IMPACT OF INVASIVE PLANTS ON ECOLOGICAL FUNCTIONING IN HAILAKANDI DISTRICT, ASSAM

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IMPACT OF INVASIVE PLANTS ON ECOLOGICAL FUNCTIONING IN HAILAKANDI DISTRICT, ASSAM

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Submitted

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DECLARATION

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I, Zingthoi Khuppi Sakachep, hereby declare that the subject matter of this thesis is the record of work done by me, that contents of this thesis did not form basis of the award of the 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 other University/Institute.

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(Zingthoi Khuppi Sakachep)

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LIST OF THE ABBREVIATION USED

˚C	Degree Celsius
ANOVA	Analysis of Variance
BD	Bulk Density
C	Carbon
C:N	Carbon:Nitrogen
cm	Centimeter
D	Simpson Index of Dominance
DMg	Species Richness
DTPA	Diethylenetriamine Penta Acetic Acid
E	Evenness Index
eds.	Editors
EDTA	Ethylenediamine tetra Acetic Acid
etc.	Et. Cetera
H’	Shannon Weiner Index
HCL	Hydrochloric Acid
IAPs	Invasive Alien Plants
i.e,	“Fd Est”, Means “That is” or “In Other Words”
IP	Invasive Plants
IUCN	International Union for Conservation of Nature and Natural Resources
AK	Available Potassium
Kg/hac	Kilogram per Hectare
mg/kg	Milligram per Kilogram
NE	Northeast
NTFPs	Non- Timber Forest Products

AP	Available Phosphorus
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SMC	Soil Moisture Content
SPSS	Statistical Package for the Social Sciences
TEA	Triethanol Amine
TN	Total Nitrogen
WHC	Water Holding Capacity
viz.	Videlicet Which Means Name

CHAPTER-1

INTRODUCTION

1.1. Definition and the concepts of Invasive Alien Plants

Invasive alien plants are referred to as those plants which are non-native and are introduced in an ecosystem intentionally or accidentally through humans or other agencies. Once invasive alien plants get established and spread successfully outside their native habitat, they can cause harm to the plant, wildlife, humans, soil-physicochemical properties, and ecosystem services (Rai and Singh, 2020). Invasive alien plants are defined by various global regulatory agencies and institutions. In this context, the International Union of Conservation for Nature (IUCN 1999) defined them as *alien species which becomes established in natural or semi-natural ecosystems or habitats as an agent of change and threatens native biological diversity*. Convention on Biological Diversity (CBD) defined invasive alien plants as *the species introduced deliberately or unintentionally outside their natural habitats where they can establish themselves, invade, out-compete natives and take over the new environments* (CBD News, 2001). Further, as per Global Invasive Species Programme (GISP), "*Invasive alien are non-native organisms that cause or have the potential to cause harm to the environment, economies, or human health*" (GISP, 2003).

1.2. Comparison between the native and Invasive Alien Plants

Invasive alien plants outside the native range reproduce rapidly (Ratnayake, 2014). They usually have a long flowering period compared to the native plants (Pysek, *et al.,* 2003). In general, an infestation of invasive alien plants enhances the net primary productivity and increases the soil nitrogen cycling through which the nearby plants get affected (Rout and Callaway, 2009). Compared to the native plants, the invasive alien plants can better uptake or utilize the soil nutrients (Thorpe, *et al.,* 2006), thereby resulting in a comparatively high growth rate (Daehler, 2003). Funk and Vitousek (2007) reported that the native plants are better in the utilization of the available resources, as compared to invasive alien plants. The colonial invasive alien plants inhibit the growth and development of the native plants (Webster, *et al.,* 2006). Further, invasive alien plants make the habitat more prone to biological invasion with their highly competitive nature of resources and high adaptive capacity (Ratnayake, 2014).

1.3. Effects of plant invasion on the global environment

In the changing environmental/climatic variables, the invasive alien plants dramatically affect the environment on a regional national, and global scale. Invasive alien plants interact with other anthropogenic changes (e.g., land-use/climate change) in the environment to alter the biodiversity and ecosystem processes, especially in intensely invaded habitats (Vila, *et al.*, 2007).

The environmental effects include biotic interaction (Bartz and Kowarik, 2019) that changes the structure and composition of habitat leading to homogenization of flora (Cushman and Gaffney, 2010). The invasive alien plants change the composition of the plant biodiversity and that induces ecological damage (Bartz, *et al.,* 2010).

Altogether, invasive alien plants are a key challenge to biodiversity conservation and restoration ecologists worldwide. The invasive alien plants usually bring adverse changes in the ecosystem services (Bartz and Kowarik, 2019) and human livelihood (Pejchar and Mooney, 2009). In this aspect, Rai and Singh, (2020) also reported that the invasive alien plants altered the biodiversity distribution, ecosystem services, as well as socio-economic or livelihood. Furthermore, other researchers reported that invasive plants lead to decreased native biodiversity through degradation of wildlife habitat, thus adversely affecting productivity, ecosystem properties, and ecosystem functioning (Masters and Sheley, 2001; Davies and Svejcar, 2008).

1.4. Impact on the soil attributes

Invasive alien plants affect the soil attributes by changing the soil microbial communities (Weidenhmer and Callaway, 2010) and physico-chemical characteristics (Tiedemann and Klemmenson, 1986, Callaway, *et al.*, 1991), biogeochemical/nutrient cycling (Kell, *et al.,* 1998). Various allelopathic and antimicrobial toxic compounds released by several invasive alien plants (Weidenhmer and Callaway, 2010) can subsequently increase the nutrient availability and chelate toxic metals in the soil (Li, *et al.*, 2007).

In the topsoil (of 15cm), the infestation of *Amaranthus viridis* (Amaranthaceae) increased the concentrations of Nitrogen (N), Carbon (C), and Phosphorus (P) (Weidenhmer and Callaway, 2010). Further, *Eupatorium* invasion was also facilitated on nutrient-enriched soil substrata (Srivastava, 2014). Some other invasive alien plants adversely influenced the agricultural lands by excreting toxic volatile compounds in the soil (Saxena, 1991). The invasion ecology of *Lantana camara* (Verbenaceae) is observed to be correlated with changes in N cycling (Sharma and Raghubanshi, 2009). In this aspect, Dogra, *et al.,* (2009), reported that *Ageratum conyzoides* (Asteraceae) altered the physico-chemical properties of soil in the invaded area.

1.5. Impact on Ecological and Socio-economy

Plants invasion is generally considered an issue of public concern which influences future economic and social development. Plant invasion damages the economy and impacts the ecology of invaded landscapes (Davis, 2009). Several studies revealed that the plant invaders have adverse effects and lead to the extinction of native plant species due to competitive exclusion, niche displacement, and hybridization of invasive alien plants (Mooney and Cleland, 2001). For example, *Datura innoxia* (Solanaceae) caused the delay in seedling growth of the neighboring plants (Sood, *et al.,* 2011). Lantana invasion changed the structure and composition of the plant communities and enhanced the stretch of the infested area by making it prone to further invasions (Prasad, 2012). Invasive alien plants also suppressed the regeneration potential of native plants (Hirmath and Sundaram, 2013). In this aspect, *Leucaena leucocephala* (Fabaceae) altered the growth of the orchards by obstructing the light penetrations (Chou, 1980).

In the last few decades, there is an increasing impact of invasive alien plants on native plant biodiversity which potentially threatened ecological functioning. Human activities are playing a vital role in the spreading of invasive plants in novel ecosystems within a short period. Loss of native prairies of the Great Plains due to the plant invasion increased and their conversion to grasslands disturbed the ecosystem functioning in North America (Samson, *et al.,* 2004, Greer, *et al.*, 2014). The increased spread of various alien plants at an alarming rate outside their native ranges and the different parts of the world considered them as noxious in the global scenario. They are distributed widely throughout the world in the diverse ecosystem (Aravidhan and Rajendran, 2014). Further, Pepsi, *et al.,* (2018) reported that the invasive alien plants significantly impacted the agriculture systems.

In the context of effects on ecological functioning, *L. camara, Chromolaena odorata, Mikania micrantha, Imperata cylindrica, Clidemia hirta,* and *L. leucocephala* are ranked among the world 100 worst invasive alien plants (Global Invasive Species Database, 2018). These invasive alien plants adversely impact the socio-economy, native biodiversity, and soil physico-chemical properties. The ecological approach in plant invasion has been mostly based on (a) biological and ecological features or attributes promoting the invasive success of particular species (Newsome and Noble, 1986; Rejmanek, 1995) and (b) the habitat characteristics and invasibility of plant communities (Rejmanek, 1989). Plant invasion is also considered a form of biological pollution and a significant component of environmental changes leading to the extinction of native species worldwide (Srivastava, *et al.,* 2014).

In the global assessment report on biodiversity and ecosystem services, 21 countries put forward since 1970 about 70% increasing matter of several biotic invaders reported in the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2019). Further, invasive alien plant species contribute to about 25% of the global plant extinction as per the estimation by the IUCN-Red Data List (IUCN, 2017).

1.6. Impacts of plant invasion in India/ Northeast India

India is rich in vegetation and one of the mega diversity countries of the world (Sinha, *et al.,* 2010). The rich vegetative diversity of India is attributed to varied climatic conditions. The rapid industrialization, urbanization, and land-use change created stress on the abiotic environment (soil and water) and native vegetation. However, invasive alien plants successfully colonized such stressed habitats which facilitated their spread (Linders *et al.,* 2018). Further, Vitousek, *et al.,* (1997) reported that the involvement of humans in the ecosystem disturbances facilitates plant invasion through habitat fragmentation, land-use change, global climate change disruption, and elevation Nitrogen (N) availability. Invasive Plants or weeds transmogrify the landscapes of urban forests and affect the phytosociology of native species in a complex and intricate manner (Rai, 2013). North-Eastern India, a part of Eastern Himalaya is recognized as a global biodiversity hotspot (Myers, *et al.*, 2000). Forest Survey of India revealed that this region covers one-third of the forest cover (>41.5% of geographical area) of India (FSI, 2017). The biodiversity region of North-eastern India covers diversified forest types and is home to numerous endemic/indigenous plants. However, in the last few decades, this Indo-Burma global biodiversity hotspot has experienced significant loss in the forest covers because of biotic pressure, shifting cultivation, agricultural expansion, and urbanization (Jha, *et al.*, 2000; Sloan, *et al.,* 2014). Such disturbances created a state of disequilibrium in the environmental conditions, which made the north-eastern region vulnerable to plant invasion (Tilman and Lehman, 2001). According to Moles, *et al.,* (2008), such vulnerability of ecosystems to invasion may be explained based on the concept of availability of 'vacant niches' i.e., unfilled opportunities for additional species in ecosystems or by creating new 'ecological opportunities' for occupancy by the invasive alien plants. The various hypothesis has been introduced by the various researcher to understand the invasiveness of the alien plants in the new habitats e.g., the evolution of increased competitive ability (Rai, 2021), novel weapons (Callaway and Ridenour, 2004), enemy releases hypothesis and disturbance hypothesis (Dar, *et al.,* 2019).

1.7. Impact of invasive alien plants in Assam

Assam falls under the Indo-Burma biodiversity hotspot region, with the rich diversity of angiospermic plants. The study from the various researchers reported that the hotspots region became infested by the invasive alien plants. In this respect, Adhikari, *et al.*, (2015) reported that the hotspot regions are having a high risk of invasion in the event of environmental disturbances and alteration in climatic variables.

The state of Assam is widely recognized for its protected areas in India. In this context, Choudhury, *et al.*, (2017) reported that the invasive alien plants with their high rate of proliferation reduced the diversity of grassland ecosystems in the protected area, thus making them unsuitable for the herbivores. In Assam, the vegetation was adversely affected by the simultaneous spread of the invasive alien plants that degraded the wildlife habitat. The habitat of rhino (*Rhinoceros unicornis*) in the different National Parks (NP) and Wildlife Sanctuary (WS) of Assam is affected by the invasive alien plants (Lahkar, *et al.*, 2011). For example, Kaziranga NP was affected by *Mimosa* invasion, Rajiv Gandhi Orang NP by *Mimosa species* and *M. micrantha*; Manas NP by *C. odorata*, and the Pobitora WS was influenced by the *Ipomea species* (Lahkar, *et. al.*, 2011). Invasive plants are a significant threat to the agroecosystems in Assam and the state mainly depends on the agriculture sector for livelihood (Sakachep and Rai, 2021). In this respect, Das and Duarah (2013), worked on invasive alien plant species on the roadside areas of Jorhat, Assam, and reported *A. conyzoides* as a common weed in the crop fields which reduced agricultural productivity. Similarly, another case study on agriculture systems observed the harmful effects of *A. conyzoides* to crop growth and productivity (Kaur, *et al.*, 2011). Invasive alien plants such as *C. odorata*, *M. micrantha*, and the *L. camara* reduces crop production (Shah, *et al.*, 2020). Tree species *L. leucocephala* became invaders in some areas of the tropical and sub-tropical regions (Wolfe and Van Bloem, 2012). In this respect, Kunwar, (2003) reported that *L. leucocephala* contributes as a transformer of the indigenous plant ecosystems.

1.8. Interactions in Invasion Ecology

Interactions in the plant community occur due to competition and/or when the supply of one nutrient affects the absorption, distribution, and function of another nutrient (Robson and Pitmon, 1983). The invasive alien plant gives direct competition to natives during the community interactions (Plant-Plant and Plant-Soil) for light and space, soil nutrient cycling, etc. (Weidenhamer and Callaway, 2010; Kumar, 2021). In light of these effects on ecosystem functioning, invasive plant species diminish the number of native plant species and may even lead to extinction, niche displacement, and hybridization (Mooney and Cleland, 2001).

1.8.1. Plant- Plant interaction

In plant-plant interaction, it has been observed that the extent of plant invasion is highly noticeable along the disturbance gradient. The interaction of the invasive alien plants and the native plants can result in severe threats to environmental quality and ecosystem services (Bartz and Kowarik, 2019). Invasive alien plants are very good competitors and highly tolerant species when compared with native plants (Bottollier-Curtet, *et al.,* 2013). They compete with the native plants by affecting reproduction (Stanley and Stout, 2011), nutritional uptake (Stout and Tiedeken, 2017), and the hydrological cycle (Cao and Natuhara, 2020).

1.8.2. Plant- Soil interactions

Plant-soil interaction can be abiotic or biotic meaning that plant composition can alter the chemical composition of the soil (abiotic) and the microbial composition (biotic) of the soil or vice versa (Pickrett, *et al.,* 2018). Invasive plants affect native plants either directly by competition for soil resources, light, and space or indirectly through alteration of ecosystem processes, services, and ecological functioning such as soil nutrient cycling and pollination (Goodell, 2008). In this respect, Ehrenfeld (2003) stated that the soil carbon (C) and nutrients pools were often modified by biotic invasions and that the direction and magnitude of the impacts were usually determined by the composition of the invaded community and soil properties. Productivity can be altered by invasive alien plants as they use soil resources more efficiently and hence eventually eliminate native diversity (Dukes and Mooney, 2004). Alteration of nutrient cycling has additional implications on soil fertility and primary production in invaded habitats. Nitrogen (N) is an important macronutrient in the crop field which enhances soil fertility. Exotic plant species are often faster-growing with a higher demand for N (Mackown, *et al.,* 2009) and consequently can deplete N more rapidly than native plant species which are slower-growing and adapted to N-poor soil (Vallano, *et al.,* 2012). Further, elevation in the level of Soil Organic Matter (SOM), Nitrogen (N), Phosphorus (P), and Potassium (K) in the invaded site of *C. odorata* (Mandal and Joshi, 2014).

1.9. Phyto-sociology study

The phytosociological study is a description of the population dynamic of each plant species occurring in the habitat (Mishra, *et al.,* 2012) and other words the distribution and characterization of the vegetation in the habitat. In this aspect, Stefanowicz *et al.*, (2018) reported that invasive alien plants can cause modification in the abundance, diversity, and structure of the plant diversity. Secretariat of the Convention on Biological Diversity (SCBD, 2001) reported that the particular invasive alien plants can severely threaten ecosystem functioning in terms of structure and function and enhance their vulnerability. Further, invasive alien plants can dominate the understorey to strangle the sapling and suppresses the indigenous plants regeneration in the forest ecosystem (Denslow, 2002).

The spectrum of vegetation in diversity indices is determined by using Shannon-weaver Index (H'), the evenness index of the community by Pielou's index (E), species richness by Margalef's Index (R), and the species dominance by Simpson's Index (D), and the similarity coefficient by the Sorenson's Similarity Index (β).

Different quadrat sizes (1×1m, 5×5m, and 10×10m) that enumerate herb, shrub, and tree layers, respectively (Mishra, 1968). The quantitative analysis of vegetation for Density, Abundance, Frequency (Curtis and Mclntos, 1950), Relative Density, Relative Abundance, Relative Frequency, and Important Value Index (Phillips, 1959).

1.10. Soil Physico-chemical properties

The Physico-chemical properties of soil are considered indicators of soil quality. In this sense, the plant invaders cause alteration of the soil physico-chemical properties, thereby potentially impact the plant community. Richardson, (1998) reported the same that the invasive alien plants alter the soil nutrient cycling. Based on the particular invasive species like *C. odorata* showed that its infestation in the forest had significantly decreased Soil Moisture Content (SMC), Water Holding Capacity

(WHC), Soil Organic Carbon (SOC), Nitrogen (N), and Phosphorus compared to the soils in the adjacent natural non-invaded sites while in contrast the soil Bulk Density (BD) was observed high (Debnath, *et al.*, 2018). Among physico-chemical properties, the soil temperature is a significant factor that influences attributes and microbiological processes present in soil (Pepper and Brusseau, 2019). SMC is the amount of water in the soil and it maintains the compaction and the texture of the soil. BD indicates the compactions of the soil, and it varies from soil to soil. It is the ratio of the mass of dry soil to its volume. The soil pore spaces fill up by the air and water called the Soil Porosity. Percolation and distribution of the roots get influenced by their soil porosity. Among physical characteristics, the WHC is the maximum amount of water held in the soil. Further, WHC is controlled primarily by soil texture and SOM. In respect of chemical characteristics, pH identifies the nature (acidic, neutral, and alkaline) of the soil. Also, pH in soil influences the solubility of nutrients of the plants, and it is further affected by the mineralogy, climate, and weathering.

Among chemical attributes, SOC is of paramount importance, and infect is a combination of an organic and inorganic form of soil. It is an indicator of soil health and improves the soil's structural stability by promoting aggregate formation (Liu, *et al.*, 2019). In this respect, SOM is the organic constituent in soil. It is responsible for the function of residue and litter decomposition. SOM is comprised of micro and macronutrients as well. Another chemical attribute, Total Nitrogen (TN) is widely identified as an essential nutrient for plants. Plants require more N as compare to other nutrients. Plants obtain its N in the forms of Ammonium ($NH4^{+}$) and Nitrate ($NO3^{-}$) ions. Importantly, the Carbon: Nitrogen Ratio (C: N ratio) is the mass of Carbon and the mass of nitrogen in the soil which determines the extent of litter decomposition in soil. Similarly, Available Phosphorus (AP) is also necessary for better growth and development for plants. It presents organic and inorganic forms in soil. Plants obtain P in the form of Phosphate ions (HPO_4^{2} and H_2PO^{4-}) from the soil solution. Available Potassium (AK) is one of the essential macronutrients which are abundantly found in soil. In soil, exchangeable and water-soluble forms of nutrients are of paramount importance in the context of plant colonization. Plants obtain K from the soil in the form of potassium ions (K^{+}).

1.11. SCOPE OF STUDY

From the last few decades, there have been rapid rising issues on the impact of invasive alien plants in various aspects of biodiversity and conservation worldwide. Invasive plants, owing to their ecological mechanisms/aggressive nature can expand their zone of habitation in quick succession, spread over large areas, and threaten the native plants, soil and bring about the paradigm shift in ecological functioning. The invasive plant species compete directly with native species for light, moisture, soil nutrient, and space. The impact of invasive plants species in native plant species, communities, and ecosystems is manifested in terms of plant-plant interaction and plant-soil interaction.

Physico-chemical characteristics of soils vary in space and time because of variation in topography, climate, weathering processes, vegetation cover, microbial activities, and several other biotic and abiotic factors. The study of soil physico-chemical properties provides an insight into invader and native plant traits and assessing their environmental impacts. Biodiversity is not evenly distributed; therefore, their prioritization is essential to minimize the effect of invasive alien plants on native plants, especially at the sites of prime ecological relevance i.e., Northeast India underlying in an Indo-Burma hotspot region. With the novel environmental condition like climatic suitability, moderate temperature and the seasonal precipitation in these area makes the invasive alien plants succession, distributed or spread very quick.

1.12. OBJECTIVES

1. To evaluate the impact of invasive plants on native plant diversity at selected sites.
2. To evaluate the impact of invasive plants on soil Physico-chemical properties at selected sides.
3. To compare the invaded site with non-invaded one.

CHAPTER 2

REVIEW OF LITERATURE

Impact of Invasive Alien Plants in Ecological Functioning

International regulatory institution i.e., CBD, anticipates that biological invasions are considered as the second-worst threat after habitat destruction (CBD, 1992; Shiferaw, *et al.,* 2018). Plant invaders were found to be noxious to crops and the native plants diversity (Nayak and Satapathy, 2015). interfere in nutrient cycling and lead to the extinction of biodiversity (Kariyawasam, *et al.,* 2020; Rai, 2021; Qu, *et al.,* 2021). In this respect, Richardson, *et al.,* (2000) also reported that 50-80% of invaders exert harmful effects and 10% of the invasive alien plants change the form or nature of the ecosystem over the substantial area, thereby termed as "transformer".

Since, for the past few decades, the cover of the natural forest is under severe threat from plant invaders. The large numbers of seeds produced by invasive alien plants get dispersed over long distances through the animal (Van Leeuwen, 2018), wind (Egawa, 2017), and other sources natural sources, and eventually they get established in a new habitat (Nathan, *et al.,* 2008) in the absence of their natural competitors (Kunwar, 2003). The fast adaptability, nature of the establishment, and growth rate of invasive alien plants enable them to cover the forest floor quickly and efficiently reproduce/colonize in the new habitat (Ratnayake, 2014). Because of these ecological attributes, invasive alien plants replace the native vegetation and are considered to be the primary cause of global biodiversity loss (Khanduri, *et al.,* 2017).

In the long term, invasive alien plants are considered as the driver of global environmental change (Sharma, *et al.,* 2005). Further, the dominance of plant invaders impacts the ecosystem processes, biotic interactions, and multiple ecosystem services which change the composition of indigenous plant communities (Vila and Hulme, 2017). Therefore, invasive alien plants contribute substantially to the global problem of biodiversity loss (Pysek, *et al.,* 2008; Ni, *et al.,* 2021), with concomitant altered fire regimes (Gaertnes, *et al.,* 2014), soil nutrient cycling (Ehrenfeld, 2010), species extinctions, and ecosystem services (Van Wilgen, *et al.,* 2008).

2.1. Global impacts of Invasive Alien Plants on Ecological Functioning

Globally, plant invaders are now widely considered a burning ecological issue because of their threats to the natural forest (Kumar and Prasad, 2014) and the protected areas (Rai and Singh, 2021). In this aspect, Lagmaier and Lapin (2020) investigated and observed the adverse impacts of invasive alien plants on forest regeneration in the temperate forest of Europe. Invasive alien plants reduce the number of native plant species and may even lead to their extinction owing to ecological mechanisms of competitive exclusion, niche displacement, and hybridization (Mooney and Cleland, 2001).

In addition to ecological effects, the rapid spread of invasive alien plants influences several socio-economic impacts. Therefore, invasive alien plants damage the ecosystems in terms of both economy and ecology; however, socio-economic effects are rather difficult to assess (Pimentel, *et al.,* 2005). For example, the constant increase of invasive alien plants with the rate of 76% was noted in the year 1970-2007 which resulted in an overall economic loss of 12 billion euro/ year (Bultchart, *et al.,* 2010; Genovesi, *et al.,* 2015). Further, the United States Department of Agriculture (USDA, 2010) reported that the invasive plants have invaded over half of the non-Federal rangelands and comprised more than 50% of the plant cover on a mere 6.6% of the land surface. The survey of Northern central Tanzania on socio-economic status reported that *C. odorata* adversely impacted the live stocks, reduced native diversity (of grasses, shrubs, and trees), and caused a decline in crop yields up to 50% (Shackleton, *et al.,* 2017). In this context, *M. micrantha* spread was observed in north-eastern India and China at an alarming rate which perturbed the ecological functioning of forestry/agro-forestry systems (Guo, *et al.,* 2018).

Invasive alien plants pose serious threats to agro-ecosystems. In this context, Kato-Naguchi, (2001) identified *A. conyzoides* as dominant weeds in upland agricultural systems of South East Asia. In this sense, *A. conyzoides* adversely affected the agricultural systems by reducing crop production through multiple mechanisms especially allelopathy (Negi, *et al.,* 2020). Another invasive alien plant, *M. micrantha* (herbaceous climber) and *L. leucocephala* (tree) are included in the world's 100 worst weeds due to the associated allelopathic effects that suppressed the growth of the neighboring crops and native plants (Banerjee, *et al.,* 2017).

Several plant invaders alter the disturbance regimes (including fire, soil erosion, and flooding), or act as agents of disturbance themselves (Mack and D'Antonio, 1998). The increase in soil nutrient concentrations has been reported widely in many plant-invaded communities (Dassonville, *et al.,* 2008; Gomez-Aparicio and Canham, 2008; Liao, *et al.,* 2008; Rodgers, *et al.,* 2008; Rout and Chrzanowski, 2009). Such changes in soil attributes correlate with anthropogenic disturbances that often facilitated the biotic invasions (Pysek, *et al.,* 2010). Also, increased N deposition can create positive feedback for invasive alien plants which are capable of accessing N inputs quickly, thereby attaining high biomass and leaf-nitrogen concentrations (Ponette-Gonzalez, *et al.,* 2021).

Along with the potential effects on vegetation, the documented impacts of invasive alien plants on soil properties are diverse (Rai and Singh, 2020). Several studies reported increased soil nutrient stock at sites infested with invasive alien plants when compared with uninvaded ecosystems (Scott, *et al.,* 2001; Duda, *et al.,* 2003; Liao, *et al.,* 2008). The efficient resource utilization of invasive alien plants can be the underlying mechanism that might increase the competitive colonization ability of non-native plants compared to natives (White, *et al.,* 1997; Kolb, *et al.,* 2002). Nutrient enrichment in the soil promotes plant invasion (Wedin and Tilman, 1996; Bakker and Berendse, 1999; Kolb, *et al.,* 2002; Rai, 2013). In this respect, Sharma and Raghubanshi (2009) studied the impact of *L. camara* vegetative understory invasions on soil N availability in forest ecosystems (Vindhyan forests, India) and observed that alteration in litter inputs and chemistry beneath the Lantana canopy positively and significantly altered soil N availability, N-mineralization, and total soil N. Further, in Lantana infested landscapes, SMC, pH, SOC, and TN were significantly elevated (Osunkoya and Perrett, 2011). Likewise, garden and greenhouse experiments also showed that high nutrient availability can increase the ability of non-native plant species to compete with native plants (Wedin and Tilman, 1993; Nernberg and Dale, 1997; Kolb, *et al.*, 2002). The competition for the resources is very high between invasive alien plants and native plants (Daehler, 2003; Totland, *et al.*, 2006). However, in the majority of studies, plant invaders outperformed the natives in view of comparatively efficient resource utilization.

2.2. Impact of Invasive Alien Plants on Ecological Functioning in India

India is one of the 12 mega biodiversity countries of the world and represents 11% of the world's flora in about 2.4% of the global landmass (Chitale, *et al.*, 2014). Ni (2011) reported that India is a rich centre of biodiversity due to its wide range of climatic conditions and geography. It hosts four biodiversity world hot spots, namely the Western Ghats, Sundaland, the Eastern Himalayas, and the Indo-Burma region (Balasubramanian, 2017). Those regions are enriched with high levels of endemism and species diversity. Indian forests cover 22.5% of the country's geographical area and harbor more than 1700 angiosperms (Irewin and Narasimha, 2011). Incidentally, from the list of 100 world worst invasive species, 11 plant invaders are recorded in India (Lowe, *et al.*, 2000).

The floristic survey of invasive alien plants was done by various workers which determined that the introduction of some invasive alien plants in India was initially as ornamental plants. For example, plant invaders such as *A. conyzoides* (Kaur, *et al.*, 2012), *C. odorata* (Mondal and Ray, 2017), *Ipomoea carnea* (Chaudhuri, *et al.*, 1994), *L. camara* (Kannan, *et al.*, 2013) initially introduced as ornamental plants. Whereas, *M. micrantha* was introduced to mitigate soil erosion and enhance soil fertility (Randerson, 2003). On the other hand, *P. hysterophorus* was accidentally introduced due to international trade in India (Kohli, *et al.*, 2006). In this context, Lowe, *et al.*, (2000) reported that most of the invasive plant species were from Tropical America and introduced in the Indian subcontinent as fodder crops or ornamentals in the early part of the last century. The introduction of invasive alien plants in India eventually created threats for the indigenous plants, animals, and human health (Singh, *et al.*, 2020).

The invasive alien plants are noted as good colonizers especially in disturbed areas, exerting considerable ecological damage to threatened and endemic species, thereby reduce the ecosystem carrying capacity and increase the maintenance cost of croplands (Dutta and Mukherjee, 2015). Also, soil microbial activities have adversely affected the agroecosystems, subsequently causing a reduction in crop productivity. There is an increasing degree of threats to the indigenous agroecosystem plants by the invasive alien plants in different parts of India. In this respect, *A. conyzoides, P. hysterophorus, Eupatorium adenophorum,* and *L. camara* are invaders that pose threat to indigenous crop plants under various habitats such as plains, hills, and mountains (Dogra, *et al.,* 2010).

Several invasive alien plants like *L. camara* are one of the most commonly distributed invasive alien plants in India (Sundaram, *et al.,* 2012). *L. camara* forms dense thickets that livestock cannot penetrate and adversely impact them (Rai 2015). *L. camara* can grow individually as clumps to outcompete the native plant species (Babu, *et al.,* 2009). It has also been demonstrated that allelopathic potential also considerably reduced the seedling vigor of native species (Gentle and Duggin, 1997; Day, *et al.,* 2003). For example, *L. camara* leaves are toxic when ingested by domestic livestock or native mammals (Goulson and Derwent, 2004). Furthermore, *M. micrantha* was introduced during Second World War to Camouflage the airfield of Northeast India (Tripathi, *et al.,* 2012). However, at present, it has infested 15 states including one of the conservation sites of Western Ghats (Banerjee and Dewanji, 2012; Benarjee, *et al.,* 2017).

Few researchers such as Alexander, *et al.,* (2016) worked on the plant invasion ecology of the mountain and alpine ecosystem to investigate the current status and identify the future challenges. The mountain ecosystems are assumed to be less affected by the plant invaders as compared to the surrounding lowlands. The study of Averett, *et al.,* (2016) also reported that the mountainous ranges are considered to be the least invaded among the ecosystem. However, in the last few decades, anthropogenic disturbances increased the risk of plant invaders in the mountainous ranges. Therefore, now in the present scenario, the mountainous ranges of the Indian Himalayan are disturbed by plant invaders. For example, Thapa, *et al.,* (2018) determined the dynamic spread of invasive plants in the mountainous ranges of the Himalayas. Another study determined that the global climatic change and various anthropogenic activities in the mountainous ecosystem made them vulnerable to plant invasion (Lamsal, *et al.,* 2018). Further, the increasing global temperature allows warm-climate species to succeed at higher latitudes and also caused a potential reduction in the growth performance of certain native species (Daehler, 2009). The advantage of climatic suitability facilitated the invasive plants to colonize the novel sites within a short period (Finch, *et al.,* 2021). For example, Kumar and Bihari (2015) worked on the diversity of invasive alien plants in the Dhenkanal district of Odisha and reported that the climatic conditions of the region facilitated their spread. The accelerating growth of invasive plants was considered as an outcome of the changing environmental conditions or the climatic condition (Finch, *et al.,* 2021), habitat fragmentations (Dutta, 2018) industrialization, and urbanization (Reynolds, 2021).

Impacts of invasive alien plants (*A. conyzoides, L. camara,* and *P. hysterophorum*) on native vegetation were studied by Kohli, *et al.,* (2004). In their study, Kohli, *et al.,* (2004) reported that these plant invaders adversely affected the structural and compositional status of native plant communities in the lower and the middle ranges of Himalaya. Dogra, *et al.,* (2009) reported that *A. conyzoides* became a strong invader in the Shivalik hill in Himachal Pradesh and its increased density and abundance caused the extinction of the native species. Further, Raghubanshi and Tripathi (2009) worked on the disturbance and habitat fragmentation in facilitating the plant invaders of the dry tropical forest of Vidhyan high land. They concluded that the Lantana invasion changed the forest structure, resulting in species diversity loss and the creation of homogeneous, mono-specific Lantana invaded understorey in the Vindhyan forest patches.

Invasive alien plant with phenotypic plasticity plays a vital role in any ecosystem (Raghubanshi and Tripathi, 2009). The quick successional properties of the invasive plants are increasing over the past decades. Further, invasive alien plants rapidly acclimatize to novel introduced landscapes by creating symbiotic interactions (Wardle, *et al.,* 2004). The indirect effect of plant invaders is better participation in soil nutrient cycling which tilted the competitive outcome in their favor (Hawkes, *et al.,* 2005).

Roadsides are the disturbing environment that is suited to invasive alien plants (Rentch, *et al.,* 2005). Roadsides are reported to act as reservoirs of alien plant propagules (Parendes and Jones, 2000). Roadside provides habitat and potential dispersal corridors for exotic plant species (Amor and Stevens, 1975). Dar, *et al.,* (2015) worked on roadside plant invasion and their study revealed that roads serve as a corridor for the spread of alien plant species in the mountainous regions of Kashmir valley, India. Nutrient runoff from the mountains to the agricultural field played a vital role in the spread of invasive plants on the roadsides (Lazaro-Loro and Ervin, 2019).

2.3. Impact of Invasive Alien Plants on Ecological Functioning in the North-eastern States of India

In India, the northeast region is an extension of the eastern Himalayas. Northeast India comprises eight (8) states- Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura, and Sikkim. It has stable geological history, moderate climate, heavy and uniform rainfall, which support a wide range of sub-tropical forest ecosystems (Champion and Seth, 1968). Northeast India is taxonomically very diverse in terms of genetic and species diversity and falls under the 34 biodiversity hotspots of the world (Myers, *et al.,* 2000). Northeast India is considered as the Indo-Burma hot spot of plant diversity (Myers, 1988; Groombridge, 1992; Behera, *et al.,* 2002). Phytogeographically its primitive plant species are regarded as a "treasure trove" forest of ancient and unique vegetation (Champion and Seth, 1968). Takhtajan (1969) has considered Himalayan plants as the Cradle of flowering plants.

The north-eastern India is recognized as biogeographical gateway to India's richest biodiversity zone and is unique for its genetic resources (Chakravarty, *et al.,* 2012). The forest of Northeast India is composed of evergreen rainforest, semi-evergreen, and moist deciduous forest (Srivastava and Mohnot, 2001). Several researchers performed ecological assessment of invasive alien plants in the hotspot region and found that the hotspots regions are vulnerable to plant invasion (Adhikari, *et al.,* 2015). In this respect, Early, *et al.*, (2016) reported that about one-sixth of the global land surface of biodiversity hotspots is highly vulnerable to biological invasion.

It has been noticed that the invasive alien plants in the north-eastern states are rising constantly in the last few decades. Invasive alien plants intensify the biodiversity conservation challenges (Didham, *et al.*, 2005). Decline in crop production due to the allelopathic nature of the invasive alien plants (Debnath, *et al.*, 2015) and other competitive nature of invasive alien plants make them harmful to the native vegetation or crops. Further, Barua, *et al.*, (2013) reported that the invasive alien plants in Assam owing to their competitive nature have serious interference in the pasture and the forest ecosystem. Further, according to the action in the ecosystem, they suggested the invasive alien plants like *C. odorata* and *M. micrantha* as “drivers” while *Imperata cylindrica, L. camara, and M. pudica* were noted as “passenger" followed by *P. hysterophorus* as “back seat driver”.

In the assessment of the successful spread of invasive alien plants in the hotspot regions, several important findings were revealed by several ecological investigations. The researchers determined that the widespread of the invasive alien plants is mainly due to the climatic conditions and other available natural resources. Further, the suitable climatic variables helped for the rapid growth of the invasive plants in the north-eastern Himalayan region which led to drastic changes by reducing the native diversity (Lamsal, *et al.*, 2018). For example, resources availability and the presence of favorable environmental gradients promote the biological invasion in the biodiversity hotspot regions (Adhikari, *et al.*, 2015). Similarly, Pandey and Sharma (2013) also determined that climatic conditions have a significant influence on the success of plant invaders.

The forest lands of the north-eastern region of India are tightly regulated through soil-plants interaction (Ramakrishnan and Kushwaha, 2001). Plant-soil feedback plays a significant role in plant invasion ecology (Fukano, *et al.*, 2013). Due to anthropogenic perturbations, the forests of India’s hotspots are under extreme anthropogenic pressure as explained through a case study on the Niligiri biosphere reserve (Baskaran, *et al.*, 2012) and another case studied by Rai (2012b) in an Indo-Burma hotspot. In Indian

Himalayan Region, comprehensive studies on invasive species are still scanty (Sekar, 2012; Rai and Singh, 2021) as there is less attention and knowledge about their ecological mechanisms.

2.4. Impact of Invasive Alien Plants on Ecological Functioning in Assam

The protected area is the home of wildlife, and the habitat of wildlife is negatively affected by the introduction, establishment, and spread of invasive alien plants (Hiremath and Sundaram, 2013). Assam is the easternmost state in the Indian sub-continent. Pertaining to biodiversity, De and Medhi (2014) determined that Assam is rich in floral diversity with different kinds of rare and endemic plants (epiphytes, ferns, and various angiosperms). Assam is famous for its 50% of India's total tea garden (Sarmah, 2020) and protected areas (Khan, *et al.,* 2017). The Ministry of Environment and Forest, Government of Assam reported that presently there are 7 national parks and 18 wildlife sanctuaries, and the protected area network in Assam, occupying 0.40 million ha which covers about 4.98% of the state's geographical area. Thus, Assam is an important NE state with rich native and endemic biodiversity. The protected areas in Assam are the home of wildlife that is being threatened by the introduction, establishment, and spread of invasive alien plants (Hiremath and Sundaram, 2013).

The massive growth of invasive plants is one of the major challenges faced by forest authorities. In the earlier stage of the growth of the invasive plants, it is easy to eradicate them. However, Invasive Alien Plants are difficult to manage when they cover a wide habitat range. Plant invaders are good competitors to native species in a diverse environment and can adapt better to changing climatic conditions (Bradford, *et al.,* 2007). This property is ascribed to their phenotypic plasticity (Rai and Singh, 2021). The protected areas are vulnerable to changes and invasive species act like drivers of change by changing the ecosystem functions as well as their multiple attributes (Dassonville, *et al.,* 2008; Choudhury, *et al.,* 2017).

Several plant invaders impacted the geographical landscapes of Assam. In this respect, Lahkar, *et al.,* (2011) reported that *M. pudica* is an invasive plant whose introduction in Assam for the first time noticed in the tea gardens as a nutrient-rich crop (for its nitrogen-containing property) which can enhance tea productivity and hence the regional economy. Nevertheless, owing to the rapid colonizing nature, Mimosa infested new habitats and covered the large patches of the tea garden. Also, Mimosa invaded the Rhinoceros habitat of Kaziranga National Park (Vattakkavan, *et al.,* 2002). In Rajiv Gandhi Orang NP Mimosa entered tea gardens and established itself in the grasslands of rhino-bearing parks (Lahkar, 2011). Another study was done by Uma, *et al.*, (2011) on the protected areas and reported that the grassland range of Brahmaputra floodplain, Kaziranga National Park, and Rajiv Gandhi Orang National Park are environmentally important habitats for threatened mega-herbivores and other important fauna of the region. However, Pathak, *et al.,* (2019) also reported that in recent times *L. camara*, *A. conyzoides*, and *P. hysterophorus* are the invasive alien plants that proliferated in these Himalayan regions of extreme relevance to biodiversity and wildlife.

Plant invaders can cause a significant reduction in crop productions. Invasive alien plants like *M. micrantha* are harmful to the tea plantation and other crops in Assam. Also, *M. micrantha* invasion influenced soil N availability and resulted in transformation of lands through allelopathy (Chen, *et al.,* 2009). In this respect, Vijay (2015) worked on the invasive plant *M. micrantha* and noted it as a major threat to native diversity and crops. Herein, the reduction in crop productivity was observed to be in the range of 10-15%, depending upon the intensity of weed growth. Also, *M. micrantha* drastically suppressed the growth of associated plant species, mainly by reducing the availability of light, by rapidly forming a dense cover over the host plants, and simultaneously secreting allelochemicals in their close vicinity (Tripathi, *et al.,* 2012). The invaded area of invasive alien plants reduced the biomass and productivity of the native plants, besides influencing the crops (Teixeira, *et al.,* 2020). The wildlife habitat depends on the native plant species that are adversely affected by the plant invasion (Rai and Singh 2020). Further, the study done by Meyer, *et al.,* (2021) determined that the pressure created by the invasive alien species in the invaded habitats disturbed the biological communities and reduced the biodiversity.

2.5. Impact of Invasive Alien Plants on Ecological Functioning in Hailakandi District

Hailakandi district is situated in the southern part of Assam. Assessment by the Indian State of Forest Report (2017) reported that the total geographical area covered by the forest of the district is 58.25%. Hailakandi district mainly depends upon the agricultural sector for livelihood. The various researchers determined that Invasive Alien Plants can harm the arable agroecosystems. Further, Guillemaud, *et al.,* (2011) determined that agriculture is closely related and impacted by plant invaders. Likewise, the study was done by Mankad, (2016) also reported that invasive alien plants threatened the biosecurity and increased the investment cost of the farmers trying to eradicate the plant invaders. The invasive alien plants affected food security by reducing crop production (Crook, *et al.,* 2011).

Various invasive alien plants affect native species from the cropland to the natural forest. For example, Vijayan and Joy (2019) reported that *M. micrantha* significantly affected the Teak (*Tectona grandis*) plantation and tea plantation sites. In this context, *L. leucocephala* occupied a large area in agricultural and pasture lands (Peng, *et al.,* 2019). Also, Lantana invasion can cause a decrease in the species richness in the forest (Kumar, *et al.,* 2021). The study done by Sakachep and Rai (2021) on the influences of the plant invaders in the Hailakandi district observed that *A. conyzoides, C. odorata, L. camara,* and *M. micrantha* perturb the ecosystem functioning and hence native vegetation.

In recent decades, Hailakandi district experienced an increased depletion of the forest cover due to multiple anthropogenic activities (Sakachep and Rai, 2019). The growing anthropogenic modifications frequently disturbed forest patches, altered natural regimes, and increased the extent of habitat loss or fragmentation (Davies and Pullin, 2007). Further, Rai and Singh (2020) opined that the persistence of invasive species can result in the decline of the local indigenous biodiversity of North East India.

As per the research done on the adaptability of the invasive alien plants, Joshi, *et al.,* (2015) reported that invasive alien plants grow firmly between the tree gaps. The vigorous growth of the invaders then enables them to compete directly with the small plants/ seedlings for resources (e.g., water and soil nutrients) (Buss, *et al.*, 2018). Further, the study was done by Zhang, *et al.*, (2019) revealed that the invasive plants interrupt interactions between soil communities and native plants, consequently driving their success in novel habitats.

Furthermore, the persistent colonies of alien plants perennially alter the structure and function of forest ecosystems by inhibiting the growth and development of native species (Webster, *et al.,* 2006). In forests, invasive species are a serious hindrance to conservation and sustainable use of biodiversity with significant undesirable impacts on the goods and services provide by the ecosystem (Khanduri, *et al.*, 2017). Since Hailakandi district fall in the Indo Burma hotspot region, the ecological investigation is pertinent to identify the invasive alien plants, elucidate their effects, and formulate sustainable strategies for their containment.

CHAPTER 3

METHODOLOGY

3.1 Study Area

Assam is one of the eight north-eastern states of India. Dispur is the capital of Assam. Assam is famous for its tea gardens, silk, protected areas and its location with-in a global Biodiversity Hotspot. The state is situated in the south eastern part of Himalaya's along Brahmaputra (North) and Barak River Valleys (South). Assam covers 78,438km^2 and constitutes 36.11% of total forest area. Assam lies at the Latitude 26º8'52.9548''N and Longitude 91º43'52.9572''E between the foot hills of Eastern Himalayas and Patkai and Naga Hill Ranges (Geology and mineral resources of Assam, 2009). The state shares its borders with Arunachal Pradesh, Nagaland, Manipur, Meghalaya, Mizoram, Tripura, and West Bengal. Bangladesh, Myanmar and Bhutan are the three international borders shares shared by the state. Forest of the state has very diverse encompasses tropical evergreen forest, deciduous forest, broad-leaved hill forest, pine, swamp forest and grassland. Summer starts in the state from March to May and winter starts from November to February. Assam experiences tropical monsoon (southwest monsoon), climate with high humidity and heavy rainfall. Monsoon starts from April to October but heavy rainfall from June to September (Jhajharia, *et al.*, 2012). Rainfall varies from 1600mm to 4300mm and the average rainfall of the state is 2900mm. The average temperature ranges from 4ºC to 37ºC (Geology and mineral resources of Assam, 2009).

Present study was conducted in the Hailakandi district of Assam. It is situated in the southern part of Assam. It lies between 24º.41'4.8840''N Latitude and 92º 33'51.6204''E Longitude and at an elevation of about 680 metres above sea level. The vegetation of the region is diversely spread. It is mostly represented by tropical moist evergreen and tropical moist semi-evergreen forest type (Champion and Seth 1968). The geographical area of Barak valley is 22,244 km^2 and the region harbours major plant diversity of Assam. Since, the geographical area of the Hailakandi district is 1327 km^2, therefore it represents a major fraction of plant diversity lying in the Barak valley of Assam. Inner Line Reserve Forest and the Katakhal Reserve Forest are the two reserve forests in the district. The percentage of the forest cover to geographical area (includes very dense, moderately dense, and the open forest) of the district as per the Indian State of Forest Report (ISFR) year -2011, 2013, 2015, 2017 and 2019 are 59.23%, 59.46%, 59.28, 58.25% and 58.35%, respectively and it consists of both plain and hilly areas. The district has got inter-district border with Mizoram in its southern side and on the other sides with the two other district of Barak Valley, namely Karimganj and Cachar. The tributary of Barak is flowing in this district. The district accounts an average rainfall of 2993 mm/year (Ministry of water resource, Guwahati, 2013). The temperature of this area varies from a maximum of 32˚C and minimum of 15˚C respectively (Mazumder and Gupta, 2013). The district, rainfall controlled by southwest monsoon. The climatic condition of the district is subtropical, warm and highly humid.

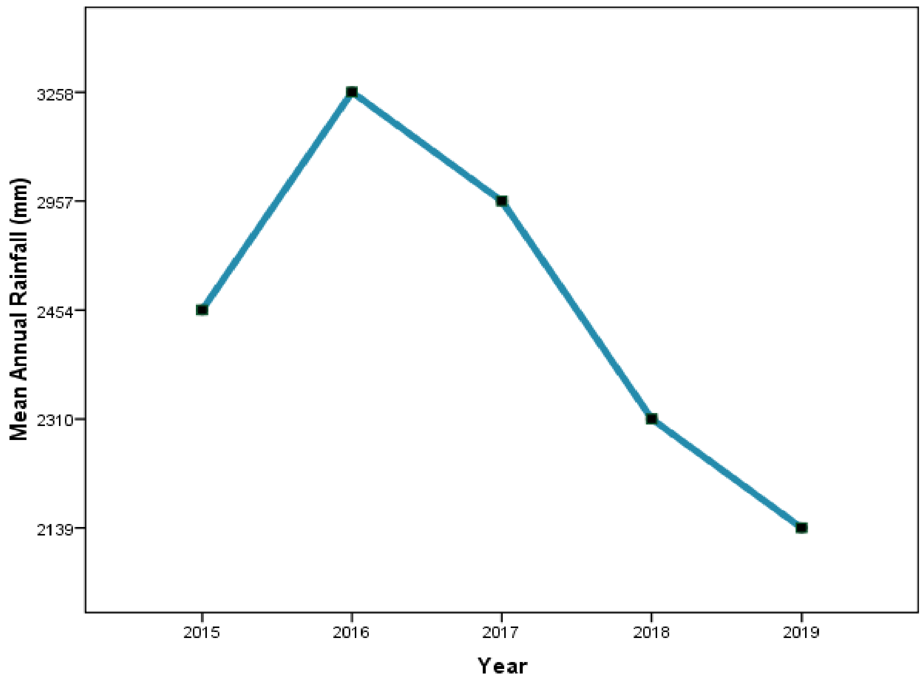


Figure 1. Rainfall data of Hailakandi district from 2015 to 2019.

(***Sources*:** Office of the Executive Engineer water resources (investigation) Hailakandi sub-division and Office of the Executive Engineer water resources (investigation) Badarpur division, Assam, India).

3.2 Description of Study

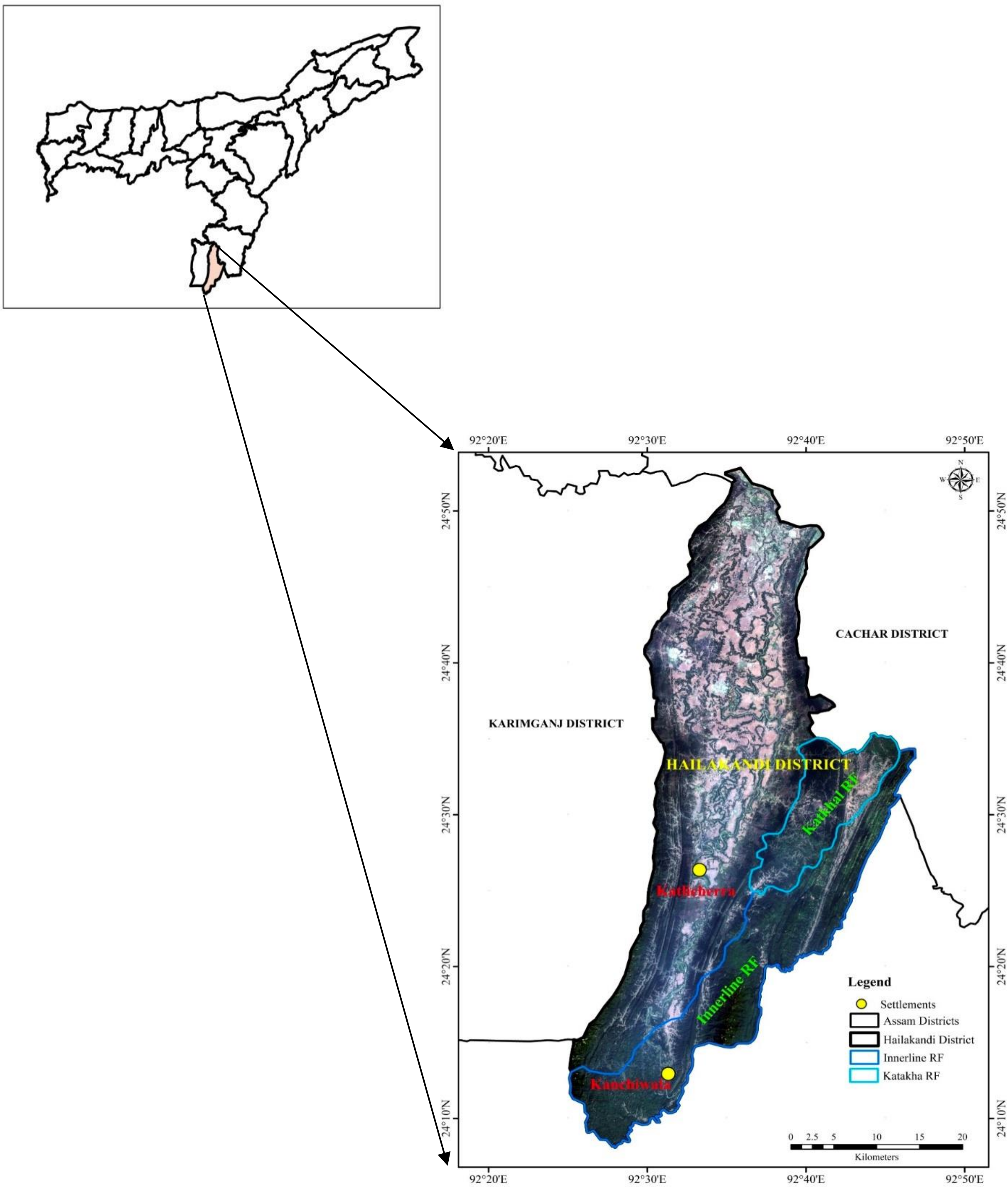
The site selection for the present study was based on the disturbance gradient as per Sagar *et al.,* (2003). Accordingly, the gradients were delineated as disturbed (i.e., invaded) and the moderately disturbed site (i.e., non-invaded) in the district of Hailakandi, Assam. The distance between the two-study site was 48km which was adequate enough to compare the result in view of similar edapho-climatic conditions.

3.2.1. Site-I

Katlicherra (Site-I) lies between Latitude is 24º 28’3.9216’’N and the longitude is 92º 31’25.7724’’E. Katlicherra was identified and selected as the disturbed/invaded site with the luxuriant growth of alien plants/or weeds near by the agricultural field, railway lines, and the roadside.

3.2.2. Site-II

Kanchiwala (Site-II) lies between Latitude is 24º 13’15’’N and 92º31’15’’E Longitude and comes under Inner Line Reserve Forest. Kanchiwala was the hillock, moderately disturbed or non-invaded areas.



Map 3.1. Map showing the study sites.

3.3 METHODS

The present work has been done from August 2016 to July 2018.

3.3.1 Analytical Methods Pertaining to Biodiversity and Phyto-sociology

The vegetation has been analyzed by means of random sampling to give most representative composition of both invaded and noninvaded vegetation sites. The applied indices to be as follow:

a). **Shannon diversity index (Shannon, 1949)**

$$H' = \sum_{i=1}^{s} \left(\frac{n_i}{N}\right) \ln \left(\frac{n_i}{N}\right)$$

b). **Evenness index (Pielou's index, 1975)**

$$E = \frac{H'}{\ln S}$$

c). **Margalef's index of species richness (Margalef, 1958)**

$$R = \frac{(S-1)}{\ln N}$$

d). **Simpson's index of dominance (Simpson, 1949)**

$$D = \sum \frac{ni(ni-1)}{N(N-1)}$$

Where,

S= Total number of species

N= total number of individuals of all the species, and

n_i=number of individuals of the i^{th} species.

e). **Sorensen' Similarity Index (Sorensen, 1948)**

$$\beta = \frac{2c}{S_1 + S_2}$$

Where,

S_1= number of species in community 1,

S_2= number of species in community 2 and

c = number of species common to both communities.

3.3.2. Quantitative or Phyto-sociological Analysis

The phytosociological study has been analyses on herb (1x1m), Shrub (5x5m)

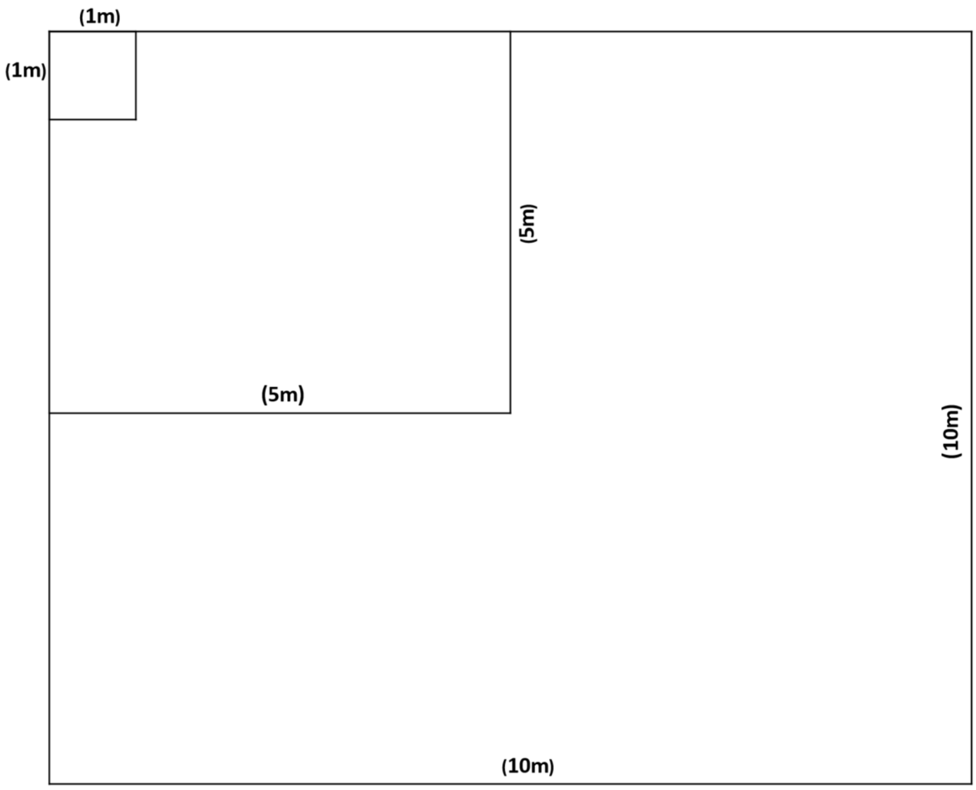


Figure 2. Structure of Quadrat study

and Tree (10x10m) for density, frequency, abundance, relative density relative frequency, relative abundance and important value index by using following formulas:

a) Density

Density is the total number of individuals of each species in all the quadrats divided by the total number of quadrats studied.

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

b) Basal Area (BA)

$$\text{BA} = \pi r^2$$

Where,

$\pi = 3.142$

r = ((Diameter of the Breast Height(m))/2) ^{2}

c) Frequency (%)

The frequency is the degree of dispersion of individual species in an area and usually expressed in terms of the percentage occurrences.

$$\text{Frequency}(\%) = \frac{\text{Number of quadrat in which species occured}}{\text{Total number of quadrat studied}}$$

d) Abundance

It is the study of the number of individuals of different species in the community per unit area. The number of individuals of each species was summed up for all the quadrats divided by the total number of quadrats in which the species occurred.

$$\text{Abundance} = \frac{\text{Total number of individual of a species in all quadrat}}{\text{Total number of quadrat in which the species occured}}$$

e) Relative Density (RD)

RD is the study of numerical strength of the species in relation to the total number of individuals of all the species and calculated as:

$$\text{RD} = \frac{\text{Number of individual of the species}}{\text{Number of individuals of all the quadrat}} \times 100$$

f) Relative Frequency (RF)

RF represents the degree of dispersion of individual species in an area in relation to the number of all the species occurred.

$$\text{RF} = \frac{\text{Number of quadrat in which species occured}}{\text{Total number of individual of all the species}} \times 100$$

g) Relative Abundance (RA)

The RA was determined by the total number of individuals of the species divided by the number of quadrats in which they occur.

$$\text{RA} = \frac{\text{Total number of individual of the species}}{\text{Number of quadrat in which the species occured}}$$

h) Important Value Index (IVI)

IVI expresses the dominance and ecological succession of any species. Species IVI computed by adding the figures of relative density, relative frequency and relative dominance for that species.

$$\text{IVI} = \text{RD} + \text{RF} + \text{RA}$$

3.3.3. Soil Analysis

Collection of Soil Samples

Soil samples from the selected study sites (i.e., disturbed and moderately disturbed sites) was collected in seasonal interval *i.e.*, Pre-Monsoon (February to April), Monsoon (May to September), and Post-Monsoon (October to January) and analyses of the various soil physico-chemical parameters were performed in Environmental science laboratory, Mizoram University.

a) Soil Temperature (°C)

The ground surface has been cleared to remove litter/fallen leaves and other unwanted materials. The iron tip of the digital soil thermometer is inserted into the soil vertically. The reading taken soon after fluctuation is rested.

b) Bulk Density (BD)

The BD was determined by Blake and Hartge (1986). The ground soil was drawn with the help of soil corer. Then soil sample was to be oven dry for one night and weight of the dried soil be recorded and calculated from the following formula:

$$\text{BD}(\text{g/cm}^3) = \frac{\text{Weight of oven dried soil(g)}}{\text{Volume of soil core (g/cm}^3)}$$

Where,

Volume of soil core = 3.14. r^2.h

r = inside radius of cylinder (cm)

h = height of cylinder (cm).

c) Porosity (%)

Porosity is the pore space in the soil which is occupied by the air and water. It influences the percolation and distribution of water in the roots. The porosity of the soil has been calculated by the following formula:

$$\text{Soil Porosity (\%)} = 100\% - \frac{\text{Bulk density (g/cm}^3)}{\text{Particle density (g/cm}^3)} \text{ X100}$$

Where,

Particle density= 2.65 (g/cm^3)

d) Water Holding Capacity (WHC)

The weight of the keen box and the filter paper that place in the bottom of the keen box was recorded (W_1). Then the air-dried soil sample was transferred to the keen box and the weighted again (W_2). The keen box was placed in the Petri dish containing water and allowed to saturate for 24 hrs. The box was taken out from the Petri dish, whipped and recorded the wetted weight of the keen box (W_3). WHC have been calculated by using the following formula:

$$\text{WHC (\%)} = \frac{(W_3 - W_2)}{(W_2 - W_1)} \times 100$$

Where,

W_1 =Weight of box + filter paper (dried)

W_2 =Weight of box + filter paper (wetted)

(W_2 – W_1) = Weight of the Soil

W_3= Weight of keen box after overnight water absorbed

e) Soil Moisture Content (SMC)

10g weighted of freshly collected soil sample was collected in the petri-plate and kept in the oven at 105ºC for 24 hours and re-weigh the oven dried soil sample with the help of digital balance. Soil moisture content has been calculated by using the following formula:

$$\text{SMC (\%)} = \frac{W_1 - W_2}{W_2}$$

Where,

W_1 = Weight of moist soil (g).

W_2 = Weight of Oven dried soil (g).

f) pH

20 g freshly collected soil sample taken in a beaker containing 50 ml of distilled water. The soil-water mixture was stirred for 30 minutes with the help of magnetic stirrer. The solution was kept overnight and pH reading of the supernatant liquid recorded with the help of digital pH meter (Sahlemedhin and Taye, 2000).

g) Soil Organic Carbon (SOC)

SOC estimated by Walkley and Black's Rapid Dichromate Oxidation Method (1934). 0.5g oven dried 0.2mm sieved soil was taken into the 500 ml dry conical flask. 10ml of potassium dichromate was added and swirled to mix them and then 20ml of concentrated sulphuric acid was added and swirled for 2-3 times and the flash is allowed to stand for 30 minutes to cool. 200ml of distilled water followed by 10ml of orthophosphoric acid and 1ml of indicator solution was added and mixed thoroughly. Then the content was titrated with ferrous ammonium sulphate solution till the colour flashes from blue-violet to green. Simultaneously blank is run without soil.

$$\mathrm{SOC}\ (\%) = \frac{10(\mathrm{B} - \mathrm{T})}{\mathrm{B}} \times 0.003 \times \frac{100}{\mathrm{S}}$$

Where,

B=Volume of ferrous ammonium sulphate solution required for black titration in ml.

T=Volume of ferrous ammonium sulphate solution needed for soil sample in ml.

S= Weight of the soil in gram.

h) Soil Organic Matter (SOM)

The soil organic matter is estimated by Van Bemmelem factor of 1.724. The soil organic matter (%) calculated by using the following formula:

$$\text{SOM}\ (\%) = \text{Soil Organic Carbon X } 1.724$$

i) Total Nitrogen (N)

The mineralizable nitrogen which is very important for the plant is available in the soil. Kjeldahl method (Bremner and Mulvaney, 1990) was used and Wet-digestion, distillation and titration were the steps involved to determine the TN.

Wet-digestion: 5g of soil sample was transferred to the digestion tube. 5g of digestion mixture and 20ml of concentrated Sulphuric acid (H_2S0_4) was added to it. Then the digestion tube was heater for 1hour to 410ºC till the sample colour turn into colourless or light green in colour. 10ml of distilled water was added and it was shaken well. The sample was then transferred to 250ml of volumetric flask. 40ml of 40% sodium hydroxide (NaOH) and 20ml of Boric acid (H_3BO_3) in Erlenmeyer flask, and few drops of indicators Methyl Red and Bromocresol Green was added.

Distillation: The flask was placed in the receiver end then distillation process was run for 6min.

Titration: The H_3BO_3 containing flask was titrated against 0.1 N Hydrochloric acid (HCl) orH_2S0_4 till the solution turns into pink colour. The Burette reading was recorded. The percentage of the TN was calculated with the help of the following formula:

$$\text{TN}(\%) = \frac{(\text{T}_1 - \text{T}_2)\ \times \text{N} \times\ 1.4}{\text{W}}$$

Where,

T_1= Volume of titrant used against sample (ml)

T_2= Volume of titrant used against distilled water (Blank) (ml)

N = Normality of titrant (0.01 N HCl)

W = Weight of soil/ spoils (g)

j) Carbon:Nitrogen Ratio (C:N Ratio)

The C:N Ratio was calculated by the following equation:

$$\text{C: N Ratio (\%)} = \frac{\text{SOC}}{\text{TN}}$$

k) Available Phosphorus (P)

2.5g of the soil sample treated with 25ml of Bray and Kurtz no.1 extract in the conical flask. A pinch of activated charcoal was added, the suspension was shaken for 5min and then filtration of the solution through Whatman filter paper No. 42. Secondly 5ml of an aliquot extract was taken in 25ml of volumetric flask. 3 drops of p-nitrophenol indicator, 3-5 drops of 0.5M sodium bicarbonate was added. With 2.5 M H_2SO_4 acidification was done with each sample then the solution was diluted with distilled water up to the mark. Blank was run without soil. Then absorbance of blanks, standards, and the samples was readied after 10min on the spectrometer. The method that use to analyzed the available Phosphorus was done by Bray and Kurtz (1945) by using the following formula:

$$\text{AP(kg/ha)} = \text{R x} \frac{50}{5} \text{x} \frac{1}{5} \text{x } 2.24$$

$$= \mu\text{g of p x } 4.48$$

Where,

R= µg of Phosphorus in aliquot (obtained from standard curve).

l) Available Potassium (AK)

The AK is the major sources for the plants. 5g of soil has been treated with 25ml of 1N neutral ammonium acetate solution in the conical flask. Then the conical flask was shaken for 30mins on the mechanical shaker and the soil solution was filtered through Whatman No. 42. The availability of K in soil has been analyzed by the Flame photometer (Jackson, 1973) method by the following formula:

$$\text{AK(kg/ha)} = \text{R x} \frac{\text{V}}{\text{W}} \text{x} \frac{224 \text{ x } 10^6}{10^6}$$

Where,

R = ppm of K in the extract

V = Volume of the soil extract in ml

W= Weight of air-dry samples taken for extraction in g.

3.3.4. Statistical Analysis

The statistical analysis was performed by using the software SPSS (16.0.) for the variance of (ANOVA) and Pearson’s correlation and MS excel.

CHAPTER 4

RESULT AND DISCUSSION

Floristic Diversity

The floristic diversity of Hailakandi district is rich and comprised of diverse forest types, attributed to distinct environmental attributes such as rainfall variations with warm and humid temperatures. However, the forest of this district in Assam underwent tremendous changes over a while due to the land-use change in view of commercial encroachment and other socio-economic demands like the requirement of timbers. The increasing demand for timbers was observed as one of the main reasons for the degradation of the forest resources in Inner Line Reserve Forest (ILRF) (Dattagupta and Gupta, 2013). **Figure 4** represents the percentage of the species composition of both the sites and **Figure 3** which shows the comparison of Katlicherra (invaded site) and Kanchiwala (non-invaded site). The diversity indices (**Table 4**) and the phyto-sociological study of the herbaceous layer (**Table 7, Table 10**, and **Table 13)** in the present study are shown in this chapter.

4.2 Composition of the species

Herbs

A total of 39 herbs species were encountered at both the sites which belonged to 34 genera and 23 families. From the study, Asteraceae was the most dominant family recorded at both the study sites. This observation was in corroboration with Srivastava *et. al.,* (2014) that Family Asteraceae is comprised of dominant weeds with a higher reproductive potential, as compared to the other families. Kumar and Bihari (2015) reported Asteraceae as a phytosociologically dominant family with the representation of 19.23% in Dhenkanal of Odisha, India. Likewise, Sheikh and Dixit, (2017) also reported that the Asteraceae family was more invasive than the other families in the other part of India.

Further, species composition based on a percentage (%) demonstrated that the herbs (38%) layer was the most dominant among the investigated layers. A similar result was reported by the various workers in their specific study sites (Srivastava, *et al.*, 2014). For example, Mallick, *et al.*, (2019) in the urban area of India and Srivastava, *et al.*, (2014) in north-east Uttar Pradesh, Kumar, *et al.*, (2018) in Odisha noted the dominance of herbaceous layer during vegetation analysis. It is in view of fact that herbs have more tolerance to harsh conditions and have great viability to grow in any condition which helps to become more invasive than shrub and tree layers (Srivastava, *et al.*, 2014).

M. micrantha was noted as a common climber, encountered at both the study sites particularly at Katlicherra (invaded site). Accordingly, Mikania invasion caused destruction in the different protected areas of Assam and resulted in the transformation and the eradication of the native plants (Gogoi, 2001; Sankaran and Srinivasan, 2001). Biodiversity reduction by *M. micrantha* invasion which ranges from the agricultural land to the forest land in Western Ghat was reported owing to their tremendous spread in view of climber habit (Kaur, *et al.*, 2011). It works as a suppressor to the crops and nearby native plants as determined by the various studies (Huang, *et al.*, 2009; Vijayan and Joy, 2019).

Shrubs

A total of 30 shrubs species were recorded from both the study sites that belonged to 25 genera and 18 families. Concerning shrubs layer, Solanaceae (4) and Malvaceae (4) were the dominant families at Katlicherra (invaded site) and Kanchiwala (non-invaded site). Family Solanaceae is well known for its long fruiting period, which further creates biological invasions in the selected habitat. In this context, Sood, *et al.*, (2011), determined that plants of Solanaceae like *Datura innoxia* have serious threats by suppression to sapling growth of nearby native or endemic vegetation.

Tree

From both the sites, a total of 33 tree species belonging to 28 Genera and 16 families were recorded. In this respect, Fabaceae was observed to be the most dominant family at Katlicherra (invaded site) with 5 genera and 5 species. However, the Moraceae family was the most dominant recorded at Kanchiwala (non-invaded site) with 2 genera and 5 species. On the other hand, the species composition in the tree layer was 32% of the total as reflected in **Figure 4**. Further, **Figure 3** indicates that at Kanchiwala, the heterogeneity was more pronounced compared to site Katlicherra i.e., a higher number of the tree species.

Table 1. Species composition in different layers in the study sites.

Individuals	Number of the Families	Number of the Genera	Number of the Species
Herbs	24	36	39
Shrubs	18	25	30
Trees	16	28	33

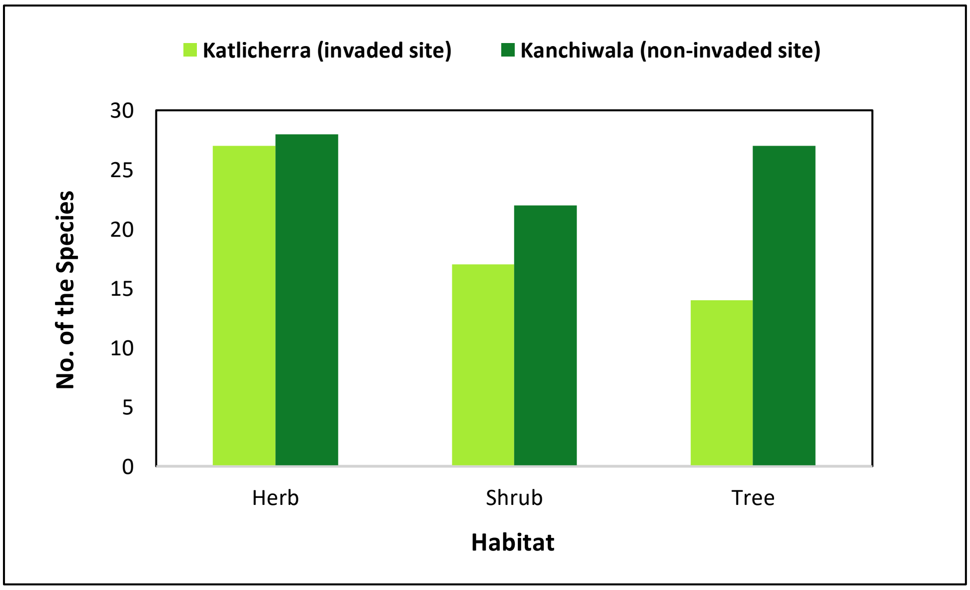


Figure 3. Comparison of species composition

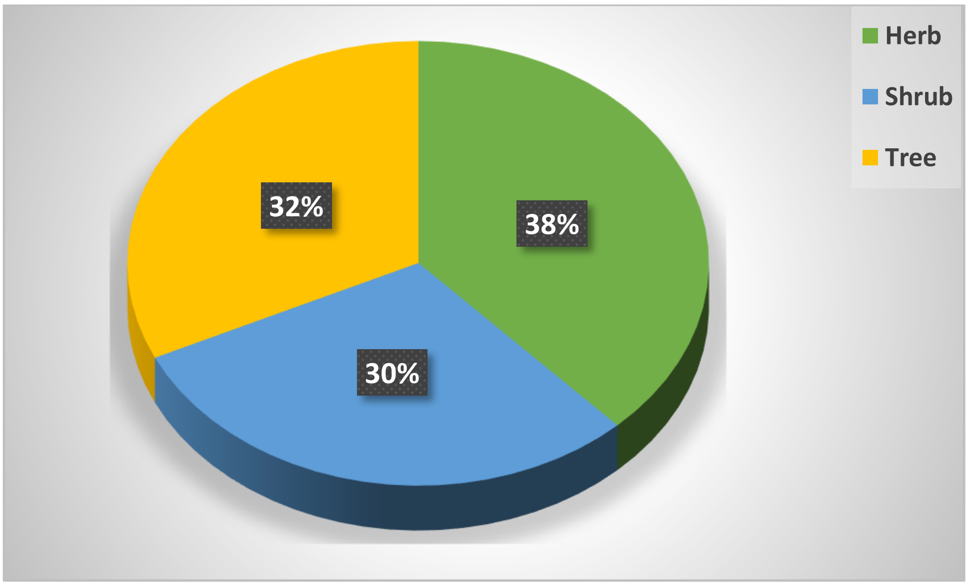


Figure 4. Species Composition in percentage

Table 2. Predominant families and their species composition of the study sites

Sl. No.	Family	Species
1	Asteraceae	9
2	Lamiaceae	9
3	Fabaceae	6
4	Caesalpiniaceae	6
5	Euphorbiaceae	6
6	Malvaceae	6
7	Rubiaceae	5
8	Moraceae	5
9	Solanaceae	5

Origin of the species diversity

The maximum invasive alien plants (herb) species encountered in the present study were native to the American continent. Accordingly, Lowe, *et al.*, (2000) reported in their study that the majority of invasive alien plants in India belonged to the American continent. A similar observation was reported by Singh, *et al.*, (2010) in Utter Pradesh; Sekar, (2012) in the Indian Himalayan region, Debnath and Debnath, (2017) in the northeastern hilly state of Tripura, and Sakachep and Rai (2021) in Hailakandi district, Assam. However, on the other hand, shrubs and trees recorded in the present study mostly belonged to Asian Continents in relation to origin (**Table 3**). The origins and habitats of the recorded species were identified from the various available works in existing literature (Matthew, 1969; Saxena, 1991; Mooney and Hobbs, 2000; Pandey, 2000; Rao and Murugan, 2006; Sekar, 2012; Debnath, *et al.*, 2015; Srivastava, *et al.*, 2014; Wagh and Jain, 2015; Debnath and Debnath, 2017; Singh and Kumari, 2017; Singh and Kumari, 2019; Sarma, *et al*., 2019; Bagum and Kiran, 2020; Sakachep and Rai, 2021).

Table 3. List of the plant species in the study sites along with their family, origin, and habitat.

Sl. No.	Name of the Species	Family	Origin	Habitat
1	*Acanthospermum hispidum* DC.	Asteraceae	Brazil	Herb
2	*Achyranthes aspera* L.	Amaranthaceae	Australia	Herb
3	*Ageratum conyzoides* L.	Asteraceae	Tropical America	Herb
4	*Albizia procera* (Roxb.) Benth.	Fabaceae	Southeast Asia and India	Tree
5	*Alstonia scholaris* (L.) R. Br.	Apocynaceae	Southern China, TropicalAsia, Australia	Tree
6	*Alternanthera paronychioides* St. -Hill.	Amaranthaceae	Tropical America	Herb
7	*Amaranthus viridis* L.	Amaranthaceae	Tropical America	Herb
8	*Anisomeles indica* (L.) Kuntze	Lamiaceae	-	Herb
9	*Antidesma acidum* Retz.	Phyllanthaceae	Indian Subcontinent to South- Central	Shrub

			China and Indo-China, Java	
10	*Begonia hatacoa* Buch. – Ham.ex D.Don	Begoniaceae	Nepal	Herb
11	*Neolamarckia cadamba* (Roxb.) Bosser	Rubiaceae	-	Tree
12	*Artocarpus lakoocha* Buch. -Ham.	Moraceae	Indian subcontinent and SE Asia	Tree
13	*Blumea lacera* (Burm.f.) DC.	Asteraceae	Tropical America	Herb
14	*Bridelia stipularis* (L.) Blume	Phyllanthaceae	-	Shrub
15	*Calotropis gigantean* (L.) W. T. Aiton	Asclepiadaceae	Tropical Africa	Shrub
16	*Cassia alata* L.	Caesalpiniaceae	West Indies	Shrub
17	*Cassia floribunda* (Cav.) H.S. Irwin & Barneby	Caesalpiniaceae	-	Shrub
18	*Cassia hirsuta* (L.) H.S.Irwin & Barneby	Caesalpiniaceae	Tropical America	Herb
19	*Cassia occidentalis* L.	Caesalpiniaceae	Tropical South Africa	Herb
20	*Cassia sophera* L.	Caesalpiniaceae	Tropical America	Shrub
21	*Cassia tora* L.	Caesalpiniaceae	Tropical South Africa	Herb
22	*Chassalia curviflora* (Wallich) Thwaites	Rubiaceae	Southeast Asia	Shrub
23	*Chloris barbata* Sw.	Poaceae	Tropical America	Herb
24	*Chromolaena odorata* (L.) R.M. King & H.Rob	Asteraceae	Tropical America	Shrub
25	*Chukrasia tabularis* A.Juss.	Meliaceae	Tropical Asia	Tree
26	*Cleome gynandra* L.	Cleomaceae	Tropical America	Herb
27	*Cleome rutidosperma* DC.	Cleomaceae	Tropical Africa	Herb
28	*Clerodendrum glandulosum* Lindl.	Lamiaceae	India	Shrub
29	*Clerodendrum infortunatum* L.	Lamiaceae	Tropical Asia	Shrub
30	*Clidemia hirta* (L.) D. Don	Melastomataceae	Southern America	Shrub
31	*Corchorus tridens* L.	Tiliaceae	Tropical Africa	Herb
32	*Cordia myxa L.*	Boraginaceae	Eastern Mediterranean Region to Eastern India	Tree

33	*Crassocephalum crepidioides* (Benth.) S. Moore	Asteraceae	Tropical America	Herb
34	*Crotalaria pallida* Ait.	Fabaceae	Colombia, Mexico, Panama	Herb
35	*Commelina erecta L.*	Commelinaceae	Tropical Africa, Indian Subcontinent to southern China, Peninsular Malaysia.	Herb
36	*Cyperus rotundus* L.	Cyperaceae	Eurasia	Herb
37	*Datura innoxia* Mill.	Solanaceae	Tropical America	Shrub
38	*Datura metel* L.	Solanaceae	Tropical America	Shrub
39	*Debregeasia longifolia* (Burm.f.) Wedd.	Urticaceae	China to Tropical Asia, Vanuatu	Shrub
40	*Delonix regia* (Boj. Ec Hook.) Raf	Fabaceae	Madagascar	Tree
41	*Dioscorea sativa* L.	Dioscoreaceae	-	Shrub
42	*Dipterocarpus turbinatus* C.F. Gaertn	Dipterocarpaceae	North-eastern India, mainland Southeast Asia	Tree
43	*Duabanga grandiflora* (Roxb. ex DC.) Walp.	Lythraceae	Asia, Oceania	Tree
44	*Dysoxylum binectariferum* Hiern.	Meliaceae	-	Tree
45	*Eclipta prostrata* (L.) L.	Asteraceae	Tropical America	Herb
46	*Euphorbia hirta* L.	Euphorbiaceae	India	Herb
47	*Ficus auriculata* Lour.	Moraceae	India, Bhutan, Nepal, Myanmar, Thailand, Vietnam, South China	Tree
48	*Ficus racemosa* L.	Moraceae	Australia, Tropical Asia	Tree
49	*Ficus religiosa* (L.)	Moraceae	Indian subcontinent, Indo- China	Tree
50	*Ficus variegata* (Blume)	Moraceae	India, Southern China, Indonesia, Malaysia	Tree
51	*Gmelina arborea* Roxb.	Lamiaceae	India, Sri Lanka, Myanmar.	Tree
52	*Grewia abutilifolia* W. Vent ex Juss.	Malvaceae	Tropical and Subtropical Asia	Shrub

53	*Grewia asiatica* L.	Malvaceae	China, South-East Asia	Shrub
54	*Imperata cylindrica* (L.) Raeusch.	Poaceae	Asia	Herb
55	*Ipomoea carnea* Jacq.	Convolvulaceae	Tropical America	Shrub
56	*Ipomoea hederifolia* L.	Convolvulaceae	Tropical America	Herb
57	*Justicia adhatoda* L.	Acanthaceae	Asia	Shrub
58	*Lantana camara* L.	Verbenaceae	Tropical America	Shrub
59	*Laportea bulbifera* (Siebold & Zucc.) Wedd.	Urticaceae	Russian Far East to Tropical Asia	Herb
60	*Leucaena leucocephala* (Lam.) de Wit	Fabaceae	Central America	Tree
61	*Leucas aspera* (Willd.) Link	Lamiaceae	India	Herb
62	*Lindernia ruellioides* (Colsm.) Pennell	Linderniaceae	Tropical Asia	Herb
63	*Litsea glutinosa* (Lour.) C.B.Rob.	Lauraceae	India, Southern China, Malaysia, Australia, Western Pacific Islands	Tree
64	*Macaranga denticulate* (Blume) Müll.Arg.	Euphorbiaceae	Southern China to Tropical Asia	Tree
65	*Macaranga peltata* (Roxb.) Müll.Arg.	Euphorbiaceae	India, Sri Lanka, West Indo- China	Tree
66	*Maesa ramentacea* (Roxb.) A.DC.	Primulaceae	China to Tropical Asia.	Tree
67	*Mallotus paniculatus* (Lam.) Müll.Arg.	Euphorbiaceae	Tropical and Subtropical Asia to North and Northeastern Queensland	Tree
68	*Mallotus roxburghianu* Müll.Arg.	Euphorbiaceae	Nepal to China, Myanmar	Tree
69	*Mangifera indica* L.	Anacardiaceae	Indo-Burma	Tree
70	*Melastoma malabathricum* L.	Melastomataceae	Asia, Australia	Shrub
71	*Microcos paniculata* L.	Malvaceae	Tropical and South Africa to India	Shrub
72	*Mikania micrantha* Kunth	Asteraceae	Tropical America	Climber
73	*Mimosa pudica* L.	Mimosaceae	Brazil	Herb
74	*Morinda angustifolia* Roxb.	Rubiaceae	Tropical and Subtropical Asia to North Australia.	Shrub

75	*Mussaenda roxburghii* Hook.f.	Rubiaceae	Central Himalaya to North Myanmar	Shrub
76	*Oroxylum indicum* (L.) Benth. ex Kurz	Bignoniaceae	Indian Subcontinent	Tree
77	*Oxalis corniculata* L.	Oxalidaceae	Europe	Herb
78	*Parthenium hysterophorus* L.	Asteraceae	Tropical America	Herb
79	*Peltophorum pterocarpum* (DC.) K.Heyne	Fabaceae	Southeastern Asia	Tree
80	*Premna barbata* Wall.ex Schauer	Lamiaceae	Pakistan to Myanmar	Shrub
81	*Premna bengalensis* C.B.Clarke	Lamiaceae	Indian Subcontinent to Indo-China	Tree
82	*Phyllanthus urinaria* L.	Phyllanthaceae	-	Herb
83	*Polygonum barbatum* L.	Polygonaceae	India	Herb
84	*Pterygota alata* (Roxb.) R. Br.	Malvaceae	India	Tree
85	*Rauvolfia serpentina* (L.) Benth. ex Kurz	Apocynaceae	Indo / Java	Shrub
86	*Ricinus communis* L.	Euphorbiaceae	South America	Shrub
87	*Sarcochlamys pulcherrima* (Roxb.) Gaud.	Urticaceae	-	Shrub
88	*Scoparia dulcis* L.	Scrophulariaceae	Tropical America	Herb
89	*Senna siamea* (Lam.) Irwin et Barneby	Fabaceae	South and Southeast Asia	Tree
90	*Solanum anguivi* L.	Solanaceae	Northeaster Africa and Middle East	Shrub
91	*Solanum nigrum* L.	Solanaceae	Eurasia	Herb
92	*Solanum torvum* Sw.	Solanaceae	Eurasia	Shrub
93	*Spermacoce ocymoides* Burm.f.	Rubiaceae	-	Herb
94	*Sterculia foetida* L.	Malvaceae	East Africa and North Australia	Tree
95	*Synedrella nodiflora* (L.) Gaertner	Asteraceae	West Indies	Herb
96	*Syzygium jambolanum* (L.) Skeels.	Mrytaceae	Indian Subcontinent	Tree
97	*Tectona grandis* L.f.	Lamiaceae	South and Southeast Asia	Tree
98	*Toona ciliata* M. Roem.	Meliaceae	Tropical Asia, Tropical Australia	Tree

99	*Torenia violacea* (Azaola ex Blanco) Pennell	Linderniaceae	Tropics and Subtropics	Herb
100	*Triumfetta rhomboidea* Jacq.	Tiliaceae	Tropical America	Herb
101	*Urena lobata* L.	Malvaceae	West Indies	Shrub
102	*Vitex pubescens* L.	Lamiaceae	South and Southeast Asia	Tree

4.3. Diversity Indices

In the herbaceous layer, high diversity of invasive alien plants was recorded at Katlicherra (invaded site) where *A. conyzoides* (H'=0.30, E=0.056, DMg=6.680, D= 0.028) followed by *M. micrantha* were dominant and co-dominant plant invaders, respectively. Whereas, at Kanchiwala (non-invaded site), *Triumfetta rhomboidea* was recorded with the highest diversity indices (H'=0.20, E=0.038, DMg=2.668, D=0.006) (**Table 4**). In general, the invasive alien plants grow more vigorously at the invaded area, resulting in a decrease in the diversity of nearby plants and reduced crop production.

In the Shrubs layer, *C. odorata* (H'=0.336, E=0.076, DMg=8.132, D=0.107) followed by *L. camara* (H'=0.259, E=0.054, DMg=2.919, D=0.014) were observed with the highest diversity indices recorded at Katlicherra (invaded) site. Whereas, *L. camara* and *U. lobata* (H'=0.220, E=0.045, DMg=2.260, D= 0.009) were planted invaders with the highest diversity indices recorded in the shrub layer at Kanchiwala (non-invaded site) (**Table 5**). Some invasive alien plants like *C. odorata, U. lobata, and L. camara* were therefore well distributed at both the study site. Interestingly, Choudhury, *et al.,* (2017) in their study confirmed that some invasive alien plants can grow in various habitats from plains to hills and the growth and distribution of these invasive alien plants threaten or inhibits the native plants diversity (Dogra, *et al.*, 2010). Wang, *et al.,* (2017) reported that the out from the native range alien plants promotes the dominance of the clonal plants and decreases the evenness of communities in the heterogeneous habitat.

U. lobata is a noxious invasive alien plant, invasive weed, and very difficult to control (Awan, *et al.*, 2014). Biological invasion in any habitation with extensive growth becomes a reason for the loss of native plants. Accordingly, Dogra, *et al.,* (2009) reported that more than 47% of the native species were lost due *L. camara* invasion.

The diversity indices calculated in relation to trees layer are shown in **Table 6** which indicated that at Katlicherra (invaded site) alien plant i.e., *L. leucocephala* (H'=0.333, E=0.078, DMg=3.496, D=0.046) was noted with higher diversity indices value followed by *Oroxylum indicum* (H'=0.307, E= 0.072, DMg=2.797, D=0.030). Thus, *L. leucocephala* and *O. indicum* were recorded the highest diversity indices, at Katlicherra (invaded site). While at Kanchiwala (non-invaded site) *Toona ciliata* (H'=0.191, E= 0.042, DMg=1.315, D=0.005) was observed with the highest diversity indices followed by *Dipterocarpus turbinatus, L. leucocephala,* and *Tectona grandis* (**Table 6**).

Layer wise Sorenson's Similarity Index during present vegetation analysis showed that the herbs at Katlicherra (invaded site) and Kanchiwala (non-invaded site) were about 0.60 similar followed by shrubs, and trees with computed similarity of 0.46, and 0.35, respectively.

Table 4. Diversity indices in the herbaceous layer of the study sites.

	Biodiversity Indices	Shannon Weiner Index (H’)		Evenness Index (E)		Species Richness (DMg)		Simpson Index of Dominance (D)	
Sl. No.	SITES / SPECIES	Katlicherra (Invaded site)	Kanchiwala (Non-invaded site)	Katlicherra (Invaded site)	Kanchiwala (Non-invaded site)	Katlicherra (Invaded site)	Kanchiwala (Non-invaded site)	Katlicherra (Invaded site)	Kanchiwala (Non-invaded site)
1	*Acanthospermum hispidum* DC.	0.168	0.109	0.031	0.021	2.227	0.953	0.003	0.001
2	*Achyranthes aspera* L.	0.025	0.133	0.005	0.025	0	1.334	0	0.002
3	*Ageratum conyzoides* L.	0.300	0.184	0.056	0.035	6.680	2.287	0.028	0.004
4	*Alternanthera paronychioides* St. -Hill.	0.043	-	0.008	-	0.186	-	0	-
5	*Amaranthus viridis* L.	0.043	-	0.008	-	0.186	-	0	-
6	*Anisomeles indica* (L.) Kuntze	-	0.133	-	0.025	-	1.334	-	0.002
7	*Begonia hatacoa* Buch. -Ham. ex D.Don	-	0.109	-	0.021	-	0.953	-	0.001
8	*Blumea lacera* (Burm.f.) DC.	0.141	0.066	0.026	0.012	1.670	0.381	0.002	0
9	*Cassia hirsuta* (L.) H.S.Irwin & Barneby	-	0.122	-	0.023	-	1.144	-	0.001
10	*Cassia occidentalis* L.	0.086	0.096	0.016	0.018	0.742	0.762	0	0.001

11	*Cassia tora* L.	0.043	0.144	0.008	0.027	0.186	1.525	0	0.002
12	*Chloris barbata* Sw.	0.059	-	0.011	-	0.371	-	0	-
13	*Cleome gynandra* L.	0.110	-	0.020	-	1.113	-	0.001	-
14	*Cleome rutidosperma* DC.	-	0.122	-	0.023	-	1.144	-	0.001
15	*Corchorus tridens* L.	-	0.144	-	0.027	-	1.525	-	0.002
16	*Crassocephalum crepidioides* (Benth.) S. Moore	0.059	0.081	0.011	0.015	0.371	0.572	0	0
17	*Crotalaria pallida* Ait.	0.176	-	0.033	-	2.412	-	0.004	-
18	*Commelina erecta* L.	0.110	-	0.020	-	1.113	-	0.001	-
19	*Cyperus rotundus* L.	0.025	-	0.005	-	0	-	0	-
20	*Dioscorea sativa* L.	-	0.109	-	0.021	-	0.953	-	0.001
21	*Eclipta prostrata* (L.) L.	0.184	0.096	0.034	0.018	2.598	0.762	0.004	0.001
22	*Euphorbia hirta* L.	0.141	0.081	0.026	0.015	1.670	0.572	0.002	0
23	*Imperata cylindrica* (L.) Raeusch.	0.099	-	0.018	-	0.928	-	0.001	-
24	*Ipomoea hederifolia* L.	-	0.096	-	0.018	-	0.762	-	0.001
25	*Laportea bulbifera* (Siebold & Zucc.) Wedd.	-	0.096	-	0.018	-	0.762	-	0.001
26	*Leucas aspera* (Willd.) Link	0.205	-	0.038	-	3.155	-	0.006	-

27	*Lindernia ruellioides* (Colsm.) Pennell	-	0.109	-	0.021	-	0.953	-	0.001
28	*Mikania micrantha* Kunth	0.225	0.192	0.042	0.036	3.711	2.478	0.009	0.005
29	*Mimosa pudica* L.	0.099	0.109	0.018	0.021	0.928	0.953	0.001	0.001
30	*Oxalis corniculata* L.	0.043	0.133	0.008	0.025	1.443	1.334	0	0.002
31	*Parthenium hysterophorus* L.	0.121	0.133	0.022	0.025	1.299	1.334	0.001	0.002
32	*Phyllanthus urinaria* L.	0.059	0.081	0.011	0.015	0.371	0.572	0	0
33	*Polygonum barbatum* L.	0.184	0.048	0.034	0.009	2.598	0.191	0.004	0
34	*Scoparia dulcis* L.	0.059	-	0.011	-	0.371	-	0	-
35	*Solanum nigrum* L.	0.043	-	0.008	-	0.186	-	0	-
36	*Spermacoce ocymoides* Burm.f.	0.059	0.096	0.011	0.018	0.371	0.762	0	0.001
37	*Synedrella nodiflora* (L.) Gaertner	-	0.109	-	0.021	-	0.953	-	0.001
38	*Torenia violacea* (Azaola ex Blanco) Pennell	-	0.109	-	0.021	-	0.953	-	0.001
39	*Triumfetta rhomboidea* Jacq.	-	0.200	-	0.038	-	2.668	-	0.006

Table 5. Diversity indices in the shrub layer of the study sites.

	Biodiversity Indices	Shannon Weiner Index (H')		Evenness Index (E)		Species Richness (DMg)		Simpson Index of Dominance (D)	
Sl. No.	SITES / SPECIES	Katlicherra (Invaded site)	Kanchiwala (Non-invaded site)	Katlicherra (Invaded site)	Kanchiwala (Non-invaded site)	Katlicherra (Invaded site)	Kanchiwala (Non-invaded site)	Katlicherra (Invaded site)	Kanchiwala (Non-invaded site)
1	*Antidesma acidum* Retz.	-	0.107	-	0.022	-	0.616	-	0.001
2	*Bridelia stipularis* (L.) Blume	-	0.125	-	0.026	-	0.822	-	0.001
3	*Calotropis gigantean* (L.) W. T. Aiton	0.040	-	0.008	-	0	-	0	-
4	*Cassia alata* L.	0.113	-	0.024	-	0.626	-	0.001	-
5	*Cassia floribunda* (Cav.) H.S. Irwin & Barneby	0.068	-	0.014	-	0.209	-	0	-
6	*Cassia sophera* L.	0.068	0.064	0.014	0.013	0.209	0.205	0	0
7	*Chassalia curviflora* (Wallich) Thwaites	-	0.037	-	0.008	-	0	-	0
8	*Chromolaena odorata* (L.) R.M. King & H.Rob	0.366	0.197	0.076	0.041	8.132	1.849	0.107	0.006
9	*Clerodendrum glandulosum* Lindl.	0.068	0.064	0.014	0.013	0.209	0.205	0	0
10	*Clerodendrum infortunatum* L.	0.240	0.107	0.050	0.022	2.502	0.616	0.011	0.001

11	*Clidemia hirta* (L.) D. Don	-	0.107	-	0.022	-	0.616	-	0.001
12	*Datura innoxia* Mill.	0.068	-	0.014	-	0.209	-	0	-
13	*Datura metel* L.	0.068	-	0.014	-	0.209	-	0	-
14	*Debregeasia longifolia* (Burm.f.) Wedd.	-	0.157	-	0.032	-	1.233	-	0.003
15	*Grewia abutilifolia* W. Vent *ex* Juss.	-	0.125	-	0.026	-	0.822	-	0.001
16	*Grewia asiatica* L.	-	0.172	-	0.035	-	1.438	-	0.004
17	*Ipomoea carnea* Jacq.	0.229	-	0.048	-	2.294	-	0.009	-
18	*Justicia adhatoda* L.	0.092	0.087	0.019	0.018	0.417	0.411	0	0.001
19	*Lantana camara* L.	0.259	0.220	0.054	0.045	2.919	2.260	0.014	0.009
20	*Melastoma malabathricum* L.	0.193	0.125	0.040	0.026	1.668	0.822	0.005	0.001
21	*Microcos paniculata* L.	-	0.185	-	0.038	-	1.644	-	0.005
22	*Morinda angustifolia* Roxb.	-	0.220	-	0.045	-	2.260	-	0.009
23	*Mussaenda roxburghii* Hook.f.	-	0.185	-	0.038	-	1.644	-	0.005
24	*Premna barbata* Wall. ex Schauer	-	0.107	-	0.022	-	0.616	-	0.001
25	*Rauvolfia serpentina* (L.) Benth. ex Kurz	-	0.064	-	0.013	-	0.205	-	0

26	*Ricinus communis* L.	0.132	-	0.027	-	0.834	-	0.001	-
27	*Sarcochlamys pulcherrima* (Roxb.) Gaud.	-	0.107	-	0.022	-	0.616	-	0.001
28	*Solanum anguivi* L.	0.040	-	0.008	-	0	-	0	-
29	*Solanum torvum* Sw.	0.113	0.142	0.024	0.029	0.626	1.027	0.001	0.002
30	*Urena lobata* L.	0.113	0.220	0.024	0.045	0.626	2.260	0.001	0.009

Table 6. Diversity indices in the tree layer of the study sites.

Sl. No.	Biodiversity Indices / SITES / SPECIES	Shannon Weiner Index (H')		Evenness Index (E)		Species Richness (DMg)		Simpson Index of Dominance (D')	
		Katlicherra (Invaded site)	Kanchiwala (Non-invaded site)	Katlicherra (Invaded site)	Kanchiwala (Non-invaded site)	Katlicherra (Invaded site)	Kanchiwala (Non-invaded site)	Katlicherra (Invaded site)	Kanchiwala (Non-invaded site)
1	*Albizia procera* (Roxb.) Benth.	0.184	0.108	0.043	0.024	0.932	0.438	0.932	0.001
2	*Alstonia scholaris* (L.) R. Br.	0.184	-	0.043	-	0.932	-	0.004	-
3	*Anthocephalus cadamba* Roxb. Miq.	-	0.081	-	0.018	-	0.219	-	0
4	*Artocarpus lakoocha* Buch. -Ham.	-	0.132	-	0.029	-	0.657	-	0.001
5	*Chukrasia tabularis* A.Juss.	0.059	0.108	0.014	0.024	0	0.438	0	0.001
6	*Cordia myxa* L.	-	0.081	-	0.018	-	0.219	-	0
7	*Delonix regia* (Boj. Ec Hook.) Raf	0.059	-	0.014	-	0	-	0	-
8	*Dipterocarpus turbinatus* C.F. Gaertn	-	0.173	-	0.038	-	1.095	-	0.003
9	*Duabanga grandiflora* (Roxb. ex DC.) Walp.	0.059	0.154	0.0136	0.034	0	0.876	0	0.002

10	*Dysoxylum binectariferum* Hiern.	-	0.081	-	0.018	-	0.219	-	0
11	*Ficus auriculata* Lour.	-	0.081	-	0.018	-	0.219	-	0
12	*Ficus racemosa* L.	-	0.154	-	0.034	-	0.876	-	0.002
13	*Ficus religiosa* (L.)	-	0.048	-	0.010	-	0.000	-	0
14	*Ficus variegata* (Blume)	-	0.108	-	0.024	-	0.438	-	0.001
15	*Gmelina arborea* Roxb.	-	0.132	-	0.029	-	0.657	-	0.001
16	*Leucaena leucocephala* (Lam.) de Wit	0.333	0.173	0.078	0.038	3.496	1.095	0.046	0.003
17	*Litsea glutinosa* (Lour.) C. B. Rob.	-	0.132	-	0.029	-	0.657	-	0.001
18	*Macaranga denticulata* (Blume) Müll.Arg.	-	0.132	-	0.029	-	0.657	-	0.001
19	*Macaranga peltata* (Roxb.) Müll.Arg.	-	0.108	-	0.024	-	0.438	-	0.001
20	*Maesa ramentacea* (Roxb.) A. DC.	-	0.154	-	0.034	-	0.876	-	0.002
21	*Mallotus paniculatus* (Lam.) Müll.Arg.	-	0.108	-	0.024	-	0.438	-	0.001
22	*Mallotus roxburghianus* Müll.Arg.	-	0.108	-	0.024	-	0.438	-	0.001
23	*Mangifera indica* L.	0.131	-	0.031	-	0.466	-	0.001	-

24	*Oroxylum indicum* (L.) Benth. ex Kurz	0.307	0.108	0.072	0.024	2.797	0.438	0.030	0.001
25	*Peltophorum pterocarpum* (DC.) K.Heyne	0.159	0.081	0.037	0.018	0.699	0.219	0.002	0
26	*Premna bengalensis* C.B.Clarke	-	0.081	-	0.018	-	0.219	-	0
27	*Pterygota alata (*Roxb.*)* R. Br.	-	0.132	-	0.029	-	0.957	-	0.001
28	*Senna siamea* (Lam.) Irwin et Barneby	0.059	-	0.014	-	0	-	0	-
29	*Sterculia foetida* L.	0.225	-	0.052	-	1.398	-	0.008	-
30	*Syzygium jambolanum* (L.) Skneels.	0.059	-	0.014	-	0	-	0	-
31	*Tectona grandis* L.f.	-	0.173	-	0.038	-	1.095	-	0.003
32	*Toona ciliata* M. Roem.	-	0.191	-	0.042	-	1.315	-	0.005
33	*Vitex pubescens* L.	-	0.081	-	0.018	-	0.219	-	0

Density

The density of *A. conyzoides* (1.233) was observed to be the highest while it was recorded least for *Achyranthus aspera* and *Cyprus rotundus* at Katlicherra (invaded) site. Whereas, at Kanchiwala (non-invaded) site, *T. rhomboida* (0.500) was noted with the highest density and least in the case of *Polygonum barbatum*.

In the case of shrubs at the Katlicherra (invaded) site, *C. odorata* (1.333) recorded the highest density followed by *L. camara* (0.50) while it was least for *Solanum anguivi* and *Calotropis gigantean* (**Table 8**). While at Kanchiwala, *L. camara*, *Morinda angustifolia*, and *U. lobata* were recorded with the highest density of 0.40.

Diameter at Breast Height (DBH)

The DBH has been classified into four different classes i.e., **10-20cm, 20-30cm, 30-40cm, 40-50cm** in **Class-I, Class-II, Class-III,** and **Class-IV** respectively (**Table 5**). At Katlicherra, Class- II was the most diverse with 29 individuals followed by Class-III (19), Class-IV (9), and Class-I (16). Similarly, at Kanchiwala the distribution of the tree species at the DBH are classified more diverse in Class-II with 52 followed by Class-III, Class-IV, and Class-I with 18, 14, and 12 individuals respectively. At Katlicherra (invaded site), the basal area of all the tree species was calculated as 2108.4 cm^2. *Chukrasia scholaris* and *Senna siamea* were recorded in Class-II while *Delonix regia* and *Duabanga grandiflora* were noted in class-IV.

The total basal area of the tree species at the Kanchiwala (non-invaded) site was estimated to be 2786.7 cm^2. The most diverse class with 1381.1 cm^2 (Class-II) belonged to *C. tabularis, Cordia myxa, D. turbinatus, Ficus auriculata, Ficus racemosa, Ficus religiosa, Macaranga peltata*, and *Pterygota alata* followed by *Ficus variegata* (Class-III), *Neolamarckia cadamba*, and *T. grandis* (Class-IV), and *O. indicum* and *Premna bengalensis* recorded in Class-I.

L. leucocephala (0.533), *O. indicum* (0.433), and *T. grandis* (0.333) were recorded with the highest densities recorded at Katlicherra (invaded) site. While at Kanchiwala (non-invaded site), *Toona ciliata* (0.233) was recorded with the highest density followed by *D. turbinatus*, *L. leucocephala*, and *T. grandis* (0.20).

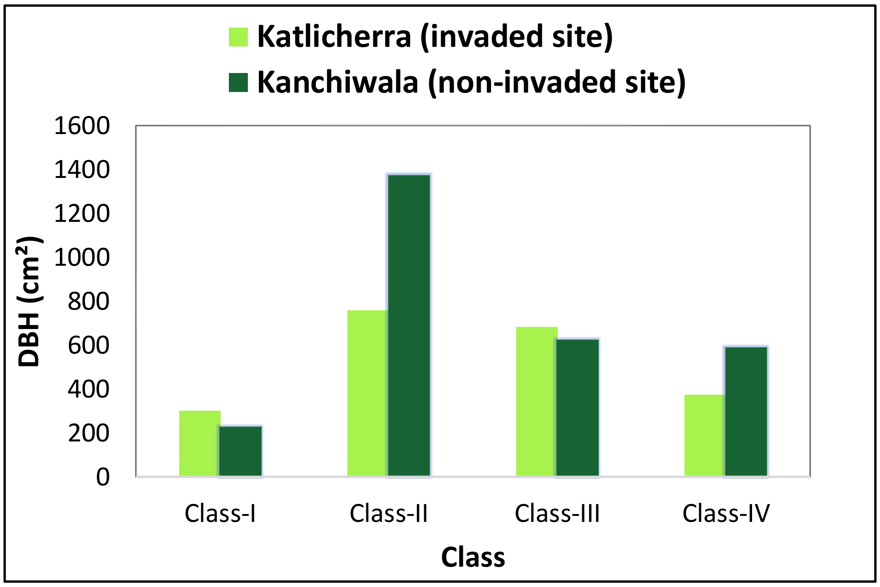


Fig. 5: DBH and Class of trees at Katlicherra and Kanchiwala.

Frequency

The frequency (herb layer) was recorded highest for *A. conyzoides* (50) followed by *L. aspera* (40), *M. micrantha* (36.67), and others at Katlicherra (invaded site). Whereas, at Kanchiwala (non-invaded site), the frequency of *T. rhomboidea* (40) was the highest followed by *M. micrantha* (36.67) and *A. conyzoides* (33.33).

Frequency (shrubs layer) at Katlicherra was calculated highest for *C. odarata* (66.67), followed by *L. camara* (26.67), *C. infortunatum*, and *I. carnea* (20.00). While at Kanchiwala (non-invaded) site *Morinda angustifolia* (30.00) recorded the highest frequency followed by *Grewia flavescens*, *L. camara* (26.67), and *U. lobata* (23.33).

L. leucocephala (46.67) recorded the highest frequency followed by *O. indicum* (36.67) and *T. grandis* (30.00) and *Sterculia foetida* (20.00) at Katlicherra. *L. leucocephala, D. turbinatus,* and *T. ciliata* (16.67), and the least were *F. religiosa* and *P. bengalensis* with 0.20 frequency recorded at Kanchiwala (non-invaded) site.

Abundance

Abundance in the case of herbs was recorded highest for *P. hysterophorus* (4.00), and least for plants like *A.* a*spera, Amaranthus viridis*, *Crassocephalum crepidiodes,* and *Cyperus rotundus* at Katlicherra (invaded site). However, at Kanchiwala (non-invaded site), *Blumea lacera* (3.00) was noted for the highest abundance while *P. barbatum* (1.00) was recorded with the least abundance (**Table 7**).

Among shrubs, *C. infortunatum* (2.167) was estimated with the highest abundance followed by *U. lobata, I. carnea, C. odarata*, and *Cassia alata* at Katlicherra (invaded site). Whereas, at Kanchiwala (non-invaded site) *D. longifolia* (3.50) was estimated recorded with the highest abundance, *Melastoma malabathricum* (2.50), followed by *Mussaenda roxburghii* (2.250) *Cassia sophera, Clerodendrum glandulosum, Clerodendrum infortunatum, Rauvolfia serpentina,* and others (**Table 8**).

In vegetation analysis, abundance was highest for *Mangifera indica* (1.50) followed by *Peltophorum pterocarpum* (1.333), *Alstonia scholaris,* and *T. ciliata* with 1.250 at Katlicherra. While *Maesa ramentacea* (1.667), *Mallotus roxburghianus* (1.50), and *T. ciliata* (1.40) were recorded with the highest abundance at Kanchiwala (**Table 9**).

Table.7: Density, Frequency and Abundance in the herbaceous layer of study sites.

	SITES	**KATLICHERRA (Invaded Site)**			**KANCHIWALA (Non-invaded Site)**		
Sl. No.	Name of the species	Density	Frequency	Abundance	Density	Frequency	Abundance
1	*Acanthospermum hispidum* DC.	0.433	16.667	2.600	0.200	10	2
2	*Achyranthes aspera* L.	0.033	3.333	1	0.267	16.667	1.600
3	*Ageratum conyzoides* L.	1.233	50	2.467	0.433	33.333	1.300
4	*Alternanthera paronychioides* St. -Hill.	0.067	3.333	2	-	-	-
5	*Amaranthus viridis* L.	0.067	6.667	1	-	-	-
6	*Anisomeles indica* (L.) Kuntze	-	-	-	0.267	16.667	1.600
7	*Begonia hatacoa* Buch. -Ham. ex D.Don	-	-	-	0.200	13.333	1.500
8	*Blumea lacera* (Burm.f.) DC.	0.333	13.333	2.500	0.100	3.333	3
9	*Cassia hirsuta* (L.) H.S.Irwin & Barneby	-	-	-	0.233	20	1.167
10	*Cassia occidentalis* L.	0.167	13.333	1.250	0.167	10	1.667
11	*Cassia tora* L.	0.067	3.333	2	0.300	26.667	1.125

12	*Chloris barbata* Sw.	0.100	6.667	1.500	-	-	-
13	*Cleome gynandra* L.	0.233	13.333	1.750	-	-	-
14	*Cleome rutidosperma* DC.	-	-	-	0.233	13.333	1.750
15	*Corchorus tridens* L.	-	-	-	0.300	23.333	1.286
16	*Crassocephalum crepidioides* (Benth.) S. Moore	0.100	10	1	0.133	6.667	2
17	*Crotalaria pallida* Ait.	0.467	23.333	2	-	-	-
18	*Commelina erecta* L.	0.233	13.333	1.750	-	-	-
19	*Cyperus rotundus* L.	0.033	3.333	1	-	-	-
20	*Dioscorea sativa* L.	-	-	-	0.200	13.333	1.500
21	*Eclipta prostrata* (L.) L.	0.500	20	2.500	0.167	13.333	1.250
22	*Euphorbia hirta* L.	0.333	16.667	2	0.133	6.667	2
23	*Imperata cylindrica* (L.) Raeusch.	0.200	16.667	1.200	-	-	-
24	*Ipomoea hederifolia* L.	-	-	-	0.167	10	1.667
25	*Laportea bulbifera* (Siebold & Zucc.) Wedd.	-	-	-	0.167	10	1.667
26	*Leucas aspera* (Willd.) Link	0.600	40	1.500	-	-	-
27	*Lindernia ruellioides* (Colsm.) Pennell	-	-	-	0.200	10	2

28	*Mikania micrantha* Kunth	0.700	36.667	1.909	0.467	36.667	1.273
29	*Mimosa pudica* L.	0.200	10	2	0.200	13.333	1.500
30	*Oxalis corniculata* L.	0.067	6.667	1	0.267	20	1.333
31	*Parthenium hysterophorus* L.	0.267	6.667	4.00	0.267	16.667	1.600
32	*Phyllanthus urinaria* L.	0.100	6.667	1.500	0.133	10	1.333
33	*Polygonum barbatum* L.	0.500	23.333	2.143	0.067	6.667	1
34	*Scoparia dulcis* L.	0.100	6.667	1.500	-	-	-
35	*Solanum nigrum* L.	0.067	6.667	1	-	-	-
36	*Spermacoce ocymoides* Burm.f.	0.100	6.667	1.500	0.167	10	1.667
37	*Synedrella nodiflora* (L.) Gaertner	-	-	-	0.200	10	2
38	*Torenia violacea (*Azaola *ex* Blanco*)* Pennell	-	-	-	0.200	13.333	1.500
39	*Triumfetta rhomboidea* Jacq.	-	-	-	0.500	40	1.250

Table. 8: Density, Frequency and Abundance in the Shrub layer of study sites.

	SITES	**KATLICHERRA (Invaded Site)**			**KANCHIWALA (Non-invaded Site)**		
Sl. No.	Name of the Species	Density	Frequency	Abundance	Density	Frequency	Abundance
1	*Antidesma acidum* Retz.	-	-	-	0.133	10	1.333
2	*Bridelia stipularis* (L.) Blume	-	-	-	0.167	16.667	1
3	*Calotropis gigantean* (L.) W. T. Aiton	0.033	3.333	1	-	-	-
4	*Cassia alata* L.	0.133	6.667	2	-	-	-
5	*Cassia floribunda* (Cav.) H.S. Irwin & Barneby	0.067	6.667	1	-	-	-
6	*Cassia sophera* L.	0.067	6.667	1	0.067	3.333	2
7	*Chassalia curviflora* (Wallich) Thwaites	-	-	-	0.033	3.333	1
8	*Chromolaena odorata (*L.) R.M. King & H.Rob	1.333	66.667	2	0.333	23.333	1.429
9	*Clerodendrum glandulosum* Lindl.	0.067	6.667	1	0.067	3.333	2
10	*Clerodendrum infortunatum* L.	0.433	20	2.167	0.133	6.667	2
11	*Clidemia hirta* (L.) D. Don	-	-	-	0.133	10	1.333
12	*Datura innoxia* Mill.	0.067	6.667	1	-	-	-
13	*Datura metel* L.	0.067	6.667	1	-	-	-
14	*Debregeasia longifolia* (Burm.f.) Wedd.	-	-	-	0.233	6.667	3.500
15	*Grewia abutilifolia* W.Vent ex Juss.	-	-	-	0.167	10	1.667
16	*Grewia asiatica* L.	-	-	-	0.267	16.667	1.600

17	*Grewia flavescens* Juss.	-	-	-	0.300	26.667	1.125
18	*Ipomoea carnea* Jacq.	0.400	20	2	-	-	
19	*Justicia adhatoda* L.	0.100	10	1	0.100	6.667	1.500
20	*Lantana camara* L.	0.500	26.667	1.875	0.400	26.667	1.500
21	*Melastoma malabathricum* L.	0.300	16.667	1.800	0.167	6.667	2.500
22	*Morinda angustifolia* Roxb.	-	-	-	0.400	30	1.333
23	*Mussaenda roxburghii* Hook.f.	-	-	-	0.300	13.333	2.250
24	*Premna barbata* Wall. ex Schauer	-	-	-	0.133	0	1.333
25	*Rauvolfia serpentina* (L.) Benth. ex Kurz	-	-	-	0.067	3.333	2
26	*Ricinus communis* L.	0.167	13.333	1.250	-	-	-
27	*Sarcochlamys pulcherrima* (Roxb.) Gaud.	-	-	-	0.133	10	1.333
28	*Solanum anguivi* L.	0.033	3.333	1		-	
29	*Solanum torvum* Sw.	0.133	10	1.333	0.200	16.667	1.200
30	*Urena lobata* L.	0.133	6.667	2	0.400	23.333	1.714

Table.9: Density, Frequency and Abundance in the Tree layer of study sites.

	SITES	KATLICHERRRA (Invaded Site)			KANCHIWALA (Non-invaded Site)		
Sl. No.	Name of the species	Density	Frequency	Abundance	Density	Frequency	Abundance
1	*Albizia procera* (Roxb.) Benth.	0.167	16.667	1	0.100	10	1
2	*Alstonia scholaris* (L.) R. Br.	0.167	13.333	1.250	-	-	-
3	*Anthocephalus cadamba* Roxb. Miq.	-	-	-	0.067	6.667	1
4	*Artocarpus lakoocha* Buch. -Ham.	-	-	-	0.133	10	1.333
5	*Chukrasia tabularis* A. Juss.	0.033	3.333	1	0.100	10	1
6	*Cordia myxa* L.	-	-	-	0.067	6.667	1
7	*Delonix regia* (Boj. Ec Hook.) Raf	0.033	3.333	1	-	-	-
8	*Dipterocarpus turbinatus* C.F. Gaertn	-	-	-	0.200	16.667	1.200
9	*Duabanga grandiflora* (Roxb. ex DC.) Walp.	0.033	3.333	1	0.167	13.333	1.250
10	*Dysoxylum binectariferum* Hiern.	-	-	-	0.067	6.667	1
11	*Ficus auriculata* Lour.	-	-	-	0.067	6.667	1
12	*Ficus racemosa* L.	-	-	-	0.167	13.333	1.250
13	*Ficus religiosa* (L.)	-	-	-	0.033	3.333	1
14	*Ficus variegata* (Blume)	-	-	-	0.100	10	1
15	*Gmelina arborea* Roxb.	-	-	-	0.133	13.333	1
16	*Leucaena leucocephala* (Lam.) de Wit	0.533	46.667	1.143	0.200	16.667	1.200

17	*Litsea glutinosa* (Lour.) C. B. Rob.	-	-	-	0.133	13.333	1
18	*Macaranga denticulata (*Blume*)* Müll.Arg.	-	-	-	0.133	10	1.333
19	*Macaranga peltata* (Roxb.) Müll.Arg.	-	-	-	0.100	10	1
20	*Maesa ramentacea* (Roxb.) A. DC	-	-	-	0.167	10	1.667
21	*Mallotus paniculatus* (Lam.) Müll.Arg.	-	-	-	0.100	10	1
22	*Mallotus roxburghianus* Müll.Arg.	-	-	-	0.100	6.667	1.500
23	*Mangifera indica* L.	0.100	6.667	1.500	-	-	-
24	*Oroxylum indicum* (L.) Benth. ex Kurz	0.433	36.667	1.182	0.100	10	-
25	*Peltophorum pterocarpum* (DC.) K.Heyne	0.133	10	1.333	0.067	6.667	1
26	*Premna bengalensis* C.B.Clarke	-	-	-	0.067	3.333	2
27	*Pterygota alata* (Roxb.) R. Br.	-	-	-	0.133	10	1.333
28	*Senna siamea* (Lam.) Irwin et Barneby	0.033	3.333	1	-	-	-
29	*Sterculia foetida* L.	0.233	20	1.167	-	-	-
30	*Syzygium jambolanum* (L.) Skeels.	0.033	3.333	1	-	-	-
31	*Tectona grandis* L.f.	0.333	30	1.111	0.200	20	1
32	*Toona ciliata* M. Roem.	0.167	13.333	1.250	0.233	16.667	1.400
33	*Vitex pubescens* L.	-	-	-	0.067	6.667	1

Relative Density (RD)

Plant invaders such as *A. conyzoides* (16.895) recorded the highest RD followed by *M. micrantha* (9.589) and *Leucas aspera* (8.219) at Katlicherra (invaded site). Whereas, at Kanchiwala (non-invaded site) *T. rhomboidea* (7.895) was recorded the highest RD followed by *M. micrantha* (7.368) and *A. conyzoides* (6.842).

Shrub invaders of Katlicherra i.e., *C. odorata* (33.058) was noted with the highest RD followed by *L. camara* (12.397), *C. infortunatum* (10.744), *I. carnea* (9.917), and others. While at Kanchiwala (non-invaded) site, *L. camara*, *M. angustifolia,* and *U. lobata* were noted with RD= 9.231 followed by *C. odorata* (7.692), *Grewia flavescens* (6.923), and others (**Table 10**).

At Katlicherra (invaded site), *L. leucocephala* (21.918) recorded the highest RD followed by *O. indicum* (17.808), *T. grandis* (13.699), and *S. foetida* (9.589). *T. ciliata* (7.292) followed by *D. turbinatus, L. leucocephala,* and *T. grandis* with 6.250 RD at Kanchiwala (non-invaded site).

Relative Frequency (RF)

Among herbs *A. conyzoides* (13.043) were recorded with the highest RF followed by *L. aspera* (10.435), *M. micrantha* (9.565), and *A. aspera* and *C. rotundus* were noted with the least RF of 0.870 at Katlicherra (invaded site). However, at Kanchiwala (non-invaded site), *M. micrantha* (8.462), *A. conyzoides* (7.692), *Cassia tora* (6.154), and *Corchorus tridens (*5.385) were noted with the highest RF recorded.

Among shrubs at Katlicherra, *C. odorata* (28.17) followed by *L. camara* (11.27) were recorded with the highest RF and the least while *Calotropis gigantean* and *Solanum anguivi* were recorded with 1.41 RF values. However, at Kanchiwala (non-invaded site) *M. angustifolia* (10.29*), G. flavescens,* and *L. camara* (RF= 9.41) and the least RF (1.18) were recorded for *Cassia sophera* and *Chassalia curviflora*.

Katlicherra (invaded site), trees of *L. leucocephala* (22.22) followed by *O. indicum* (17.460), *T. grandis* (14.286) were among the highest RF recorded followed by and *T.*

grandis (7.229) *T. ciliata, D. turbinatus, L. leucocephala* with the same RF of 6.024 at Kanchiwala (non-invaded).

Relative Abundance (RA)

Pertaining to Relative Abundance (RA) among layers of vegetation analysis *P. hysterophorus* (8.409) recorded highest RA followed by *Acanthospermum hispidum* (5.466), *Blumea lacera,* and *Eclipta prostrata* (5.256), *A. conyzoides* (5.185), and others were recorded at Katlicherra. While at Kanchiwala, *Blumea lacera* (6.737) recorded the highest RA followed by *A. hispidum, C. crepidioides, Euphorbia hirta, Lindernia ruellioides, Synedrella nodiflora,* and others (**Table 10**).

Further, at Katlicherra *C. infortunatum* (8.87) recorded the highest RA followed by *C. alata, C. odorata, I. carnea,* and *U. lobata* with RA 8.19, and the least was *C. gigantean, Cassia floribunda,* and *C. sophera* (**Table 11**). While at Kanchiwala, *Debregeasia longifolia* (9.55) recorded the highest RA followed by *Melastoma malabathricum* (6.82), *Mussaenda roxburghii* (6.14), and least was *C. curviflora* with RA=0.769.

In the case of trees of Katlicherra, *L. leucocephala* (17.551) recorded the highest RA followed by *O. indicum* (17.460), *T. grandis* (16.872) and the least RA was for *D. grandiflora* (1.408). While at Kanchiwala, *T. ciliate* (8.431) recorded the highest RA followed by *M. ramentacea* (7.786), *D. turbinatus* (6.562), *D. grandiflora* (6.067), *L. leucocephala* (5.735), and *T. grandis* (5.595) (**Table 12)**.

Table 10. RD, RF, and RA in the herbaceous layer of study sites.

	SITES	KATLICHERRA (Invaded Site)			KANCHIWALA (Non-invaded Site)		
Sl. No.	Name of the species	RD	RF	RA	RD	RF	RA
1	*Acanthospermum hispidum* DC.	5.936	4.348	5.466	3.158	2.308	4.491
2	*Achyranthes aspera* L.	0.457	0.870	2.102	4.211	3.846	3.593
3	*Ageratum conyzoides* L.	16.895	13.043	5.185	6.842	7.692	2.919
4	*Alternanthera paronychioides* St. -Hill.	0.913	0.870	4.204	-	-	-
5	*Amaranthus viridis* L.	0.913	1.739	2.102	-	-	-
6	*Anisomeles indica* (L.) Kuntze	-	-	-	4.211	3.846	3.593
7	*Begonia hatacoa* Buch. -Ham. ex D.Don	-	-	-	3.158	3.077	3.368
8	*Blumea lacera* (Burm.f.) DC.	4.566	3.478	5.256	1.579	0.769	6.737
9	*Cassia hirsuta* (L.) H.S.Irwin & Barneby	-	-	-	3.684	4.615	2.620
10	*Cassia occidentalis* L.	2.283	3.478	2.628	2.632	2.308	3.743
11	*Cassia tora* L.	0.913	0.870	4.204	4.737	6.154	2.526
12	*Chloris barbata* Sw.	1.370	1.739	3.153	-	-	-
13	*Cleome gynandra* L.	3.196	3.478	3.679	-	-	-
14	*Cleome rutidosperma* DC.	-	-	-	3.684	3.077	3.930

15	*Corchorus tridens* L.	-	-	-	4.737	5.385	2.887
16	*Crassocephalum crepidioides* (Benth.) S. Moore	1.370	2.609	2.102	2.105	1.538	4.491
17	*Crotalaria pallida* Ait.	6.393	6.087	4.204	-	-	-
18	*Commelina erecta* L.	3.196	3.478	3.679	-	-	-
19	*Cyperus rotundus* L.	0.457	0.870	2.102	-	-	-
20	*Dioscorea sativa* L.	-	-	-	3.158	3.077	3.368
21	*Eclipta prostrata* (L.) L.	6.849	5.217	5.256	2.632	3.077	2.807
22	*Euphorbia hirta* L.	4.566	4.348	4.204	2.105	1.538	4.491
23	*Imperata cylindrica* (L.) Raeusch.	2.740	4.348	2.523	-	-	-
24	*Ipomoea hederifolia* L.	-	-	-	2.632	2.308	3.743
25	*Laportea bulbifera* (Siebold & Zucc.) Wedd.	-	-	-	2.632	2.308	3.743
26	*Leucas aspera* (Willd.) Link	8.219	10.435	3.153	-	-	-
27	*Lindernia ruellioides* (Colsm.) Pennell	-	-	-	3.158	2.308	4.491
28	*Mikania micrantha* Kunth	9.589	9.565	4.013	7.368	8.462	2.858
29	*Mimosa pudica* L.	2.740	2.609	4.204	3.158	3.077	3.368
30	*Oxalis corniculata* L.	0.913	1.739	2.102	4.211	4.615	2.994
31	*Parthenium hysterophorus* L.	3.653	1.739	8.409	4.211	3.846	3.593
32	*Phyllanthus urinaria* L.	1.370	1.739	3.153	2.105	2.308	2.994
33	*Polygonum barbatum* L.	6.849	6.087	4.505	1.053	1.538	2.246

34	*Scoparia dulcis* L.	1.370	1.739	3.153	-	-	-
35	*Solanum nigrum* L.	0.913	1.739	2.102	-	-	-
36	*Spermacoce ocymoides* Burm.f.	1.370	1.739	3.153	2.632	2.308	3.743
37	*Synedrella nodiflora* (L.) Gaertner	-	-	-	3.158	2.308	4.491
38	*Torenia violacea* (Azaola ex Blanco) Pennell	-	-	-	3.158	3.077	3.368
39	*Triumfetta rhomboidea* Jacq.	-	-	-	7.895	9.231	2.807

Table 11. RD, RF, and RA in the shrub layer of study sites.

	SITES	KATLICHERRA (Invaded Site)			KANCHIWALA (Non-invade Site)		
Sl. No.	Name of the species	RD	RF	RA	RD	RF	RA
1	*Antidesma acidum* Retz.	-	-	-	3.077	3.529	3.638
2	*Bridelia stipularis* (L.) Blume	-	-	-	3.846	5.882	2.728
3	*Calotropis gigantean* (L.) W. T. Aiton	0.826	1.408	4.094	-	-	-
4	*Cassia alata* L.	3.306	2.817	8.188	-	-	-
5	*Cassia floribunda* (Cav.) H.S. Irwin & Barneby	1.653	2.817	4.094	-	-	-
6	*Cassia sophera* L.	1.653	2.817	4.094	1.538	1.176	5.457
7	*Chassalia curviflora* (Wallich) Thwaites	-	-	-	0.769	1.176	2.728
8	*Chromolaena odorata (*L.) R.M. King & H.Rob	33.058	28.169	8.188	7.692	8.235	3.898
9	*Clerodendrum glandulosum* Lindl.	1.653	2.817	4.094	1.538	1.176	5.457
10	*Clerodendrum infortunatum* L.	10.744	8.451	8.871	3.077	2.353	5.457
11	*Clidemia hirta* (L.) D. Don	-	-	-	3.077	3.529	3.638
12	*Datura innoxia* Mill.	1.653	2.817	4.094	-	-	-
13	*Datura metel* L.	1.653	2.817	4.094	-	-	-
14	*Debregeasia longifolia* (Burm.f.) Wedd.	-	-	-	5.385	2.353	9.549
15	*Grewia abutilifolia* W.Vent ex Juss.	-	-	-	3.846	3.529	4.547

16	*Grewia asiatica* L.	-	-	-	6.154	5.882	4.365
17	*Grewia flavescens* Juss.	-	-	-	6.923	9.412	3.069
18	*Ipomoea carnea* Jacq.	9.917	8.451	8.188	-	-	-
19	*Justicia adhatoda* L.	2.479	4.225	4.094	2.308	2.353	4.093
20	*Lantana camara* L.	12.397	11.268	7.677	9.231	9.412	4.093
21	*Melastoma malabathricum* L.	7.438	7.042	7.369	3.846	2.353	6.821
22	*Morinda angustifolia* Roxb.	-	-	-	9.231	10.588	3.638
23	*Mussaenda roxburghii* Hook.f.	-	-	-	6.923	4.706	6.139
24	*Premna barbata* Wall. ex Schauer	-	-	-	3.077	3.529	3.638
25	*Rauvolfia serpentina* (L.) Benth. ex Kurz	-	-	-	1.538	1.176	5.457
26	*Ricinus communis* L.	4.132	5.634	5.118	-	-	-
27	*Sarcochlamys pulcherrima* (Roxb.) Gaud.	-	-	-	3.077	3.529	3.638
28	*Solanum anguivi* L.	0.826	1.408	4.094	-	-	-
29	*Solanum torvum* Sw.	3.306	4.225	5.459	4.615	5.882	3.274
30	*Urena lobata* L.	3.306	2.817	8.188	9.231	8.235	4.677

Table 12. RD, RF, and RA in the tree layer of study sites.

	SITES	KATLICHERRA (Invaded Site)			KANCHIWALA (Non-invaded Site)		
Sl. No.	Name of the species	RD	RF	RA	RD	RF	RA
1	*Albizia procera* (Roxb.) Benth.	6.849	7.937	7.618	3.125	3.614	2.907
2	*Alstonia scholaris* (L.) R. Br.	6.849	6.349	8.729	-	-	-
3	*Anthocephalus cadamba* Roxb. Miq.	-	-	-	2.083	2.410	1.942
4	*Artocarpus lakoocha* Buch. -Ham.	-	-	-	4.167	3.614	3.879
5	*Chukrasia tabularis* A.Juss.	1.370	1.587	1.311	3.125	3.614	2.968
6	*Cordia myxa* L.	-	-	-	2.083	2.410	1.837
7	*Delonix regia* (Boj. Ec Hook.) Raf	1.370	1.587	1.584	-	-	-
8	*Dipterocarpus turbinatus* C.F. Gaertn	-	-	-	6.250	6.024	6.562
9	*Duabanga grandiflora* (Roxb. ex DC.) Walp.	1.370	1.587	1.408	5.208	4.819	6.067
10	*Dysoxylum binectariferum* Hiern.	-	-	-	2.083	2.410	1.937
11	*Ficus auriculata* Lour.	-	-	-	2.083	2.410	1.933
12	*Ficus racemosa* L.	-	-	-	5.208	4.819	2.527
13	*Ficus religiosa* (L.)	-	-	-	1.042	1.205	0.979
14	*Ficus variegata* (Blume)	-	-	-	3.125	3.614	2.821

15	*Gmelina arborea* Roxb.	-	-	-	4.167	4.819	3.914
16	*Leucaena leucocephala* (Lam.) de Wit	21.918	22.222	17.551	6.250	6.024	5.735
17	*Litsea glutinosa* (Lour.) C. B. Rob.	-	-	-	4.167	4.819	3.632
18	*Macaranga denticulata* (Blume) Müll.Arg.	-	-	-	4.167	3.614	4.119
19	*Macaranga peltata* (Roxb.) Müll.Arg.	-	-	-	3.125	3.614	2.713
20	*Maesa ramentacea* (Roxb.) A. DC.	-	-	-	5.208	3.614	7.786
21	*Mallotus paniculatus* (Lam.) Müll.Arg.	-	-	-	3.125	3.614	2.589
22	*Mallotus roxburghianus* Müll.Arg.	-	-	-	3.125	2.410	3.831
23	*Mangifera indica* L.	4.110	3.175	7.147	-	-	-
24	*Oroxylum indicum* (L.) Benth. ex Kurz	17.808	17.460	15.161	3.125	3.614	2.816
25	*Peltophorum pterocarpum* (DC.) K.Heyne	5.479	4.762	5.856	2.083	2.410	1.884
26	*Premna bengalensis* C.B.Clarke	-	-	-	2.083	1.205	3.791
27	*Pterygota alata* (Roxb.) R. Br.	-	-	-	4.167	3.614	5.185
28	*Senna siamea* (Lam.) Irwin et Barneby	1.370	1.587	1.563	-	-	-
29	*Sterculia foetida* L.	9.589	9.524	6.602	-	-	-
30	*Syzygium jambolanum* (L.) Skeels.	1.370	1.587	1.480	-	-	-
31	*Tectona grandis* L.f.	13.699	14.286	16.872	6.250	7.229	5.595
32	*Toona ciliata* M. Roem.	6.849	6.349	7.116	7.292	6.024	8.431
33	*Vitex pubescens* L.	-	-	-	2.083	2.410	1.620

Important Value Index (IVI)

In the present study, IVI at Katlicherra was highest for *A. conyzoides* (35.124) followed by *M. micrantha* (23.168), *L. aspera* (21.807), and the least IVI was noted in the case of *Cyperus rotundus* (3.428). While at Kanchiwala site, *T. rhomboidea* (19.932) was recorded with the highest IVI value followed by *M. micrantha* (18.688), *A. conyzoides* (17.454), and the least for *C. crepidioides* and *Euphorbia hirta* (IVI=8.135) (**Table 13**)

In the shrubs layer at Katlicherra (as shown in **Table 14),** *C. odorata* (69.415), *L. camara* (31.341), *C. infortunatum* (28.065) *I. carnea* (26.556), and *M. malabathricum* (21.850) were the five plant invaders recorded with the high IVI. While at Kanchiwala, the IVI of shrubs *M. angustifolia* (23.457), *L. camara* (22.735), *U. lobata* (22.143), *C. odorata* (19.825), *and Grewia flavescens* (19.404) were recorded with high values. The present study revealed that *L. camara* is a strong invader as per the phytosociological study and IVI.

Among trees at Katlicherra (invaded site) (**Table 15**), *L. leucocephala* (61.691) was recorded with the highest IVI followed by *O. indicum* (50.429), *T. grandis* (44.857), and the least was in the case of *C. tabularis* (4.268). However, at Kanchiwala (non-invaded) the tree species that recorded highest were *T. ciliata* (21.747), T. *grandis* (19.074), *D. grandiflora* (16.095), and the least IVI was recorded in the case of *Vitex pubescens* (6.112). Henceforth, *L. leucocephala* with high IVI was most abundant at invaded site of Katlicherra.

The phytosociological analysis of both sites during the present study revealed that the tree layer played a crucial role in ecological functioning. Earlier studies also revealed that *Leucaena sp*. rapidly spread which seriously affected the environment in Taiwan (Chen *et al*., 2012). Further, *L. leucocephala* was observed to exert a high allelopathic effect to restrain the renewal and regenerative growth of native seedling trees (Chou and Kuo, 1986). At the non-invaded site of forest Kanchiwala (non-invaded site) was lesser in the diversity of *L. leucocephala* compared with the invaded site. Chen *et al.,* (2012) reported that it was quite difficult for *L. leucocephala* to penetrate into intact or undisturbed forest ecosystems.

Notably, the study of Huebner (2020) determined that the mature tree has a low chance of invasions compared to the herbs and the shrubs layer. But in terms of the biological invasion, the forested landscapes are still under control to some extent. Similarly, Martin *et. al.,* (2009) reported that in forest land, the biological invasions are still under control or relatively slow compared to the anthropogenic areas.

L. leucocephala can invade easily in the cultivated as well as fallow land invasion and conveys drastic changes in the vegetation composition (Peng, 2019). Marod, *et al.,* (2012) determined *L. leucocephala* restricted the natural forest rejuvenation by growing aggressively that decreasing light transmission to the forest floor. Furthermore, Chou (1980) reported that *L. leucocephala* is responsible for the alteration of the native plants by the secretion of the allelochemical exudates from the root.

Table 13. IVI in the herbaceous layer of study sites

	SITES	KATLICHERRA (Invaded Site)	KANCHIWALA (Non-invaded Site)
Sl. No.	Name of the Species	IVI	IVI
1	*Acanthospermum hispidum* DC.	15.750	9.957
2	*Achyranthes aspera* L.	3.428	11.649
3	*Ageratum conyzoides* L.	35.124	17.454
4	*Alternanthera paronychioides* St. -Hill.	5.987	-
5	*Amaranthus viridis* L.	4.755	-
6	*Anisomeles indica* (L.) Kuntze	-	11.649
7	*Begonia hatacoa* Buch. -Ham. ex D.Don	-	9.603
8	*Blumea lacera* (Burm.f.) DC.	13.30	9.085
9	*Cassia hirsuta* (L.) H.S.Irwin & Barneby	-	10.919
10	*Cassia occidentalis* L.	8.389	8.682
11	*Cassia tora* L.	5.987	13.417
12	*Chloris barbata* Sw.	6.262	-
13	*Cleome gynandra* L.	10.354	-
14	*Cleome rutidosperma* DC.	-	10.69
15	*Corchorus tridens* L.	-	13.009
16	*Crassocephalum crepidioides* (Benth.) S. Moore	6.081	8.135
17	*Crotalaria pallida* Ait.	16.684	-
18	*Commelina erecta* L.	10.354	-
19	*Cyperus rotundus* L.	3.428	-
20	*Dioscorea sativa* L.	-	9.603
21	*Eclipta prostrata* (L.) L.	17.322	8.515
22	*Euphorbia hirta* L.	13.118	8.135
23	*Imperata cylindrica* (L.) Raeusch.	9.610	-
24	*Ipomoea hederifolia* L.	-	8.682
25	*Laportea bulbifera* (Siebold & Zucc.) Wedd.	-	8.682
26	*Leucas aspera* (Willd.) Link	21.807	-

27	*Lindernia ruellioides* (Colsm.) Pennell	-	9.957
28	*Mikania micrantha* Kunth	23.168	18.688
29	*Mimosa pudica* L.	9.553	9.603
30	*Oxalis corniculata* L.	4.755	11.820
31	*Parthenium hysterophorus* L.	13.801	11.649
32	*Phyllanthus urinaria* L.	6.262	7.407
33	*Polygonum barbatum* L.	17.441	4.837
34	*Scoparia dulcis* L.	6.262	-
35	*Solanum nigrum* L.	4.755	-
36	*Spermacoce ocymoides* Burm.f.	6.262	8.682
37	*Synedrella nodiflora* (L.) Gaertner	-	9.957
38	*Torenia violacea (*Azaola *ex* Blanco*)* Pennell	-	9.603
39	*Triumfetta rhomboidea* Jacq.	-	19.932

Table.14: IVI in the Shrub layer of study sites

	SITES	KATLICHERRA (Invaded Site)	KANCHIWALA (Non-invaded Site)
Sl. No.	Name of the species	IVI	IVI
1	*Antidesma acidum* Retz.	-	10.244
2	*Bridelia stipularis* (L.) Blume	-	12.457
3	*Calotropis gigantean* (L.) W. T. Aiton	6.329	-
4	*Cassia alata* L.	14.311	-
5	*Cassia floribunda* (Cav.) H.S. Irwin & Barneby	8.564	-
6	*Cassia sophera* L.	8.564	8.172
7	*Chassalia curviflora* (Wallich) Thwaites	-	4.674
8	*Chromolaena odorata (*L.) R.M. King & H.Rob	69.415	19.825
9	*Clerodendrum glandulosum* Lindl.	8.564	8.172
10	*Clerodendrum infortunatum* L.	28.065	10.887
11	*Clidemia hirta* (L.) D. Don	-	10.244
12	*Datura innoxia* Mill.	8.564	-
13	*Datura metel* L.	8.564	-
14	*Debregeasia longifolia* (Burm.f.) Wedd.	-	17.287
15	*Grewia abutilifolia*	-	11.923
16	*Grewia asiatica* L.	-	16.402
17	*Grewia flavescens* Juss.	-	19.404
18	*Ipomoea carnea* Jacq.	26.556	-
19	*Justicia adhatoda* L.	10.799	8.753
20	*Lantana camara* L.	31.341	22.735
21	*Melastoma malabathricum* L.	21.850	13.020

22	*Morinda angustifolia* Roxb.	-	23.457
23	*Mussaenda roxburghii* Hook.f.	-	17.768
24	*Premna barbata* Wall. ex Schauer	-	10.244
25	*Rauvolfia serpentina* (L.) Benth. ex Kurz	-	8.172
26	*Ricinus communis* L.	14.884	-
27	*Sarcochlamys pulcherrima* (Roxb.) Gaud.	-	10.244
28	*Solanum anguivi* L.	6.329	-
29	*Solanum torvum* Sw.	12.990	13.772
30	*Urena lobata* L.	14.311	22.143

Table 15. IVI in the Tree layer of study sites.

	SITES	KATLICHERRA (Invaded Site)	KANCHIWALA (Non-invaded Site)
Sl. No.	Name of the Species	IVI	IVI
1	*Albizia procera* (Roxb.) Benth.	22.404	9.647
2	*Alstonia scholaris* (L.) R. Br.	21.928	-
3	*Anthocephalus cadamba* Roxb.	-	6.435
4	*Artocarpus lakoocha* Buch. -Ham.	-	11.660
5	*Chukrasia tabularis* A.Juss.	4.268	9.707
6	*Cordia myxa* L.	-	6.330
7	*Delonix regia* (Boj. Ec Hook.) Raf	4.541	-
8	*Dipterocarpus turbinatus* C.F. Gaertn	-	18.836
9	*Duabanga grandiflora* (Roxb. ex DC.) Walp.	4.365	16.095
10	*Dysoxylum binectariferum* Hiern.	-	6.430
11	*Ficus auriculata* Lour.	-	6.426
12	*Ficus racemosa* L.	-	12.554
13	*Ficus religiosa* (L.)	-	3.226
14	*Ficus variegata* (Blume)	-	9.560
15	*Gmelina arborea* Roxb.	-	12.900
16	*Leucaena leucocephala* (Lam.) de Wit	61.691	18.009
17	*Litsea glutinosa* (Lour.) C. B. Rob.	-	12.618
18	*Macaranga denticulata* (Blume) Müll.Arg.	-	11.900
19	*Macaranga peltata* (Roxb.) Müll.Arg.	-	9.453
20	*Maesa ramentacea* (Roxb.) A. DC.	-	16.609

21	*Mallotus paniculatus* (Lam.) Müll.Arg.	-	9.329
22	*Mallotus roxburghianus* Müll.Arg.	-	9.366
23	*Mangifera indica* L.	14.432	-
24	*Oroxylum indicum* (L.) Benth. ex Kurz	50.429	9.555
25	*Peltophorum pterocarpum* (DC.) K.Heyne	16.098	6.377
26	*Premna bengalensis* C.B.Clarke	-	7.079
27	*Pterygota alata* (Roxb.) R. Br.	-	12.966
28	*Senna siamea* (Lam.) Irwin et Barneby	4.520	-
29	*Sterculia foetida* L.	25.715	-
30	*Syzygium jambolanum* (L.) Skeels.	4.437	-
31	*Tectona grandis* L.f.	44.857	19.074
32	*Toona ciliata* M. Roem.	20.315	21.747
33	*Vitex pubescens* L.	-	6.112

Soil Physico-chemical Analysis

The physico-chemical properties of the soil were analyzed during the study period (the year 2016-2018) at the Katlichera (invaded) site and Kanchiwala (non-invaded) site of Hailakandi District, Assam. The soil analysis at both the study sites was conducted during Monsoon, Post-Monsoon, and Pre-Monsoon to depict a seasonal variation.

The various soil parameters examined at the study sites i.e., Katlicherra (invaded site) and Kanchiwala (non-invaded site) were different. From the soil analysis of soil parameters, it has been reported that the soil at Katlicherra has low WHC, SMC, SOC, SOM, TN, AP, and AK when compared with the Kanchiwala. The descriptive Mean and the Standard Error of both sites are reported in **Table 16**. **ANOVA** of soil physico-chemical properties on response to soil depth and seasonal variation is reported in **Table 17** and **18** respectively**.** In this aspect, **Appendix 1** and **2** are the computed Pearson Correlation coefficient (***r***) of study sites.

Table 16. Descriptive analysis of soil parameters at Katlicherra and Kanchiwala

PARAMETERS	**KATLICHERRA**	**KANCHIWALA**
Temperature (°C)	26.622±0.411	24.097±0.425
Bulk Density (BD)	1.297±0.007	1.174±0.003
Porosity	51.042±0.270	55.713±0.115
Water Holding Capacity (WHC)	43.739±0.772	51.342±0.914
Soil Moisture Content (SMC)	24.579±0.676	28.655±0.630
pH	5.252±0.054	5.097±0.041
Soil Organic Carbon (SOC)	0.858±0.042	1.395±0.047
Soil Organic Matter (SOM)	1.479±0.072	2.406±0.081
Total Nitrogen (TN)	0.614±0.059	0.945±0.090
Carbon:Nitrogen (C:N) Ratio	1.878 ±0.185	2.124±0.291

Available Phosphorus (P)	16.553±1.339	33.112±3.539
Available Potassium (K)	43.049±1.51	54.431±1.971

Note: Values indicate Mean± Standard Error

a) Soil Temperature

The recorded soil temperature at Katlicherra of the surface soil (0-15cm) was 27.087±0.579 and the sub-surface (15-30cm) was 26.167±0.579 with **F**= 1.29 and ***p*** >0.05. Based on the season the soil temperature ranged from 27.064°C, 23.666°C, and 29.136°C in monsoon, post-monsoon, and pre-Monsoon respectively. However, at Kanchiwala the soil temperature was recorded 24.316±0.60 in the case of surface soil while for sub-surface it was observed 23.878±0.616 with **F**= 0.259 and ***p***>0.05 (**Table 16**). Seasonal variations in soil temperature were recorded as 25.142±0.189, 20.896±0.183, and 26.253±0.452 during monsoon, post-monsoon, and pre-monsoon, respectively (**Table 17).** The soil temperature plays a very important role and is also correlated with plant germinations. The case study by Hou, *et al., (*2014) reported that the extremely high soil temperature causes a risk of plant invasion which adversely influences native plants. Similarly, Song, *et al.,* (2010a) determined that the native plant species have less temperature tolerance compared to the non-native species. Due to the phenotypic plasticity, invasive alien plants can tolerate harsh environmental conditions (Gratani, 2014, Zheng, *et al.,* 2021). The findings in the Pearson Correlation Coefficient of the soil temperature at both the sites are displayed in **Appendix 1** and **2**. The interaction of the plant and soil-driven a change in the physicochemical properties of soil. The plant invaders either directly or indirectly affect the soil physical attributes, chemistry, and the ecosystem's functioning (Weidenhamer and Callaway, 2010).

Figure 6 shows the soil temperature was recorded higher at Katlicherra (invaded site) in the surface and the sub-surface soil as compared to Kanchiwala. Some of the alien plants in the intensively disturbed /harsh environmental conditions of the present study demonstrated their adaptability to grow vigorously at Katlicherra (invaded site). The study was done by Maja, *et al.*, (2008) on *M. micrantha* distribution and ecology in Taiwan, observed that invasive alien plants grow well under light-intensive conditions and in disturbed areas. Likewise, *P. hysterophorus* can germinate and grow in a broad range of low to high temperatures (Sankanran, 2008).

b) Bulk Density (BD)

The Soil BD at the Katlicherra (invaded site) was recorded higher in comparison to Kanchiwala (non-invaded Site). Likewise, Sharma and Paul (2020) also recorded higher soil BD at the invaded site. The BD of soil at Katlicherra in the surface soil and sub-surface soil were 1.288±0.010 and 1.307±0.010 respectively with **F**= 1.744 and ***p***>0.05. As per the season seasonal variation monsoon (285±0.009), post-monsoon (1.321±0.013), and pre-monsoon (1.286±0.013) with **F**=3.161 at ***p***>0.05.

The BD at Kanchiwala surface soil and the sub-surface soil were1.168±0.005 and 1.179±0.004, respectively with F=3.023 at ***p***>0.05. During the Monsoon (1.166±0.005), post-Monsoon (1.178±0.005), and Pre-Monsoon (1.177±0.005) with **F**=1.535 at ***p***>0.05 were recorded.

Notably, the belowground interactions (soil-microbes) are associated with the extensive spread of invasive alien plants (Jack *et al.*, 2017) and influence on the soil physico-chamical (Rai and Singh, 2021). The litter deposition, water diffusion, and channels of the rooting system are highly influenced by the decrease in the BD of the soil (Weidenhamer and Callaway, 2010).

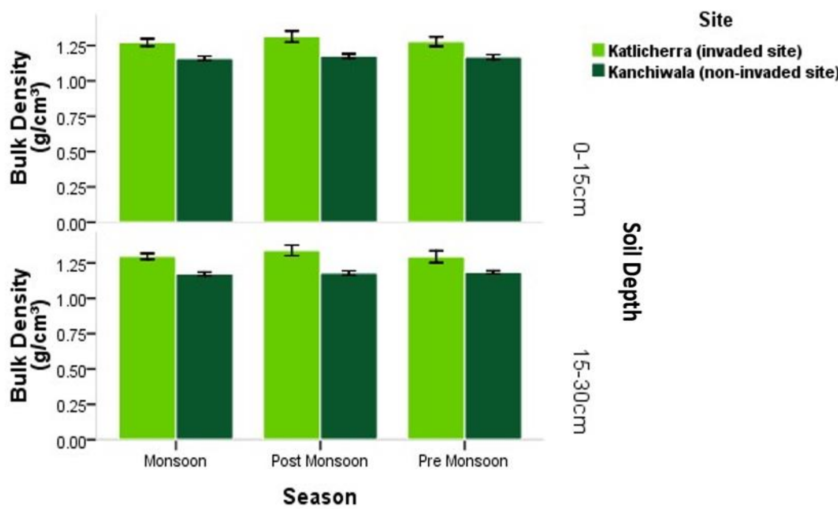


Figure 7. Soil BD (g/cm^3) on response to soil depth and seasonal variation in the study sites.

c) Soil Porosity

The Soil Porosity recorded at both sites was observed with an inverse trend as of the soil BD. **Figure 8** has shown that the porosity of the soil at Katlicherra decreased as the depth was increasing. Based on the seasonal variation Monsoon (51.525±0.328), post-Monsoon (50.139±0.485), and Pre-Monsoon (51.462±0.489) with F=3.161 and at $\boldsymbol{p}>0.05$ were reported. Porosity showed a negative and significant relation ($\boldsymbol{r}=-1.000^{**}$) with soil BD.

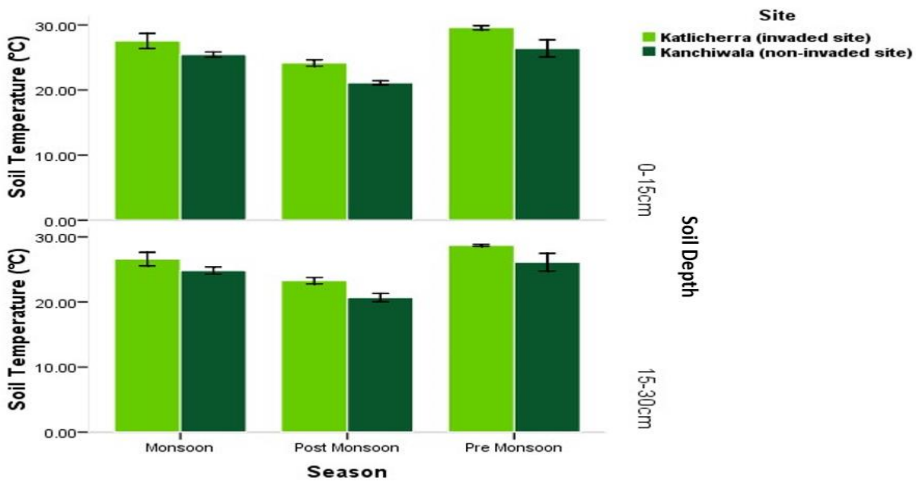


Figure 6. Soil Temp. (ºC) on response to soil depth and seasonal variation in the study sites

Likewise, the Soil Porosity at Kanchiwala is 55.908±0.174 in the surface soil and 55.518±0.141 (sub-surface soil) decreased with an increase in depth of the soil with **F**=3.023 at ***p***>0.05. Seasonally 55.994±0.19 (Monsoon), 55.557±0.197 (post-Monsoon), and 55.588±0.199 (Pre-Monsoon) with **F**=1.535 at ***p***>0.05. The Pearson Correlation coefficient of the soil porosity was significant and negatively correlated with the soil BD (***r***=-1.000**).

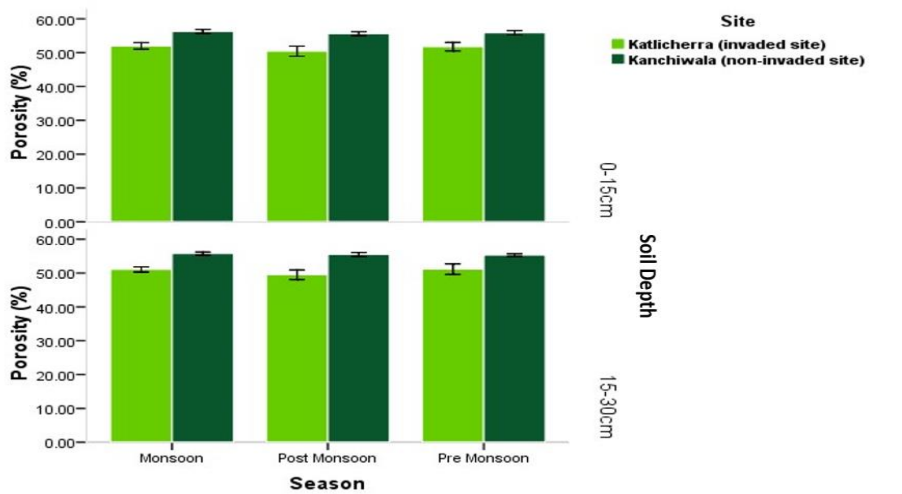


Figure 8. Soil porosity (%) on response to soil depth and seasonal variation in the study sites.

Figures 7 and **8** show BD and the Porosity values of the soil. The study revealed that the Kanchiwala (non-invaded site) have lower than Katlicherra (invaded site) but the porosity of the soil at Kanchiwala is inverted to the soil BD. Invasive alien plants impact the soil by altering in the soil porosity (Lone, *et al.*, 2019). Similarly, Radcliffe, *et al.*, (2002) determined that the pore and the size of the soil pore are highly influences by the invasive alien plants.

d) Water Holding Capacity (WHC)

The surface soil (44.126±1.141) and the sub-surface (43.353±1.064) with **F**=0.246 at ***p***>0.05 at Katlicherra. Seasonally Monsoon (49.833±0.539), post-Monsoon (39.914±0.218), and Pre-Monsoon (41.472±0.415) reported in (**Table 17).** WHC was noted with a positive significant correlation with Porosity (***r***=0.373*).

The surface soil (52.424±1.273) and the sub-soil (50.261±1.298) with **F**=1.416 at ***p***>0.05. Monsoon (57.717±0.408), post-Monsoon (45.182±0.495), and Pre-Monsoon (51.128±0.649) marked with seasonal variations recorded at Kanchiwala. WHC was positively correlated with the Temperature (***r***=0.646**). Vasquez-Valderrama, *et al.*, (2020) determined in the case study that the invasive alien plants influence the soil ecosystem on the tropical dry forested land. It also indicates that the uptake capacity of the invasive alien plants was higher than the native plants.

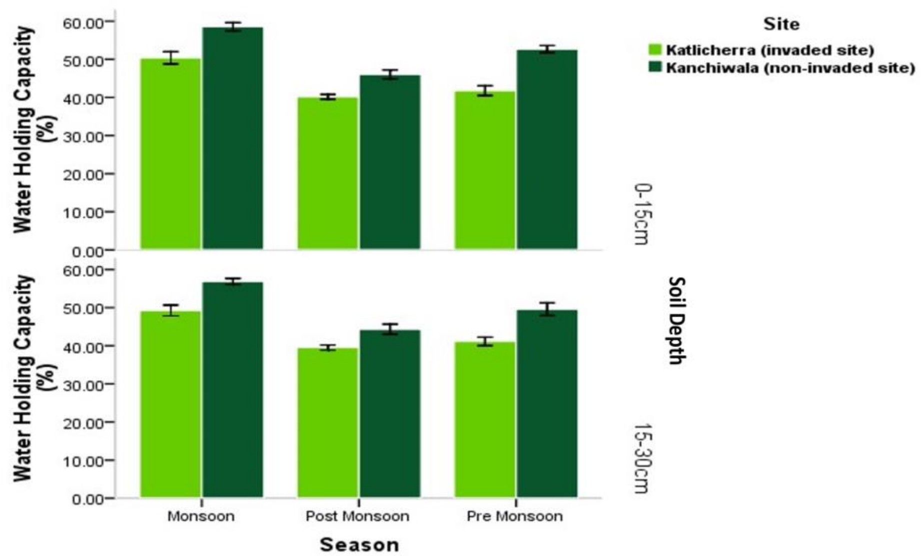


Figure 9. WHC (%) on response to Soil Depth and Seasonal Variation in the study sites.

In response to the soil physical properties, WHC is affected by invasive plants at Katlicherra (invaded site). **Figure 9** indicates that the water uptake capacity of the invasive alien plants from the soil is much higher than the native plants. In this respect, Lone *et al.*, (2019) reported that the rate of evaporation is quick by the growth of the rapid growth of the invasive plant with the time that often leads to a decrease in the SMC. Further, Vasquez-Valderrama, *et al* (2020), determined that extensive increases in the effect on the soil WHC result in an alteration of the soil ecosystem on the tropical dry forested land.

e) Soil Moisture Content (SMC)

The SMC at Katlicherra of the soil surface and the sub-surface were 25.268±0.928 and 23.889±0.982 with **F**=1.041 at ***p***>0.05. Based on the seasonal variation 29.705±0.274, 20.610±0.378, and 23.422±0.446 were recorded during Monsoon, Post-Monsoon, and Pre-Monsoon respectively. SMC negative correlation with BD (***r***=-0.401*) and Porosity (***r***=-0.401*) whereas, SMC was positively correlated with Temperature (*r*=0.403*) and WHC at (***r***=0.956**).

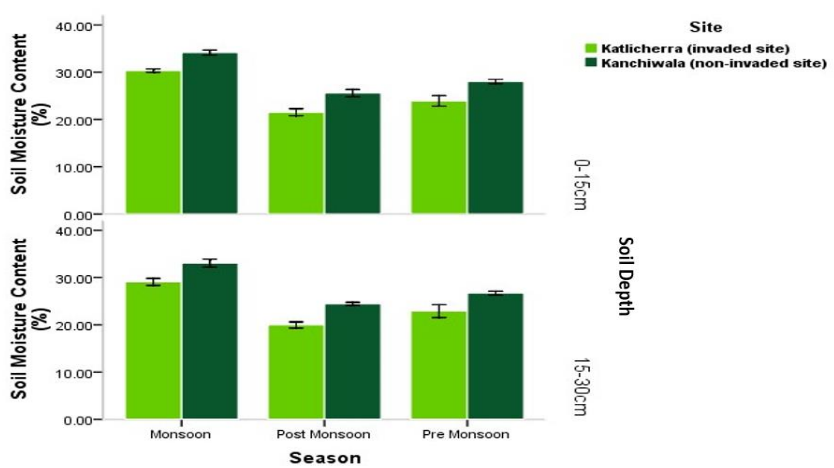


Figure 10. SMC (%) in response to soil depth and seasonal variation in the study sites.

The recorded surface and sub-surface values of SMC at Kanchiwala (non-invaded site) were 29.256±0.888 and 28.055±0.898 with **F**=0.904 and ***p***>0.05. Monsoon (33.588±0.292), Post Monsoon (25.004±0.270), and Pre-Monsoon (27.374±0.250) were marked with slight seasonal variations. SMC was negatively correlated with Porosity and BD (***r***=-0.362*; ***r***=-0.362*) and positively correlated with soil temperature and WHC at

(r=0.514**; r=0.935**). The SMC at Katlicherra was low compared to the Kanchiwala **Figure 10**.

SMC is a very important parameter in soil physical property and it is affected by the various environmental factors where the invasive alien plants act as one of the important factors or drivers of change. The widespread of the invasive alien plants will adversely impact the soil moisture in the future. He, (2014) determined that SMC over time and space, the alien shrubs invade aggressively assesses the availabilities of the soil resources to the native plants.

f) Soil pH

The pH at Katlichera in the surface and the sub-surface of the soil were 5.446±0.077 and 5.058±0.043. Based on the seasonal variation the pH during Monsoon, Post-Monsoon, and Pre-Monsoon were 5.180±0.054, 5.313±0.087, and 5.263±0.130 with **F**= 0.494 and p>0.05.

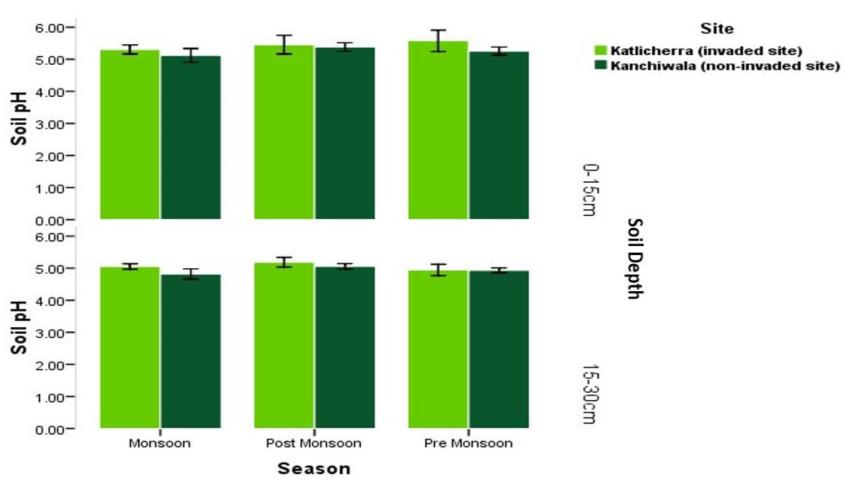


Figure 11. Soil pH on response to Soil Depth and Seasonal Variation in the study site.

5.256±0.051 and 4.938±0.039 were the recorded value in the surface and the sub-surface of the soil at Kanchiwala. Monson (4.973±0.079), Post Monsoon (5.221±0.062), and the Pre-Monsoon (5.097±0.060) with F=3.406 and $p<0.05$ were recorded as per seasonal variation. The pH of the soil in both sites is reported in **Table 16** and **Figure 11**. The soil pH of the district is acidic nature, during the rainy season the acidity of the soil is more. Simba, *et al.*, (2013) mentioned the changes in the soil pH due to the invasive plants.

g) Soil Organic Carbon (SOC)

The SOC at Katlicherra was 0.919±0.059 and 0.797±0.058 recorded for the surface and the sub-surface soil with **F**= 2.183 and at $\boldsymbol{p}>0.05$. Monsoon (0.572±0.023), Post Monsoon (0.861±0.026), Pre-Monsoon (1.140±0.030) were reported in (**Table 17**). SOC was negatively correlated with SMC ($\boldsymbol{r}=-0.591^{**}$), and positively correlated with Temperature and WHC at ($\boldsymbol{r}=0.369^{*}$; $\boldsymbol{r}=0.725^{**}$).

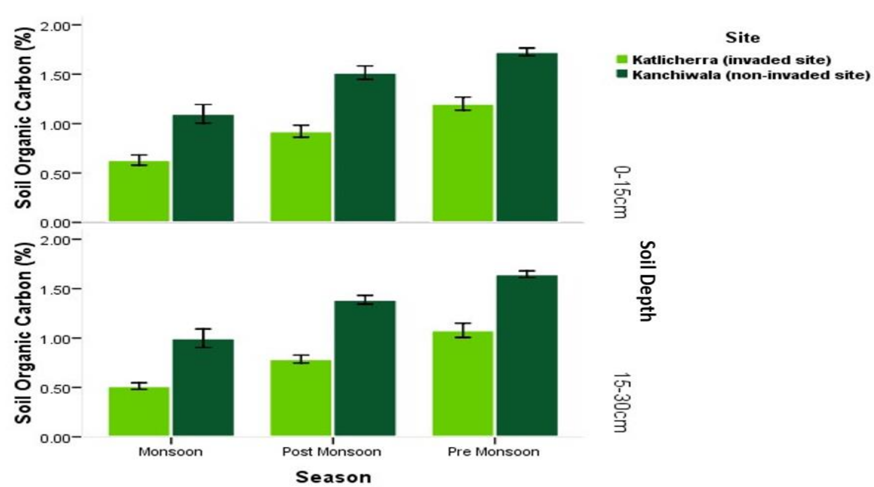


Figure 12. SOC (%) on response to soil depth and seasonal variation of the study sites.

The surface and the sub-surface soil at Kanchiwala were recorded at 1.447±0.066 and 1.344±0.067 with F= 1.209 at *p*>0.05. Based on the seasonal variation 1.049±0.035, 1.452±0.027, and 1.686±0.017 were recorded during Monsoon, Post Monsoon, and Pre-Monsoon. SOC was negatively correlate with WHC (*r*=-0.568**), SMC (*r*=-0.697**), and positively correlate with pH at (*r*=0.414*).

h) Soil Organic Matter (SOM)

SOM at Katlicherra varies from Surface and the sub-surface soil was recorded 1.583±0.101 and 1.374±0.099 with **F**=2.169 and ***p***>0.05. Seasonally Monsoon (0.987±0.040), Post Monsoon (1.483±0.044), and Pre-Monsoon (1.966±0.051) were recorded. Pearson correlation coefficient indicates that the SOM was negative relationship with SMC (***r***=-0.591**) and positively correlated with Temperature (r=0.369*), WHC (***r***=0.725**) and SOC (***r***=1.000**).

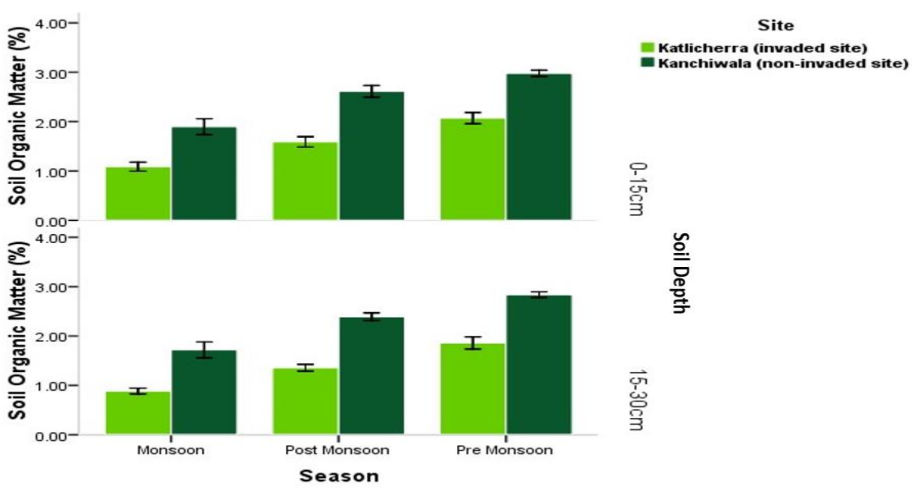


Figure 13. SOM (%) in response to soil depth and seasonal variation of the study sites.

The surface and the sub-surface soil at Kanchiwala as recorded are 2.496±0.114 and 2.316±0.115 with **F**= 1.224 and ***p***>0.05. Monsoon (1.808±0.061), Post Monsoon (2.502±0.047), and Pre-Monsoon (2.907±0.030) were the recorded values on a seasonal basis. SOM was negative correlation with WHC (***r***=-0.567**), and SMC (***r***=-.697**) and SOM positively correlated with pH (***r***=0.413*) and SOC (***r***=1.000**).

The SOC (**Figure 12**) and SOM (**Figure 13**) were recorded highest during the Pre-Monsoon and least during Monsoon in both the study sites. SOC and SOM play as media for the proper growth and development of plant diversity. The decrease of the SOC and SOM during the Monsoon season is due to various factors which lead to soil infertility. Invasive species like *A. conyzoides* (Dogra, *et al.,* 2009), *C. odorata* (Wei, *et al.,* 2017), *L. camara* (Osunkoya and Perrett, 2010; Rai, 2015), *M. micrantha* (Li, *et al.,* 2006) contribute to the alterations of soil fertility. Invasive alien plants are highly responsible for changes in the SOC. Another study reveals that the invasion of shrubs in the grassland ecosystem can change the quantitative and the qualitative carbon sources can be leads a decline in the SOC (Amundson, 2001).

i) Total Nitrogen (TN)

TN at Katlicherra the surface (0.647±0.087) and sub-surface (0.581±0.083) of the soil with **F**=0.305 and at ***p***>0.05. Monsoon (0.257±0.033), Post Monsoon (0.547±0.052), and Pre-Monsoon (1.038±0.039) were the recorded values as per the seasonal variation. The TN was negatively significant with WHC (***r***= -0.530**) and positively correlate with Temperature (***r***= 0.421*), SOC (***r***= 0.819**), and SOM (***r***= 0.820**).

At Kanchiwala, the surface and the sub-surface of the soil were 1.044±0.138 and 0.846±0.116 with **F**= 1.212 and ***p***>0.05. Monsoon (0.336±0.045), Post Monsoon (1.211±0.112), Pre-Monsoon (1.288±0.111) as per the seasonal variation. TN were negatively correlated with WHC (***r***=-0.554**), and SMC (***r***=-0.702**). Further TN was positively correlating with pH (***r***=0.454**), SOC (***r***=0.790**), and SOM (***r***=0.791**). Soil TN reported in **Figure 14.** Liao, *et al.,* (2007) determined that the plants' community structure influences the TN of the soil. Corbin and D’Antonio, (2004) reported same that exotic plants may significantly change by the fast consumption and restoration of soil N.

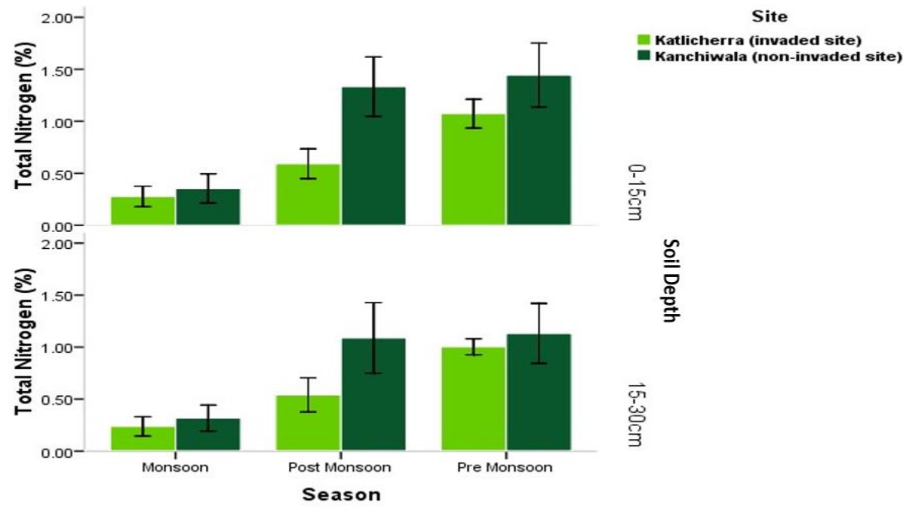


Figure 14. TN (%) on response to soil depth and seasonal variation of the study sites.

j) Carbon:Nitrogen (C:N) Ratio

The C: N Ratio at Katlicherra in the surface and the sub-surface of soil were 1.879±0.264 and 1.877±0.267. Seasonally, 2.761±0.408, 1.753±0.179, and 1.120±0.061 were recorded during Monsoon, Post Monsoon, and Pre-Monsoon respectively. The Pearson Correlation Coefficient indicates that C:N ratio was negatively correlated with Temperature SOC (***r***=-0.486**), SOM (***r***=-0.487**), and TN (***r***=-0.769**) and positively correlated with WHC (***r***=0.362*) and SMC (***r***=.0387*).

The surface soil (1.947±0.356) and sub-surface soil (2.301±0.468) with **F**=0.362 and ***p***>0.05. Monsoon (3.770±0.644), Post Monsoon (1.267±0.116), and the Pre-Monsoon (1.335±0.109) were the recorded values in Kanchiwala based on seasonal variation. C: N ratio negatively correlated with SMC (***r***=-0.625**), pH (***r***=-0.428**), SOM (***r***=-0.733**), and TN (***r***=-0.748**). Further, C:N ratio was positively correlated with WHC (***r***=0.584**) and SOC (***r***=0.733**). C: N ratio of the soil reported in **Figure 15**.

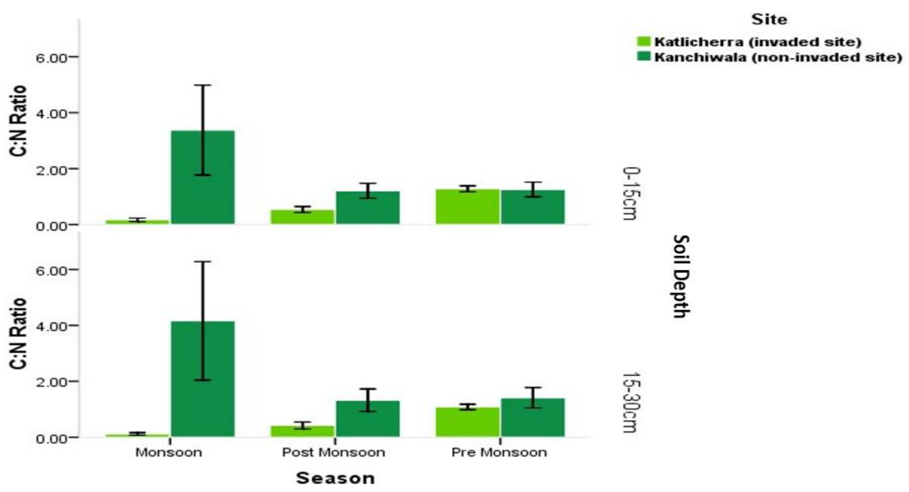


Figure 15. C: N Ratio on response to soil depth and seasonal variation of the study sites.

As per the study the C: N in the surface soil is recorded lower than the sub-surface soil. The C: N ratio was notable influenced by the growth of the invasive alien plants. Zhang, *et al.*, (2021) reported that the invasive species influences the SOC and the availability of N potentially.

k) Available Phosphorus (P)

The Available P at Katlicherra depth of the soil in the soil surface (17.438±1.918) and the sub-surface (15.669±1.902) with **F**=0.429 and ***p***>0.05. Seasonally 8.509±0.494, 18.610±2.297, and 22.541±1.442 were recorded during Monsoon, Post Monsoon, and Pre-Monsoon. **Appendix 1** revealed that P was negatively significant with WHC (-0.705**) and SMC (-0.624**). Further, the P was positively correlated with SOC, SOC, and TN at 0.788**, 0.788**, 0.474** respectively.

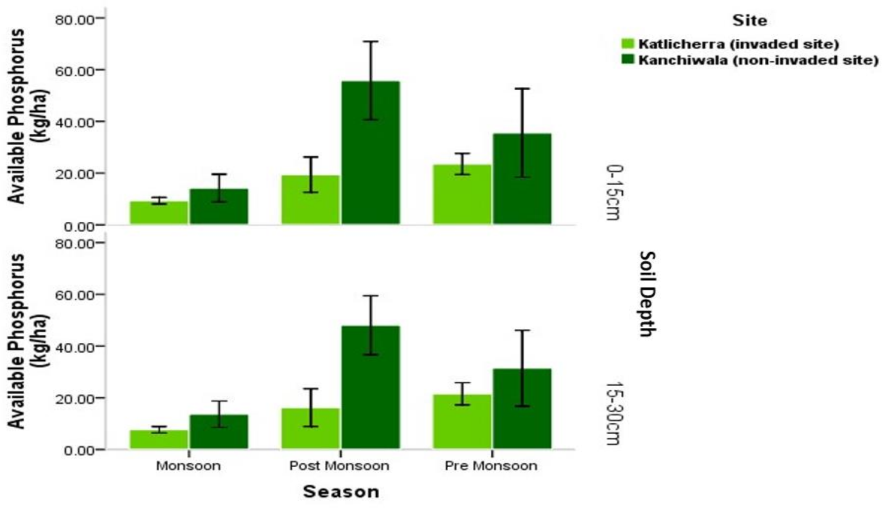


Figure 16. Available P (kg/ha) on response to soil depth and seasonal variation of the study sites**.**

The surface soil and the sub-surface soil were 35.166±5.514 and 31.057±4.547 with **F**=0.331 at ***p***>0.05. Monsoon (13.940±1.761), Post Monsoon (51.907±4.666), and Pre-Monsoon (33.488±5.400) were the recorded values during the seasonal variations. The Pearson Correlation Coefficient indicates that the P was negatively correlates with Temperature (***r***=-0.367*), and WHC (***r***=-0.646**). Positively correlated with SMC (***r***=0.669**), SOC (***r***=0.469**), SOM (***r***=0.468**), TN (***r***=0.526**), and C: N (***r***=0.549**). The Availability of P (**Figure 16**) and K (**Figure 17**). Katlicherra (invaded site) is reported as nutrient-poor compares to Kanchiwala. Low soil nutrients in the invaded area reported by Lone, *et al.*, (2019) cause invasive plants' uptake of soil nutrients in the high amount for their own benefits.

l) Available Potassium (AK)

The surface soil and the sub-surface soil at Katlicherra were 44.554±1.688 and 41.545±1.530 with **F**=1.746 at ***p***>0.05. Based on the seasonal variation, Monsoon (35.460±0.935), Post Monsoon (49.611±0.889), and Pre-Monsoon (44.078±1.317). In the Pearson Correlation Coefficient AK was negative correlation with Temperature

(r= -0.357*), WHC (r= -0.850**), and SMC (r= -0.822**). Positively correlated with SOC (r=0.577**), SOM (r= 0.576**), TN (r= 0.336*), and P (r= 0.687**).

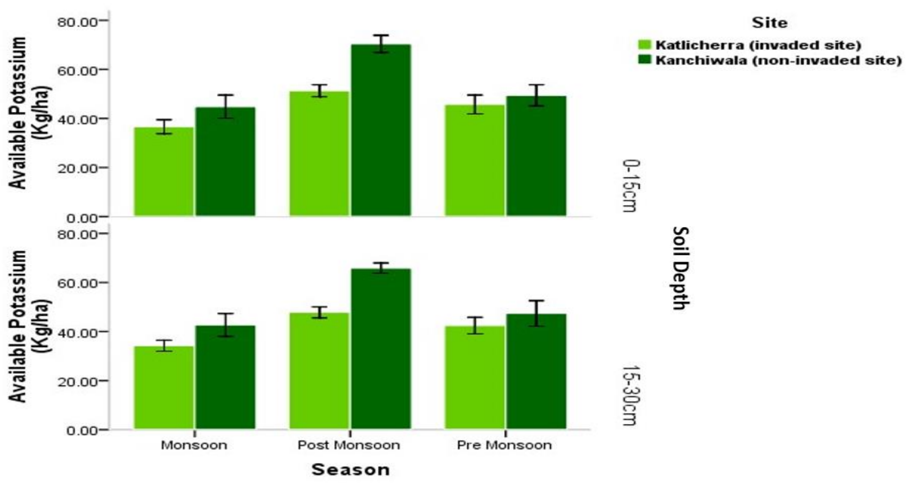


Figure 17. Available K (kg/ha) on response to soil depth and seasonal variation of the study sites.

Furthermore, at Kanchiwala the surface and the sub-surface of the soil are 54.877±2.930 and 51.985±2.678 with **F**=0.531 at p>0.05. Monsoon (43.762±1.610), Post Monsoon (68.188±1.182), and Pre-Monsoon (48.412±1.644). K was negatively correlation with WHC (r= -0.776**), SMC (r= -0.713**), and P (r= -0.846**). Whereas, Temperature (r= 0.696**), pH (r= 0.409*), TN (r= 0.427**), and C: N ratio (r= 0.485**) positively correlated with K. The Availability of the soil K at the invaded site recorded less compare to the non-invaded site of Kanchiwala. But from the study of the various workers has reported that the Availability of K is high in the invaded site and cause of that they further favored the invasion of other alien plant species (Openly, *et al.*, 2012).

Table 17. ANOVA of soil physico-chemical properties on response to soil depth in the study sites.

PARAMETERS	KATLICHERRA (Invaded Site)				KANCHIWALA (Non-invaded Site)			
	0-15cm	**15-30cm**	**F**	***P***	**0-15cm**	**15-30cm**	**F**	***p***
Temp.	27.087±0.579	26.167±0.579	1.29	0.264	24.316±0.60	23.878±0.616	0.259	0.614
BD	1.288±0.010	1.307±0.010	1.744	0.195	1.168±0.005	1.179±0.004	3.023	0.091
Porosity	51.394±.379	50.690±0.376	1.744	0.195	55.908±0.174	55.518±0.141	3.023	0.091
WHC	44.126±1.141	43.353±1.064	0.246	0.623	52.424±1.273	50.261±1.298	1.416	0.242
SMC	25.268±0.928	23.889±0.982	1.041	0.315	29.256±0.888	28.055±0.898	0.904	0.348
pH	5.446±0.077	5.058±0.043	19.368	0	5.256±0.051	4.938±0.039	24.647	0
SOC	0.919±0.059	0.797±0.058	2.183	0.149	1.447±0.066	1.344±0.067	1.209	0.279
SOM	1.583±0.101	1.374±0.099	2.169	0.15	2.496±0.114	2.316±0.115	1.224	0.276
TN	0.647±0.087	0.581±0.083	0.305	0.585	1.044±0.138	0.846±0.116	1.212	0.279
C:N Ratio	1.879±0.264	1.877±0.267	0	0.995	1.947±0.356	2.301±0.468	0.362	0.551
P	17.438±1.918	15.669±1.902	0.429	0.517	35.166±5.514	31.057±4.547	0.331	0.569
K	44.554±1.688	41.545±1.530	1.746	0.195	54.877±2.930	51.985±2.678	0.531	0.471

Mean ± Standard error; significant at 0.05

Table 18. ANOVA of oil Physico-chemical properties on response to seasonal variation in the study sites.

PARAMETERS	KATLICHERRA (Invaded Site)					KANCHIWALA (Non-invaded Site)				
	Monsoon	Post Monsoon	Pre Monsoon	F	*P*	Monsoon	Post Monsoon	Pre Monsoon	F	*p*
Temp.	27.064±0.397	23.666±0.214	29.136±0.158	100.147	0	25.142±0.189	20.896±0.183	26.253±0.452	87.595	0
BD	1.285±0.009	1.321±0.013	1.286±0.013	3.161	0.055	1.166±0.005	1.178±0.005	1.177±0.005	1.535	0.23
Porosity	51.525±0.328	50.139±0.485	51.462±0.489	3.16	0.055	55.994±0.195	55.557±0.197	55.588±0.199	1.535	0.231
WHC	49.833±0.539	39.914±0.218	41.472±0.415	167.395	0	57.717±0.408	45.182±0.495	51.128±0.649	141.598	0
SMC	29.705±0.274	20.610±0.378	23.422±0.446	156.169	0	33.588±0.292	25.004±0.270	27.374±0.250	267.33	0
pH	5.180±0.054	5.313±0.087	5.263±0.130	0.494	0.615	4.973±0.079	5.221±0.062	5.097±0.060	3.406	0.045
SOC	0.572±0.023	0.861±0.026	1.140±0.030	116.578	0	1.049±0.035	1.452±0.027	1.686±0.017	136.404	0
SOM	0.987±0.040	1.483±0.044	1.966±0.051	117.348	0	1.808±0.061	2.502±0.047	2.907±0.030	136.672	0
TN	0.257±0.033	0.547±0.052	1.038±0.039	88.274	0	0.336±0.045	1.211±0.112	1.288±0.111	31.182	0
C:N Ratio	2.761±0.408	1.753±0.179	1.120±0.061	10.159	0	3.770±0.644	1.267±0.116	1.335±0.109	13.854	0
P	8.509±0.494	18.610±2.297	22.541±1.442	20.681	0	13.940±1.761	51.907±4.666	33.488±5.400	20.014	0
K	35.460±0.935	49.611±0.889	44.078±1.317	44.889	0	43.762±1.610	68.188±1.182	48.412±1.644	74.993	0

Mean ± Standard error; significant at 0.05

Appendix 1. Pearson Correlation coefficient (***r***) values of soil physicochemical properties in Katlicherra (invaded site)

		a	***b***	***c***	***d***	***e***	***f***	***g***	***h***	***i***	***j***	***k***	***l***
a	Temp.	1											
b	BD	-0.258	1										
c	Porosity	0.257	-1.000**	1									
d	WHC	0.231	-.373*	.373*	1								
e	SMC	.403*	-.401*	.401*	.956**	1							
f	pH	0.008	-0.179	0.179	-0.028	-0.021	1						
g	SOC	.369*	0.04	-0.04	-.725**	-.591**	0.181	1					
h	SOM	.369*	0.04	-0.04	-.725**	-.591**	0.181	1.000**	1				
i	TN	.421*	-0.102	0.102	-.530**	-.445**	0.261	.819**	.820**	1			
j	C:N Ratio	-0.029	0.019	-0.019	.362*	.387*	-0.206	-.486**	-.487**	-.769**	1		
k	AP	0.081	0.15	-0.15	-.705**	-.624**	-0.169	.788**	.788**	.474**	-0.324	1	
l	AK	-.357*	0.285	-0.285	-.850**	-.822**	0.085	.577**	.576**	.336*	-0.249	.687**	1

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

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

Appendix.2: Pearson Correlation coefficient (***r***) values of the soil physicochemical properties in Kanchiwala (non-invaded site)

		a	***b***	***c***	***d***	***E***	***f***	***g***	***h***	***i***	***j***	***k***	***l***
a	Temp.	1											
b	BD	-0.022	1										
c	Porosity	0.022	-1.000**	1									
d	WHC	.646**	-0.325	0.325	1								
e	SMC	.514**	-.362*	.362*	.935**	1							
f	pH	-0.204	-0.149	0.149	-0.263	-0.274	1						
g	SOC	0.033	0.147	-0.146	-.568**	-.697**	.414*	1					
h	SOM	0.034	0.147	-0.147	-.567**	-.697**	.413*	1.000**	1				
i	TN	-0.306	-0.029	0.029	-.554**	-.702**	.454**	.790**	.791**	1			
j	C:N Ratio	0.295	-0.024	0.024	.584**	.625**	-.428**	-.733**	-.733**	-.748**	1		
k	AP	-.367*	0.13	-0.13	-.646**	-.669**	0.327	.469**	.468**	.526**	-.549**	1	
l	AK	-.696**	0.212	-0.212	-.776**	-.713**	.409*	0.316	0.315	.427**	-.485**	.846**	1

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

CHAPTER 5

CONCLUSSION AND RECOMMENDATION

Plant diversity plays a key role in sustaining environmental health and provides multiple ecosystem services. From the herbaceous to the tree layers, each stratified layer influences the ecosystem's functioning in their specific way. But on the other hand, the invasive alien plant species that are introduced to the novel habitats pose a severe threat to native plant diversity. The competition between the invasive alien plant with nearby plants can adversely influence the diversity of the native plant and also interfere with the soil nutrient uptakes. The aggressive ecological, adaptive, and competitive attributes of the alien plants make them invasive in the new habitat. Based on the results of the present study, the conclusions and recommendations are divided into two-part according to their interactions (i.e., Plant-Plant Interaction and Plant-Soil Interactions).

5.1.1 Plant-Plant and Plant-Soil Interactions

- From the layer-wise study on vegetation analysis at Katlicherra (invaded) and Kanchiwala (non-invaded) sites, the herbaceous layer recorded the highest Sorenson's Similarity index (β) i.e., herbaceous layer (β= 0.60), Shrub (β= 0.46) and Tree (β= 0.35). Further, percentage-wise species composition in herbaceous (38%) was recorded highest among the layers. From the study, it can be concluded that herbaceous plants can smoothly spread while in contrast herbs have an adaptive property to become established in any ecosystem. The herbaceous layer is the understorey of the forest ecosystem and plays a vital role in ecosystem functioning. Therefore, frequent seasonal checking of the vegetative growth of the herbaceous layer should be prioritized as the invasive alien plants like *C. odorata*, *C. hirta*, *I. cylindrica*, *L. camara*, *L. leucocephala*, and *M. mirantha* (world 100 invasive alien plants) were recorded as invasive at the study sites.

- The Asteraceae (9) family was recorded as the dominant family in terms of the phytosociological study of invasive alien plants. Invasive alien plants in the family Asteraceae are reproductively efficient with clusters of flowers and seeds. They efficiently disperse the vegetative and reproductive units through the medium of wind, water, other natural and human media. From the study, it can be concluded the invasive alien plants of the Asteraceae family dispersed very quickly in view of their reproductive potential. Therefore, during the fruiting and the flowering season plucking-off of the flowers and fruits are recommended to prevent their spread.

- The invasive alien plants like *A. conyzoides* (H'= 0.300, E= 0.056, DMg= 6.680, D= 0.028), *M. micrantha* (H'= 0.225, E= 0.042, DMg= 3.711), *C. odorata* (H'= 0.366, E= 0.076, DMg= 8.132, D= 0.107) and *L. camara* (H'= 0.259, E= 0.054, DMg= 2.919, D= 0.014) were the most dominant at the Katlicherra (invaded) site. Further, phytosociological study of the herbaceous layer revealed that *M. micrantha* (D= 0.009) at site Katlicherra and site Kanchiwala (D= 0.005) was noted as perennial creeper which was recorded at both study sites. The growth of *M. micrantha* is highly noticeable near the plantation sites at Katlicherra (invaded site). During the active period, *M. micrantha* grows very fast, climb and later it suppresses nearby plants by forming a dense covering over their canopy thereby, by stopping the light penetration for the nearby plants including trees. So, the early clearance of invasive alien plants is required to stop or slow down their luxuriant growth and further dispersion. Further, long-term vegetation and soil analysis are warranted to elucidate the plants invasion ecology and formulate sustainable management strategies.

- The aggressive spread of the specific invasive alien plants creates an environment that promotes the entry of other plant invaders. As per the study, *A. conyzoides* (IVI= 35.124), *C. odorata* (IVI= 69.415), *L. camara* (IVI= 31.341), *C. infortunatum* (IVI=28.065), and *M. malabathricum* (IVI= 21.850) are the species recorded that promotes homogeneity in a habitat which is clearly visible at Katlicherra (invaded) site. Further, it has been found that invasive plants enter into the new habitat from the gap space between the shrubs and trees and thereafter effortlessly proliferate. Therefore, the results at the invaded site validate "Empty Niche Hypothesis (ENH)". Also, "Novel Weapon Hypothesis (NWH)" may also facilitate the spread of plant invaders. The studies concluded that the possibility of colonization of invasive alien plants was high in the new habitat due to the absence of natural competitors. Therefore, planting different varieties of economically valuable shrubs and trees in invasive prone areas (disturbed or invaded site) is suggested to avoid species homogeneity.

- The phenotypic plasticity of some alien plants enables them to adapt easily and colonize in the novel environment which leads to adverse effects on native diversity. From the present study, *C. odorata* and *L. camara* were alien plants species that were found to be strong invaders at Katlicherra (invaded site). Thus, eradication of such strong invaders is to be done by burned-off soon after drying or after their life span period with proposed or proper supervision.

- *A. conyzoides* (IVI= 35.124) and *C. odorota* (IVI= 69.415), deriving their origin from Tropical America were the most dominant at Katlicherra (invaded site). Hence, the studies revealed that the invasive alien plants suppress the diversity of the native plants and also transform the habitat for further biological invasion. In other words, owing to good colonizing nature, invasive alien plants suppress the native plants and the tree seedling. Therefore, the study suggested that the invasive alien plants should be ecologically investigated and the control measure should be implemented to prevent their spread at early stages to minimize adverse impacts on native plant diversity.

- The fast-growing *L. leucocephala* (Fabaceae) was the most abundant, IVI= 61.691 at Katlichetrra (invaded site). The study also revealed that *L. leucocephala* is a strong invader as well as it has the good adaptive property to grow in diverse ecosystems (heterogeneity habitats). It is a strong invader, a good N-fixer, and at the same time utilizes the soil nutrient rapidly, thereby adversely impacting the diversity of nearby native plants. Further, *L. leucocephala* is one of the trees that produce the number of fruiting and germinate in multiple that prohibit the nearby plants. Henceforth, management of the *L. leucocephala* for the improvement of the understorey vegetations is necessary for adequate ecosystem functioning.

- The phyto-sociological analysis at Katlicherra (invaded site) revealed homogeneity compared to the non-invaded site of Kanchiwala (non-invaded site). Therefore, from the study, it has been concluded that the invasive alien plants in the district are under control to some extend at the Kanchiwala (non-invaded) site when compared to Katlicherra (invaded) site. As per the study, the invasive alien plants recorded in the study are impacting biodiversity by colonizing in habitat and creating habitat homogeneity, and eventually influencing the soil physico-chemical properties. Meanwhile, the anthropogenic destruction of vegetation deteriorates the physico-chemical properties of soil. Henceforth, the study concluded that explicit knowledge about the ecology of invasive alien plants and their effects on soil physico-chemical properties in a long term can assist in their sustainable management. Therefore, in addition to long-term ecological studies of plant invaders, the study recommended that the increased awareness of the indigenous people on the impact of invasive plants avoid or minimize biological invasion in the future.

- Compared to non-invaded site of Kanchiwala (surface soil= 24.316±0.60 and sub-surface= 23.878±0.616) Katlicherra (surface soil= 27.087±0.579 and sub-surface= 26.167±0.579) was recorded with high soil temperature. Soil SOC at Katlicherra (surface soil= 0.919±0.059 and sub-surface soil= 0.797±0.058), SOM (surface soil= 1.583±0.101 and sub-surface soil= 1.374±0.099), TN (surface soil= 0.647±0.087 and sub-surface soil= 0.581±0.083), Available P (surface soil= 17.438±1.918 and sub-surface soil= 15.669±1.902) and Available K (surface soil= 44.554±1.688 and sub-surface soil= 41.545±1.530) low soil nutrients but there was a luxuriant growth of the invasive alien plant (the agricultural lands, roadsides, and plantation). Hence, from the study, it can be assumed that the invasive alien plants tolerate high-temperature and grow in the soil with minimal nutrient availability. Therefore, present results on plant-soil interactions validate the "Resource Hypothesis (RH)" responsible for success of plant invaders. So, proper scrutiny of invasive plants is warranted which usually grow near the agricultural field, roadside, and other disturbed areas with non-uniform nutrient fluxes.

- The soil macronutrient during Monsoon at Katlicherra was observed as TN= 0.257±0.033, P= 8.509±0.494) and K= 35.460±0.935. Meanwhile, at Kanchiwala (the non-invaded site), NPK were 0.336±0.045, 13.940±1.761, and 43.762±1.610, respectively. The tree canopies and the understorey plants retain the soil nutrient and their roots act as an anchor by locking the soil components. Reduction of the soil macronutrient due to the insufficient soil coverage and the nutrient runoff, especially during Monsoon (**Table 17** & **18**) was due to the inadequate coverage of the soil surface recorded at both sites. Therefore, it is possible that the land-use changes, felling of trees for the

Shifting or Jhum-cultivation, road constructions, etc. are equally responsible for the destruction of vegetation and depleted soil minerals/nutrients of the Hailakandi district. Thus, the study proposed or recommended to reduce the unusual cutting of trees in the forest land to protect the soil minerals and nutrients from leaching/run-off and hence avoid the recruitments of invasive alien plants between the gaps created in forest land. The second alternative measure or recommendation is the collaboration of Indigenous people with the Government and Non-governmental organizations (NGOs) to avoid the risk of plant invasion in the district.

Apart from the interactions between the plant species and with the soil, the knowledge about the invasive alien plants is a very new topic for the district. The limited database on plant invaders and the perception of the indigenous people on the invasive alien plants is still unclear. Therefore, more future researches need to be performed on the impact of invasive alien plants in the district.

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Photo plate1. Photo showing alien plants recorded from the study sites: *Ipomoea carnea, Melastoma malabathricum, Oxalis corniculate, Urena lobata, Mimosa pudica, Ipomoea hederifolia, Solanum torvum, Crassocephalum crepidioides, Acanthospermum hispidum*

Scoparia dulcis, Solanum nigrum, Solanum anguivi, Cassia hissuta, Amaranthus viridis, Cassia tora, Parthenium hysterophorus, Datura innoxia and *Leucaena leucocephala*

(a)

(b)

(c)

(d)

(e)

Photo plate 2. Photo showing invasion of: (a) Ageratum (b) Chromolaena (c) Clerodendrum (d) Lantana and (e) Mikani

BIO-DATA AND BIBLIOGRAPHY OF THE CANDIDATE

NAME : Zingthoi Khuppi Sakachep

FATHER'S NAME : Chungliangula Sakachep

SEX : Female NATIONALITY : Indian

CATEGORY : Schedule Tribe (H)

PERMANENT ADDRESS : D/o Chunglianngula Sakachep House No. 24, Village: Kalidas Punji, Pin: 788161, District: Hailakandi, Assam

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EDUCATIONAL QUALIFICATIONS

Sl. No.	Name of the Examination	Year of Passing	Name of the Board/University	Percentage/Grade
1	All India Secondary School Examination (Class 10th)	2004	CBSC	59.8
2	All India Senior School Certificate Examination (Class 12th)	2007	CBSE	56.2
3	Bachelor of Science	2012	Assam University	47.3
4	Master of Science (Environmental Science)	2014	Mizoram University	75.1

PARTICULAR OF THE CANDIDATE

NAME OF CANDIDATE	: Zingthoi Khuppi Sakachep
DEGREE	: Doctor of Philosophy
DEPARTMENT	: Environmental Science
TITLE OF THESIS	: Impact of Invasive Plants on Ecological Functioning in Hailakandi District, Assam.
DATE OF ADMISSION	: 11. 08. 2015
APPROVAL OF RESEARCH PROPOSAL	
1. BOS	: 7.04.2016
2. SCHOOL BOARD	:13.04.2016
3. MZU REGISTRATION NO. & DATE	:5922 Of 2012
4. PH.D. REGISTRATION NO.	: MZU/Ph.D./894 of 13.04.2016

HEAD

Department of Environmental Sciences

LIST OF PUBLICATION

1. **Sakachep, Z. K**. and Rai, P. K. (2019). Status of Soil Nutrients in Inner Line Reserve Forest of Hailakandi District, Assam. *Natural Resource Management for Sustainable Development*. Today and Tomorrow's Printers and Publishers, New Delhi. pp. 449-452.

2. **Sakachep, Z. K.** and Rai, P. K. (2021). Influence of Invasive Alien Plants on Vegetation of Hailakandi District, Assam, North-East, India. *Indian Journal of Ecology*. 48(1): 261-266.

3. **Sakachep, Z. K.** and Rai, P. K. (2021). Impact assessment of invasive alien plants on soil organic carbon (SOC) status in disturbed and moderately disturbed patches of Hailakandi district in an Indo Burma hotspot region. *Indian Journal of Ecology*, 48(6):1698-1704.

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STATUS OF SOIL NUTRIENTS IN INNER LINE RESERVE FOREST OF HAILAKANDI DISTRICT, ASSAM

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Abstract

Soil nutrients play an important role in the success of invasive alien plants under disturbance regimes. The Inner Line Reserve Forest (ILRF) is situated in the southern part of Assam. Total forest covers 398.49 Km^2 areas. Local communities are dependent on the ILRF for their livelihood practices by logging and encroachment. From such practices in ILRF highlight the reducing soil nutrient status/level, due to the deficiency of the soil nutrient, it is difficult for the land to be productive for the long term. Macronutrients such as Nitrogen (N), Phosphorus (P) and Potassium (K) are considered as the important soil nutrients because these three nutrients are the primarily essential nutrients required for the healthy growth and development of the plants. The NPK contents of the soil have been estimated seasonally (i.e., Monsoon, post-monsoon and pre-monsoon). From the study, nutrient i.e. Nitrogen was highest during pre-monsoon and lowest during monsoon, Phosphorus was recorded highest during post-monsoon and lowest during monsoon while Potassium was highest during post-monsoon and lowest during monsoon.

Key words: *Inner Line Reserve Forest, Plants invasion ecology; Macronutrient, Nitrogen, Phosphorus and Potassium.*

INTRODUCTION

Assam falls under the Indo-Burma biodiversity hotspot region with an enormous diversity of epiphytes, ferns and angiosperm plants (Rai, 2012). Inner Line Reserve Forest (ILRF) of Assam in the north-eastern region of

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Influence of Invasive Alien Plants on Vegetation of Hailakandi District, Assam, North-East, India

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Abstract: The invasive alien plants are introduced to an ecosystem and extend their geographical occupancy with the potential to perturb the native vegetation. Aim of the present study was to study the vegetation analysis of Katlicherra block in the Hailakandi district (Barak valley) of North-East (NE) India to assess the diversity of invasive alien plants (IAPs). In this study, the vegetation analysis was done in agriculture systems, roadside, and railway side to delineate the impacts of anthropogenic disturbance on phytosociology. In vegetation analysis random quadrat methods were used. Phyto-sociological analysis revealed that the recorded plants belonged to 23 different families, 36 genera and 44 species. Further, habitat-wise, 27 herbs and 17 shrubs were recorded and the Asteraceae was noted as the dominant family. Among the recorded plants *Ageratum conyzoides, Chromolaena odorata, Lantana camara* and *Mikania micrantha* were noted as the aggressive and noxious invaders. Therefore, further ecological investigations are warranted to provide an insight into underlying invasion mechanisms. The results of such invasive-native interactions are prerequisite for formulating management strategies to safeguard the biodiversity of this study area lying in an Indo-Burma hotspot region.

Keywords: Invasive alien plants, *Ageratum conyzoides, Chromolaena odorata, Lantana camara, Mikania micrantha*

Plant invasion is an important component of ongoing global change and can potentially alter the structure and /functions of the recipient ecosystem (Rai 2015a, Ricciardi et al 2017, Zhang et al 2019). The invasive alien plants (IAPs) perturb the agriculture sustainability and food security. The IAPs can be introduced in pristine geographical landscapes either accidentally or intentionally due to easy dispersal by the pollinators and the human interference. Human mediated biotic invasions can result from dispersion roads, highways, railways, and other anthropogenic perturbations leading to habitat fragmentation (Mararakanye et al 2017). After the transportation, IAPs establish, colonize, and reproduces in the new habitat due to aggressive ecological traits/allelochemical, out-competing the native (Ratnayake 2014, Rai and Singh 2020). Several workers have studied, documented, and provided catalogue of the IAPs in a different parts of the world (Srivastava et al 2014, Singh et al 2015, Debnath and Debnath 2017, Singh et al 2018, Rajasekaran et al 2020). Such studies provide the unique opportunities for the researchers to understand on the impact of plant invasion (Debnath and Debnath 2017). Further, 17 per cent global land area noted vulnerable to invasion (Early et al 2016), however, the mechanism that make the species more vulnerable to the ecosystem are poorly understood (Sharma et al 2005, Srivastava et al 2014).

Needs for the better data and technologies to support more accurate empirical assessments of IAPs damages and control costs are required (Olson 2006). Therefore, the present study aimed to investigate the influence of IAPs on the diversity of native plants. It is worth mentioning that early detection and management needs can be prioritized only after-vegetation analysis and the evaluation of phyto-sociological status of the invasive plants in Katlicherra block of Hailakandi district, Assam, North East India.

MATERIAL AND METHODS

Katlicherra block of Hailakandi district, Assam has been selected for the study site. Initially, the district of Hailakandi had five developmental blocks viz. Aglapur, Hailakandi, Lala, Katlicherra and the south Hailakandi block. Whereas, south Hailakandi is the largest and the Katlicherra is the smallest block of the district. The total area of Katlicherra block is 674 km². The altitude is 45 meters above the sea level and falls under 24.46721º N and 92.5572º E. The average rainfall of district is 2993mm and the average temperature ranges from 30ºC- 36ºC during summer and 10ºC- 20ºC during winter (Anonymous 2013).

Vegetation analysis: The phyto-sociological analysis is to understand the floristic vegetation characteristics, to estimate the species richness and diversity (Curtis and McItosh 1950). For the vegetation analysis, 30 quadrats laid down for herbs (1×1m) and shrubs (5×5m) randomly in Katlicherra. The quantitative/phyto-sociological analysis has been done by the density, percentage of frequency,

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Impact Assessment of Invasive Alien Plants on Soil Organic Carbon (SOC) Status in Disturbed and Moderately Disturbed Patches of Hailakandi District in an Indo Burma Hotspot Region

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Abstract: Invasive alien plants introduced in novel ecosystem either accidentally or intentionally can perturb the diversity of native plants and concomitantly influence the soil nutrient dynamics. The present study aimed to investigate the impact of the invasive alien plants (IAPs) on the native vegetation diversity and the soil in forestry/agro-forestry ecosystems of Hailakandi District, Assam. This region is of extreme ecological relevance as it underlies in an Indo Burma hotspot region. In this study, an ecological investigation is performed along disturbance gradient to emphasise the plant-plant and plant-soil interrelationship. A total of 68 plant species were recorded in vegetation analysis during the ecological assessment of IAPs. The similarity index in herbs and the shrubs layer were 0.56 and 0.46, respectively. Meanwhile in soil analysis, the soil organic carbon (SOC) and the soil organic matter (SOM) were noted higher in the moderately disturbed site, when compared with the disturbed site. The study further observed that land use change significantly influences and plays a crucial role for the landscape spread of IAPs. Also, they alter native vegetation composition and cause depletion in SOC and SOM. This plant invasion ecology studies therefore predicted that land use changes increased pressure on the natural ecosystems, especially during the monsoon season.

Keywords: Invasive alien plants, Plant-plant interactions, Plant- soil interactions, Indo-Burma hotspot, Land use change

In current Anthropocene era, biological invasion is among most severe ecological threat and widely considered as key challenge for biodiversity conservation. In Indian biodiversity perspective, 40% of flora is identified as aliens (Rai 2012, Iyer et al 2019). Invasive alien plants (IAPs) are well adapted to diverse ecosystem due to the fast growth, adapted life cycle events, hardiness, and quick rates of reproduction (Sekar 2012, Kopelson 2014, Rai and Singh 2021). Their landscape spread is particularly devastating to forest ecosystem by forming a dense monoculture ground cover, thereby, suppressive to native and endemic forestry/agro-forestry vegetation (Zhang et al 2019).

Indian subcontinent with four global biodiversity hotspots is rich and importantly among these three i.e., the Western Ghats, Himalayas, and the Indo-Burma importantly accounts for 11% of the world's plant diversity (Rai 2015, Iyer et al 2019). In this aspect, Indo-Burma hotspot is comprised with rich diversity of ethno-medicinal plants linked with human health (Rai and Lalramnghinghlova 2011a, b). The impact of the IAPs are not only limited to the habitat destruction of native plants. Rather, their adverse effects extend to soil process (Ehrenfeld 2003, Rai 2021), as IAPs trigger the changes in biogeochemical cycling and soil nutrient dynamics (Rai 2013, Bjeckner et al 2007, Rai and Singh 2020). Interestingly, these alterations in soil attributes can vary across different seasons. In this respect, the effects of IAPs on Soil Carbon (SC) storage and sequestration are of major concern (Peltzer et al 2010) as soils are the largest terrestrial organic carbon pool (Rai 2009, Craig et al 2015). In this aspect, widespread changes in atmospheric carbon dioxide (CO_2) concentrations induced due to the plants invasions could have important climate change implications (Rai 2018, Rai and Singh 2020). The plants diversity and or the distribution may lead to changes in the soil C and due to which the Net Primary Productivity (NPP) also get affected (Raizada et al 2008). The fragmentation of forest ecosystem due to IAPs impacts the soil C-content by influencing the NPP in the invaded areas (Williamson and Fitter 1996, Raizada et al 2008).

Anthropogenic disturbances can remarkably exacerbate the problem of IAPs spread. For example, Honnay et al (1999) determined that the forest disturbances boost the IAPs diversity. Likewise, the age old traditional practice of unregulated shifting cultivation can also perturb the soil quality and environmental sustainability (Rai 2009, 2017). Therefore, the human interferences play the vital role in conversion of intact forest ecosystem into disturbed fragmented ecosystem, thereby making the site ripe for the arrival of IAPs. In this sense, Mukaromah and Imron (2018) concluded that there is luxuriant growth of the IAPs at the

ABSTRACT

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ABSTRACT

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IMPACT OF INVASIVE PLANTS ON ECOLOGICAL FUNCTIONING IN HAILAKANDI DISTRICT, ASSAM

Abstract

Invasive alien plants are considered to be the second most serious threat after habitat destruction. Global Invasive Species Programme (GISP) defined invasive alien plants as "*Invasive alien are non-native organisms that cause or have the potential to cause harm to the environment, economies, or human health*". In the changing environmental/climatic variables, the invasive alien plants dramatically affect the environment on a regional, national, and global scale. Invasive alien plants are very good competitors and highly tolerant species when compared with native plants. Invasive alien plants altered the biodiversity distribution, ecosystem services, as well as socio-economic or livelihood prospects. The effect of invasive alien plants on the soil attributes are exerted by changing the soil physico-chemical characteristics and biogeochemical/nutrient cycling. The allelopathic and antimicrobial toxic compounds released by several invasive alien plants can subsequently increase the nutrient availability in the soil and subsequently chelate toxic metals. Therefore, invasive plant species compete directly with native species for light, moisture, soil nutrient, and space. The impact of invasive plants species in native plant species, communities, and ecosystems is manifested in terms of plant-plant interaction and plant-soil interaction. The study site (i.e., Hailakandi district) was situated in the southern part of Assam i.e., i) Katlicherra (Site-I) lies between Latitude is 24°28'3.9216''N and the longitude is 92° 31'25.7724''E. ii) Kanchiwala (Site-II) lies between Latitude is 24°13'15''N and 92°31'15''E Longitude.

The objective of the present study was: i). To evaluate the impact of invasive plants on native plant diversity at selected sites. ii). To evaluate the impact of invasive plants on soil Physico-chemical properties at selected sides. iii). To compare the invaded site with non-invaded one.

The spectrum of vegetation in diversity indices was determined by using Shannon-weaver Index (H'), the evenness index of the community by Pielou's index (E), species

richness by Margalef's Index (R), and the species dominance by Simpson's Index (D), and the similarity coefficient by the Sorenson's Similarity Index (β). Different quadrat sizes (1x1m, 5x5m, and 10x10m) that enumerate herb, shrub, and tree layers, respectively. The quantitative analysis of vegetation was counted to estimate Density, Abundance, Frequency, Relative Density (RD), Relative Abundance (RA), Relative Frequency (RF), and Important Value Index (IVI).

In the phytosociological study, a total of 102 species were recorded from both the study sites. In the herbaceous layers, 39 species, 36 genera, and 23 families were documented and Asteraceae was the most dominant family at both the study sites. A total of 30 shrubs species were recorded from both the study sites that belonged to 25 genera and 18 families. In the tree layer, 33 species, 28 genera, and 16 families were recorded. Further, the study revealed that the maximum invasive alien plants species encountered in the present study were native to the American continent. At Katlicherra (i.e., invaded site) *Ageratum conyzoides* recorded highest diversity indices followed by *Mikania micrantha*. However, at Kanchiwala (non-invaded site), *Triumfetta rhomboidea* was recorded with highest diversity indices. Further, *Chomolaena odorata* followed by *Lantana camara* were observed with the highest diversity indices at Katlicherra (invaded) site. Whereas, *L. camara* and *Urena lobata* were planted invaders with the highest diversity indices calculated in the shrub layer at Kanchiwala (non-invaded site).

The diversity indices calculated concerning trees layerindicated that at Katlicherra (invaded site) alien plant i.e., Leucaena was noted with higher diversity indices value followed by *Oroxylum indicum*. While at Kanchiwala (non-invaded site) *Toona ciliata* was observed with the highest diversity indices followed by *Dipterocarpus turbinatus, L. leucocephala*, and *Tectona grandis*. Layer wise Sorenson's Similarity Index during present vegetation analysis showed that the herbs at Katlicherra (invaded site) and Kanchiwala (non-invaded site) were about 0.60 similar followed by shrubs and trees with computed similarity index values of 0.46, and 0.35, respectively.

In the present study, IVI at Katlicherra was highest for *A. conyzoides* followed by *M. micrantha*, *Leucas aspera*, and the least IVI was noted in the case of *Cyperus rotundus*.

While at the Kanchiwala site, *T. rhomboidea* was recorded with the highest IVI value followed by *M. micrantha*, *A. conyzoides*, and the least for *C. crepidioides* and *Euphorbia hirta*.

The shrubs layer at Katlicherra *C. odorata*, *L. camara*, *C. infortunatum*, *I. carnea*, and *M. malabathricum* were the five plant invaders recorded with the high IVI. While at Kanchiwala, the IVI of shrubs *M. angustifolia*, *L. camara*, *U. lobata*, *C. odorata, and Grewia flavescens* were recorded with high values. The present study revealed that *L. camara* is a strong invader as per the phytosociological study and IVI. Among trees at Katlicherra (invaded site), *L. leucocephala* was recorded highest IVI followed by *O. indicum*, *T. grandis*, and the least was in the case of *C. tabularis*. However, at Kanchiwala (non-invaded), the tree species that recorded highest IVI values were *T. ciliata*, T. *grandis*, *D. grandiflora*, while the least IVI was recorded in the case of *Vitex pubescens*. Henceforth, *L. leucocephala* with high IVI was most abundant at invaded site of Katlicherra.

The Physico-chemical properties of soil are the indicators of soil quality. Bulk Density (BD), Porosity, Soil Moisture Content (SMC), Water Holding Capacity (WHC), pH, Soil Organic Carbon (SOC), Soil Organic Matter (SOM), Total Nitrogen (TN), Carbon: Nitrogen ratio (C: N ratio), Available Phosphorus (AP), and Available Potassium (AK) are the crucial parameters in analysing the interaction between 'soil-plants' at the study sites. The soil was collected during Monsoon, Post-Monsoon, and Pre-Monsoon to depict a seasonal variation with the soil depth i.e., 0-15cm (Surface soil) and (ii) 15-30cm (Sub-surface soil). High nutrient in surface soil was recorded when compared to the sub-soil. The non-invaded site (Kanchiwala) recorded higher soil physico-chemical characteristics (Porosity, WHC, SMC, SOC, SOM, TN, C: N ratio, AP, and AK) compared to the invaded area (Katklicherra). This indicates that the soil physico-chemical properties are significantly influenced by the rapid increase of invasive alien plants.

As per the Global Invasive Species Database (GISD, 2018) *C. odorata, C. hirta, I. cylindrica, L. camara, L. leucocephala, and M. micrantha* are recognized as world's 100 worst invasive plants which were encountered in present study sites and especially dominated at the invaded site (Katlicherra). Therefore, the prioritization is essential to minimize the effect of invasive alien plants on native plants, especially at the sites of prime ecological relevance. In Last few decades, this Indo-Burma global biodiversity hotspot has experienced significant loss in the forest covers because of biotic pressure, shifting cultivation, agricultural expansion, urbanization that contributed to the rapid increase of the invasive alien plants. Invasive alien plants found to spread more efficiently in the habitats stressed with anthropogenic stressors which eventually perturb abiotic environment (soil and water) and native vegetation. Since, Assam falls under the Indo-Burma biodiversity hotspot region, the long-term ecological investigation and sustainable management strategies are warranted in future perspective.