IMPACT OF ANTHROPOGENIC DISTURBANCES ON PHYTO-DIVERSITY AND SOIL CHARACTERISTICS ALONG DISTURBANCE GRADIENT IN THE TROPICAL FORESTS OF AIZAWL DISTRICT, MIZORAM

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IMPACT OF ANTHROPOGENIC DISTURBANCES ON PHYTO-DIVERSITY AND SOIL CHARACTERISTICS ALONG DISTURBANCE GRADIENT IN THE TROPICAL FORESTS OF AIZAWL DISTRICT, MIZORAM

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SUPERVISOR'S CERTIFICATE

I certify that **Madhurima** has prepared her thesis entitled "**Impact of Anthropogenic Disturbances on Phyto-Diversity and Soil Characteristics along Disturbance Gradient in the Tropical Forests of Aizawl District, Mizoram**", for the award of degree of Doctor of Philosophy of the Mizoram University, under my guidance. She has carried out the work at the Department of Environmental Science, Mizoram University.

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I **Madhurima**, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to do the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/Institute.

This is being submitted to the Mizoram University for the **Degree of Doctor of Philosophy in Environmental Science.**

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TABLE OF CONTENTS

	Page No.
Supervisor`s Certificate	i
Declaration Certificate	ii
Acknowledgements	iii - iv
Contents	v
List of Tables	vi - vii
List of Figures	viiii-ix

Chapters		Page No.
CHAPTER 1:	INTRODUCTION	1-21
CHAPTER 2:	REVIEW OF LITERATURE	22-48
CHAPTER 3:	METHODOLOGY	49-60
CHAPTER 4:	RESULTS	61-161
CHAPTER 5:	DISCUSSION	162-187
CHAPTER 6:	CONSERVATION STRATEGIES	188-196
CHAPTER 7:	SUMMARY AND CONCLUSIONS	197-205

APPENDICES

REFERENCES

BIO –DATA OF THE CANDIDATE

PARTICULARS OF THE CANDIDATE

LIST OF TABLES

Page No.

Table 3. 1: Sectoral Share to GSVA (2018- 2019) 52

Table 4. 1: Ambient air temperature during 2022 62

Table 4. 2: Ambient air temperature during 2023 62

Table 4. 3: Seasonal variation in relative humidity along disturbance gradient during 2022 63

Table 4. 4: Seasonal variation in relative humidity along disturbance gradient during 2023 63

Table 4. 5: Canopy cover, light interception and phyto sociological characteristics of selected forest stands along the disturbance gradient 64

Table 4. 6: Community characteristics of tree species in the undisturbed, moderately disturbed and highly disturbed forest stands 68

Table 4. 7: Community characteristics of tree species in the undisturbed stand 72

Table 4. 8: Community characteristics of tree species in the moderately disturbed forest stand 78

Table 4. 9: Community characteristics of tree species in the highly disturbed forest stand 83

Table 4. 10: Species dominance along the disturbance gradient, based on the Importance Value Index (IVI) 88

Table 4. 11: Family dominance along a disturbance gradient 95

Table 4. 12: Community characteristics of shrub species in the undisturbed, moderately disturbed and highly disturbed forest stands 99

Table 4. 13: Community characteristics of shrub species in the undisturbed forest stand 100

Table 4. 14: Community characteristics of shrub species in the moderately disturbed forest stand 102

Table 4. 15: Community characteristics of shrub species in the highly disturbed forest stand 106

Table 4. 16: Species dominance along the disturbance gradient, based on the Importance Value Index (IVI) 110
Table 4. 17: Family dominance along the disturbance gradient 115
Table 4. 18: Community characteristics of herbs in the undisturbed, moderately disturbed and highly disturbed forest stands 117
Table 4. 19: Community characteristics of herbaceous species in the undisturbed forest stand 118
Table 4. 20: Community characteristics of herbaceous species in the moderately disturbed forest stand 120
Table 4. 21: Community characteristics of herbaceous species in the highly disturbed forest stand 124
Table 4. 22: Seasonal variation in soil temperature along disturbance gradient during 2022 134
Table 4. 23: Seasonal variation in soil temperature along disturbance gradient during 2023 135
Table 4. 24: Seasonal variation in soil texture along the disturbance gradient during 2022 136
Table 4. 25: Seasonal variation in soil texture along the disturbance gradient during 2023 136
Table 4. 26: Summarized table of one way ANOVA for physico-chemical properties of soil 136
Table 4. 27: Summarized table of one-way ANOVA for physico-chemical properties of soil 154
Table 4. 28: Demographic data of respondents from the survey 156
Table 4. 29: Descriptive statistics of the questionnaire 159

LIST OF FIGURES

Page No.

Figure 1. 1: Multi-fold values of Bio diversity 3

Figure 3. 1: Map of the study area 54

Figure 4. 1: Overall diversity of selected forest stands along the disturbance gradient 65

Figure 4. 2: No. of species of trees, shrubs and herbs along the disturbance gradient 66

Figure 4. 3: No. of individuals of trees, shrubs and herbs along the disturbance gradient. 66

Figure 4. 4: Species dominance curve along the disturbance gradient, based on the Importance Value Index (IVI) 94

Figure 4. 5: Family dominance-distribution curve along the disturbance gradient 96

Figure 4. 6: Basal area and tree density in the undisturbed stand 97

Figure 4. 7: Basal Area and tree density in the moderately disturbed stand. 97

Figure 4. 8: Basal Area and tree density in the highly disturbed stand 98

Figure 4. 9: Species dominance-distribution curve along the disturbance gradient. 114

Figure 4. 10: Family dominance-distribution curve along the disturbance gradient. 116

Figure 4. 11: Shannon Weiner Diversity Index for trees, shrubs and herbs along the disturbance gradient 130

Figure 4. 12: Simpson's Dominance Index for trees, shrubs and herbs along the disturbance gradient 131

Figure 4. 13: Margalef's Index for trees, shrubs, and herbs along the disturbance gradient 132

Figure 4. 14: Evenness Index for trees, shrubs and herbs along the disturbance gradient. 133

Figure 4. 15: Seasonal variation in Soil pH along disturbance gradient during 2022. 137

Figure 4. 16: Seasonal variation in Soil pH along disturbance gradient during 2023. 137

Figure 4. 17: Seasonal variation in Soil Moisture Content along Disturbance gradient during 2022. 139
Figure 4. 18: Seasonal variation in Soil Moisture Content along Disturbance gradient during 2023. 139
Figure 4. 19: Seasonal variation in Bulk Density along disturbance gradient during 2022. 141
Figure 4. 20: Seasonal variation in Bulk Density along disturbance gradient during 2023. 141
Figure 4. 21: Seasonal variation in Water Holding Capacity along Disturbance gradient during 2022 143
Figure 4. 22: Seasonal variation in Water Holding Capacity along Disturbance gradient during 2023. 143
Figure 4. 23: Seasonal variation in soil organic carbon content along Disturbance gradient during 2022 144
Figure 4. 24: Seasonal variation in Soil Organic Carbon content along disturbance during 2023 145
Figure 4. 25: Seasonal variation in soil organic matter along disturbance gradient for during 2022 146
Figure 4. 26: Seasonal variation in soil organic matter content along Disturbance gradient during 2023 146
Figure 4. 27: Seasonal variation in potassium content along disturbance gradient during 2022 148
Figure 4. 28: Seasonal variation in exchangeable potassium content along disturbance gradient during 2023 148
Figure 4. 29: Seasonal variation in total nitrogen content along disturbance gradient during 2022 150
Figure 4. 30: Seasonal variation in Total Nitrogen content along disturbance gradient during 2023 150
Figure 4. 31: Seasonal variation in available phosphorus content along disturbance gradient during 2022 152
Figure 4. 32: Seasonal variation in available phosphorous content along disturbance gradient during 2023 152

Chapter 1

INTRODUCTION

1.1 Overview

Humans from the dawn of civilization have derived innumerable benefits from biodiversity resources. These resources are essential for human survival and also contribute towards economic development, it's very crucial for ecosystem functioning and stability (Singh, 2002). An estimation of economic value and benefits derived from 17 ecological services and 16 biomes was extrapolated to approximately US $ 16–54 trillion per year (Costanza et al., 1997).

The term biodiversity is formed by amalgamation of two-word bio meaning "life" and diversity meaning "variety". Biological diversity is defined by the Convention on Biological Diversity (CBD) as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (CBD, 1992; vanVliet and deGroot, 2003). The convention brought light on the ongoing crisis of biological diversity loss across the globe and 193 countries came together to promote the conservation of biodiversity.

1.1 Types of Biodiversity

The term biodiversity encompasses all the life forms on earth. Biodiversity which has been categorised into three levels and each level is equally crucial for ensuring the adaptability, stability and ability of ecosystems to endure environmental changes. The conservation of biodiversity is necessary at each level plays a key role in providing ecosystem services. The three levels of biodiversity are at the genetic, species, and ecosystem levels.

Genetic diversity refers to the genetic variations present within a particular species. These variations in genetic structure such as DNA within species are very significant as they enhance the survival of species in changing environments (Frankham et al., 2002). Species diversity is the number of different species present in a specific area or ecosystem. Ecosystems exhibiting a high level of species diversity have higher resilience towards ecological disturbances (Tilman, 1988). Ecosystem diversity encompasses variations present in ecosystems, within the geographic area such as forests, deserts, marshes, wetlands, grasslands, and oceans. Diverse ecosystems facilitate the existence of a broad array of species and genetic variation. The ecosystem diversity is significant as the provision of several ecosystem services, including water purification, carbon sequestration, and soil fertility, is essential for human well-being (Millennium Ecosystem Assessment, 2005).

Biological resources are globally distributed, although their distribution is uneven (Tittensor et al., 2010). According to Gaston (2000), species diversity fluctuates with latitude, and terrestrial biodiversity is generally highest near the equator. The interplay of four major factors such as speciation, dispersal, disturbance, and environmental heterogeneity constitutes the processes that determine the patterns and levels of variety (Levin, 1992). A rich and diverse ecosystem allows greater access to biological resources. Diversity also enhances the net primary productivity of an ecosystem, while the nutrient loss is reduced (Singh, 2002). The diversity at ecosystem's level enhances the resilience of ecosystem to environmental disturbances and is likely to harbour species capable of thriving amid natural or anthropogenic perturbations. These reselinat species compensat for the loss of lost species and thereby recovery of ecosystem (Arhonditsis et al., 2006; Doll et al., 2022; Iftekhar et al., 2022; Yates et al., 2018).

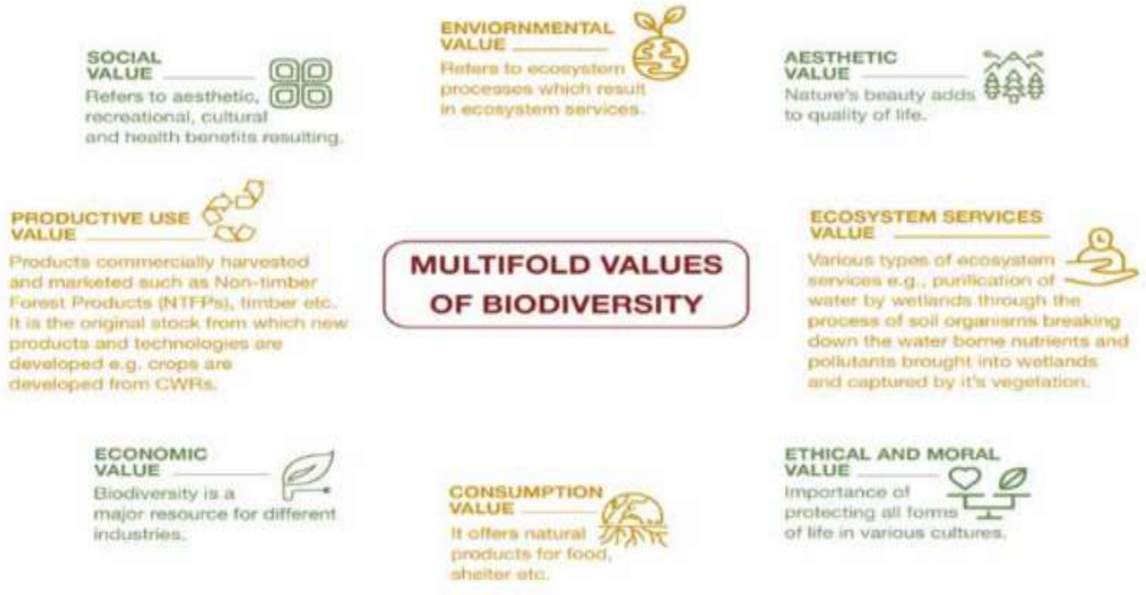


Figure 1. 1: Multi-fold values of Biodiversity.

Source: India’s National Biodiversity Action Plan (2019).

1.2 Biodiversity Crisis

The existence of the ongoing biodiversity crisis is being widely recognised as a genuine concern. There is a high risk of extinction of species that have not been discovered yet. Overpopulation, global warming, urbanisation, energy use, pollution, agricultural growth, desertification, and overexploitation have increased pressure on biological resources. This has led to the current and ongoing sixth mass extinction. Approximately 300-350 vertebrates and almost 400 invertebrates have gone extinct in the last 400 years (GBO, 2010). As the twenty-first century is facing the sixth mass extinction, it poses a threat to the earth's biodiversity and the ecological function, stability and services that support life. The anthropogenic activities, causing extinction can alter the earth's ecosystems and threaten human well-being. The rate of biodiversity loss is worrying and requires effective conservation efforts. Preserving biodiversity for future generations requires the implementation of conservation activities, the adoption of sustainable behaviours, and the fostering of global cooperation. Through coordinated efforts, the consequences of this crisis can be alleviated and preserve the remaining species on our planet.

The rapid and exponential increase in human population has placed immense pressure and strain on biological diversity, as it is being exploited to meet the demands of human needs. The population growth in has resulted in high unemployment rates among young people and intensified competition over scanty and limited natural resources. This has further led to a significant influx of people moving from rural regions to larger urban centres. By 2050, 50% of the population will reside in urban regions due to the availability of economic opportunities and improved infrastructure for healthcare, education, and recreation. The urban population in 1900 was roughly 200 million, and by 2014 it had increased to nearly 4 billion, by 2050 it may increase by 2.5 more billion people (WUP, 2014). The urban expansion of larger cities to accommodate the growing population and provide their requirements entails a trade-off with biodiversity. The change of land use and the expansion of urban areas with substantial concrete infrastructure facilitate the emergence of urban heat islands, intensifying the issue of global warming.

The report published by UNEP (2001) identified habitat destruction, over-exploitation, pollution and invasive species introduction as major causes of loss of biodiversity in India. Concern regarding the loss of biodiversity gained huge attention at the Earth Summit held in Rio in 1992, thus creating a need for an understanding of ecological function to conserve biodiversity. Biodiversity loss has extensive ramifications for ecosystems, human communities, and the planet earth in its entirety. Ecosystem functioning depends on the interaction among the biotic and abiotic components and the interplay between species to operate and sustain effectively. The extinction of a single species may trigger a series of after-effects within an ecosystem which may have devastating consequences, resulting in the disruption of vital functions provided by the ecosystem, such as pollination, water purification, and climate regulation. In addition, the decline in species leads to a reduction in genetic variety, which is crucial for adjusting to changes in the environment. This, in turn, increases the susceptibility of agriculture and ecosystems to diseases and pests (Diaz et al., 2019).

Biodiversity loss can be hazardous to food security, human health, and livelihoods. A significant portion of the global impoverished population relies directly on biodiversity for their sustenance, depending on flora and fauna for nourishment, medicinal uses, and livelihood resources. At a global scale, the sixth mass extinction has been intensified by climate change, by interfering with the processes of storing and capturing carbon (Shivanna, 2020). Forests, wetlands, and oceans have vital functions in the regulation of the Earth's climate through the absorption of carbon dioxide. As these ecosystems deteriorate, their capacity to retain carbon decreases, which adds to the greenhouse effect and intensifies global warming (Cardinale et al., 2012) leading to rapid erosion of biodiversity.

1.3 Threats to Biodiversity

Land use change, deforestation, fragmentation of forested areas, shifting cultivation, introduction of invasive species, agricultural activities, industrialisation, and human habitation are the major concerns towards biodiversity loss, having detrimental impacts on the environment and climate. The primary factor contributing to deforestation in the past decade is the increase in agriculture (FAO and UNEP, 2020). The forests are the storehouse of genetic diversity, they are also crucial for bio-geochemical cycling of various nutrients at a global scale, they also play a key role in mitigating climate change and pollution reduction. Therefore, deforestation and forest fragmentation cause a decline in biodiversity and have detrimental effects on the water cycle and other bio-geo chemical cycles. The land use change further contributes to the increased threat of global warming.

Climate change has altered the distribution of rainfall and temperature, resulting in the migration of invasive species to areas that have optimum climatic conditions for their survival, thus increasing the proliferation of invasive species in these regions, and displacing native species. The species that are foreign to the ecosystem but can reproduce and survive in the new ecosystem become naturalised.

These naturalised species then proliferate and compete with the native species for resources. The native species are threatened and are not able to survive as the exotic species have no natural predators in the new ecosystem and higher reproductive rates as well as better adaptivlity. In many case studies it have been reported the invasive species have eradicated the native species to extinction. The introduction of such species into an ecosystem can be traced back to the colonization period and the introduction can be both intentional and unintentional. This invasive species has become a greater threat than deforestation as it has become responsible for causing around 40% of all animal extinctions (Harrop, 2011). The phenomenon of globalisation facilitated the transformation of the world into a global village, but it also resulted in the introduction of new or exotic species in pristine ecosystem. The new species though brought for asthetic or benfeical purposed became invasive. The current change in temperature, due to global warming, has also increased the proliferation of invasive species in certain regions, displacing the native species.

1.4 Plant Diversity

Plant diversity is essential for preserving ecological equilibrium, as each and every species fulfils its distinct functions in ecosystems. Plant communities enhance resilience to environmental changes, including climate change and habitat degradation (Tilman, 1988; Tilman et al., 2014). The identification of plant species, understanding their role in the ecosystem and community study of plant diversity, their function and structure aids in the development of plans for their management and conservation. Conservation efforts are crucial in areas with endemism (Myers et al., 2000). Furthermore, its rich genetic diversity among plants provides agricultural sustainability by serving as a reservoir of genetic resources which can be utilised to enhance crop varieties resistance to pests, diseases, and climatic resilience (Altieri, 1999).

Plant variety along with biotechnological advancement research have facilitated the discoveries of new medications and cures, as the plants medicinal properties are being utilized. The indigenous people are store house knowlwdge pertaing to plant. These ethnobotanical expertise of indigenous people is an essential asset for pharmacological research (Cox, 2000). Plant variety possesses religious, cultural and economic value in many communities as people depend on a various plant species for sustenance, housing, and traditional medicinal purposes (Balick and Cox, 1997). The northeastern part India is renowned for its abundant plant diversity, which encompasses a wide range of endemic, uncommon, and commercially significant species, making it a biodiversity hotspot. This region, which exhibits diverse landforms, weather patterns, and cultural variations, has a substantial portion of India's overall plant species, rendering it a crucial place for conservation endeavours.

A significant number of plant species are endemic to Northeast India due to its distinctive geological characteristics. The northeastern region is well known for its orchid diversity, having over 800 species, many of which are endemic to this region (Chowdhery, 2001; Kumar et al., 2022). The ethnically diverse populations in Northeast India mainly depend on indigenous plant species for sustenance, medicinal purposes, and many cultural traditions. The traditional knowledge linked to these plants is extremely useful for the sake of conservation and sustainable utilization (Hajra, 1996). Although Northeast India boasts a diverse range of plant species, it is confronted with substantial conservation obstacles caused by deforestation, shifting farming, and habitat degradation (Maithani, 2005; Ickowitz, 2006; Chatterjee, 2021). These activities pose a threat to numerous species, including some that are exclusive to specific regions and cannot be found elsewhere in the globe. Preserving this unique biodiversity in the region is of utmost importance, making conservation efforts crucial (Rao, 1994). A multitude of plants in Northeast India possess significant commercial and medicinal worth. Species such as *Taxus wallichiana*, commonly known as Himalayan yew, which is utilised in cancer treatment, and several *Rhododendron* species, renowned for their decorative worth, hold significant economic and therapeutic importance (Kala, 2005).

1.5 Soil Characteristics

Soil is vital for the survival and growth of plants and the maintenance of biodiversity. Factors including changes in land use, deforestation and fragmentation of forested regions, shifting cultivation, the introduction of invasive species, agricultural practices, industrialisation, and human settlement exacerbate soil degradation, thereby reducing soil fertility and contributing to desertification. Factors leading to soil deterioration include increased fertiliser use, excessive irrigation, monoculture, overgrazing, and top-soil erosion caused by wind or water.

Ensuring food security for the growing population is imperative. To meet the needs of a fast-growing population, agricultural productivity needs to be increased up to 50 per cent by the year 2050 compared to the year 2013. Food security is the state in which every individual has consistent and reliable access to enough amount of safe and nutritious food that fulfils their dietary requirements and personal food preferences, enabling them to lead an active and healthy life. The rise of agriculture production has resulted in increased demand for water supply. The construction of dams, water reservoirs, and canals created obstructions in the natural flow of aquatic ecosystems which led to the loss of aquatic biodiversity. The Green Revolution undoubtedly contributed towards the sustenance of the rapidly growing population of India and ensured food availability. The Green Revolution was the result of scientific progress, which has led to environmental damage (Subramanyachary, 2012).

The physicochemical properties of soil help to understand soil health, fertility, productivity and capability to provide ecosystem services. The physical attributes of soil are temperature, texture, structure, bulk density, water-holding capacity, porosity, and moisture content. The chemical attributes like pH, soil organic matter and nutrient content, and cation exchange capacity. It is necessary to understand and monitor these aspects for the sustainable conservation of agricultural land, forested areas and other ecosystems. The availability of nitrogen (N), phosphorus (P), and potassium (K) are crucial to determining soil fertility, as these nutrients are crucial for plant growth (Brady and Weil, 2008). The physico-chemical characteristics of soil impact its ability to retain nutrients, the accessibility of nutrients to plants, and the overall fertility of the soil. Soil pH level can affect the nutrient-holding ability of soil, the soil with higher organic carbon and nutrients is generally more productive and has higher crop yields (Hillel, 1998; Fageria, 2009). Soil pH is the measurement of the acidity or alkalinity of the soil, which is critical in determining the activity of microorganisms in soil (Thomas, 1996). The increase in soil acidity diminishes its affinity to hold nutrients like nitrogen, phosphorus and potassium while making it more susceptible towards holding heavy and toxic metals like aluminium as these become more soluble, posing a risk to plant roots (McCauley et al., 2009). Soil structure is the arrangement of soil particles into aggregates, whereas texture is the relative proportion of sand, silt, and clay particles (Singer and Munns, 2006). The physical properties of soil such as texture, structure and porosity directly affect the ability of soil to retain moisture and facilitate drainage, root penetration, and aeration.

The organic matter in soil is composed of decomposed dead and decaying plants and animals. The organic matter plays a crucial role in the nutrient cycling of an ecosystem and it is also responsible for the formation of soil structure (Bot and Benites, 2005). The organic matter enhances the arrangement of soil particles, the ability to retain water, and the accessibility of nutrients. The organic matter in soil is crucial for maintaining soil microbes and fauna, as these are essential for the cycling of nutrients and carbon storage (Lal, 2006). Soil fertility declines when the exploitation of soil for agriculture is done repetitively without ensuring the restoration of organic carbon and other nutrients (Bot and Benites, 2005). The conversion of forested areas into agricultural land also contributes towards soil degradation. The practice of shifting cultivation in the tropical regions of the world has also been identified as ecologically harmful activity as the reduced fallow period lowers the fertility of the soil.

1.6 Soil Conservation

The degradation of land has become a prominent issue of the twenty-first century worldwide. India achieved self-sufficiency in the agricultural sector with the green revolution, however, this achievement came with depletion of soil fertility and productivity, soil erosion, salinisation of agriculture fields and enhanced desertification. Soil is essential for the existence of life on our planet. Soil plays a crucial part in the bio-geochemical process by providing regulatory services. Soil serves as a carbon sink, meaning it can play a crucial role in controlling and reducing the effects of climate change. Soil degradation is the process by which the physical, chemical, and biological qualities of soil deteriorate. Gaining knowledge about the physicochemical properties of soil enables us to comprehend the soil's fertility, track changes occurring over time, and evaluate plant development and productivity. The land use patterns in the northeastern area of India are undergoing significant changes (He, 2018; Bhattacharjee et al., 2021). Consequently, the northeastern region is currently facing a significant issue of soil degradation and erosion (Barman and Das, 2022). Mizoram is extremely susceptible to soil erosion and loss. The state is located in the Indian Himalayas region and has steep slopes that render the land impassable and rough for permanent agriculture, making it more appropriate for shifting cultivation. The state currently has around 84.53% (ISFR, 2021) of its total geographical area covered by forests. However, there has been a loss in forest cover over the past decade, primarily due to the practice of shifting cultivation (ISFR, 2019). Mizoram, as a component of the Indo-Burman biodiversity hotspot, possesses a significant amount of endemic diversity inside its forest.

1.7 Plant soil interaction

The interaction between plants and soil is intricate as it encompasses physical, chemical and biological processes which are crucial for the functioning of the ecosystem, complex energy cycle, nutrients, and organic material. As soil provides the substrate for the growth of plant species it is crucial for the growth and development of plants. Soil quality plays a key role in plant nutrition as it is the source of essential nutrients like nitrogen, phosphorus, and potassium. The plants facilitate primary productivity in an ecosystem through photosynthesis. The process of photosynthesis is significant for biospheres as it encompasses the conversion of solar energy into chemical energy which is stored as organic matter in plants.

Subsequently, the organic matter reaches the soil through microbial activity in the soil layer (Smith and Read, 2008; Marschner, 2012; Bardgett and van der Putten, 2014). The decomposition of leaf litter and other organic matter provides the soil with enhanced nutritional content (Brady and Weil, 2008). The root growth of plants supports nutrient uptake in plants and also enhances soil aeration, and reduces soil erosion this interaction is a fundamental component. (Philippot et al., 2013)

Understanding soil has become essential, as the carbon sequestration in terrestrial soil can mitigate the impacts of climate change (Lal, 2004). Plants and soils are major components of the carbon cycle. The terrestrial forest ecosystem soil is the storehouse of carbon and also the receiver of carbon, and plants play a vital role in the accumulation of carbon into the soil.

1.8 Biodiversity Hotspots

Biodiversity hotspots are essential for maintaining the functional stability and health of the planet as these are bio-geographic regions rich in endemic species. These regions are home to many Indigenous communities who rely directly on local biodiversity for their livelihoods, thereby putting these hotspots under threat from human activities. These issues make conservation of these areas a concern for social justice as well as environmental preservation (Stevens et al., 2014). The concept of biodiversity hotspots was introduced by Myers in 1988, to prioritize the conservation of biodiversity rich ecosystems (Myers, 1988). There are two major criteria for a region to be classified as a biodiversity hotspot. These criteria are, that it must contain at least 1,500 species of vascular plants as endemics and it should have lost at least 70% of its original habitat (Mittermeier et al., 2004). These criteria highlight the urgency of conserving these areas, as they represent regions with both high levels of unique biodiversity and major habitat loss. There are 35 hotspots across the globe distributed in 17 countries (Williams et al., 2011). The hotspots cover merely 2.3% of the Earth's land surface, and yet these are home to half of the world's plant species and 43% of bird, mammal, reptile, and amphibian species (Myers et al., 2000; Mittermeier et al., 2004). The hotspots provide various ecosystem services, such as regulatory carbon sequestration, water purification, and soil fertility or provisioning services of timber and firewood. The biodiversity hotspots in tropical rainforests are critical for regulating the global climate by storing vast amounts of carbon (Laurance et al., 2014).

Biodiversity hotspots have immense ecological significance but are under threat due to increased human activities. The main factors causing habitat loss in these regions are deforestation, agriculture, urbanisation, and climate change. The conversion of land for agricultural purposes is very destructive, as it frequently results in the irreversible loss of habitats that are difficult to restore (Brooks et al., 2002; Schickhoff et al., 2024). Climate change is altering the optimum conditions and environment that are essential for the survival of species, which is perhaps causing changes in the fundamental niche of species. This supports the species that can adapt easily thereby eliminating the species to extinction when unable to adapt rapidly enough (Parmesan, 2006).

Preserving biodiversity hotspots requires holistic strategies that incorporate the preservation and safeguarding of existing habitats, the rehabilitation and reforestation of degraded areas, and community engagement. Nevertheless, considering the vast ecosystem of hotspots and limited availability of resources allocated for conservation, the involvement of local communities in conservation initiatives by advocating for sustainable livelihoods that alleviate the strain on natural resources (Kremen et al., 2008) will boost the conservation efforts. Furthermore, equitable distribution of the resources derived needs to be considered as the indigenous people are the rightful owners of these resources. Global collaboration is needed to tackle the worldwide dangers posed by biodiversity hotspots, including climate change, poaching, tree felling, logging and illicit wildlife trafficking (CBD, 2010).

Biodiversity hotspots are invaluable repositories of the natural world. Preserving these areas is important not just for conserving biodiversity but also for the ecosystem services that support human existence. There is an urgent need for and intensifying the conservational efforts to protect these ecosystems from human threat and for future generations.

1.10 Ecological Disturbances

Naeem, et al., (1994), Tilman (1988) and Tilman et al., (2014) have established the relationship between biological diversity and ecosystem functioning is very significant. Ecological disturbances are events that disrupt the natural function and composition of an ecosystem. Disturbance can be categorised and quantified using characteristics such as type, frequency, and intensity, whereas perturbation and stress are measured in terms of deviations in steady-state variables (Rykiel, 1985). These disturbances can be classified into two categories natural and anthropogenic disturbances. Forest fires, hurricanes, tornadoes, and volcanic eruptions are natural disturbances whereas deforestation, pollution, industrialisation, agriculture expansion and urbanization are anthropogenic disturbances. The natural disturbances become anthropogenic disturbances such as forest fires. Normally forest fire occurs due to natural circumstances in the forest, but when they are caused by to burning of forests during shifting cultivation or other human activities, it is classified as anthropogenic disturbances.

Natural disturbance is an inherent characteristic of all the existing ecosystems. Discrete events that are not caused by human intervention but alter the structure and resource availability of an ecosystem can be referred to as natural disturbances (Lindenmayer and Franklin, 2002; Zhu and Liu, 2004). Natural disturbances are integral to ecosystem dynamics because they play a critical role in shaping plant communities by clearing dead biomass, recycling nutrients, and promoting seed germination (Pausas and Keeley, 2009). Disturbances such as hurricanes and storms can alter forest structure by uprooting trees, thus creating gaps that allow light to reach the forest floor, promoting biodiversity. Forest ecosystems are resilient and well adapted to natural disturbance (Turner, 2010) they respond by evolving regeneration strategies that are synchronised with disturbance (Keeley et al., 2011). Ecological disturbances, both natural and anthropogenic, have a profound impact on the ecosystem. While natural disturbances are crucial for maintaining ecological dynamics and biodiversity, human activities often exacerbate these disturbances, leading to long-term negative consequences. Understanding ecological disturbances is necessary to mitigate its impacts on biodiversity and ecosystem services. Disturbance whether natural or anthropogenic are major ecological force that affects both forest structure and functioning (Gogoi and Sahoo, 2018).

Anthropogenic disturbances, however, often lead to more severe and lasting impacts. Deforestation, driven by logging, agriculture, and urban development, results in habitat loss and fragmentation, disrupting species populations and ecological processes (Foley et al., 2005). The pollution caused by industrial activities, agriculture, and urban runoff introduces harmful substances into ecosystems, affecting water quality, soil health, and organism health. Pollution, particularly from plastic waste, has devastating impacts on marine ecosystems, harming wildlife through ingestion and entanglement, and introducing toxic chemicals into the food web (Awuchi and Awuchi, 2019).

These Anthropogenic activities are also responsible for causing global warming, climate change, change in land use patterns, fragmentation and introduction of invasive species in native ecosystems that have altered the course of natural disturbance leading to sudden changes in the ecosystem (Frelich, 2002; Hughes et al., 2013). These anthropogenic impacts cause loss of biodiversity especially in underdeveloped and developing regions (Mishra et al., 2008).

Disturbance is also a major factor in determining the type of plant communities in the natural ecosystem and the status of soil nutrients (Armesto and Pickett, 1985). Plants and soil are interlinked as plants derive nutrients from soil and the soil physico-chemicals affect the growth and distribution of the plant community.

The effects of ecological disturbances depend upon disturbance type, intensity, and ecosystem resilience and the impact of disturbances can be both negative and positive. Studies show moderate levels of natural disturbances can enhance biodiversity by creating a heterogeneity of habitats within the ecosystem and at different successional stages. The periodic flooding rejuvenates floodplains and diversifies the aquatic and terrestrial ecosystems (Junk et al., 1989). The levels of disturbances and their types have differential impacts on forest communities (Halpern and Spies, 1995). However, excessive or prolonged disturbances often lead to the degradation and deterioration of the ecosystem.

Anthropogenic disturbances cause habitat degradation, loss of biodiversity, and disruption of ecosystem services. Deforestation in tropical rainforests has led to significant carbon emissions, contributing to climate change with changes in global weather patterns (Malhi et al., 2008). Therefore, it is necessary to understand the effects of disturbances as by understanding and addressing the causes and effects of ecological disturbances, we can enhance ecosystem resilience and sustainability, ensuring the continued provision of vital ecosystem services.

1.11 Conservation of biodiversity

Biodiversity encompasses all the existing life forms on Earth. It is essential for the well-being of ecosystems and the survival of the human race as it offers essential services such as sustenance, potable water, medication, and climate control. Nevertheless, human activities such as deforestation, pollution, overexploitation, and climate change pose an unparalleled threat to biodiversity. The preservation of biodiversity is essential for sustaining the stability and adaptability of ecosystems, promoting sustainable development, and safeguarding the natural legacy for future generations. Effective management and mitigation of ecological disturbances require a multi-faceted approach. Conservation strategies must balance allowing natural disturbances to maintain ecological processes while minimising anthropogenic impacts. The establishment of fire management practices in Mediterranean ecosystems has been successful in reducing wildfire risk while maintaining fire-adapted species (Keeley et al., 2011; Keeley, 2012).

Preserving biodiversity relies heavily on the crucial actions of habitat protection and restoration, which involve safeguarding existing habitats and revitalizing those that have been degraded. There is a need for more provisions for the establishment of protected areas, such as national parks and animal reserves, which can effectively protect ecosystems under immense human treat, and critical habitats rich in endemic biodiversity. The delineation of protected areas, which function as sanctuaries for a wide range of species and ecosystems. These protected areas such as national parks and wildlife sanctuaries, serve the purpose of protecting vital ecosystems from anthropogenic disturbances. The creation of marine protected zones may be effective in improving fish populations and revitalizing marine ecosystems (Sala and Giakoumi, 2018).

Furthermore, it is crucial to incorporate biodiversity conservation into agricultural and urban planning, in addition to protected areas. Sustainable agriculture practices, such as agroforestry and organic farming, enhance biodiversity by establishing habitats for diverse species and minimising the use of chemicals. Urban green spaces and infrastructure that promote and support rich diversity are helpful in reducing the negative effects of habitat fragmentation and provide support for wildlife in urban areas. The integration of sustainable approaches into the ongoing agriculture fisheries, forestry and development can mitigate the negative effects of human activities on biodiversity. This encompasses the adoption of eco-friendly and sustainable methods such as the reduction of the usage of pesticides and fertilisers while increasing the use of organic manure and composts, reduction in single-use plastics and the implementation of sustainable fisheries management to avoid excessive exploitation (Tilman et al., 2011).

The use of native species for reforestation and habitat restoration initiatives can effectively restore ecosystems and serve as a sanctuary for endangered species (Haddad et al., 2015). Restoration ecology plays a crucial role in mitigating the effects of disturbances. Restoration efforts, such as reforestation, wetland rehabilitation, and pollution cleanup, aim to return ecosystems to their natural states and enhance their resilience. Community involvement is essential in these efforts, as local knowledge and participation can improve the effectiveness and sustainability of restoration projects (Aronson et al., 2010). Additionally, policies and regulations are vital for controlling anthropogenic disturbances. Enforcing stricter pollution controls, promoting sustainable land-use practices, and integrating biodiversity considerations into development planning can significantly reduce human-induced ecological disruptions.

Implementation of action plans and strategies that address mitigating climate change is crucial for safeguarding biodiversity. To achieve this, it is necessary to reduce the amount of greenhouse gases released into the atmosphere by shifting dependency on fossil fuels to renewable sources of energy, enhancing the effectiveness of energy usage, and protecting and conserving carbon-rich ecosystems such as tropical forests, marshes and wetlands. Multinational treaties ensuring international cooperation such as the Kyoto Protocol and Paris Agreement can facilitate global coordination as climate change and biodiversity loss are not restricted by national boundaries (IPCC, 2014).

Managing Invasive Species incorporates prevention of the introduction of invasive species and effectively managing their dissemination in an ecosystem. It is crucial for safeguarding the preservation of native species. Improved biosecurity measures at border areas, ports and airports, public awareness campaigns, and eradication initiatives can be effective strategies to accomplish the removal of invasive species (Simberloff et al., 2013).

Conservation Education and Awareness initiatives involves increasing the public knowledge and understanding towards significance of biodiversity and the negative outcomes associated with loss of biodiversity. Environmental education programs that prioritize the importance of biodiversity and the necessity of sustainable practices have the potential to motivate individuals and communities to engage in proactive measures.

1.12 Community based conservation (CBC)

Community involvement in conservation is crucial for achieving sustainable development goals and biodiversity conservation. Moreover, active participation from the community is essential for successful conservation efforts. Local communities possess profound expertise of their surroundings, acquired over multiple generations. Traditional ecological knowledge is extremely important in knowing the local native species and habitats. Indigenous tribes possess extensive knowledge of plant species, including their functionalities and contributions to the ecology. According to Berkes (2012), this knowledge can guide conservation methods that are both culturally meaningful and ecologically sound. The utilisation of indigenous knowledge and practices has played a crucial role in effectively and responsibly managing natural resources. Nepal has showcased the positive impact of community-based forest management in the restoration of damaged forests and the subsequent increase in biodiversity (Agrawal and Ostrom, 2001; Chhatre and Agrawal, 2009). Bhutan as a nation also showcases the positive impact of forest conservation. Tackling climate change is crucial for the preservation of biodiversity.

A comprehensive strategy, which incorporates the implementation of sustainable practices along with, active participation of the community is important for conservation. This can include the establishment of protected areas and the implementation of projects like Joint Forest management. Joint forest management programmes helped increase the forest cover in India by providing livelihood to villagers and local communities through non-timber forest products (Vemuri, 2008; Majhi, 2016; Biswas and Rai, 2021). Furthermore, there is a need for implementing actions to decrease greenhouse gas emissions and adopting strategies to adapt can effectively alleviate the negative effects of climate change on ecosystems and species. Preserving biodiversity encompasses not only safeguarding species but also ensuring the sustainable viability of human beings. There is an ample scope of immediate conservation measures to be implemented due to the ongoing sixth mass extinction leading to a biodiversity crisis.

Community-based conservation efforts give the local communities the authority to oversee their natural resources. By actively engaging communities in the conservation process, these programs contribute to the long-term viability and fairness of conservation efforts. The active engagement of communities in conservation activities is crucial for the successful implementation of biodiversity and plant diversity conservation programs. Indigenous people and communities are often the initial observers of environmental changes, including the decrease of specific species or the entrance of invasive species. By actively monitoring and reporting these changes, individuals can contribute to the prompt and efficient implementation of conservation measures.

A successful strategy is participatory land-use planning, which involves engaging community people in decision-making processes related to land management. This strategy guarantees that the requirements and expertise of the local population are taken into account, resulting in more enduring and environmentally friendly results. Successful integration of local agricultural techniques with conservation goals can be observed in locations such as the Amazon, where it has effectively preserved both plant diversity and agricultural productivity (Pretty et al., 2009). Communities play an essential role in the conservation of biodiversity and plant diversity. Their expertise, active involvement, and responsible management are crucial for the achievement of conservation endeavours. Through the empowerment of people and the integration of their indigenous knowledge with scientific methodologies, we may develop conservation methods that are both more sustainable and more effective. Given the increasing challenges to biodiversity, the active participation of local people will be vital in protecting the planet's ecological inheritance for future generations.

Furthermore, restoration programs conducted by keeping the focus on community-based approach have demonstrated significant potential in preserving plant diversity. These projects frequently entail the reintroduction of endemic species, the reforestation of deteriorated and degraded land, and the safeguarding of sacred forests.

Sacred groves are small areas of forest that are protected by the local communities because of their cultural or religious importance. These groves are highly diverse and serve as an example of the effectiveness of conservational efforts that are driven by local communities. In India, sacred groves provide sanctuary for threatened, rare and endangered species and thereby function as crucial repositories of biodiversity (Ormsby and Bhagwat, 2010). Although community-based conservation has achieved notable accomplishments, it also encounters various obstacles. Disputes regarding the allocation of land, insufficient financial resources, and the demands of modernity might weaken attempts to preserve the environment. Furthermore, the incorporation of indigenous knowledge alongside scientific methodologies might be intricate, necessitating meticulous handling to prevent the exclusion of local perspectives (Gadgil et al., 1993).

Nevertheless, the growing acknowledgement of the significance of communities in conservation has resulted in increased endorsement for community-based programs by governments, non-governmental and international organizations. Moreover, technological advancements specifically Geographic Information Systems (GIS) and mobile applications, can improve community-based monitoring and conservation endeavors (Schweik et al., 2003).

1.13 Scope of Study

The Himalayan region especially Mizoram, has not received adequate attention in the national agenda for sustainable development. The region has suffered from certain factors, such as low investment per unit of area, isolated developmental efforts lacking an integrated approach, poorly developed extension programmers customised to local conditions, and limited long-term studies depicting changes in the economy and ecology in the region.

The landscape of Mizoram is dominated by forests that provide habitat for numerous wildlife species. Therefore, disturbances affecting forests are a matter of serious concern. This region is mainly associated with slash-and-burn agriculture and rapid developmental activities (Maithani, 2005; Chatterjee, 2021). To address the challenges that human intervention may cause to the natural ecosystem, a deeper understanding of disturbance ecology is required (Newman, 2019). In recent years the decline in forest cover has been reported in forest report by the Ministry of Environment Forest and Climate Change, which will inevitably result in biodiversity loss. In recent decades due to industrialization and economic development, there has been a loss of traditional Mizo culture and disempowerment of local communities. Shifting cultivation (Maithani, 2005; Chatterjee, 2021), over-exploitation and hunting practices have resulted in a major threat to biodiversity loss in Mizoram. There is scanty research and documentation undertaken in the study area and thus there is a lack of baseline data on biodiversity, which has led to salient erosion of biodiversity. Therefore, there is a need for a study on plant diversity and soil characteristics to understand the forest ecology of the tropical forest of Mizoram.

Therefore, the proposed study aims to assess the impact of anthropogenic disturbance on diversity along the disturbance gradient and the soil characteristics in the tropical forest of the Aizawl district of Mizoram. Studying plant diversity is essential for understanding the complex interactions within ecosystems, conserving biodiversity, and ensuring the sustainability of natural resources.

OBJECTIVES

The major objectives of the study envisage the following:

1. To study the plant community attributes of the selected forest stands.
2. To study soil characteristics of selected forest stands.
3. To assess the impact of anthropogenic disturbances on plant community attributes and soil characteristics of selected forest stands.
4. To formulate appropriate conservation strategies to mitigate effect of disturbance on plant community attributes and soil characteristics of selected forest stands.

Chapter 2

REVIEW OF LITERATURE

2.1 International

The forest is a storehouse of biodiversity and it is also responsible for the conservation of soil and water resources (FAO, 2002). It helps us to understand the ecological processes of nature and assists in conservational planning. Tropical forests have a major contribution in maintaining global biodiversity (Sala et al., 2000; Brooks et al., 2002), and they play a key role in the functioning of the planet and the maintenance of life (Myers, 1996). Less than one-fifth of the terrestrial area of Earth is covered by tropical forests (Dinerstein et al., 2017). However, these forests are adversely affected by increasing human activity as these forests provide a wide range of ecosystem services, and directly impact the well-being of about 1.5 billion people (Lewis et al., 2015). Illegal felling of trees in forested areas, livestock overgrazing, and forest fragmentation are unsustainable practices that degrade the forest ecosystem to a great extent. The literature reveals that sustainable forest management practices are more profitable than non-sustainable forest management practices (Pearce, 2001).

Of all the ecosystems on Earth, tropical forests are among the most diverse (Whitmore, 1998). It has long been known that species richness tends to rise towards the tropics with decreasing latitude (Wallace, 1878). Tropical forests are predominantly present in developing countries. Tropical forests are amongst the most highly disturbed forests in the world. The tropical forest is under the ongoing sixth mass extinction and the destruction of forests is the key factor (Alroy, 2016). Major drivers of biodiversity change in the world in the 21st century in decreasing order of their importance are land use change, climate change, nitrogen deposition, and an increase in atmospheric CO_2 concentration due to biotic exchange (Sala et al., 2000).

Plant diversity is a critical component of global biodiversity and plays a significant role in ecosystem functioning, resilience, and productivity. The study of plant diversity encompasses various aspects, including species richness, genetic diversity, and the functional traits of plant communities. Internal studies within the field have provided significant insights into the mechanisms driving plant diversity and its implications for ecosystem processes. Numerous studies have demonstrated that higher plant diversity enhances ecosystem productivity, stability, and resilience to environmental changes. Tilman et al. (2001) argued that ecosystems with high species richness exhibited greater primary productivity and were more resistant to invasive species. This relationship is often attributed to complementary resource use among different species, which allows more efficient utilization of available resources (Cardinale et al., 2012).

Plant diversity studies have attracted researchers for decades (Whittaker, 1956; Whittaker and Woodwell, 1968; Houssard et al., 1980; Whitmore and Sidiyasa, 1986; Stark et al., 1985; Terborgh, 1985; Milne and Forman, 1986; Quinn and Robinson, 1987; Duivenvoorden and Lips, 1995; Stohlgren et al., 1997; Aravena et al., 2002; Wang et.al., 2007; Molino and Sabatier, 2001; Huang et al., 2003; Ozcelik, 2009; Soliveres and Maestre, 2014; Asare and Anders, 2016; Corlett, 2016; Dawoe, 2016). Poore (1964) attempted to explore the definition of the plant community. The "plant community" has being chosen by ecologists to define ecological units of various degrees, however the term "community" is still remaind ambiguous even though various researchers have attempted to defined it. Tansley (1949), defined plant community as "any collection of plants growing together which has as a whole a certain unity" whereas Cain and Castro (1959) described it as "an organised complex having a typical composition and structure that results from interaction through time". The plant community assessment helps us to understand its diagnosis and classification, providing insights into its structure and function (Watt, 1947). Whittaker (1965) discussed in his paper on dominance and diversity the structure of natural forests it is dominated by a few species that overshadow all the other species, some species are present and intermediate level and few are rare. The intermediate and rare species together contribute towards the diversity of forests.

He also discussed the placement of species on the logarithm scale. The significance of the diversity-dominance curve lies in its capability to represent all species of importance value index.

Furthermore, plant diversity has been shown to influence nutrient cycling and soil fertility. Diverse plant communities often support a wider range of soil microbial communities, which play a crucial role in nutrient turnover (Fornara and Tilman, 2008). This, in turn, enhances nutrient availability for plants, creating a positive feedback loop that supports sustained productivity and ecosystem health. Genetic diversity within plant species is another critical aspect of plant diversity that has significant implications for the adaptive potential of species to environmental changes. Jump et al. (2009) highlighted that genetic diversity within plant populations is crucial for adaptation to changing environmental conditions, such as climate change. In addition to adaptation, genetic diversity is also essential for the long-term survival of species. Studies have shown that populations with low genetic diversity are more susceptible to diseases and environmental stresses, leading to an increased risk of extinction (Hughes et al., 2008). International research efforts have emphasized the importance of conserving genetic diversity within plant populations to maintain their resilience in the face of global environmental changes. Functional traits, such as leaf morphology, root structure, and phenology, determine how plant species interact with their environment and contribute to ecosystem processes (Diaz et al., 2007).

Ecosystems with high functional diversity are more likely to maintain ecosystem processes, such as carbon sequestration, nutrient cycling, and water regulation, even under environmental stress (Mason et al., 2013). Functionally diverse communities are more likely to contain species that can compensate for the loss or decline of other species, thereby maintaining overall ecosystem function. Changes in temperature, precipitation patterns, and the frequency of extreme weather events are expected to alter plant community composition and reduce plant diversity in many regions (Thuiller et al., 2005). Parmesan and Yohe (2003) demonstrated that climate change is already causing shift in the distribution ranges of many plant species, leading to change in community composition. Internal research efforts are focused on modelling these shift to identify potential climate refugia where plant diversity might be preserved. McVean and Ratcliffe (1962) studied plant communities and forest vegetation of the Scottish High-lands, Europe. Bliss (1963) carried out a detailed research on plant community structure in the New Hampshire, Europe.

Aravena et al. (2002) worked in northern Chiloé Island, Chile to understand the changes in tree species richness, stand structure and soil properties. The study observed changes in tree species richness across different successional stages, indicating that early-successional stand showed profuse tree recruitment, which is crucial for biodiversity recovery. Stand structure varied significantly, with early and mid-successional stands retaining some structural components from old-growth forests, such as snags and old living trees, which support biodiversity. Soil properties were also assessed, revealing that the regeneration of forests after human activities does not seem to be greatly impaired at current rates of disturbance, although the resilience of these forest patches may be tested in the future. The study highlighted that as more forested land is disrupted by logging and fire, the representation of old-growth and late-successional stands in the landscape is decreasing, which could lead to cascading effects on biological diversity. Overall, the findings suggest that while tree recruitment is occurring, the ongoing fragmentation and isolation of forest patches may limit future biodiversity and ecosystem processes. A tree diversity study by Asigbaase et al. (2019) at in organic and conventional cocoa agroforests in Ghana revealed a distinction in family shift from organic farms to conventional farms.The most speciose families found on the organic farms were the Sterculiaceae, Moraceae, Fabaceae, and Apocynaceae and that of the conventional farms were Moraceae, Fabaceae and Apocynaceae. Similar studies have also been carried out by Laurance et al. (2018), Koh (2007), Thorington (1982), Ekanayake (2013), Shiferaw (2019).

Gentry (1988) studied changes in plant community diversity and floristic composition on environmental and geographical gradients. Kempetal (1988) studied vegetation pattern at of Gallatin County, Montana, USA. Tilman (1988) published book to report his studied on the plant strategies and the dynamics and structure of plant communities. Similar studies have been conducted by Rickard and Vaughan (1988), Gentry (1986), Niering (1987), Facelli and Pickett (1991),Vinton et al. (1993), Gunderson (1994), Petchey and Gaston (2002), O'connor (2005), Lamb and Cahill (2008), Zhang and Dong (2010), Gebrehiwot and Hundera (2014).

Gimmi et al. (2008) had reported that wood pasture and forest litter collecting were significant practices affecting nearly half of the forests in the upper Swiss Rhone valley Switzerland until the 1930s. These practices contributed to specific environmental conditions that favoured pine as a pioneer species. The implementation of forest management plans around 1930 led to a substantial reduction in the areas where these traditional practices could be conducted. This regulatory change led to increase pressure on the remaining areas where wood pasture and litter collecting were still allowed. The abandonment of wood pasture and litter collecting practices resulted in increased competition for pine trees, leading to a shift in tree species composition from pine to deciduous trees, such as downy oak. This shift may be linked to the changes in forest management and the socio-economic context of the region. The findings emphasize the importance of detailed historical information on agricultural practices and socio-economic contexts to accurately reconstruct anthropogenic disturbance regimes in forest ecosystems.

The study undertaken by Sookhdeo and Druckenbrod (2012) attempts to determine the effect of forest age and land use on the amount of organic matter contained in the soil using soil samples obtained from George Washington’s Mount Vernon plantation. These changes in soil organic matter (SOM) have important implications both for the storage of carbon within coastal plain soils subject to past agricultural land use as well as the potential of SOM to serve as an indicator of forest age in this region. Collins et al. (2017) studied the effect of fragmentation on plant community composition.

The study of soil physical properties is essential in materials science, physical properties, such as bulk density, soil moisture content, and water holding capacity, determine how soil behaves under various conditions and understand soil health. The physical properties of soil depend on factors like climatic conditions, vegetation, parent material, topography, and time (McVay et al., 2006). Soil texture defined by the relative proportions of sand, silt, and clay particles, plays a crucial role in various soil functions, including water retention, nutrient availability, and root penetration (Smith et al., 2020). It has been reported by a series of researchers that soil texture influences other soil properties. (Yoder, 1936; Williams et al., 1983; Woston and Genuchten, 1988; McVay et al., 2006). The distribution of soil texture varies widely across the globe, being the most significant physical properties and it is also influenced by factors such as climate, parent material, and topography (Zhao et al., 2021). Tropical regions often have highly weathered soils with high clay content, while temperate regions may have a mix of loamy and sandy soils (Martinez and Hall, 2022). These variations in soil texture have significant implications for land use planning and agricultural practices in different parts of the world. Soil texture is a significant determinant of agricultural yield, loamy soils, which have a balanced texture of sand, silt, and clay, and are often considered ideal for crop growth due to their ability to retain moisture while also allowing for proper drainage (Jones and Clark, 2018). In contrast, soils with high clay content tend to retain excessive moisture, leading to poor aeration and root growth, which can negatively impact crop yields (Wang et al., 2017). The presence of sand reduces the compaction of soil, however if the sand is having a high relative proportion makes the soil more prone to erosion due to it’s larger particle size and lower cohesion (Li et al., 2015). In semi-arid region sandy soils are vulnerable to wind erosion, leading to significant soil degradation and reducing agricultural productivity (Ahmed et al., 2016).

Soil organic carbon (SOC) is essential for the preservation of agricultural productivity, fertility, and soil health. It also serves as a significant element of the global carbon cycle, which aids in the mitigation of climate change. Numerous studies have underscored the significance of SOC in the sequestration of carbon. Lal (2004) underscored that the significant reduction of atmospheric CO_2 levels could be achieved by increasing SOC storage in soils, thereby contributing to the mitigation of climate change. SOC levels are influenced by a variety of factors such as climate, land use, and soil management practices. SOC accumulation is significantly influenced by climatic conditions, including temperature and precipitation (Post et al., 1982). Moreover, it has been demonstrated that SOC levels are reduced by land use changes, including the conversion of natural ecosystems to agriculture and deforestation. In addition, soil management practices are critically important in determining SOC levels. Practices that have been identified as effective for increasing SOC include the use of organic amendments, crop rotation, and conservation tillage (Guo and Gifford, 2002). Smith et al. (2008) argued that the utilization of cover crops and no-till cultivation can result in substantial increases in SOC over time. Significant spatial variability in SOC inventories has been identified in various regions of the world through research. A global assessment of SOC was done by Batjes (1996), who opined that tropical regions, notably those with forest cover, have higher SOC stocks than temperate regions. Nevertheless, these regions have experienced substantial losses in SOC as a result of intensive agricultural practices. In Europe, the levels of SOC have been decreasing as a result of changes in land use and increasingly intensive agricultural practices. Arrouays et al. (2001) conducted a study in France that demonstrated a decline in SOC levels over 20 years, primarily as a result of changes in land use and management practices.

The relationship between SOC and climate change is bi-directional. Although SOC can assist in the mitigation of climate change by sequestering carbon, it can also influence the dynamics of SOC. It is anticipated that the decomposition rates of SOC is influenced by altering precipitation patterns and rising temperatures, which could result in a rise of CO_2 emissions from soils (Davidson and Janssens, 2006). Furthermore, Schlesinger and Andrews (2000) have reported that the equilibrium between SOC inputs and outputs could be altered by increased CO_2 levels and changes in vegetation as a result of climate change, which could impact SOC stocks on a global scale.In a study Grosse et al. (2011) argued that carbon cycle in northern high-latitude regions is crucial for global climate, with significant reservoirs in soils and permafrost, storing approximately 1400-1850 Pg of soil organic carbon (SOC). Disturbances, both press (long-term) and pulse (short-term), can significantly impact

SOC dynamics, potentially leading to increased atmospheric CO_2 levels and altering climate feedback mechanisms. Key disturbance practices affecting SOC stocks include wildfires, which can change water and temperature dynamics, impacting SOC at various depths. Vegetation and micro-habitat conditions are critical in determining SOC stocks, as they influence organic C input and moisture dynamics. The interplay between soil texture, landscape physiography, and moisture conditions shapes the distribution and dynamics of SOC.

There is an ample need to understand the effect of disturbance for better understanding of ecological response of the ecosystem (Shugart et al., 1981). According to Whittaker and Levin (1977), disturbance from any source physical and biological changes in the community structure. The species of community depends upon the existing resources (Pielou, 1975). The change in community structure over time is a natural phenomenon (Schoner, 1982). Change in the community is attributed to predation and disturbance (Hay, 1985). As suggested by Petraitis et al. (1989) rare fewer disturbances created an equilibrium supporting few dominant species. Small disturbance patches can be recolonized (Thristle, 1981). High frequency and intensity of disturbance also result in few species. The generalised hypothesis is intermediate level of disturbance supports maximum diversity (Spechn, 2000). Species heterogeneity and structural asymmetry are the keys to ecosystem stability (Morris, 2010). Sousa (1979) discovered that boulder fields in the intertidal zone of California exhibited the five highest species diversity on boulders of intermediate size that were overturned at moderate frequencies. Similarly, Svensson et al. (2009) demonstrated that intermediate disturbance regimes in aquatic ecosystems exhibited a greater degree of biodiversity than low or high-disturbance regimes. Collins et al. (1995) showed that the highest species richness was supported by moderate fire frequencies in temperate grasslands in forest ecosystems. It is one of the most widely accepted theories in ecology, as these findings across diverse environments support the generality of the Intermediate Disturbance Hypothesis (IDH), a framework for comprehending the biodiversity pattern and ecological communities in a disturbed ecosystem. Fahrig (2017) employed the IDH to elucidate the patterns of species diversity in fragmented landscapes, positing that biodiversity may be improved in specific contexts by moderate levels of habitat disturbance.

The distribution of species also gets affected by disturbance. The heterogeneous availability of water and nutrients was the primary factor contributing to the clumped distribution of trees at small spatial scales in the semi-arid forests of Spain, as revealed by the work of Wiegand et al. (2007). In tropical forests, Condit et al. (2000) observed that numerous tree species exhibited aggregated patterns, which were influenced by factors such as environmental variability and seed dispersal limitations. Remote sensing and Geographic Information Systems (GIS) have facilitated the analysis of tree distribution patterns across vast spatial domains by researchers (Getzin et al., 2012).

The relationship between anthropogenic disturbances and plant diversity is intricate, as the effects can differ based on the type, intensity, and duration of the disturbance, as well as the specific ecosystem in question. Plant species richness has been demonstrated to be diminished by habitat fragmentation, a prevalent consequence of agricultural expansion and urbanization. For example, in tropical rainforests, habitat fragmentation frequently results in a decrease in the diversity and abundance of native plant species. Fragmented habitats are more susceptible to invasion by non-native plants and support fewer species, which can further reduce native biodiversity, according to research conducted in the Amazon and Southeast Asia (Laurance, et al., 2018; Koh, 2007; Thorington, 1982; Ekanayake, 2013; Shiferaw, 2019).

The introduction of pollutants and the modification of natural habitats by urbanization and industrialization have resulted in changes in the composition of plant communities. In Europe, a study discovered that urban areas exhibit a lower level of plant diversity than rural areas as a result of the high levels of pollution and habitat modification (McKinney, 2008). The accelerated industrialization of China has led to a substantial degradation of habitats, which has been associated with a reduction in the functionality of ecosystems and the diversity of plant species (Zhang et al., 2015, 2016). The diversity of plants is significantly impacted by agriculture, particularly intensive cultivation. The loss of native plant species and a reduction in overall plant diversity can result from monoculture practices, which involve the cultivation of a single crop species over a vast area. For example, the conversion of prairies to agricultural land in North America has led to a significant decrease in the number of native grassland species (Tilman et al., 2001).

Similarly, research conducted in Africa suggests that traditional farming practices, such as shifting cultivation, can result in a temporary decrease in plant diversity. However, if the land is permitted to revert to its natural form, some recovery may occur over time (Ranjan and Upadhyay, 1999; Fox et al., 2000). The impact of anthropogenic disturbances on plant diversity is further exacerbated by climate change. The suitability of habitats for numerous plant species is altered by changing precipitation patterns and rising temperatures, resulting in changes in species distributions. For example, a study conducted in the Mediterranean region discovered that the richness of plant species has decreased, notably in regions that are already significantly affected by human activities, as a result of climate change and land-use changes (Lavorel et al., 1998). The significance of combining conservation initiatives with strategies to mitigate anthropogenic disturbances is emphasized by the results of these studies. The preservation of plant diversity necessitates the preservation of large, contiguous habitats, the promotion of sustainable agricultural practices, and the reduction of urban expansion. In addition, restoration initiatives in disturbed regions can contribute to the recovery of lost biodiversity; however, the efficacy of these endeavours is frequently contingent upon the ecosystem's resilience and the severity of the disturbance (Hobbs and Harris, 2001).

Binkley (1995) has in-depth described the relationship between soil and plants. There are various ways in which plants affect the soil such as the canopy cover provided by plants affects the microclimate by regulating the temperature and humidity (Liu et al., 2020). Plant-soil interactions are critical in determining the structure and function of terrestrial ecosystems. These interactions encompass a wide range of processes, including nutrient cycling, soil formation, and the regulation of plant growth. Understanding these interactions is essential for sustainable agriculture, ecosystem restoration, and climate change mitigation. The microbial activity in the soil affects the soil nutrient, soil fertility and plant growth (Binkley, 1995; Fierer, 2017).

Therefore, plant-soil interaction, the relationship between plants and soil microbial communities becomes a crucial aspect in determining the soil characteristics influenced by vegetation. For instance, mycorrhizal fungi form symbiotic relationships with plant roots, enhancing water and nutrient uptake, particularly phosphorus (Smith and Read, 2008; Alexander and Lee, 2005). The soil microbial communities are also influenced by plant root exudates, which can contribute towards the selection and growth of specific microbial populations. Root exudates are a variety of organic compounds secreted by plant roots that can stimulate or inhibit microbial activity (Bais et al., 2006). This interaction can lead to the development of a rhizosphere, a zone of soil influenced by root secretions, which is rich in microbial activity (Philippot et al., 2013).

Nutrient cycling is a crucial process in plant-soil interactions, involving the transformation and movement of nutrients like nitrogen, phosphorus, and carbon within the soil. Plants absorb these nutrients from the soil, which are then returned to the soil through leaf litter and root decay, forming a continuous cycle (Vitousek and Howarth, 1991). The availability of nutrients in the soil significantly influences plant growth and productivity. For example, nitrogen is a key nutrient for plant growth, and its availability is largely determined by soil microorganisms that convert atmospheric nitrogen into forms that plants can absorb, such as ammonia and nitrate (Galloway et al., 2004). Similarly, the decomposition of organic matter by soil microbes releases nutrients that are essential for plant growth, thus maintaining soil fertility (Brady and Weil, 2008). Soil structure, which refers to the arrangement of soil particles into aggregates, is another critical factor in plant-soil interactions. Good soil structure improves water infiltration, root penetration, and aeration, all of which are essential for healthy plant growth (Bronick and Lal, 2005; Tang et al., 2022). Plants, in turn, influence soil structure through root growth and the production of organic matter. Roots help to bind soil particles together, forming aggregates, while organic matter from decaying plant material contributes to soil cohesion (Six et al., 2004). The interaction between plant roots and soil structure is particularly important in preventing soil erosion. Roots help to stabilize the soil, reducing the risk of erosion by water and wind (Gyssels et al., 2005).

This stabilizing effect is crucial for maintaining soil health and preventing the loss of fertile top-soil. Plant-soil feedback mechanisms refer to the reciprocal interactions between plants and soil that can either enhance or inhibit plant growth. Positive feedback occurs when plants create soil conditions that are favourable for their growth, such as increasing nutrient availability or promoting beneficial microbial communities (Bever et al., 2010). Conversely, negative feedback occurs when plants create unfavourable soil conditions, such as the accumulation of pathogens or the depletion of specific nutrients (Kulmatiski et al., 2008). These feedback mechanisms are essential for understanding plant community dynamics and ecosystem stability. For example, invasive plant species can alter soil properties in ways that inhibit the growth of native species, giving them a competitive advantage (Meisner et al., 2014).

2.2 National

The exponential population growth has put biological diversity under pressure to fulfil human needs and resulting in the ongoing sixth mass extinction. The need for creating human settlement, agriculture, and setting up industries cause deforestation and alter land use patterns. Landscape change as a result of increasing human population leading to greater resource exploitation may further lead to loss of diversity (Tewari, 2016; Singh et al., 2019).

Mega-diverse countries should have at least 5000 or more of the world's plants endemic to it, thus India is among 12 mega-diverse countries having ten biogeographic biomes supporting high diversity and numerous endemic species.

India with 2.4% of the world's landmass is home to 8% of world species. The Botanical Survey of India and the Zoological Survey of India have approximately recorded 47,000 species of plants and 81,000 species of animals. Several scientists have studied plant diversity in various types of forests situated in different parts of country (Parthasarathy and Karthikeyan, 1997; Parthasarathy and Sethi, 1997; Raizada et al., 1998; Tiwari et al., 1998; Kadavul and Parthasarathy, 1999; Chittibabu and Parthasarathy, 2000; Kumar et al., 2002; Bhuyan et al., 2003; Mishra et al., 2004, 2005, 2012; Mishra and Laloo, 2006; Pragasan and Parthasarathy, 2010; Majumdar et al., 2012; Dutta and Devi, 2013; Dutta and Devi, 2013; Gogoi and Sahoo, 2018; Leishangthem and Singh, 2018; Sahu et al., 2019; Bhutia et al., 2019; Baidya et al., 2022; Bhuyan et al., 2003).The vegetation structure and composition of rainforests in the Western Ghats have been studied by various researchers (Pascal, 1988; Rai and Proctor 1986; Pascal and Pelissier, 1996; Varghese and Balasubramanyan, 1999; Sundarapandian and Swamy, 2000; Pomeroy et al., 2003; Murthy et al., 2016; Tamhane et al., 2024). Disturbance in the Himalayan region has been studied by Khan et al. (1987), Rao et al. (1990), Mishra et al. (2004), Mishra et al. (2005), Uniyal et al. (2010). In the north-eastern region many researchers have aimed to study the vegetation and changes in vegetation due to factors like disturbance altitude and many others (Tripathi et al. 2002; Upadhaya et al., 2003; Mishra et al., 2004; Mishra et al., 2005; Devi and Yadava, 2006; Thapa et al., 2011; Dutta and Devi, 2013; Rai and Lalramnghinglova, 2010; Tiwari et al., 1998, Rai and Lalramnghinglova, 2011; Singh et al., 2015; Rai, 2012; Ao et al., 2021).

The study done by Pandey and Shukla (1999) of plant diversity and community patterns along the disturbance gradient in plantation forests of sal (*Shorea robusta*) supported the intermediate disturbance hypothesis by suggesting that intermediate-level maximum plant diversity was reported at a moderate level. Disturbance gradient was established in the plantation forests of sal (*Shorea robusta*) in Gorakhpur, revealing how different disturbance levels affect community attributes and diversity patterns. The frequency of species components increased along the disturbance gradient, showing significant fluctuations, while the density peaked in peripheral stands and then stabilized. Communities were found to be highly patchy and heterogeneous, with certain understory species like *Mallotus* and *Clerodendron* thriving under high disturbance, while non-leguminous shrubs dominated areas with intermediate disturbance. The relative density of leguminous shrubs decreased as disturbance increased, indicating a shift in community composition. The maximum Shannon's index of diversity was recorded in the stands with moderate disturbance, suggesting that moderate levels of disturbance are beneficial for maintaining biodiversity. The study concluded that disturbances should be managed to support maximum diversity, while also preserving some disturbance-tolerant species to maintain ecosystem attributes in these managed forests.

Sahu et al. (2008) reported a total of 56 species across 42 stand in the Achanakmar-Amarkantak Biosphere Reserve, covering approximately 4 ha. The number of species per site varied with stem density and basal area. The NMS ordination revealed a strong correlation between altitude and various disturbance factors, such as tree lopping and total disturbance, indicating that as altitude increased, the number of species and α-diversity decreased while basal area increased significantly. The analysis showed that species richness and diversity indices were positively associated with tree lopping and total disturbance, suggesting that human activities may enhance species diversity in certain contexts. Four distinct communities were identified based on the composition of species, with *Shorearobusta* being dominant in three of them. The *Shorea robusta –Buchanania lanzan* community exhibited the highest species richness and disturbance levels, while the *Shorea robusta -Lagerstroemia parviflora* community had the lowest. Overall, the study concluded that recent human disturbances are linked to higher species diversity, and all sites appear to follow a similar successional pattern toward dominance by *Shorea robusta*. Yaqoob et al. (2015) studied phyto-diversity and soil characteristics of shrub land of Dachigam National Park in Jammu and Kashmir. Kumar and Ram (2005) conducted a similar study in central Himalaya, Uttaranchal, still, there is a gap of study in the research site designated for the study.

Joshi et al. (2023) studied the species richness, diversity, structure, and distribution patterns across forest communities of low and mid-hills in the Central Himalaya dominated by different plant community forest types dominated with Sal (*Shorea robusta*), Chir-pine (*Pinus roxburghii*), and Banj-oak (*Quercus leucotrichophora*), and mixed-oak (*Q. lanuginosa* and *Q. floribunda*). It reported a total of 110 plant species, belonging to 53 families. Tree density was recorded maximum (884 indiv ha^{-1}) at the mixed oak stand and minimum (652 indiv ha^{-1}) recorded at the chir-pine forest; however, a maximum (51.58 m^2 ha^{-1}) total basal area (TBA) was recorded in banj-oak forest and minimum (33.42 m^2 ha^{-1}) at mixed-oak forest stand. Also Sekar et al. (2022) conducted a similar study along the altitude gradient covering high-altitude alpine regions of west Himalaya, India.

The North-East comprises of eastern Himalayas and it is geographically situated close to the two most populated nations of the world. Eastern Himalaya is referred to as a 'crisis eco-region' in the world as both India and China have massive demand for natural resources putting biodiversity under stress to derive benefits (Brooks et al., 2006). To mitigate the various anthropogenic disturbances affecting biodiversity which is very much required for human existence suggesting periodic assessment of Himalayan biodiversity (Peng et al., 2024).

The region of northeast India, comprising the states of Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura, is recognized for its rich biodiversity and varied ecosystems. This region, part of the Indo-Burma biodiversity hotspot, supports an array of flora, including a diverse array of tree species. The diversity of trees in this region is influenced by its unique climatic conditions, topographical variations, and cultural practices of indigenous communities. The north-east region of India is part of the Indo-Burman biodiversity hotspot because of its rich biodiversity with a high level of endemism (Khan et al., 1997; Kamei et al., 2009). Northeast India harbours various forest types, including tropical wet evergreen forests, tropical semi-evergreen forests, tropical moist deciduous forests, subtropical forests, and temperate forests. The diverse forest types contribute significantly to the overall tree diversity in the region. According to a study by Bhuyan (2003), tropical wet evergreen forests, particularly in Arunachal

Pradesh and parts of Assam, showcase high tree diversity with species such as *Dipterocarpusretusus*, *Hopeaodorata*, and *Mesua ferrea* dominating the canopy layer. These forests also support a rich understorey of smaller trees and shrubs. The region is home to several endemic and rare tree species. Upadhaya et al. (2013) highlighted that the state of Meghalaya alone contains numerous endemic species, including *Magnolia punduana* and *Prunus jenkinsii*. The Eastern Himalayan region, particularly Arunachal Pradesh, is noted for its high number of *Rhododendron* species, many of which are endemic and hold significant ecological and ornamental value. Indigenous communities in Northeast India have a deep-rooted relationship with their natural environment, utilizing various tree species for medicinal, nutritional, and cultural purposes. According to Singh et al. (2020), tree species such as *Terminalia chebula*, *Terminalia bellirica*, and *Phyllanthus emblica* are extensively used in traditional medicine. The ethnobotanical knowledge of these communities plays a crucial role in the conservation and sustainable use of tree biodiversity. Despite its rich biodiversity, tree species in Northeast India face numerous conservation challenges. Deforestation, shifting cultivation (jhum), and habitat fragmentation are significant threats.

Sheth et al. (2019) and Upadhaya et al. (2013) has reported that illegal logging and the conversion of forest land to agriculture are leading to the loss of habitat for many tree species. Moreover, climate change poses additional risks by altering the habitat conditions necessary for the survival of many endemic and rare species. Northeast India’s tree diversity is an invaluable asset that requires concerted conservation efforts to safeguard it for future generations. The region's unique forest types, endemic species, and ethnobotanical heritage underscore the importance of preserving this biodiversity hotspot. Sustainable management practices, coupled with the involvement of local communities, are essential for the effective conservation of tree diversity in Northeast India.

Sahu et al. (2019) reported a total number of 368 individuals from 48 species across three forest sites: Low Elevation Forest (LEF), Middle Elevation Forest (MEF), and High Elevation Forest (HEF). The species distribution for LEF: 130 individuals, 35 species, MEF: 121 individuals, 34 species, HEF: 117 individuals, 14 species. Shannon diversity index values declined with increase in elevation. The researcher also studied the Soil nutrient correlation, Species richness and diversity were positively correlated with pH, while tree density was negatively correlated with pH and other soil nutrients.

Bhutia et al. (2019) found high species richness in low-altitude forests (900 m to 1700 m asl), while high-altitude forests (2500 m to 3200 m asl) exhibited the highest mean stem diameter at breast height (DBH) and stand basal area. The family Fagaceae was identified as the most significant, contributing greatly to the total basal area and stem density across the altitudinal gradient. A notable finding was the disproportionate size class distribution, with low-altitude forests lacking trees with higher DBH. This indicates a reverse J-shape distribution of tree diameters, suggesting uneven-agedness in these forests. The study also reported the presence of large trees of *Lithocarpus pachyphyllus* (>1.5 m DBH) in high numbers at high altitudes, indicating remnants of old-growth primary forests. The results emphasize the need for conservation efforts in low-altitude forests to maintain biodiversity and improve forest structure, as these areas are crucial for ecological balance. These findings provide a comprehensive understanding of forest diversity, structure, and composition along the altitudinal gradient in Sikkim, which is essential for developing effective conservation strategies. Dutta and Devi (2015) studied the six tree species namely *Bauhinia variegata, Careya arborea, Dillenia pentagyna, Sterculia colorata, Sterculia villosa and Terminalia belerica* in the forest of Assam to understand their regeneration potential.

Majumdar et al. (2012) has extensively studied tree species diversity and stand structure along major community types in lowland primary and secondary moist deciduous forests in Tripura, Northeast India. The major communities studied were Sal-dominated and *Schima* dominated primary forests and Teak and Havea secondary communities were grouped based on two major old plantations. Alone *Schima wallichii* had a density of 85.25 trees · ha^{-1} and a basal area of 3.65 m^2 ha^{-1}.

Ao et al. (2021) studied the Stand structure, community composition, and tree species diversity of the sub-tropical forest of Nagaland. Leishangthem and Singh

(2018) did research in the Dikhuriver in Nagaland.A reverse J-shaped population curve was observed, suggesting high tree species richness and density in lower girth classes, which decreases with increasing girth size. This indicates that the riparian forest is in a less mature succession stage. The Shannon-Wiener index ranged from 1.25 to 0.73, and the Simpson diversity index varied from 0.42 to 0.93, reflecting the diversity levels across the zones. The study also noted that the upper and middle zones had a contagious distribution pattern of trees, while the lower zone exhibited a regular distribution pattern. Overall, the findings emphasize the need for conservation and management strategies to protect the riparian forest from ongoing anthropogenic pressures.

Upadhaya et al. (2003) identified a total of 738 individuals belonging to 82 species, 59 genera, and 39 families in the Ialong sacred grove, while the Raliang sacred grove had 469 individuals of 80 species, 62 genera, and 41 families. About 32% of the species were common to both groves. The study found Lauraceae family as the dominant family in the groves.

Mishra et al. (2003) studied the effect of disturbance on the population structure and natural regeneration of four dominant and economically important woody species in a broad-leaved subtropical humid forest of Meghalaya. Mishra et al. (2004) also studied the effects of anthropogenic disturbance on plant diversity and community characteristics along disturbance gradient in the sacred grove of Meghalaya, and reported drastic drop in both the basal area and tree density with degree of disturbance. There was relatively little density in the severely disturbed stand. They also reported that there is a shift in the position of species as well as families with the degree of disturbance and mild disturbance supports natural regeneration, and there is the increase in the number of monospecific families with a degree of disturbance. In all three stands, the density–girth distribution pattern revealed a progressive decline in density and an increase in girth. Additionally, there observed a continuous decline in the density of trees across several girth classes, from the highly disturbed to the undisturbed stand. The distribution of basal area across girth classes shows that, in nearly all stands, trees in the middle girth classes covered a greater area than both young and mature trees. The overall basal area of trees in various girth classes decreased as disturbance stress increased. In the moderately damaged and undisturbed stands, the dominance-distribution curve had a log-normal distribution pattern. On the other hand, the stand was severely disrupted and the curve was short and hooked. In the undisturbed stand, *Camellia cauduca*, *Eurya japonica*, and *Rhododendron arboreum* held a dominant position. However, in the moderately disturbed stand, *Euryaacuminata* took the place of *Camellia cauduca*, and in the highly disturbed stand, *Psychotriasynplocilifolia*. Between the highly disturbed and undisturbed stands, the dominant species' IVI differed significantly. Mishra et al. (2005) also reported the community characteristics population structure of ten important tree species in subtropical humid forest of Meghalaya

Lalfakawma et al. (2009) reported community composition and tree population structure in undisturbed and disturbed tropical semi-evergreen forest stands of North-East India. The plant density was higher in the disturbed stand (284,510 individuals/ha) compared to the undisturbed stand (104, 030 indi.ha^{-1}). The undisturbed stand had more tree (32) and shrub species (18) than the disturbed stand (17 tree and 16 shrub species). The disturbed stand had a higher number of herbaceous species (30) compared to the undisturbed stand (17). *Castanopsis tribuloides* dominated the undisturbed stand, while *Schimawallichii* was dominant in the disturbed stand. The undisturbed stand showed higher Shannon's Diversity and Pielou's Evenness Index compared to the disturbed stand (H' = 2.2881, E = 0.6488). The canopy and sub-canopy layers comprised 28% and 33% of the total tree species, respectively, indicating a diverse vertical structure in the forest. The number of species and stem density were greater for trees in the lower diameter at breast height class compared to those in the higher dbh class. The basal area varied with variation in species richness, higher basal area was reported with high species richness in Raliang. The curves showed high equitability and low dominance in both groves, suggesting a balanced distribution of species.

Singh et al. (2015) studied plant diversity in the Aizawl district of Mizoram and reported a significant decline in diversity with increased disturbance, shrubs, there were 26 species in undisturbed stands, 38 in moderately disturbed, and 43 in highly disturbed stands, showing an increase in shrub diversity in disturbed areas. The herbaceous layer showed 34 species in undisturbed, 48 in moderately disturbed, and 55 in highly disturbed stands, suggesting that disturbance may favour herbaceous growth. *Schima wallichii* was the dominant tree species across all stands, while *Chromolaena odorata* was the dominant shrub. *Costus speciosus* was the dominant herb in undisturbed stands, replaced by *Mimosa pudica* in disturbed stands. The study highlighted that certain tree species were sensitive to disturbance, showing reduced abundance or absence in highly disturbed areas, which reflects the impact of anthropogenic pressures like stone mining on biodiversity. The Sorenson's Index of similarity for tree species was highest (0.58) between undisturbed and moderately disturbed stands, indicating some level of similarity in species composition.

The study done in the mid-elevational forest of Central Himalaya by Khera et al. (2001) found that anthropogenic pressure was a major factor hindering ecological succession. This was evident from the complete absence of trees in higher girth classes and low recruitment of seedlings, indicating a disrupted successional trend in the community. *Coriaria nepalensis*, a non-leguminous nitrogen-fixing species, was present across all study sites. This species may play a significant role in soil restoration and the reconversion of original pine-oak forests. The study highlighted that the hilltop and hill slope areas experienced recurrent soil erosion, while the hill base showed debris deposition. The presence of anthropogenic disturbances was noted particularly on the western aspect, affecting ecosystem stability and retarding the successional process. On the eastern aspect, there was a relatively high presence of seedlings and saplings of species like *Pinusroxburghii* and *Coriarianepalensis*, indicating better regeneration conditions compared to the western aspect, which showed lower numbers due to higher anthropogenic pressure. The study reported higher diversity in disturbed ecosystems compared to undamaged oak forests, suggesting that disturbances can lead to increased species diversity, although they also hinder further succession.

Anitha et al. (2007) and Anitha et al. (2009) studied the floristic diversity of Western Ghats with changes in structural attributes of plant communities along disturbance gradients. Anitha et al. (2007) examined two habitats in the Anaikatty hills, revealing significant differences in floristic composition due to disturbance factors. The low disturbed habitat supported a 'specialist' community, while the high disturbed area contained a 'generalist' community. A total of 61 primary forest species were identified in the low-disturbed habitat, indicating its ecological importance. In contrast, the highly disturbed site had only 8 species exclusive to it. The analysis showed that increasing disturbance factors could lead to the local extinction of these primary forest species, emphasizing the need for urgent recovery programs to protect them. Data collection involved 40 quadrates of varying sizes, where 3,376 tree individuals (106 species), 8,599 shrubs (122 species), and 16,659 herbs (145 species) were recorded, highlighting the diversity present in these communities. The study utilized various statistical methods, including the Mann-Whitney U test and Spearman rank correlation, to analyze the impact of disturbance on community structure and diversity. These results underscore the critical need for conservation efforts in the face of increasing human disturbances in the Western Ghats. Similar study was conducted by Anitha et al (2009) in a dry deciduous forest of Western Ghats, India

Borah (2011) studied disturbance in Barak Valley, South Assam. The study identified distinct differences in species composition between undisturbed and disturbed forests. Dominant species in undisturbed forests included *Cynometra polyandra* and *Palaquium polyanthus*, while disturbed forests were characterized by species like *Tetrameles nudiflora* and *Mitragyna rotundifolia*. A total of 137 species were recorded, with species richness being higher in undisturbed forests. The richness was comparable to other tropical forests, but it declined with disturbance. The Shannon Weaver diversity index was higher in undisturbed forests (1.69 and 1.77) compared to disturbed forests (1.46 and 1.52), indicating greater biodiversity in the former. The density of trees ranged from 396 to 1110 trees per hectare, with undisturbed forests showing higher density and basal area compared to disturbed ones. Undisturbed forests exhibited better regeneration characteristics, with higher sapling densities than disturbed forests. However, many seedlings in disturbed areas failed to progress to later growth stages due to chronic disturbances. Continuous disturbances led to lower densities and basal areas in disturbed sites, affecting the overall stability and diversity of these forests.

Saikia et al. (2017) has reported a total of 482 plant species from the eastern Himalayan forests in Arunachal Pradesh. They found family Fabaceae as the most diverse, contributing 27 species, followed by Poaceae and Ericaceae. Notably, 49 families were represented by a single species (monotypic). The highest density and species richness were found in tropical broadleaf semi-evergreen forests in the Lohit District. The forests were also rich in invasive species, with *Ageratum conyzoides* being the most dominant herb, indicating ecological challenges. The Shannon-Wiener diversity index values were 4.64 for trees and 4.12 for herbs, suggesting high diversity in these forests. Only 14.59% of woody species were found in the seedling stage, indicating poor regeneration rates. Shalini (2021) has reported a total of 282 plant species belonging to 210 genera and 82 families from 3 forest stands in the Manipur. Shannon and Wiener's diversity index between tree, shrub and herbaceous plants varied between 2.37-3.77, 2.68-3.15 and 2.51-2.85, from stand 1 to 3 respectively.

The physico-chemical properties of soil in this region play a crucial role in determining the suitability of land for agriculture, forestry, and other land-use activities. This literature review aims to synthesize the current knowledge on the physico-chemical properties of soils in the northeastern region of India, with a focus on soil texture, pH, organic matter content, nutrient status, and soil fertility.

Soil texture in the north-eastern region of India varies significantly due to the region's diverse geology and topography. The soils are predominantly loamy to sandy loam in texture, which influences their water retention capacity and drainage. The soils of Assam's Brahmaputra valley are mostly alluvial, with a sandy loam texture, which facilitates good drainage but may require careful management for nutrient retention (Basumatary et al., 2019; Das et al., 2019). In contrast, the hill soils of Meghalaya and Nagaland are often loamy or clayey, which retain moisture better but can also be prone to waterlogging in areas with high rainfall (Tripathi and Barik, 2003; Kumar et al., 2021; Maurya et al., 2022).

The pH of soils in the north-eastern region of India is generally acidic, reflecting the high rainfall and leaching conditions prevalent in the area (Nath, 2014; Bhabai and Mukhopadhyay, 2019; Mishra and Francaviglia, 2021). Acidic soils are common in the region due to the high organic matter content and intense weathering of parent materials. Soils in Arunachal Pradesh, for example, have been reported to have pH values ranging from 4.1 to 5.5, which can limit the availability of essential nutrients such as phosphorus and molybdenum (Singh and Munth, 2013). Similarly, the acidic nature of the soils in Meghalaya, with pH values often below 5.0, is a significant factor influencing crop production and soil management practices (Tyler and Olsson, 2001; Patil et al., 2010; Wang et al., 2018; Kumar et al., 2023). The north-eastern region of India is rich in organic matter due to the dense forest cover and high biomass production. Organic carbon content in the soils of this region is generally high, contributing to the soil's fertility and structure. For instance, soils in Mizoram have been reported to have organic carbon content ranging from 1.5% to 4.5%, which is significantly higher than the national average (Lalnunmawia and Tawnenga, 2013). This high organic matter content is beneficial for maintaining soil structure, moisture retention, and nutrient availability, but it also necessitates careful management to prevent nutrient imbalances and soil acidification. The nutrient status of soils in the northeastern region varies widely depending on soil type, land use, and management practices. Nitrogen, phosphorus, and potassium are the primary nutrients of concern in the region. Studies have shown that nitrogen is generally adequate due to the high organic matter content, but phosphorus is often deficient, especially in the acidic soils (Hazarika, 2021). The availability of potassium is also variable, with some areas showing sufficient levels while others are deficient. For example, the acidic soils of Manipur and Nagaland are often low in phosphorus and potassium, necessitating the use of fertilizers to meet crop demands (Amer et al., 2014; Shi et al., 2016; Sarkar et al., 2020).

Mishra (2011) highlighted the significant impact of forest type (broad-leaved, mixed pine, and pine) on soil nutrient status, influenced by altitude and seasonal changes. It was found that the organic carbon, total nitrogen, and available phosphorus contents were generally higher in top-soil compared to sub-soil, with notable variations across different forest types and altitudes. The research indicates that the C: N ratio increased from broad-leaved to pine forests, suggesting a decline in soil fertility as one moves from polyculture to monoculture systems. The nutrient release was enhanced in broad-leaved forests due to a higher rate of litter decomposition, attributed to the diverse chemical composition of mixed litter compared to single-species litter. The findings also suggest that environmental factors such as light interception and temperature play crucial roles in determining relative humidity and, consequently, the nutrient dynamics in these forest ecosystems. Overall, the study provides the importance of maintaining diverse forest types to support soil nutrient status and ecosystem health.

Mishra (2012) studied the impact of anthropogenic disturbances on soil characteristics and micro-environment in the sub-tropical forest of Mizoram, North East India. Anthropogenic activities, such as timber extraction and fuel-wood collection, led to a significant thinning of vegetation, particularly woody plants, which altered the micro-environment and soil characteristics. There was a notable decrease in the concentration of essential nutrients organic carbon, total nitrogen, and available phosphorus from undisturbed to highly disturbed forest stands. This indicates a decline in soil fertility as disturbance increases. The study found an increase in the carbon to nitrogen (C: N) ratio from undisturbed to highly disturbed stands, suggesting a loss of soil fertility with greater disturbance. High rates of litter decomposition resulted in more acidic soil pH in the top-soil during the post-monsoon season, further indicating changes in soil chemistry due to disturbances. Organic carbon, total nitrogen, and available phosphorus were generally higher in the top-soil, although phosphorus content was often greater in the sub-soil during the post-monsoon season, likely due to leaching. These results highlight the significant effects of human activities on forest ecosystems and soil health.

Ovung et al. (2012) studied the soil properties across different land uses in steep slopes of Mizoram. The study found that different land use systems significantly affect soil exchangeable nutrients. Specifically, cultivated lands (*Acacia pennata* plantation and Current Jhum) showed poorer soil exchangeable cations compared to natural forests and Jhum fallow lands. Soils under longer fallow periods (greater than 12 years) exhibited positive changes in available nutrients, including manganese (Mn), potassium (K), magnesium (Mg), and phosphorus (P). Home gardens demonstrated moderately higher levels of available soil nutrients, indicating the benefits of sustainable management practices like organic amendments and mixed cropping. The study highlighted that soil exchangeable cations (Na, Mg, K, Ca, and Mn) were significantly influenced by both land use systems and soil depths, with a general trend of decreasing nutrient values with increasing soil depth. Overall, the findings suggest that the conversion of native forests and fallow lands to various land uses leads to soil quality degradation, emphasizing the need for sustainable practices to maintain soil health in steeply sloped regions.

Saplalrinliana et al. (2016) reported that the accumulation of forest floor litters (FFLs) significantly increased with longer fallow phases, indicating a positive relationship between fallow length and litter accumulation. Soil physicochemical properties varied, with higher values of bulk density, pH, electrical conductivity, and available phosphorus in burnt sites compared to unburnt sites. Conversely, soil organic carbon and available nitrogen were higher in unburnt sites. The study concluded that less frequent burning during longer fallow phases is more beneficial for improving the physicochemical and biochemical properties of jhum soils, supporting better nutrient cycling and soil health. These results highlight the importance of fallow length and burning practices in managing jhum soils effectively.

The conservation efforts in the region have included the establishment of protected areas, community-based forest management, and reforestation programs. In hilly regions, contour ploughing and terracing are common practices aimed at reducing soil erosion. These methods help in slowing down water runoff, allowing more time for water to infiltrate the soil, thereby reducing erosion and promoting moisture retention (Das et al., 2018). The integration of trees and shrubs into agricultural landscapes is a traditional practice in India that enhances soil fertility, reduces erosion, and improves biodiversity. Agroforestry systems have been shown to increase soil organic matter and improve soil structure (Srivastava et al., 2020; Singh et al., 2022). Mulching with crop residues or other organic materials is widely used to conserve soil moisture, suppress weeds, and reduce soil temperature fluctuations. This practice also contributes to improving soil organic carbon levels, which is crucial for maintaining soil health (Deb et al., 2015; Kumar et al., 2023).

The holistic approach of watershed management involves soil and water conservation measures, including check dams, percolation tanks, and contour bunding. These methods have significantly reduced soil erosion in several regions of India (Sharma et al., 2012; Sadar et al., 2023). The growing population in India exerts immense pressure on land resources, leading to over-cultivation and deforestation, which exacerbate soil degradation (Joshi et al., 2015; Sharma and Singh, 2018). The impacts of climate change, such as changes in rainfall patterns and increased frequency of extreme weather events such as cyclones, typhoons, flash flood, cloud brusts, pose significant threats to soil conservation efforts. These changes can accelerate soil erosion and nutrient loss (Brevik, 2013). Many smallholder farmers lack the financial resources to adopt modern soil conservation techniques, relying instead on traditional methods that may not be sufficient to combat severe soil degradation (Bhan and Behera, 2014; Mahendra, 2014). Launched by the Government of India in 2015, the Soil Health Card Scheme aims to provide farmers with information on soil nutrient status and recommend appropriate dosages of fertilizers. This initiative is expected to promote balanced fertilizer use and improve soil fertility. The increase in awareness about the long-term benefits of organic farming, there is an increasing shift towards organic practices that improve soil health and reduce dependency on chemical inputs. Organic farming enhances soil organic matter, improves soil structure, and increases microbial activity (Bhattacharyya et al., 2008; Biswas et al., 2014; Tully and McAskill, 2020). Conservation of soil requires minimal soil disturbance, crop residue retention, and crop rotation, is gaining traction in India as a sustainable approach to soil management. This practice helps in maintaining soil structure, reducing erosion, and improving water infiltration (Sharma et al., 2012; Sharma, 2021). Understanding these feedback mechanisms is also important for developing sustainable land management practices that promote healthy plant-soil interactions. Wrongful practices of tree felling, over-exploitation of forest resources, inappropriate property rights, and similar institutional arrangements, forests are under different degrees of disturbance leading to the deterioration of forest (Singh et al., 2011).

Chapter 3

METHODOLOGY

3.1 Study Area

Mizoram is one of India's thirteen Himalayan states, located in the extreme south of the country's northeastern region. The thick green forest cover, unrivalled natural beauty, a limitless diversity of flora and animals, and excellent climatic conditions throughout the state make it an ideal tourist ecotourism destination. The state offers a variety of untapped tourism destinations and activities for potential visitors. Mizoram is also known as the 'Songbird of India'. Mizoram's strategic location provides enormous opportunities for economic development. Mizoram, which borders Myanmar and Bangladesh, is a gateway for international trade with Southeast Asian countries. The economy is agrarian as agriculture employs and provides revenue for the vast majority of the state's inhabitants. The Shifting cultivation (jhum farming) has been an age old practice in the state and is still prevalent among the inhabitants.

The state has hill terrain, varying in height across the state. The hills to the west have an average height of around 1,000 meters (3,300 feet) and gradually rise to 1,300 meters (4,300 feet) to the east. Some hill ranges reach a height of 2000 meters (6600 feet). The Phawngpui Tlang, often known as the 'Blue Mountain', is Mizoram's highest peak (7,250 feet asl) and a famous tourist attraction. The state is located in a strategic location in north-eastern India, surrounded by Myanmar's international borders to the east and south and Bangladesh to the west. Strategically, it can serve as a land entry frontier for international tourists from South Asian countries while also improving India's trading links with countries like Myanmar and Bangladesh. Being the part of Himalayan range, which is young mountain system and therefore highly suseptable to earthquakes putting the study area in high seismic zone. The highly undulating hilly topography of Mizoram is made up of tertiary sedimentary rocks. Mizoram has several large river systems, including Tlawng, Tiau, Mat, Serlui, Tuipui, Tuichawng, Teirei, Tut, Tuirial, and Tuivawl. These rivers have considerable hydropower generation potential.

Mizoram translates to "land of hill people." The Mizo people's origins are unknown beyond the 1800s due to a lack of written records. Numerous research indicates that during British control in the 1800s, they moved from Myanmar to the Mizo hills. The Mizo people migrated from the province of Hunan in the People's Republic of China and settled in Myanmar, also known as Burma, in the fifteenth century A.D., according to the report "Land system of Mizoram." According to the account, the Mizos separated into six lines of chiefs (called thangura): Rokhum, Zadeng, Thangluah, Palian, Rivung, and Sailo. They continued to go westward in search of fertile land and financial success. Chatterjee et al. (2006) reported that 225 tribes to inhabit northeast India and thus understanding their culture and customs can be crucial for biodiversity conservation in north east. The main Mizo tribes are the chakma, bru, ralte, pawi/lai, hmar, and parethe.

Mizoram, the land of blue mountains and mystic beauty is one of the states of North eastern part of India, high degree of endemic species and threat to species makes it part of the Indo-Myanmar biodiversity hotspot (Devi et al., 2018). The capital of Mizoram is Aizawl district. The district shares its geographic boundary in the north by the Kolasib district, on the west by Mamit district, on the south by the Serchhip district and on the east by Champhai district. The geographic area of Aizawl district is 3,576.31 square kilometres (1,380.82 sq. km). The headquarters of the district is Aizawl City. As of 2011, it is the most populous district of Mizoram. The population of Aizawl is 400,309. The district has a population density of 113 inhabitants per square kilometre. Its population growth rate over the decade 2001-2011 was 24.07%.

3.1.1 Socio-economy

Mizos are indigenous/tribal community with strong feeling of brotherhood. They are very hospitable people which makes it very suitable for tourism. The economy of the state is agrarian. Approximately 60% of the population is involved in agriculture and allied sector. The contribution of agriculture sector in state GDP is 28.48 %. (ES, 2019). The per capita income of Mizoram for the year 2018-2019 is projected at ` 1, 68,626. The Gross State Domestic Product (GSDP) has continuously increased over the years. The low GDP contribution of agriculture can be attributed to low productivity as the soil is very young, it has low fertility. Rice is the staple food of the Mizoram people. However, the proportion of rice that is self-sufficient has declined from 53% in 2003–04 to 27% in 2010–11. According to the Krishi Vigyan Kendra Vision 2020, one of the primary challenges that states are confronted with is the enhancement of their food security. The rugged topography, steep slopes, and excessive rainfall in the Himalayan areas make permanent cultivation unfeasible. The tourism industry is being promoted as a sustainable industry.

Mizoram is a haven for ecotourism, with its lush green forests, valleys, and hills contributing to its natural beauty. The emergence of Mizoram as a centre for ecotourism will create new growth opportunities. With eight animal sanctuaries, two national parks, one tiger reserve, and several historically significant locations including Rih Dil, Lianchhiari Lunglen Tlang, Thasiama Se no neihna, Lamsial Puk, Sibuta Lung, and Kawtchhuah Ropui, the forest areas have the potential to boost ecotourism.

Mizoram's development and progress are in line with the objectives of sustainable development. The laws that the national government and the government of Mizoram developed and put into effect.

Table 3. 1: Sectoral Share to GSVA (2018- 2019)

Sl. No.	Sector	Percentage Share to GSVA
1	Agriculture (Crop Husbandry)	7.89
2	Agriculture (Animal Husbandry)	5.67
3	Forestry and Logging	14.48
4	Fishing and Aquaculture	0.44
5	Mining and Quarrying	0.41
6	Manufacturing	0.57
7	Construction	9.25
8	Electricity, Gas, Water Supply and Other Utility Services	15.54
9	Transport, Storage, Communication, and Service Related to Broadcasting	3.29
10	Trade, Repair, Hotels and Restaurants	11.80
11	Financial Services	1.53
12	Real estate, Ownership of Dwelling and Professional Services	2.89
13	Public Administration	12.47
14	Other Services	13.78

(Source: Economic Survey of India, 2019).

3.1.2 Climate

The study sites experience moderate climate throughout the year. The precipitation is high; the area falls under the influence of south-westerly wind but the rainfall is not distributed evenly thus in dry seasons water scarcity is prevalent. The monsoon season is mainly from June to September and 2400 mm is the average annual rainfall with a relative humidity of 90%. March to May during summer highest temperature is recorded lies in the range of 25°C to 32°C, October to November is autumn the relative humidity is approximately 60% and the ranges between 18°C to 25°C and in winter temperatures December to February vary from 11°C to 23°C. Mizoram lies in a High seismic activity zone and is accompanied by high precipitation thus making the rock system weak, unstable and prone to weathering. Synclinal valleys, dissected ridges with deep gorges, and faulting produced steep fault scarps in many areas (GSI, 2011).

3.1.3 Forest and vegetation

The northernmost limit of true tropical rainforests of the world is the moist to wet tropical forest of north eastern part of India’s lowland (Proctor et al., 1998). The luscious greenery of moist tropical to moist sub-tropical forests supports rich biodiversity and is a major tourist attraction. The forest report, 2017 published by the Ministry of Environment Forest and Climate Change reported 86.26% of the total geographic area of Mizoram i.e., an area of 18,748 sq km. The classification of forest reported very dense forest is 138 sq km, moderately dense forest 5,858 sq km and open forest covers an area of 12,752 sq km. the forest report of 2019 shows a decline in forest cover in Mizoram 180 sq km. 85.41% forest cover was reported in 2019 down as compared to 86.26 per cent in 2017. Champion and Seth (1968) classified the vegetation of Mizoram into three major categories that are tropical wet evergreen forest, tropical semi-evergreen forest and subtropical pine forest and Singh et al. (2002) classified the forests of Mizoram into 6 types namely, Tropical Wet Evergreen Forest, Montane sub-tropical Forest, Temperate Forests, Bamboo Forests, Quercus Forests, Jhum land.

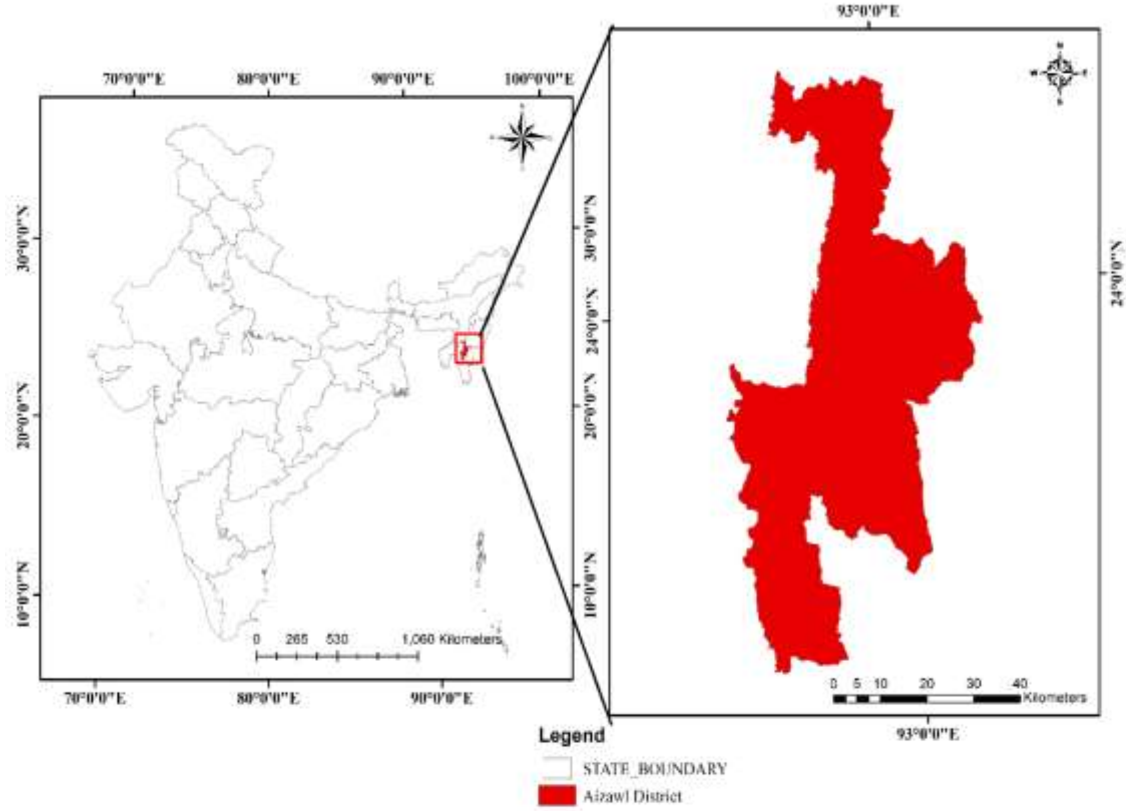


Figure 3. 1: Map of the study area

3.2 Methods

3.2.1 Site selection and sampling

The present study was carried out for two successive years i.e., during 2022 and 2023. For detailed investigation, one stand (one ha area) each representing undisturbed, moderately disturbed and highly disturbed forest patches were selected in and around Mizoram University campus, Tanhril, Aizawl, Mizoram. The disturbance index was determined following light interception using Lux meter.

3.2.2 Micro- environment

The micro-environment attributes namely, temperature, relative humidity and light interception were measured on site during the field study.

3.2.3 Vegetation analysis

Vegetation analysis of the study area was carried out following the methods as outlined in Misra (1968) and Mueller-Dombois and Ellenberg (1974). Belt transect method was appropriated for field study. The size of quadrat for trees, shrubs and herbs were fixed as 10m x10m 5m x 5m and 1m x1m respectively. The identification of plants was done with the help of local indigenous people who are involved in ethno-medicinal activities and it was cross-checked with the herbarium from the Botanical Survey of India (BSI), Eastern circle, Shillong along with herbarium of the Department of Environmental Science at Mizoram University.

During the course of investigation, the following phyto-sociological characteristics were studied.

Frequency

Number of individual species occurring in an area expressed in terms percentage is referred to as frequency. It was calculated as,

$$\text{Frequency} = \frac{\text{Number of quadrat in which species occurs}}{\text{Total number of quadrats studied}} \times 100$$

Density

Total number of individuals in a specific defined area is density of a species. It was calculated as,

$$\text{Density} = \frac{\text{Total number of individual of a species}}{\text{Total number of quadrat studied}}$$

Abundance

It is a measure of the dominance of a species and was calculated as,

$$\text{Abundance} = \frac{\text{Total number of individual of a species}}{\text{Total number of quadrat of occurrence}}$$

Basal area

Basal area of a tree is an important feature to quantify the vegetation structure and site quality (Suthari, 2013). It was calculated as,

$$\text{Basal area} = \frac{\mathbf{gb}\boldsymbol{h}^2}{\mathbf{4\pi}}$$

Where,

gbh = girth at breast height (1.3m from ground).

Importance Value Index (IVI)

Importance value index is used to determine the ecological success of a species within the community. The estimation requires relative frequency, relative density and relative abundance (Phillips, 1959).

$$\text{IVI=Relative density+Relative frequency+Relative dominace}$$

Relative Frequency

Dispersion of individual species in an area is the relative frequency that was calculated by using following formula,

$$\text{Relative Frequency (\%)} = \frac{\text{Frequecy of a species}}{\text{Frequency of all species}} \times 100$$

Relative Density

Number of individuals of a species in relation to total number of species is relative density. It was calculated by using following formula,

$$\text{Relative Density (\%)} = \frac{\text{Density of a species}}{\text{Density of all species}} \times 100$$

Relative Dominance

Dominance of a species refers to its basal area/ cover and was estimated using the formula,

$$\text{Relative Dominance (\%)} = \frac{\text{Dominace (basal area/ cover) of a species}}{\text{Dominance (basal area/ cover) of all species}} \times 100$$

3.2.4 Distribution Pattern

Following the Whitford (1949), the distribution pattern of a species was calculated by using the following formula,

Distribution Pattern = A: F Ratio

Where, A is Abundance and, F is the Frequency of a species. Based on the values, the distribution pattern may be Regular (A: F ratio up to 0.025), Random (A: F ratio from 0.025 to 0.05) and Contagious (A: ratio above 0.05).

Shannon-Weiner Diversity Index, (Shannon and Wiener, 1963)

The Shannon-Weiner Diversity Index was used to calculate the diversity of the forests, using the formula,

$$H = \sum_{s=1}^{s} \text{pilnpi}$$

Where

H' = the Shannon-Weiner index

p*i*= the proportion of individual in i^{th} species

Simpson Dominance Index, (Simpson, 1949**)**

$$Cd = \sum_{i=0}^{n} pi^2$$

Where,

P*i* = proportion of individual in the i^{th} species,

The increase in Simpson's index represents decrease in diversity

Margalef's Species Richness Index, (Margalef, 1958)

$$D_{Mg} = {(S-1)}/{lnN}$$

Where,

S = total number of species recorded

N=total number of individuals

ln =Natural Logarithm

Evenness Index, (Pielou, 1969)

$$E=\frac{H\prime}{lnS}$$

Where,

H' = Shannon-Weiner Index

S = total number of species

To understand the inter-linkages on tree community structure from undisturbed to highly disturbed forest stands, the population structure of trees was determined by segregating the individuals in different girth classes preferably 30 to 60 cm, 60 to 90cm, 90 to 120cm, 120 to 150cm, and so on.

3.3 Soil Analysis

The soil samples were collected from the undisturbed, moderately disturbed, and highly disturbed areas of forests seasonally i.e., pre-monsoon season (February-may), monsoon season (June-September), post monsoon season (october-January) from two different depths i.e., 0-10cm (Top-soil) and 10-20cm (Sub-soil) in the triplicate. The soil sample was analysed for various characteristics using the methods as described in Allen et al. (1974) and Anderson and Ingram (1993).

Soil pH: The electronic pH meter was used to measure pH of soil.

Soil Moisture: The soil moisture content was computed by the following formula,

$$\text{Moisture content (\%)} = \frac{W_1 - W_2}{W_1} \times 100$$

Bulk Density: The bulk density was used to understand the compaction of soil, and it was computed using the following formula,

$$\text{Bulk Density (D)} = \frac{(Weight\ of\ ovendried{-}dried\ soil)}{Volume\ of\ soil\ core} g/cm^3$$

Organic carbon: The Organic carbon in soil was computed by the following formula,

$$\text{Organic Carbon (\%)} = \frac{0.003 \times 10(B-T) \times 100}{B \times S}$$

Where,

B= volume of ferrous Ammonium sulphate solution required for blank titration in ml

T=volume of ferrous ammonium sulphate solution required for soil sample

S=weight of soil in gram

Total nitrogen:

The total nitrogen content of the soil was analysed using Kjeldahl Digestion method (Bradstreet, 1984) and was computed by the following formula,

$$\text{Total nitrogen (\%)} = \frac{14 \times N \times V}{v \times 1000}$$

Where

N = Normality of acid; V= volume of extractant

v= volume of sample

Available phosphorous:

Available phosphorous was determined using Olsen's method (Olsen et al., 1954), and value was calculated using following formula,

$$\text{Available phosphorous (Kg/ha)} = R \times {}^{V}\!/_{v} \times \frac{1}{S} \times (2.224 \times 10^6)/10^6$$

Where,

V = Total volume of extractant,

R=Weight of the a aliquot in mg

v= Volume of aliquot taken for analysis

S=Weight of soil

Exchangeable potassium

The estimation of exchangeable potassium ion was done by flame photometer (Ghosh *et.al,* 1983). It was calculated using following formula,

Exchangeable potassium ($Kgha^{-1}$) = $\frac{R \times V \times 224 \times 10^6}{W \times 10^6}$

Where,

V = Total volume of extractant,

R=Weight of the aliquot in mg

3.4 Socio-economic Analysis

The socio-economic assessment in the study area was done using a questionnaire. The questionnaire was prepared aiming to assess the awareness among the community, and their behavioural practices. Thereby conducting a Likert scale questionnaire-based survey. Likert scale involves several key steps to ensure the collection of reliable and valid data. The statements related to the topic of environmental concerns and awareness were used to create the questionnaire. The Likert scale used for the response to the questions has a 5-point scale ranging from "Strongly Disagree" to "Strongly Agree”. The 5 points are Strongly Disagree (1), Disagree (2), Neutral (3), Agree (4) and Strongly Agree (5) (Likert, 1932). A pilot test with a small, representative sample was done. The questionnaire was adjusted based on feedback. The random sampling method was used for sample collection. The questionnaire was administered using a few community members. The data was entered from the filled questionnaire. The data analysis was done to calculate frequency, means, and standard deviations for Likert items.

Chapter 4

RESULTS

The present research work has been carried out during 2022 and 2023 and findings on various aspects of study are presented as below.

4.1 Micro-environment

4.1.1 Ambient Air Temperature

The temperature data for the year 2022 is presented for areas categorized as undisturbed (UD), moderately disturbed (MD) and highly disturbed (HD), which refers to varying levels of environmental disturbance. In the UD stand, the pre-monsoon season was 25.3°C, reflecting a relatively mild temperature before the onset of rains. In the monsoon season 22.1°C, showed a considerable decrease as the monsoon cools the atmosphere. In the post-monsoon season 18.3°C, indicating significant cooling after the monsoon. In the stand, the pre-monsoon temperature was 29.3°C, higher than the UD stand, this could be attributed due to human activities contributing to heat build-up. The monsoon temperature was 25.66°C, cooled during the season but still warmer than the UD stand. The post-monsoon temperature was 19.6°C, slightly warmer, indicating lingering heat effects. For HD stand the pre-monsoon temperature peak was recorded as 31.6°C, followed by monsoon season as 27.3°C, and post-monsoon season as 21.6°C indicating less reduction in temperature during rains and continued heat retention in summer months respectively. The data highlights how environmental disturbances exacerbate air temperature, reducing the natural cooling effect during the monsoon and post-monsoon seasons (Table 4.1).

Table 4. 1: Ambient air temperature during 2022

Stands	Seasons		
	Pre-monsoon (°C)	Monsoon (°C)	Post-monsoon (°C)
Undisturbed	25.3±0.2372	22.1±0.1905	18.3±0.1515
Moderately disturbed	29.3±0.0816	25.66±0.2125	19.6±0.2125
Highly disturbed	31.6±0.1515	27.3±0.2494	21.6±0.1655

In 2023, air temperatures varied along the disturbance gradient and across seasons. For the UD stand, the ambient air temperatures were lowest, with 24.16°C pre-monsoon, dropping to 21.3°C during the monsoon, and further to 20.1°C post-monsoon. MD stand recorded higher temperatures, with 26.1°C pre-monsoon, 22.9°C during the monsoon, and 21.6°C post-monsoon. HD stand had the highest temperatures, reaching 26.2°C pre-monsoon, peaking at 25.7°C during the monsoon, and stabilizing at 21.9°C post-monsoon. The data highlights that disturbance levels, along with seasonal changes, strongly influence air temperature (Table 4.2).

Table 4. 2: Ambient air temperature during 2023.

Stands	Seasons		
	Pre-monsoon (°C)	Monsoon (°C)	Post-monsoon (°C)
Undisturbed	24.16±0.1784	21.3±0.1440	20.1±0.2880
Moderately disturbed	26.1±0.1606	22..9±0.3741	21.6±0.4065
Highly disturbed	26.2±0.2054	25.7±0.3399	21.9±0.1699

4.1.2 Relative Humidity

The relative humidity for the UD stand during the pre-monsoon season was 76.33%, for the monsoon season was 94.33%, and for the post-monsoon season 85.3%, still high, reflecting lingering moisture after the rains. For the stand, the pre-monsoon was 74.33%, slightly lower than in the UD stand, possibly due to human activity reducing natural humidity retention, monsoon it was 91.66%, reflecting a high but slightly reduced level compared to the UD stand for post-monsoon 80%, showed less moisture retention post-monsoon. The highly disturbed stand had the lowest pre-monsoon humidity during Pre-monsoon (71.33%), for monsoon: 85.33%, significantly lower humidity during the monsoon compared to the less disturbed stand and the lowest humidity during post-monsoon (Table 4.3).

Table 4. 3: Seasonal variation in relative humidity along disturbance gradient during 2022.

Stands	Seasons		
	Pre-monsoon (%)	Monsoon (%)	Post-monsoon (%)
Undisturbed	76.33±0.7200	94.33±0.5443	85.3±0.2721
Moderately disturbed	74.33±0.9428	91.66±0.7200	80±0.4714
Highly disturbed	71.33±1.2472	85.33±0.2721	78.33±0.9428

In 2023, relative humidity showed seasonal variation along a disturbance gradient. In UD stand, relative humidity was highest, starting at 80.6% pre-monsoon, peaking at 92% during the monsoon, and decreasing slightly to 84.33% post-monsoon. MD stand had lower humidity, with 78.3% pre-monsoon, 89.6% during the monsoon, and 83% post-monsoon. In highly disturbed stand, relative humidity was the lowest, with 74.7% pre-monsoon, rose to 89% during the monsoon, and dropped to 78.33% post-monsoon. This showed that higher disturbance levels result in lower relative humidity, with significant seasonal shifts (Table 4.4).

Table 4. 4: Seasonal variation in relative humidity along disturbance gradient during 2023.

Stands	Seasons		
	Pre-monsoon (%)	Monsoon (%)	Post-monsoon (%)
Undisturbed	80.6±0.5443	92±0.4714	84.33±0.5443
Moderately disturbed	78.3±0.9813	89.6±0.2721	83±0.8164
Highly disturbed	74.7±0.4714	89±0.4271	78.33±0.4714

4.2 Vegetation Analysis

The vegetation analysis was carried out in the UD, MD, and HD forest stands, taking into consideration 1 ha. area of each stand for detailed sampling. The degree of disturbance was classified based on the luminous intensity and canopy cover and thus delineation of UD, MD and HD was done based on the same. The areas that demonstrate over 60% of canopy cover were considered UD, for MD stand exhibited canopy cover between 20% and 60%, whilst highly disturbed stand possess less than 20% canopy cover. Light analysis indicated that the UD stand received more than 80% of light, the MD stand received approximately 60%, and the HD stand received between 10% and 40%. UD stand had 153 plant species belonging to 135 genera and 70 families. The MD stand possessed 187 plant species from 161 genera and 62 families, whereas the highly disturbed stand displayed intermediate plant diversity consisting of 165 plant species from 146 genera and 57 families. These findings underscored the substantial effects of disturbance on canopy architecture, light accessibility, and plant diversity composition within the ecosystem (Table 4.5).

Table 4. 5: Canopy cover, light interception and phytosociological characteristics of selected forest stands along the disturbance gradient.

Parameter	Stands		
	Undisturbed	Moderately Disturbed	Highly disturbed
Canopy cover (%)	> 60	20-60	<20
Average light interpretation (%)	80	50	15
No. of plant species	153	187	165
No. of genera	135	161	146
No. of family	70	62	57

The UD, MD and HD had 153, 187 and 165 species respectively across all habit types. The graph indicated that the MD stand had the highest diversity followed by highly disturbed and undisturbed. The UD stand had the highest tree species; however, the MD and highly disturbed stand was dominated by shrubs and herbaceous species respectively (Fig. 4.1).

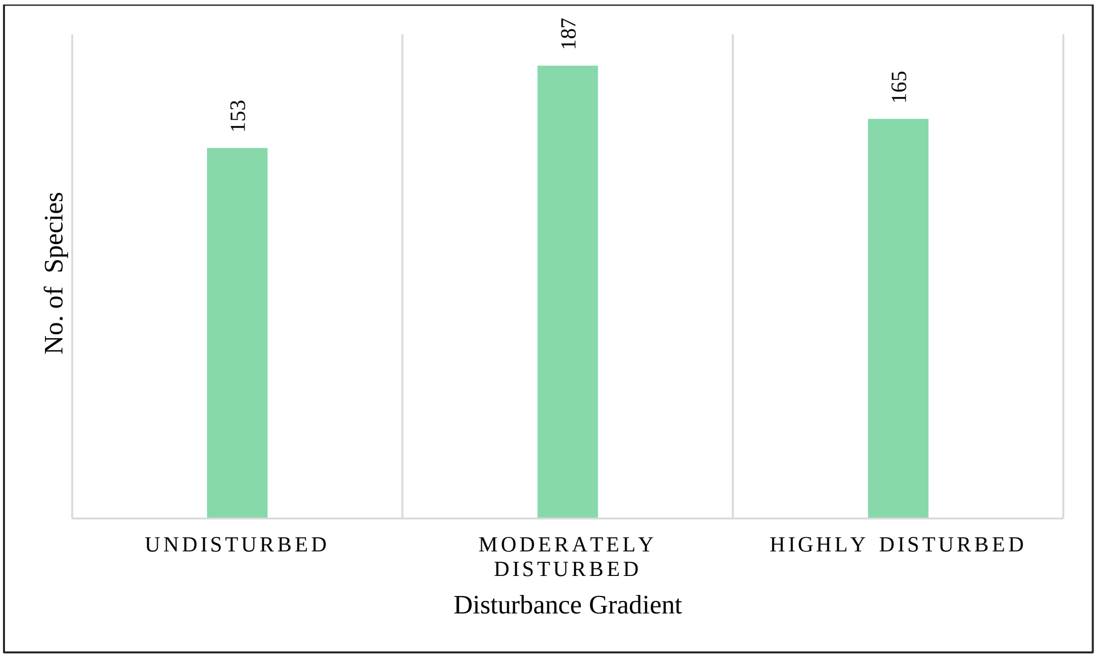


Figure 4. 1: Overall diversity of selected forest stands along the disturbance gradient.

The dominance of plant habits along the disturbance gradient was highly linked with population density. The graph showcases the change in the number of individuals across the disturbance gradient. The number of individuals of trees ranged from 539 to 993 indiv ha^{-1}. The number of individuals declined from 993 in UD to 726 in MD to 539 in HD. The number of individuals declined along the disturbance gradient (Fig. 4.2 and 4.3).

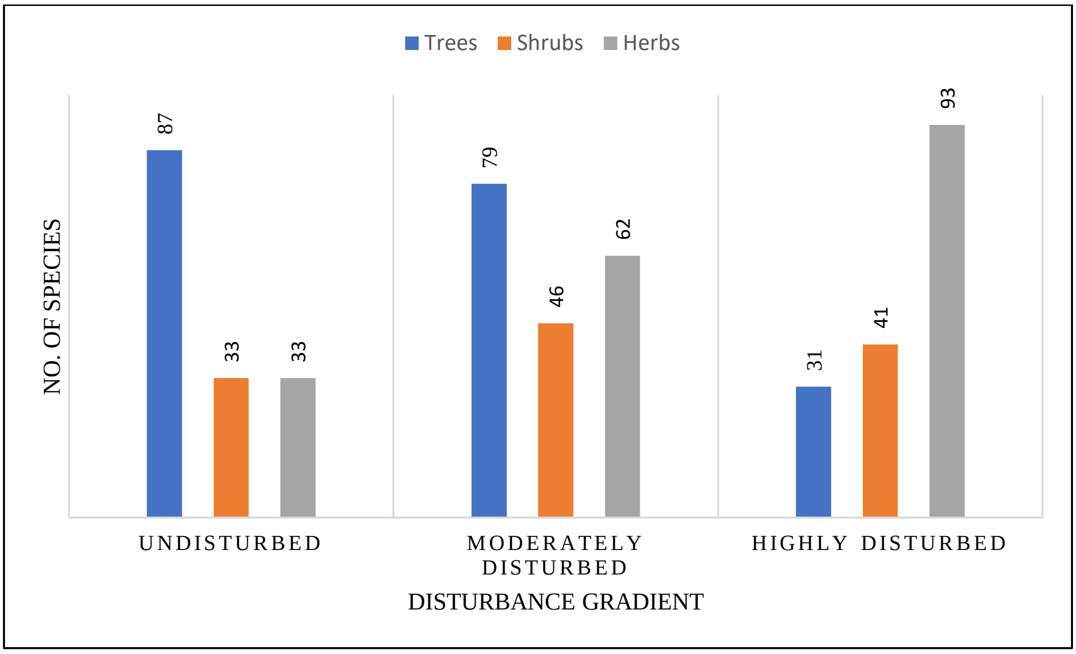


Figure 4. 2: No. of species of trees, shrubs and herbs along the disturbance gradient.

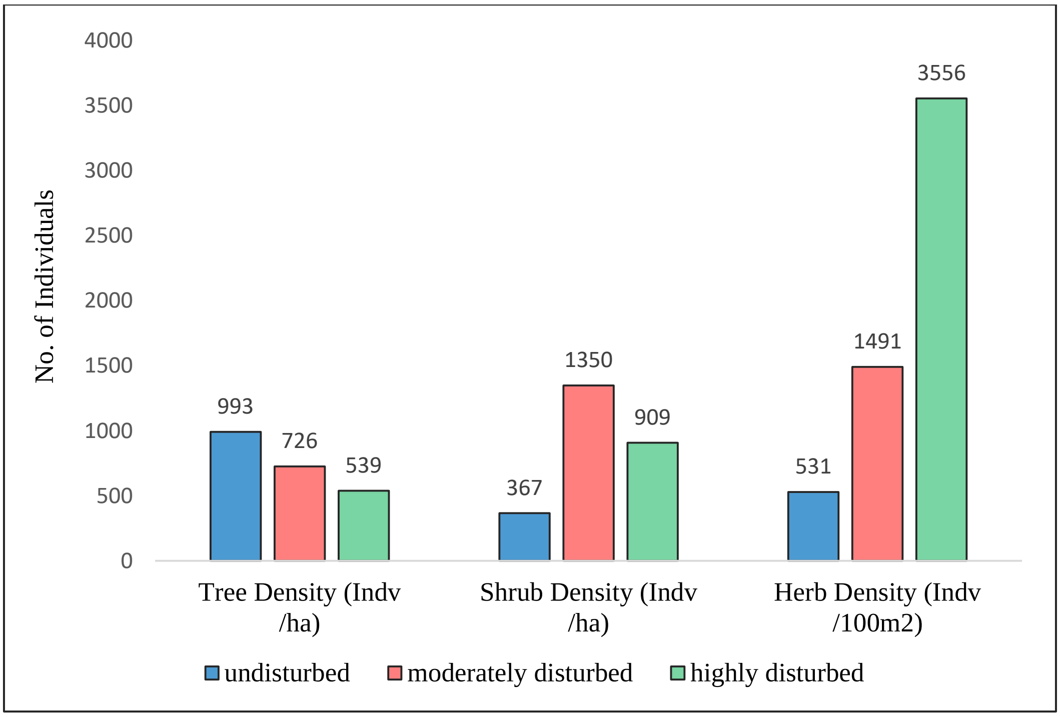


Figure 4. 3: No. of individuals of trees, shrubs and herbs along the disturbance gradient.

4.2.1. Community Characteristics of Tree Species

A total of 100 quadrats (10x10m size) were laid to sample 1 ha. area of each forest stand for determining tree community characteristics taking into consideration the individuals having GBH ≥30cm. Of the total woody species around 93 individuals were recorded from the UD stand, 87 from the MD stand and 31 from the HD stand.

A comparative analysis of phytosociological attributes across three varying degrees of disturbances has been presented in Table 4.6. The UD stand, had the highest number of species (87) belonging to genera (68), and families (40) were recorded, indicating rich plant diversity. The Shannon diversity index (H'), which measures species diversity, was also highest in this UD stand at 3.63, and the Simpson dominance index, which was 0.963, showed a relatively even distribution of species. The Margalef species richness index, at 12.46, highlights a high level of species richness, and the evenness index of 0.813 suggests that species were distributed fairly evenly across this habitat. The basal area (27.98 m^2ha^{-1}) and tree density (993 trees per hectare) emphasise the maturity and structure of the forest in these UD conditions.

In the MD stand, there was a slight decline in the values of attributes. The number of species decreased to 79, genera to 70, and families to 43. The Shannon diversity index dropped to 3.13, reflecting lower species diversity than the UD stand. The Simpson dominance index was slightly reduced to 0.932, and Margalef's species richness index was computed as 11.841, indicating a moderate loss in species richness. The Evenness index decreased to 0.737, suggesting species distribution was becoming less uniform. The basal area was reduced to 18.59 m^2ha^{-1} and tree density declined to 726 trees per ha., likely due to disturbances such as logging or habitat fragmentation.

HD stand exhibited further a significant reduction in values for all attributes. The number of species was drastically reduced to 31, genera to 27, and families to 19, reflecting biodiversity loss. The Shannon diversity index was lowest at 2.31, highlighting the diminished complexity of the ecosystem. The Simpson dominance index further decreased to 0.880, and the Margalef species richness index dropped sharply to 4.769, pointing to low species richness. The Evenness index was computed as 0.675, indicating the uneven distribution of species, whereas light-demanding species (heliophilic) possessed a relatively high value. The basal area (7.63 m^2 ha^{-1}) and tree density (539 trees per hectare) were the lowest, signifying highly degraded habitat conditions. In a nutshell, an increase in disturbance led to ecosystem degradation, loss of species and decrease in basal area and tree density.

Table 4. 6: Community characteristics of tree species in the undisturbed, moderately disturbed and highly disturbed forest stands.

Phytosociological attributes	**Stand**		
	Undisturbed	**Moderately Disturbed**	**Highly Disturbed**
No of species	87	79	31
No of Genus	68	70	27
No of Family	40	43	19
Shannon diversity index (H’)	3.63	3.13	2.31
Simpson Dominance index	0.963	0.932	0.880
Margalef’s species richness index	12.46	11.841	4.769
Evenness index (E)	0.813	0.737	0.675
Basal area ($m^2 ha^{-1}$)	27.98	18.59	7.63
Tree density ha^{-1}	993	726	539

The detailed list of plant species for UD strand and their respective families, density (number of individuals per hectare), frequency, abundance (average number per plot), and the distribution pattern highlighted that community chracterstics of forest. Fabaceae, Lauraceae, Euphorbiaceae, and Fagaceae appear frequently and hence were the dominant families with multiple species. *Castanopsis tribuloides* (83 indiv ha^{-1}) and *Callicarpa arborea* (63 indiv ha^{-1}) were the most densely populated species, indicating their dominant presence in the study area. Other species with high densities include *Bischofia javanica* (85 indiv ha^{-1}) and *Spondias pinnata* (50 indiv ha^{-1}), *Halidina cordifolia* and *Castanopsis tribuloides* show maximum frequency, reflecting their consistent occurrence across multiple sampling plots. *Aporusa dioica* and *Callicarpa arborea* also had high frequencies (23 and 61), signifying wide distribution. Abundance values range from 1.00 to 2.50, with most species showed close to 1.00, suggesting that their population per sampled plot is relatively low. Species like *Drysoxylum excelsum* and *Bombax insigne* showed higher abundance in plots where they occur. The A/F ratio helps determine whether species are clumped or evenly distributed. Species with a low A/F ratio, such as *Acacia pennata* (0.07) or *Callicarpa arborea* (0.02), indicate regular or evenly distributed patterns. Higher A/F ratios, such as *Acrocarpus fraxinifolius* (0.75) and *Engelhardia spicata* (0.75), reflect clumped or irregular patterns. Contagious (C) distribution dominates, with most species following this pattern, meaning they tend to grow in clumps or clusters. Some species like *Bischofia javanica*, *Callicarpa arborea*, and *Castanopsis tribuloides* show random (RA) distribution, suggesting they were more randomly dispersed across the study area. Certain species, such as *Acer laevigatum*, *Acer oblongum*, and *Lithocarpus dealbatus*, were less frequent and likely rarer in the ecosystem, reflecting specialized ecological niches (Table 4.7).

The phytosociological features of MD forest stand have been studied for different tree species as it aids in understanding the dominant species and their spatial distribution. Fabaceae, Moraceae, Myrtaceae, Verbenaceae, and Fagaceae were some of the most dominant families in the MD. The density of *Castanopsis tribuloides* (82 indiv ha^{-1}), *Tectona grandis, Parkia roxburghii, Phoebe attenuate,* and *Rhus succedanea* was more common than other species in the area. The species such as *Albizia procera*, *Terminalia bellirica Vernonia volkameriifolia, Vitex quinata and Xantolis assamica* which has a lower density. Higher frequency species, including *Schima wallichii* and *Gmelina arborea*, were dispersed more uniformly over plots.

The ratio of abundance to frequency is known as the A/F ratio. This ratio showed how abundance and frequency were related, giving information about the species' distribution pattern. A lower A/F ratio, like 0.01 or 0.05, indicated that although the species was widely distributed, its occurrence in each plot was reduced. On the other hand, a greater ratio (like 2.00) indicated that the species occurs in fewer plots but in higher concentrations when it does. The entire distribution of any species was categorised by its distribution pattern. The Contagious denotes a species that is more likely to appear in groups than in an even distribution throughout the landscape. A more even distribution that is random is suggested by the term Random. A few species, such *Callicarpa arborea* and *Castanopsis indica*, had random distributions, while the majority of the species in the table had clumped distributions (Table 4.8).

The structural characteristics and spatial distribution of trees within the examined area were described by parameters like density, frequency, abundance, A/F ratio, and distribution pattern of a variety of tree species for HD stand. The densities of certain species, including *Mesua ferrea* (85 indiv ha^{-1}), *Autocarpus hetrophyllus* (83 indiv ha^{-1}), *Albizia thompsonii* (82 indiv ha^{-1}), and *Mangifera indica* (65 indiv ha^{-1}), were significantly higher than those of other species, suggesting that they were common in the study area. These species were predominant in the HD stand. The extremely low densities (1-3 indiv ha^{-1}), of numerous species in the forest including *Acrocarpus fraxinifolius*, *Azadirachta indica*, *Betula alnoides*, and *Callicarpa arborea* indicate they were rare.

The widespread distribution of species such as *Autocarpus hetrophyllus* (82), *Albizia thompsonii* (81) and *Mesua ferrea* (83) was indicated by their frequent presence in multiple plots. Conversely, the frequency of the occurrence of numerous species, including *Azadirachta indica*, *Tamarindus indica*, and *Rhus chinensis*, is relatively lower, suggesting that they were more restricted to specific sites. The majority of species exhibited low abundance value that implied such species were more likely to be present in fewer numbers within plots. *Ficus benjamina* (1.50) and *Macropanax undulatus* (1.50) were among the few species that exhibited slightly higher abundance. Fabaceae, Moraceae, Anacardiaceae, Lauraceae and Myrtaceae were dominant species in HD. The distribution pattern of species is influenced by the abundance-to-frequency (A/F) ratio. The A/F ratios of the majority of the species in the table were low, with values that were either near to or below 1.00. This suggests that the distribution pattern was contagious. This pattern implies that these species were more likely to form clusters than to be evenly distributed. The distributions of species such as *Albizia thompsonii* (A/F = 0.01) and *Mesua ferrea* (A/F = 0.01) were highly contagious. A higher A/F ratio, as evidenced by *Myrica esculenta* (A/F = 2.00), is indicative of a more uniform or random distribution. The majority of species demonstrate a contagious distribution pattern; however, a few species, including *Parkia timoriana*, *Phoebe attenuata*, and *Schima wallichii*, exhibited a random distribution pattern, which implies a more dispersed occurrence without a distinct clustering pattern. In general, the forest exhibited a contagious distribution pattern, with a contagious pattern of distribution, and dominance of a few species with high density and frequency. Numerous other species exist at much lower densities. This pattern is characteristic of ecosystems with spatial heterogeneity, in which the aggregation of species is facilitated by environmental conditions (Table 4.9).

Table 4. 7: Community characteristics of tree species in the undisturbed stand.

Sl. No	Name of species	Family	Density (indiv ha^{-1})	Frequency (F)	Abundance (A)	A/F Ratio	Distribution pattern
1	*Acacia eburrea* (L.F.) Wild	Fabaceae	6	5	1.20	0.24	C
2	*Acacia pennata* (L.) Willd.	Fabaceae	32	22	1.45	0.07	C
3	*Acer laevigatum* Wall.	Aceraceae	1	1	1.00	1.00	C
4	*Acer oblongum* Wall. Ex DC.	Aceraceae	4	4	1.00	0.25	C
5	*Acrocarpus fraxinifolius* Wight.ex Arn	Caesalpiniaceae	3	2	1.50	0.75	C
6	*Albizia chinensis* (Osbeck) Merr.	Mimosoideae	4	4	1.00	0.25	C
7	*Albizia lebbeck* Benth.	Fabaceae	2	2	1.00	0.50	C
8	*Albizia odoratissima* (L.f.) Benth.	Fabaceae	3	3	1.00	0.33	C
9	*Albizia procera* (Roxb.) Benth.	Fabaceae	4	4	1.00	0.25	C
10	*Albizia thompsonii* Brandis.	Mimosoideae	1	1	1.00	1.00	C
11	*Alnus nepalensis* D. Don	Betulaceae	5	4	1.25	0.31	C
12	*Anogeissus acuminata* (Roxb. ex DC.) Wall. Ex Guill. A & Perr.	Combretaceae	1	1	1.00	1.00	C
13	*Aporosa dioica* (Roxb.) Müll.Arg.	Phyllanthaceae	32	23	1.39	0.06	C
14	*Azadirachta indica* A. Juss	Meliaceae	2	1	2.00	2.00	C

15	*Bischofia javanica* Blume.	Euphorbiaceae	85	85	1.00	0.01	RA
16	*Bombax ceiba* Linn.	Malvaceae	2	2	1.00	0.50	C
17	*Bombax insigne* Wall.	Malvaceae	3	3	1.00	0.33	C
18	*Bruinsmia polysperma* (C.B.Clarke) Steenis	Styraceae	4	2	2.00	1.00	C
19	*Callicarpa arborea* Roxb.	Verbenaceae	63	61	1.03	0.02	RA
20	*Calophyllum polyanthum* Wall. Ex choisy	Calophyllaceae	25	21	1.19	0.06	C
21	*Carallia brachiata* (Lour.) Merr.	Rhizophoraceae	2	2	1.00	0.50	C
22	*Cassia* sp.	Fabaceae	3	2	1.50	0.75	C
23	*Castronopsis indica* A.DC	Fagaceae	35	23	1.52	0.07	C
24	*Castanopsis tribuloides* (Sm.) .DC.	Fagacea	83	81	1.02	0.01	RA
25	*Cinnamomum obtusifolium* (Roxb.) Nees	Lauraceae	3	3	1.00	0.33	C
26	*Cinnamomum tamala* T.Nees and Eberm.	Lauraceae	1	1	1.00	1.00	C
27	*Cordia floribunda* (Desv.) Spreng.	Boraginaceae	2	2	1.00	0.50	C
28	*Debregeasia longifolia* (Burm. F.) Wedd.	Urticaceae	1	1	1.00	1.00	C

29	*Delonix regia* (Hook.) Raf.	Fabaceae	2	2	1.00	0.50	C
30	*Derris Robusta* (DC) Benth	Papilionoideae	4	3	1.33	0.44	C
31	*Diospyros lanceifolia* Roxb.	Ebenaceae	3	3	1.00	0.33	C
32	*Drysoxylum excelsum* Blume.	Meliaceae	5	2	2.50	1.25	C
33	*Duabanga grandiflora* (Roxb. ex DC.) Walp.	Lythraceae	3	3	1.00	0.33	C
34	*Emblica officinalis* Gaertn.	Euphorbiaceae	26	21	1.24	0.06	C
35	*Engelhardia spicata* Lechen ex Blume	Juglandaceae	3	2	1.50	0.75	C
36	*Eriobotrya bengalensis* Hook. f.	Rosaceae	22	18	1.22	0.07	C
37	*Ficus curtipes* Corner	Moraceae	1	1	1.00	1.00	C
38	*Ficus religiosa* Linn.	Moraceae	1	1	1.00	1.00	C
39	*Ficus tinctoria* gibbosa (Bl.) Corner	Moraceae	1	1	1.00	1.00	C
40	*Glochidion Khasicum* (Mull. Arg.) Hook.f.	Guttiferae	2	2	1.00	0.50	C
41	*Gmelina arborea* Roxb.	Lamiaceae	33	22	1.50	0.07	C
42	*Haldina cordifolia* (Roxb.) Ridsdale	Rubiaceae	42	42	1.00	0.02	RA
43	*Liquidambar excelsa* (Noronha) Oken	Altingiaceae	4	4	1.00	0.25	C
44	*Lithocarpus dealbatus* (Hook.f. and Thomson ex Miq.) Rehder	Fagaceae	1	1	1.00	1.00	C

45	*Macaranga denticulata* (Blume) Müll.Arg.	Euphorbiaceae	5	5	1.00	0.20	C
46	*Macaranga indica* Wight	Euphorbiaceae	26	26	1.00	0.04	RA
47	*Machilus villosa* (Roxb.) Hook. Fil.	Lauraceae	5	5	1.00	0.20	C
48	*Macropanax undulatus* (Wall. ex G.Don) Seem	Araliaceae	24	24	1.00	0.04	RA
49	*Mallotus* sp.	Euphorbiaceae	28	21	1.33	0.06	C
50	*Meliosma pinnata* (Roxb.) Maxim.	Meliosmaceae	3	3	1.00	0.33	C
51	*Melastoma nepalensis* Lodd	Melastomataceae	1	1	1.00	1.00	C
52	*Olea dioica* Roxb.	Oleaceae	1	1	1.00	1.00	C
53	*Olea salicifolia* Wall. Ex G.Don	Oleaceae	27	22	1.23	0.06	C
54	*Oreocnide integrifolia* (Gaud.) Miq.	Urticaceae	1	1	1.00	1.00	C
55	*Oroxylum indicum* (L.) Kurz	Bignoniaceae	1	1	1.00	1.00	C
56	*Ostodes paniculata* Blume	Euphorbiaceae	1	1	1.00	1.00	C
57	*Persea glaucescens* (Nees) Long	Lauraceae	1	1	1.00	1.00	C
58	*Persea odoratissima* (Nees) Kosterm.	Lauraceae	2	2	1.00	0.50	C
59	*Phoebe attenuata* (Nees) Nees	Lauraceae	23	17	1.35	0.08	C
60	*Phoebe cooperiana* Kanj. & Das.	Lauraceae	20	19	1.05	0.06	C
61	*Phoebe hainesiana* Brandis	Lauraceae	23	22	1.05	0.05	RA

62	*Pithecellobium angulatum* Benth	Mimosaceae	5	4	1.25	0.31	C
63	*Premna racemosa* Wall. ex Schauer	Verbenaceae	3	2	1.50	0.75	C
64	*Prunus napaulensis* (Ser.) Steud	Rosaceae	26	19	1.37	0.07	C
65	*Quercus glauca* Thunb.	Fagaceae	29	22	1.32	0.06	C
66	*Randia wallichii* Hooker f.	Rubiaceae	2	2	1.00	0.50	C
67	*Rhus chinensis* Mill.	Anacardiaceae	3	3	1.00	0.33	C
68	*Schefflera wallichiana* (Wight & Arn.) Harms	Araliaceae	2	2	1.00	0.50	C
69	*Schima wallichii* (DC.) Choisy	Theaceae	24	18	1.33	0.07	C
70	*Spondias pinnata* (L. f.) Kurz	Anacardiaceae	50	30	1.67	0.06	C
71	*Sterculia hamiltinii* (Kuntz)	Malvaceae	2	2	1.00	0.50	C
72	*Sterculia villosa* Roxb.	Malvaceae	36	25	1.44	0.06	C
73	*Styrax serrulatum* Roxb.	Styracaceae	1	1	1.00	1.00	C
74	*Symplocos theifolia* D.Don	Symplocaceae	1	1	1.00	1.00	C
75	*Syzygium claviflorum (*Roxb.) Wall. ex Steud.	Myrtaceae	1	1	1.00	1.00	C
76	*Syzygium cumini* (L.) Skeels	Myrtaceae	18	18	1.00	0.06	C
77	*Tectona grandis* Linn. f.	Lamiaceae	2	2	1.00	0.50	C
78	*Terminalia bellirica* (Gaertn.) Roxb.	Combretaceae	1	1	1.00	1.00	C

79	*Toddalia asiatica* (L.) Lam.	Rutaceae	1	1	1.00	1.00	C
80	*Toona ciliata* M. Roem.	Meliaceae	1	1	1.00	1.00	C
81	*Toxicodendron succedaneum* (L.) Kuntze	Anacardiaceae	1	1	1.00	1.00	C
82	*Ulmus lancifolia* Roxb.	Ulmaceae	1	1	1.00	1.00	C
83	*Vitex quinata* F.N.Williams	Verbenaceae	1	1	1.00	1.00	C
84	*Wendlandia grandis* (Hook.f.) Cowan	Rubiaceae	22	18	1.22	0.07	C
85	*Wendlandia paniculata* (Roxb.) DC.	Rubiaceae	1	1	1.00	1.00	C
86	*Xantolis assamica* (C. B. Clarke) P. Royen	Sapotaceae	1	1	1.00	1.00	C
87	*Xylia xylocarpa* (Roxb.) Taub.	Fabaceae	1	1	1.00	1.00	C

Abbreviation: C- Contagious distribution, RA- Random distribution, R-Regular distribution.

Table 4. 8: Community characteristics of tree species in the moderately disturbed forest stand.

Sl No.	Name of species	Family	Density (indiv ha^{-1})	Frequency (%)	Abundance	A/F Ratio	Distribution pattern
1	*Acacia eburrea* (L.F.) Wild	Fabaceae	5	5	1.00	0.20	C
2	*Acacia pennata* (L.) Willd.	Fabaceae	23	21	1.10	0.05	C
3	*Acer oblongum* Wall. ex DC.	Sapindaceae	2	2	1.00	0.50	C
4	*Acrocarpus fraxinifolius* Wight.ex Arn	Caesalpiniaceae	3	3	1.00	0.33	C
5	*Albizia chinensis* (Osbeck) Merr.	Fabaceae	5	5	1.00	0.20	C
6	*Albizia lebbeck* Benth.	Fabaceae	2	2	1.00	0.50	C
7	*Albizia procera* (Roxb.) Benth.	Fabaceae	1	1	1.00	1.00	C
8	*Albizia thompsonii* Brandis	Fabaceaee	1	1	1.00	1.00	C
9	*Alnus nepalensis* D. Don	Betulaceae	2	2	1.00	0.50	C
10	*Anogeissus acuminata* (Roxb. ex DC.) Wall. ex Guillem. & Perr	Combretaceae	1	1	1.00	1.00	C
11	*Artocarpus heterophyllus* Lam	Moraceae	2	2	1.00	0.50	C
12	*Ardisia solanacea* (Poir.) Roxb.	Myrsinaceae	1	1	1.00	1.00	C
13	*Artocarpus lakoocha* Roxb. (AL)	Moraceae	3	3	1.00	0.33	C
14	*Aporosa octandra* (Buch.-Ham. ex D.Don)	Phyllanthaceae	1	1	1.00	1.00	C

15	*Bischofia javanica* Blume	Phyllanthaceae	2	2	1.00	0.50	C
16	*Bombax ceiba* Wall.	Malvaceae	1	1	1.00	1.00	C
17	*Bruinsmia polysperma* (C.B.Clarke) Steenis	Styraceae	1	1	1.00	1.00	C
18	*Callicarpa arborea* Roxb.	Verbenaceae	24	22	1.09	0.05	RA
19	*Calophyllum polyanthum* Wall. Ex choisy	Calophyllaceae	3	2	1.50	0.75	C
20	*Carallia brachiata* (Lour.) Merr.	Rhizophoraceae	1	1	1.00	1.00	C
21	*Castanopsis indica* A.DC.	Fagaceae	23	22	1.05	0.05	RA
22	*Castronopsis tribuloides* A.DC	Fagaceae	82	82	1.00	0.01	C
23	*Cinnamomum obtusifolium* (Roxb) Nees	Lauraceae	1	1	1.00	1.00	C
24	*Canthium dicoccum* (Gaertn.) Merr.	Rubiaceae	2	2	1.00	0.50	C
25	*Debregeasia longifolia* (Burm. F.) Wedd.	Urticaceae	2	2	1.00	0.50	C
26	*Derris Robusta* (DC) Benth	Papilionoideae	1	1	1.00	1.00	C
27	*Dimocarpus longan* Lour.	Sapindaceae	3	3	1.00	0.33	C
28	*Diospyros lanceifolia* Roxb.	Ebenaceae	5	5	1.00	0.20	C
29	*Drysoxylum excelsum* Blume	Meliaceae	1	1	1.00	1.00	C
30	*Dubanga grandifolia* (Roxb. ex DC.) Walp.	Lythraceae	3	3	1.00	0.33	C
31	*Emblica officinalis* Gaertn	Phyllanthaceae	5	5	1.00	0.20	C

32	*Engelhardtia spicata* Lesch.Ex Blume	Junglandaceae	1	1	1.00	1.00	C
33	*Eugenia macrocarpa* Cham. & Schltdl.	Myrtaceae	3	3	1.00	0.33	C
34	*Ficus curtipes* Corner	Moraceae	1	1	1.00	1.00	C
35	*Ficus pyriformis* Hook. & Arn	Moraceae	1	1	1.00	1.00	C
36	*Ficus* sp.	Moraceae	1	1	1.00	1.00	C
37	*Ficus religiosa* L.	Moraceae	1	1	1.00	1.00	C
38	*Gmelina arborea* Roxb. ex Sm.	Lamiaceae	23	23	1.00	0.04	RA
39	*Haldina cordifolia* (Roxb.) Ridsdale	Rubiaceae	21	21	1.00	0.05	RA
40	*Liquidambar excelsa* (Noronha) Oken	Altingiaceae	3	3	1.00	0.33	C
41	*Lithocarpus dealbatus* (Hook.f. & Thomson ex Miq.) Rehder	Fagaceae	1	1	1.00	1.00	C
42	*Macaranga denticulata* (Blume) Müll.Arg.	Euphorbiaceae	1	1	1.00	1.00	C
43	*Macaranga indica* Wight	Euphorbiaceae	5	5	1.00	0.20	C
44	*Mallotus* sp.	Euphorbiaceae	2	2	1.00	0.50	C
45	*Mangifera* sp.	Anacardiaceae	1	1	1.00	1.00	C
46	*Meliosma pinnata* (Roxb.) Maxim.	Meliosmaceae	3	2	1.50	0.75	C
47	*Memecylon grande* Retz.	Melastomataceae	2	2	1.00	0.50	C
48	*Morus macroura* Miq.	Moraceae	1	1	1.00	1.00	C

49	*Myrica esculenta* Buch.-Ham. ex D.Don	Myricaceae.	3	2	1.50	0.75	C
50	*Oreocnide integrifolia* (Gaud.) Miq.	Urticaceae	2	2	1.00	0.50	C
51	*Oroxylum indicum* (L.) Kurz	Bignoniaceae	5	4	1.25	0.31	C
52	*Ostodes paniculata* Blume	Euphorbiaceae	2	2	1.00	0.50	C
53	*Palaquium polyanthum* (Wall. Ex G. Don) Baill.	Sapotaceae	1	1	1.00	1.00	C
54	*Parkia roxburghii* G.Don	Fabaceae	65	62	1.05	0.02	
55	*Parkia timoriana* (DC.) Merr.	Fabaceae	21	21	1.00	0.05	RA
56	*Persea glaucescens* (Nees) Long	Lauraceae	2	1	2.00	2.00	C
57	*Phoebe attenuata* (Nees) Nees	Lauraceae	25	22	1.14	0.05	RA
58	*Phoebe cooperiana* P. C. Kanj. & Das.	Lauraceae	5	5	1.00	0.20	C
59	*Pithecellobium angulatum* Benth	Mimosaceae	1	1	1.00	1.00	C
60	*Premna racemosa* Wall. ex Schauer	Verbenaceae	2	2	1.00	0.50	C
61	*Randia wallichii* Hooker f.	Rubiaceae	4	4	1.00	0.25	C
62	*Rhus chinensis* Mill.	Anacardiaceae	2	1	2.00	2.00	C
63	*Rhus succedanea* Linn. var. acuminata (DC) Hook.	Anacardiaceae	45	41	1.10	0.03	RA
64	*Schima wallichii* (DC.) Choisy	Theaceae	89	83	1.07	0.01	
65	*Sterculia villosa* Roxb.	Malvaceae	85	81	1.05	0.01	

66	*Styrax serrulatum* Roxb.	Styracaceae	3	3	1.00	0.33	C
67	*Syzygium claviflorum* (Roxb.) Wall. ex Steud	Myrtaceae	2	2	1.00	0.50	C
68	*Syzygium cuminii* var. axillare (Gamble)	Myrtaceae	2	2	1.00	0.50	C
69	*Tamarindus indica* Linn.	Fabaceae	1	1	1.00	1.00	C
70	*Tectona grandis* Linn. f.	Lamiaceae	65	61	1.07	0.02	
71	*Terminalia bellirica* (Gaertn.) Roxb.	Combretaceae	1	1	1.00	1.00	C
72	*Toddalia asiatica* (L.) Lam	Rutaceae	2	2	1.00	0.50	C
73	*Toona ciliata* M. Roem.	Meliaceae	1	1	1.00	1.00	C
74	*Vernonia volkameriifolia* D.C.	Asteraceae	1	1	1.00	1.00	C
75	*Vitex canescens* Kurz	Lamiaceae	2	2	1.00	0.50	C
76	*Vitex quinata* F.N.Williams	Verbenaceae	1	1	1.00	1.00	C
77	*Wendlandia grandis* (Hook.f.) Cowan	Rubiaceae	1	1	1.00	1.00	C
78	*Wendlandia budleioides* Wall. Ex. Wight & Am	Rubiaceae	1	1	1.00	1.00	C
79	*Xantolis assamica* (C. B. Clarke) P. Royen	Sapotaceae	1	1	1.00	1.00	C

Abbreviation: C- Contagious distribution, RA- Random distribution, R-Regular distribution.

Table 4. 9: Community characteristics of tree species in the highly disturbed forest stand.

Sl. No.	Name of tree species	Family	Density (D) (indiv ha^{-1})	Frequency (F)	Abundance (A)	A/F Ratio	Distribution Pattern
1	*Acrocarpus fraxinifolius* Arn.	Leguminosae	1	1	1.00	1.00	C
2	*Acacia pennata* (Linn.) Willd.	Fabaceae	2	2	1.00	0.50	C
3	*Albizia chinensis* (Osbeck) Merr.	Fabaceae	63	63	1.00	0.02	C
4	*Albizia thompsonii* Brandis.	Fabaceae	82	81	1.01	0.01	C
5	*Aporosa octandra* (Buch. -Ham. ex D.Don)	Phyllanthaceae	2	2	1.00	0.50	C
6	*Artocarpus heterophyllus* Lam.	Moraceae	83	82	1.01	0.01	C
7	*Azadirachta indica* A. Juss	Meliaceae	1	1	1.00	1.00	C
8	*Bauhinia variegata* Linn.	Fabaceae	1	1	1.00	1.00	C
9	*Betula alnoides* Buch. -Ham. Ex.Don	Betulaceae	3	3	1.00	0.33	C
10	*Callicarpa arborea* Roxb.	Verbenaceae	1	1	1.00	1.00	C
11	*Calophyllum polyanthum* Wall. ex Choisy	Calophyllaceae	1	1	1.00	1.00	C
12	*Castanopsis tribuloides* (Sm.).	Fagaceae	2	2	1.00	0.50	C
13	*Cinnamomum cassia* (L.) J.Presl	Lauraceae	1	1	1.00	1.00	C

14	*Ficus benjamina* Linn.	Moraceae	3	2	1.50	0.75	C
15	*Ficus curtipes* Corner	Moraceae	1	1	1.00	1.00	C
16	*Macaranga indica* Wight	Euphorbiaceae	2	2	1.00	0.50	
17	*Macropanax undulatus* (Wall. Ex G. Don) Seem.	Araliaceae	3	2	1.50	0.75	C
18	*Mangifera indica* Linn.	Anacardiaceae	65	63	1.03	0.02	R
19	*Mesua ferrea* Linn.	Clusiaceae	85	83	1.02	0.01	R
20	*Morus nigra* Linn.	Moraceae	1	1	1.00	1.00	C
21	*Myrica esculenta* Buch. -Ham. ex D.Don	Myricaceae	2	1	2.00	2.00	C
22	*Oroxylum indicum* (L.) Kurz	Bignoniaceae	1	1	1.00	1.00	C
23	*Parkia timoriana* (DC.) Merr	Fabaceae	62	61	1.02	0.02	RA
24	*Phoebe attenuata* (Nees) Nees	Lauraceae	43	42	1.02	0.02	RA
25	*Rhus chinensis* Mill.	Anacardiaceae	1	1	1.00	1.00	C
26	*Schima wallichii* (DC.) Choisy	Theaceae	22	21	1.05	0.05	RA
27	*Syzygium claviflorum* (Roxb.) Wall. ex Steud.	Myrtaceae	1	1	1.00	1.00	C
28	*Syzygium cuminii* var. Axillare (Gamble).	Myrtaceae	1	1	1.00	1.00	C
29	*Tamarindus indica* L.	Fabaceae	1	1	1.00	1.00	C

30	*Toxicodendron succedaneum* (L.) Kuntze	Anacardiaceae	1	1	1.00	1.00	C
31	*Wendlandia grandis* (Hook.f.) Cowan	Rubiaceae	1	1	1.00	1.00	C

Abbreviation: C- Contagious distribution, RA- Random distribution, R-Regular distribution.

4.2.2 Dominance-distribution of tree species

The Importance Value Index (IVI) of various tree species in the undisturbed forest (UD), indicated the ecological significance of each species within the community. IVI combines factors such as relative density, frequency, and dominance to determine the overall importance of a species in the ecosystem. *Bischofia javanica* holds the highest IVI (26.00), making it the most dominant species in the UD forest. *Callicarpa arborea* (IVI 19.04), *Castanopsis tribuloides* (IVI 24.09), and *Halidina cordifolia* (IVI 14.06) were other notable species with high IVI values, reflecting their strong presence and role in the ecosystem. Some species with moderate IVI values include *Sterculia villosa* (IVI 14.74), *Emblica officinalis* (IVI 12.17), and *Gmelina arborea* (IVI 9.89), which also play significant roles in the community structure. On the other end, species like *Acer laevigatum* (IVI 0.40), *Symplocos theifolia* (IVI 0.52), and *Oroxylum indicum* (IVI 0.49) had very low IVI values, indicating a lesser ecological role or lower abundance in the forest. The data suggests that a small number of species dominate the forest, while a wide variety of species had a limited presence, contributing to the forest's overall biodiversity (Table 4.10).

The IVI for various species in a MD forest provides insights into the ecological structure and species composition under such disturbance conditions. *Schima wallichii* had the highest IVI (34.07), making it the most dominant species in this MD ecosystem. It is closely followed by *Castanopsis tribuloides* (IVI 31.02), *Parkia roxburghii* (IVI 30.65), and *Sterculia villosa* (IVI 30.46), all of which play critical roles in the forest structure and composition. Other significant species with relatively high IVI values include *Tectona grandis* (IVI 24.31), *Rhus succedanea* (IVI 14.96), and *Gmelina arborea* (IVI 9.03), indicating their substantial contributions to the species diversity and ecological functioning of the forest. Some species, such as *Acacia pennata* and *Callicarpa arborea*, were also important, although their roles were slightly less dominant compared to the aforementioned species. Many other species, including *Acacia eburrea* and *Diospyros lanceifolia*, play moderate roles in the community, contributing to the diversity and resilience of the ecosystem. Conversely, species like *Pithecellobium angulatum*, *Tamarindus* *indica*, and *Dimocarpus longan* showed lower IVI values, indicating either lower abundance or reduced ecological significance in this MD environment. Overall, in MD had a mix of dominant, moderately important, and less significant species, with a few species showed strong ecological dominance. The MD ecosystem still maintains a diverse range of species, though the dominance of certain species suggests shifts in the community structure due to disturbance (Table 4.10).

The IVI for various tree species in the HD forest stand reflected the significant changes in species composition and dominance as a result of disturbances. *Mesua ferrea* had the highest IVI (45.77), indicating that it is the most dominant species in this HD environment, likely thriving under conditions that were less favourable for other species. *Albizia chinensis* (IVI 43.61) and *Albizia thompsonii* (IVI 41.72) also show high dominance, suggesting they had adapted well to the altered ecosystem and contributed significantly to the forest's structure. *Autocarpus hetrophyllus* (IVI 39.86) and *Parkia timoriana* (IVI 36.23) further underscores the dominance of certain species in this disturbed ecosystem, reflecting a community structure where a few species become more prominent. *Mangifera indica* (IVI 32.35) and *Phoebe attenuata* (IVI 23.89) also play substantial roles in the ecosystem, though their IVI values were lower than the top species, indicating a shift in the species hierarchy. *Schima wallichii* (IVI 11.05), a species that was highly dominant in the MD stand, played a much smaller role in the HD setting, likely impacted by the changes in environmental conditions. A large number of species, such as *Acacia pennata* (IVI 1.836), *Betula alnoides* (IVI 1.762), and *Macropanax undulatus* (IVI 1.572), had very low IVI values, suggesting they were either less resilient or less competitive in this HD environment. These species, though still present, contribute minimally to the overall forest structure. Several species, like *Morus nigra* (IVI 0.40), *Rhus chinensis* (IVI 0.45), and *Syzygium claviflorum* (IVI 0.46), had very low IVI values, indicating their diminished role in the ecosystem due to the high levels of disturbance. Overall, the HD ecosystem is characterized by a few dominant species with high IVI values, while a large number of species show reduced ecological importance. This suggests a loss of biodiversity and a more simplified community structure as a result of the disturbance (Table 4.10).

Table 4. 10: Species dominance along the disturbance gradient, based on the Importance Value Index (IVI).

Species Rank	Name of species	IVI (UD)	Name of species	IVI (MD)	Name of species	IVI (HD)
1	*Bischofia javanica* Blume.	26.00	*Schima wallichii* (DC.) Choisy	34.07	*Mesua ferrea* Linn.	45.77
2	*Castanopsis tribuloides* (Sm.). DC.	24.09	*Castronopsis tribuloides* A. DC	31.02	*Albizia chinensis* (Osbeck) Merr.	43.61
3	*Callicarpa arborea* Roxb.	19.04	*Parkia roxburghii* G.Don	30.65	*Albizia thompsonii* Brandis	41.72
4	*Sterculia villosa* Roxb.	14.74	*Sterculia villosa* Roxb.	30.46	*Artocarpus heterophyllus* Lam.	39.86
5	*Haldina cordifolia* (Roxb.) Ridsdale	14.06	*Tectona grandis* L. f.	24.31	*Parkia timoriana* (DC.) Merr	36.23
6	*Emblica officinalis* Gaertn.	12.17	*Rhus succedanea* Linn. var. acuminata (DC) Hook.	14.96	*Mangifera indica* L	32.35
7	*Acacia pennata* (L.) Willd.	10.58	*Acacia pennata* (L.) Willd.	14.21	*Phoebe attenuata* (Nees) Nees	23.89
8	*Spondias pinnata* (L. f.) Kurz	9.71	*Callicarpa arborea* Roxb.	12.00	*Schima wallichii* (DC.) Choisy	11.05
9	*Gmelina arborea* Roxb. ex Sm.	9.25	*Castanopsis indica* A.DC.	11.96	*Ficus benjamina* L.	4.74
10	*Prunus napaulensis* (Ser.) Steud	9.00	*Phoebe attenuata* (Nees) Nees	9.26	*Acacia pennata* (L.) Willd.	2.85
11	*Macropanax undulatus* (Wall. ex G.Don) Seem	8.99	*Gmelina arborea* Roxb. ex Sm.	9.03	*Acrocarpus fraxinifolius* Arn.	1.86
12	*Mallotus* sp.	8.29	*Parkia timoriana* (DC.) Merr.	8.45	*Betula alnoides* Buch.-Ham. Ex.Don	1.76
13	*Schima wallichii* (DC.) Choisy	8.11	*Haldina cordifolia* (Roxb.) Ridsdale	7.17	*Aporosa octandra* (Buch.-Ham. ex D.Don) Vickery	1.64
14	*Castronopsis indica* A.DC	7.77	*Acacia eburrea* (L.F.) Wild	3.38	*Macropanax undulatus* (Wall. Ex G. Don) Seem	1.57

15	*Eriobotrya bengalensis* (Roxb.) Hook.f.	7.61	*Albizia chinensis* (Osbeck) Merr.	2.74	*Wendlandia grandis* (Hook.f.) Cowan	1.13
16	*Wendlandia grandis* (Hook.f.) Cowan	7.61	*Diospyros lanceifolia* Roxb.	2.67	*Azadirachta indica* A. Juss	1.08
17	*Aporusa dioica* (Roxb.) Müll.Arg	7.28	*Phoebe cooperiana* P. C. Kanj. & Das.	2.15	*Macaranga indica* Wight	0.91
18	*Macaranga indica* Wight	7.26	*Macaranga indica* Wight	2.09	*Bauhinia variegata* Linn.	0.85
19	*Calophyllum polyanthum* Wall. Ex choisy	7.18	*Acrocarpus fraxinifolius* Wight.ex Arn	2.03	*Syzygium cumini* (L.) Skeels	0.85
20	*Quercus glauca* Thunb.	6.73	*Emblica officinalis* Gaertn	1.99	*Castanopsis tribuloides* (Sm.)	0.78
21	*Olea salicifolia* Wall. Ex G.Don	6.60	*Oroxylum indicum* (L.) Kurz	1.92	*Toxicodendron succedaneum* (L.) Kuntze	0.70
22	*Phoebe attenuata* (Nees) Nees	6.58	*Myrica esculenta* Buch.-Ham. ex D.Don	1.72	*Myrica esculenta* Buch.-Ham. ex D.Don	0.63
23	*Phoebe cooperiana* P. C. Kanj. & Das.	5.79	*Randia wallichii* Hooker f.	1.57	*Tamarindus indica* L.	0.54
24	*Phoebe hainesiana* Brandis	5.17	*Liquidambar excelsa* (Noronha) Oken	1.47	*Callicarpa arborea* Roxb	0.50
25	*Syzygium cumini* (L.) Skeels	4.87	*Artocarpus lakoocha* Roxb. (AL)	1.31	*Cinnamomum cassia* (L.) J.Presl	0.50
26	*Acacia eburrea* (L.F.) Wild	2.19	*Styrax serrulatum* Roxb.	1.27	*Oroxylum indicum* (L.) Kurz	0.48
27	*Albizia procera* (Roxb.) Benth.	1.87	*Dimocarpus longan* Lour.	1.26	*Syzygium claviflorum* (Roxb.) Wall. ex Steud.	0.46
28	*Derris Robusta* (DC) Benth	1.79	*Calophyllum polyanthum* Wall. Ex *choisy*	1.20	*Rhus chinensis* Mill.	0.45

29	*Albizia chinensis* (Osbeck) Merr.	1.62	*Dubanga grandifolia* (Roxb. ex DC.) Walp.	1.18	*Ficus curtipes* Corner	0.43
30	*Pithecellobium angulatum* Benth	1.60	*Persea glaucescens* (Nees) Long	1.13	*Calophyllum polyanthum* Wall. ex Choisy	0.42
31	*Machilus villosa* (Roxb.) Hook. Fil.	1.56	*Vitex canescens* Kurz	1.11	*Morus nigra* Linn	0.40
32	*Albizia odoratissima* (L.f.) Benth.	1.47	*Acer oblongum* Wall. ex DC.	1.10		
33	*Acer oblongum* Wall. ex DC.	1.47	*Eugenia macrocarpa* Cham. & Schltdl.	1.10		
34	*Alnus nepalensis* D. Don	1.41	*Premna racemosa* Wall. ex Schauer	1.08		
35	*Bombax insigne* Wall.	1.40	*Mallotus* sp.	1.07		
36	*Diospyros lanceifolia* Roxb.	1.40	*Ostodes paniculata* Blume	1.02		
37	*Meliosma pinnata* (Roxb.) Maxim.	1.40	*Bischofia javanica* Blume	0.98		
38	*Liquidambar excelsa* (Noronha) Oken	1.38	*Toddalia asiatica* (L.) Lam	0.96		
39	*Macaranga denticulata* (Blume) Müll.Arg.	1.16	*Albizia lebbeck* Benth.	0.94		
40	*Drysoxylum excelsum* Blume	1.06	*Canthium dicoccum* (Gaertn.) Merr.	0.92		
41	*Acrocarpus fraxinifolius* Wight.ex Arn	1.04	*Artocarpus heterophyllus* Lam	0.91		
42	*Premna racemosa* Wall. ex Schauer	0.95	*Oreocnide integrifolia* (Gaud.) Miq.	0.91		
43	*Bruinsmia polysperma* (C.B.Clarke) Steenis	0.89	*Meliosma pinnata* (Roxb.) Maxim.	0.90		

44	*Engelhardia spicata* Lechen ex Blume	0.86	*Debregeasia longifolia* (Burm. F.) Wedd.	0.79		
45	*Azadirachta indica* A. Juss	0.82	*Syzygium claviflorum* (Roxb.) Wall. ex Steud	0.79		
46	*Cinnamomum obtusifolium* (Roxb.) Nees	0.80	*Alnus nepalensis* D. Don	0.79		
47	*Rhus chinensis* Mill.	0.80	*Memecylon grande* Retz.	0.79		
48	*Duabanga grandiflora* (Roxb. ex DC.) Walp.	0.79	*Bruinsmia polysperma* (C.B.Clarke) Steenis	0.77		
49	*Delonix regia* (Hook.) Raf.	0.77	*Syzygium cuminii* var. Axillare (Gamble)	0.75		
50	*Albizia lebbeck* Benth.	0.76	*Palaquium polyanthum* (Wall. Ex G. Don) Baill.	0.59		
51	*Sterculia hamiltinii* (Kuntz)	0.74	*Ficus pyriformis* Hook. & Arn	0.54		
52	*Cassia* sp.	0.66	*Rhus chinensis* Mill.	0.53		
53	*Glochidion Khasicum* (Mull. Arg.) Hook.f.	0.63	*Carallia brachiata* (Lour.) Merr.	0.51		
54	*Bombax ceiba* Linn.	0.61	*Morus macroura* Miq.	0.51		
55	*Carallia brachiata* (Lour.) Merr.	0.60	*Pithecellobium angulatum* Benth	0.51		
56	*Tectona grandis* L. f.	0.60	*Terminalia bellirica* (Gaertn.) Roxb.	0.51		
57	*Cordia floribunda* (Desv.) Spreng.	0.56	*Albizia thompsonii* Brandis	0.49		
58	*Persea odoratissima* (Nees) Kosterm.	0.56	*Albizia procera* (Roxb.) Benth.	0.48		

59	*Schefflera wallichiana* (Wight & Arn.) Harms	0.53	*Bombax ceiba* Wall.	0.48		
60	*Ficus religiosa* Linn.	0.49	*Wendlandia grandis* (Hook.f.) Cowan	0.48		
61	*Randia wallichii* Hooker f.	0.46	*Wendlandia budleioides* Wall. Ex. Wight & Am	0.48		
62	*Oroxylum indicum* (L.) Kurz	0.45	*Xantolis assamica* (C. B. Clarke) P. Royen	0.48		
63	*Debregeasia longifolia* (Burm. F.) Wedd.	0.42	*Vernonia volkameriifolia* DC	0.47		
64	*Albizia thompsonii* Brandis.	0.41	*Ardisia solanacea* (Poir.) Roxb.	0.45		
65	*Anogeissus acuminata* (Roxb. ex DC.) Wall. Ex Guill. & Perr.	0.40	*Anogeissus acuminata* (Roxb. ex DC.) Wall. Ex Guillem. & Perr	0.45		
66	*Acer laevigatum* Wall.	0.37	*Macaranga denticulata* (Blume) Müll.Arg.	0.45		
67	*Melastoma nepalensis* Lodd.	0.36	*Aporosa octandra* (Buch.-Ham. ex D.Don)	0.44		
68	*Xantolis assamica* (C. B. Clarke) P. Royen	0.36	*Cinnamomum obtusifolium* (Roxb) Nees	0.44		
69	*Toxicodendron succedaneum* (L.) Kuntze	0.33	*Ficus religiosa* L.	0.44		
70	*Ficus tinctoria gibbosa* (Bl.) Corner	0.32	*Ficus* sp.	0.42		
71	*Ostodes paniculata* Blume	0.31	*Lithocarpus dealbatus* (Hook.f. & Thomson ex Miq.) Rehder	0.42		

72	*Olea dioica* Roxb.	0.30	*Drysoxylum excelsum* Blume	0.41		
73	*Toddalia asiatica* (L.) Lam	0.30	*Engelhardtia spicata* Lesch.Ex Blume	0.40		
74	*Ficus curtipes* Corner	0.29	*Derris Robusta* (DC) Benth	0.39		
75	*Styrax serrulatum* Roxb.	0.28	*Mangifera* sp.	0.39		
76	*Toona ciliata* M. Roem.	0.28	*Vitex quinata* F.N.Williams	0.39		
77	*Ulmus lancifolia* Roxb.	0.28	*Toona ciliata* M. Roem.	0.38		
78	*Oreocnide integrifolia* (Gaud.) Miq.	0.27	*Ficus curtipes* Corner	0.38		
79	*Cinnamomum tamala* T.Nees & Eberm.	0.26	*Tamarindus indica* Linn.	0.38		
80	*Lithocarpus dealbatus* (Hook.f. & Thomson ex Miq.) Rehder	0.26				
81	*Terminalia bellirica* (Gaertn.) Roxb.	0.26				
82	*Vitex quinata* F.N.Williams	0.26				
83	*Xylia xylocarpa* (Roxb.) Taub.	0.23				
84	*Wendlandia paniculata* (Roxb.) DC.	0.23				
85	*Syzygium claviflorum (*Roxb.) Wall. ex Steud.	0.23				
86	*Persea glaucescens* (Nees) Long	0.22				
87	*Symplocos theifolia* D.Don	0.22				

The species rank based upon the Importance Value Index (IVI) on the log scale was used to determine the species dominance curve. The dominant curve in the UD and MD stands was log-normal representing the stable and complex community, whereas a short-hooked curve was reported in HD stand representing the unstable community (Fig. 4.4).

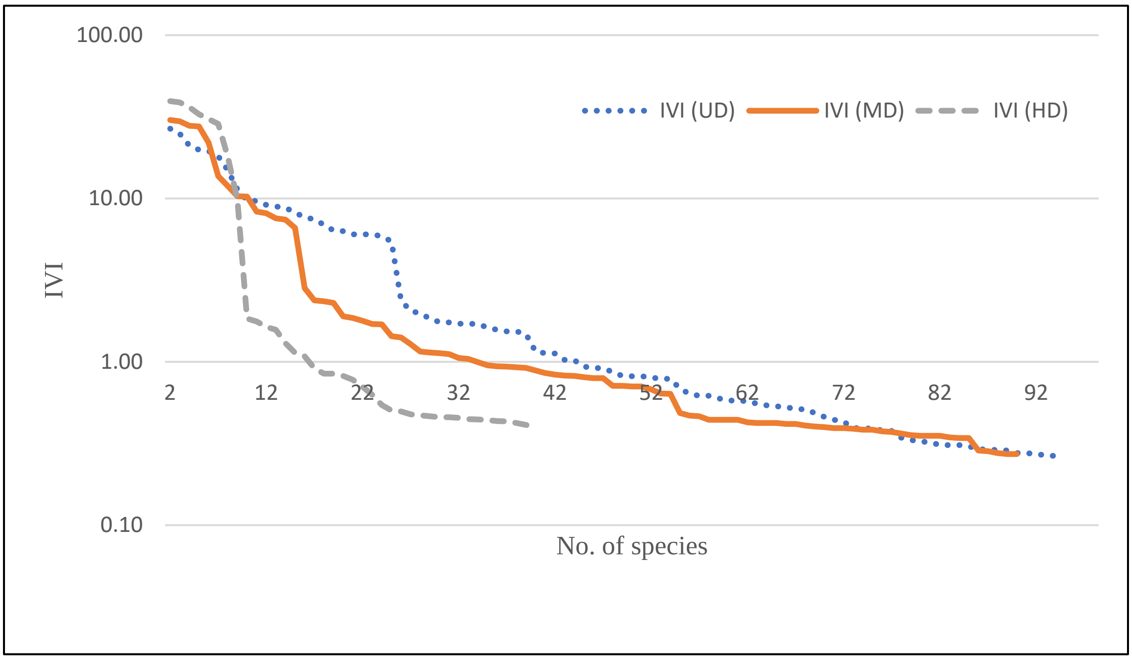


Figure 4. 4: Species dominance curve along the disturbance gradient, based on the Importance Value Index (IVI).

4.2.3: Family dominance-distribution of tree species

In the UD fabaceae was the most dominant family (10 species) followed by Lauraceae (8 species) and Euphorbiaceae (6 species). In the MD fabaceae was the most dominat family (10 species) followed by Moraceae (6 species) and Lauraceae (6 species). In the HD abaceae was the most dominat family (6 species) followed by Moraceae (4 species) and Anacardiaceae (3 species). Table 4.11

Table 4. 11: Family dominance along a disturbance gradient.

Family Rank	Family	No. of species (UD)	Family	No. of species (MD)	Family	No. of species (HD)
1	Fabaceae	10	Fabaceae	10	Fabaceae	6
2	Lauraceae	8	Moraceae	7	Moraceae	4
3	Euphorbiaceae	6	Lauraceae	5	Anacardiaceae	3
4	Fagacea	4	Rubiaceae	5	Lauraceae	2
5	Malvaceae	4	Anacardiaceae	4	Myrtaceae	2
6	Rubiaceae	4	Euphorbiaceae	4	Araliaceae	1
7	Anacardiaceae	3	Fagaceae	3	Betulaceae	1
8	Meliaceae	3	Lamiaceae	3	Bignoniaceae	1
9	Mimosoideae	3	Myrtaceae	3	Calophyllaceae	1
10	Moraceae	3	Phyllanthaceae	3	Clusiaceae	1
11	Verbenaceae	3	Verbenaceae	3	Euphorbiaceae	1
12	Aceraceae	2	Asteraceae	2	Fagaceae	1
13	Combretaceae	2	Combretaceae	2	Leguminosae	1
14	Lamiaceae	2	Malvaceae	2	Meliaceae	1
15	Myrtaceae	2	Meliaceae	2	Myricaceae	1
16	Oleaceae	2	Sapindaceae	2	Phyllanthaceae	1
17	Rosaceae	2	Sapotaceae	2	Rubiaceae	1
18	Styracaceae	2	Urticaceae	2	Theaceae	1
19	Urticaceae	2	Altingiaceae	1	Verbenaceae	1
20	Altingiaceae	1	Betulaceae	1		
21	Araliaceae	1	Bignoniaceae	1		
22	Betulaceae	1	Caesalpiniaceae	1		
23	Bignoniaceae	1	Calophyllaceae	1		
24	Boraginaceae	1	Cannabaceae	1		
25	Caesalpiniaceae	1	Ebenaceae	1		
26	Calophyllaceae	1	Ericaceae	1		
27	Ebenaceae	1	Junglandaceae	1		
28	Guttiferae	1	Lythraceae	1		
29	Juglandaceae	1	Melastomataceae	1		
30	Leguminosae	1	Meliosmaceae	1		
31	Lythraceae	1	Mimosaceae	1		
32	Melastomataceae	1	Myricaceae.	1		
33	Meliosmaceae	1	Myrsinaceae	1		
34	Papilionoideae	1	Oleaceae	1		

35	Phyllanthaceae	1	Papilionoideae	1		
36	Rhizophoraceae	1	Rhamnaceae	1		
37	Rutaceae	1	Rhizophoraceae	1		
38	Symplocaceae	1	Rutaceae	1		
39	Theaceae	1	Scrophulariaceae	1		
40	Ulmaceae	1	Styracaceae	1		
41			Styracaceae	1		
42			Symplocaceae	1		
43			Theaceae	1		

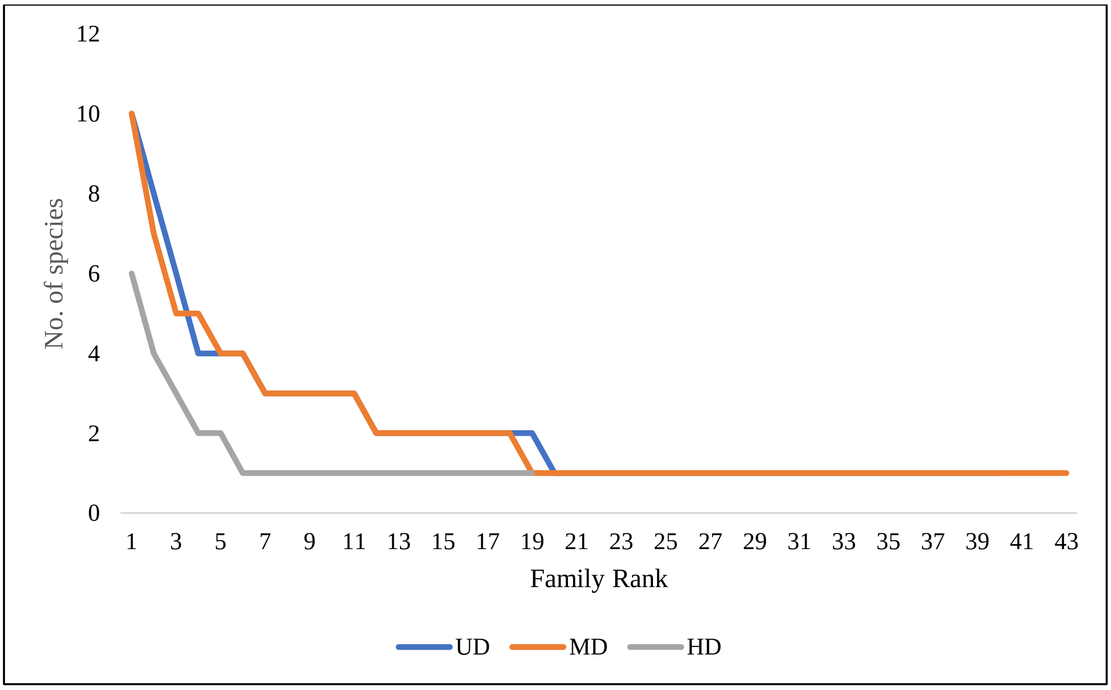


Figure 4. 5: Family dominance-distribution curve along the disturbance gradient.

4.2.4 Population Structure of Tree Species

The basal area and tree density in different girth classes along the disturbance gradient give an insight into the population structure of the forest. In all stands basal area and tree density were highest in girth class 30-60 cm, except the highest basal area in the girth class 90-120 cm under UD. Moreover, the girth class was reduced from 210-240 cm in UD to 150-180 cm in MD to 120-150 cm in HD stand, this could be attributed to disturbance (Fig. 4.6, 4.7 and 4.8).

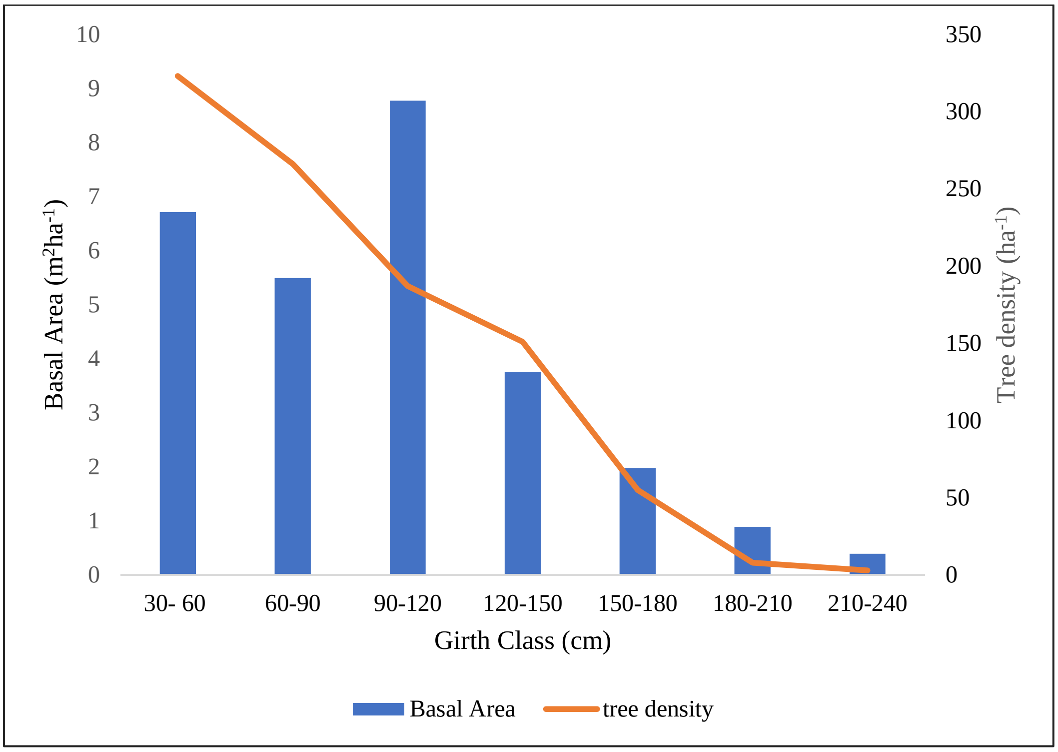


Figure 4. 6: Basal area and tree density in the undisturbed stand.

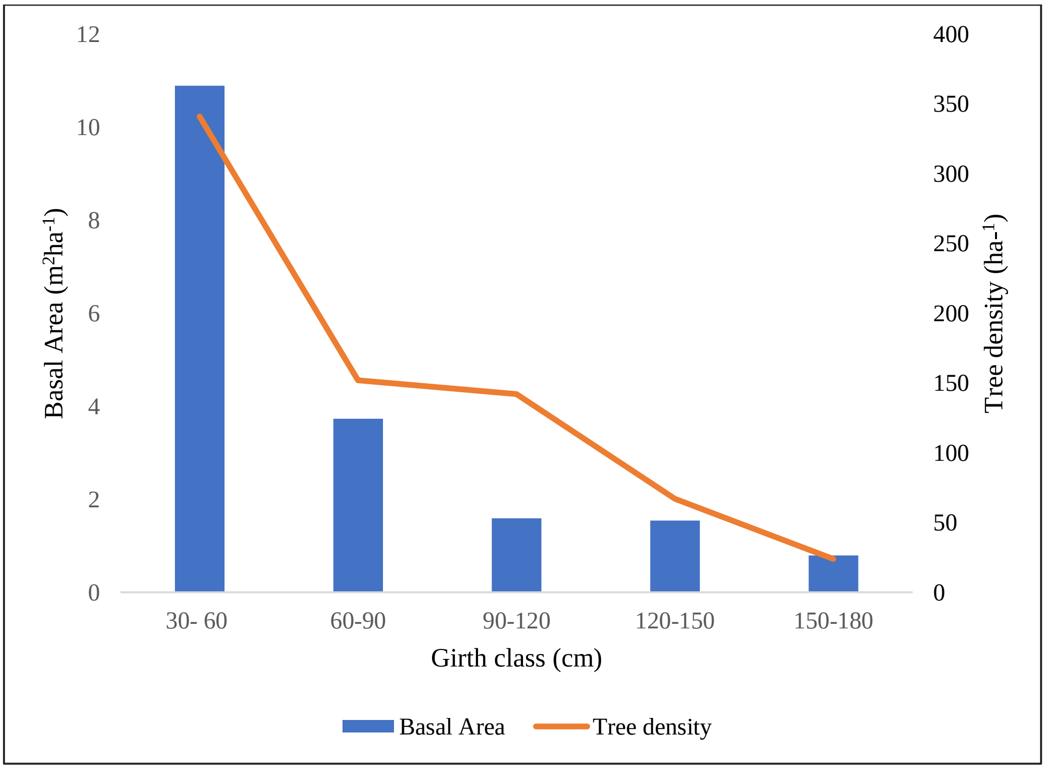


Figure 4. 7: Basal Area and tree density in the moderately disturbed stand.

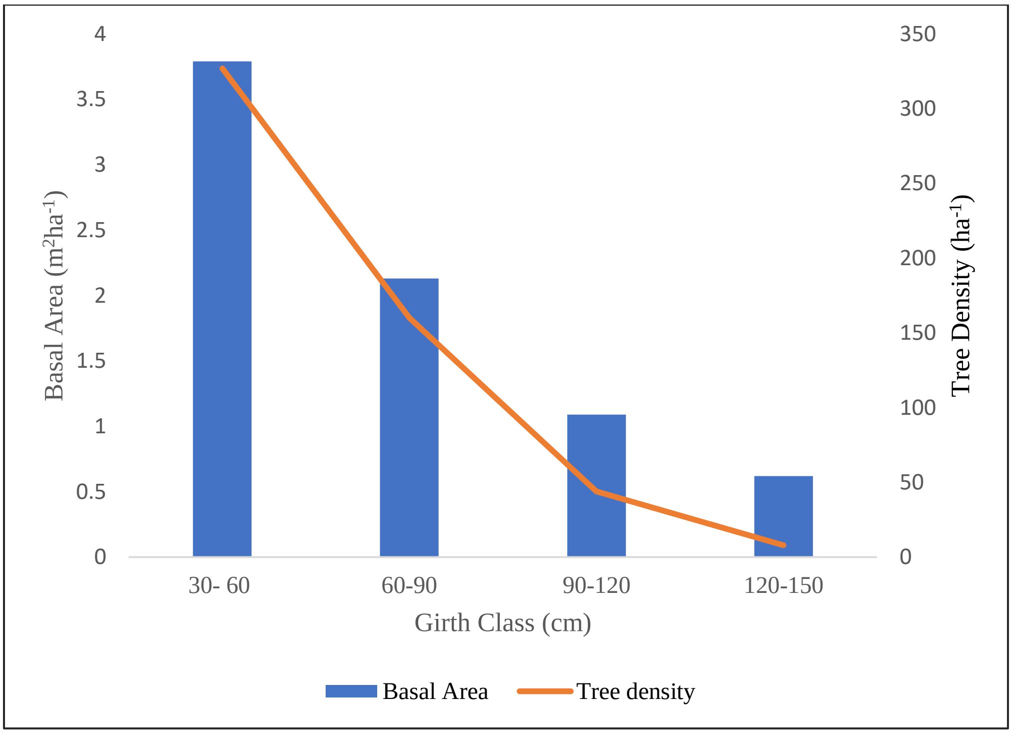


Figure 4. 8: Basal Area and tree density in the highly disturbed stand.

4.3 Community characteristics of shrub species

A total of 33 species belonging to 31 genera and 22 families, 46 species belonging to -41 genera and 25 families, and 41 species belonging to 38 genera and 27 families were recorded from UD, MD and HD stands. The Shannon Diversity Index (H') is the measure of overall diversity and is computed as 3.34 in UD, 3.62 in MD and 3.48 in HD. The Simpson index of Dominance was 0.962 in UD, 0.968 in MD and 0.963 in HD. Margalef's Species Richness index was highest in MD (7.21) as moderate disturbance supports high species richness followed by HD and UD in decreasing order of values. The Evenness index declined slightly as disturbance increased, with the highest value in the UD stand (0.958) and the lowest in the HD stand (0.938). (Table 4.12).

Table 4. 12: Community characteristics of shrub species in the undisturbed, moderately disturbed and highly disturbed forest stands.

	Stands		
Phytosociological attributes	Undisturbed	Moderately Disturbed	Highly Disturbed
Number of species	33	46	41
Number of genera	31	41	38
Number of Family	22	25	27
Shannon diversity index	3.34	3.62	3.48
Simpson dominance index	0.962	0.968	0.963
Margalef`s species richness index	4.87	7.21	5.87
Evenness index	0.958	0.942	0.938

The various shrub species, their families, and key ecological parameters such as density, frequency, abundance, A/F ratio, and distribution pattern are given in Table 4.13, 4.14 and 4.15. A total of 33 shrub species were reported from UD, 46 from MD and 41 from HD. The *Rubus birmanicus* was the most dominat species in UD. *Chromolaena odorata* was the most shrub species dominat species in MD (Table 4.13 to 4.15).

Table 4. 13: Community characteristics of shrub species in the undisturbed forest stand.

Sl no.	Name of species	Family	Density (D) (Indiv ha^{-1})	Frequency (F)	Abundance (A)	A/F Ratio	Distribution Pattern
1	*Bauhinia divaricata* Plum. ex L.	Fabaceae	25	14	1.79	0.13	C
2	*Berberis camcina* Hook.f.	Berberidaceae	23	12	1.92	0.16	C
3	*Blumea lanceolaria* (Roxb.) Druce	Asteraceae	13	6	2.17	0.36	C
4	*Bridelia stipularis* (L.) Blume.	Phyllanthaceae	28	22	1.27	0.06	C
5	*Butea parviflora* (Roxb)	Leguminosae	23	14	1.64	0.12	C
6	*Camellia caudate* Wall.	Theaceae	21	21	1.00	0.05	RA
7	*Cissus repens* Lam.	Vitaceae	31	15	2.07	0.14	C
8	*Dalbergia stipulacea* Roxb.	Leguminosae	12	8	1.50	0.19	C
9	*Debregeasia longifolia* (Burm.f.) Wedd.	Urticaceae	35	22	1.59	0.07	C
10	*Desmodium gyroids* (Roxb. ex Link)	Fabaceae	28	15	1.87	0.12	C
11	*Dicellostyles jujubifolia* (Griff.) Benth.	Malvaceae	10	8	1.25	0.16	C
12	*Dioscorea sikkimensis* Prain & Burkill	Dioscoreaceae	29	15	1.93	0.13	C

13	*Elatostema dissectum* Wedd.	Urticaceae	5	2	2.50	1.25	C
14	*Eranthemum palatiferum* Nees var. elata	Acanthaceae	25	17	1.47	0.09	C
15	*Flemingia macrophylla* (Willd) Kuntze ex Merr	Fabaceae	19	9	2.11	0.23	C
16	*Flemingia stricta* Roxb.	Fabaceae	17	13	1.31	0.10	C
17	*Garcinia cowa* Roxb ex Choisy	Clusiaceae	43	18	2.39	0.13	C
18	*Inula cappa* (Buch.-Ham. ex D.Don) DC.	Asteraceae	21	9	2.33	0.26	C
19	*Ipomoea cymosa* Roth var. Macra C.B.Clarke	Convolvulaceae	37	15	2.47	0.16	C
20	*Ligustrum robustum* (Roxb.) Blume	Oleaceae	30	22	1.36	0.05	C
21	*Lycopodium* sp.	Lycopodiaceae	9	7	1.29	0.14	C
22	*Merremia umbellata* (L.) Hallier f.	Convolvulaceae	22	15	1.47	0.07	C
23	*Mussaenda roxburghii* Hook.f.	Rubiaceae	30	18	1.67	0.06	C
24	*Mycetia longifolia* (Wall.) Kuntze	Rubiaceae	10	9	1.11	0.11	C
25	*Osbeckia* sp.	Melastomaceae	13	3	4.33	0.33	C
26	*Polygonum chinense* L.	Polygonaceae	14	4	3.50	0.25	C
27	*Rhus succedanea* Linn.	Anacardiaceae	33	18	1.83	0.06	C

28	*Rhus typhina* Linn.	Anacardiaceae	14	8	1.75	0.13	C
29	*Rourea minor* (Gaertn.) Alston	Connaraceae	3	3	1.00	0.33	C
30	*Rubus birmanicus* Hook. f.	Rosaceae	53	10	5.30	0.10	C
31	*Tetrastigma bracteolatum* (Wall.) Planch.	Vitaceae	19	9	2.11	0.11	C
32	*Tithonia diversifolia* (Hemsl.) A.Gray	Asteraceae	11	5	2.20	0.20	C
33	*Toddalia asiatica* (L.) Lam.	Rutaceae	3	3	1.00	0.33	C

Abbreviation: C- Contagious distribution, RA- Random distribution, R-Regular distribution.

Table 4. 14: Community characteristics of shrub species in the moderately disturbed forest stand.

Sl no.	Name of species	Family	Density (D) (Indiv ha^{-1})	Frequency (F)	Abundance (A)	A/F Ratio	Distribution Pattern
1	*Bauhinia divaricata*. Plum. ex L.	Fabaceae	26	17	1.53	0.09	C
2	*Berberis* sp.	Berberidaceae	23	13	1.77	0.14	C
3	*Bridelia stipularis* (L.) Blume.	Phyllanthaceae	47	27	1.74	0.06	C
4	*Butea parviflora* (Roxb)	Fabaceae	34	25	1.36	0.05	RA
5	*Camellia caudate* Wall.	Theaceae	45	34	1.32	0.04	RA

6	*Camellia sinesnsis* (L.) Kuntze.	Theaceae	10	8	1.25	0.16	C
7	*Campylotropis thomsonii* (Benth. ex-Baker) Schindl.	Verbenaceae	15	14	1.07	0.08	C
8	*Campylotropis eriocarpa* (Maxima)	Fabaceae	11	4	2.75	0.69	C
9	*Citrus maxima* (Brum.) Merr.	Rutaceae	23	21	1.10	0.05	RA
10	*Chromolaena odorata* (L.) King & Rob	Asteraceae	82	42	1.95	0.05	RA
11	*Cissus repens* Lam.	Vitaceae	14	6	2.33	0.39	C
12	*Clerodendrum infortunatum* Linn.	Verbenaceae	21	14	1.50	0.11	C
13	*Crotalaria hirsute* Willd	Fabaceae	16	6	2.67	0.44	C
14	*Dalbergia stipulacea* Roxb.	Fabaceae	12	5	2.40	0.48	C
15	*Debregeasia longifolia* (Burm. F.) Wedd.	Urticaceae	12	4	3.00	0.75	C
16	*Dendrocnide sinuata* (Bl.) Chew	Urticaceae	16	7	2.29	0.33	C
17	*Desmodium gyroides* (Roxb. ex Link)	Fabaceae	43	32	1.34	0.04	RA
18	*Drysoxylum excelsum* Blume	Meliaceae	16	12	1.33	0.11	C
19	*Dubanga grandifolia* (Roxb. ex DC.) Walp.	Lythraceae	15	6	2.50	0.42	C
20	*Garcinia cowa* Roxb ex Choisy	Clusiaceae	16	5	3.20	0.64	C

21	*Jasminum laurifolium* Roxb. ex Hornem.	Oleaceae	13	3	4.33	1.44	C
22	*Lantana camara* Linn	Verbenaceae	43	29	1.48	0.05	RA
23	*Lepionurus sylvestris* Blume	Opiliaceae	17	13	1.31	0.10	C
24	*Lespedeza elliptica* Benth	Fabaceae	13	3	4.33	1.44	C
25	*Mycetia longifolia* (Wall.) Kuntze	Rubiaceae	16	5	3.20	0.64	C
26	*Mussaenda globra* Vahl	Rubiaceae	41	38	1.08	0.03	RA
27	*Mussaenda roxburghii* Hook.f.	Rubiaceae	39	21	1.86	0.09	C
28	*Ostodes paniculata* Blume.	Euphorbiaceae	11	5	2.2	0.44	C
29	*Palaquium polyanthum* (Wall. Ex G. Don) Baill.	Sapotaceae	29	12	2.21	0.20	C
30	*Piptanthus nepalensis* (Hook.) D.Don.	Fabaceae	33	14	2.35	0.16	C
31	*Pithecellobium angulatum* Benth.	Mimosaceae	16	13	1.231	0.09	C
32	*Randia longifolia* C.Gust.	Rubiaceae	11	2	5.50	2.75	C
33	*Rourea minor* (Gaertn.) Alston	Connaraceae	23	3	7.67	2.56	C
34	*Rubus birmanicus* Hook.f.	Rosaceae	45	28	1.61	0.06	C
35	*Smilax ovalifolia* Roxb	Smilacaceae	39	29	1.34	0.05	RA
36	*Solanum xanthocarpum* Schrad. &	Solanaceae	21	21	1.00	0.05	RA

	Wendl.						
37	*Tetrastigma bracteolatum* (Wall.) Planch.	Vitaceae	27	13	2.08	0.16	C
38	*Tetrastigma leucostaphylum* (Dennst.) N.P.Balakr.	Vitaceae	23	23	1.00	0.04	RA
39	*Thunbergia grandiflora* (Roxb. ex Rottl.) Roxb.	Acanthacea	85	41	2.07	0.05	RA
40	*Tithonia diversifolia* (Hemsl.) A.Gray	Asteraceae	55	22	2.50	0.11	C
41	*Tragia involucrate* L.	Euphorbiaceae	18	11	1.64	0.15	C
42	*Urena lobata* Linn.	Malvaceae	110	55	2.00	0.04	RA
43	*Vitex canescens* Kurz	Lamiaceae	28	21	1.33	0.06	C
44	*Vitis barbata* Wall.	Vitaceae	33	22	1.50	0.07	C
45	*Wendlandia paniculata* (Roxb.) DC.	Rubiaceae	22	14	1.57	0.11	C
46	*Zanthoxylum armatum* DC.	Rutaceae	42	25	1.68	0.07	C

Abbreviation: C- Contagious distribution, RA- Random distribution, R-Regular distribution.

Table 4. 15: Community characteristics of shrub species in the highly disturbed forest stand.

Sl no	Name of species	Family	Density (D) (indiv ha^{-1})	Frequency (F)	Abundance (A)	A/F Ratio	Distribution Pattern
1	*Aspidopterys nutans* (Roxb.)	Malpighiaceae	25	15	1.67	0.11	C
2	*Bauhinia camcina* L.	Fabaceae	45	26	1.73	0.07	C
3	*Berberis* sp.	Berberidaceae	16	13	1.23	0.09	C
4	*Bridelia stipularis* (L.) Blume.	Phyllanthaceae	22	16	1.38	0.09	C
5	*Butea parviflora* Roxb. ex G.Don	Fabaceae	36	22	1.64	0.07	C
6	*Cajanus cajan* (Linn.) Millsp**.**	Fabaceae	23	25	0.92	0.04	RA
7	*Campylotropis thomsonii* (Benth. ex-Baker) Schindl.	Verbenaceae	12	8	1.50	0.19	C
8	*Cassia occidentalis* L.	Fabaceae	11	9	1.22	0.14	C
9	*Cissus repens* Lam.	Vitaceae	17	11	1.55	0.14	C
10	*Dalbergia stipulacea* Roxb.	Fabaceae	33	14	2.36	0.17	C
11	*Debregeasia longifolia* (Burm.f.) Wedd.	Urticaceae	27	24	1.13	0.05	RA
12	*Desmodium gyroides* (Roxb. ex-Link)	Fabaceae	13	3	4.33	1.44	C

13	*Dicellostyles jujubifolia* (Griff.) Benth. & Hook.	Malvaceae	13	11	1.18	0.11	C
14	*Dioscorea* sp.	Dioscoreaceae	16	10	1.60	0.16	C
15	*Flemingia stricta* Roxb.	Fabaceae	15	13	1.15	0.09	C
16	*Garcinia cowa* Roxb ex Choisy	Clusiaceae	5	5	1.00	0.20	C
17	*Gossypium herbaceum* Linn.	Malvaceae	11	5	2.20	0.44	C
18	*Hibiscus fragrans* Roxb.	Malvaceae	17	6	2.83	0.47	C
19	*Hibiscus hispidissimus* Griff.	Malvaceae	10	4	2.50	0.63	C
20	*Hibiscus sabdariffa* L.	Malvaceae	8	3	2.67	0.89	C
21	*Hodgsonia macrocarpa* (Blume) Cogn	Cucurbitaceae	11	10	1.10	0.11	C
22	*Ipomoea cymosa* (Desr.) Roem. & Schult.	Convolvulaceae	16	5	3.20	0.64	C
23	*Lantana camara* Linn	Verbenaceae	45	15	3.00	0.20	C
24	*Lasianthus hookeri* Clarke ex Hooker	Rubiaceae	15	5	3.00	0.60	C
25	*Lepisanthes senegalensis* (Juss. ex Poir.) Leenh	Sapindaceae	12	10	1.20	0.12	C
26	*Melastoma nepalensis* Lodd	Melastomataceae	19	11	1.73	0.16	C

27	*Merremia umbellata (*L.) Hallier f.	Convolvulaceae	9	8	1.13	0.14	C
28	*Mussaenda gandra* Vahl	Rubiaceae	55	28	1.96	0.07	C
29	*Mussaenda roxburghii* Hook. f.	Rubiaceae	65	25	2.60	0.10	C
30	*Persicaria wallichii* W. Greuter & Burdet	Polygonaceae	22	2	11.00	5.50	C
31	*Piptanthus nepalensis* (Hook.) D.Don.	Papillionaceae	25	11	2.27	0.21	C
32	*Rourea minor* (Gaertn.) Alston	Connaraceae	4	3	1.33	0.44	C
33	*Rubus birmanicus* Hook. f.	Rosaceae	23	13	1.77	0.14	C
34	*Solanum xanthocarpum* Schrad. & Wendl.	Solanaceae	3	3	1.00	0.33	C
35	*Tetrastigma bracteolatum* (Wall.) Planch.	Vitaceae	12	4	3.00	0.75	C
36	*Tetrastigma leucostaphylum* (Dennst.) N.P.Balakr.	Vitaceae	18	10	1.80	0.18	C
37	*Tithonia diversifolia* (Hemsl.) A.Gray	Asteraceae	25	21	1.19	0.06	C
38	*Tragia involucrata* Linn.	Euphorbiaceae	34	14	2.43	0.17	C
39	*Urena lobata* Linn.	Malvaceae	86	24	3.58	0.15	C

40	*Vitex canescens* Kurz	Lamiaceae	19	9	2.11	0.23	C
41	*Vitis barbata* Wall.	Vitaceae	16	10	1.60	0.16	C

Abbreviation: C- Contagious distribution, RA- Random distribution, R-Regular distribution.

4.3.1 Dominance-distribution of shrub species

The dominance distribution of species was determined based on IVI values. The most dominant species was *Rourea minor* (IVI-27.78) in the UD and followed by *Mycetia longifolia* (IVI-21.26) and *Toddalia asiatica* (IVI-17.25) in the UD**,** *Zanthoxylum armatum* (IVI-19.51) in the MD and followed by *Pithecellobium angulatum* (IVI-18.92) and Urena lobata (IVI-15.44), and *Butea parviflora* (IVI-44.24) in the HD and followed by *Mussaenda gandra* (IVI-22.37) and *Bridelia stipularis* (IVI-19.21) (Table 4.16).

Table 4. 16: Species dominance along the disturbance gradient, based on the Importance Value Index (IVI).

Species Rank	Name of species	IVI (UD)	Name of species	IVI (MD)	Name of species	IVI (HD)
1	*Rourea minor* (Gaertn.) Alston	27.78	*Zanthoxylum armatum* DC.	19.51	*Butea parviflora* Roxb. ex G.Don	44.24
2	*Mycetia longifolia* (Wall.) Kuntze	21.26	*Pithecellobium angulatum* Benth	18.92	*Mussaenda gandra* Vahl	22.37
3	*Toddalia asiatica* (L.) Lam.	17.25	*Urena lobata* Linn.	15.44	*Bridelia stipularis* (L.) Blume	19.21
4	*Rubus birmanicus* Hook.f.	15.82	*Lantana camara* Linn	13.65	*Urena lobata* Linn.	15.40
5	*Garcinia cowa* Roxb ex Choisy	15.48	*Wendlandia paniculata* (Roxb.) DC.	13.55	*Mussaenda roxburghii* Hook. f.	14.99
6	*Rhus succedanea* Linn	13.22	*Palaquium polyanthum* (Wall. Ex G. Don) Baill.	12.47	*Dalbergia stipulacea* Roxb.	12.54
7	*Tetrastigma bracteolatum* (Wall.) Planch.	11.09	*Chromolaena odorata* (L.) R.M. King & H. Rob	12.16	*Tetrastigma leucostaphylum* (Dennst.) N.P.Balakr.	12.27

8	*Debregeasia longifolia* (Burm.f.) Wedd.	10.19	*Thunbergia grandiflora* (Roxb. ex Rottl.) Roxb.	11.66	*Debregeasia longifolia* (Burm.f.) Wedd.	10.70
9	*Bridelia stipularis* (L.) Blume	10.03	*Butea parviflora* (Roxb)	10.01	*Bauhinia acuminata* L.	10.55
10	*Ligustrum robustum* (Roxb.) Blume	9.96	*Mussaenda globra* Vahl	8.29	*Lantana camara* Linn	9.77
11	*Blumea lanceolaria* (Roxb.) Druce	9.40	*Desmodium gyroides* (Roxb. ex Link)	8.27	*Vitis barbata* Wall.	9.01
12	*Mussaenda roxburghii* Hook.f.	9.31	*Bridelia stipularis* (L.) Blume.	8.00	*Cajanus cajan* (Linn.) Millsp**.**	7.81
13	*Camellia caudate* Wall.	9.10	*Camellia caudate* Wall.	7.83	*Tithonia diversifolia* (Hemsl.) A.Gray	7.22
14	*Cissus repens* Lam	9.06	*Dubanga grandifolia* (Roxb. ex-DC.) Walp.	7.63	*Tragia involucrata* Linn.	6.81
15	*Ipomoea cymosa* Roth var. macra C.B.Clarke	8.80	*Mycetia longifolia* (Wall.) Kuntze	7.39	*Piptanthus nepalensis* (Hook.) D.Don.	6.16
16	*Rhus typhina* L.	8.38	*Drysoxylum excelsum* Blume	7.24	*Vitex canescens* Kurz	5.90
17	*Dioscorea sikkimensis* Prain & Burkill	7.70	*Rubus birmanicus* Hook.f.	7.12	*Aspidopterys nutans* (Roxb.)	5.85
18	*Eranthemum palatiferum* Nees var. Elata	7.70	*Tithonia diversifolia* (Hemsl.) A.Gray	6.98	*Rubus birmanicus* Hook.f.	5.48
19	*Butea parviflora* (Roxb)	7.63	*Smilax ovalifolia* Roxb	6.79	*Berberis* sp.	4.53
20	*Desmodium gyroids* (Roxb. ex-Link)	7.62	*Campylotropis thomsonii* (Benth. ex-Baker) Schindl.	6.69	*Melastoma nepalensis* Lodd	4.39
21	*Bauhinia divaricata*. Plum. ex L.	6.89	*Citrus maxima* (Brum.) Merr.	6.42	*Flemingia stricta* Roxb.	4.36
22	*Merremia umbellata* (L.) Hallier f.	6.66	*Mussaenda roxburghii* Hook.f.	5.92	*Cassia occidentalis* L.	4.20

23	*Berberis camcina* Hook.f.	6.18	*Bauhinia divaricata* Plum. ex L.	5.57	*Cissus repens* Lam.	4.16
24	*Flemingia stricta* Roxb.	6.10	*Vitis barbata* Wall.	5.39	*Dicellostyles jujubifolia* (Griff.) Benth. & Hook.	3.97
25	*Inula cappa* (Buch.-Ham. ex D.Don) DC.	5.60	*Vitex canescens* Kurz	4.84	*Dioscorea* sp.	3.84
26	*Flemingia macrophylla* (Willd) Kuntze ex Merr	5.11	*Tetrastigma leucostaphylum* (Dennst.) N.P.Balakr.	4.75	*Hibiscus fragrans* Roxb.	3.78
27	*Dalbergia stipulacea* Roxb.	4.90	*Ostodes paniculata* Blume	4.39	*Desmodium gyroides* (Roxb. ex Link)	3.70
28	*Dicellostyles jujubifolia* (Griff.) Benth.	4.88	*Berberis* sp.	4.37	*Persicaria wallichii* W. Greuter & Burdet	3.53
29	*Polygonum chinense* Linn.	4.35	*Solanum xanthocarpum* Schrad. & Wendl.	4.30	*Lepisanthes senegalensis* (Juss. ex Poir.) Leenh	3.40
30	*Elatostema dissectum* Wedd.	3.46	*Piptanthus nepalensis* (Hook.) D.Don.	3.91	*Lasianthus hookeri* C. B. Clarke ex J. D. Hooker	3.37
31	*Osbeckia* sp.	3.27	*Garcinia cowa* Roxb ex Choisy	3.83	*Hodgsonia macrocarpa* (Blume) Cogn	3.29
32	*Lycopodium* sp.	2.99	*Tetrastigma bracteolatum* (Wall.) Planch.	3.81	*Campylotropis thomsonii* (Benth. ex Baker) Schindl.	3.11
33	*Tithonia diversifolia* (Hemsl.) A.Gray	2.84	*Clerodendrum infortunatum L.*	3.57	*Ipomoea cymosa* (Desr.) Roem. & Schult.	2.81
34			*Dendrocnide sinuata* (Bl.) Chew	3.48	*Merremia umbellata (*L.) Hallier f.	2.69
35			*Debregeasia longifolia* (Burm. F.) Wedd.	3.45	*Hibiscus hispidissimus* Griff.	2.64
36			*Dalbergia stipulacea* Roxb.	3.30	*Garcinia cowa* Roxb ex Choisy	2.49

37			*Lepionurus sylvestris* Blume	3.00	*Hibiscus sabdariffa* L.	2.41
38			*Tragia involucrate* L.	2.76	*Tetrastigma bracteolatum* (Wall.) Planch.	2.39
39			*Rourea minor* (Gaertn.) Alston	2.17	*Gossypium herbaceum* Linn	2.26
40			*Crotalaria hirsute* Willd.	1.97	*Rourea minor* (Gaertn.) Alston	1.38
41			*Cissus repens* Lam.	1.82	*Solanum xanthocarpum* Schrad. & Wendl.	1.01
42			*Camellia sinensis* (L.) Kuntze	1.79		
43			*Campylotropis eriocarpa* (Maxima)	1.57		
44			*Jasminum laurifolium* Roxb. ex Hornem.	1.48		
45			*Lespedeza elliptica* Benth	1.37		
46			*Randia longifolia* C.Gust.	1.16		

The Species dominance-distribution curve is plotted with the ranking of species based on their Importance Value Index. In the case of shrubs, a log-normal curve has been observed in all stands, indicating a stable community (Fig. 4.9).

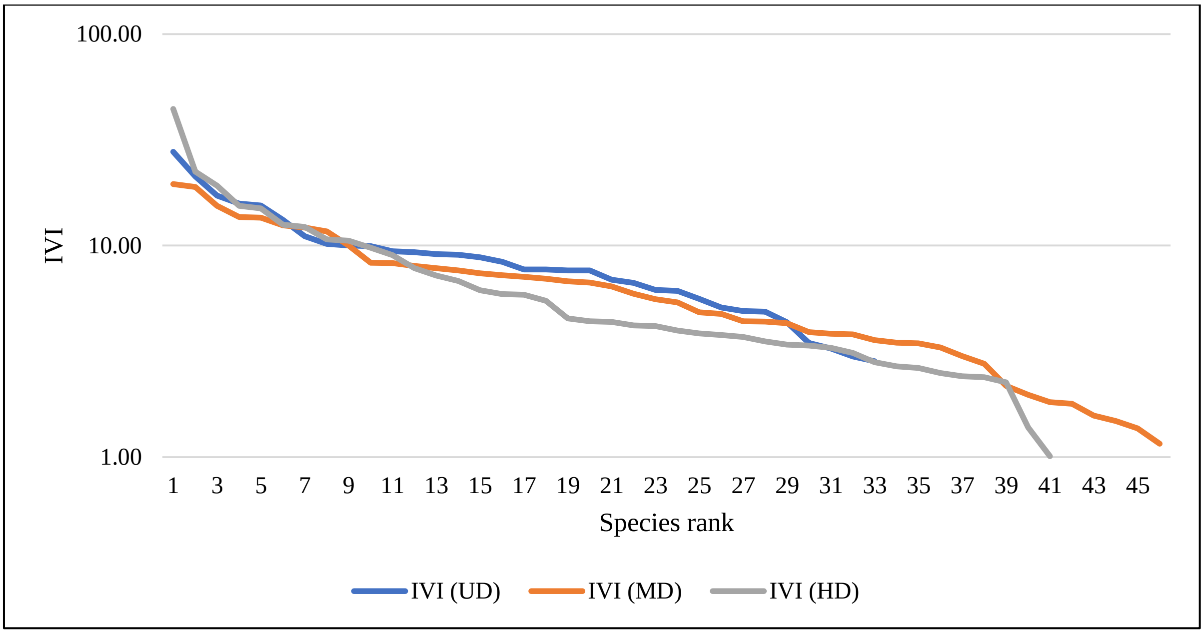


Figure 4. 9: Species dominance-distribution curve along the disturbance gradient.

4.3.2 Family dominance

The family dominance was determined on account of the number of species in the respective family. The most dominant family was Fabaceae (4 species) and was followed by Asteraceae (3 species) and Anacardiaceae Convolvulaceae, Leguminosae, Rubiaceae, Urticaceae, and Vitaceae (2 species each) in the UD; Fabaceae (8 species) and was followed by Rubiaceae (5 species) and Rubiaceae, Verbenaceae (3 species each) in the MD; Fabaceae (7 species) and followed by Malvaceae (6 species) and Vitaceae (4 species) in the HD. The Fabaceae maintained its dominance in all stands, however, there is a shift in the position of co-dominant families along the degree of disturbance. The family dominance curve indicates a large number of mono-specific families with a higher number in HD (Table 4.17).

Table 4. 17: Family dominance along the disturbance gradient.

Family Rank	Family	No. of species (UD)	Family	No. of species (MD)	Family	No. of species (HD)
1	Fabaceae	4	Fabaceae	8	Fabaceae	7
2	Asteraceae	3	Rubiaceae	5	Malvaceae	6
3	Anacardiaceae	2	Verbenaceae	3	Vitaceae	4
4	Convolvulaceae	2	Vitaceae	3	Rubiaceae	3
5	Leguminosae	2	Asteraceae	2	Convolvulaceae	2
6	Rubiaceae	2	Euphorbiaceae	2	Verbenaceae	2
7	Urticaceae	2	Rutaceae	2	Asteraceae	1
8	Vitaceae	2	Theaceae	2	Berberidaceae	1
9	Acanthaceae	1	Urticaceae	2	Clusiaceae	1
10	Berberidaceae	1	Acanthacea	1	Connaraceae	1
11	Clusiaceae	1	Berberidaceae	1	Cucurbitaceae	1
12	Connaraceae	1	Clusiaceae	1	Dioscoreaceae	1
13	Cucurbitaceae	1	Connaraceae	1	Euphorbiaceae	1
14	Dioscoreaceae	1	Lamiaceae	1	Lamiaceae	1
15	Euphorbiaceae	1	Lythraceae	1	Malpighiaceae	1
16	Lycopodiaceae	1	Malvaceae	1	Melastomataceae	1
17	Malvaceae	1	Meliaceae	1	Papillionaceae	1
18	Melastomaceae	1	Mimosaceae	1	Phyllanthaceae	1
19	Oleaceae	1	Oleaceae	1	Polygonaceae	1
20	Orchidaceae	1	Opiliaceae	1	Rosaceae,	1
21	Phyllanthaceae	1	Phyllanthaceae	1	Sapindaceae	1
22	Polygonaceae	1	Rosaceae	1	Solanaceae	1
23	Rosaceae	1	Sapotaceae	1	Urticaceae	1
24	Rutaceae	1	Solanaceae	1		
25	Theaceae	1				

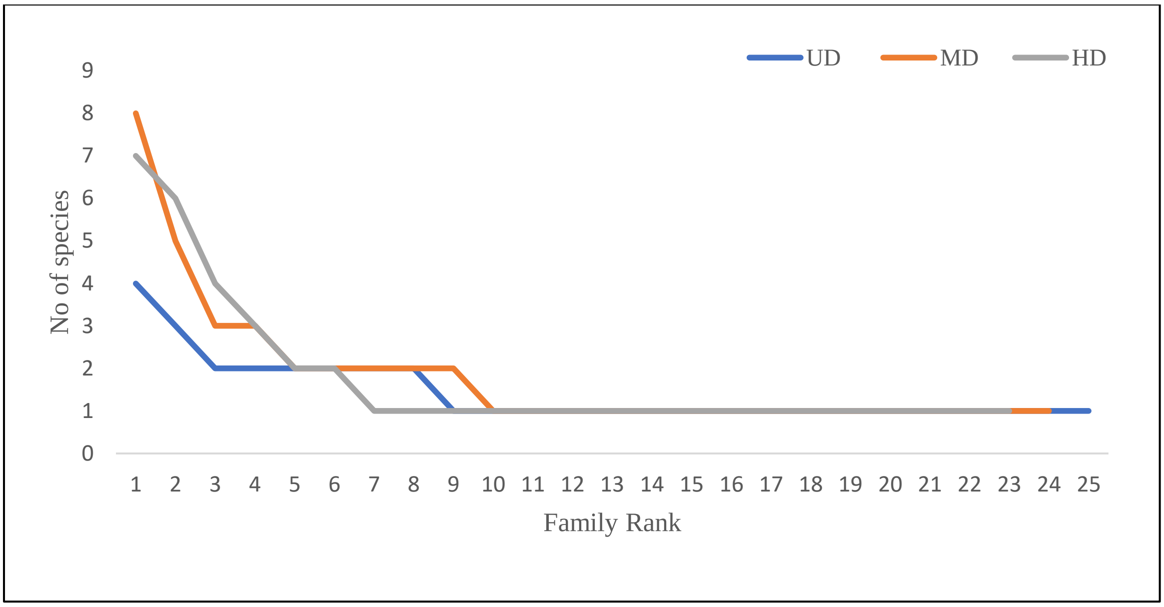


Figure 4. 10: Family dominance-distribution curve along the disturbance gradient.

4.4 Community Characteristics of Herbaceous Species

A total of 33 species belonging to 30 genera and 23 families from the UD, 62 species belonging to 51 genera and 22 families from the MD, and 93 species belonging to 81 genera and 33 families from the HD were reported during the investigation. The number of individuals per 100 m² was increased sharply from 531 in the UD to 3,556 in the HD. The Shannon diversity index, a measure of species diversity, reflected the trend, increasing from 3.29 in the UD to 3.95 in the HD. However, the Simpson dominance index varied from 0.948 in HD to 0.971 in UD. Margalef's index increased drastically from 4.251 in UD to 11.54 in HD. On the other hand, the evenness index declined from 0.957 in UD to 0.759 in HD (Table 4.18).

Table 4. 18: Community characteristics of herbs in the undisturbed, moderately disturbed and highly disturbed forest stands.

Phytosociological attributes	Undisturbed stand	Moderately Disturbed stand	Highly Disturbed stand
Number of Species	33	62	93
Number of Genus	30	51	81
Number of Family	23	22	33
Density (per100m^2)	531	1491	3556
Shannon diversity index	3.29	3.754	3.953
Simpson Dominance index	0.971	0.959	0.948
Margalef`s species richness index	4.251	7.424	11.54
Evenness index	0.957	0.910	0.759

In the UD forest stand species namely *Eragrostis nutans* (Poaceae) was the most dominant species, exhibited the highest density (67 individuals per 100m^2), and was followed by *Cyrtococcum accrescens* and *Ichnanthus vicinus* (both Poaceae). *Eragrostis nutans* also had lower frequency and highest abundance (11.17), indicating clumped distribution. In MD stand species namely *Bambusa tulda* and *Dendrocalamus hamiltonii* (Poaceae) were most dominant species, having density as 120 individuals per 100m^2 each, and was followed by *Pseudostachyum polymorphum* and *Bambusa nutans*. *Desmodium laxiflorum* from the Fabaceae family showed highest abundance (45) and very low frequency, reflecting restricted area of distribution. In HD stand *Kyllinga brevifolia* (Cyperaceae) was the most dominant species with the highest density at 340 individuals per 100m^2, and it was followed by *Imperata cylindrica* and *Eragrostis nutans*. *Solanum nigrum* has the highest abundance (14.06) and low frequency indicating clumped distribution (Table 4.19 to 4.21).

Table 4. 19: Community characteristics of herbaceous species in the undisturbed forest stand.

Sl no	Name of species	Family	Density (per $100m^2$)	Frequency (F)	Abundance (A)	A/F Ratio
1	*Aspidopterys nutans* (Roxb. Ex.DC.)	Malpighiaceae	11	9	1.22	0.14
2	*Adiantum caudatum* Linn	Pteridaceae	35	12	2.92	0.24
3	*Asplenium nidus* D. Don	Aspleniaceae	2	2	1.00	0.50
4	*Byttneria pilosa* Roxb.	Sterculiaceae	7	7	1.00	0.14
5	*Chamaecostus cuspidatus* (Nees & Mart.) C.D.Specht	Costaceae	5	5	1.00	0.20
6	*Commelina sikkimensis* C.B.Clarke	Commelinaceae	7	7	1.00	0.14
7	*Costus speciosus* (Koen) Sm.	Zingiberaceae	9	5	1.80	0.36
8	*Curanga amara* (Juss)	Solanaceae	3	1	3.00	3.00
9	*Cynoglossum wallichii* G.Don	Boraginaceae	12	8	1.50	0.19
10	*Cyperus cyperoides* (Linn.) Kuntz	Dioscoreaceae	5	5	1.00	0.20
11	*Cyrtococcum accrescens* (Trin) Stap f.	Poaceae	55	14	3.93	0.28
12	*Desmodium floribundum* (D. Don.) Sweet ex G. Don.	Fabaceae	32	12	2.67	0.22
13	*Dendrocalamus hamiltonii* Nees & Arn. ex Murno	Poaceae	5	5	1.00	0.20
14	*Desmodium triquetrum* (Linn.) D C.	Fabaceae	5	3	1.67	0.56

15	*Dicranopteris linearis* (Burm.f.)	Gleicheniaceae	2	2	1.00	0.50
16	*Diplazium maximum* (D. Don) C. Chr.	Athyriaceae	5	5	1.00	0.20
17	*Elatostema dissectum* Wedd.	Urticaceae	10	7	1.43	0.20
18	*Eragrostis nutans* (Retz) Nees ex steud	Poaceae	67	6	11.17	1.86
19	*Elatostema sessile* J.R.Forst. & G.Forst.	Utricaceae	3	3	1.00	0.33
20	*Globba multiflora* Wall.	Zingiberaceae	8	4	2.00	0.50
21	*Ichnanthus vicinus* (Bail.) Merr	Poaceae	55	14	3.93	0.28
22	*Impatiens laevigata* Wall. ex-Hook. f. & Thomson	Balsaminaceae	5	3	1.67	0.56
23	*Laportea crenulata* Gaud.	Asteraceae	42	15	2.80	0.19
24	*Leptochilus ellipticus* (Thunb.) Noot	Polypodiaceae	11	9	1.22	0.14
25	*Lysionotus serratus* D. Don	Gesneriaceae	9	5	1.80	0.36
26	*Lycopodium cernuum* Linn	Lycopodiaceae	8	5	1.60	0.32
27	*Lygodium flexuosum* (Linn.) Swartz	Lygodiaceae	25	8	3.13	0.39
28	*Ophiorrhiza ochroleuca* Hook.f.	Rubiaceae	1	1	1.00	1.00
29	*Ophiorrhiza trichocarpa* Bl.	Rubiaceae	5	5	1.00	0.20
30	*Persicaria wallichii* W. Greuter & Burdet	Polygonaceae	30	20	1.50	0.08
31	*Pothos cathcartii* Schott.	Araceae	2	7	0.29	0.04
32	*Pronephrium nudatum* Roxb.	Thelypteridaceae	43	11	3.91	0.36

33	*Urtica dioica* L.	Urticaceae	8	8	1.00	0.13

Table 4. 20: Community characteristics of herbaceous species in the moderately disturbed forest stand.

Sl no	Name of species	Family	Density (per 100m^2)	Frequency (F)	Abundance (A)	A/F Ratio
1	*Achyranthes aspera* Linn.	Amaranthaceae	22	1	22.00	22.00
2	*Achyranthes bidentata* Blume.	Amaranthaceae	2	1	2.00	2.00
3	Aeschynomene indica Linn	Papilionaceae	1	1	1.00	1.00
4	*Ageratum conyzoides* Linn	Asteraceae	22	9	2.44	0.27
5	*Argyreia speciosa* (Linn. f.)	Convolvulaceae	12	2	6.00	3.00
6	*Aspidopterys nutans* (Roxb. Ex.DC.)	Malpighiaceae	3	1	3.00	3.00
7	*Bidens biternata* (Lour.) Merr. & Sherff	Asteraceae	24	11	2.18	0.20
8	*Bambusa nutans* Wall.	Poaceae	112	13	8.62	0.66
9	*Bambusa tulda* Roxb.	Poaceae	120	13	9.23	0.71
10	*Bambusa bambos* (L.) Voss	Poaceae	101	17	5.94	0.35
11	*Campylotropis capillipes* (Franch.) Schindl.	Fabaceae	3	3	1.00	0.33
12	*Cardamine hirsute* Linn.	Brassicaceae	2	2	1.00	0.50
13	*Cardamine macrophylla* Willd	Brassicaceae	2	2	1.00	0.50

14	*Centella asiatica* (L.)	Apiaceae	13	2	6.50	3.25
15	*Commelina sikkimensis* Clarke	Commelinaceae	12	2	6.00	3.00
16	*Conyza bonariensis* (L.) Cronquist.	Asteraceae	15	5	3.00	0.60
17	*Cortaderia selloana* (Schult. & J.H. Schult.) Asch	Poaceae	16	2	8.00	4.00
18	*Crassocephalum crepidioides* (Benth.) S.Moore	Asteraceae	13	2	6.50	3.25
19	*Cyperus cyperoides* (L.) Kuntze	Cyperaceae	10	5	2.00	0.40
20	*Cyrtococcum accrescens* (Trin) Stapf.	Poaceae	15	5	3.00	0.60
21	*Dendrobium falconeri* Hook.	Orchidaceae	1	1	1.00	1.00
22	*Dendrocalamus hamiltonii* Nees & Arn. ex Munro	Poaceae	120	11	10.91	0.99
23	*Dendrocalamus strictus* (Roxb.) Nees	Poaceae	56	12	4.67	0.39
24	*Desmodium laxiflorum* DC.	Fabaceae	45	1	45.00	45.00
25	*Desmodium triquetrum* (L.) DC.	Fabaceae	3	1	3.00	3.00
26	*Dichrocephala integrifolia* (L.f.) Kuntze	Asteraceae	16	1	16.00	16.00
27	*Diplazium maximum* (D.Don) C.Chr.	Athyriaceae	11	1	11.00	11.00
28	*Eragrostis nutans* (Retz.) Nees ex Steud.	Poaceae	67	13	5.15	0.40
29	*Eranthemum palatiferum* (Nees)	Acanthaceae	1	1	1.00	1.00

30	*Imperata cylindrica* (L.)	Poaceae	22	10	2.20	0.22
31	*Inula cappa* (Buch. -Ham. ex D.Don)	Asteraceae	3	3	1.00	0.33
32	*Ichnanthus vicinus* (Bailey) Merr.	Poaceae	18	10	1.80	0.18
33	*Lespedeza cuneata* (Dum. Cours.) G. Don	Fabaceae	5	1	5.00	5.00
34	*Lycopodium cernuum* L.	Lycopodiaceae	3	3	1.00	0.33
35	*Lygodium flexuosum* (L.) Sw.	Lygodiaceae	2	2	1.00	0.50
36	*Mikania micrantha* (L.) Kunth ex HBK	Asteraceae	5	5	1.00	0.20
37	*Mimosa pudica* L.	Fabaceae	11	3	3.67	1.22
38	*Murdannia simplex* (Vahl) Brenan	Commelinaceae	2	2	1.00	0.50
39	*Musa paradisiaca* L.	Musaceae	23	13	1.77	0.14
40	*Musa* sp.	Musaceae	11	11	1.00	0.09
41	*Oxalis corniculata* L.	Oxalidaceae	50	20	2.50	0.13
42	*Parthenium hysterophorus* Linn.	Asteraceae	20	10	2.00	0.20
43	*Panicum punctatum* Burm.f.	Poaceae	10	10	1.00	0.10
44	*Paspalum longifolium* Roxb.	Poaceae	85	13	6.54	0.50
45	*Phrynium capitatum* Willd.	Marantaceae	30	12	2.50	0.21
46	*Pseudostachyum polymorphum* Munro	Poaceae	115	15	7.67	0.51
47	*Psophocarpus tetragonolobus* (L.) DC.	Fabaceae	5	1	5.00	5.00
48	*Pteridium aquilinum* (L.) Kuhn	Dennstaedtiaceae	5	2	2.50	1.25

49	*Rottboellia exaltata* Lf	Poaceae	15	5	3.00	0.60
50	*Saccharum longisetosum* (Andersson) V.Naray. ex Bor	Poaceae	26	9	2.89	0.32
51	*Schizachyrium brevifolium* (Sw.) Nees ex Buse	Poaceae	20	18	1.11	0.06
52	*Schizachyrium semiberbe* Nees	Poaceae	24	8	3.00	0.38
53	*Schizostachyum polymorphum* (Munro)	Poaceae	52	13	4.00	0.31
54	*Schizostachyum dullooa* (Gamble)	Poaceae	2	5	0.40	0.08
55	*Sida mysorensis* Linn.	Malvaceae	35	5	7.00	1.40
56	*Solanum khasianum* C.B.Clarke	Solanaceae	2	2	1.00	0.50
57	*Solanum nigrum* Linn	Solanaceae	3	3	1.00	0.33
58	*Sporobolus diander* (Retz.) P.Beauv.	Poaceae	17	7	2.43	0.35
59	*Thysanolaena maxima* Roxb.	Poaceae	8	8	1.00	0.13
60	*Triumfetta pilosa* Roth.	Malvaceae	15	5	3.00	0.60
61	*Vigna unguiculata* (L.) Walp.	Fabaceae	5	5	1.00	0.20
62	*Vernonia attenuata* DC	Asteraceae	2	2	1.00	0.50

Table 4. 21: Community characteristics of herbaceous species in the highly disturbed forest stand.

Sl no	Name of species	Family	Density (per $100m^2$)	Frequency	Abundance	A/F Ratio
1	*Abelmoschus esculentus* (L.) Moench	Malvaceae	22	2	11.00	5.50
2	*Achyranthes aspera* L.	Amaranthaceae	12	2	6.00	3.00
3	*Achyranthes bidentata* Blume	Amaranthaceae	14	2	7.00	3.50
4	*Aeschynomene indica* Linn.	Papilionaceae	17	7	2.43	0.35
5	*Ageratum conyzoides* Linn.	Asteraceae	200	19	10.12	2.47
6	*Amaranthus viridis* Linn.	Amaranthaceae	5	5	1.00	0.20
7	*Anisochilus pallidus* Wall. ex Benth.	Lamiaceae	10	10	1.00	0.10
8	*Bambusa bambos* (L.) Voss	Poaceae	33	12	2.75	5.00
9	*Bambusa nutans* Wall	Poaceae	35	10	3.50	0.35
10	*Bambusa tulda* Roxb.	Poaceae	20	8	2.50	0.31
11	*Benincasa hispida* (Thunb.) Cogn.	Cucurbitaceae	2	2	1.00	0.50
12	*Bidens biternata* (Lour.) Merr. & Sherff	Asteraceae	110	2	55.00	27.50
13	*Bidens pilosa* (Linn.)	Asteraceae	13	11	1.18	0.11
14	*Blechnum orientale* L.	Blechnaceae	8	8	1.00	0.13
15	*Boenninghausenia albiflora* (Hook.) Rchb. ex Meisn.	Rutaceae	4	4	1.00	0.25

16	*Borreria stricta* (Lf) K.Schum.	Rubiaceae	2	2	1.00	0.50
17	*Botrychium lanuginosum* Wall. ex Hook. & Grev.	Ophioglossaceae.	7	7	1.00	0.14
18	*Capsicum annuum* Linn.	Solanaceae	3	1	3.00	3.00
19	*Capsicum frutescens* Linn.	Solanaceae	1	1	1.00	1.00
20	*Centella asiatica* L	Apiaceae	15	5	3.00	0.60
21	*Conyza bonariensis* (L.) Cronquist	Asteraceae	45	5	9.00	1.80
22	*Cortaderia selloana* (Schult. & J.H. Schult.) Asch	Poaceae	50	10	5.00	0.50
23	*Crassocephalum crepidioides* (Benth.) S.Moore	Asteraceae	5	5	1.00	0.20
24	*Curcuma longa* Linn.	Zingiberaceae	5	5	1.00	0.20
25	*Cynodon dactylon* (Linn.) Pers.	Poaceae	10	10	1.00	0.10
26	*Cyperus cyperoides* (L.) Kuntze	Cyperaceae	235	35	6.71	0.19
27	*Cyperus rotundus* L.	Cyperaceae	8	8	1.00	0.13
28	*Cyrtococcum accrescens* (Trin) Stapf.	Poaceae	17	15	1.13	0.08
29	*Dendrobium falconeri* Hook.	Orchidaceae	2	1	1.00	22.00
30	*Dendrocalamus hamiltonii* Nees & Arn. ex Munro	Poaceae	30	7	4.29	0.61
31	*Desmodium laxiflorum* DC.	Fabaceae	8	8	1.00	0.13
32	*Desmodium triquetrum* (L.) DC.	Fabaceae	8	4	2.00	0.50
33	*Dichanthium annulatum* (Forssk.) Stapf	Poaceae	60	15	4.00	0.27
34	*Dichrocephala integrifolia* (L.f.) Kuntze	Asteraceae	9	9	1.00	0.11

35	*Drymaria diandra* Blume	Caryophyllaceae	3	3	1.00	0.33
36	*Drymaria villosa* Schltdl. & Cham.	Fabaceae	4	4	1.00	0.25
37	*Eragrostis nutans* (Retz.) Nees ex Steud.	Poaceae	257	32	8.03	0.25
38	*Galinsoga parviflora* (Cav.)	Asteraceae	2	2	1.00	0.50
39	*Gynura bicolor* (Roxb. ex Willd.) DC.	Asteraceae	9	8	1.13	0.14
40	*Ichnanthus vicinus* (F.M.Bailey) Merr.	Poaceae	5	5	1.00	0.20
41	*Impatiens chinensis* Linn.	Balsaminaceae	11	4	2.75	0.69
42	*Imperata cylindrica* (L.) Raeusch.	Poaceae	295	40	7.38	0.18
43	*Ipomoea hederifolia* L.	Convolvulaceae	8	8	1.00	0.13
44	*Kyllinga brevifolia* Rottb.	Cyperaceae	340	25	13.60	0.54
45	*Laggera flava* (DC.) Benth. & Hook.f.	Asteraceae	10	9	1.11	0.12
46	*Lactuca indica* L.	Asteraceae	11	1	11.00	11.00
47	*Lepidagathis hyaline* Nees in Wall.	Acanthaceae	5	5	1.00	0.20
48	*Lobelia angulata* G.Forst.	Campanulaceae	7	7	1.00	0.14
49	*Lobelia colorata* Sweet.	Campanulaceae	11	3	3.67	1.22
50	*Lycopodium cernuum* L.	Lycopodiaceae	12	5	2.40	0.48
51	*Lygodium flexuosum* (L.) Sw.	Lygodiaceae	8	8	1.00	0.13
52	*Melocalamus compactiflora* (Kurz)	Poaceae	50	8	6.25	0.78
53	*Melocanna baccifera* (Roxb) Kurz	Poaceae	10	10	1.00	0.10

54	*Melochia corchorifolia* Linn	Malvaceae	6	6	1.00	0.17
55	*Mikania micrantha* (L.) Kunth ex HBK	Asteraceae	8	8	1.00	0.13
56	*Mimosa pudica* L	Fabaceae	50	21	2.38	0.11
57	*Mucuna pruriens* (Linn.) DC	Fabaceae	18	8	2.25	0.28
58	*Murdannia simplex* (Vahl) Brenan	Commelinaceae	23	2	11.50	5.75
59	*Musa* sp.	Musaceae	15	8	1.88	0.23
60	*Myriactis wallichii* Less.	Asteraceae	10	10	1.00	0.10
61	*Oxalis corniculata* L.	Oxalidaceae	24	4	6.00	1.50
62	*Paspalum longifolium* Roxb.	Poaceae	35	26	1.35	0.05
63	*Phaseolus vulgaris* L.	Fabaceae	13	6	2.17	0.36
64	*Polygonum hydropipe*r Linn.	Polygonaceae	15	5	3.00	0.60
65	*Phyllanthus glaucus* Wall. Ex Müll.Arg.	Phyllanthaceae	8	8	1.00	0.13
66	*Physalis minima* Linn.	Solanaceae	18	12	1.50	0.13
67	*Peperomia pellucida* (L.) Kunth	Piperaceae	6	6	1.00	0.17
68	*Plantago major* Linn.	Plantaginaceae	13	2	6.50	3.25
69	*Pennisetum polystachion* (L.) Schult.	Poaceae	45	21	2.14	0.10
70	*Polygonum alatum* Buch. -Ham. Ex D.Don	Polygonaceae	11	10	1.10	0.11
71	*Polygonum chinense* Linn.	Polygonaceae	10	10	1.00	0.10
72	*Parthenium hysterophorus* Linn.	Asteraceae	19	7	2.71	0.39

73	*Psophocarpus tetragonolobus* (L.) DC.	Fabaceae	12	5	2.40	0.48
74	*Sacciolepis indica* (L.) Chase	Poaceae	205	15	13.06	8.20
75	*Scleria terrestris* Linn.	Cyperaceae	19	8	2.38	0.30
76	*Scoparia dulcis* Linn.	Scrophulariaceae	38	8	4.75	0.59
77	*Sechium edule* (Jacq.) Sw.	Cucurbitaceae	16	6	2.67	0.44
78	*Sida mysorensis* Linn.	Malvaceae	21	2	10.50	5.25
79	*Sinarundinaria griffithiana* (Munro)	Poaceae	30	7	4.29	0.61
80	*Solanum khasianum* C.B.Clarke	Solanaceae	17	4	4.25	1.06
81	*Solanum nigrum* Linn.	Solanaceae	220	**15**	14.06	8.80
82	*Spermacoce latifolia* Aubl.	Rubiaceae	25	5	5.00	1.00
83	*Sporobolus diander* (Retz.) P.Beauv.	Poaceae	250	**25**	10.00	10.00
84	*Thysanolaena maxima* (Roxb.), Kuntze	Poaceae	55	23	2.39	0.10
85	*Trichosanthes cucumerina* L.	Cucurbitaceae	14	1	14.00	14.00
86	*Triumfetta pilosa* Roth	Malvaceae	12	2	6.00	3.00
87	*Urtica dioica* L.	Urticaceae	27	7	3.86	0.55
88	*Urtica urens* L.	Urticaceae	50	4	12.50	3.13
89	*Tithonia rotundifolia* (Mill.) S. F. Blake.	Asteraceae	45	5	9.00	1.80
90	*Vigna unguiculata* L. Walp	Fabaceae	16	5	3.20	0.64
91	*Vernonia attenuata* DC.	Asteraceae	12	2	6.00	3.00

92	*Zea mays* L.	Poaceae	20	2	10.00	5.00
93	*Zingiber officinale* Rosc.	Zingiberaceae	2	2	1.00	0.50

4.5 Comparative account of diversity- dominance indices

4.5.1 Shannon-Weiner Diversity Index

The Shannon-Weiner Diversity Index was computed for different plant habits along the disturbance gradient. Trees showed the highest diversity in the UD stand (3.63). As disturbance increased, the diversity dropped to 3.18 in the MD stand and further to 2.31 in the highly disturbed stand, suggesting that tree diversity sharply declines with an increase in the degree of disturbance. Shrubs, on the other hand, showed an increase in diversity from 3.34 in the UD stand to 3.56 in the MD stand and the lowest value of 3.23 in the highly disturbed stand. The highest value in the MD stand indicated that moderate disturbance supports the growth of shrub species at a large. Herb**s** showed the lowest diversity in the UD stand (2.91), but their diversity increased significantly with disturbance, reaching 3.42 in the MD stand and peaking at 3.64 in the highly disturbed stand. This indicated that herbs thrive in more disturbed environments, potentially due to less competition or different ecological dynamics (Fig. 11).

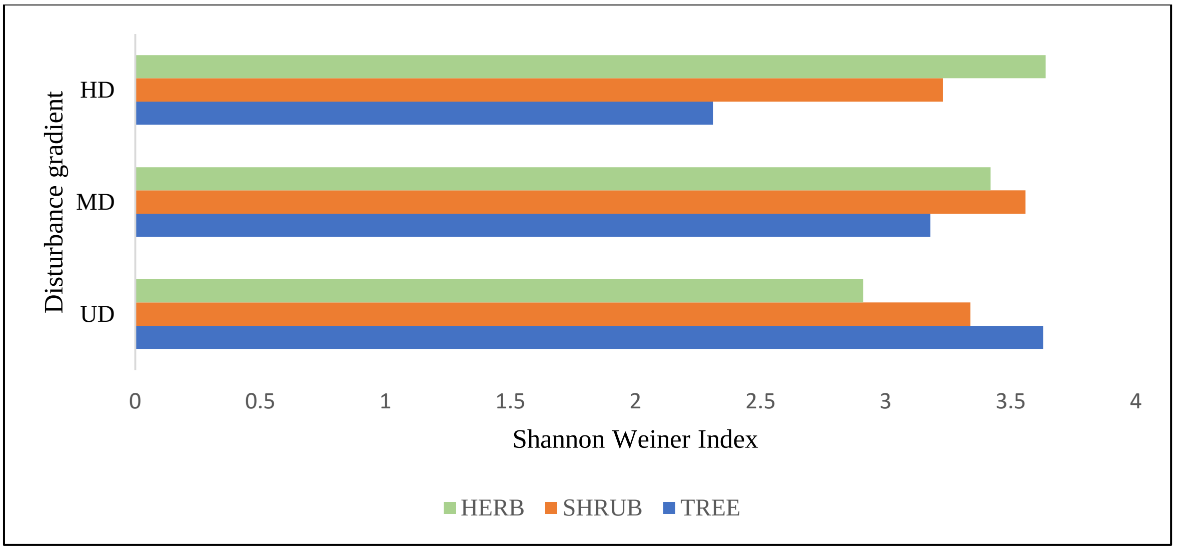


Figure 4. 11: Shannon Weiner Diversity Index for trees, shrubs and herbs along the disturbance gradient.

4.5.2 Simpson's Dominance Index

Simpson's Index is the measure of dominance. Trees exhibited the highest value in the UD stand (0.963). However, as disturbance increased, the Simpson's Index dropped to 0.932 in the MD stand and further to 0.880 in the HD stand. This showed a significant reduction in tree dominance as disturbances escalated. Shrubs maintained consistently high values, with the index slightly increasing from 0.963 in the UD stand to 0.968 in the MD stand, suggesting that moderate disturbances might benefit shrub dominance. In a highly disturbed stand, the index decreased slightly to 0.954, but it remained high, indicating that shrubs were relatively resilient to disturbances. Herbs show the lowest diversity in UD stand (0.935), but their diversity increased with the degree of disturbance. The index rose to 0.957 in the MD stand and remained at 0.955 in the highly disturbed stand, indicating that herbs, like shrubs, adapt well to the disturbed stand (Fig. 4.12).

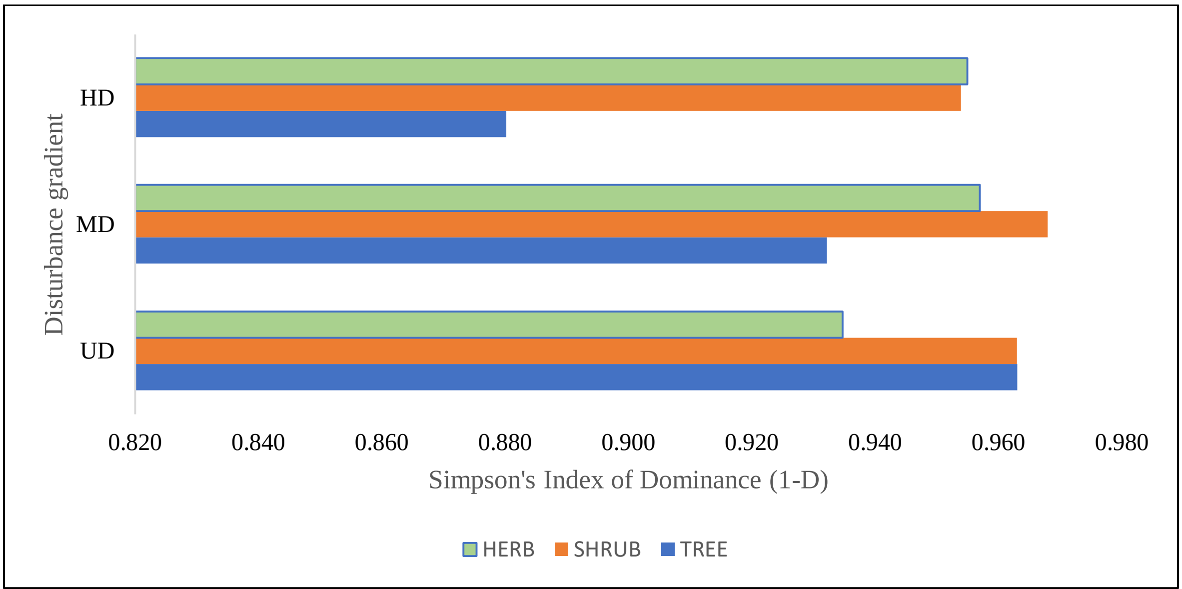


Figure 4. 12: Simpson's Dominance Index for trees, shrubs and herbs along the disturbance gradient.

4.5.3 Margalef's Index

Margalef's Index is a measure of species richness, with higher values indicating greater species diversity. Trees exhibited the highest Margalef's Index value in the UD stand (12.462). However, the Index value declined slightly to 11.841 in the MD stand and drastically decreased to 4.770 in the highly disturbed stand, indicating a significant loss of tree species with the increase in the degree of disturbance. Shrubs showed a reverse trend, with an increase in value from 4.875 in the UD stand to 7.208 in the MD stand, suggesting that moderate disturbance supports shrub diversity. However, in the highly disturbed stand, the value dropped slightly to 6.132 but higher than the UD stand. Herbs possessed the lowest value in the UD stand (5.098), increased to 8.348 in the MD stand and reached a peak of 11.333 in the highly disturbed stand. This indicates that herbaceous species thrive in disturbed forests as large gaps are created due to disturbance (Fig 4.13).

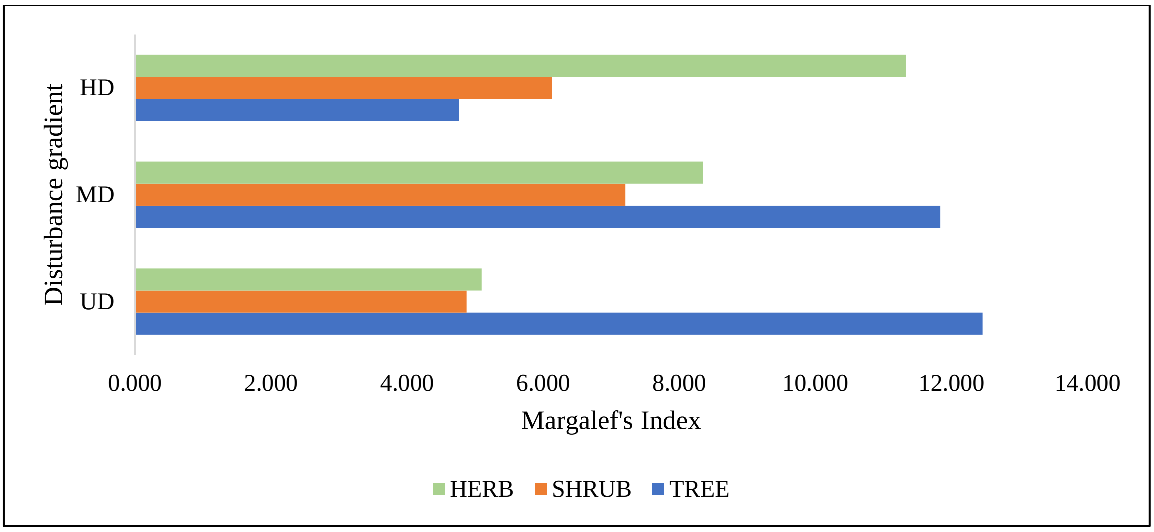


Figure 4. 13: Margalef's Index for trees, shrubs, and herbs along the disturbance gradient

4.5.4 Evenness Index

The Evenness Index reflects the even distribution of species within a community. The higher values indicates a more equitable distribution of species. In the UD stand, the tree evenness index was computed to be 0.813, which dropped to 0.728 in the MD stand and to 0.675 in the highly disturbed stand. This decline suggests that tree species become more unevenly distributed as disturbances intensify. Shrubs had a higher evenness index of 0.958 in the UD stand and 0.948 in the MD stand, and it dropped to 0.892 in the HD stand. Herbs showed moderate evenness across the disturbance gradient. The evenness index was computed as 0.778 in the highly disturbed stand; however, the values were slightly higher in the UD and MD stands. The lowest value in the highly disturbed stand indicates the proper growth of certain species under disturbed conditions (Fig. 4.14).

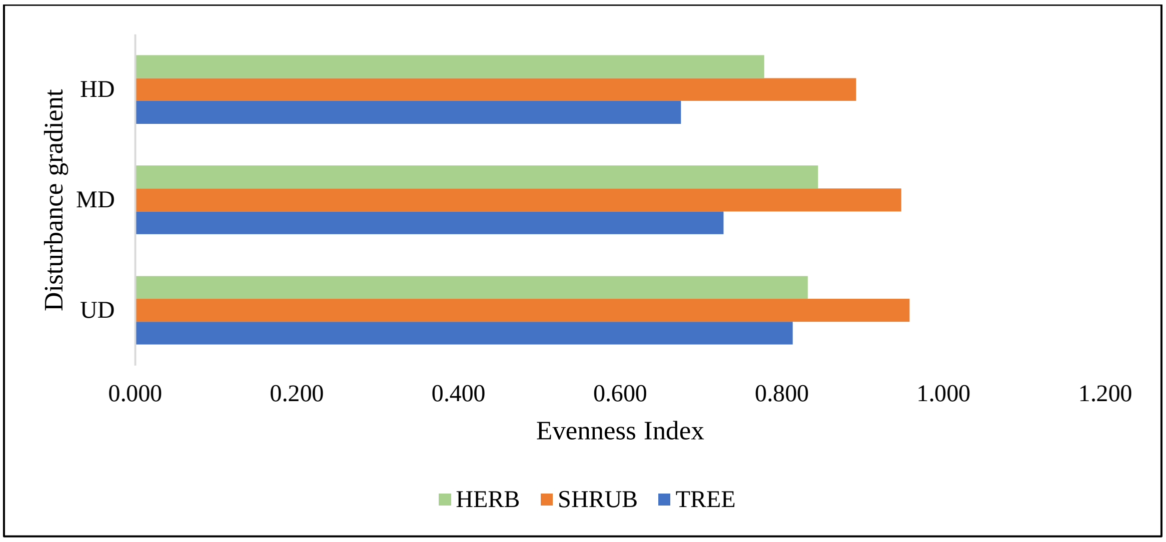


Figure 4. 14: Evenness Index for trees, shrubs and herbs along the disturbance gradient.

4.6 Soil Analysis

4.6.1 Soil temperature

During 2022, soil temperature ranged between 15.1°C and 22.3°C. The values varied from 15.1°C (monsoon, 10-20 cm depth) to 21.2°C (pre-monsoon, 0-10 cm depth) in the UD stand, 17.3 °C (post-monsoon, 10-20 cm depth) to 22.1°C (pre-monsoon, 0-10 cm depth) in the MD stand, and 20.1°C (monsoon, 10-20 cm depth) to 22.3°C (post-monsoon, 10-20 cm depth) in the HD stand. Normally, higher temperatures were recorded in the top-soil (0-10 cm depth) (Table 4.22).

During 2023, soil temperature ranged between 15.6°C and 25.6°C. The values varied from 15.6°C (monsoon, 10-20 cm depth) to 21.7°C (pre-monsoon, 0-10 cm depth) in the UD stand, 19.9 °C (post-monsoon, 10-20cm depth) to 23.4°C (pre-monsoon, 0-10 cm depth) in the MD stand, and 20.3°C (post-monsoon, 10-20cm depth) to 25.6°C (pre-monsoon, 0-10cm depth) in the HD stand. Normally, higher temperatures were recorded in the top-soil (0-10cm depth). The top-soil (0-10cm depth) possessed higher values in all cases and pre-monsoon season experienced high temperatures (Table 4.23).

Normally, there was a rise in soil temperature with an increase in the degree of disturbance, irrespective of soil depth and season.

Table 4. 22: Seasonal variation in soil temperature along disturbance gradient during 2022.

Forest stand	Soil depth (cm)	Pre-monsoon season (°C)	Monsoon season (°C)	Post-monsoon season (°C)
Undisturbed	0-10	21.2±0.1632	16.1±0.3344	16.9±0.2721
	10-20	17.1±0.1515	15.1±0.4320	15.8±0.5987
Moderately disturbed	0-10	22.1±0.2357	20.6±0.1360	18.2±0.1905
	10-20	18.3±0.1962	18.6±0.4784	17.3±0.1186
Highly disturbed	0-10	21.9±0.0720	20.9±0.0471	20.6±0.2612
	10-20	20.6±0.2841	20.1±0.1186	22.3±0.1655

Table 4. 23: Seasonal variation in soil temperature along disturbance gradient during 2023.

Forest stand	Soil depth (cm)	Pre-monsoon season (°C)	Monsoon season (°C)	Post-monsoon season (°C)
Undisturbed	0-10	21.7±0.2160	18.3±0.1962	19.6±0.0981
	10-20	19.3±0.1632	15.6±0.1440	18.3±0.2721
Moderately disturbed	0-10	23.4±0.3681	20.6±0.2357	20.3±0.1905
	10-20	22.8±0.1655	20.1±0.2494	19.9±0.1186
Highly disturbed	0-10	25.6±0.2867	24.3±0.2325	21.92±0.2612
	10-20	23.2±0.2054	21.1±0.4109	20.3±0.1655

4.6.2 Soil Texture

The soil had 66.40% sand, 15.05% silt, and 17.55% clay in the UD stand; 78.16% sand, 9.52% silt and 12.32%, clay in the MD stand; 81.63% sand 8.10% silt and 10.27% clay. The findings reveal that the soil texture stands as loamy sand in the UD and MD, however, it appears sandy loam in the HD stand (Table 4.24).

During 2023, the sand content ranged from 62.23% to 81%, the silt content from 8.10% to 15.05 and clay ranged from 10.27 to 17.55%. The soil in the UD stand possessed a sand content of 62.23%, silt of 17.13% and clay of 19.55%, classifying it as loamy sand. In the MD stand, the sand content was 70.38%, silt content was 12.40% and clay amounted to 17.22%, classifying it as loamy sand. In the HD stand the sand content was 83.33%, the silt content was 5.40% and clay was 10.27%, classifying it as a sandy loam (Table 4.25).

Generally, as disturbance levels increased, the sand content increased while the silt and clay contents decreased.

Table 4. 24: Seasonal variation in soil texture along the disturbance gradient during 2022.

Forest stand	Sand (%)	Silt (%)	Clay (%)	Soil texture
Undisturbed	66.40	15.05	17.55	Loamy sand
Moderately disturbed	78.16	9.52	12.32	Loamy sand
Highly disturbed	81.63	8.10	10.27	Sandy loam

Table 4. 25: Seasonal variation in soil texture along the disturbance gradient during 2023.

Forest stand	Sand (%)	Silt (%)	Clay (%)	Soil texture
Undisturbed	62.23	17.13	19.55	Loamy sand
Moderately disturbed	70.38	12.40	17.22	Loamy sand
Highly disturbed	83.33	5.40	10.27	Sandy loam

4.6.3 Soil pH

The soil pH during 2022 ranged between 4.42 and 5.79. The values varied from 5.15 (pre-monsoon, 10-20 cm depth) to 5.79 (post-monsoon, 0-10cm depth), in the UD stand. The value range was 4.42 (monsoon, 10-20 cm depth) to 5.25 (pre-monsoon, 0-10 cm depth), in the MD stand. The values varied from 4.35 (monsoon, 10-20 cm depth) to 4.95 (monsoon, 0-10 cm depth) in the HD stand (Fig 4.15).

During 2023, the soil pH ranged from 4.35 and 5.53. The values varied from 4.73 (pre-monsoon, 10-20 cm depth) to 5.53 (monsoon, 0-10 cm depth) in the UD stand, 4.29 (monsoon, 10-20 cm depth) to 5.51 (post-monsoon, 0-10 cm depth) in the MD stand, and 4.35 (pre-monsoon, 10-20 cm depth) to 5.43 (post-monsoon, 0-10 cm depth) in the HD stand (Fig 4.16).

Normally, across all seasons and disturbances, the pH at all stands was lower in the sub-soil. The soil pH showed a positive and significant correlation with soil moisture content ($r = 0.501$, $p < 0.01$), water holding capacity ($r = 0.283$, $p < 0.05$), potassium ($r = 0.301$, $p < 0.05$), total nitrogen ($r = 0.529$, $p < 0.01$), and negative correlation with bulk density ($r = -0.532$, $p < 0.01$). Appendix-1.

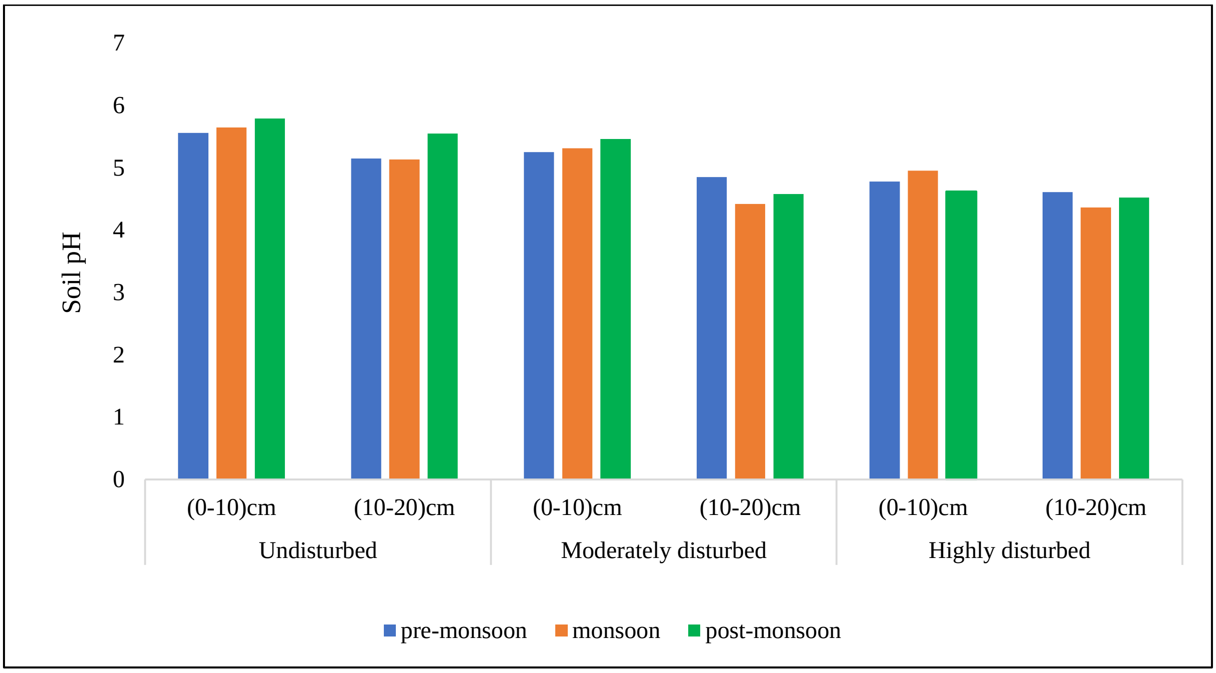


Figure 4. 15: Seasonal variation in Soil pH along disturbance gradient during 2022.

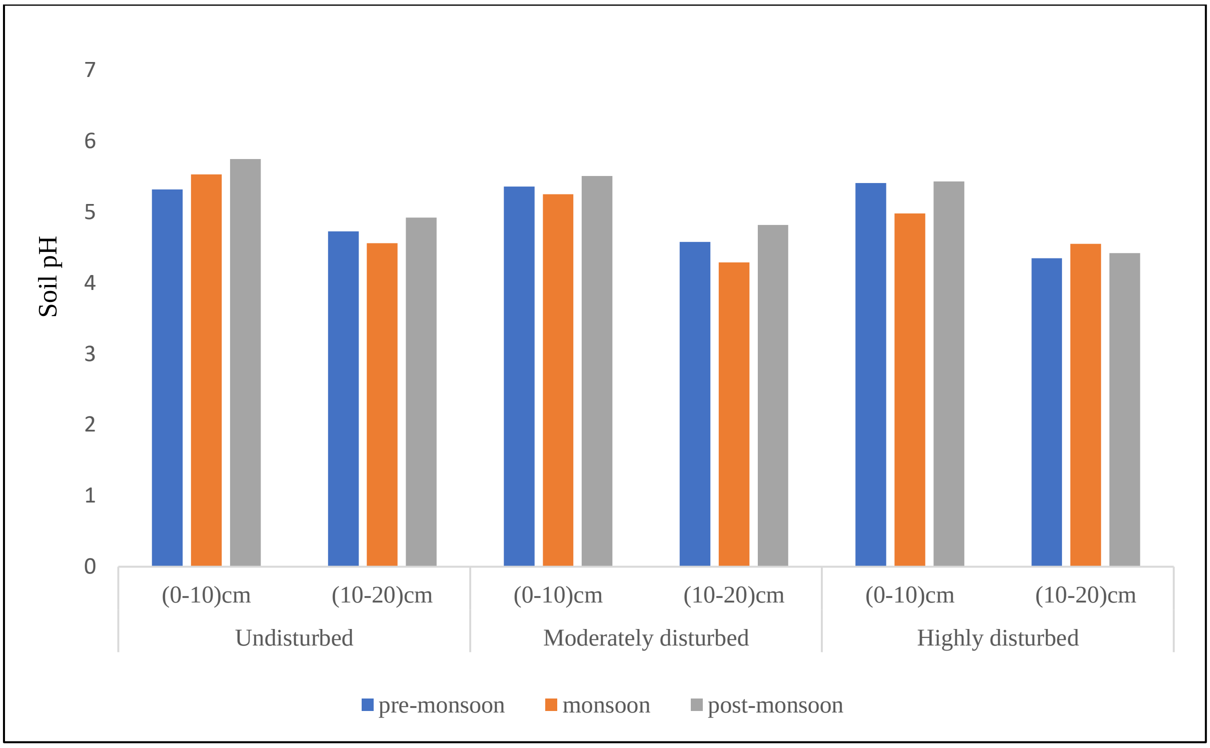


Figure 4. 16: Seasonal variation in Soil pH along disturbance gradient during 2023.

4.6.4 Soil Moisture Content (SMC)

The SMC during 2022 ranged from 11.7% to 30.4%. The values varied from 22.2% (pre-monsoon, 10-20 cm depth) to 32.4% (monsoon, 0-10 cm depth) in the UD forest stand, and from 14.5% (pre-monsoon, 0-10 cm depth) to 27.5% (monsoon, 10-20 cm depth) in the MD stand; The values varied from 10.5% (pre-monsoon, 0-10 cm depth) to 15.6% (monsoon, 10-20 cm depth) in the HD stand (Fig 4.17).

For the year 2023, the SMC ranged between 10.5% and 32.4%. The values varied from 27.5% (monsoon, 10-20 cm depth) to 32.42% (monsoon, 0-10 cm depth) in the UD forest stand, and from 14.5% (pre-monsoon, 0-10 cm) and 27.5% (monsoon, 10-20 cm) in the MD stand. The values varied from 11.5% (pre-monsoon, 0-10 cm) to 15.6% (monsoon, 0-10 cm) in the HD stand (Fig 4.18).

In all cases, moisture content was higher during the monsoon season, followed by post-monsoon pre-monsoon seasons. The UD stand had more moisture content irrespective of seasons and soil depth. The soil moisture content showed a positive and significant correlation with soil pH ($r = 0.501$, $p < 0.01$), water holding capacity ($r = 0.540$, $p < 0.01$), available phosphorus ($r = 0.391$, $p < 0.01$), exchangeable potassium ($r = 0.661$, $p < 0.01$), total nitrogen ($r = 0.498$, $p < 0.01$), and negative and significant correlation with bulk density ($r = -0.604$, $p < 0.01$). Appendix-1.

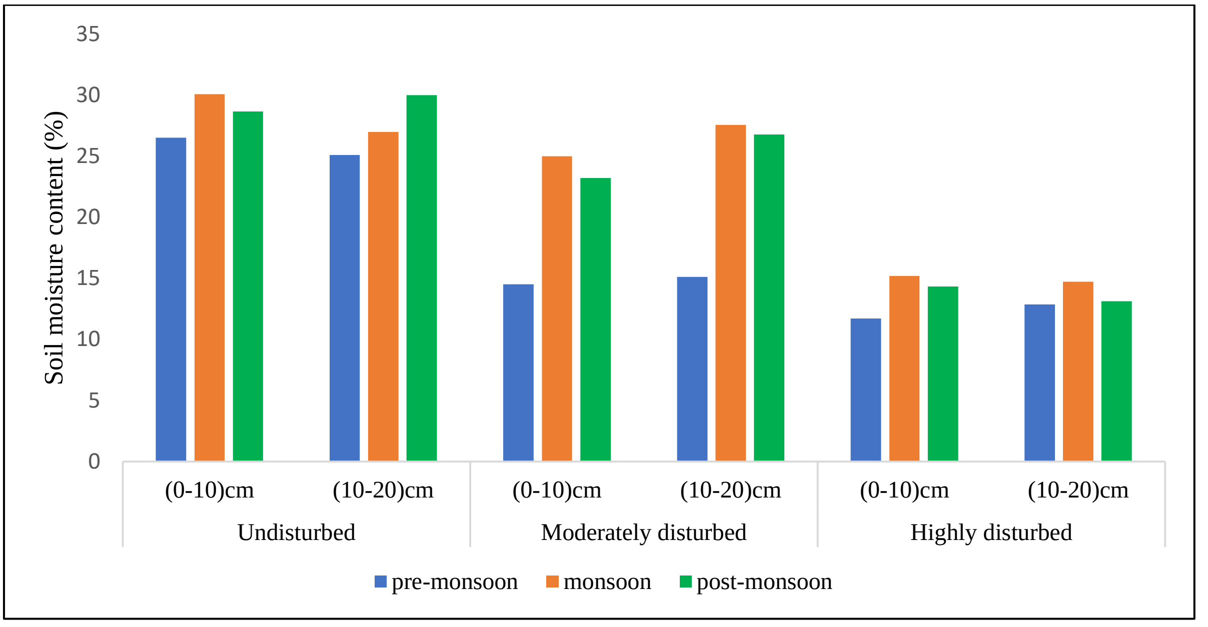


Figure 4. 17: Seasonal variation in Soil Moisture Content along disturbance gradient during 2022.

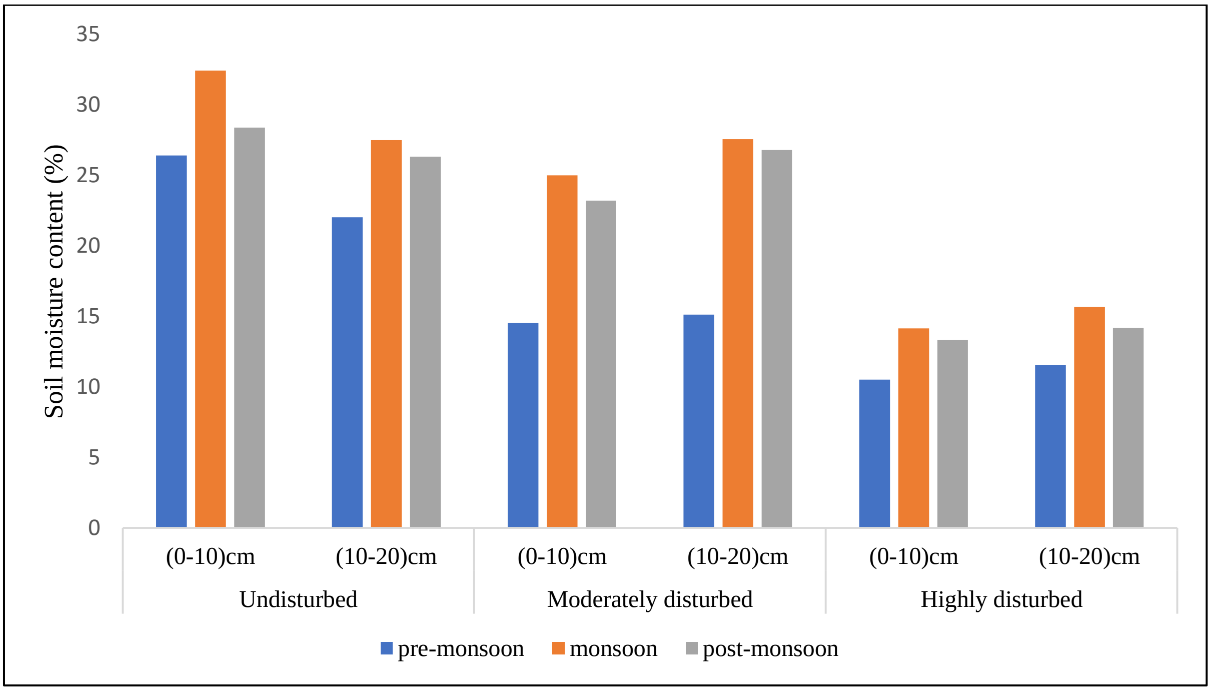


Figure 4. 18: Seasonal variation in Soil Moisture Content along disturbance gradient during 2023.

4.6.5 Bulk Density (BD)

During the year 2022, bulk density ranged between 0.59 g cm^{-3} and 1.21 g cm^{-3}. The value varied from 0.59 g cm^{-3} (monsoon, 0-10 cm depth) to 0.78 g cm^{-3} (pre-monsoon, 10-20 cm depth) in the UD stand; from 0.6 g cm^{-3} (monsoon, 0-10 cm depth) to 0.89 g cm^{-3} (pre-monsoon, 10-20 cm depth) in the MD stand; from 1.03 g cm^{-3} (pre-monsoon, 0-10 cm depth) to 1.21 g cm^{-3} (post-monsoon, 10-20 cm depth) in the HD stand (Fig. 4.19).

During the year 2023, the Bulk density ranged between 0.51 and 1.33. The value varied from 0.51 g cm^{-3} (monsoon, 0-10 cm depth) to 0.83 g cm^{-3} (post-monsoon, 10-20 cm depth) in the UD stand; from 0.72 g cm^{-3} (monsoon, 0-10 cm depth) to 0.97 g cm^{-3} (monsoon, 10-20 cm depth) in the MD stand; from 1.05 g cm^{-3} (monsoon, 0-10 cm depth) to 1.33 g cm^{-3} (monsoon, 10-20 cm depth) in the HD stand (Fig. 4.20).

Overall, across all seasons the bulk density was lower in the top-soil and higher in the sub-soil, with the highest value in the HD stand. The bulk density was negatively correlated with soil pH ($r = -0.532$, $p < 0.01$), soil moisture content ($r = -0.604$, $p < 0.01$), water holding capacity ($r = -0.541$, $p < 0.01$), available phosphorus ($r = -0.549$, $p < 0.01$), exchangeable potassium ($r = -0.853$, $p < 0.01$), and total nitrogen ($r = -0.496$, $p < 0.01$). Appendix-1.

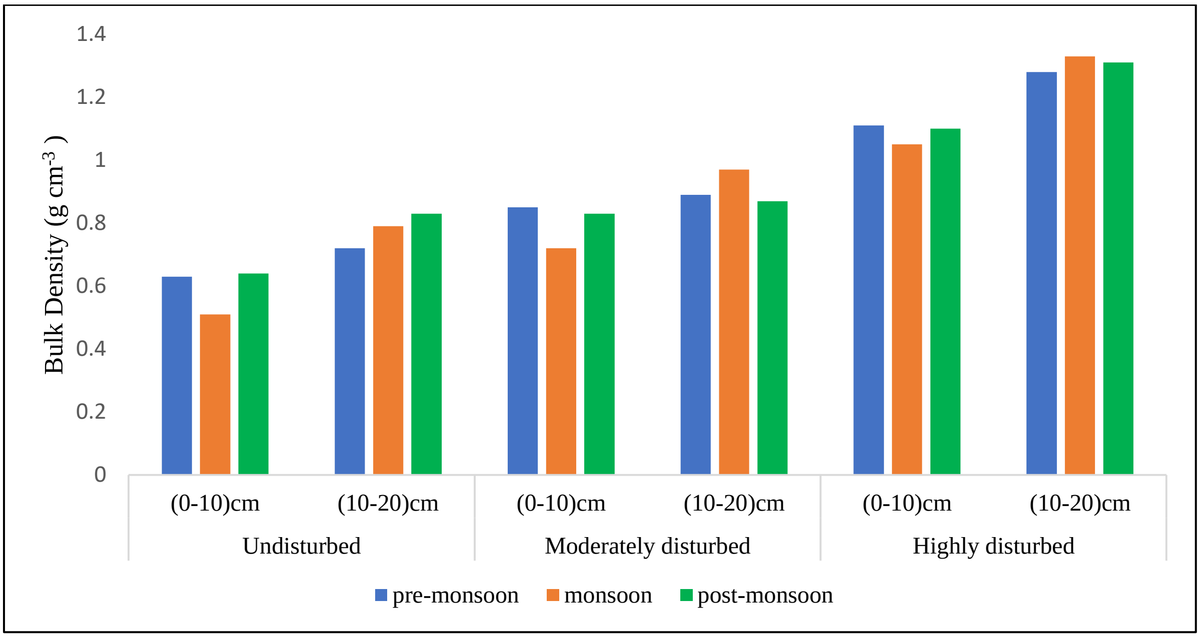


Figure 4. 19: Seasonal variation in Bulk Density along disturbance gradient during 2022.

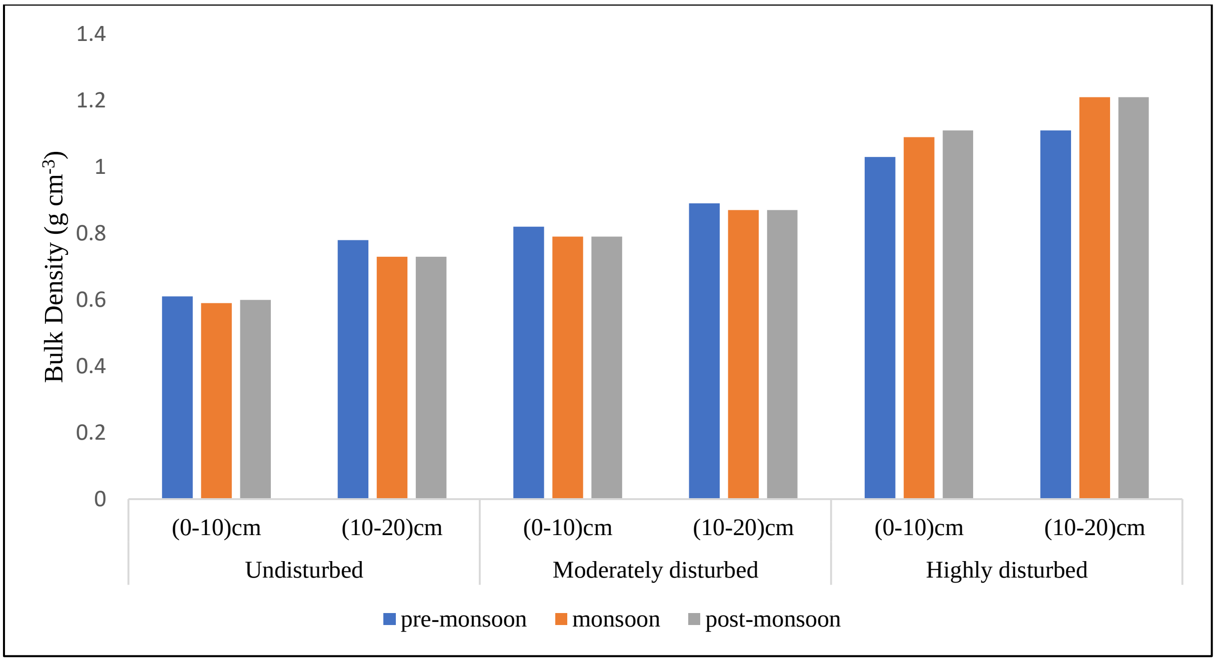


Figure 4. 20: Seasonal variation in Bulk Density along disturbance gradient during 2023.

4.6.6 Water Holding Capacity (WHC)

The WHC during the year 2022 ranged from 30% to 62%. The value varied from 45% (pre-monsoon, 10-20 cm depth) to 62% (monsoon, 0-10 cm depth) in the UD stand; from 48% (pre-monsoon, 10-20 cm) and 53% (post-monsoon and pre-monsoon, 0-10 cm depth) in the MD stand; from 30% (pre-monsoon, 0-10 cm depth) to 42% (monsoon, 0-10 cm depth) in the HD stand (Fig. 4.21).

The WHC during the year 2023 ranged from 31% to 58%. The value varied from 45% (pre-monsoon, 10-20 cm depth) to 55% (monsoon, 0-10 cm depth) in the UD stand; from 51% (pre-monsoon, 0-10 cm) and 58% (post-monsoon, 10-20 cm) in the MD stand; from 31% (pre-monsoon, 0-10 cm) to 36% (monsoon, 10-20 cm) in the HD stand (Fig. 4.22).

Overall, the UD and MD stands exhibited higher WHC, particularly during the monsoon season, while the HD stand had the lowest WHC throughout all seasons and depths.

The water holding capacity showed a positive and significant relationship with Soil pH ($r = 0.283$, $p < 0.05$), soil moisture content ($r = 0.540$, $p < 0.01$), available phosphorus ($r = 0.719$, $p < 0.01$), exchangeable potassium ($r = 0.595$, $p < 0.01$), total nitrogen ($r = 0.400$, $p < 0.01$), and negative correlation with bulk density ($r = -0.541$, $p < 0.01$). Appendix-1.

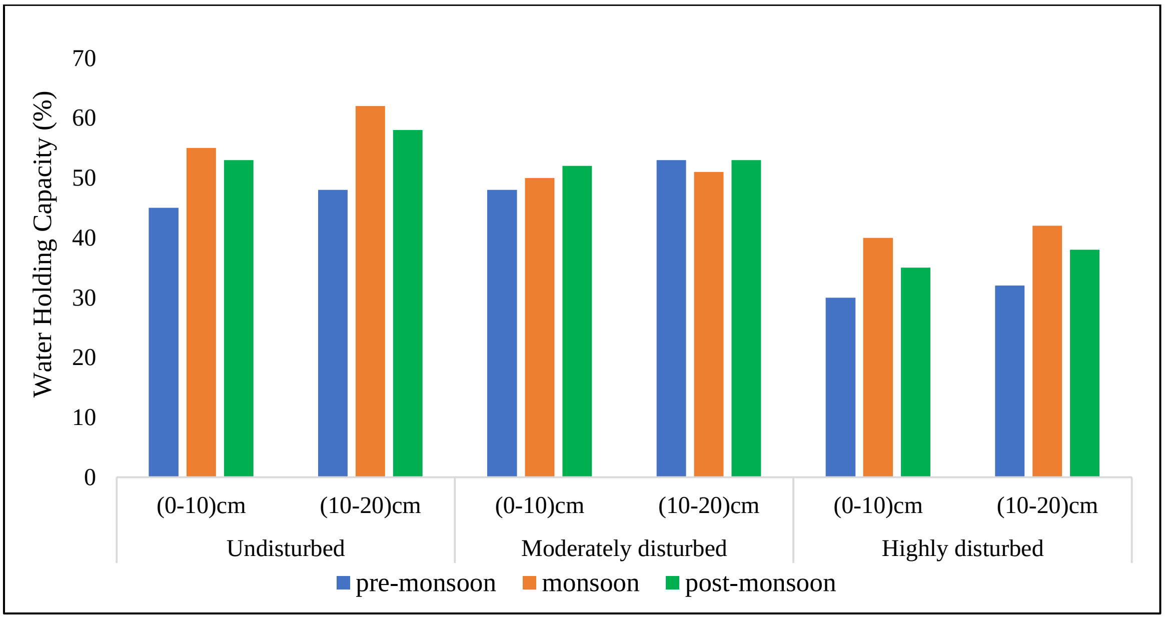


Figure 4. 21: Seasonal variation in Water Holding Capacity along disturbance gradient during 2022.

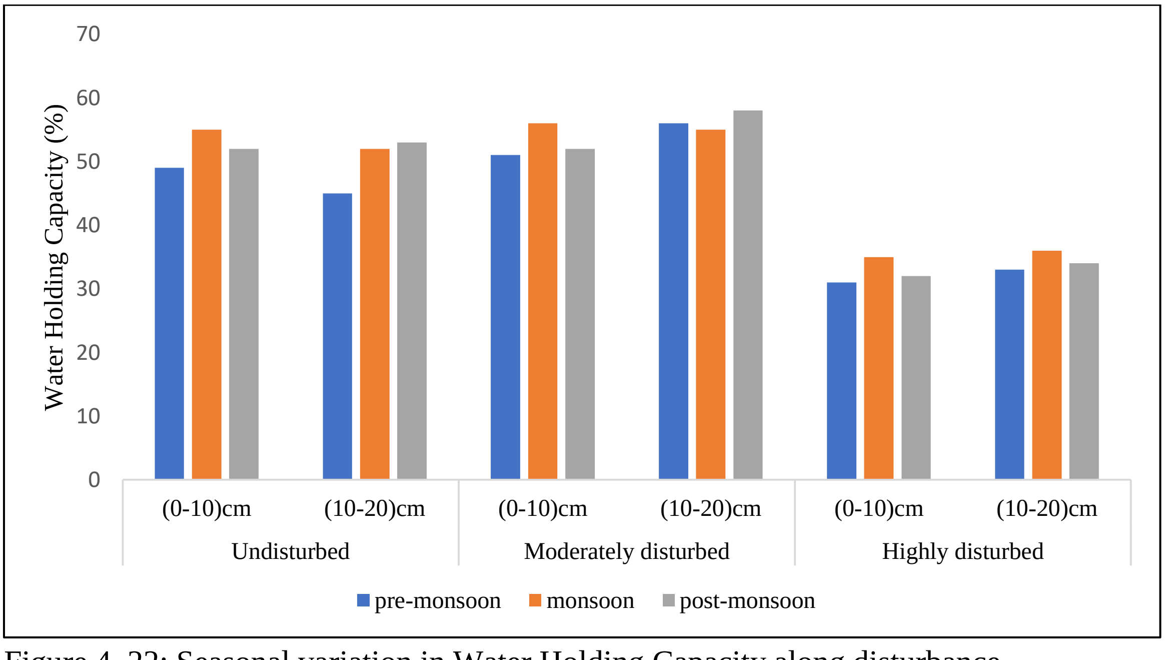


Figure 4. 22: Seasonal variation in Water Holding Capacity along disturbance gradient during 2023.

4.6.7 Soil Organic Carbon

The SOC during the year 2022, the SOC ranged from 0.612 to 1.391%. The value varied from 0.672% (pre-monsoon, 10-20 cm depth) to 1.391% (monsoon, 0-10 cm depth) in the UD stand; from 0.702 % (post-monsoon, 10-20 cm depth) to 0.899% (monsoon, 10-20 cm depth) in the MD stand; from 0.515% (pre-monsoon, 10-20 cm depth) to 0.956% (monsoon, 0-10 cm depth) in the HD stand (Fig. 4.23).

During the year 2023, it ranged from. 0.551 to 1.211%. The value varied from 0.621% (pre-monsoon, 10-20 cm depth) to 1.211% (monsoon, 0-10 cm depth) in the UD stand; from 0.719 % (pre-monsoon, 10-20 cm) to 0.966% (monsoon, 0-10 cm) in MD stand; from 0.551% (pre-monsoon, 10-20 cm) to 0.973% (post-monsoon, 10-20 cm) in the HD stand (Fig. 4.24).

The findings reveal that the undisturbed forest stand had higher soil organic carbon irrespective of seasons. The study showed soil organic carbon has weak and statistically insignificant and positive correlation with other soil parameters. Appendix-1.

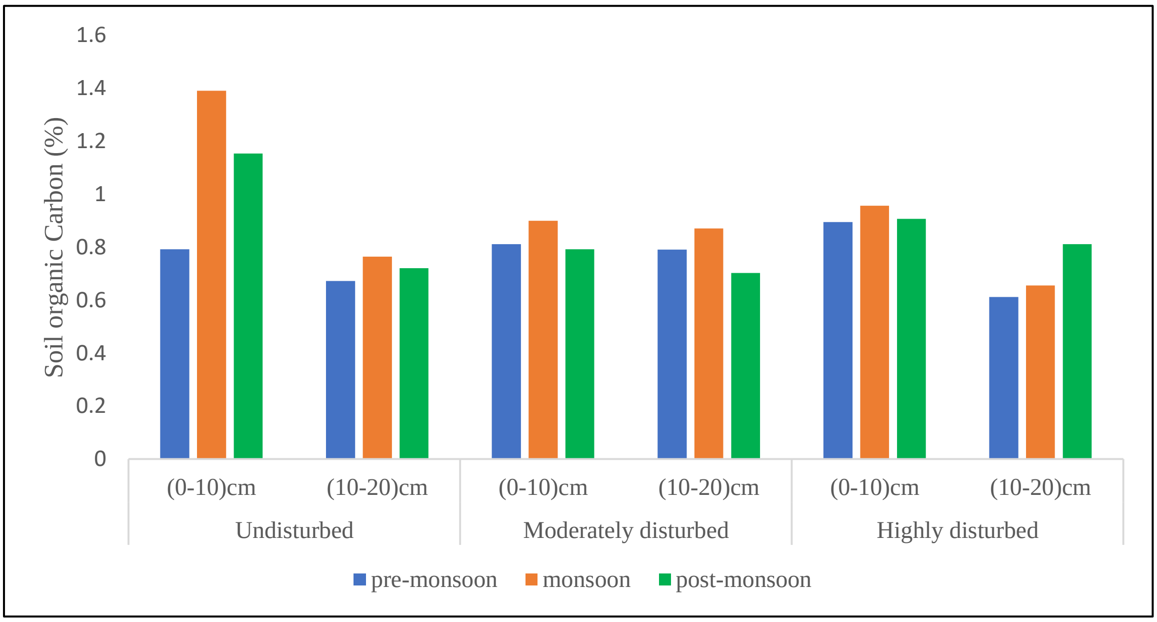


Figure 4. 23: Seasonal variation in soil organic carbon content along disturbance gradient during 2022.

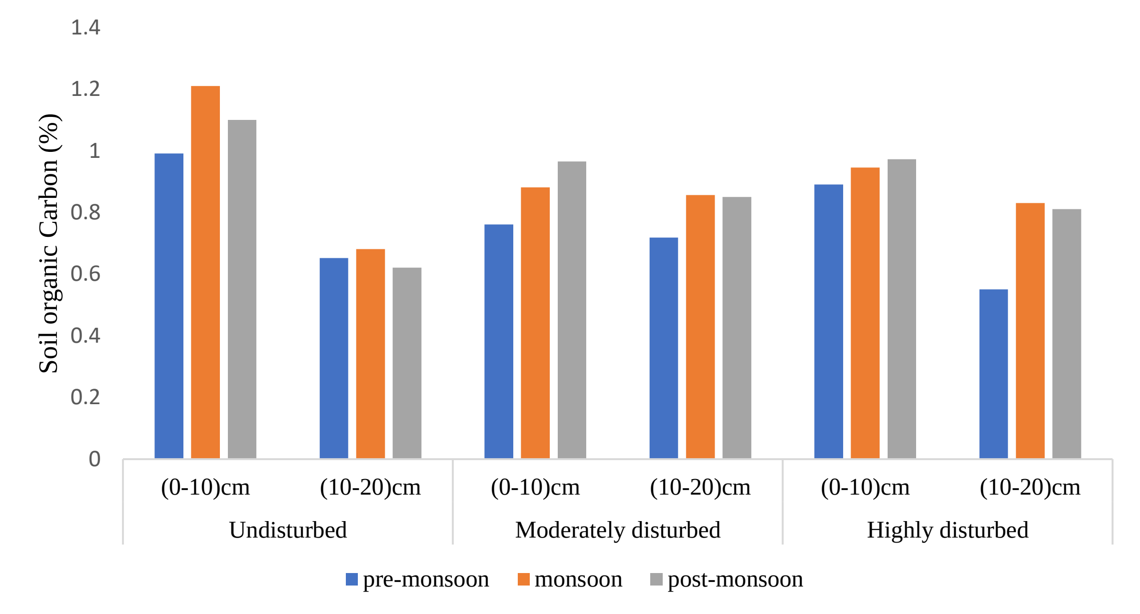


Figure 4. 24: Seasonal variation in Soil Organic Carbon content along disturbance during 2023.

4.6.8 Soil Organic Matter

The soil organic matter (SOM) for the year 2022 ranged between 1.059% and 2.247%. The value varied from 1.163% (pre-monsoon, 10-20 cm depth) to 2.406% (monsoon, 0-10 cm depth) in the UD stand; from 1.214% (post-monsoon, 10-20 cm depth) to 1.555% (monsoon, 0-10 cm depth) in the MD stand; from 1.059% (pre-monsoon, 10-20 cm depth) to 1.654% (pre-monsoon, 0-10 cm depth) in the HD stand (Fig. 4.25).

For the year 2023, the SOM ranged between 0.953 and 2.095%. The value varied from 1.074% (post-monsoon, 10-20 cm depth) to 2.095% (monsoon, 0-10 cm depth) in the UD stand; from 1.244 (pre-monsoon, 10-20 cm depth) to 1.671% (post-monsoon, 0-10 cm depth) in the MD stand; from 0.953% (pre-monsoon, 10-20 cm depth) to 1.683% (post-monsoon, 10-20 cm depth) in the HD stand (Fig, 4.26).

Normally, the highest SOM values occur in the monsoon season at the top-soil, while the lowest values are seen in the pre-monsoon season at a depth of 10-20 cm. Overall, SOM was highest in UD stand during the pre-monsoon season. The soil organic matter has positive and significant correlation with soil organic matter (r = 1.000, p < 0.01), but the correlation with various other soil parameters is rather weak and statistically insiginificant. Appendix-1.

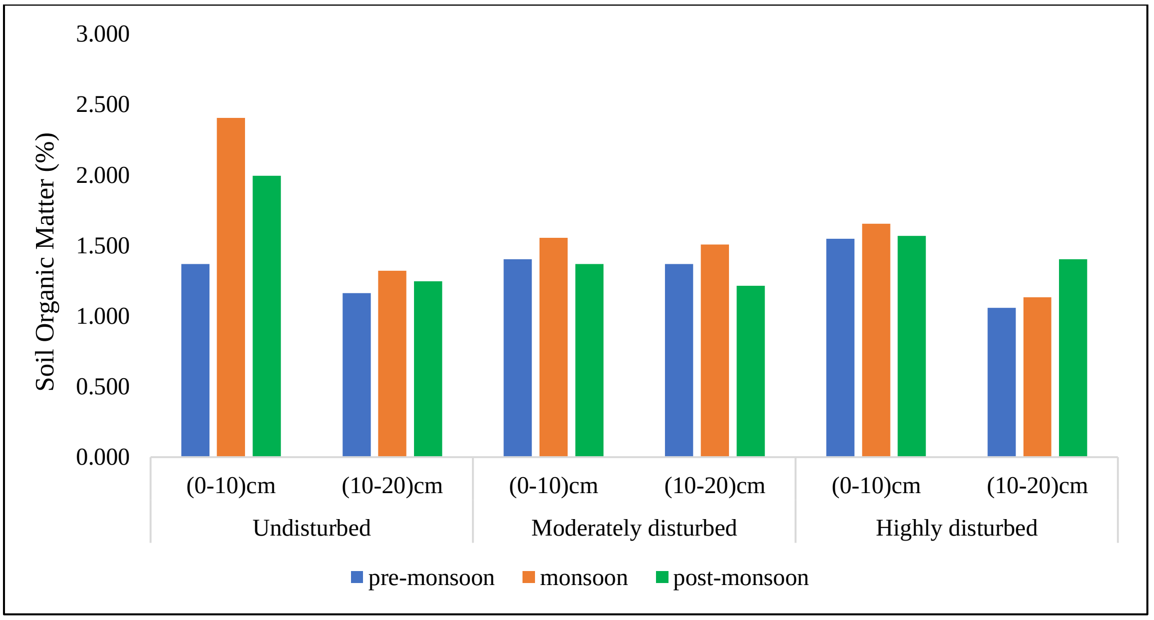


Figure 4. 25: Seasonal variation in soil organic matter along disturbance gradient for during 2022.

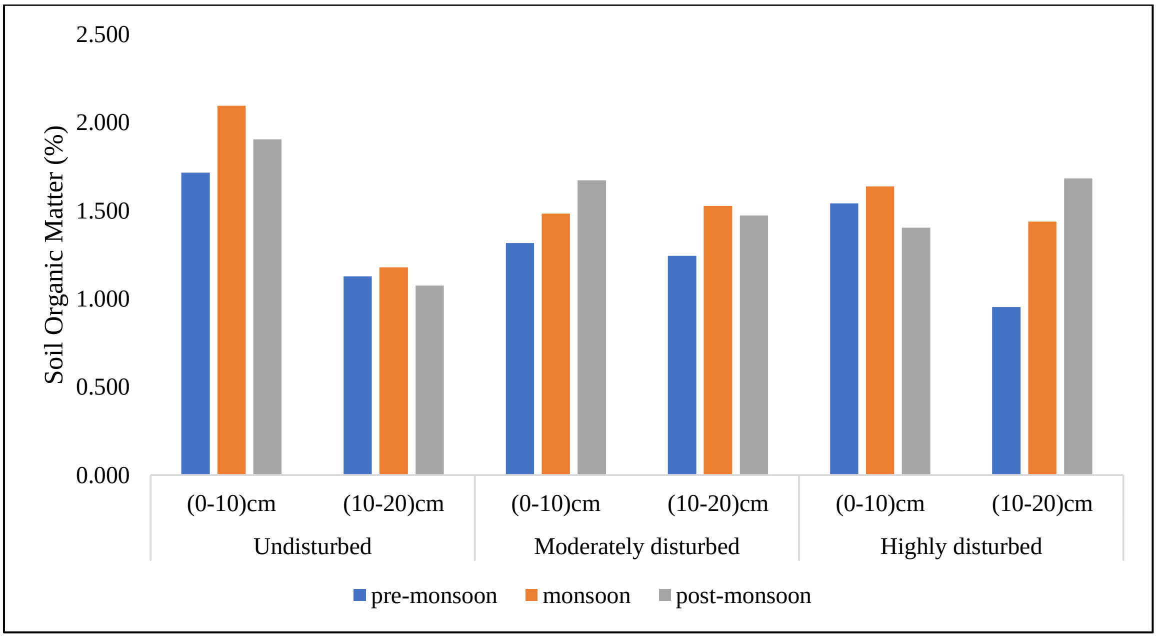


Figure 4. 26: Seasonal variation in soil organic matter content along disturbance

gradient during 2023.

4.6.9 Exchangeable Potassium

During the study 2022, the exchangeable potassium content in the soil ranged from 27.52 kg ha^{-1} to 72.24 kg ha^{-1}. The value varied from 63.72 kg ha^{-1} (monsoon, 10-20 cm) to 72.24 kg ha^{-1} (monsoon, 0-10 cm) in the UD stand. The value varied from 45.17 kg ha^{-1} (pre-monsoon, 0-10 cm) to 55.02 kg ha^{-1} (post-monsoon, 0-10 cm) in the MD stand. The value varied from 27.52 kg ha^{-1} (post-monsoon, 10-20 cm) to 36.41 kg ha^{-1} (monsoon, 0-10 cm) in the HD stand (Fig. 4.27).

The value of potassium during the year 2023, ranged from 29.52 kg ha^{-1} to 77.33 kg ha^{-1} across different sampling stand, depths, and seasons. The value varied from 65.23 kg ha^{-1} (pre-monsoon, 10-20 cm) to 77.33 kg ha^{-1} a (monsoon, 0-10 cm) in the UD stand. The value varied from 43.01 kg ha^{-1} (pre-monsoon, 0-10 cm) to 53.11 kg ha^{-1} (post-monsoon, 0-10 cm) in the MD stand. The value varied from 29.52 kg ha^{-1} (post-monsoon, 10-20 cm) to 43.93 kg/ha (monsoon, 10-20 cm) in the HD stand (Fig. 4.28).

Normally, throughout the seasons, the HD stand showed the lowest potassium content, especially during pre-monsoon. Overall, potassium content decreased with increasing soil disturbance. The exchangeable potassium has a positive correlation with Soil pH ($r = 0.301$, $p < 0.05$), soil moisture content ($r = 0.661$, $p < 0.01$), water holding capacity ($r = 0.595$, $p < 0.01$), available phosphorus ($r = 0.594$, $p < 0.01$) and total nitrogen ($r = 0.588$, $p < 0.01$), and negative and significant correlation with bulk density ($r = -0.853$, $p < 0.01$). Appendix-1.

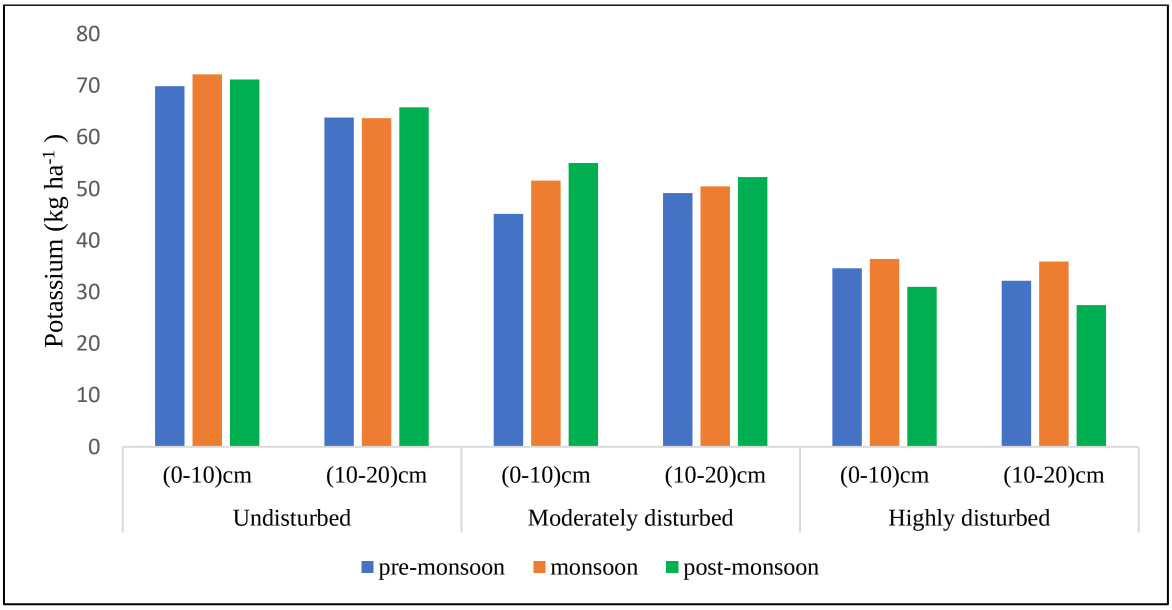


Figure 4. 27: Seasonal variation in potassium content along disturbance gradient during 2022.

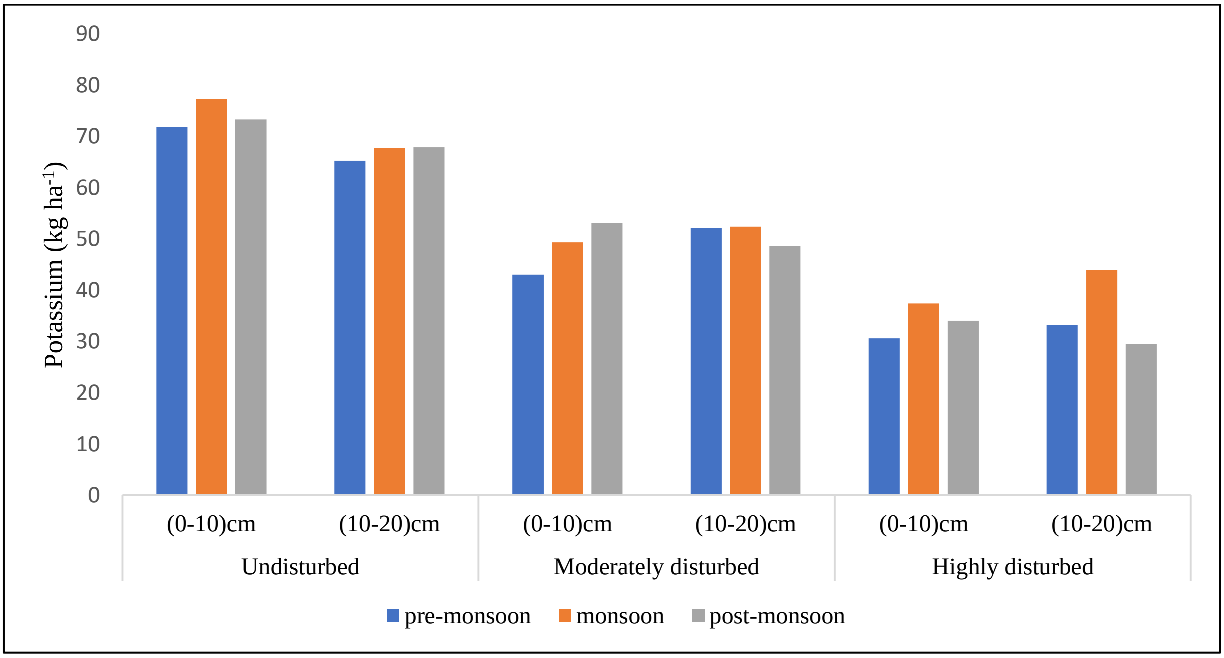


Figure 4. 28: Seasonal variation in exchangeable potassium content along disturbance gradient during 2023.

4.6.10 Total Nitrogen Content

During the year 2022, the TNC ranged from 0.03% to 0.29%. The value varied from 0.15% (pre-monsoon, 10-20 cm depth) to 0.29% (post-monsoon, 0-10 cm depth) in the UD stand. The MD stand had nitrogen values varying between 0.13% (post-monsoon, 10-20 cm depth) and 0.23% (post-monsoon, 0-10 cm depth). In the HD stand, the nitrogen content was lowest, with values ranging from 0.03% (pre-monsoon, 10-20 cm depth) to 0.18% (post-monsoon, 0-10 cm depth). (Fig. 4.29).

For the year 2023, the TNC ranged from 0.05% to 0.49%. The value varied from 0.18% (pre-monsoon, 10-20 cm depth) to 0.49% (post-monsoon, 0-10 cm depth) in the UD stand. In the MD stand, values ranged from 0.09% (pre-monsoon, 10-20 cm depth) to 0.35% (monsoon, 0-10 cm depth). The value varied from 0.05% (pre-monsoon, 10-20 cm depth) to 0.21% (monsoon, 0-10 cm depth) in the HD stand (Fig. 4.30).

The TNC levels were generally found to be higher in the top-soil compared to sub-soil across all disturbance levels. The total nitrogen showed a positive and significant correlation with soil pH ($r = 0.529$, $p < 0.01$), soil moisture content ($r = 0.498$, $p < 0.01$), water holding capacity ($r = 0.400$, $p < 0.01$), available phosphorus ($r = 0.522$, $p < 0.01$), exchangeable potassium ($r = 0.588$, $p < 0.01$). Appendix-1.

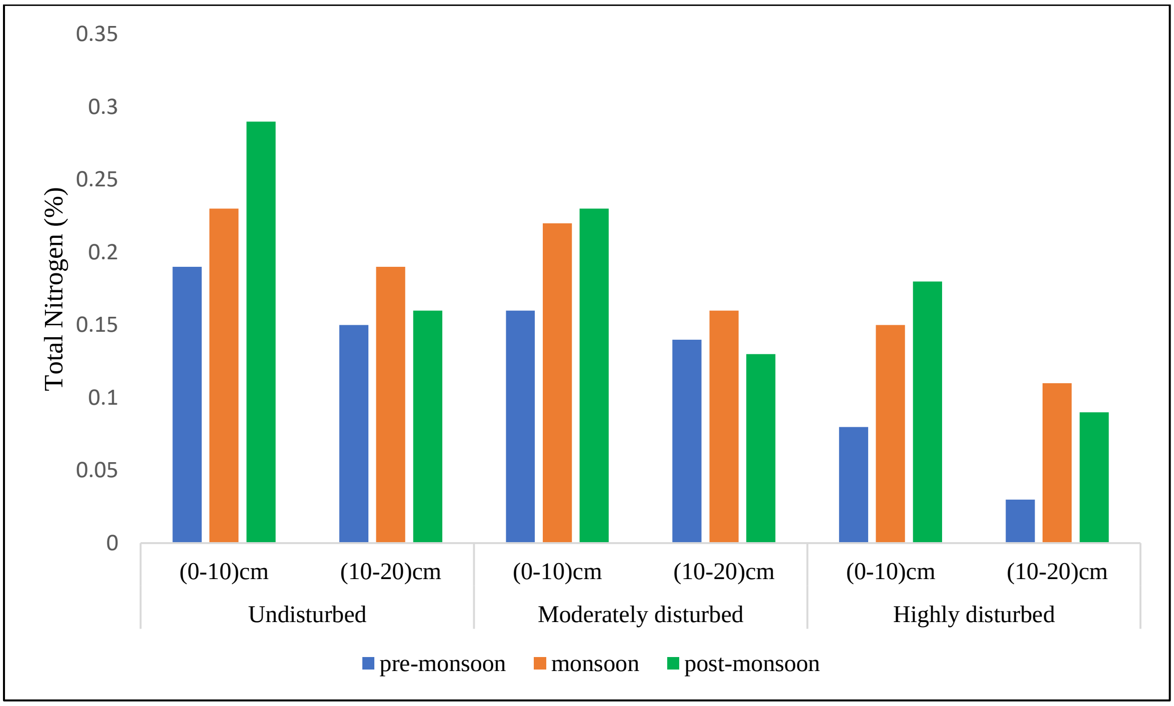


Figure 4. 29: Seasonal variation in total nitrogen content along disturbance gradient during 2022.

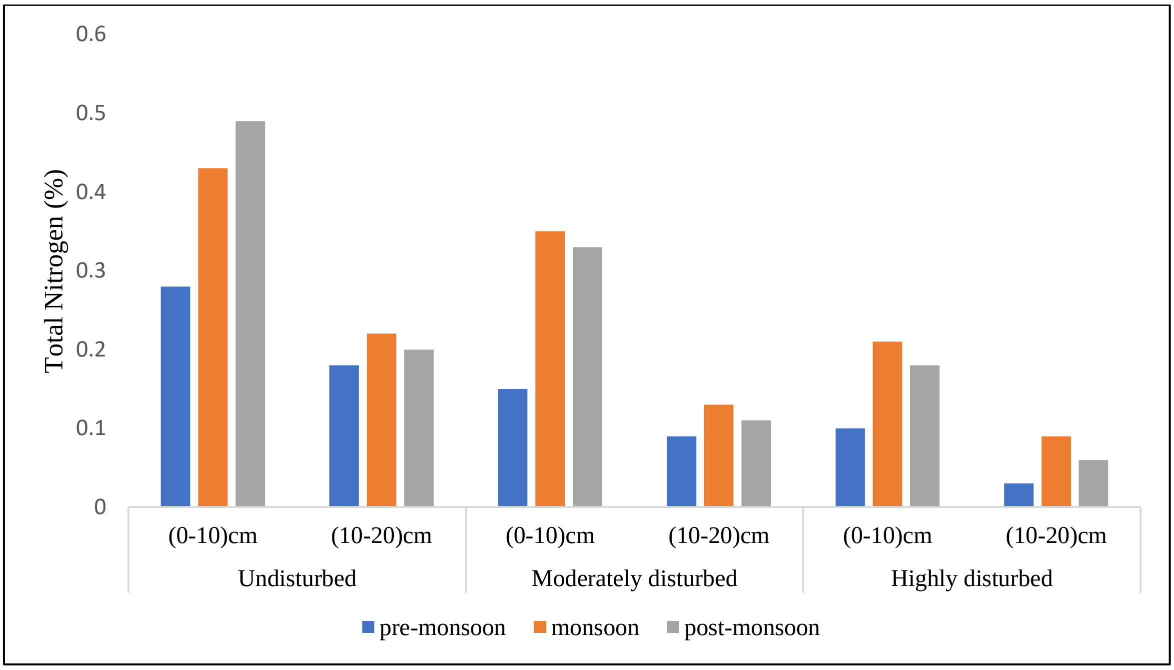


Figure 4. 30: Seasonal variation in Total Nitrogen content along disturbance gradient during 2023.

4.6.11 Available phosphorus

For the year 2022, the available phosphorus ranged from 0.312 kg ha^{-1} to 0.911 kg ha^{-1}. For the UD stand, phosphorus values ranged from 0.492 kg ha^{-1} (post-monsoon, 0-10 cm depth) to 0.883 kg ha^{-1} (monsoon, 10-20 cm depth). In the MD stand, phosphorus content varied between 0.614 kg ha^{-1} (pre-monsoon, 10-20 cm depth) and 0.911 kg ha^{-1} (monsoon, 0-10 cm depth). In HD stand, phosphorus levels ranged from 0.312 kg ha^{-1} (pre-monsoon, 0-10 cm depth) to 0.386 kg ha^{-1} (monsoon, 10-20 cm depth). (Fig. 4.31).

For the year 2023, available phosphorus content in the soil ranged from 0.204 kg ha^{-1} to 0.991 kg ha^{-1} across different sampling stand, depths, and seasons. For the UD stand, phosphorus levels ranged from 0.532 kg ha^{-1} (pre-monsoon, 0-10 cm depth) to 0.991 kg ha^{-1} (monsoon, 0-10 cm depth). In the MD stand, phosphorus ranged from 0.502 kg ha^{-1} (pre-monsoon, 10-20 cm depth) to 0.912 kg ha^{-1} (post-monsoon, 0-10 cm depth). In the HD stand, phosphorus content was lowest overall, ranging from 0.204 kg ha^{-1} (pre-monsoon, 10-20 cm) to 0.467 kg ha^{-1} (monsoon, 0-10 cm). (Figure 4.32).

The available phosphorus was normally higher in sub-soil irrespective of the degree of disturbance. The available Phosphorus showed a positive and significant correlation with soil moisture content ($r = 0.391$, $p < 0.01$), water holding capacity ($r = 0.719$, $p < 0.01$), exchangeable potassium ($r = 0.594$, $p < 0.01$), total nitrogen ($r = 0.522$, $p < 0.01$), and negative correlation with bulk density ($r = -0.549$, $p < 0.01$). Appendix-1.

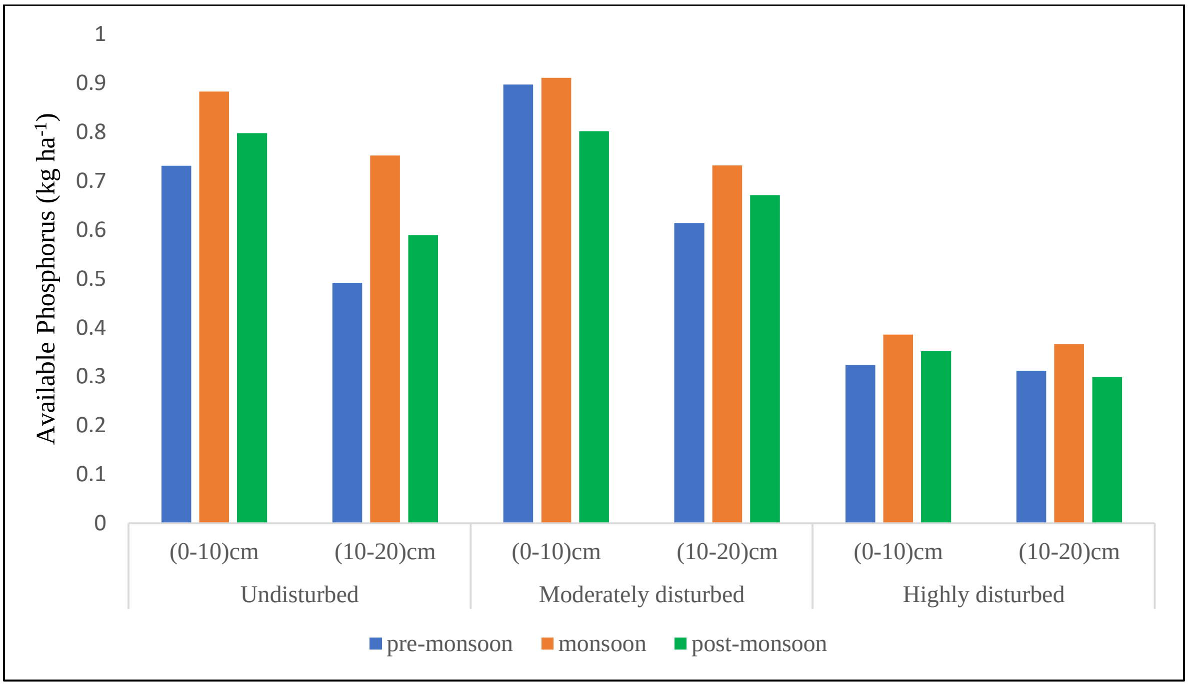


Figure 4. 31: Seasonal variation in available phosphorus content along disturbance gradient during 2022.

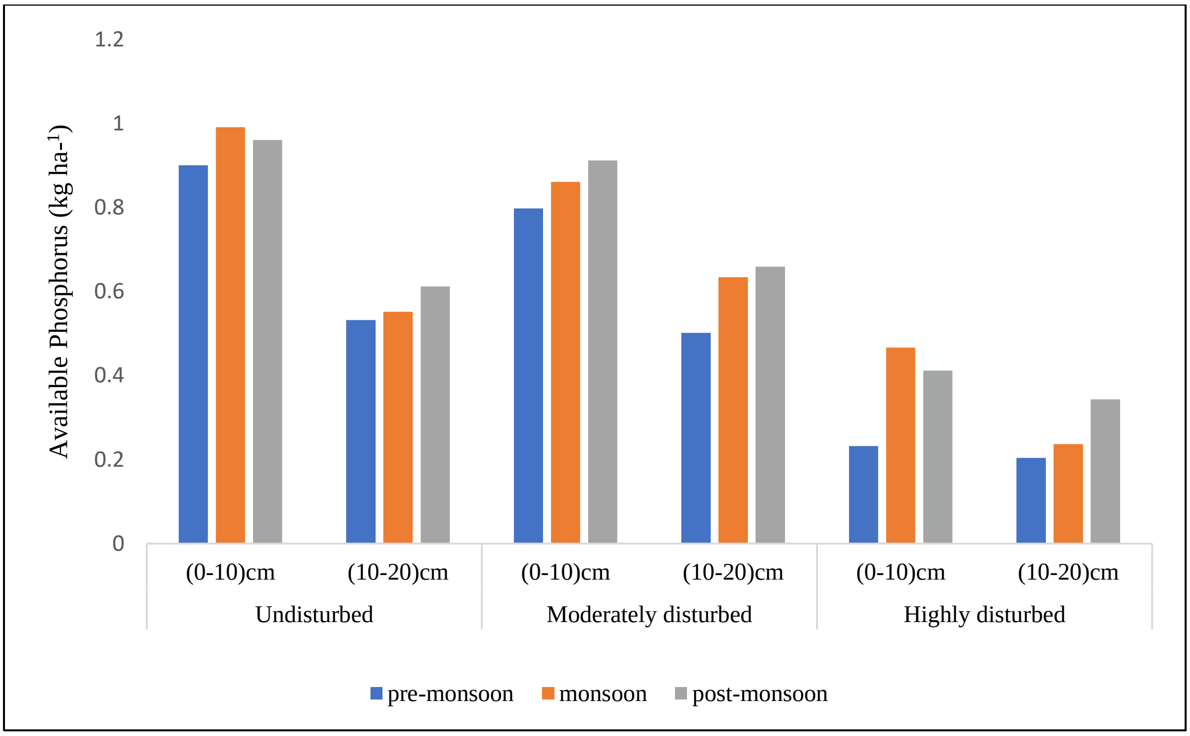


Figure 4. 32: Seasonal variation in available phosphorous content along disturbance gradient during 2023.

4.6.12 Statistical analysis (One-way ANOVA) for physico-chemical characteristics of soil

4.6.12.1 Effect of disturbance gradient

The one-way ANOVA results indicates that the ecological disturbance gradient has a statistically significant effect on soil properties such as soil moisture content, bulk density, water holding capacity, total nitrogen, available phosphorus, and exchangeable potassium as all show highly significant differences across the disturbance levels ($p < 0.001$), suggesting that these properties are strongly influenced by the degree of ecological disturbance. These findings can be infered as the changes in disturbance intensity can lead to measurable alterations in soil structure and nutrient dynamics. In contrast, soil pH, organic carbon, and soil organic matter did not exhibit significant variation across the disturbance gradient ($p > 0.05$), indicating that these factors may be more resilient or less sensitive to such changes. The analysis highlights the important role of ecological disturbance in shaping soil physical and chemical characteristics. Appendix-1.

Table 4. 26: Summarized table of one way ANOVA for physico chmical properties of soil.

Source of variation	Df	F value	Sig
soil pH	2	2.269	0.114
Soil moisture content	2	21.098	0.000
Bulk density	2	71.409	0.000
Water holding capacity	2	64.313	0.000
Soil organic carbon	2	1.889	0.162
Soil organic matter	2	1.885	0.162
Total nitrogen	2	9.420	0.000
Available phosphorus	2	44.500	0.000
Exchangeable potassium	2	276	0.000

4.6.12.2 Effect of soil depth

The one-way ANOVA was applied to the soil physico-chemical properties of soil to determine the effect of depth on soil properties. The results indicate that several soil properties exhibit statistically significant differences specifically soil moisture content, bulk density, water holding capacity, total nitrogen, available phosphorus, and exchangeable potassium as all have p-values are less than 0.05, demonstrating strong evidence that their means differ significantly among the groups. The soil properties such as soil pH, soil organic carbon and soil organic matter have p-values greater than 0.05, suggesting the effect of depth is not significant. Appendix-1.

Table 4. 27: Summarized table of one-way ANOVA for physico-chemical properties of soil.

Source of variation	Df	F value	sig
Soil pH	1	36.616	.000
Soil moisture content	1	0.039	.844
Bulk density	1	4.788	.033
Water holding capacity	1	.030	.862
Soil organic carbon	1	10.710	.002
Soil organic matter	1	10.191	.002
Total nitrogen	1	16.746	.000
Available phosphorus	1	.639	.428
Exchangeable potassium	1	.386	.537

4.7 Socio-economic Assessment

The socio-economic status, attitude and perception of local communities play a significant role in the conservation of forests and their wildlife. Therefore, the demographic assessment of respondents was done to develop a better understanding of their socio-economic status and attitude as it will also help in suggesting the conservation strategies suitable for the study area. The demographic parameters were categorized by age, gender, educational qualification, educational stream, occupation, monthly income, and type of resident. Each category includes the number of respondents, and standard deviation and standard error were computed to check the significance and validity of the information. The information was procured through the questionnaire. A total of 300 respondents participated in the survey, and they answered 33 closed sets of questionnaires. The question section contained two sections. The first section consisted of demographic parameters, while the second set of questions aimed to understand their attitude towards the environment and conservation. Respondents aged 18-25 were the largest group with 245 participants, followed by 25-30 (37 respondents), 30-35 (13), below 18 (4), and 35-50 (1). The standard deviation and error for those under 18 were 0.52176 and 0.03012, respectively. In gender the males were 122 and 178 females were also surveyed. Most respondents were post-graduates or above (179), followed by graduates (109), 12+ (9), and 10+ (3). The standard deviation for the 10+ category was 0.85582, with a standard error of 0.03507. Humanities and language dominated with 132 respondents, followed by science (87), commerce and management (79), and vocational or others (2). The occupation for the majority were student**s** (282), while a smaller number were employed (12), self-employed (4), or unemployed (2). The monthly income bracket of Rs. 30,000-50,000 had the highest number of respondents (111), followed by Rs. 15,000-30,000 (90), below Rs. 15,000 (85), and Rs. 50,000-100,000 (14). The residence type was accessed for the respondents**.** Respondents numbered 155 were urban while 145 respondents lived in rural areas. The survey sample depicts that there is a dominance of students, postgraduates, and urban residents (Table 4.26).

Table 4. 28: Demographic data of respondents from the survey.

Demographic parameters	Particulars	Frequency (No. of respondents)	Standard deviation	Standard error
Age	Below 18	4	.052176	0.03012
	18-25	245		
	25-30	37		
	30-35	13		
	35-50	1		
Gender	Male	122	0.49203	0.002841
	Female	178		
Educational Qualification	10+	3	0.85582	0.03507
	12+	9		
	Graduate	109		
	Post graduate and above	179		
Educational stream	Science	87	0.85582	0.04941
	Commerce and management	79		
	Humanities and Language	132		
	Vocational or others	2		
Occupation	Student	282	0.38250	0.02208
	Employed	12		
	Self-employed	4		
	unemployed	2		
Monthly Income (Rs.)	Below 15000	85	0.90017	0.05197
	15000-30000	90		
	30000-50000	111		
	50000-100000	14		
	1000000 or above	Nil		
Resident type	Urban	155	0.50056	0.02890
	Rural	145		

The respondents rated their agreement with various statements related to biodiversity, environmental conservation, and related issues, using a Likert scale from "Strongly Disagreed" to "Strongly Agreed." For each statement, the count of responses in each category (Strongly Disagreed, Disagreed, Neutral, Agree, and

Strongly Agree) is shown, along with standard deviation and standard error values to measure response variability. On question-based to access biodiversity loss and its consequences, most respondents agreed that biodiversity loss and its consequences were significant concerns. A large portion (258) agreed, while only a few disagreed. The standard deviation (0.40045) and error (0.02312) were low and showed high consensus. In the questions about forest cover decline, there is more variability with 72 neutral responses and 35 disagreeing that forest cover had declined. However, the majority still agree (193). The higher standard deviation (0.69587) reflects this division whereas for the decline in wild animal and bird populations, the majority (250) agreed that there is a decline in wildlife populations, though 30 respondents were neutral, and very few (16) disagree. The relatively higher standard deviation (0.53875) indicated slightly more variability in views. In the question about the understanding of the shifting cultivation and awareness towards its effects on biodiversity and forest cover loss, most respondents agreed. (257 and 265 respectively), with very few expressing neutral or opposing views. The low standard deviation values (0.41698 and 0.36593) indicate strong consensus.

Furthermore, for a deeper understanding of the impact of climate change on rainfall, the belief that climate change affects rainfall in the region is nearly unanimous, with 279 agreeing and no disagreement. The extremely low standard deviation (0.26500) reflects this overwhelming agreement. There is a positive attitude towards eco-friendly and sustainable behaviour as there is strong agreement on the benefits of water conservation (214 agreed), waste reduction (227 agreed), and recycling (268 agreed). However, views on conserving rainwater show a broader spread (77 strongly agreed) than other statements. Hunting and cutting trees were widely seen as wrong, with most agreeing (274 and 272 respectively). The standard deviation for both statements was low (0.32687 and 0.32197), showed consensus. The necessity of conservation “Most agreed” on the necessity of environmental and biodiversity conservation (224 and 255, respectively), with low standard deviation values reflecting agreement.

Towards community involvement in conservation, respondents strongly agreed that community participation is essential for environmental conservation, with only 19 neutral responses and no disagreement. For compensatory payment and monetary support towards conservation, the views were more divided. The questions about environmental impacts and the concept of "polluter's pay," were met with higher neutral and disagreement responses. Standard deviation values were higher (0.50921 for compensatory payments and 0.72830 for polluter's pay), indicating less consensus. Overall, there is strong agreement on the need for conservation and protection of biodiversity and the environment, with low standard deviation values indicating a consensus. However, the consensus is divided on monetary compensation. Statements regarding monetary participation and compensatory payments showed more variability, suggesting respondents were less uniformly aligned on these issues. The overall Disagreement was low across all questions, very few respondents strongly disagreed, with most either agreed or expressing neutrality.

Table 4. 29: Descriptive statistics of the questionnaire.

	Questions/ Response	Strongly Disagree	Disagree	Neutral	Agree	Strongly Disagree	Std. deviation	Std. Error
1.	The issues related to biodiversity loss and its consequences	0	2	16	258	24	0.40045	0.02312
2.	The decline in the population of wild animals and birds in the region	0	16	30	250	4	0.53875	0.03111
3.	The decline in the forest cover in the region	0	35	72	193	0	0.69587	0.04018
4.	Shifting cultivation leads to biodiversity loss	0	3	16	257	24	0.41698	0.02407
5.	Shifting cultivation leads to forest cover loss	0	2	23	265	10	0.36593	0.02113
6.	Rainfall is affected by climate change in the region	0	0	10	279	11	0.26500	0.01530
7.	Hunting of wild animals or birds is the wrong practice	0	2	12	274	12	0.32687	0.01887
8.	Cutting down trees in forested areas is wrong practice	0	1	13	272	14	0.32197	0.01859
9.	Conserving rainwater is the right practice	0	2	9	214	77	0.50905	0.02939
10.	Reducing waste daily is a good practice	0	1	15	227	57	0.48615	0.02807
11.	Recycling the waste is a good practice	0	1	9	268	22	0.34016	0.01964

12.	Conservation and protection of the environment is necessary	0	0	13	224	63	0.47572	0.02747
13.	Biodiversity conservation is necessary	0	1	10	255	34	0.39870	0.02302
14.	Forest conservation will conserve biodiversity	0	1	15	268	16	0.32653	0.01885
15.	Indigenous knowledge conservation will help in biodiversity conservation	0	0	14	266	20	0.33662	0.01943
16.	Forest conservation will help in increasing rainfall	0	1	15	269	15	0.33715	0.01947
17.	Conservation of forests will help mitigate climate change	0	0	25	256	19	0.38309	0.02212
18.	Conservation and protection of the environment will help the local community	0	0	9	268	23	0.32379	0.01869
19.	Community participation is the key to environmental conservation.	0	0	19	263	18	0.35176	0.02031
20.	Air, water, land, forest, biodiversity are common property resource	0	2	13	271	14	0.38338	0.02213
21.	I support the idea of compensatory payment for environment	0	10	20	251	19	0.50921	0.02940
22.	I support concept of polluter's pay principle	0	20	25	201	54	0.72830	0.04205
23.	I support for a pay of compensation for cutting down trees	0	27	91	140	42	0.82931	0.04788

24.	Monetary participate in biodiversity conservation	0	1	11	208	79	0.51738	0.02987
25.	Participate in donation towards disaster reliefs	0	1	14	197	88	0.54472	0.03145
26.	I Volunteer participation in conservation efforts	0	1	14	202	83	0.53642	0.03097

DISCUSSION

The findings of the present investigation have been discussed and interpreted taking into consideration the effects of disturbance gradient, as follows:

5.1 Vegetation Analysis

Monitoring forest community structure and biodiversity is essential for assessing ecosystem health and directing conservation initiatives. Furthermore, monitoring the structure of forest communities helps us understand the effects and consequences of man-made and natural disturbances, including logging, agriculture, and climate change. These activities can lead to habitat fragmentation, species loss, and community composition alterations. Assessing and monitoring biodiversity is crucial for determining species conservational status (Nielsen et al., 2009) and community structure (Favila and Halffter, 1997; Bitani et al., 2023).

The vegetation analysis of selected forest stands along the disturbance gradient which indicated a drastic change in species composition with varied diversity, dominance and evenness.

The species richness in all stands was relatively high (153 species,187 species and 167 species in the undisturbed, moderately disturbed and highly disturbed stands, respectively irrespective of plant habits in comparison with other types of forest, which is the characteristic feature of tropical forests (Wright, 1996; 2007). The high species richness can be attributed to the edapho-climatic conditions of the study area that favours plant growth and natural regeneration (Tuomisto et al., 2014; Ramos et al., 2020).

The high tree diversity in the undisturbed forest signifies a stable and complex community. The findings are in conformity with the work of Gaston (2000) who argued that intact forests experience stable climatic conditions for millions of years enabling species to specialise and co-exist, enhancing overall species diversity. The spatial heterogeneity can also be a factor responsible for high species richness (Griffin et al., 2009), therefore high species richness in the study area can be attributed to habitat heterogeneity within tropical forests. According to Tang et al. (2020), greater habitat heterogeneity favours higher species richness compared to homogeneous habitats. The diversification of plant and animal species also occure during prolonged periods of climatic stability (Qian and Ricklefs, 2016). The high species richness reported during the present investigation could also be expressed by the fact that the forests selected for the study are part of Indo-Burman biodiversity hotspots. The findings of the present study are in conformity with the aforesaid statements.

The undisturbed natural forests are sable and structurally complex, this complexity allows for niche differentiation, which reduces competition and permits a higher number of species to co-exist (Loreau and Mazancourt, 2013). These forests maintain intricate nutrient cycling processes that support a variety of life forms. The decomposition of organic matter and the symbiotic relationships between species, such as mycorrhizal fungi and trees, enhance soil fertility, promoting plant diversity (Wardle et al., 2004).

The number of species was highest in the moderately disturbed forest stand supporting the intermediate disturbance hypothesis (Connell, 1978, 2002). Mishra et al. (2004) have also reported that mild disturbance favours species richness, as small gaps created due to disturbance lead to species turnover. Moderate disturbances prevent dominance by a few species and maintain a dynamic environment that supports a wide range of organisms. Moderate disturbance like selective logging has been shown to maintain or even increase the biodiversity of habitat by creating new opportunities for colonisation (Sheil and Burslem, 2003). In ecosystems subjected to frequent or intense disturbances, many species may be unable to recover or recolonise, resulting in low diversity due to the harsh and constantly changing conditions (Mackey and Currie, 2001). Some researchers have argued that the relationship between ecological disturbances and diversity is more complex than originally proposed by researchers and may vary depending on the type of ecosystem and the nature of the disturbance (Huston, 1979; Fox, 2013). Taking into account all the plant habits (herbs, shrubs and trees), the moderately and highly disturbed stands have more species richness than the undisturbed stand. An increase in species richness with increasing disturbance has been reported by Pandey and Singh (1985). The findings on species richness are in conformity with the work of Tripathi (2002), Bhuyan et al. (2003), Mishra et al. (2004), Upadhaya et al. (2004), Mishra et al. (2005), Nath et al. (2005), Lalchhuananawma and Lalramnghinglova (2008), Lalfakawma et al. (2009) and Tripathi et al. (2010).

The prevalence of plant families varied markedly among undisturbed, moderately disturbed, and highly disturbed stand, indicating the influence of disturbance on species composition. In undisturbed stand, the most prevalent families were Fabaceae, Lauraceae, Euphorbiaceae and Fagaceae. The occurrence of Lauraceae and Fagaceae signifies the preservation of biodiversity in undisturbed stand, as both families are typically linked to mature forest ecosystems and suggest minimal human disturbance (Sharma et al., 2020). The significant prevalence of Fabaceae, a family recognised for its nitrogen-fixing characteristics, underscores its contribution to soil fertility in undisturbed regions (Jishtu and Goraya, 2019). In moderately disturbed stand, the leading families were Fabaceae, Moraceae, Lauraceae, Rubiaceae and Anacardiaceae. The transition in dominance, marked by the rise of Moraceae and Rubiaceae, indicates the proliferation of species that exhibit greater disturbance tolerance or are pioneer species capable of flourishing in disrupted habitats (Sagar et al., 2003; Sharma et al., 2023). The occurrence of Fabaceae in both undisturbed and moderately disturbed stands demonstrates its ecological adaptability and resilience to disruption. In the highly disturbed stand, the species richness in the respective dominant family reduced sharply with Fabaceae, Moraceae, Anacardiaceae, Lauraceae and Myrtaceae. Moreover, there was a decline in the number of disturbance sensitive families such as Lauraceae and on the other hand, the number of disturbance-tolerant families like Anacardiaceae and Myrtaceae increased, underscoring the influence of disturbance on plant community composition. This indicates a tendency towards species exhibiting more generalist or opportunistic characteristics in significantly damaged settings (Chaturvedi et al., 2017; Kumar et al., 2022). The findings are in conformity with the work of Mishra et al. (2005), Tripathi (2002) and Tripathi et al. (2010).

The distribution of trees based on the girth class may be regarded as the indicator of the population structure of forests. (Khan et al., 1987; Newton and Smith, 1988; Newbery and Gartlan, 1996; Barik et al., 1992, 1996). The population structure of tree species along the disturbance gradient helps in understanding the dynamics of tree populations, their reproductive success and how trees respond to environmental changes due to disturbances. The moderately disturbed stand harbours the maximum number of young trees in the lowest girth class; however, number of mature trees was highest in the undisturbed stand. The findings reveal that the small gaps created in the moderately disturbed stand due to disturbance facilitated the survival and growth of young trees. The disturbance caused the reduced girth class with the increase in the degree of disturbance. A similar observation was also reported by Mishra et al. (2004, 2005). Anthropogenic disturbances, including logging and land-use changes, also alter tree population structure by removing large, mature trees and affecting species composition (Chazdon, 2003). By studying the age and size distributions of tree populations, ecologists can infer the successional stage of the forest and predict its future trajectory (Connell and Slatyer, 1977).

Logging and timber extraction are the major disturbances that alter the distribution of tree species and resulting in change in species composion and colonisation. Researchers have suggested selective logging for timber extraction, favours the growth of non-timber light-demanding species removing dominant canopy trees, thereby increasing light availability for understory and mid-canopy species. According to Barik et al. (1996), logging operations in north-eastern India increased the abundance of species that require light while decreasing the abundance of species that can withstand shadow. Furthermore, selective logging and deforestation in tropical forests often result in reduced species richness and simplified community structure, with long-term impacts on ecosystem stability (Gardner et al., 2009).

As the disturbance gradient moves along, the tree density progressively drops. The young tree density is lowest in the undisturbed area and highest in the moderately disturbed area, followed by the highly disturbed area. The tree density declined with an increased disturbance gradient (Borah and Garkoti, 2011; Sahu et al., 2008; Sahoo et al., 2020). This decline signifies a decrease in both tree diversity and abundance as disturbances escalate, resulting in smaller trees and seedlings prevailing in disturbed environments (Whitmore, 1998). The effect of disturbance on the structure of the forest is demonstrated by the basal area and tree density.

The basal area is crucial sign of the biomass and health of a forest, which is calculated as the cross-sectional area of trees per hectare at breast height (Chave et al., 2014). The basal area (27.98 m^2/ha) is much higher in the undisturbed stand, indicating a mature, healthy forest with huge, well-established trees (Mishra et al., 2004; Borah and Garkoti, 2011). The basal area decreased dramatically with the increase in disturbance. According to Laurance et al. (1997), this indicated that disturbances like logging, deforestation, and changes in land use lower the biomass of forests because they remove larger trees. The basal area of the stands also declined with an increase in disturbance (Sangma and Mishra, 2017; Mishra et al., 2004). Many similar studies have reported this decline in the basal area with disturbance (Chittibabu and Parthasarathy, 2000; Mishra et al., 2004; Nath et al., 2005; Borah and Garkoti, 2011; Sangma and Mishra, 2017). The correlation between basal area and tree density was positive and significant for all stand. The disturbance caused a sharp decline in tree density and total basal area from the undisturbed to highly disturbed stand (Mishra et al., 2004, 2005; Airi and Rawal, 2017).

The distribution of species along the disturbance gradient illustrates plant communities' response to differing environmental stress levels. In undisturbed stand, trees are predominant with 87 species documented, indicating a stable ecosystem characterised by well-established tree species typical of mature forests (Whitmore, 1998). As disturbances intensified, the diversity of tree species declined markedly with 79 species in moderately disturbed stand and merely 31 species in highly disturbed stand. This pattern indicates that disturbances like deforestation or logging caused the decrease in tree diversity, typically by eliminating larger, more susceptible species (Laurance et al., 1997). In Mizoram, Malsawmsanga (2011) identified 84 tree species in Phawngpui National Park, Lawngtlai District; Lalrinkimi and Lallianthanga (2019) documented 74 tree species in Aizawl District; Devi et al. (2018) reported 125 species in the Reiek forest and also Lalzarzovi and Lalnuntluanga (2022) reported 94 tree species in the Reiek Forest, Mamit District. Lalfakawma et al. (2009) reported 67 species in Aizawl district in the undisturbed forest. The elevated species richness of undisturbed woods is attributable to climatic and geographical factors (Tiwari et al., 1998). A similar trend in the result was also established by Mishra et al. (2005), Borah et al. (2021), and Sahoo et al. (2020). In the present study, there was a shift in the position of dominant species along the disturbance gradient as *Bischofia javanica* in the undisturbed stand was replaced by *Schima wallichii* in the moderately disturbed stand and *Mesua ferrea* in the highly disturbed stand. A similar trend in results was also reported by Mishra et al. (2004).

The variation in the plant community structure and organisation over time is a natural phenomenon (Schoener, 1986). Anthropogenic disturbances significantly affect the natural course of the structural change of an ecosystems, particularly altering the species richness, diversity, dominance, and basal area. These disturbances encompass deforestation, alterations in land use, logging, urbanisation, and agriculture. Ecological functions and equilibrium often get disrupted by shocks and perturbations, thus altering the intra and inter-species relationships, community structure, and resource availability. The high shrub species richness in the moderately disturbed stand indicated that moderate disturbances may enhance conditions for shrub growth, potentially through increased light availability (Grime, 2001). Similarly, the quantity of herb species increases significantly in highly disturbed stand, suggesting that herbs exhibit greater resilience and can rapidly establish themselves in disturbed environments, frequently taking advantage of diminished competition and available space (Turner et al., 1998). As the disturbance increases the dominance of trees decline promoting increased shrub growth in moderate levels of disturbance and herbaceous species dominance disturbance often promotes the growth of shrubs and herbs, reducing the abundance of slower-growing species (Connell, 1978). An increase in shrub and herbaceous species is indicative of flourishing undergrowth diversity (Ram et al., 2004; Kumar and Ram, 2005).

The primary trigger for the proliferation of herbaceous species post-disturbance is the increased availability of light. In undisturbed forests, the dense canopy typically limits light penetration to the forest floor, hence impeding the growth of herbaceous plants. Disturbances create canopy gaps, allowing sunlight to penetrate the forest floor and promoting conditions favourable for light-demanding herbaceous plants. The herbaceous species rapidly colonise disturbed stand, exploiting the newly available resources before the recovery of other vegetation, including trees. (Grime, 2001; Uytvanck and Hoffmann, 2009). The number of herbaceous species increases significantly with the increase in the degree of disturbance suggesting that herbs exhibit greater resilience and can rapidly establish themselves in disturbed environments, frequently taking advantage of diminished competition and available space (Turner et al., 1998). A similar trend in results was also established by past workers (Lalfakawama et al., 2009; Malsawmsanga, 2011; Lalzarzovi and Lalnuntluanga, 2022) who carried out research in different forests in Mizoram.

The highly disturbed area is chronically affected by anthropogenic activity as they are situated relatively near human settlements. The sharp increase in the number of herbaceous species in highly disturbed stand could be attributed to larger gaps of trees allowing increased sunlight facilitating survival and growth of herbs. However, prolonged dominance of these species can have long-term ecological consequences such as the increase in invasive species eliminating native plants and altering ecosystem processes such as nutrient cycling and fire regimes (D'Antonio and Vitousek, 1992). The dominance of herbaceous species such as ferns and grasses has been shown to slow the regeneration of woody species, particularly in stand subjected to repeated disturbances (Finegan, 1996). The disturbed stand is continuously being used for shifting cultivation, firewood collection and grazing. The clearing and burning of land for jhum enhance the growth of herbaceous vegetation (Mishra and Ramakrishnan, 1983; Kumar and Ram, 2005; Yadav, 2013).

The abundance and distribution of a species are influenced by the equilibrium among birth rates, mortality rates, immigration, and emigration (Begon et al., 2006). The majority of tree species in the undisturbed forest stand showed contagious distribution which is characteristic of natural forests showing predominance of clumped distribution (Ondm, 1971). Similar studies have also reported predominance of contagious distribution (Mishra and Laloo, 2006; Upadhaya et al., 2004; Metha et al., 1997; Pandey and Shukla, 2002).

The Shannon diversity index of the tree species decreased with increasing disturbance (Uniyal et al., 2010). However, the highest value of the Shannon index for shrub species was observed in the moderately disturbed stand. (Lalchhuananawma and Lalramnghinglova, 2008; Malsawmsanga, 2011; Lalrinkimi and Lallianthanga, 2019; Lalzarzovi and Lalnuntluanga, 2022; Uniyal et al., 2010; Bdoor, 2016, 2017; Sangma and Mishra, 2017; Sahoo et al., 2020). On the contrary, the diversity index for herbaceous species was found in increasing order with increase in degree of disturbance gradient (Duchok et al., 2005; Uniyal et al., 2010; Sangma and Mishra, 2017).

The Simpson's index helps to compare diversity across different communities and over time, particularly when environmental changes might favour the proliferation of certain species over others (Begon et al., 2006). The Simpson's index of dominance for tree species was highest for undisturbed forests suggesting that the ecosystem is dominated by a few species, with most individuals likely belonging to these dominant species. It was followed by moderately disturbed and highly disturbed. The Simpson index values for shrubs across all levels of disturbance, are relatively high and stable, indicating that, while disturbance alters diversity, no single species overwhelmingly dominates the community in any condition suggesting a more balanced and stable community. The dominance index is reportedly inversely proportional to the diversity index. The studies done by researchers have reported similar results. (Sagar et al., 2003; Lalchhuananawma and Lalramnghinglova, 2008;

Sangma and Mishra, 2017; Sahu, 2008; Borah et al., 2021).

A biodiversity metric Margalef's Index compares species richness to the natural logarithm of the population size. It sheds light on how species variety reacts to alterations or disruptions in the environment. Margalef's Index dropped with increase in degree of disturbance indicating a drastic reduction in tree species richness as disturbance increases in the context of India's disturbance gradients. Given that larger, more diversified forests give way to fewer species in disturbed ecosystems, it is suggested that disturbances like deforestation and changes in land use greatly limit the diversity of tree species (Chandrashekara and Ramakrishnan, 1994; Bdoor, 2016; Sangma and Mishra, 2017).

For shrubs, Margalef's Index was highest in moderately disturbed stand, the decline in highly disturbed indicates that intense disturbance begins to reduce the ability of different species to coexist, as habitat degradation may limit resources and space. This suggests that mild shocks provide the right environment more light and space, for shrub development (Jha and Singh, 1990). The herbs show the most variety in highly disturbed stand. Herbs are often found in disturbed habitats where they quickly spread throughout open stand and have an advantage over less competitive plants (Pandey and Shukla, 2001). Overall, Margalef's Index shows how different vegetation types are affected by disturbance in different ways, with trees being most damaged and herbs benefiting from it. Higher values suggest greater species diversity.

The plant community structure and species composition varied greatly from undisturbed to highly disturbed stands. This variation can be attributed to anthropogenic disturbances like the felling of trees, shifting cultivation, cattle grazing and sandstone mining and developmental activities, leading to habitat loss and forest fragmentation. Thus, inferred from the result that anthropogenic disturbances do have an impact on diversity as there is an obvious decline in the diversity index with an increase in the disturbance index. Disturbances create heterogeneous habitats, affecting tree species composition, structure, and distribution. These results are in conformity with the works of other researchers (Tripathi and Barik, 2003; Mishra et al., 2004, 2005). Tripathi (2002) has argued that shifting cultivation leads to forest fragmentation and species composition changes in north-eastern India. Arunachalam et al. (2010) supported the results of the study by highlighting that climate change might lead to the upward migration of certain species in response to warming temperatures.

The dominance-diversity curve is a graphical representation for the distribution of species, indicating stability and complexity of an ecological community. The partitioning of realised niche space among different species is described by the lognormal series, which is the outcome of the species' evolutionary diversification along the niche characteristics that it exploits (Whittaker, 1965). It provides insight into the relative dominance of species and overall biodiversity in an ecosystem by plotting species abundance against their rank, from the most to the least abundant species. The dominance diversity curve is significant to understanding the stability of the community. The dominance diversity curve was plotted using IVI and species rank often on a logarithmic scale. The shape of the curve reflects the balance between dominant and rare species and is influenced by factors such as competition, resource availability, and disturbance. Log-normal dominance distribution curve in the undisturbed and moderately disturbed stands depicts the stable and complex community, whilst short- hooked curve in the highly disturbed stand indicating unstable community (Kadavul and Parthasarathy, 1999; Visalakshi, 1995; Mishra et al., 2004; Sharma et al., 2018; Devi et al., 2018). The undisturbed forest possessed a stable curve which is indicative of stable and climax stages of succession exhibiting more even distribution and shallower curves as species richness and evenness increase (Tilman, 1985). Disturbed ecosystems often exhibit steep dominance-diversity curves, as a few opportunistic species dominate after disturbance (Odum, 1969).

Thus, it is evident from the results obtained from vegetation assessment from this study that as the disturbance affects the species richness, diversity, dominance, evenness, population structure and distribution (Kumar and Ram, 2003; Mishra et al., 2004; Sangma and Mishra, 2017).

The species common in all stands showed high ecological amplitude with regards to degree of disturbance. The tree species present in all stands are *Acacia pennata, Acrocarpus fraxinifolius, Albizia chinensis, Albizia thompsonii, Callicarpa arborea, Calophyllum polyanthum, Castanopsis tribuloides, Ficus curtipes, Macaranga indica, Oroxylum indicum, Phoebe attenuate, Rhus chinensis, Schima wallichii, Syzygium claviflorum, Syzygium cumini* and *Wendlandia grandis.* Similarly, shrub species namely *Bridelia stipularis, Butea parviflora, Cissus repens, Dalbergia stipulacea, Debregeasia longifolia, Desmodium gyroides, Garcinia cowa, Lycopodium sp., Mussaenda roxburghii, Rourea minor, Rubus birmanicus, Tetrastigma bracteolatum* and *Tithonia diversifolia* are common in all stands. The herbaceous species present in all stands are *Cyperus cyperoides, Cyrtococcum accrescens, Dendrocalamus hamiltonii, Desmodium triquetrum, Eragrostis nutans, Lycopodium cernuum,* and *Lygodium flexuosum*. The species restricted to undisturbed stand are vulnerable to anthropogenic disturbance. Such species are *Acer laevigatum, Albizia odoratissima, Aporosa dioica, Cassia sp, Cinnamomum tamala, Cordia floribunda, Delonix regia, Eriobotrya bengalensis, Olea dioica, Olea salicifolia, Phoebe hainesiana, Quercus glauca, Schefflera wallichiana, Spondias pinnata, Sterculia hamiltinii, Symplocos theifolia, Ulmus lancifolia* and *Wendlandia paniculata* under tree category; *Berberis camcina, Blumea lanceolaria, Druce Elatostema dissectum, Eranthemum palatiferum, Flemingia macrophylla, Flemingia stricta, Garcinia cowa, Ipomoea cymosa, Inula cappa, Ligustrum robustum, Merremia umbellate, Osbeckia sp. Polygonum chinense, Rhus succedanea, Rhus typhina, Tetrastigma bracteolatum* and *Toddalia asiatica* under shrub category; *Adiantum caudatum, Asplenium nidus, Byttneria pilosa, Chamaecostus cuspidatus, Costus speciosus, Dicranopteris linearis, Elatostema dissectum, Elatostema sessile, Globba multiflora, Impatiens laevigata, Laportea crenulata, Leptochilus ellipticus, Lysionotus serratus, Ophiorrhiza ochroleuca, Ophiorrhiza trichocarpa, Persicaria wallichii, Pothos cathcartii, Pronephrium nudatum* and *Urtica dioica* under herb category. The species restricted to the highly disturbed stand indicating that either such species are shade intolerant or can not compete with primary species. The species confined to highly disturbed forest stand are *Bauhinia variegate, Betula* *alnoides, Cinnamomum cassia, Ficus benjamina, Mangifera indica, Mesua ferrea* and *Morus nigra* under tree category; *Aspidopterys nutans, Bauhinia camcina, Cajanus cajan, Cassia occidentalis, Dioscorea* sp, *Gossypium herbaceum, Hibiscus fragrans, Hibiscus hispidissimus, Hibiscus sabdariffa, Hodgsonia macrocarpa, Lasianthus hookeri, Lepisanthes senegalensis, Mussaenda gandra, Persicaria wallichii, Solanum xanthocarpum* and *Urena lobate* under shrub category; *Abelmoschus esculentus, Amaranthus viridis, Anisochilus pallidus, Benincasa hispida, Bidens pilosa , Blechnum orientale, Boenninghausenia albiflora, Capsicum annuum, Capsicum frutescens, Curcuma longa, Cynodon dactylon, Dichanthium annulatum, Drymaria diandra, Lobelia colorata, Peperomia pellucida, Physalis minima, Polygonum hydropiper, Solanum nigrum* and *Tithonia rotundifolia* under herb category (Appendix-2). A similar trend in results has been reported by Mishra et al. (2004).

5.2 Microclimate and Soil Analysis

Microclimate is the atmospheric conditions in a particular place that diverge from the broader climate of the surrounding region. Factors like canopy cover and topographical variation provide shading make the shady areas cooler in the forest floor, in the undisturbed forest ecosystem while exposed areas receive more sunlight, resulting in a range of microhabitats (Chen et al., 1999). The microclimate does affect factors like soil composition, vegetation cover, topography, and water availability, influencing small-scale environmental variables that can substantially affect the species diversity, and also leading towards the establishment of numerous niches that accommodate a diverse array of species. Factors like temperature, relative humidity, and soil composition affect the germination, growth and reproduction of plant species in the area (Mishra et al., 2004; Mishra, 2010). These soil tempreture changes along the disturbance gradient might be attributed to alterations in micro-site or habitat conditions resulting due to the changes in the canopy disturbances (Baker, 1986). Rao et al. (1990) stated that microclimatic characteristics of the forest floor and micro-environmental conditions under the forest canopy can influence the regeneration of trees by seeds. The humidity was higher for the undisturbed stand

and lower in highly disturbed stand, this can also be attributed to reduction in canopy cover with increase in level of disturbance. On the contrary, the ambient temperature showed the opposite trend in results, as it is obvious that open canopy due to disturbance led to high temperature. The microclimate is markedly affected due to disturbance and it has been corroborated by similar studies (Mishra et al., 2004; Mishra and Laloo, 2006; Lu et al., 2024).

The soil temperature was highly influenced by ambient temperature as an open canopy facilitated more absorption of solar radiation, and as a result, a similar trend was established in the case of soil temperature (Krishna, 2013; Barman and Das, 2022). Normally, soil temperature decreases from top-soil to sub-soil, with some exceptions in the case of moderately disturbed stand. This trend is probably caused by the higher insulation provided by the soil layers, which lessens heat transfer to deeper levels. This indicates that disturbance levels and seasonal changes significantly influence soil temperature. The lower temperature in all stands during the monsoon season and variation in values in respective seasons in successive years may be the result of cloud cover and rainfall along with the microclimatic factors. The soil's surface is affected by latitude, season, air conditions and temperature (Hillel, 2007) and the amount of solar radiation reaching it (Brady and Weil, 2016). The findings depict that soil temperature has a positive correlation with air temperature (Hillel, 2007).

There is a marked seasonal variation in soil temperature, with pre-monsoon values being the highest, followed by monsoon and post-monsoon. The decrease in soil temperature from pre-monsoon to monsoon is likely due to the onset of the rainy season, which cools the soil surface. The post-monsoon period continues to show lower temperatures, as the cumulative effects of rainfall and reduced solar radiation result in cooler soils. For undisturbed soil the temperature drops from the pre-monsoon to monsoon, and further down in the post-monsoon period. A similar pattern is observed across all disturbance levels, with the post-monsoon period consistently showing the lowest temperatures. This seasonal cooling effect is more pronounced in undisturbed soils, likely because undisturbed soils maintain better moisture retention and have a more intact structure, which aids in temperature regulation.

The soil pH was impacted by disturbance as the undisturbed stand often had higher pH values than the highly disturbed stand. The soil pH of highly disturbed stand is lower than undisturbed, making the disturbed soil more acidic. This pattern is seen in all seasons. Additionally, disturbance may result in greater exposure to subsurface materials, which typically have lower pH values. (Mishra, 2010, 2011; Ovung et al., 2021, Kumar et al., 2017).

In comparison to the monsoon period, the post-monsoon pH values were higher. This can be due to the reduced precipitation, indicating that monsoon leaching has lasted. The pH dropped for highly disturbed stand, can be indicative of seasonal influence. The soil pH value was also influenced by the depth of the soil, as the sub-soil often had higher pH values than the top-soil. This pattern holds for all seasons and disturbance levels. Sub-soil may have a higher soil pH because subsurface conditions there are more stable and less susceptible to surface-level disturbances and organic acid leaching (Mishra, 2010, 2011; Bünemann et al., 2018). The soil pH showed a positive and significant correlation with soil moisture content, water holding capacity, potassium, total nitrogen, and negative correlation with bulk density.

Throughout the year and disturbance, the soil pH value was consistently lower in lower depths. Thus, soil pH value obtained in the study can be inferred that the sub-soils can better withstand seasonal variations in soil pH, perhaps as a result of reduced microbial activity and organic matter turnover in these strata. As water percolates through the soil and washes away basic cations, creating more acidic conditions, this trend is probably caused by enhanced leaching of nutrients during heavy rainfall (Meena et al., 2020). Lalchhuananawma and Lalramnghinglova (2008) and Lalsangzuala (2023) reported similar results in the soil in Mizoram. The findings on soil pH is in line with past workers (Ramchhanliana, 2018; Singh and Tripathi, 2020; Singh et al., 2020; Lalsangzuala, 2023). The acidity in the soil has been attributed due to two major causes one being acidic parent material and secondly the leeching of basic caused by heavy rainfall (Mishra and Saithantluanga, 2000; Mishra, 2010; Colney and Nautiyal, 2013).

The texture of the soil is defined by the relative proportion of sand, silt and clay their proportion of various constituents determines their properties. Soil texture also plays a crucial role in soil moisture retention and temperature regulation. The impact of soil texture on moisture retention capacity and temperature fluctuations is significant, with sandy soils heating and cooling quickly due to increased porosity, while clayey soils store more moisture and exhibit slower temperature fluctuations. Soil texture influences the soil properties such as moisture retention capacity, hence impacting soil temperature. Sandy soils, due to their increased porosity, experience quick heating and cooling, in contrast to clayey soils, which store greater moisture and demonstrate slower temperature fluctuations (Brady and Weil, 2016). The texture of the soil varied from sandy loam and loamy sand. The highly disturbed stand soil had higher sand content than the undisturbed and moderately disturbed stand. The higher sand content of highly disturbed soil can be attributed to the degradation of natural forest soil (Temjen et al., 2022). Similar soil texture has been reported by Sagar et al. (2003); Colney and Nautiyal (2013); Singha and Tripathi (2017); Manpoong and Tripathi (2019); Singh et al. (2020).

Soil pores play a significant role in the uptake of nutrients and moisture, but soil compaction negatively affects the volume of the soil pores (Eden et al., 2011). Bulk density is the measure of soil density, therefore higher value of bulk density can be inferred from highly compact soil and reduced soil pores. This can adversely affect the plant root growth and yield. The top-soil had a lower bulk density across all stand whereas the sub-soil had a higher bulk density. The bulk density showed a significant impact of disturbance as it was significantly lower for undisturbed stand soil than highly disturbed stand soil (Mishra and Laloo, 2006; Manpoong and Tripathi, 2019). The bulk density also varied with depth as generally the upper depth had lower bulk density compared to top-soil. The higher bulk density at highly disturbed stand can be due to degradation of natural forest leads and shifting cultivation (Zolfaghari and Hajabbasi, 2008).

The soil moisture content and texture significantly influence soil erosion rates, with different physiographic regions experiencing varying rates based on terrain, slope, land use practices, and population pressure (Mishra and Francaviglia, 2021). In the monsoon season, the soil moisture content showed an increase across disturbance, this may be because of the heavy rainfall during the monsoon. In the pre-monsoon season, the soil moisture content of undisturbed soil is higher than the soil moisture content of moderately and highly disturbed soils, this can be attributed to the high canopy cover provided by natural forest. The amount of water available for plant growth, hydrological cycles, and soil health all depend on soil moisture. A silar trend in results also established by Mishra and Laloo (2006) and Manpoong and Tripathi (2019).

The soil moisture content was lower for the highly disturbed stand in the upper depth, this can be due to the lack of vegetation and canopy cover that exposes the soil surface to loss of moisture and erosion (Mishra and Laloo, 2006). The soil moisture is retained through good soil structure, high organic matter, high soil porosity and less compaction, thus the undisturbed stand had higher moisture content, showing casing good soil health. Hence the lack of soil porosity and increased compaction can also be the factor behind the lack of moisture in highly disturbed. (Singh et al., 2019). Furthermore, disturbed soils typically have lower infiltration and higher surface runoff, which further reduces their capacity to hold onto moisture. This suggested that even after the monsoon season, disturbed soils may experience long-term difficulties with water retention (Sharma et al., 2016). The soil moisture content for the sub-soil was higher than the top-soil across the disturbance gradient. The higher moisture content in sub-soil for undisturbed and moderately disturbed as opposed to top-soil, can be attributed to decreased evaporation and improved water infiltration (Tiwari et al., 2017).

The water-holding capacity is a significant parameter in understanding the soil quality. The reduction in water holding capacity can lead to a decline in soil moisture availability, which can further diminish crop yields and increase vulnerability to droughts (Mandal et al., 2017). The water-holding capacity was the highest value at the undisturbed stand and lowest for the highly disturbed across all seasons. Disturbed soils exhibit a reduced capacity to absorb and retain moisture despite receiving the same amount of rainfall, highlighting the significance of soil structure and vegetation cover in water retention (Shi et al., 2016). As the soil texture indicated higher sand content in the highly disturbed soils, it may be the cause of reduced water holding capacity. (Jat et al., 2018; Aggarwal et al., 2003; Aggarwal and Pasricha, 2011). Deforestation along with intensive agriculture, especially monoculture and excessive tillage, can also reduce water holding capacity (Tyler and Olsson, 2001; Kumar et al., 2012; Kumar et al., 2016). Furthermore, the sandy soils, have low water retention capacity compared to clay soils (Jat et al., 2018). Soil porosity and organic matter content also affect the water holding capacity (Kumar et al., 2017; Li et al., 2022).

Soil organic carbon (SOC) and organic matter (SOM) are vital components of soil fertility, affecting nutrient availability, water retention, and microbial activity. Soil organic carbon is a key indicator of soil health (Lungmuana et al., 2016; Tripathi, 2018) as it is essential to hold nutrients and water, reducing the risk of soil erosion (Lal, 2004). The land use change (Yang et al., 2004) and burning during the jhum cultivation have been associated with the decline in soil organic carbon in the northeastern region of India (Mishra, 2011; Mishra and Saithantluanga, 2000).

Soil organic carbon content fluctuates significantly across the disturbance gradient, with undisturbed soils showing relatively stable soil organic carbon levels across seasons. This consistent increase in soil organic carbon in undisturbed soils can be attributed to the accumulation of organic matter, minimal soil erosion, and stable microbial activity (Bhattacharyya et al., 2008).

The monsoon season generally showed higher soil organic carbon values across the disturbance gradient. The monsoon promotes the decomposition of plant residues and enhances microbial activity, leading to an increase in soil organic carbon. In moderately disturbed soils the soil organic carbon rises in the pre-monsoon to monsoon. However, post-monsoon, soil organic carbon tends to decrease slightly, particularly in disturbed soils. The decrease may be due to the depletion of organic matter and accelerated decomposition under moist post-monsoon conditions (Sharma and Prasad, 1995; Singh et al., 2014) The highly disturbed stand soils showed a decline in soil organic carbon from monsoon to post-monsoon, this decline may also be due to the result from rapid organic matter decomposition, increased soil erosion, and lower organic inputs from vegetation due to disturbance (Jat et al., 2020). The study reported lower soil organic carbon than other similar studies (Kumar et al., 2023; Sagar et al., 2003; Singh et al., 2017).

The soil organic carbon at the moderately and highly disturbed stand was lesser than in the undisturbed stand, this reduction can likely be due to increased soil erosion, loss of organic matter, soil texture and disruption of microbial processes that are essential for carbon stabilization (Lal, 2019). Normally, the top soils experienced notable declines in soil organic carbon, particularly during the pre-monsoon period, indicating that the beneficial effects of the monsoon on soil organic carbon are not sustained in environments (Bordoloi and Sharma, 2022; Kieta et al., 2022) which may be because of luxuriant growth of herbaceous vegetation (Mishra and Laloo, 2006).

The increase in soil organic carbon, especially from the monsoon to the post-monsoon period. This can be attributed to increased microbial activity during the fallow period which allows the plant residues, roots, and litter to accumulate on the soil surface, which enhances soil organic carbon as organic matter is incorporated into the soil (Yang et al., 2004). As the impact on soil organic carbon is highly dependent on the cycle length and intensity of jhum cultivation reduced cycles with short fallow periods can have the opposite effect. Disturbed soils often experience greater exposure to environmental factors such as rain and wind, which exacerbate carbon loss (Olson et al., 2016).

Soil depth plays a significant role in determining soil organic carbon levels. The surface layer benefits from the addition of organic matter from plant litter and other sources, while the sub-soil experiences lower organic inputs and microbial activity (Kumar et al., 2017). In the present study generally, the top-soil contained higher soil organic carbon compared to sub-soil. This trend is consistent with the understanding that organic matter accumulates at the surface due to the deposition of plant residues and microbial activity (Mishra, 2011; Bhattacharyya et al., 2008; Mishra and Francaviglia, 2021). This has been corroborated by similar studies (Mishra and Laloo, 2006; Mishra, 2011; Bhattacharyya et al., 2008; Biswas et al., 2014; Lalsangzuala, 2023). The moderately disturbed stand soil displayed stable soil organic carbon or a slight increase in soil organic carbon for sub-soil, this increase is likely due to the buildup of plant residues and the slow decomposition of organic material in a stable environment (Ghosh et al., 2016), it can also be attributed to increase in precipitation and a decrease in temperature (Jobbagy and Jackson, 2000). The soil organic carbon results are in conformity with the work done by Arunachalam and Pandey (2003); Mishra and Laloo (2006); Mishra (2010); Lalnunmawia et al. (2013); Saplalrinliana et al. (2016); Zodinpuii et al. (2016); Lalnunthari et al. (2019) Tripathi et al. (2020) and Madhurima and Mishra (2023).

The shifting cultivation and logging being the major disturbance for north eastern region (Barik et al., 1996; Ranjan and Upadhyay, 1999; Fox et al., 2000; Ickowitz, 2006) alters the chemical properties of soil (Zodinpuii et al., 2016, Sati, 2019). It also causes for soil fertility loss (Maithani, 1996). The deficiency of nutritional content is characteristic of soil in the study area. The lower level of all nutrients at all stands is indicative of lower soil fertility. Moreover, the top-soil normally possessed slightly higher nutritional content than sub-soil. A similar trend in results has also been reported by past workers (Tawnenga et al., 1997; Savant and Patnaik, 1998; Lalnunmawia and Tawnenga, 2013).

Plant growth requires nitrogen, phosphorus and potassium which can be influenced by land usage, soil disturbance, and seasonal fluctuations. The total nitrogen, phosphorus and potassium varied across the soil depths, disturbance levels, and seasons showing how environmental and human variables affect macronutrient dynamics.

Nitrogen is essential for amino acids, proteins, and chlorophyll, in plants as it’s is essential to sustain plant growth and good yeild. Undisturbed soils have the higher nitrogen content in all seasons and depths. The nitrogen dynamics in undisturbed soils allows microbial break down organic materials and restoring the nitrogen (Olson et al., 2016; Brevik, 2013). In contrast, highly disturbed soils had far reduced nitrogen, it declined from monsoon to post-monsoon. The post-monsoon nitrogen level may drop may be due to the erosion, leaching and reduced organic matter inputs in disturbed soils (Sharma et al., 2017; Singh and Singh, 2020). Therefore in the disturbed soils, due to lower nitrogen levels can lead to reduced crop productivity without addition of fertilizers (Vitousek and Howarth, 1991; Compton and Boone, 2000 and Lal, 2019).The total nitrogen content in moderately disturbed soils was higher in top-soil and increased from pre-monsoon to monsoon season and declined during post-monsoon. This shows that moderate disturbance loses nitrogen through runoff, leaching and luxuriant growth of herbaceous vegetation (Mishra and Laloo, 2006, Bhattacharyya et al., 2008; Mishra; 2011, Biswas et al., 2014). During the monsoon season, nitrogen concentration rises across all disturbance levels. Monsoon-induced microbial activity decomposing the plant litter, organic waste and other sources causes the release of nitrogen into the soil (Mishra and Laloo, 2006; Mishra, 2011; Patil et al., 2010; Bordoloi and Sharma, 2022; Kieta et al., 2022; Li et al., 2017). Moderately disturbed stand soil also showed increased nitrogen during the monsoon. Nitrogen content decreases or stabilises post-monsoon, especially in disturbed soils. Leaching and runoff during the rainy season may reduce nitrogen levels post-monsoon. Taking into consideration the disturbance gradient, the soil in highly disturbed stand possessed low nutrients. Olson et al. (2016) also reported a similar trend in results.

Phosphorus is an essential macronutrient for root development and energy transfer. Phosphorus was highest in undisturbed and moderately disturbed stand soils, especially in top-soil. Monsoon phosphorus levels are greater due to organic phosphorus mineralisation and increased microbial activity (Bhattacharyya et al., 2016; Babu et al., 2023). However, highly disturbed soils have less phosphorus. After significant rainfall, highly disturbed soils may mineralise organic matter, increasing phosphorus concentration (Jat et al., 2020). The phosphorus content was higher in moderately disturbed stand soils compared to highly disturbed stand soils, thus indicating positive impact of moderate disturbance (Lal, 2019). The top-soil regularly has more phosphorus than sub-soil this can be attributed to organic inputs from plant residues and microbial activities boost nutrient content in the surface layer. Similarly potassium were present in high quantity at undisturbed forest strands which can be due to the biochemical processes in soil that modify the availability of nutrient status through microbial activities. In general, macro nutrients nitrogen concentration, exchangeable potassium and available phosphorus content at highly disturbed soils were lower than undisturbed forest that may be due to the disturbance, as it alters the natural bio-geo chemical processes. The nutrients further decreased from monsoon to post-monsoon and in sub-soil, this can also be attributed to poor nitrogen cycling, microbial activity and lower organic inputs in lower strata (Jat et al., 2020). The results are in conformity with similar studies that has been done (Lalnunmawia et al., 2013; Saplalrinliana et al., 2016; Zodinpuii et al., 2016; Lal, 2019; Lalnunthari et al., 2019).

Overall, the statistical analysis correlation and ANOVA was applied. The statical analysis correlation was applied to the soil characterstic reported in the study (Castrignanò et al., 2000; Chandra et al., 2016; Sun et al., 2019; Lu et al., 2023). The soil pH showed a positive and significant correlation with soil moisture content, water holding capacity, potassium, and total nitrogen (Mohd-Aizat et al., 2014). The bulk density was negatively correlated with soil pH, soil moisture content, and water holding capacity, available phosphorus, exchangeable potassium, and total nitrogen (Heuscher et al., 2005). The exchangeable potassium has a positive correlation with soil pH, soil moisture content, water holding capacity, available phosphorus and total nitrogen. The total nitrogen showed a positive and significant correlation with soil pH, soil moisture content, water holding capacity, available phosphorus, exchangeable potassium. The available phosphorus showed a positive and significant correlation with soil moisture content, water holding capacity, exchangeable potassium, total nitrogen, and negative correlation with bulk density. The one way ANOVA was applied to the physico-chemical properties the highlight the substantial impact on several key soil properties, which may be due to ecological disturbance and depth of soil (Mishra et al., 2005; Adhikari and Hartemink, 2016; Adugna and Abegaz, 2016; Srivastava et al., 2020; Tang et al., 2022). The soil moisture content, bulk density, water holding capacity, total nitrogen, available phosphorus, and exchangeable potassium were significantly affected by the variation across the disturbance gradient where as specifically soil moisture content, bulk density, water holding capacity, total nitrogen, available phosphorus, and exchangeable potassium were significantly affected by depth.

Socio-economic Assessment for suggestive conservation measures

To access the people awareness, the questionnaire method was used. The collected demographic data offers insights into the respondents' profiles across multiple dimensions, including age, gender, education, and occupation, income, and residence status.

The age distribution of responses indicates that the predominant group is aged 18-25 years, including 245 individuals, so suggesting a younger demographic. Few respondents were categorised as below 18 years, aged 25-30 years and aged 30-35 years, with merely ekone responder aged between 35-50 years. The prevalence of younger participants may suggest that the survey sample is aimed at youth, particularly given that the primary occupation is students. The younger generation is essential for comprehending behaviours, preferences, and attitudes, particularly in rising economies such as India, where the youth constitute a significant portion of the population (Verma and Srivastava, 2024). The gender distribution reveals a nearly equal representation, though the female respondents are slightly higher in number than male respondents. The increased proportion of female respondents may be ascribed to particular variables, like the emphasis on education-related surveys, in which females tend to be more responsive (Curtin et al., 2000). This balance indicates a gender-neutral methodology in data collection, ensuring equitable representation of both genders across several criteria.

Regarding educational qualifications, the majority of respondents possessed post-graduate or higher degrees, followed by undergraduate degrees. This elevated level of education signifies a highly educated sample, probably attributable to the emphasis on student and urban demographics. A limited number of respondents possessed education only up to 10+, indicating a modest representation of less educated demographics. The educational streams are represented majority into humanities and language, followed by science and by commerce and management, with very few from vocational or other streams. This underscores the preference for conventional academic pathways over vocational education, a prevalent tendency in metropolitan regions of India (Ahmad and Nath, 2017). The occupational data indicates that the predominant group of respondents consists of students, hence reinforcing the emphasis on a younger population. A limited number are employed, self-employed or unemployed this can also be inferred as a majority of respondents are students. This distribution indicates that the students are highly willing to participate in surveys as well as the study site is located in the vicinity of educational institutions, having young professionals migrating from academia. A substantial number of respondents belonged to the monthly income ranges of Rs. 15,000-30,000 and Rs. 30,000-50,000, indicative of a middle-income urban demographic. Notably, there were no participants with an income of Rs. 100,000 or higher, suggesting that the sample fails to represent higher-income demographics, perhaps due to the preponderance of students (Mishra and Kumar, 2018; Saini et al., 2022). The data indicates a rather even distribution between urban and rural inhabitants. This equitable representation is essential for comprehending the disparities in attitudes and behaviours between rural and urban populations. The urban emphasis illustrates the persistent trend of urbanisation, as young individuals, especially students, go to cities for educational prospects (Oketayo and Olaleye, 2016; Zago, 2016).

The study investigates perspectives on biodiversity loss, forest conservation, climate change, and community engagement for environmental sustainability. Taking into account the decline of biodiversity and its implications, the majority of responders concur with the statement concerning biodiversity loss. This signifies that the issue is broadly recognised, with minimal divergence in answers, corroborated by prior studies on the effects of biodiversity loss by Diaz et al. (2019). The statement decrease in wild animal and bird populations exhibited marginally greater volatility, as the majority cohort that wildlife populations have declined in the study area, corroborating global patterns identified in biodiversity surveys (WWF, 2020). The respondents exhibit significant variability in their degrees of agreement concerning forest cover decrease. A significant majority agreed whereas few remained neutral, for loss of forest cover in the study area. However, it had few responses that opposed the notion, suggesting a degree of uncertainty in understanding the alterations to forest cover.

Participants predominantly concur that shifting cultivation results in biodiversity loss and deforestation, corroborating research that emphasises the ecological consequences of this technique (Myers et al., 2000). The majority agreed that climate change influences rainfall in the region which signified a strong consensus, aligning with climate models that associate regional rainfall variations with global climate changes (IPCC, 2021). The data indicated major support for conservation initiatives concerning hunting, deforestation, water preservation, and waste management. As respondents concur that hunting wild animals or birds is unethical, and oppose deforestation, aligning with ethical considerations in conservation biology (Soulé, 1985).

In the statement involving monetary and economic incentives for conservation participants exhibited greater variability concerning compensatory payments for environmental initiatives. Although many individuals support such initiatives, a considerable segment of respondents articulated neutral or dissenting opinions, potentially indicative of economic apprehensions or insufficient understanding of payment methods (Engel et al., 2008).

Community Participation has been established as a significant component of conservation by researchers. The assertions on community engagement in environmental conservation, encompassing donations and volunteer efforts, garnered substantial endorsement, as a majority of the respondents affirmed that local involvement is crucial. This underscores the significance of community-driven conservation initiatives, as examined in participatory governance frameworks (Agrawal and Ostrom, 2001).

Many research has indicated that biodiversity loss might result in ecological imbalance and impact human well-being (Cardinale et al., 2012). Participants largely concur that climate change has influenced the precipitation in the study area, corroborated by evidence indicating that climate change affects hydrological cycles (Kundzewicz and Gerten, 2015). The attitude towards concerns regarding biodiversity and climate change, by the respondents expressed were strong apprehension regarding biodiversity loss and the reduction of forest cover. The agreement of majority indicates a general recognition and awareness of the adverse effects of these environmental issues. Responses indicated a consensus that shifting farming resulted in biodiversity loss and forest cover reduction. This corresponds with research highlighting that shifting farming may lead to deforestation and the deterioration of forest ecosystems (Folke et al., 2004; Schulze and Mooney, 2012; Gasparatos and Willis, 2015).

There is widespread consensus that forest conservation and activities such as rainwater conservation are vital. These perspectives show the worldwide movements aimed at advancing sustainability via conservation initiatives Environmental protection and its advantages for local communities indicated that respondents perceived a relationship between conservation and community welfare. The participants exhibit moderate endorsement for compensatory payments for environmental services and financial involvement in biodiversity protection. This aligns with international dialogues regarding the implementation of payment for ecosystem services to promote conservation (Engel et al., 2008). The principle of "polluter pays" garners moderate consensus, reflecting ambivalence regarding responsibility for environmental harm. This notion has been contested regarding its efficacy and equity in numerous environmental programs (Pearce, 2001).

Chapter 6

CONSERVATION STRATEGIES

The present study aimed to understand the impact of anthropogenic disturbance on plant diversity and soil characteristics. It was observed that the impact of disturbance on plant communities is primarily due to logging and shifting cultivation, led to decline in tree diversity along with the disturbance gradient. The decline in tree diversity with increase in disturbance led to a reduction in canopy cover, which further altered the micro-environment. The degradation of forest and change in micro- environment further altered the soil characteristics along the disturbance gradient. Therefore, there is ample scope for formulation of appropriate management and conservation strategies to mitigate the impact of disturbance. The community awareness, support and involvement have become essential to achieve success in conservational efforts and management.

The study area is unique based on the geographic location, indigenous community, fragile ecosystem and pristine forest. Therefore, there is an ample scope for a site-specific research approach to the conservation of the ecosystem.

The forest has become an intangible part of the local communities that consist of indigenous people in the study area. These communities have lived in harmony with the forest and nature from time immemorial. Therefore, inculcating the local communities is essential for the conservation of plant diversity and soil health and also ensuring the successful implementation, protection and management efforts. The local community is a significant stakeholder in conservation at grass root level as they are directly dependent on biodiversity for livelihood and sustenance. Therefore, indigenous people are an integral part of all conservation efforts. The questionnaire-based survey was conducted to understand the awareness, attitude, and perception of the local community in and around the study area, which may provide a baseline information for the community-based management approaches.

The collaborative approach involving local communities in the protection, management, and sustainable use of plant resources will make conservation more sustainable. Community-based Conservation (CBC) strategies also empower local communities, acknowledging their traditional knowledge and stake in maintaining biodiversity. The measures to be taken for proper conservation of biological resources may be as follows.

6.1 Reforestation and Afforestation

The survey revealed that the respondents are well aware of the loss of forests and its fragmentation and scope for reforestation and afforestation of the damaged and degraded ecosystems. The study also found that human-induced disturbances like logging and jhum cultivation have led to reduced forest cover and followed by loss of plant diversity from undisturbed to highly disturbed forest stands. Taking into account the community's positive attitude towards conservation, it is obvious that the indigenous people will be agreed to support any initiative by the government aimed at reforestation and afforestation. Furthermore, the respondents also demonstrated an understanding of the impact of forest cover loss and climate change on the rainfall and biodiversity.

The focus of afforestation, tree planting, ecological restoration, and eco-development initiatives should be on degraded and environmentally vulnerable areas. The reforestation and eco-restoration methods needs in depth understanding of plant species. The use native plant species needs to be used to enhance biodiversity. Seed dispersal and pollination are crucial for plant reproduction and ecological diversity. Seed dispersal entails plant and animal relationship. By leveraging this interactions with animals, the plant species can form mutualistic relationships that benefits both parties. The plants achieve wider distribution, and animals receive sustenance. The government has also implemented social forestry and then joint forest management (JFM) involving the local communities following equitable sharing of benefits arising from activities.

6.2 Ethnobotanical Knowledge Preservation

The local indigenous communities in the study area have evolved with native flora and fauna enriched with indigenous knowledge of native flora. They know the properties of plants and their uses like medicinal plants and food crops. This knowledge is getting eroded and therefore now more than ever we need to conserve this knowledge. The survey showed that the respondents do understand the significance of indigenous knowledge and believe in its conservation. Documentation and utilisation of indigenous knowledge aid in preserving species that may otherwise go extinct. To accomplish these, community cultural heritage programs need to be organised that catalogue native plants and their applications. This will definitely promote knowledge sharing and respect for biodiversity within the community.

In fact, the traditional ethnobotanical knowledge is inherent in some elderly aged people. In past few decades, there is decline in interest among young generation due to urbanisation and negligence of such knowledge by the government. To encourage young generation towards traditional system on herbal medicines, there is a need of integrated research approach involving local indigenous community, NGOs and Government. This unique knowledge needs to be documented with due recognition of local indigenous people involved and they may be rewarded accordingly, as indigenous knowledge on herbal medicines is linked with the biodiversity conservation at a large. The national and state biodiversity authorities have assisted the Biodiversity Management Committees (BMCs) in preparing People's Biodiversity Registers, which will preserve local traditional knowledge and safeguard intellectual property rights.

6.3 Sustainable Farming Practices

Keeping in view the current practice of non-scientific and unsustainable jhum or slash/burn agriculture, there is an urgent need for encouraging sustainable agriculture in Mizoram. Sustainable farming is an agricultural methodology that aims to produce food crops along with the conservation of the environment and natural resources. It incorporates methods like crop rotation, multiple cropping, organic fertilizers, water conservation, and soil health to ensure sustained productivity. The survey showed the younger generations are highly aware of the negative implications of the shifting cultivation. Thus, there is a need to mitigate the ecological damage and forest loss. Adopting Sustainable agricultural practices is crucial for maintaining soil health, water quality, biodiversity, and ensuring long-term food security. Silvopasture, forest farming, crop rotation, horticulture, and agroforestry are some of the techniques of farming used in sustainable agriculture that may help in safeguarding and enhancing soil fertility by minimising tree felling, forest degradation, water conservation and mitigating soil erosion. Practices such as crop rotation, organic farming, agroforestry, and no-till farming bolster resilience to climate change and augment food yields while preserving soil integrity.

Terrace farming, contour bundling and farming are highly effective farming techniques as the study area has hilly terrain. These farming methods are also effective for reducing the loss of top fertile soil as run-off during monsoon season, thus preserving soil fertility and reducing soil erosion. Integrated farming system is also economical agricultural systems appropriate for the study area. This system aims in the principles of efficient utilisation of agricultural waste and optimal use of available resources and labour. It encompasses the combining of aquaculture, animal husbandry, and poultry with existing agriculture practices. Sustainable methods also enhance carbon sequestration, advancing climate action objectives. Moreover, sustainable agriculture can also increase farmers' income by fostering a balanced and healthy agricultural system that will benefit both humans and the environment.

6.4 Agroforestry

The state of Mizoram is highly engaged in shifting cultivation which has become highly unsustainable due to its reduced fallow period. The promotion of agroforestry in the study area is a sustainable alternative, as it integrates the cultivation of trees and shrubs with traditional crops into agricultural landscapes. It can help the community by supporting both conservation and livelihoods. This reduces habitat fragmentation, supports soil health, and provides multiple ecosystem services. Sustainable farming practices such as organic farming, permaculture, and crop rotation can help conserve soil and native plant biodiversity.

Subsistence-based agroforestry system has been practiced by indigenous people, and past studies argued that agroforestry supports improvement in soil fertility.

6.5 Non-Timber Forest Product (NTFP)

The NTFP`s serve as a vital source of livelihood for indigenous communities. The NTFP comprises fruits, nuts, medicinal plants, resins, fibers, fungi, etc. These products help locals economically, by selling products in the local market without causing any ecological damage to forests. The survey showed that the respondents recognized tree felling as the major cause for forest destruction and biodiversity loss. The government needs to promote initiatives namely sustainable harvesting of medicinal plants, fruits, or fibres from the forests, and provide financial incentives to local harvesters to conserve wild plant population. The JFM can provide local subsistence needs, such as fuel wood, fodder, and non-timber forest produce, while preventing forest degradation and preserving environmental benefits.

6.6 Ecotourism

The scenic beauty and landscape of the Mizoram is alluring and appealing for nature-based tourism. The growth of responsible and eco-friendly tourism will definitely generate employment and job opportunities for local communities. Ecotourism is the best alternative for economic growth and it also fosters biodiversity protection by encouraging eco-friendly ways to travel to natural environments, where tourists gain knowledge about local traditions and biodiversity conservation measures. The revenue generated through eco-tourism further helps in funding conservation initiatives, including habitat preservation, reforestation, and invasive species management, thus directly supporting biodiversity conservation. Ecotourism by recognising ecosystems as sources of tourism revenue, offers communities economic incentives to manage natural environments instead of overexploiting them. The survey shows the local community is well aware of the significance of the conservation of flora and fauna, therefore the local guides and educational initiatives by locals may be helpful in cultivating conservation ethics among visitors. The ecotourism will ultimately create a synergy that will help the local community in generating sustainable income along with biodiversity conservation as an asset for preserving natural habitats.

6.7 Education and Community Awareness Programmes

Education and community awareness help in creating a better understanding of the need for environmental protection and conservation. The survey was indicative of the attitude of youth being more inclined towards conservational efforts as well as more awareness towards the environmental crisis. Environmental education and outreach programs are also effective tools that help in raising awareness of the importance of plant diversity in environmental management. These programmes empower communities to make sustainable choices. The activities to be adopted include workshops, school programmes, and public events focusing on native plants and ecosystem services.

6.8 Legal and Policy Support for Community Rights

Legislations aimed towards safeguarding the forests and rights of indigenous communities, they are crucial and responsible for sustainable management of natural resources. Strong legislations and policies at global, national, regional and local government need to align with a community-based approach where the community is given priority in decision-making and conservational efforts. The communities also need support in ensuring that communities have legal rights to manage their land and resources. Non-governmental organisations (NGOs) can also play a significant role in advocating for land rights and supporting policies that enable community-based conservation. The recognition of the legal rights of Indigenous people and communities has been proven to have enhanced conservation and management of forested areas.

6.9 Community-Based Land Management and Restoration

The local communities can rehabilitate damaged lands through traditional methods of reforestation and watershed management. The use of native and endemic flora is more suitable for increasing tree cover and restoration of degraded lands as they promote the growth of native fauna and also mitigate the soil. Various strategies for including the community in the establishment of community-managed forests and conservation areas, granting residents the ability to determine management policies.

Implementation of *In-situ* conservation technique especially plantation in gaps is the best community based management practice with involvement of the local indigenous people, for restoration of degraded ecosystem on sustained basis. The site-specific selection of species is of paramount importance, and nursery technology needs to be standardized for species selected for plantation. The selection of species for re-vegetating disturbed forest may be taken into consideration on priority as native species to enhance biodiversity, species attractive to frugivore to encourage seed dispersal, species forming mutualistic relationship with animals to faster wildlife population, species with poorly dispersed species (heavy seeds) to facilitate colonization, fast growing species to occupy site and to exclude weeds as weed infestation is very common in study area due to luxuriant growth supported by prolonged rainy months, threatened species to conserve such species, species tolerant of poor soil to facilitate rehabilitation, nitrogen fixing species to improve soil fertility, economically important species to provide economic goods, fire tolerant species as shifting cultivation is traditionally practiced in the state of Mizoram where slash and burn of forests are very common during February to April every year, making the study area prone to the fire.

6.10 Soil health management

The soil degradation and desertification have become major concern of twenty first century. Therefore, the restoration of soil health and its management practices are on top priority. The soil characteristics and plants community attributes have intricate relationship, hence major way to achieve increased soil fertility is through increasing vegetation cover by reforestation using the species tolerant of poor soil as these species facilitate rehabilitation of degraded ecosystem. In the present investigation showed the impact of disturbances, as the decline in tree density, diversity and canopy cover led to deterioration in soil health. The disturbed soil observed decline in soil moisture content, soil organic carbon, soil organic matter, nitrogen, potassium and phosphorus values. Thus, losing its fertility and productivity.

A site-specific solution for soil treatment is necessary. Fertiliser application for soil health management must be tailored to the specific needs of the site. The disturbed stand soils exhibit acidity; lime treatment can effectively mitigate this acidity. Nitrogen-fixing organisms can enhance soil fertility in nitrogen-deficient areas. The application of microbial inoculation will enhance soil organic carbon levels.

6.11 Community Seed Banks and Seed Networks

The outcome of present investigation has reported significant decline in plant diversity with increased rate of disturbance. The threatened and rare species may become lost if not conserved. The local community also needs encouragement for the use of local varieties and preventing genetic erosion. Thus, *ex-situ* conservation through seed banks becomes necessary to protect the genetic diversity. These seed banks can be operated and maintained by communities through traditional methods of seed conservation, this will help in conserving plant genetic diversity and offer farmers access to diverse and resilient crop varieties. The agricultural adaptability and sustainability also depends on resilient crop varieties to ensure food security in the ongoing climate change. The plant genetic resources are used for scientific discoveries and research, the genetic resources also contribute towards biotechnology and bioprospecting.

6.12 Resilience and Adaptation and Capacity Building

The past studies have argued that the plant communities with high species richness and diversity are more resilient to ecological perturbation as their recovery from any disaster or disturbances to its original status is sooner than disturbed ecosystem. Therefore, there is a need to conserve species diversity to support self-sustaining forest ecosystem. In regards to the local community, they are also vulnerable to the disturbances affecting the forests as they are directly dependent on the biodiversity resources. Therefore, the community needs to become the first respondent. The survey revealed that the community understands the need for eco-friendly behaviour and good practices that may help in conservation and sustainable use of existing resources.

There is utmost scope for implementation of mitigation measures to reduce the existing impact of environmental degradation and it includes forest conservation, native species plantation on degrading ecosystem, shift from jhum to sustainable agriculture, and watershed restoration. As the efforts are being made to mitigate the negative impacts of environmental degradation, people need to be equipped for developing resilience and to adapt the changing climatic conditions, to ensure sustainable planning and management that help in making the community resilient.

The Ministry of Environment, Forests and Climate Change, Government of India along with the state government has been working to ensure forest conservation and management to a great pace. Tough initiatives are already exiting there is an ample scope for introduction of better and improved provisions to assist in environmental conservation.

Chapter 7

SUMMARY AND CONCLUSION

Plant diversity is essential for preserving ecological equilibrium, as each and every species fulfil distinct functions in ecosystems. Plant communities enhance resilience of ecosystem to environmental changes, including climate change and habitat degradation (Tilman, 1988). Soil serves as a substrate for the biological cycling of various air gases and the filtration and storage of water within the global hydrological cycle (Koch el al., 2013). The ecosystem services provided by soil is vital for functioning of ecosystem, mitigation of climate change, food security, regulation of various biogeochemical cycle. The intricate relationship between plants and soil is essential to ecosystem functioning, involving complex physical, chemical, and biological interactions (Lal, 2004; Bardgett and van der Putten, 2014). The study area is part of indo-burman biodiversity hotspot which is a fragile ecosystem having immense ecologically significance. As the threat and vulnerability are increasing due to anthropogenic disturbances such as rapid urbanisation, land use change and changing climate. There is need to understand the effect of the disturbance for ensuring conservation of biodiversity.

Ecological disturbances are defined as are any perturbation biotic or abiotic in the natural environmental conditions that cause significant alterations in an ecosystem. These disturbances can be natural, such as wildfires, hurricanes, and volcanic eruptions, or anthropogenic, such as deforestation, shifting cultivation (Fox et al., 2000; Ickowitz, 2006), pollution, and urbanization. The interaction of four factors namely speciation, dispersal, disturbance and environmental heterogeneity are forces responsible for pattern and level of diversity (Levin, 1992). Rich and abundant diversity allows greater access to various biological resources and hence net primary production is increased and nutrient loss is reduced. (Singh, 2002). The diversity of the ecosystem makes it resistant to environmental disturbance and is likely to contain species that would thrive through natural or imposed perturbations in the ecosystem and compensate for the loss of other members (Stapanian, 1997). The report published by UNEP (2001) identified habitat destruction, over-exploitation, pollution and invasive species introduction as major causes of loss of biodiversity in India. Concern regarding the loss of biodiversity gained huge attention at the Earth summit held in Rio in 1992, thus creating a need for an understanding of ecological function to conserve biodiversity. Biodiversity hotspots are anticipated to be particularly susceptible to climate change due to their endemic species possessing limited geographic distributions (Sandel et al., 2011; Brown et al., 2020).

It is necessary to conserve and preserve the plant diversity as they maintain the ecological equilibrium, by fulfilling their distinct functions in ecosystems. Comprehending the range of plant species is crucial for the field of conservation biology. Understanding the impact of disturbance is crucial for managing ecosystems and mitigating their impacts on biodiversity and ecosystem services. Tough ecologists have attempted to study disturbance for many decades, it still has not been understood yet. The study aimed to prepare inventory and study community characteristics of the plant diversity and soil characteristics along disturbance gradient.

The objectives of the study were to study the plant community attributes of the selected forest stands and its soil characteristics. The study also aimed to assess the impact of anthropogenic disturbances on plant community attributes and soil characteristics of selected forest stands and also to formulate appropriate conservation strategies to mitigate effect of disturbance on plant community attributes and soil characteristics of selected forest stands.

Mizoram is the land of Blue Mountains and mystic beauty. It is among the seven sister states of North eastern part of India. The high degree of endemic species and threat to species makes it part of the Indo-Myanmar biodiversity hotspot (Devi et al., 2018). The capital of Mizoram is Aizawl district. The district shares its geographic boundary in the north by the Kolasib district, on the west by Mamit district, on the south by the Serchhip district and on the east by Champhai district. The geographic area of Aizawl district is 3,576.31 square kilometres (1,380.82 sq.

km). The headquarters of the district is Aizawl City. As of 2011, it is the most populous district of Mizoram. The population of Aizawl is 400,309. The district has a population density of 113 inhabitants per square kilometre. Its population growth rate over the decade 2001-2011 was 24.07%.

Moderate climate is present throughout the year. The precipitation is high as the area falls under the influence of south-westerly wind. Tough the rainfall is high it is not evenly distributed, thus water scarcity is prevalent during the dry seasons. The monsoon season is mainly from June to September with average annual rainfall of 2400 mm and relative humidity of ninety percent. The months March to May during summer have the highest temperature lies in the range of 25°C to 32°C, the months of October to November is autumn the relative humidity is approximately 60% and the ranges between 18°C to 25°C and in winter temperatures December to February vary from 11°C to 23°C.

Vegetation analysis of the study area was carried out following the methods as outlined in Misra (1968) and Mueller-Dombois and Ellenberg (1974). Belt transect method was appropriated for field study. The size of quadrat for trees, shrubs and herbs were fixed as 10m x10m 5m x 5m and 1m x1m respectively. A total of 100 quadrats (10x10m size) were laid to sample 1 ha. area of each forest stand for determining tree community characteristics taking into consideration the individuals having GBH ≥30cm. The community characteristic was studied by parameters such as frequency, density, abundance, basal area, importance value index, relative density, relative frequency and Relative dominance. The Distribution Pattern, population structure, Shannon-Weiner Diversity Index, Simpson Dominance Index, Margalef’s Species Richness Index and Pielou’s Evenness Index were used for comparative assessment among the three stands. The soil samples were collected from the undisturbed, moderately disturbed, and highly disturbed areas of forests seasonally i.e., pre-monsoon season (February-March), monsoon season (July-August), post monsoon season (November-December) from two different depths i.e., 0-10cm (Top-soil) and 10-20cm (Sub-soil) in the triplicate. The soil physico-chemical properties studied were temperature, texture, pH, moisture content, bulk density, water holding capacity, soil organic carbon, soil organic matter nutrient concentrations (nitrogen, phosphorus, potassium) along disturbance gradient. The standard methods were applied for analysis of various soil parameter (Allen et al., 1934; Anderson and Ingram, 1993). Soil Texture was analysed using hydrometer method. The pH of the soil was determined in 1:5 soil: water suspension with the help of a glass electrode. Soil temperature was measured by using a soil thermometer. SOC content of the soil samples was determined by titrimetric method as reported by Walkley and Black (1934). Core method was applied for determining soil density. Soil Organic Moisture using oven dried method (Anderson and Ingram, 1993). The total nitrogen using titrimetric method (Walkley and Black 1934). Exchangeable potassium using flame photometer and available phosphorus using Spectrophotometer.

Three forest strands undisturbed, moderately disturbed and highly disturbed were selected on the basis of disturbance gradients for the study. The undisturbed forest stand had > 60% canopy cover, the moderately disturbed stand had 20-60% canopy cover and the highly disturbed stand <20% canopy cover. The Average light interpretation was 80%, 50% and 15% for undisturbed, moderately disturbed and highly disturbed respectively. The ambient air temperature was lower in undisturbed forest stand and higher in the highly disturbed forest stand whereas the humidity was high in undisturbed stand and lower in highly disturbed stands.

In the present study across the disturbance gradient, the result revealed that plant community characteristics did change due to disturbance. The species richness, dominance, diversity and evenness were also affected by disturbance. The undisturbed stands reported 161 species, 135 genus and 70 families consisting of that includes 97 trees, 33 shrubs and 31 herbs. The moderately disturbed stand had 187 species, 161 genus and 62 families that consist of 82 trees, 46 shrubs and 50 herbs. The highly disturbed stand had 165 species, 146 genus and 57 families that consists of 33 trees, 43 shrubs and 93 herbs. The moderately disturbed stand had the highest diversity, supporting the intermediate disturbance hypothesis.

The study reported shift in the in dominant species and family as well as shift in dominance of plant habit. The study also observed tree diversity declined along the disturbance gradient, whereas the shrub species increased in the moderately disturbed and herb diversity sharply increased in the highly disturbed stand. The Shannon diversity index of tree species declined as it was also affected by disturbance, the diversity of tree species declined along disturbance gradient, the evenness index also followed similar trend. The highest value of the Shannon index for shrub species was observed in the moderately disturbed stand and the diversity index for herbaceous species was also found highest in the highly disturbed.

The importance value index of species was calculated using relative density, relative dominance and relative abundance. The IVI of tree, shrub and herb also varied based upon their basal area, density and frequency. The species diversity dominance curve showed the undisturbed forest are stable communities where as the curve of highly disturbed stand showed unstable community.

The number of individuals of trees ranged from 993-539 indiv ha^{-1}. The number of individuals declined from 993 in undisturbed to 726 in moderately disturbed to 539 in highly disturbed. The decline in tree density and basal area of tree species across disturbance gradient indicated the impact of disturbance. Continuous disturbances led to lower tree densities and basal areas in disturbed stand, affecting the overall stability and diversity of these forests. The population structure of the three stands showed the impact of disturbances like forest clearing by tree felling and logging. The study reported shift in position of dominant tree species along disturbance gradient. The *Bischofia javanica* was the dominant species in the undisturbed stand, it was replaced by *Schima wallichii* in the moderately disturbed stand and *Mesua ferrea* in the highly disturbed stand.

A total of 33 shrub species belonging to 31 genera and 22 families, 46 shrub species belonging to 41 genera and 25 families, and 41 shrub species belonging to 38 genera and 27 families were recorded from UD, MD and HD stands.

The Shannon Diversity Index (H') is the measure of overall diversity and computed as 3.34 in UD, 3.62 in MD and 3.48 in HD. The Simpson index of Dominance was 0.962 in UD, 0.968 in MD and 0.963 in HD. Margalef's Species Richness index was highest in MD (7.21) as moderate disturbance supports high species richness, and followed by HD and UD in deceasing order of values. Evenness index declined slightly as disturbance increased, with the highest value in UD stand (0.958) and the lowest in a HD stand (0.938).

The dominance-distribution of species was determined on the basis of IVI values. The most dominant species was *Rourea minor* (IVI-27.78) in the UD and followed by *Mycetia longifolia* (IVI-21.26) and *Toddalia asiatica* (IVI-17.25) in the UD**,** *Zanthoxylum armatum* (IVI-19.51) in the MD and followed by *Pithecellobium angulatum* (IVI-18.92) and Urena lobata (IVI-15.44), and *Butea parviflora* (IVI-44.24) in the HD and followed by *Mussaenda gandra* (IVI-22.37) and *Bridelia stipularis* (IVI-19.21).

The most dominant family was Fabaceae (4 species) and was followed by Asteraceae (3 species) and Anacardiaceae, Convolvulaceae, Leguminosae, Rubiaceae, Urticaceae, Vitaceae (2 species each) in the UD; Fabaceae (8 species) and was followed by Rubiaceae (5 species) and Rubiaceae, Verbenaceae (3 species each) in the MD; Fabaceae (7 species) and followed by Malvaceae (6 species) and Vitaceae (4 species) in the HD.

A total of 33 species belonging to 30 genera and 23 families from the UD, 62 species belonging to 51 genera and 22 families from the MD, and 93 species belonging to 81 genera and 33 families from the HD were reported during investigation. The number of individuals per 100 m^2 was increased sharply from 531 in the UD to 3,556 in the HD.

The Shannon diversity index, a measure of species diversity, reflects this trend, increasing from 3.29 in the UD to 3.953 in the HD. However, the Simpson dominance index varied from 0.948 in HD to 0.971 in UD. Margalef's index increased drastically from 4.251 in UD to 11.54 in HD. On the other hand, the evenness index declined from 0.957 in UD to 0.759 in HD. Trees showed the highest diversity in an UD stand (3.63). As disturbance increased, the diversity declined to 3.18 in MD stand and further to 2.31 in highly disturbed stand, suggesting that tree diversity sharply declines with increased in the degree of disturbance.

Shrubs, on the other hand, showed an increase in diversity from 3.34 in UD stand to 3.56 in MD stand and least value of 3.23 in highly disturbed stand. The highest value in the MD stand indicated that moderate disturbance supports growth of shrub species at a large.

Herbs showed the lowest diversity in UD stand (2.91), but their diversity increased significantly with disturbance, reaching 3.42 in MD stand and peaking at 3.64 in highly disturbed stand. This indicated that herbs thrive in more disturbed environments, potentially due to less competition or different ecological dynamics.

The soil moisture content was strongly influenced by the degree of disturbance, with undisturbed stand soils having consistently high moisture content throughout the years. The water-holding capacity of the soil, influenced by its texture, plays a vital role in retaining moisture and impacting soil temperature and overall soil health. The disturbed soil was less productive and nutrient deficit.

Soil organic carbon is a key indicator of soil health, and it is essential to hold nutrients and water, reducing the risk of erosion. The land use change and burning during the jhum cultivation have been associated with the decline in soil organic carbon in north-eastern region of India. The present study also reported lower values of soil organic in the disturbed area. The soil properties deteriorated along the disturbance gradient thus, showing the negative impact of disturbances.

Human-induced disturbances drastically modify soil qualities, affecting its physical structure and chemical composition. Soil compaction, erosion, and alterations in organic matter composition frequently occur in disturbed environments, adversely impacting plant growth. The soil in the present study indicated the impact of disturbances due to decline tree density, diversity and canopy cover led to deterioration in soil health.

A survey was conducted to access the socio-economic status of the local community in the vicinity of forests. . A total of 300 respondents participated in the survey. The information was procured through questionnaire were related to the attitude and perception of local community towards environmental conservation and awareness. The majority of respondents were younster. In gender the females were slightly males were also surveyed. Most respondents were post-graduates or above and humanities and language dominated the respondents.

The majority cohort that wildlife populations have declined in the study area, corroborating global patterns identified in biodiversity surveys. Participants predominantly concur that shifting cultivation results in biodiversity loss and deforestation, corroborating research that emphasises the ecological consequences of this technique although many individuals support such initiatives, a considerable segment of respondents articulated neutral or dissenting opinions, potentially indicative of economic apprehensions or insufficient understanding of payment methods. Tough the attitude is positive towards conservational efforts and behavioural changes, the consensus was not unified towards monetary compensation.

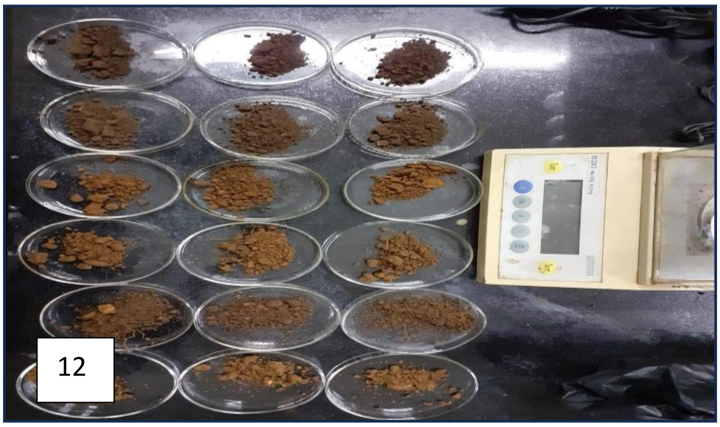
The major conservation strategies suggested are specific to the study area based on the awareness survey conducted among the local community as well as to mitigate the effect of disturbance revealed in the present study. Reforestation and Afforestation, Ethnobotanical Knowledge Preservation, Sustainable Farming Practices, Agroforestry, Non-Timber Forest Product (NTFP), Ecotourism, Education and Community Awareness Programs, Legal and Policy Support for Community Rights, Community-Based Land Management and Restoration, Soil health management, Data Collection and Monitoring, Community Seed Banks and Seed Networks, Resilience and Adaptation and Capacity building.

The present study highlighted the impact of disturbance on plant community, soil characteristics and community perception and awareness for conservational strategies. Based upon the major findings it can be concluded the effect of disturbance was evident on both plant diversity and soil characteristics. As the plant and soil are interlinked in the biosphere the decline in tree diversity due to led to decline in canopy cover which in return altered the micro climatic conditions which ultimately effected the soil quality. The study also found species richness was highest in moderate level of disturbances. Thus it can be argued that moderate disturbance had positive impact on for species richness as it increased the diversity, therefore it can be concluded that disturbances at moderation and controlled can be beneficial for the ecosystem. However if the intensity of disturbance is high, there may be loss of biodiversity and erosion of soil. The outcome of present study will also help in developing database for the study area for further biodiversity study and conservational efforts.

Photo plate 1: Bird eye view of the study site

Photo plate 2 and 3: Field work for plant and soil sampling

Photo plate 4, 5, 6, 7, 8 and 9: Field work for plant and soil sampling



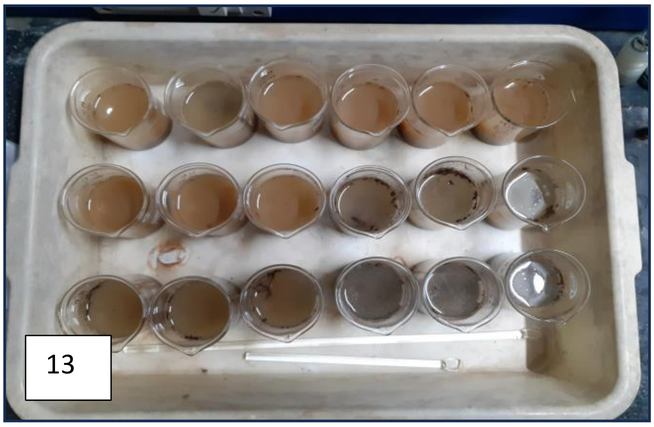
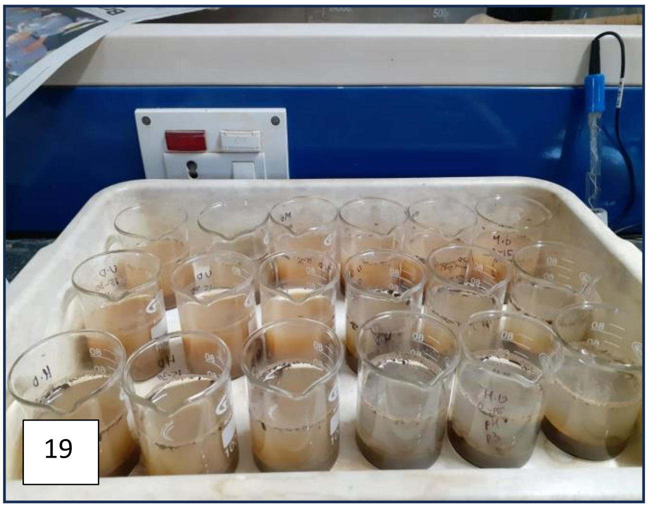


Photo plate No 10, 11, 12, 13, 14 and15: Soil sample laboratory analysis



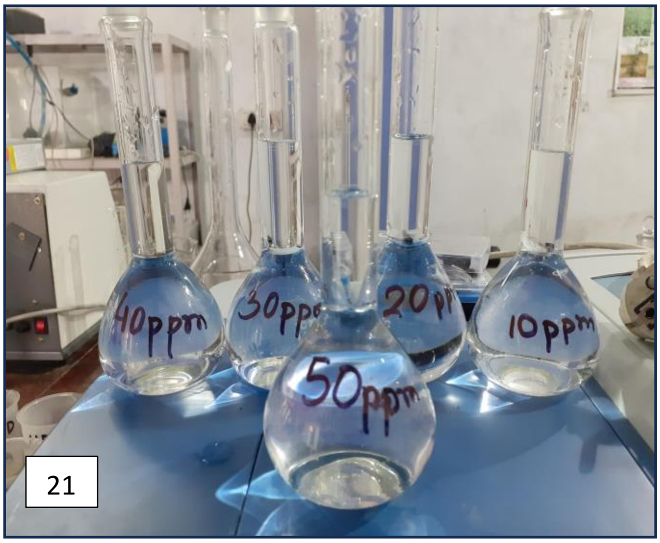


Photo plate 16, 17, 18, 19, 20 and 21: Soil sample laboratory analysis

Photo plate 22, 23, 24 and 25: Plant sample collection and sampling site

Photo plate 26 and 27: Plant sample collection and sampling site

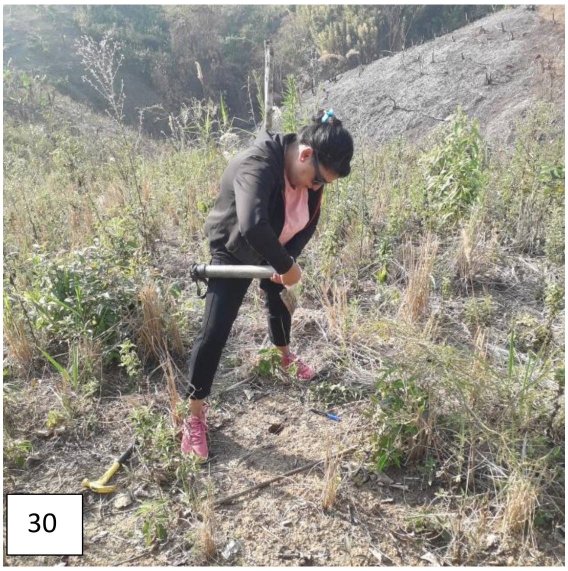


Photo plate 28, 29 and 30: Plant sample collection and sampling site.

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Appendices

Appendix-1

a. Correlation matrix of physico-chemical characteristics of soil along disturbance gradient.

Correlations										
		soil pH	soil_moisture_content	bulk_density	water_holding_capacity	organic_carbon	soil_organic_matter	total_nitrogen	Avaliable_phosphorus	Exchangeable_potassium
soil pH	Pearson Correlation	1	.501**	-.532**	.283*	.171	.172	.529**	.246	.301*
	Sig. (2-tailed)		.000	.000	.038	.215	.215	.000	.073	.027
	N	54	54	54	54	54	54	54	54	54
soil_moisture_content	Pearson Correlation	.501**	1	-.604**	.540**	.101	.102	.498**	.391**	.661**
	Sig. (2-tailed)	.000		.000	.000	.468	.465	.000	.003	.000
	N	54	54	54	54	54	54	54	54	54
bulk_density	Pearson Correlation	-.532**	-.604**	1	-.541**	.023	.023	-.496**	-.549**	-.853**
	Sig. (2-tailed)	.000	.000		.000	.868	.869	.000	.000	.000
	N	54	54	54	54	54	54	54	54	54
water_holding_capacity	Pearson Correlation	.283*	.540**	-.541**	1	-.069	-.069	.400**	.719**	.595**
	Sig. (2-tailed)	.038	.000	.000		.620	.620	.003	.000	.000
	N	54	54	54	54	54	54	54	54	54
organic_carbon	Pearson Correlation	.171	.101	.023	-.069	1	1.000**	-.004	-.096	-.182

	Sig. (2-tailed)	.215	.468	.868	.620		.000	.975	.492	.187
	N	54	54	54	54	54	54	54	54	54
soil_organic_matter	Pearson Correlation	.172	.102	.023	-.069	1.000**	1	-.003	-.095	-.182
	Sig. (2-tailed)	.215	.465	.869	.620	.000		.980	.494	.188
	N	54	54	54	54	54	54	54	54	54
total_nitrogen	Pearson Correlation	.529**	.498**	-.496**	.400**	-.004	-.003	1	.522**	.588**
	Sig. (2-tailed)	.000	.000	.000	.003	.975	.980		.000	.000
	N	54	54	54	54	54	54	54	54	54
Avaliable_phosphorus	Pearson Correlation	.246	.391**	-.549**	.719**	-.096	-.095	.522**	1	.594**
	Sig. (2-tailed)	.073	.003	.000	.000	.492	.494	.000		.000
	N	54	54	54	54	54	54	54	54	54
Exchangeable_potassium	Pearson Correlation	.301*	.661**	-.853**	.595**	-.182	-.182	.588**	.594**	1
	Sig. (2-tailed)	.027	.000	.000	.000	.187	.188	.000	.000	
	N	54	54	54	54	54	54	54	54	54

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

b. Correlation of soil temperature (0-10 cm) and air temperature

Correlations			
		air temp	soil temp A
air temp	Pearson Correlation	1	.737
	Sig. (2-tailed)		.472
	N	3	3
soil temp A	Pearson Correlation	.737	1
	Sig. (2-tailed)	.472	
	N	3	3

c. Correlation of soil temperature (10-20 cm) and air temperature

Correlations			
		air temp	soil temp B
air temp	Pearson Correlation	1	.986
	Sig. (2-tailed)		.107
	N	3	3
soil temp B	Pearson Correlation	.986	1
	Sig. (2-tailed)	.107	
	N	3	3

d. One-way ANOVA table for disturbance gradient

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
soil pH	Between Groups	.833	2	.416	2.269	.114
	Within Groups	9.359	51	.184		
	Total	10.192	53			
soil_moisture_content	Between Groups	1165.577	2	582.788	21.098	.000
	Within Groups	1408.748	51	27.623		
	Total	2574.325	53			

bulk_density	Between Groups	1.454	2	.727	71.409	.000
	Within Groups	.519	51	.010		
	Total	1.973	53			
water_holding_capacity	Between Groups	3343.780	2	1671.890	64.313	.000
	Within Groups	1325.795	51	25.996		
	Total	4669.575	53			
organic_carbon	Between Groups	.246	2	.123	1.889	.162
	Within Groups	3.315	51	.065		
	Total	3.560	53			
soil_organic_matter	Between Groups	.733	2	.367	1.885	.162
	Within Groups	9.921	51	.195		
	Total	10.655	53			
total_nitrogen	Between Groups	.133	2	.067	9.420	.000
	Within Groups	.360	51	.007		
	Total	.494	53			
Available_phosphorus	Between Groups	2.230	2	1.115	44.500	.000
	Within Groups	1.278	51	.025		
	Total	3.508	53			
Exchangeable _potassium	Between Groups	11091.218	2	5545.609	276.861	.000
	Within Groups	1021.547	51	20.030		
	Total	12112.765	53			

e. One-way ANOVA table for soil depth

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
soil pH	Between Groups	.833	2	.416	2.269	.114
	Within Groups	9.359	51	.184		
	Total	10.192	53			
soil_moisture_content	Between Groups	1165.577	2	582.788	21.098	.000
	Within Groups	1408.748	51	27.623		
	Total	2574.325	53			
bulk_density	Between Groups	1.454	2	.727	71.409	.000
	Within Groups	.519	51	.010		
	Total	1.973	53			
water_holding_capacity	Between Groups	3343.780	2	1671.890	64.313	.000
	Within Groups	1325.795	51	25.996		
	Total	4669.575	53			
organic_carbon	Between Groups	.246	2	.123	1.889	.162
	Within Groups	3.315	51	.065		
	Total	3.560	53			
soil_organic_matter	Between Groups	.733	2	.367	1.885	.162
	Within Groups	9.921	51	.195		
	Total	10.655	53			
total_nitrogen	Between Groups	.133	2	.067	9.420	.000
	Within Groups	.360	51	.007		
	Total	.494	53			

Available_phosphorus	Between Groups	2.230	2	1.115	44.500	.000
	Within Groups	1.278	51	.025		
	Total	3.508	53			
Exchange _potassium	Between Groups	11091.218	2	5545.609	276.861	.000
	Within Groups	1021.547	51	20.030		
	Total	12112.765	53			

Appendix-2

Phyto-diversity in the undisturbed (UD), moderately disturbed (MD) and highly disturbed (HD) forest stands.

	Name of species	***Undisturbed***	***Moderately Disturbed***	***Highly Disturbed***
1.	*Acacia eburrea* (L.F.) Wild	+	+	-
2.	*Acacia pennata* (L.) Willd.	+	+	+
3.	*Acer laevigatum* Wall.	+		
4.	*Acer oblongum* Wall. ex DC.	+	+	
5.	*Acrocarpus fraxinifolius* Arn.	+	+	+
6.	*Albizia chinensis* (Osb.) Merr.	+	+	+
7.	*Albizia lebbeck* Benth.	+	+	
8.	*Albizia odoratissima* (L.f.) Benth.	+		
9.	*Albizia procera* (Roxb.)Benth.	+	+	
10.	*Albizia thompsonii* Brandis	+	+	+
11.	*Alnus nepalensis* D. Don	+	+	
12.	*Anogeissus acuminata* (Roxb. ex DC.) Wall. ex Guill. & Perr.	+	+	
13.	*Aporosa octandra* (Buch.-Ham. ex D.Don)		+	+
14.	*Aporosa dioica* (Roxb.) Müll.Arg.	+		
15.	*Ardisia solanacea* (Poir.) Roxb.		+	
16.	*Artocarpus heterophyllus* Lam		+	+
17.	*Artocarpus lakoocha* Roxb. (AL)		+	
18.	*Azadirachta indica* A. Juss.	+		+
19.	*Bauhinia variegate* L.			+
20.	*Betula alnoides* Buch.-Ham. Ex.Don			+
21.	*Bischofia javanica* Blume.	+	+	
22.	*Bombax ceiba* Wall.	+	+	
23.	*Bombax insigne* Wall.	+		

24.	*Bruinsmia polysperma* (C.B.Clarke) Steenis	+	+	
25.	*Callicarpa arborea* Roxb	+	+	+
26.	*Calophyllum polyanthum* Wall. ex Choisy	+	+	+
27.	*Canthium dicoccum* (Gaertn.) Merr.		+	
28.	*Carallia brachiata* (Lour.) Merr.	+	+	
29.	*Cassia sp.*	+		
30.	*Castanopsis indica* A.DC.	+	+	
31.	*Castanopsis tribuloides* (Sm.) .DC.	+	+	+
32.	*Cinnamomum cassia* (L.) J.Presl			+
33.	*Cinnamomum obtusifolium* (Roxb) Nees	+	+	
34.	*Cinnamomum tamala* T.Nees & Eberm.	+		
35.	*Cordia floribunda* (Desv.) Spreng.	+		
36.	*Debregeasia longifolia* (Burm. F.) Wedd.	+	+	
37.	*Delonix regia* (Hook.) Raf.	+		
38.	*Derris Robusta* (DC) Benth	+	+	
39.	*Dimocarpus longan* Lour.		+	
40.	*Diospyros lanceifolia* Roxb.	+	+	
41.	*Drysoxylum excelsum* Blume	+	+	
42.	*Dubanga grandifolia* (Roxb. ex DC.) Walp.	+	+	
43.	*Emblica officinalis* Gaertn.	+	+	
44.	*Engelhardia spicata* Lechen ex Blume	+	+	
45.	*Eriobotrya bengalensis* (Roxb.) Hook.f.	+		
46.	*Eugenia macrocarpa* Cham. & Schltdl.		+	
47.	*Ficus benjamina* L.			+
48.	*Ficus curtipes* Corner	+	+	+
49.	*Ficus pyriformis* Hook. & Arn		+	
50.	*Ficus religiosa* L.	+	+	
51.	*Ficus* sp.		+	
52.	*Ficus tinctoria* G.Forst.	+		

53.	*Glochidion Khasicum* (Mull. Arg.) Hook.f.	+		
54.	*Gmelina arborea* Roxb. ex Sm.	+	+	
55.	*Haldina cordifolia* (Roxb.) Ridsdale	+	+	
56.	*Liquidambar excelsa* (Noronha) Oken	+	+	
57.	*Lithocarpus dealbatus* (Hook.f. & Thomson ex Miq.) Rehder	+	+	
58.	*Macaranga denticulata* (Blume) Müll.Arg.	+	+	
59.	*Macaranga indica* Wight	+	+	+
60.	*Machilus villosa* (Roxb.) Hook. fil.	+		
61.	*Macropanax undulatus* (Wall. Ex G. Don) Seem	+		+
62.	*Mallotus* sp.	+	+	
63.	*Mangifera indica* L.			+
64.	*Mangifera* sp.		+	
65.	*Melastoma nepalensis* Lodd	+		
66.	*Meliosma pinnata* (Roxb.) Maxim.	+	+	
67.	*Memecylon grande* Retz.		+	
68.	*Mesua ferrea* L.			+
69.	*Morus macroura* Miq.		+	
70.	*Morus nigra* Linn			+
71.	*Myrica esculenta* Buch.-Ham. ex D.Don		+	+
72.	*Olea dioica* Roxb.	+		
73.	*Olea salicifolia* Wall. Ex G.Don	+		
74.	*Oreocnide integrifolia* (Gaud.) Miq.	+	+	
75.	*Oroxylum indicum* (L.) Kurz	+	+	+
76.	*Ostodes paniculata* Blume	+	+	
77.	*Palaquium polyanthum* (Wall. Ex G. Don) Baill.		+	
78.	*Parkia roxburghii* G.Don		+	

79.	*Parkia timoriana* (DC.) Merr.		+	+
80.	*Persea glaucescens* (Nees) Long	+	+	
81.	*Persea odoratissima* (Nees) Kosterm.	+		
82.	*Phoebe attenuata* (Nees) Nees	+	+	+
83.	*Phoebe cooperiana* P. C. Kanj. & Das.	+	+	
84.	*Phoebe hainesiana* Brandis	+		
85.	*Pithecellobium angulatum* Benth	+	+	
86.	*Premna racemosa* Wall. ex Schauer	+	+	
87.	*Prunus napaulensis* (Ser.) Steud	+		
88.	*Quercus glauca* Thunb.	+		
89.	*Randia wallichii* Hooker f.	+	+	
90.	*Rhus chinensis* Mill.	+	+	+
91.	*Rhus succedanea* Linn. var. acuminata (DC) Hook.		+	
92.	*Schefflera wallichiana* (Wight & Arn.) Harms	+		
93.	*Schima wallichii* (DC.) Choisy	+	+	+
94.	*Spondias pinnata* (L. f.) Kurz	+		
95.	*Sterculia hamiltinii*(Kuntz)	+		
96.	*Sterculia villosa* Roxb.	+	+	
97.	*Styrax serrulatum* Roxb.	+	+	
98.	*Symplocos theifolia* D.Don	+		
99.	*Syzygium claviflorum* (Roxb.) Wall. ex Steud.	+	+	+
100.	*Syzygium cumini* var. axillare (Gamble)	+	+	+
101.	*Tamarindus indica L.*		+	+
102.	*Tectona grandis L. f.*	+	+	
103.	*Terminalia bellirica* (Gaertn.) Roxb.	+	+	
104.	*Toddalia asiatica* (L.) Lam	+	+	
105.	*Toona ciliata* M. Roem.	+	+	
106.	*Toxicodendron succedaneum* (L.) Kuntze	+		+

107.	*Ulmus lancifolia* Roxb.	+		
108.	*Vernonia volkameriifolia* DC		+	
109.	*Vitex canescens* Kurz		+	
110.	*Vitex quinata* F.N.Williams	+	+	
111.	*Wendlandia budleioides* Wall. Ex. Wight & Am		+	
112.	*Wendlandia grandis* (Hook.f.) Cowan	+	+	+
113.	*Wendlandia paniculata* (Roxb.) DC.	+		
114.	*Xantolis assamica* (C. B. Clarke) P. Royen	+	+	
115.	*Xylia xylocarpa* (Roxb.)Taub.	+		
	Name of species (Shrubs)	***Undisturbed***	***Moderately Disturbed***	***Highly Disturbed***
116.	*Aspidopterys nutans (Roxb.)*			+
117.	*Bauhinia camcina L.*			+
118.	*Bauhinia divaricata. Plum. ex L.*	+	+	
119.	*Berberis camcina Hook.f.*	+		
120.	*Berberis sp.*	+	+	
121.	*Blumea lanceolaria (Roxb.) Druce*	+		
122.	*Bridelia stipularis (L.) Blume*	+	+	+
123.	*Butea parviflora Roxb. ex G.Don*	+	+	+
124.	*Cajanus cajan (Linn.) Millsp.*			+
125.	*Camellia caudate L.*	+	+	
126.	*Camellia sinesnsis*		+	
127.	*Campylotropis eriocarpa (Maxima)*		+	
128.	*Campylotropis thomsonii (Benth. ex Baker) Schindl.*		+	+
129.	*Cassia occidentalis L.*			+
130.	*Chromolaena odorata (L.) King & Rob.*		+	
131.	*Cissus repens Lam.*	+	+	+
132.	*Citrus maxima (Brum.) Merr.*		+	

133.	*Clerodendrum infortunatum L.*		+	
134.	*Crotalaria hirsuta Willd.*		+	
135.	*Dalbergia stipulacea Roxb*	+	+	+
136.	*Debregeasia longifolia (Burm. F.) Wedd.*	+	+	+
137.	*Dendrocnide sinuata (Bl.) Chew*			
138.	*Desmodium gyroides (Roxb. ex Link)*	+	+	+
139.	*Dicellostyles jujubifolia (Griff.) Benth. & Hook.*	+		+
140.	*Dioscorea sikkimensis Prain & Burkill*	+		
141.	*Dioscorea sp.*			+
142.	*Drysoxylum excelsum Blume*		+	
143.	*Dubanga grandifolia (Roxb. ex DC.) Walp.*		+	
144.	*Elatostema dissectum Wedd.*	+		
145.	*Eranthemum palatiferum Nees var. elata*	+		
146.	*Flemingia macrophylla (Willd) Kuntze ex Merr*	+		
147.	*Flemingia stricta Roxb.*	+		+
148.	*Garcinia cowa Roxb ex Choisy*	+	+	+
149.	*Gossypium herbaceum Linn*			+
150.	*Hibiscus fragrans Roxb.*			+
151.	*Hibiscus hispidissimus Griff.*			+
152.	*Hibiscus sabdariffa L.*			+
153.	*Hodgsonia macrocarpa (Blume) Cogn*			+
154.	*Inula cappa (Buch.-Ham. ex D.Don) DC.*	+		
155.	*Ipomoea cymosa (Desr.) Roem. & Schult.*	+		+
156.	*Jasminum laurifolium Roxb. ex Hornem.*		+	
157.	*Lantana camara Linn*		+	+
158.	*Lasianthus hookeri C. B. Clarke ex J. D. Hooker*			+
159.	*Lepionurus sylvestris Blume*		+	

160.	*Lepisanthes senegalensis (Juss. ex Poir.) Leenh*			+
161.	*Lespedeza elliptica Benth*		+	
162.	*Ligustrum robustum (Roxb.) Blume*	+		
163.	*Lycopodium sp.*	+	+	+
164.	*Melastoma nepalensis Lodd*			+
165.	*Merremia umbellate (L.) Hallier f.*	+		+
166.	*Mussaenda gandra Vahl*		+	+
167.	*Mussaenda roxburghii Hook. f.*	+	+	+
168.	*Mycetia longifolia (Wall.) Kuntze*	+	+	
169.	*Osbeckia sp.*	+		
170.	*Ostodes paniculata Blume*		+	
171.	*Palaquium polyanthum (Wall. Ex G. Don) Baill.*		+	
172.	*Persicaria wallichii W. Greuter & Burdet*			+
173.	*Piptanthus nepalensis (Hook.) D.Don.*		+	+
174.	*Pithecellobium angulatum Benth*		+	
175.	*Polygonum chinense L*	+		
176.	*Randia longifolia C.Gust.*		+	
177.	*Rhus succedanea Linn*	+		
178.	*Rhus typhina L.*	+		
179.	*Rourea minor (Gaertn.) Alston*	+	+	+
180.	*Rubus birmanicus Hook.f.*	+	+	+
181.	*Smilax ovalifolia Roxb*		+	
182.	*Solanum xanthocarpum L.*		+	+
183.	*Tetrastigma bracteolatum (Wall.) Planch.*	+	+	+
184.	*Tetrastigma leucostaphylum (Dennst.) N.P.Balakr.*		+	
185.	*Thunbergia grandiflora (Roxb. ex Rottler)*		+	
186.	*Tithonia diversifolia (Hemsl.) A.Gray*	+	+	+

187.	*Toddalia asiatica (L.) Lam.*	+		
188.	*Tragia involucrate Linn.*		+	+
189.	*Urena lobata Linn.*		+	+
190.	*Vitex canescens Kurz*		+	+
191.	*Vitis barbata Wall.*		+	+
192.	*Wendlandia paniculata (Roxb.) DC.*		+	
193.	*Zanthoxylum armatum DC.*		+	
	Name of species (Herbs)	***Undisturbed***	***Moderately Disturbed***	***Highly Disturbed***
194.	*Abelmoschus esculentus (L.) Moench*			+
195.	*Achyranthes aspera L.*		+	+
196.	*Achyranthes bidentate Blume*		+	+
197.	*Adiantum caudatum Linn*	+		
198.	*Aeschynomene indica Linn*		+	+
199.	*Ageratum conyzoides Linn*		+	+
200.	*Amaranthus viridis Linn*			+
201.	*Anisochilus pallidus Wall. ex Benth.*			+
202.	*Argyreia speciose (Linn. f.)*		+	
203.	*Aspidopterys nutans (Roxb. Ex.DC.)*	+	+	
204.	*Asplenium nidus D. Don*	+		
205.	*Bambusa bambos (L.)*		+	+
206.	*Bambusa nutans Wall*		+	+
207.	*Bambusa tulda Roxb.*		+	+
208.	*Benincasa hispida (Thunb.) Cogn.*			+
209.	*Bidens biternata (Lour.) Merr. & Sherff*		+	+
210.	*Bidens pilosa (Linn.)*			+
211.	*Blechnum orientale L.*			+
212.	*Boenninghausenia albiflora (Hook.) Rchb. ex Meisn.*			+
213.	*Borreria stricta (Lf) K.Schum.*			+
214.	*Botrychium lanuginosum Wall. ex Hook.*			+

	& Grev.			
215.	*Byttneria pilosa Roxb .*	+		
216.	*Campylotropis capillipes (Franch.) Schindl.*		+	
217.	*Capsicum annuum Linn.*			+
218.	*Capsicum frutescens Linn.*			+
219.	*Cardamine hirsute Linn*		+	
220.	*Cardamine macrophylla Willd*		+	
221.	*Centella asiatica (L.)*		+	+
222.	*Centella asiatica (L.)*			
223.	*Chamaecostus cuspidatus*	+		
224.	*Commelina sikkimensis Clarke*	+	+	
225.	*Conjza bonariensis (L.) Cronquist*		+	+
226.	*Cortaderia selloana (Schult. & J.H. Schult.) Asch*		+	+
227.	*Costus speciosus (Koen) Sm.*	+		
228.	*Crassocephalum crepidioides (Benth.) S.Moore*		+	+
229.	*Curanga amara Juss.*	+		
230.	*Curcuma longa (L.)*			+
231.	*Cynodon dactylon (Linn.) Pers.*			+
232.	*Cynoglossum wallichii*	+		
233.	*Cyperus cyperoides (L.) Kuntze*	+	+	+
234.	*Cyperus rotundus (L.)*			+
235.	*Cyrtococcum accrescens (Trin) Stap f*	+	+	+
236.	*Dendrobium falconeri Hook.*		+	+
237.	*Dendrocalamus hamiltonii Nees & Arn. ex Munro*	+	+	+
238.	*Dendrocalamus strictus (Roxb.) Nees*		+	
239.	*Desmodium floribundum (D. Don.) Sweet ex G. Don.*	+		

240.	*Desmodium laxiflorum DC.*		+	+
241.	*Desmodium triquetrum (L.) DC.*	+	+	+
242.	*Dichanthium annulatum (Forssk.) Stapf*			+
243.	*Dichrocephala integrifolia (L.f.) Kuntze*		+	+
244.	*Dicranopteris linearis (Burm.f.)*	+		
245.	*Diplazium maximum (D.Don) C.Chr.*	+	+	
246.	*Drymaria diandra Blume*			+
247.	*Drymaria villosa Schltdl. & Cham.*			+
248.	*Elatostema dissectum Wedd.*	+		
249.	*Elatostema sessile J.R.Forst. & G.Forst.*	+		
250.	*Eragrostis nutans (Retz) Nees ex steud*	+	+	+
251.	*Eranthemum palatiferum (Nees)*		+	
252.	*Galinsoga parviflora (Cav.)*			+
253.	*Globba multiflora Wall.*	+		
254.	*Gynura bicolor (Roxb. ex Willd.) DC.*			+
255.	*Ichnanthus vicinus (Bail.) Merr*	+	+	+
256.	*Impatiens chinensis Linn.*			+
257.	*Impatiens laevigata Wall.*	+		
258.	*Imperata cylindrical (L.)*		+	+
259.	*Inula cappa (Buch.-Ham. ex D.Don)*		+	
260.	*Ipomoea hederifolia*			+
261.	*Kyllinga brevifolia Rottb.*			+
262.	*Lactuca indica L.*			+
263.	*Laggera flava (DC.) Benth. & Hook.f.*			+
264.	*Laportea crenulata Gaud.*	+		
265.	*Lepidagathis hyaline Nees in Wall.*			+
266.	*Leptochilus ellipticus (Thunb.) Noot*	+		
267.	*Lespedeza cuneata (Dum. Cours.) G. Don*		+	
268.	*Lobelia angulata G.Forst.*			+
269.	*Lobelia colorata Sweet*			+

270.	*Lycopodium cernuum Linn*	+	+	+
271.	*Lygodium flexuosum (Linn.) Swartz*	+	+	+
272.	*Lysionotus serratus D. Don*	+		
273.	*Melocalamus compactiflora (Kurz)*			+
274.	*Melocanna baccifera (Roxb) Kurz*			+
275.	*Melochia corchorifolia Linn*			+
276.	*Mikania micrantha (L.) Kunth ex HBK*		+	+
277.	*Mimosa pudica L*		+	+
278.	*Mucuna pruriens(linn.) DC*			+
279.	*Murdannia simplex (Vahl) Brenan*		+	+
280.	*Musa paradisiaca L.*		+	
281.	*Musa sp.*		+	+
282.	*Myriactis wallichii Less.*			+
283.	*Ophiorrhiza ochroleuca Hook.f.*	+		
284.	*Ophiorrhiza trichocarpa Bl.*	+		
285.	*Oxalis corniculata L.*		+	+
286.	*Paspalidium punctatum (Burm.f.) A.Camus*		+	
287.	*Parthenium hysterophorus Linn.*		+	+
288.	*Paspalum longifolium Roxb.*		+	+
289.	*Pennisetum polystachion (L.) Schult.*			+
290.	*Peperomia pellucida (L.) Kunth*			+
291.	*Persicaria wallichii W. Greuter & Burdet*	+		
292.	*Phaseolus vulgaris L.*			+
293.	*Phrynium capitatum Willd.*		+	
294.	*Phyllanthus glaucus Wall. ex Müll.Arg.*			+
295.	*Physalis minima L.*			+
296.	*Plantago major Linn*			+
297.	*Polygonum alatum Buch.-Ham.*			+
298.	*Polygonum chinense L.*			+
299.	*Polygonum hydropiper Linn.*			+

300.	*Pothos cathcartii Schott.*	+		
301.	*Pronephrium nudatum Roxb.*	+		
302.	*Pseudostachyum polymorphum Munro.*		+	
303.	*Psophocarpus tetragonolobus (L.) DC.*		+	+
304.	*Pteridium aquilinum (L.) Kuhn*		+	
305.	*Rottboellia exaltata Lf*		+	
306.	*Saccharum longesetosum (Andersson) V.Naray. ex Bor*		+	
307.	*Sacciolepis indica (L.) Chase*			+
308.	*Schizachyrium brevifolium (Sw.) Nees ex Buse*		+	
309.	*Schizachyrium semiberbe Nees.*		+	
310.	*Schizostachyum dullooa (Gamble)*		+	
311.	*Schizostachyum polymorphum (Munro)*		+	
312.	*Scleria terrestris Linn*			+
313.	*Scoparia dulcis Linn*			+
314.	*Sechium edule (Jacq.) Sw.*			+
315.	*Sida mysorensis Linn*		+	+
316.	*Sinarundinaria griffithiana (Munro)*			+
317.	*Solanum khasianum C.B.Clarke*		+	+
318.	*Solanum nigrum Linn*		+	+
319.	*Spermacoce latifolia Aubl.*			+
320.	*Sporobolus diander (Retz.) P.Beauv.*		+	+
321.	*Thysanolaena maxima (Roxb.) Kuntze*		+	+
322.	*Tithonia rotundifolia (Mill.) Blake*			+
323.	*Trichosanthes cucumerina L.*			+
324.	*Triumfetta pilosa Roth*		+	+
325.	*Urtica dioica L.*	+		+
326.	*Urtica urens L.*			+
327.	*Vernonia attenuata DC*		+	+
328.	*Vigna unguiculata (L.) Walp.*		+	+

329.	*Zea mays L.*			+
330.	*Zingiber officinale L.*			+

Biodata

MADHURIMA

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EDUCATIONAL QUALIFICATION

Examination	Year of passing	Subjects	Marks (%/CGPA)	Board/School/University
10th or Equivalent	2009	English, Hindi, Mathematics, Science, Social Science, Introductory IT	83.1	Notre Dame Academy, Munger, Bihar (CBSE)
12th or Equivalent	2011	Biology, Physics. Chemistry, English, Economics	73.6	Notre Dame Academy, Munger, Bihar (CBSE)
Bachelor's Degree	2016	Zoology (Honours)	69.00	Patna Women's College, Patna University
Master Degree	2018	Environmental Science	82.30 (Gold Medalist)	Central University of South Bihar
National Eligibility Test (NET)	2017	Environmental Science	Qualified	University Grant Commission (UGC)
Post Graduate Diploma	2024 (Online Mode)	Tourism and Environmental Law	A+	Centre for Environmental Law, WWF-India and National Law University, Delhi
Professional Certificate Course (3 Months ArcGIS)	2023 (Online)	3 Months ArcGIS	Completed	International Institute of Geospatial Science and Technology (IIGST)

RESEARCH EXPERIENCE

- **Summer Internship** Title- To Study Insect Population across the Habitat Type in Yamuna Biodiversity Park

- **Dissertation Title in M.Sc**.- Mosquito Larval Abundance and Their Biocontrol in Urban Rural Ecological Gradient.

PUBLICATION IN JOURNALS

- **Madhurima** and B.P. Mishra (2024). To study the Physico-Chemical properties of soil in the Aizawl Destrict, Mizoram. *Journal of Emerging Technologies and Innovative Research* (JETIR). Vol. 11(8). Pp. b393- b398. ISSN: 2349-5162.
- **Madhurima** and, B P Mishra (2023). Assessment of Impact of Anthropogenic Disturbances on Soil Characteristics in the Subtropical Forests of Aizawl, Mizoram, *Indian Journal of Science and Technology.* Vol 16(SP1), Pp. 158- 164.(Web of science)
- **Madhurima**, Pankaj Kumar and B.P Mishra (2023). Management of Soil Health and Attending Food Security. *Bihar Journal of Public Administration*, 0974- 2735 pp-701 (UGC CARE)
- Lalnunthari Ngente, **Madhurima** and B.P. Mishra (2023). Linear regression model and interrelationship among water quality attributes of Tuikual river in Aizawl District, Mizoram, *Journal of Emerging Technology and Innovative.* Vol 10 (11) pp-36
- B. P. Mishra, John Lianngura, **Madhurima,** O. P. Tripathi (2022). Air pollution tolerance index of selected roadside plant species in Aizawl, Mizoram, India, *Current Science*, 1249- 1251, Vol. 122 (11).

CONFERENCE PRESENTATION

- **Madhurima** (2024). Impact of disturbance on plant diversity and soil properties in Aizawl district, Mizoram, in the International Conference on “Climate Change and Natural Resources Management for Sustainable Development” (ICNS-n2024), Organized by School of Earth Sciences and Natural Resources Management, Mizoram University from 13th – 15th March, 2024.
- **Madhurima** (2022). Assessment of the impact of ecological disturbance on the physical and chemical properties of soil in the sub-tropical forest of

Aizawl district, Mizoram, at the Earth Science discipline technical session in the 4th Mizoram Science Congress, organized by Mizoram Science, Technology and Innovation Council (MISTIC) in collaboration with Mizo Academy of Science (MAS), Mizo Science Society (MSS), Mizoram Mathematics Society (MMS), Biodiversity and Nature Conservation Network (BIOCONE) and Mizoram Information and Technology Society (MITS) on 24th – 25th November, 2022.

- **Madhurima** (2022). The changing dynamics of shifting cultivation and implication of government policies. Organized by Department of Management, Mizoram University and Sponsored by Rajiv Gandhi National Institute of Youth Development, Ministry of Youth Affairs and Sports, Government of India, Sriperumbudur. Held on 26th and 27th May, 2022.

WORKSHOP PARTICIPATION

Title/Academic Session/ Subject	Organizing Institution (with City and Country)	Period
Advanced Laboratory Training on the Quality Analysis of Co-compost, Biochar and Faecal sludge	Anil Agarwal Environment Training Institute (AAETI) A unit for Science and Environment, Rajsthan	20-24, December 2022
Geoinformatics Hands on Training Workshop	Pachunga University College, Aizawl, Mizoram	23-27, May 2022
High-End Workshop on Quality Control and standardization of Herbal Raw Material for Value Addition and Sustainable Development in North East	Department of horticulture, Aromatic and Medicinal Plants, Mizoram University	16-21, September 2022

AWARDS AND HONOURS

Name of the Honour/ Award	Awarding Agency	Year of award	International/ National/ State/University level
Best paper	Amity University	17-02-2022	International

presentation award			
Best paper presentation award	Mizoram University	29-03-2023	National
Best paper presentation award	Mizoram University	15-03-2024	International
Gold Medal (Topper) in M.Sc (Academic Session 2016-18)	Central University of South Bihar	20-10-2023	University

PROFESSIONAL RESPONSIBILITIES AND EXPERIENCES

- Treasurer, Eco-club, Mizoram University. Active participation in speech contests, debate competitions and other activity hosted by club.
- Organizing Secretory: Active role in organizing conferences "National seminar on Himalayan Knowledge Network" organized by the Department of Environmental Science, Mizoram University.
- Organizing Secretory: Active role in organizing Workshop cum Awareness program on "climate Change and Natural Resource Management" Workshop organized by the Department of Environmental Science, Mizoram University.
- Organizing Secretory: "Nature Walk" by Eco Club and Mizoram Pollution Control Board
- Delivered talk as Resource person: Awareness Program on Reduction of Single Use Plastics 14.02.2023.
- Delivered talk as Resource person: Awareness Program on "Healthy Food and Healthy Lifestyle' 13.03.2023

DECLARATION

I declare that the information provided above are true to the best of my knowledge and belief.

Place: Aizawl
Date: **(Madhurima)**

PARTICULARS OF THE CANDIDATE

NAME OF THE CANDIDATE	:	Madhurima
DEGREE	:	Ph.D.
DEPARTMENT	:	Environmental Science,
TITLE OF THESIS	:	Impact of Anthropogenic Disturbances on Phyto-Diversity and Soil Characteristics along Disturbance Gradient in the Tropical Forests of Aizawl District, Mizoram
Date of Admission	:	11.11.2020
APPROVAL OF RESEARCH PROPOSAL :		
DRC	:	27.04.2021
BOS	:	29.04.2021
School Board	:	05.05.2021
MZU Registration Number	:	2100410
Ph.D Registration	:	MZU/Ph.D./1708 of 11.11.2020
Extension (If Any)	:	NIL

(HEAD)

Department of Environmental Science

ABSTRACT

IMPACT OF ANTHROPOGENIC DISTURBANCES ON PHYTO-DIVERSITY AND SOIL CHARACTERISTICS ALONG DISTURBANCE GRADIENT IN THE TROPICAL FORESTS OF AIZAWL DISTRICT, MIZORAM

AN ABSTRACT SUBMITTED IN THE PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

MADHURIMA

MZU REGISTRATION NO.: 2100412

Ph.D. REGISTRATION NO.: MZU/Ph.D./1708 of 11.11.2020

DEPARTMENT OF ENVIRONMENTAL SCIENCE

SCHOOL OF EARTH SCIENCE AND NATURAL RESOURCES MANAGEMENT

JUNE, 2025

IMPACT OF ANTHROPOGENIC DISTURBANCES ON PHYTO-DIVERSITY AND SOIL CHARACTERISTICS ALONG DISTURBANCE GRADIENT IN THE TROPICAL FORESTS OF AIZAWL DISTRICT, MIZORAM

BY

MADHURIMA

Department of Environmental Science

Prof. B.P. MISHRA

Supervisor

Department of Environmental Science

Submitted

In the partial fulfillment of the requirement of the Degree of Doctor of Philosophy in Environmental Science of Mizoram University, Aizawl

ABSTRACT

The Himalayan region especially Mizoram, has not received adequate attention in the national agenda for sustainable development. The region has suffered from certain factors, such as, low investment per unit of area, isolated developmental efforts lacking integrated approach, poorly developed extension programmes customized to local conditions, limited long-term studies depicting changes in economy and ecology in the region.

The landscape of Mizoram is dominated by forest that provides habitat for numerous wildlife species. In north eastern region of India namely Mizoram forest disturbance is a matter of serious concern. This region is mainly associated with slash and burn agriculture and rapid developmental activities (Gogoi *et al*. 2017). To address the challenges human intervention may cause to the natural ecosystem, a deeper understanding of disturbance ecology is required (Newman, 2019). In recent year decline in forest cover has been reported in forest report by Ministry of environment forest and climate change, which will inevitably result in biodiversity loss. In recent decades due to industrialization and economic development there is loss of traditional Mizo culture and disempowerment of local communities along with Shifting cultivation, over exploitation and hunting practice has resulted as major threat to biodiversity loss in Mizoram, it has also reported due under study there lack of baseline data of biodiversity has led to salient erosion of biodiversity, thus a need to study plant diversity and soil characteristics to understand forest ecology of sub-tropical forest of Mizoram is need of the hour.

Therefore, the proposed study aims to assess the impact of anthropogenic disturbance on diversity along disturbance gradient and the soil characteristics in sub-tropical forest of Aizawl district of Mizoram. Studying plant diversity is essential for understanding the complex interactions within ecosystems, conserving biodiversity, and ensuring the sustainability of natural resources.

OBJECTIVES

The major objectives of the study are the following:

1. To study the plant community attributes of the selected forest stands.

2. To study soil characteristics of selected forest stands.

3. To assess the impact of anthropogenic disturbances on plant community attributes and soil characteristics of selected forest stands.

4. To formulate appropriate conservation strategies to mitigate effect of disturbance on plant community attributes and soil characteristics of selected forest stands.

Mizoram translates to "land of hill people”. Mizoram, the land of blue mountains and mystic beauty is one of the 8 states of North eastern part of India, high degree of endemic species and threat to species makes it part of the Indo-Myanmar biodiversity hotspot (Devi, *et.al*; 2018). The state has hill terrain, varying in height across the state. The hills to the west have an average height of around 1,000 meters (3,300 feet) and gradually rise to 1,300 meters (4,300 feet) to the east. Some hill ranges reach a height of 2000 meters (6600 feet). The Phawngpui Tlang, often known as the 'Blue Mountain', is Mizoram's highest peak (7,250 feet asl). Mizoram's strategic location provides enormous opportunities for economic development. Mizoram, which borders Myanmar and Bangladesh, is a gateway for international trade with Southeast Asian countries. The economy is agrarian as agriculture employs and provides revenue for the vast majority of the state's inhabitants. The Shifting cultivation (jhum farming) has been an age old practice in the state and is still prevalent among the inhabitants

The capital of Mizoram is Aizawl district. The district shares its geographic boundary in the north by the Kolasib district, on the west by Mamit district, on the south by the Serchhip district and on the east by Champhai district. The geographic area of Aizawl district is 3,576.31 square kilometres (1,380.82 sq. km). The headquarters of the district is Aizawl City. As of 2011, it is the most populous district of Mizoram. The population of Aizawl is 400,309. The district has a population density of 113 inhabitants per square kilometre. Its population growth rate over the decade 2001-2011 was 24.07%. The site selection and sampling present study was carried based on the disturbance gradient for out for two successive years i.e., during 2022 and 2023. For detailed investigation, one stand (one ha area) each representing undisturbed, moderately disturbed and highly disturbed forest patches were selected in and around Mizoram University campus, Tanhril, Aizawl, Mizoram.

The micro-environment attributes namely, temperature, relative humidity and light interception were measured on site during the field study. The Vegetation analysis of the study area was carried out following the methods as outlined in Misra (1968) and Mueller-Dombois and Ellenberg (1974). Belt transect method was appropriated for field study. The size of quadrat for trees, shrubs and herbs were fixed as 10m x10m 5m x 5m and 1m x1m respectively. The community characteristic was studied by parameters such as frequency, density, abundance, basal area, importance value index, relative density, relative frequency and Relative dominance. The Distribution Pattern, population structure, Shannon-Weiner Diversity Index, Simpson Dominance Index, Margalef's Species Richness Index and Pielou's Evenness Index were used for comparative assessment among the three stands.

The soil samples were collected from the undisturbed, moderately disturbed, and highly disturbed areas of forests seasonally i.e., pre-monsoon season (February-March), monsoon season (July-August), post monsoon season (November-December) from two different depths i.e., 0-10cm (Top-soil) and 10-20cm (Sub-soil) in the triplicate. The physico-chemical properties studied were soil temperature, soil texture, soil pH, soil moisture content, bulk density, soil water holding capacity, soil organic carbon, soil organic matter nutrient concentrations (nitrogen, phosphorus, potassium) along disturbance gradient at two different depth. The analysis of these parameters was done in laboratory at Mizoram University.

A total of 100 quadrats (10x10m size) were laid to sample 1 ha. area of each forest stand for determining tree community characteristics taking into consideration the individuals having GBH ≥30cm. Of the total woody species around 93 individuals were recorded from the UD stand, 87 from the MD stand and 31 from the HD stand.

The Shannon diversity index (H'), which measures species diversity, was also highest in this UD site at 3.63, and the Simpson dominance index, which was 0.963, showed a relatively even distribution of species. The Margalef species richness index, at 12.46, highlights a high level of species richness, and the Evenness index of 0.813 suggests that species were distributed fairly evenly across this habitat. The basal area (27.98 m^2ha^{-1}) and tree density (993 trees per hectare) emphasize the maturity and structure of the forest in these UD conditions.

The number of species decreased to 79, genera to 70, and families to 43. The Shannon diversity index dropped to 3.13, reflecting lower species diversity than the UD stand. The Simpson dominance index was slightly reduced to 0.932, and Margalef's species richness index was computed as 11.841, indicating a moderate loss in species richness. The Evenness index decreased to 0.737, suggesting species distribution was becoming less uniform. The basal area was reduced to 18.59 m^2ha^{-1} and tree density declined to 726 trees per ha., likely due to disturbances such as logging or habitat fragmentation.

HD stand exhibited further a significant reduction in values for all attributes. The number of species was drastically reduced to 31, genera to 27, and families to 19, reflecting biodiversity loss. The Shannon diversity index was lowest at 2.31, highlighting the diminished complexity of the ecosystem. The Simpson dominance index further decreased to 0.880, and the Margalef species richness index dropped sharply to 4.769, pointing to low species richness. The Evenness index was computed as 0.675, indicating the uneven distribution of species, whereas light-demanding species (heliophilic) possessed a relatively high value. The basal area (7.63 m^2ha^{-1}) and tree density (539 trees per hectare) were the lowest, signifying highly degraded habitat conditions. In a nutshell, an increase in disturbance led to ecosystem degradation, loss of species and decrease in basal area and tree density.

Fabaceae, Lauraceae, Euphorbiaceae, and Fagaceae appear frequently and hence were the dominant families with multiple species in UD. Fabaceae, Moraceae, Myrtaceae, Verbenaceae, and Fagaceae were some of the most dominant families in the MD. Fabaceae, Moraceae, Anacardiaceae, Lauraceae and Myrtaceae were dominat species in HD.

The IVI combines factors such as relative density, frequency, and dominance to determine the overall importance of a species in the ecosystem. *Bischofia javanica* holds the highest IVI (27.43), making it the most dominant species in the UD forest followed by *Castanopsis tribuloides* (IVI 25.27), and *Halidina cordifolia* (IVI 14.99). *Schima wallichii* had the highest IVI (31.60), making it the most dominant species in this MD ecosystem. It is closely followed by *Castanopsis tribuloides* (IVI 29.04), *Sterculia villosa* (IVI 28.69), and *Parkia roxburghii* (IVI 27.44), all of which play critical roles in the forest structure and composition.

Mesua ferrea had the highest IVI (45.77), indicating that it is the most dominant species in this HD environment, likely thriving under conditions that were less favourable for other species. *Albizia chinensis* (IVI 43.61) and *Albizia thompsonii* (IVI 41.72) also show high dominance, suggesting they had adapted well to the altered ecosystem and contributed significantly to the forest's structure. *Autocarpus hetrophyllus* (IVI 39.86) and *Parkia timoriana* (IVI 36.23) further underscore the dominance of certain species in this disturbed ecosystem, reflecting a community structure where a few species become more prominent.

A total of 33 species belonging to 31 genera and 22 families, 46 species belonging to -41 genera and 25 families, and 41 species belonging to 38 genera and 27 families were recorded from UD, MD and HD stands. The Shannon Diversity Index (H’) is the measure of overall diversity and computed as 3.34 in UD, 3.62 in MD and 3.48 in HD. The Simpson index of Dominance was 0.962 in UD, 0.968 in MD and 0.963 in HD. Margalef’s Species Richness index was highest in MD (7.21) as moderate disturbance supports high species richness, and followed by HD and UD in deceasing order of values. Evenness index declined slightly as disturbance increased, with the highest value in UD stand (0.958) and the lowest in a HD stand (0.938).

The soil moisture content was strongly influenced by the degree of disturbance, with undisturbed stand soils having consistently high moisture content throughout the years. The water-holding capacity of the soil, influenced by its texture, plays a vital role in retaining moisture and impacting soil temperature and overall soil health. The disturbed soil observed decline in soil moisture content, soil organic carbon, soil organic matter, nitrogen, potassium and phosphorus values. Thus, losing its fertility and productivity.

Soil organic carbon is a key indicator of soil health, and it is essential to hold nutrients and water, reducing the risk of erosion. The land use change and burning during the jhum cultivation have been associated with the decline in soil organic carbon in north-eastern region of India. The present study also reported lower values of soil organic in the disturbed area. The soil properties deteriorated along the disturbance gradient thus, showing the negative impact of disturbances.

Human-induced disturbances drastically modify soil qualities, affecting its physical structure and chemical composition. Soil compaction, erosion, and alterations in organic matter composition frequently occur in disturbed environments, adversely impacting plant growth. The soil in the present study indicated the impact of disturbances due to decline tree density, diversity and canopy cover led to deterioration in soil health.

A survey was conducted to access the socio-economic status of the local community in the vicinity of forests. . A total of 300 respondents participated in the survey. The information was procured through questionnaire were related to the attitude and perception of local community towards environmental conservation and awareness. The respondents aged 18-25 were the largest group with 245 participants. In gender the females were slightly males were also surveyed. Most respondents were post-graduates or above and humanities and language dominated the respondents.

The majority cohort that wildlife populations have declined in the study area, corroborating global patterns identified in biodiversity surveys. Participants predominantly concur that shifting cultivation results in biodiversity loss and deforestation, corroborating research that emphasises the ecological consequences of this technique although many individuals support such initiatives, a considerable segment of respondents articulated neutral or dissenting opinions, potentially indicative of economic apprehensions or insufficient understanding of payment methods.

The major conservation strategies suggested are specific to the study area based on the awareness survey conducted among the local community as well as to mitigate the effect of disturbance revealed in the present study. The major conservation strategies are Reforestation and Afforestation, Ethnobotanical Knowledge Preservation, Sustainable Farming Practices, Agroforestry, Non-Timber Forest Product (NTFP), Ecotourism, Education and Community Awareness Programs, Legal and Policy Support for Community Rights, Community-Based Land Management and Restoration, Soil health management, Data Collection and Monitoring, Community Seed Banks and Seed Networks, Resilience and Adaptation and Capacity building.

The effect of disturbance was evident on both plant diversity and soil characteristics. The decline in tree diversity due to led to decline in canopy cover which in return altering the micro climatic conditions. The study also found moderate disturbance support highest species richness and thus, concluding disturbance when controlled can have positive impact on the ecosystem. However if the intensity of disturbance is high or frequent is can led to biodiversity erosion.

Based on the findings of the present study, it can be argued that there is an ample scope for integrated approach involving Government, NGOs and local communities for proper management of forests and conservation of biodiversity on sustained basis.