formulating according to the climatic factors so that less damage or negative impact will observed in the forest stand. Temperature doesn’t have any impact on the management activities due to less correlation. Silvicultural operations and management practices need to observe to reduced the damages and protect and conserve their mountainous forest for future generation.

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Annex-I (Scientific name of Plant species found during the research activities in two sites (Kamalbad and Malkandi Forest) Family and altitude of the species were also mentioned next)

Scientific Name	Family	Altitude m
Acer caesium Wall. ex Brandis,	Aceraceae	2000-3500m
Acer pictum auct.,	Aceraceae	2000-3500m
Pistacia integerrima J. L. Stewart,	Anacardiaceae	450-2000m
Hedera nepalensis K. Koch,	Araliaceae	1000-3000m
Berberis lycium Royle in Trans.,	Berberidaceae	
Alnus nitida (Spach) Endl.Gen.,	Betulaceae	1000-2900m
Betula utilis D.Don,	Betulaceae	3000-4500m
Sarcococca saligna (D.Don) Muell.-Arg.	Buxaceae	Up to 3000m
Lonicera webbiana Wall.,	Caprifoliaceae	2000-4000m
Viburnum grandiflorum Wall. ex DC.,	Caprifoliaceae	1500-3000m
Viburnum nervosum D. Don,	Caprifoliaceae	1500-3000m
Cornus macrophylla Wall.,	Cornaceae	1500-2700m
Corylus colurna L.,	Corylaceae	1600-3300m
Diospyros lotus L.,	Ebenaceae	±1500m
Rhododendron arboreum Sm.,	Ericaceae	1500-2500m
Euphorbia wallichii Hook. f.,	Euphorbiaceae	2400-3400m
Quercus dilatata Royle,	Fagaceae	1600-2900m
Quercus glauca Thunb.,	Fagaceae	700-2000m
Quercus ilex L.,	Fagaceae	1800-3000m
Quercus incana Roxb.,	Fagaceae	1000-2700m
Quercus semecarpifolia Smith in Rees	Fagaceae	
Ribes himalense Decne.	Grossulariaceae	2000-3400m
Parrotia persica (DC.) C.A.Mey.	Hamamelidaceae	
Aesculus indica Wall.,	Hippocastanaceae	1200-3300m
Juglans regia L.,	Juglandaceae	1000-3300m
Plectranthus barbatus Andrews,	Labiatae	
Ficus palmata Forssk.,	Moraceae	2500
Olea glandulifera Wall.	Oleaceae	600-1800m
Paeonia emodi Wall.	Paeoniaceae	3200m
Indigofera heterantha Wall.,	Papilionaceae	
Abies pindrow Royle,	Pinaceae	2500-3500m
Cedrus deodara Roxb.)	Pinaceae	2000-3000m

Picea smithiana Wall.,	Pinaceae	2500-3300m
Pinus roxburghii Sargent,	Pinaceae	600-1800m
Pinus wallichiana A.B. Jackson	Pinaceae	1800-3500m
Actaea spicata L.,	Ranunculaceae	2000-3300m
Anemone obtusiloba D. Don,	Ranunculaceae	
Clematis montana Buch.-Ham.,	Ranunculaceae	2000-3000m
Rhamnus virgata Roxb.,	Rhamnaceae	
Cotoneaster humilis Dunn,	Rosaceae	
Fragaria nubicola (Hook.f.) Lindl.,	Rosaceae	1500-3600m
Prunus cornuta Wall. ex Royle,	Rosaceae	
Prunus cornuta Wall.,	Rosaceae	
Prunus padas L.,	Rosaceae	
Pyrus pashia Buch.-Ham.,	Rosaceae	
Rosa macrophylla Lindl.,	Rosaceae	1800-2800m
Rosa moschata Herrm.	Rosaceae	1000-2500m
Rosa webbiana Wall.,	Rosaceae	1000-2500m
Rubus armeniacus Focke.,	Rosaceae	
Sorbus aucuparia L.,	Rosaceae	
Populus alba L.,	Salicaceae	
Populus ciliata Wall.,	Salicaceae	2000-3000m
Salix flabellaris Andersson in Kung.	Salicaceae	Up to 4000m
Taxus baccata L.,	Taxaceae	1800-3000m
Ulmus wallichiana Planch.,	Ulmaceae	2200-3000m
Viola kashmiriana W. Becker,	Violaceae	2000-2700m

Annex-II (Picto-representation)

Mix Blue Pine Forest (Southern Aspect)

High Altitude Mixed forest

Regeneration coupe Sub Tropical Chir Forest

Blue Pine patch near the grazing areas

Remaining Stump Sub mature growth

Mixed species composition in single tree SS

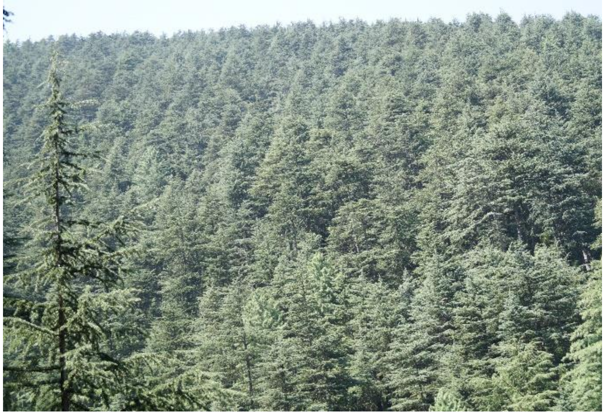
Blue pine in Group selection system

Deodar Patch (afforestation)

Single tree selection system forest

Group selection system

River side view of temperate forest



Over stocked forest growth

Selection system observed

Plectranthus Spp.

Mixed Confirous trees

Crown Closure

Plectranthus Spp

Multiple palatable species

Rhododendron Spp (Threaten spp)

Potentilla Spp

Carum Spp

Sarcococca Spp

Sarcococca saligna

Persicaria Spp.


Mushrooms

Soil sampling pit


Starch wood (tree damages/ Disturbance)

Mushrooms


Lizards (Reptiles)

Soil profile

Soil Sampling

Growth stand structure (DBH)

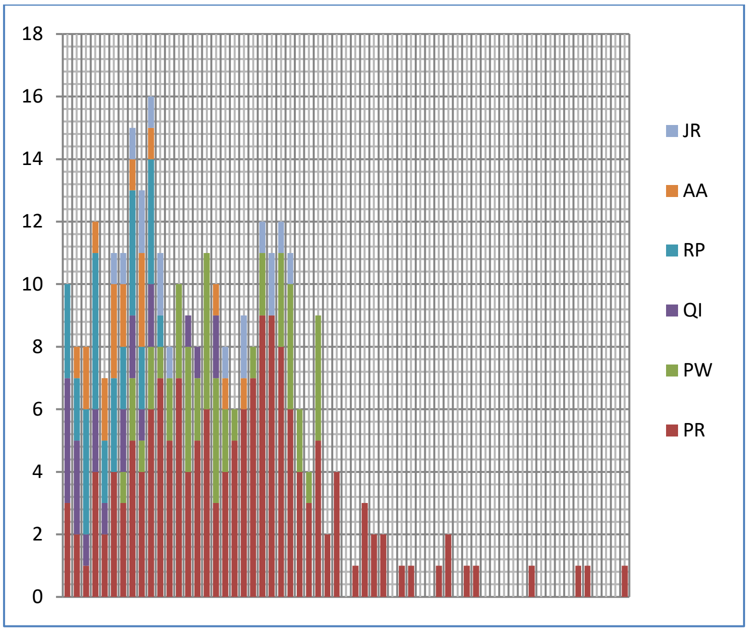
Disease and Insect (Disturbance)

Vegetation sampling (quadrate)

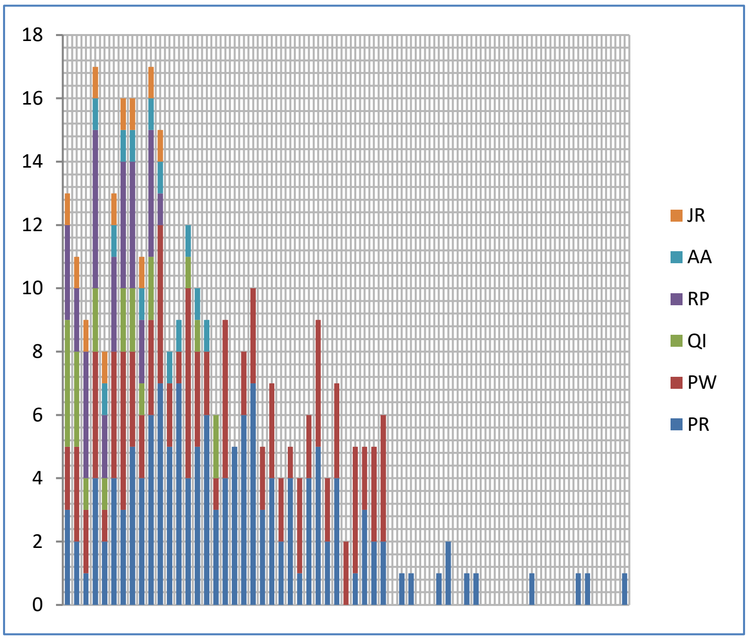
Distance and data recording

Social data

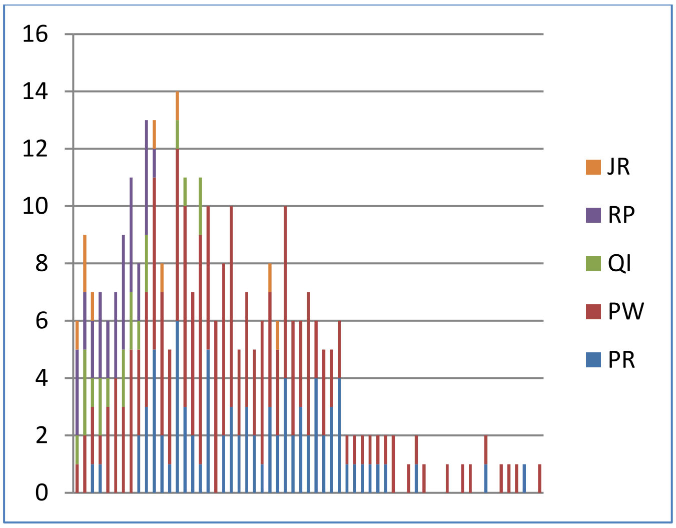
Annex-III (Stand level structure along altitudinal gradient) Y-axis number of stems whereas x-axis shows diameter started from 12cm to 132cm, 1200 m altitude with continuation of altitude upto 2800m.



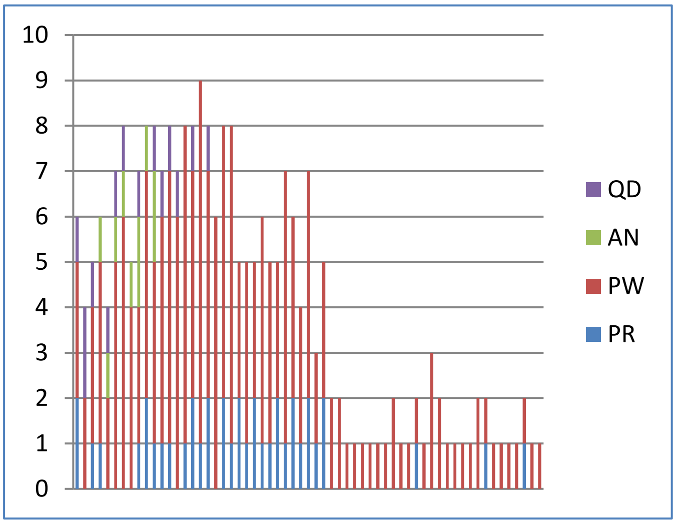
1200m



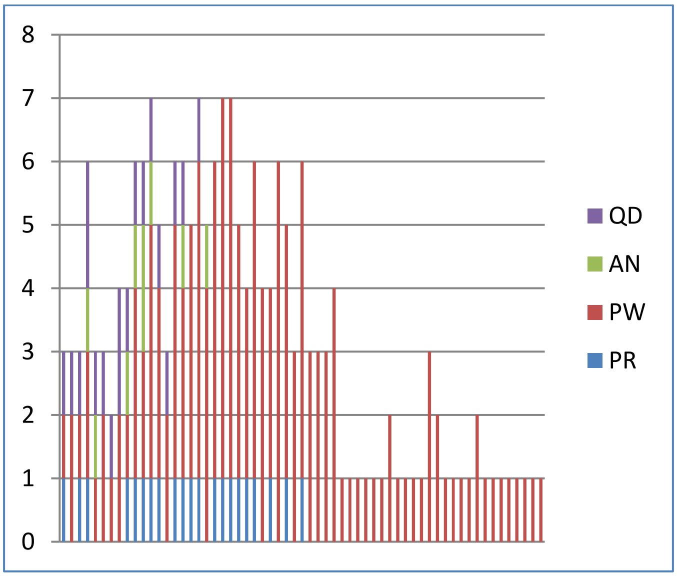
1300m



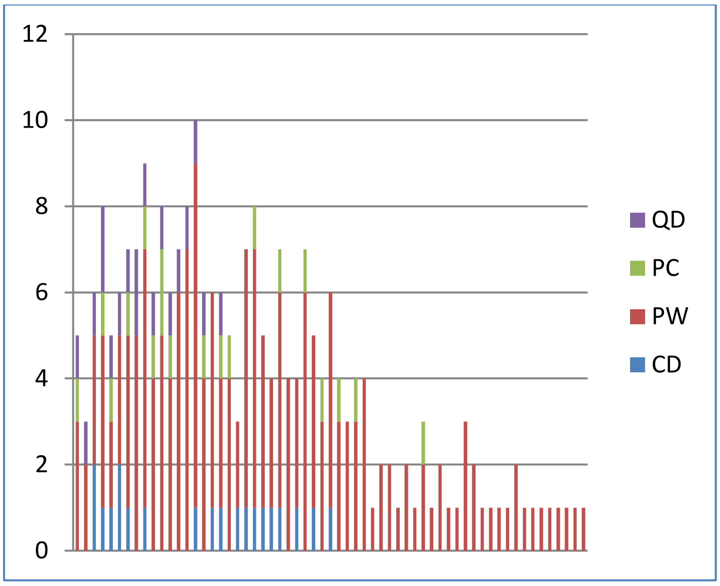
1400m



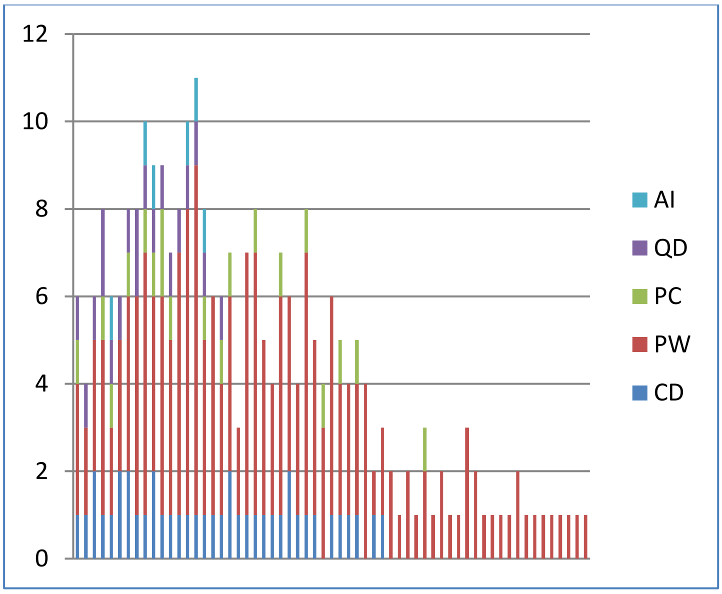
1500m



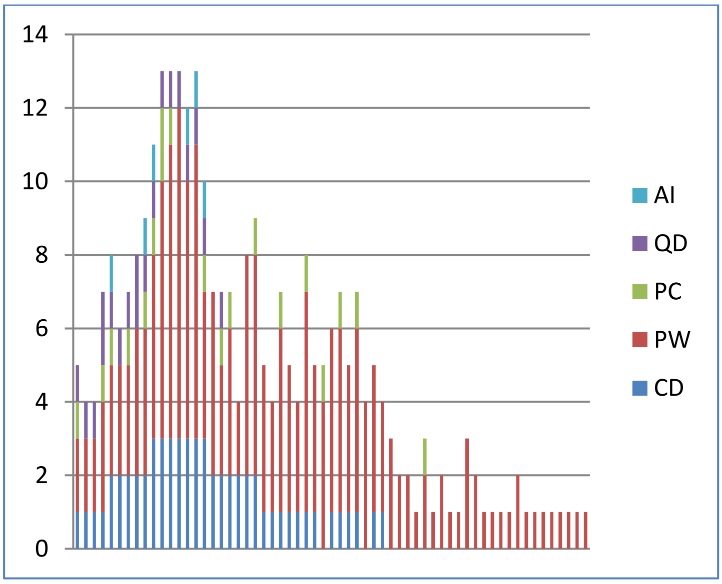
1600m



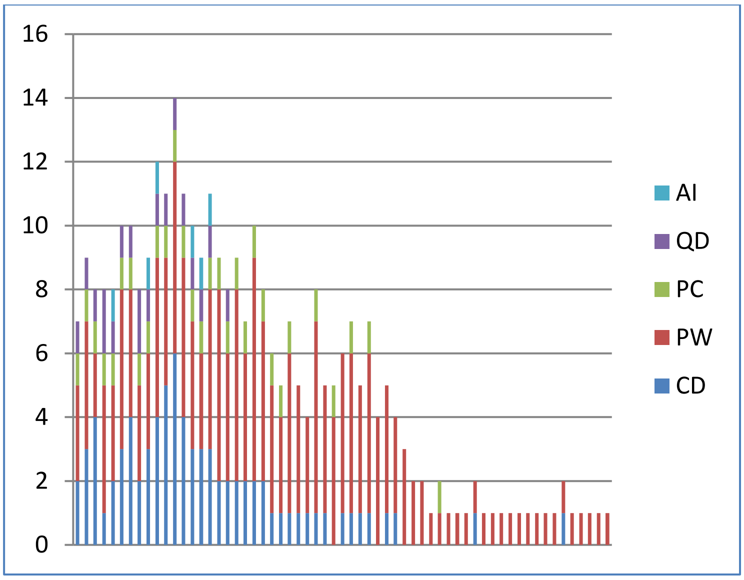
1700m



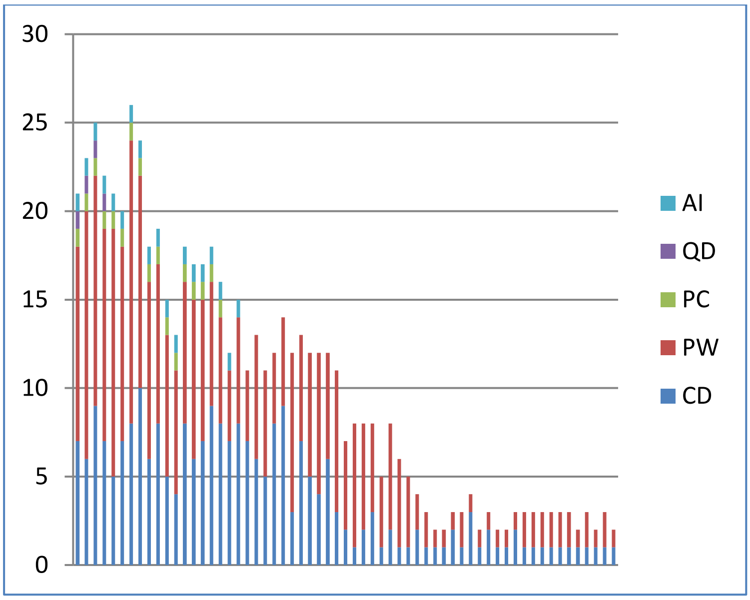
1800m



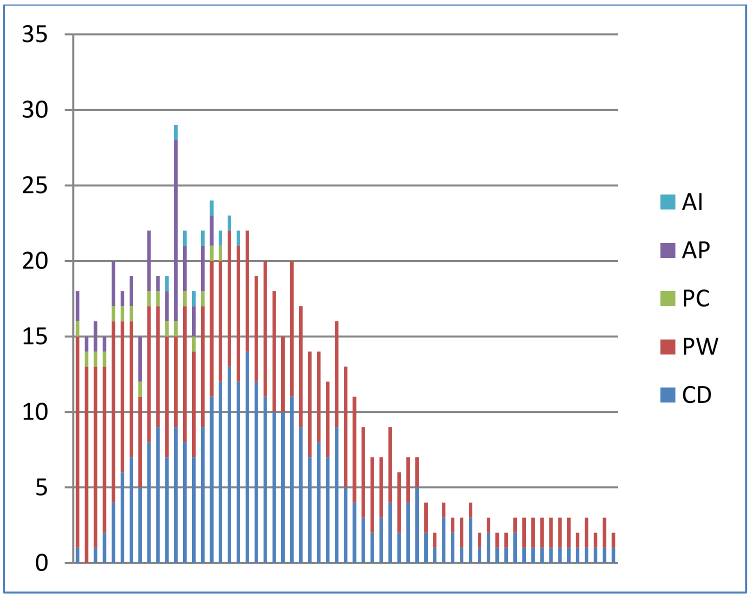
1900m



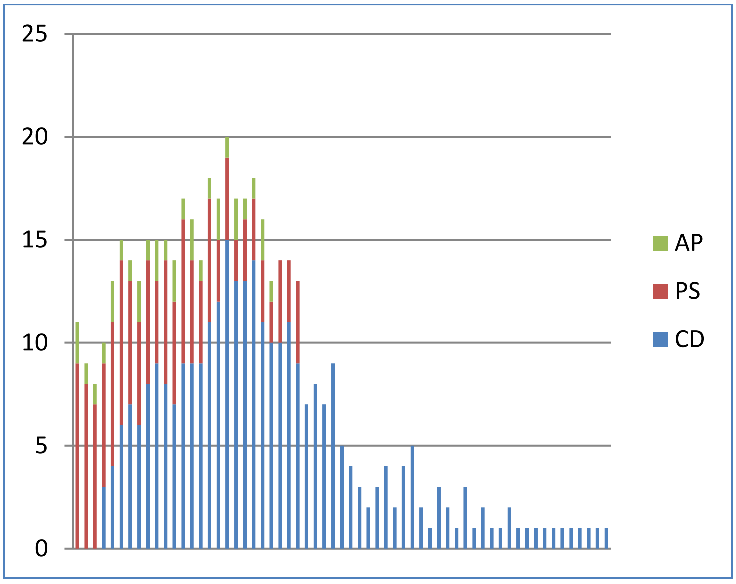
2000m



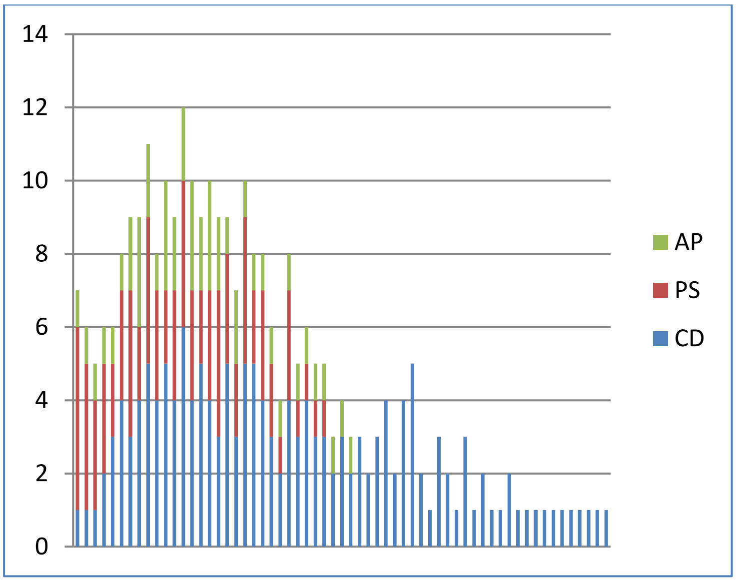
2100m



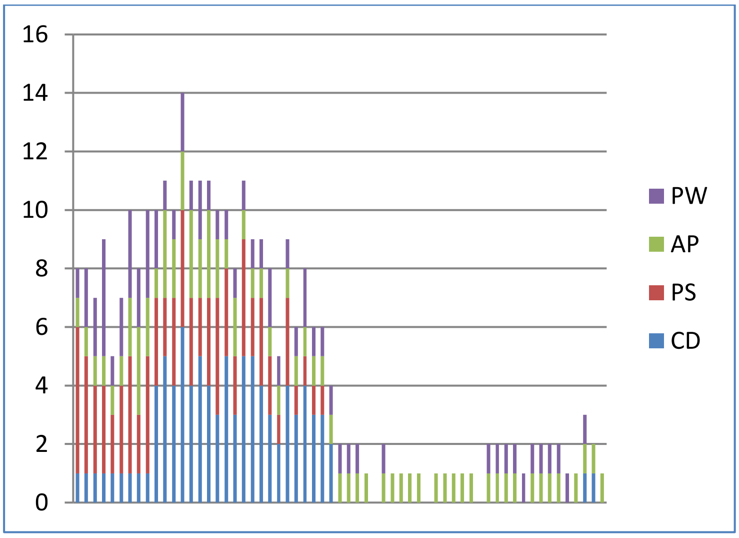
2200m



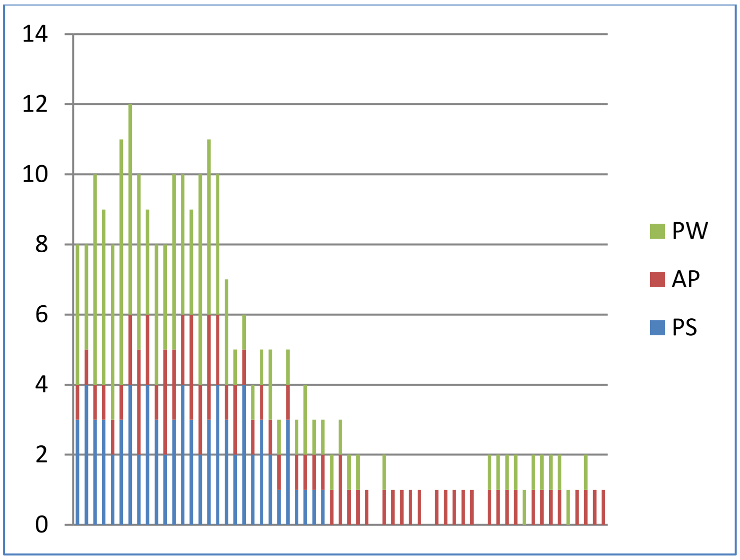
2300m



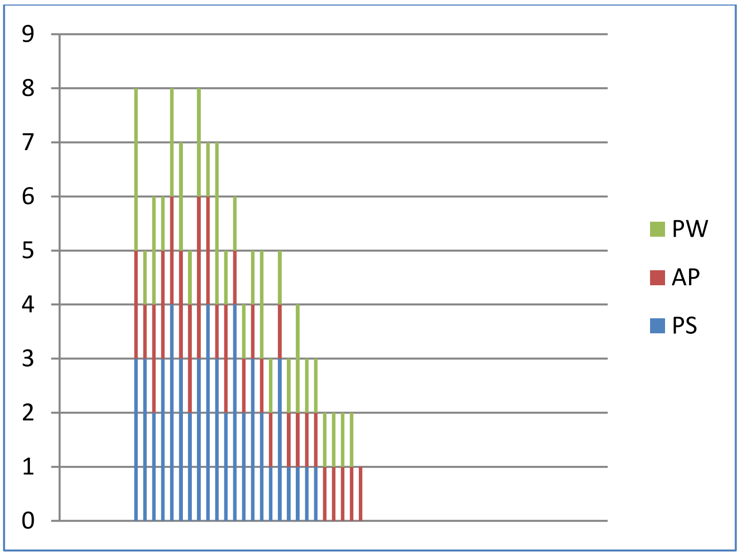
2400m



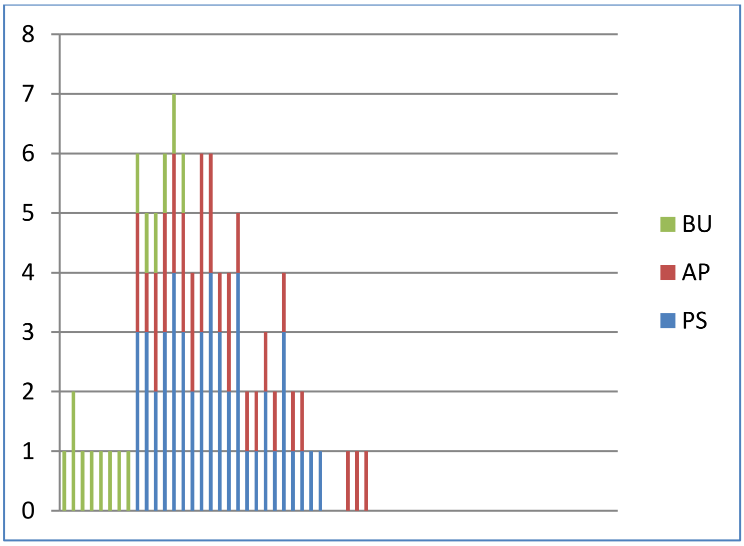
2500m



2600m



2700m



2800m

Annex-IV (Forest classification according Champion, Seth and Khattak 1994)

	Forest subdivision	Localities / Altitude	Species
A	**Lower Western Himalayan Temperate forests**		
i	Low-level blue pine forest (*Pinus wallichiana* A.B. Jackson)	Loon Bagla, Jhelum division, Kashmir / 1982–2134 m	*Pinus wallichiana*, *Quercus dilatata* Royle, *Taxus baccata* L., *Viburnum nervosum* D. Don, *Indigofera heterantha* Wall., *Paeonia emodi* Wall.
ii	Moist deodar forest (*Cedrus deodara* Roxb.)	Malkandi Compartment 1/2, Shogran, Kagan Valley / 2286 m Ashkot Compartment 13, Keran division, Lower Nilam valley, Kashmir / 1676–1982 m	*Cedrus deodara*, *Pinus wallichiana*, *Picea smithiana* Wall., *Abies pindrow* Royle, *Quercus dilatata*, *Quercus ilex* L., *Aesculus indica* Wall., *Prunus cornuta* Wall., *Acer caesium* Wall., *Viburnum nervosum*, *Rosa macrophylla* Lindl., *Berberis lycium* Royle in Trans., *Hedera nepalensis* K. Koch, *Clematis montana* Buch.-Ham.
iii	Western mixed coniferous forest	Ashkot, Lower Nilam valley, Kashmir / 2286–2438 m Shogran, Kagan valley / 2362 m Dungagali water catchment, Murree Hills / 2438–2591 m	*Cedrus deodara*, *Pinus wallichiana*, *Picea smithiana*, *Abies pindrow*, *Taxus baccata*, *Aesculus indica*, *Prunus padas* L., *Juglans regia* L., *Ulmus wallichiana* Planch., *Populus ciliata* Wall., *Acer caesium*, *Viburnum nervosum*, *Anemone obtusiloba* D. Don, *Actaea spicata* L., *Hedera nepalensis*, *Rosa moschata* Herrm.
iv	Ban oak forest (*Quercus incana* Roxb.)	Sehri Bari Reserve Forest compartment 58, Ghoragali, Murree Hills / 1829 m Loon Bagla (near Chakar), Muzaffarabad forest division, Swat, Abbottabad / 1646 m	*Quercus incana* Roxb., *Cornus macrophylla* Wall., *Pistacia integerrima* J. L. Stewart, *Quercus dilatata*, *Pinus wallichiana*, *Pyrus pashia* Buch.-Ham., *Diospyros lotus* L., *Ficus palmata* Forssk., *Pinus roxburghii* Sargent, *Prunus padas*., *Indigofera heterantha*, *Rhamnus virgata* Roxb., *Viburnum grandiflorum* Wall. ex DC., *Hedera nepalensis*, *Quercus glauca* Thunb., *Olea glandulifera* Wall.
v	Moru oak forest (*Quercus dilatata* Royle)	Loon Bagla compartment 3, Muzaffarabad division, Kashmir / 1829–2134 m Near Dungagali, Murree Hills / 2438 m	*Quercus dilatata*, *Pinus wallichiana*, *Populus ciliata*, *Ulmus wallichiana*, *Abies pindrow*, *Taxus baccata*, *Prunus cornuta*, *Juglans regia*, *Cornus macrophylla*, *Viburnum nervosum*, *Berberis lycium*. *Fragaria*

			nubicola (Hook.f.) Lindl., *Viola kashmiriana* W. Becker, *Hedera nepalensis, Euphorbia wallichii* Hook. f.,
B	**Upper West Himalayan fir and mixed broadleaved forest**		
i	Upper West Himalayan fir and mixed broadleaved forest	Upper Mushkin, Astor Valley, Gilgit / 3200 m	*Abies pindrow*, *Pinus wallichiana*, *Picea smithiana*, *Betula utilis* D.Don, *Sorbus aucuparia* L., *Salix flabellaris* Andersson in Kung., *Lonicera webbiana* Wall., *Fragaria nubicola.*
ii	Kharsu oak forest (*Quercus semecarpifolia* Smith in Rees)	Keran division, Upper Nilam Valley, Kashmir / 2900 m Swat / 2896–3200 m Kagan division, Hazara / 3200 m	*Quercus semecarpifolia* Smith in Rees, *Abies pindrow*.
C	**Edaphic, seral and Degraded type of Himalayan moist temperate forests**		
i	Moist temperate deciduous forest	Pahlgam, Lidder Valley, Kashmir / 2134 m Makanai Forest, Shogran, Kaghan division / 2591 m Dungagali, Murree Hills / 2438 m	*Padus cornuta* Wall. ex Royle, *Aesculus indica*, *Juglans regia*, *Acer caesium* Wall. ex Brandis, *Ulmus wallichiana*, *Corylus colurna* L., *Viburnum grandiflorum*, *Acer pictum* auct., *Parrotia persica* (DC.) C.A.Mey., *Salix flabellaris*, *Hedera nepalensis*, *Rosa moschata, Populus ciliata, Ulmus wallichiana*, *Quercus dilatata*, *Clematis montana* Buch.-Ham., *Fragaria nubicola*.
ii	Populus-Salix flabellaris Andersson in Kung. forest	Upper part of moist temperate forest / 2743 m	*Populus ciliata*, *Salix flabellaris* Andersson in Kung. *Pinus wallichiana*.
iii	Alder forest	Kagan, Siran Valley Dir and Swat / 915–1829 m	*Alnus nitida (Spach)* Endl.Gen., *Salix flabellaris* Andersson in Kung. *Populus ciliate.*
iv	Riverain blue pine forest	Extended into the dry zone, recorded in Kagan, Dir and Nilam Valley / 1524–3048 m	*Pinus wallichiana*, *Alnus nitida (Spach)* Endl.Gen., *Populus ciliata*, *Salix flabellaris.* Some *Cedrus* and *Picea* on a higher level and on lower *Pinus roxburghii.*
v	High-level blue forest	Upper Mushkin Forest, Astor Valley, Gilgit / 2743 m	*Pinus wallichiana*, *Picea smithiana*, *Rosa webbiana* Wall., *Berberis lycium*, *Lonicera webbiana*, *Rubus armeniacus* Focke., *Ribes himalense* Decne. *Populus alba* L., *Betula utilis, Salix flabellaris*.
vi	Secondary blue pine forest	Paryai Reserve Forest, Siran division / 1981 m	*Pinus wallichiana*, *Cedrus deodara*, *Populus ciliata*,

	(*Pinus wallichiana* A.B. Jackson)	Shinkiari-Kund ridge, Siran division / 1829 m Miandam Forest, Swat / 2073 m Ghoradhaka, Murree Hills / 2286 m Loon Bagla, Muzaffarabad division, Kashmir / 1981–2133 m	*Quercus dilatata*, *Rhododendron arboreum* Sm., *Prunus cornuta* Wall., *Viburnum nervosum*, *Berberis lycium*, *Rubus armeniacus*, *Viola kashmiriana*, *Hedera nepalensis*, *Quercus incana*, *Indigofera heterantha*, *Fragaria nubicola*. *Diospyros lotus*, *Aesculus indica*, *Ulmus wallichiana*, *Taxus baccata*, *Cornus macrophylla*.
vii	Himalayan moist temperate scrub	Lower Jhelum Valley or areas where trees are eliminated through biotic agencies / 1238 m	*Plectranthus barbatus* Andrews, *Berberis lycium*, *Indigofera heterantha*, *Cotoneaster humilis* Dunn, *Sarcococca saligna* (D.Don) Muell.-Arg.
viii	Pohu Scrub (*Parrotia persica* (DC.) C.A.Mey.)	Kashmir in the valley to the north of Jhelum, Swat Valley and Kagan / 1828–2438 m	*Parrotia persica*
ix	Himalayan temperate parkland	Middle and higher elevations Kagan Valley and Kashmir valley / 2286 m	Coniferous and broadleaved mostly forbs and grasses.
x	Himalayan temperate pastures	Last stage of degradation of the original broadleaved and coniferous forests. Better-drained slight banks between the flatter trampled ground / 2145–2655 m	*Pinus wallichiana*, and mostly forbs.

Annex-V (Plot Information, Soil)

Altitude (cm)	Slope (%)	Density (%)	Avg; Soil Depth (cm)	Aspect	Species Composition	Altitude (cm)	Slope (%)	Density (%)	Avg; Soil Depth (cm)	Aspect	Species Composition
1200	5	39	26.42	SW	PR, PW, QI	1300	5	39	26	SW	PR, PW, QI
	10	39		SE	PR, PW, QI		10	59		SE	PR, PW, QI, RP, A, AN,QD, CD
	20	39		NW	PR, PW, QI		20	61		NW	PR, PW, QI, RP, A, AN,QD, CD
	40	73		NE	PR, PW, QI, RP, A, AN,QD		40	76		NE	PR, PW, QI, RP, A, AN,QD
	60	52		N	PR, PW, QI, RP, A, AN,QD		60	52		N	PR, PW, QI, RP, A, AN,QD
	80	48		S	PR, PW, QI, RP, A, AN,QD		80	46		S	PR, PW, QI, RP, A, AN,QD
	100	18		E	PR, PW, QI, RP		100	13		E	PR, PW, QI, RP
1400	5	39	23.71	SW	PR, PW, QI	1500	0.39	39	21.57	SW	PR, PW, QI
	10	59		SE	PR, PW, QI, RP, A, AN,QD, CD		0.59	59		SE	PR, PW, QI, RP, A, AN,QD, CD
	20	61		NW	PR, PW, QI, RP, A, AN,QD, CD		0.61	61		NW	PR, PW, QI, RP, A, AN,QD, CD
	40	73		NE	PR, PW, QI, RP, A, AN,QD		0.73	73		NE	PR, PW, QI, RP, A, AN,QD
	60	58		N	PR, PW, QI, RP, A, AN,QD		0.52	52		N	PR, PW, QI, RP, A, AN,QD

Altitude (cm)	Slope (%)	Density (%)	Avg; Soil Depth (cm)	Aspect	Species Composition	Altitude (cm)	Slope (%)	Density (%)	Avg; Soil Depth (cm)	Aspect	Species Composition
	80	0.49		S	PR, PW, QI, RP, A, AN,QD		0.48	48		S	PR, PW, QI, RP, A, AN,QD
	100	0.11		E	PR, PW, QI, RP		0.19	19		E	PR, PW, QI, RP
1600	5	39	22	SW	PR, PW, QI	1700	5	39	22.42	SW	PR, PW, QI
	10	59		SE	PR, PW, QI, RP, A, AN,QD, CD		10	59		SE	PR, PW, QI, RP, A, AN,QD, CD
	20	61		NW	PR, PW, QI, RP, A, AN,QD, CD		20	61		NW	PR, PW, QI, RP, A, AN,QD, CD
	40	73		NE	PR, PW, QI, RP, A, AN,QD		40	73		NE	PR, PW, QI, RP, A, AN,QD
	60	52		N	PR, PW, QI, RP, A, AN,QD		60	52		N	PR, PW, QI, RP, A, AN,QD
	80	48		S	PR, PW, QI, RP, A, AN,QD		80	48		S	PR, PW, QI, RP, A, AN,QD
	100	21		E	PR, PW, QI, RP		100	22		E	PR, PW, QI, RP
1800	5	39	23	SW	PR, PW, QI	1900	5	39	24.14	SW	PR, PW, QI
	10	59		SE	PR, PW, QI, RP, A, AN,QD, CD		10	59		SE	PR, PW, QI, RP, A, AN,QD, CD
	20	61		NW	PR, PW, QI, RP, A, AN,QD, CD		20	61		NW	PR, PW, QI, RP, A, AN,QD, CD
	40	73		NE	PR, PW, QI, RP, A, AN,QD		40	73		NE	PR, PW, QI, RP, A, AN,QD

Altitude (cm)	Slope (%)	Density (%)	Avg; Soil Depth (cm)	Aspect	Species Composition	Altitude (cm)	Slope (%)	Density (%)	Avg; Soil Depth (cm)	Aspect	Species Composition
	60	52		N	PR, PW, QI, RP, A, AN,QD		60	52		N	PR, PW, QI, RP, A, AN,QD
	80	48		S	PR, PW, QI, RP, A, AN,QD		80	48		S	PR, PW, QI, RP, A, AN,QD
	100	22		E	PR, PW, QI, RP		100	21		E	PR, PW, QI, RP
2000	5	39	25.57	SW	PR, PW, QI	2100	5	39	28	SW	PR, PW, QI
	10	59		SE	PR, PW, QI, RP, A, AN,QD, CD		10	59		SE	PR, PW, QI, RP, A, AN,QD, CD
	20	61		NW	PR, PW, QI, RP, A, AN,QD, CD		20	61		NW	PR, PW, QI, RP, A, AN,QD, CD
	40	73		NE	PR, PW, QI, RP, A, AN,QD		40	73		NE	PR, PW, QI, RP, A, AN,QD
	60	52		N	PR, PW, QI, RP, A, AN,QD		60	52		N	PR, PW, QI, RP, A, AN,QD
	80	48		S	PR, PW, QI, RP, A, AN,QD		80	48		S	PR, PW, QI, RP, A, AN,QD
	100	19		E	PR, PW, QI, RP		100	19		E	PR, PW, QI, RP
2200	5	39	29.85	SW	PR, PW, QI	2300	5	39	32.85	SW	PR, PW, QI
	10	59		SE	PR, PW, QI, RP, A, AN,QD, CD		10	59		SE	PR, PW, QI, RP, A, AN,QD, CD
	20	61		NW	PR, PW, QI, RP, A, AN,QD, CD		20	61		NW	PR, PW, QI, RP, A, AN,QD, CD

Altitude (cm)	Slope (%)	Density (%)	Avg; Soil Depth (cm)	Aspect	Species Composition	Altitude (cm)	Slope (%)	Density (%)	Avg; Soil Depth (cm)	Aspect	Species Composition
	40	73		NE	PR, PW, QI, RP, A, AN,QD		40	73		NE	PR, PW, QI, RP, A, AN,QD
	60	51		N	PR, PW, QI, RP, A, AN,QD		60	52		N	PR, PW, QI, RP, A, AN,QD
	80	48		S	PR, PW, QI, RP, A, AN,QD		80	48		S	PR, PW, QI, RP, A, AN,QD
	100	17		E	PR, PW, QI, RP		100	16		E	PR, PW, QI, RP
2400	5	39	33.71	SW	PR, PW, QI	2500	5	39	32.28	SW	PR, PW, QI
	10	59		SE	PR, PW, QI, RP, A, AN,QD, CD		10	59		SE	PR, PW, QI, RP, A, AN,QD, CD
	20	61		NW	PR, PW, QI, RP, A, AN,QD, CD		20	61		NW	PR, PW, QI, RP, A, AN,QD, CD
	40	73		NE	PR, PW, QI, RP, A, AN,QD		40	73		NE	PR, PW, QI, RP, A, AN,QD
	60	52		N	PR, PW, QI, RP, A, AN,QD		60	52		N	PR, PW, QI, RP, A, AN,QD
	80	48		S	PR, PW, QI, RP, A, AN,QD		80	48		S	PR, PW, QI, RP, A, AN,QD
	100	16		E	PR, PW, QI, RP		100	16		E	PR, PW, QI, RP
2600	5	39	31	SW	PR, PW, QI	2700	5	31	30.14	SW	PR, PW, QI
	10	59		SE	PR, PW, QI, RP, A, AN,QD, CD		10	53		SE	PR, PW, QI, RP, A, AN,QD, CD

Altitude (cm)	Slope (%)	Density (%)	Avg; Soil Depth (cm)	Aspect	Species Composition	Altitude (cm)	Slope (%)	Density (%)	Avg; Soil Depth (cm)	Aspect	Species Composition
	20	61		NW	PR, PW, QI, RP, A, AN,QD, CD		20	43		NW	PR, PW, QI, RP, A, AN,QD, CD
	40	73		NE	PR, PW, QI, RP, A, AN,QD		40	69		NE	PR, PW, QI, RP, A, AN,QD
	60	52		N	PR, PW, QI, RP, A, AN,QD		60	49		N	PR, PW, QI, RP, A, AN,QD
	80	48		S	PR, PW, QI, RP, A, AN,QD		80	41		S	PR, PW, QI, RP, A, AN,QD
	100	11		E	PR, PW, QI, RP		100	09		E	PR, PW, QI, RP
2800	5	31	26	SW	PR, PW, QI	2900	5	29	25	SW	PR, PW, QI
	10	51		SE	PR, PW, QI, RP, A, AN,QD, CD		10	49		SE	PR, PW, QI, RP, A, AN,QD, CD
	20	57		NW	PR, PW, QI, RP, A, AN,QD, CD		20	51		NW	PR, PW, QI, RP, A, AN,QD, CD
	40	53		NE	PR, PW, QI, RP, A, AN,QD		40	59		NE	PR, PW, QI, RP, A, AN,QD
	60	52		N	PR, PW, QI, RP, A, AN,QD		60	40		N	PR, PW, QI, RP, A, AN,QD
	80	48		S	PR, PW, QI, RP, A, AN,QD		80	39		S	PR, PW, QI, RP, A, AN,QD
	100	09		E	PR, PW, QI, RP		100	07		E	PR, PW, QI, RP
3000	5	25	22.71	SW	PR, PW, QI	3100	5	21	21	SW	PR, PW, QI

Altitude (cm)	Slope (%)	Density (%)	Avg; Soil Depth (cm)	Aspect	Species Composition	Altitude (cm)	Slope (%)	Density (%)	Avg; Soil Depth (cm)	Aspect	Species Composition
	10	28		SE	PR, PW, QI, RP, A, AN,QD, CD		10	21		SE	PR, PW, QI, RP, A, AN,QD, CD
	20	28		NW	PR, PW, QI, RP, A, AN,QD, CD		20	21		NW	PR, PW, QI, RP, A, AN,QD, CD
	40	29		NE	PR, PW, QI, RP, A, AN,QD		40	21		NE	PR, PW, QI, RP, A, AN,QD
	60	21		N	PR, PW, QI, RP, A, AN,QD		60	19		N	PR, PW, QI, RP, A, AN,QD
	80	21		S	PR, PW, QI, RP, A, AN,QD		80	18		S	PR, PW, QI, RP, A, AN,QD
	100	07		E	PR, PW, QI, RP		100	06		E	PR, PW, QI, RP
3200	5	21	16.85	SW	PR, PW, QI	3300	5	15	15.14	SW	PR, PW, QI
	10	19		SE	PR, PW, QI, RP, A, AN,QD, CD		10	15		SE	PR, PW, QI, RP, A, AN,QD, CD
	20	18		NW	PR, PW, QI, RP, A, AN,QD, CD		20	15		NW	PR, PW, QI, RP, A, AN,QD, CD
	40	17		NE	PR, PW, QI, RP, A, AN,QD		40	11		NE	PR, PW, QI, RP, A, AN,QD
	60	17		N	PR, PW, QI, RP, A, AN,QD		60	10		N	PR, PW, QI, RP, A, AN,QD
	80	14		S	PR, PW, QI, RP, A,		80	09		S	PR, PW, QI, RP, A,

Altitude (cm)	Slope (%)	Density (%)	Avg; Soil Depth (cm)	Aspect	Species Composition	Altitude (cm)	Slope (%)	Density (%)	Avg; Soil Depth (cm)	Aspect	Species Composition
					AN,QD						AN,QD
	100	07		E	PR, PW, QI, RP		100	06		E	PR, PW, QI, RP
3400	5	11	14.54	SW	PR, PW, QI	3500	5	09	13	SW	PR, PW, QI
	10	10		SE	PR, PW, QI, RP, A, AN,QD, CD		10	09		SE	PR, PW, QI, RP, A, AN,QD, CD
	20	10		NW	PR, PW, QI, RP, A, AN,QD, CD		20	09		NW	PR, PW, QI, RP, A, AN,QD, CD
	40	10		NE	PR, PW, QI, RP, A, AN,QD		40	08		NE	PR, PW, QI, RP, A, AN,QD
	60	09		N	PR, PW, QI, RP, A, AN,QD		60	60		N	PR, PW, QI, RP, A, AN,QD
	80	08		S	PR, PW, QI, RP, A, AN,QD		80	06		S	PR, PW, QI, RP, A, AN,QD
	100	06		E	PR, PW, QI, RP		100	05		E	PR, PW, QI, RP
3600	5	01	11.85	SW	PR, PW, QI						
	10	01		SE	PR, PW, QI, RP, A, AN,QD, CD						
	20	01		NW	PR, PW, QI, RP, A, AN,QD, CD						
	40	01		NE	PR, PW, QI, RP, A, AN,QD						
	60	01		N	PR, PW, QI, RP, A,						

Altitude (cm)	Slope (%)	Density (%)	Avg; Soil Depth (cm)	Aspect	Species Composition	Altitude (cm)	Slope (%)	Density (%)	Avg; Soil Depth (cm)	Aspect	Species Composition
					AN,QD						
	80	01		S	PR, PW, QI, RP, A, AN,QD						
	100	01		E	PR, PW, QI, RP						

Annex-VI (Published Articles)

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PAST AND PRESENT SILVICULTURAL SYSTEMS AND TENDING OPERATIONS IN HIMALAYAN MOIST TEMPERATE FORESTS OF PAKISTAN

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Abstract

Himalayan moist temperate forests have the highest contributing values in the forest resources of Pakistan. These forests provide timber for commercial and domestic use, non-wood forest products that are abundantly available for local farmers and the international market. These forests are also source of fresh water to the lowlands. Locals and nomads are highly dependent on these forests for their livestock production. Silvicultural systems and tending operations are important management tools for the optimization and utilization of forest resources. Edaphic and biotic factors are also influenced by these systems for biomass production. There are two different silvicultural systems applied in the management: protection and conservation, i.e. selection system (also including group selection) and clear felling system. The group selection and clear felling system were applied for experimental purpose in the 1980s. At present, only selection system with 3D's (dead, dying and diseased), and damaged trees logging is accepted in different parts of the Himalayan moist temperate forest. Before 1992, 1.9 % and 88.6 % of activities were found for clear felling and selection system, respectively. Tending operations are also inactive in different parts of the forests. Tending activities i.e. weeding 21.1 %, cleaning 88.6 %, thinning 16.1 % and improvement felling 1.43 % average, were recorded to examine the active status in the study area. Studies must be conducted for the protection, conservation and management optimisation of these valuable forest resources.

Key words: afforestation, harvesting system, Himalayan temperate forest, management activities, species composition.

Introduction

Ecologically and biologically Pakistan is one of the richest countries, including high mountains of Himalayan, Karakorum and Hindu Kush and deep Indian ocean with high diversity (Hussain 1984). Forest ecosystems are one of the major parts of the natural richness. Production is one of the key elements of forest resources and their services especially in the coniferous forests (Müller et al. 2019). These forests are the major source of palatable plant species (Khan 1985), they also provide fuel-wood and medicinal plants to the local community (Sher and Al-Yemeni 2011). Due to the heavy exploitation, intensive utilization and recreational activities (Rashid et al. 2011) in these valuable ecological niches, the fauna and floristic community become near to extinct (Al-Yemeni and Sher 2010, Sher and Al-Yemeni

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Original Article

Forest disturbance and degradation in western Himalayan moist temperate forest of Pakistan

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Abstract

This research aims to investigate forest disturbances and the underlying factors driving forest degradation in the past several decades in the western Himalaya, Pakistan. The results revealed four major disturbance sources (geological, climatic, biotic, and anthropogenic). Data (frequency of events) were recorded using point and fixed area methods (0.1 ha). The analysis shows average frequency (0.045 or 27% of disturbance) through climatic sources (natural fire, wind, snow & floods, which shows the impact of climate change on these mountains; Landslides damaged large areas (11%–16 %) through a geological source. Humans also have a great impact on land clearing for agriculture and infrastructure (35%) from logging, shifting cultivation and counter fire. Most of the disturbances occurred on higher altitudes (>2,800 m a.s.l.), whereas the mid-range elevation (1,900–2,700 m a.s.l.) were only influenced by snow. The landslide was recorded on low elevation (>1,900 m a.s.l.), but there are some landslide events that were observed on a higher elevation. This study focused on the stability of mountain forests for long-term planning. Anthropogenic activities need to be restricted and more afforestation projects need to plan, that increase the forest-covered area.

Keywords: Disturbance, Altitude, Degradation, Moist-temperate climate, Sustainability

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Introduction

Temperate forest zone covers about one-fourth of the forest land of the world, most of these forests lie in mountainous regions (Frelich, 2002), and thus are highly sensitive to natural disturbances (White, 1979). Historically, there are some disturbance events in the mountainous regions because of the ecology of the mountains (Rogers and Station, 1996; Siebert and Belsky, 2014). The scale and level of ecological disturbances are often determined by topography, site variation and other ecological factors (Pickett and White, 1985). Ecological factors (biotic and abiotic) vary with altitude and aspect (Picó et al., 2008). The structural dynamics of the forest depend on natural disturbance (White, 1979). Structural dynamics and topographic diversity in the mountain regions lead to ecological disturbances in these forests; They are landslides, landslips, rock-falls, fires, wind-throws, herbivore/grazing, snow damages, floods, and

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Impact of silvicultural system on natural regeneration in Western Himalayan moist temperate forests of Pakistan

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Abstract: Site conditions (topography, aspect, moisture availability, humus thickness, light exposure, and grazing activities) play a vital role in the germination and regeneration process. The research was conducted in the Himalayan moist temperate forest. The research site was divided based on the silvicultural system (group selection system and single-tree selection system) into 148 plots and 150 plots, respectively. The group selection system was examined on the site of 2 ha which was clear-felled under a project in the 1980's. The present study examined the impact of silvicultural systems on regeneration. The frequency table was used, and relative frequency was calculated for the species and silvicultural system, density per m^2 was also calculated. Diversity indices were calculated through taxa, dominance, Simpson's index, Shannon index, evenness, equitability, and fisher alpha. Ten taxa were found in both silvicultural systems, with individual repetition of 17 and 15 taxa, respectively. Group selection is more compact visibly as compared to the single-tree selection system. The single-tree selection system is more diversified in species composition, stand structure, moisture availability, and less humus availability. The study also highlights future predictions for the conservation of these forests, which are highly sensitive and a hotspot for wildlife and climate change phenomena. Silvicultural practices such as silvicultural system, cleaning, weeding, thinning operations are regularly practiced, which can reduce the negative impact on these productive forests.

Keywords: diversity; mountain forest; stand structure; species composition; watershed

The regeneration gap leads to the forest ecosystem deterioration and degradation of forest stand structure (Barnes et al. 1998). To investigate the life cycle of forest stands, the regeneration process and factors influence the process needs to be identified (Guo et al. 2003). Heterogeneity of forest stands with species composition influences the rate of regeneration (Chen et al. 2007). To maintain the ecosystem of forests, the regeneration process needs to be properly managed through artificial and natural regeneration (Kent, Coker 1992). In the naturally regenerated forest ecosystem plants may die or recruit to the understorey when after the competition they became a part of the overstorey (Barnes et al. 1998). Regeneration methods that were found in woody vegetation are vegetative, viable seed bank, dormant and persistent seed bank, fire-induced opening of cones, widely wind-dispersed seeds, locally dispersed seeds, and persistent juveniles (Grime 1988; Barnes et al. 1998). Seed production in forest crops influences the rate of growth (diameter and height) which affects timber production (Morris 1951; Tappeiner 1969).

Natural regeneration in the high mountains is the only source of growing stock. Almost every forest species is regenerated through seeds except some special broadleaved species (Yadava et al. 2017). On the other hand, vegetative reproduction (layering) of natural regeneration occurs more often than seed production in extreme site and cli-