IMPACT OF *Lantana camara* L. INVASION ON VEGETATION DIVERSITY AND SOIL MICROBIAL POPULATION IN DHADING, CENTRAL NEPAL

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OCTOBER, 2023

DECLARATION

I, Binita Pandey, hereby declare that the work enclosed here is entirely my own, except where states otherwise by reference or acknowledgement, and has not been published or submitted elsewhere, in whole or in part, for the requirement for any other degree or professional qualification. Any literature, data or works done by others and cited within this thesis has been given due acknowledgement and listed in the reference section.

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Date 8th September 202

RECOMMENDATION

This is to recommend that the Master's thesis entitled "**Impact of *Lantana camara* L. Invasion on Vegetation Diversity and Soil Microbial Population in Dhading, Central Nepal**" is carried out by Binita Pandey under our supervision. The entire work is based on original scientific investigations and has not been submitted for any other degree in any institutions. We therefore, recommend this thesis work to be accepted for the partial fulfillment of Master's Degree in Botany.

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ABSTRACT

Lantana camara L. a plant from Verbenaceae family is one of the 100 worst invasive plant. This present study was conducted to assess the impact of *Lantana camara* L. on vegetation and soil microbes in Dhunibesi municipality, Dhading, Nepal. Random stratified sampling method was used with two categories: Invaded and Non-invaded. Total of 100 quadrates, 50 quadrates in each category of 10×10m were laid and inside of each plot three sub-plots of 5×5m for shrubs and 1×1m for herbs were laid in each category. Vegetation and soil attributes were studied in each category. A total of 159 species (103 in invaded and 139 in non-invaded sites) belonging to 73 families were recorded from the study sites. The density and frequency of other plant species were decreased in the area invaded by *L. camara* as compared to the non-invaded sites. Plant density, Simpson's diversity (D), Concentration of dominance, Shannon-wiener index (H), Species richness and evenness varied significantly (t-test, $p<0.05$) among the categories. These variables were lowest in invaded sites and highest in non-invaded sites. Analysis of similarity index showed the significant change, ($p<0.05$) in vegetation composition among the invasion and non invasion condition for all growth forms. pH of soil was found higher in invaded sites than the non-invaded sites but the change in pH was not significant.

Invasion of *L. camara* also influenced the soil microbe population. Population of bacteria and fungi were found significantly higher in non-invaded sites and lower in invaded sites. A total of 34 species (29 from non-invaded and 22 from invaded sites) of fungi were recorded from the soil of study sites. The species richness of fungi was found significantly higher in non-invaded sites. The study concludes that the invasion of *L. camara* changes the vegetation density, frequency, species diversity, evenness and species composition along with soil pH, soil microbe population and fungal species composition. The significant differences in these parameters suggest that *L. camara* is changing the vegetation and soil microbe composition and diversity in Dhunibesi so required to manage and remove the *L. camara* for the protection of species diversity.

Keywords: *Invasive species, Species Diversity, Soil microbe interaction, Impact*

ACRONYMS AND ABBREVIATIONS

AMF	Arbuscular Mycorrrhizal Fungi
CFU	Colony Forming Units
DHM	Department of Hydrology and Meterology
ºC	Degree Celcius
ha	Hectare
i.e.	That is
IAPS	Invasive Alien Plant Species
IS_j	Jaccard's Similarity Index
IUCN	International Union for Conservation of Nature
IVI	Importance Value Index
Max	Maximun
Min	Minimum
mm/yr	Millimeter per year
PDA	Potato Dextrose Agar
PH	Negative Logarithmic Hydrogen ion
Sp.	Species
SPSS	Statistical Package for Social Science

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1. INTRODUCTION

1.1 Background

Invasive alien species are a non-native biological entity that may be plants, animals, fungi, viruses and bacteria that are introduced and spread outside their natural habitats and threaten biological diversity of introduced area. Invasive species produce large number of reproductive offspring, often produce large number of seeds that may disperse widely and remain living in the soil for long period of time and sustain several self-replacing populations over several life cycles (Richardson et al., 2011). Invasion is defined as a whole process from transportation of plants or plant propagules to new location, its introduction into new location, its colonization, naturalization to spread of population outside of area where first introduced (Catford et al., 2009).

Invasive plant species have become one of the major threats of plant biodiversity loss (Holmes et al., 2000; Sharma and Raghubanshi,2005, Tiwari et al., 2005). At least 10% of the world's vascular plants have the capacity to invade different ecosystems and affect native biota in a direct or indirect way (Singh et al., 2015). Globally, 6075 species of vascular plants have been reported as invasive (Royal Botanical Garden Kew, 2017). In context to Nepal, 182 flowering plant species belonging to 49 families and 129 genera comprising the 2.8% of Nepal's flora are naturalized and 27 species belonging to 14 families and 24 genera representing 0.5% of Nepal's flora are invasive (Shrestha & Shrestha, 2021).

Lantana camara L. a plant from Verbenaceae family is one of the 100 worst invasive plant (Lowe et al., 2000). This plant is native to West Indies and now it is distributed to different countries like Australia, Pacific islands, Thailand, Cambodia, India etc. In Nepal, it was first reported in 1966 by Yamazaki (Shrestha 2016). For the first time, it was recorded in eastern Nepal from the plains of North-east India. And now, it can be found in different habitat from 75 to 1700m above the sea level all over the Nepal (Shrestha 2016). It is mainly found in forest, shrubland, grassland and agroecosystem in terai, Siwalik and hilly region of Nepal (Shrestha 2016, Tiwari 2005).

The distribution of *Lantana camara* species shows a severe threat of an ecosystem in hot spot area (Sharma et al., 2005), and threatening the floristic vegetation and water resources in South Africa (Holmes et al., 2000), evergreen rain forests of the Eastern Highland of Zimbabwe (Timberlake & Musokonyi, 1994) etc. The expansion of the invasion is due to expansion of global trade, use of exotic plant for ornamental and horticultural purposes, nature of plant to grow in all types of well drained soils and in a wide rainfall range from seasonal dry forest to rain forest and is also drought resistant (Ayesha, 2006). *Lantana camara* produces a large number of seeds and is dispersed by birds. Under condition of high light, soil water and soil minerals, germination of seeds is rapid and can compete against native species and can become the dominant understory species blocking the natural succession process and reducing biodiversity (Ayesha, 2006).

Due to the wide spreading nature of *Lantana camara,* they form a monoculture stands and displace the native species, disrupting the ecosystem processes. It also reduces the carrying capacity of rangelands, increase the risk of fire damage and decrease the regeneration capacity of other species including trees (Shrestha, 2016). The allelo-chemicals released by roots and shoots in the soil also inhibit the growth of neighboring plants (Yadav et al., 2004, Tiwari et al., 2005). Different allelo-chemicals, such as phenolic compounds, sesquiterpenes, triterpenes and a flavonoid are found in the extracts, essential oil, residues and rhizosphere soil of *L. camara.* These allelo-chemicals inhibit the regeneration process of local and indigenous plant species by reducing their germination and seedling growth and enhancing their mortality (Kato-Noguchi & Kurniadie, 2021).

These secondary metabolites not only inhibit the growth of plants, they also can alter or disrupt below ground mutualism between native species and mycorrhizae (Stinson et al., 2006). The release of these compounds on the soil influences the microbial communities. Changes in the physical or chemical attributes of the soil modifies the living communities in the invaded soil thus affecting a soil food web and total soil microbial communities (Kourtev et al., 2003).

1.2 Statement of problem

Lantana camara has invaded most of the grassland and bare land of Dhunibesi Municipality. This may result in the decrease in species diversity or even extinction of some native plant species. *L. camara* invasion in Dhunibesi may alter the vegetation structure, species composition. Furthermore, it is gradually spreading its habitat from grassland, bare land to forest area and agro ecosystem. Its invasion can adversely affect the land-use pattern of the Dhunibesi. The spreading and subsequently formation of mono-cultural stands of *L. camara* may affect the beautiful scenery of the area.

1.3 Justification

Invasion of *Lantana camara* are increasing in frequency and severity resulting in reduction in biodiversity, loss of habitat etc. The ecosystem structure, functions and biodiversity has been changed due to the invasion of *L. camara* and displaced indigenous plants. Invasion of this species modifies the community in various ways that include alteration of native species diversity, evenness and richness. Following the encroachment of the invasive alien species *L. camara* in the Dhunibesi Municipality, there is need to establish its impact on local plant species in order to develop management strategies.

Many studies have documented the allelopathic impact of *L. camara* on different plants (Achhireddy & Singh, 1984, Bansal, 1998, Mishra, 2015, Sharma et al., 2017). However, till the date, few studies have been carried out to consider the effect of invasive species *L. camara* on the native vegetation of this area. Based on these findings, it is imperatives that the impact of *L. camara* invasion to be assess. This might contribute to a better understanding of the impact of the species on the environment and helps to develop management strategies on future.

1.4 Objectives of the study

General objective

To determine the impact of *L. camara* on plant diversity, soil microbes and soil pH.

Specific objectives

- To study the effects of *L. camara* invasion on vegetation composition and diversity.
- To study the effects of *L. camara* invasion on soil pH.
- To study the effects of *L. camara* invasion on soil microbe population.

2. LITERATURE REVIEW

2.1 INVASIVE SPECIES IN NEPAL

Invasion of biological invasive species are increasing day by day across space and time ultimately causing difficult for its management (Shrestha et al., 2017). Climate of the today's world are changing rapidly. Thus, changing climates are likely to intensify invasion of invasive species by increasing climatically suitable areas of species (Shrestha & Shrestha, 2021). Biological invasions have been considered as one of the major components of global environmental changes and become a cause of loss of native biodiversity (Ricciardi et al. 1998). With the increase in globalization, global trade, Human movement etc intensity of biological invasion has been increasing in all parts of the world (Simberloff, 2000). The problems of invasive species are increasing in both developed and developing countries but the problems are being severe mainly in developing due to the lack of plenty of resources and expertise for proper adaptation and mitigation (Siwakoti et al, 2016).

Nepal is located in the cross road of six floristic region of Asia i.e Sino-Japanese, Southeastern Asiatic, Indian, Sudano-Zambian, Irano-Turranean and Central Asiatic consisting all the floral elements present in all region (Dobremez, 1976). Due to the wide range of elevation gradient, heterogeneity in geomorphology and climatic condition, species belonging to every environment may find suitable habitat (Tiwari, 2005). Imbalance in Nepal's International trade with import to export ratio also play a major role in invasion of new species (Shrestha et al, 2017). Till the date, about 182 alien flowering plant species are recognized to be naturalized in Nepal, out of which 27 species are invasive. Among which four species i.e *Chromolaena odorata, Eicchornia crassipes, Lantana camara* and *Mikania micarantha* belongs to the world's worst invasive alien species (Lowe et al., 2000).

In Nepal, species richness and distribution pattern of Invasive plant species varies with altitude and phytogeographic regions (Eastern, Western and Central Nepal). Maximum number of IAPS is found on the southern part of the country (Shrestha, 2016). Naturalized and Invasive plant species are distributed on the basis of climate of their native region. Majority of the IAPS of Nepal (74%) are native to tropical Americas followed by Europe (8.4%) (Bhattarai et al. 2014), so their number is high in the Tarai and Siwalik having tropical to sub-tropical climate (Tiwari et al., 2005, Shrestha et al., 2017). Few species like *Ageratina adenophora, Galinsoga quadriradiata* etc has been reported from the high mountains. Until now, no IAPS has been reported from the high Himal which shows that on increasing the elevation, the species richness of IAPS across vegetation types declines (Shrestha et al., 2017). On the basis of phyto-geographic region, Central Nepal is the zone where number of naturalized species and IAPS are higher than that of Western and Eastern Nepal (Shrestha & Shrestha, 2021).

2.2 Characteristics of invasive species

A species to be an invasive they must be capable of establishing self-sustaining population in areas of invasion and produce a significant change in terms of vegetation composition, structure or ecosystem processes (Vilsteensaari et al., 2000). Study done by Macdonald et al (1991) in South Africa showed that most of the successful alien invaders have high shoot to root ratios than native plants species which they displace. Higher and faster germination rate of invader species than that of native species also enhance the processes of invasion (Klink, 1996). Invasive species often produces prolific seed that may disperse widely and that may remain in the soil for long period of time (Heffernan,1998). Strong vegetative growth, abundant seed production capacity, high ability to establish over large areas, high adaptation for wind and insect pollinations are the characters that help them to establish and spread in an area of introduction (Tiwari et al., 2005).

High reproductive fecundity, high ability of spreading to their new location, capability of surviving in a wide range of climatic condition, high capability of resource utilization and allelopathic effects to native species help the invasive species to survive and spread in the area where they are introduced (Ratnayak, 2014). Phenotypic plasticity and genetic differentiation, lack of predators and pathogens, production of large number of viable seeds with successful dispersal mechanism facilitate the invasive species to adapt in a new habitat and environmental heterogeneity (Ratnayak, 2014). Differ in trait complexes, high resource acquisition and low defense investment of invasive species than its coexisting native species are the characteristics that helps the invasive species to spread in new habitats (Mathakutha et al., 2019).

2.3 Invasive characteristics of *L. camara*

Lantana camara has a number of biological characteristics that help it to become an invasive species. It has a wide geographical range i.e 35°N- 35°S beyond its native range and become naturalized about 60 countries (Day et al., 2003). This wider distribution of *L. camara* indicates the threats on different habitats and ecosystems including hotspot areas (Sharma et al., 2005).

Low mortality rate of mature *L. camara* in its naturalized range in presence of high light, soil moisture and soil nutrient and highly competitive ability of *L. camara* help the plant to displace and replace native species (Sahu and Panda, 1998). High rate of invasion is also due to the presence of high percentage of fruit formation and presence of a range of pollinators (Sharma et al., 2005). The processes of invasion are enhanced by nutrient additions, with animal droppings, canopy removal and soil disturbance, forming a good seed-bed (Gental and Duggin, 1998).

Invasiveness characteristics of *L. camara* is also increased due to homeostatic fitness and phenotypic plasticity (Sharma et al., 2005). It has a very effective competition capacity with the native colonizers and has capacity to interrupt the regeneration capacity of the indigenous plant species by decreasing germination rate and early growth rate ultimately increasing mortality rate (Sharma et al., 2005). It reduces productivity of the native plants by competing strongly for moisture and nutrients (Day et al., 2003).

Different allelopathic substances are produce in the shoot and root of *L. camara* that altered habitat of local species and decrease the population of native flora and fauna (Tiwari et al., 2005). *L. camara* bear about fourteen phenolic compounds that show direct effect in germination of seed and growth of young plants (Sharma et al., 2005).

Gentle and Duggin (1998), studied that increased on the density of *L. camara* increased the suppression of native species due to allelopathic impacts. On the basis of concentration of allelo-chemicals, the growth of plant either promote or inhibit. The concentration of allelochemicals decreases from leaf, stem to root increasing the leaf toxic to the animals that feed on it (Achhireddy and Singh, 1984). *L. camara* contains several allelochemicals like phenolic compounds, sesquiterpenes, triterpenes and a falvonoids. Release of these chemicals in the rhizosphere soil under its canopy and neighboring environment from plant parts can inhibit the germination and growth of other plants species (Kato-Noguchi and Kurniadie, 2021). Morphological variation and high genetic diversity, survival at 4.5-8.5 pH, 1000-4000 mm annual rainfall, tolerant capacity to shade etc contribute to invasion into non-native range (Kato-Noguchi and Kurniadie, 2021).

Increase in transport, trade and travel increased the rate of introduction of invasive species. Prolific seed production throughout the year, high germination rate at any time of the year, seeds viability for longer periods, its ability of vegetative propagation, better competition capability and wide spread geographic range help in successful dispersal (Abebe, 2018).

2.4 Impacts of *Lantana camara*

Invasive alien species is considered as one of the major threats of ecosystem degradation. Invasive species alter the structure and composition of natural ecosystem, disrupt its ecology and displace the native species by degrading the landscape's uniqueness and its resources like amount of space, water, sunlight, soil structure, soil composition and soil nutrient contents (Tiwari et al., 2005). They are capable of hybridizing with the native plant that ultimately result in changes to a plant's genetic makeup (Kunwar and Acharya, 2013).

Due to the rapid increased in trade and travel throughout the world, the rate of movement of new species either intentionally or unintentionally also increased. When these species established in a new place, adverse impacts on economy and environment will be increased (Yaduraj et al., 2000). They have caused hundreds of species extinctions through the process of competition, predation, hybridization, transmission of pathogens and disruption of local ecosystems services (Andreu and Vila, 2011).

Introduction of invasive species altered the species composition and structure indirectly by modifying soil environment and directly through allelopathic means. Alteration in physical and chemical properties of soil, alter the competitive potential and availability of light by the invasion of new species, indirectly changes in floral composition.

Modification in environmental condition usually lead to an increase in some species at the loss of others (Clegg, 1999).

Day et al. 2003 pointed that *Lantana camara* has capacity of blocking succession and displacing native species, which ultimately reduced in biodiversity. Infestation of *Lantana* bring visible changes in the structure and composition of native communities. Increased in *Lantana* in forest understorey decreased the community biomass and increased the foliage component in the vegetation (Bhatt et al., 1994). Invasion of *Lantana camara* reduced the seedling growth of almost all species and reduced the growth of mature trees and shrubs (Lamb 1988).

Invasive alien plant species are the biological polluters and have capacity to hybridize with native plant relatives causing the unnatural changes to a plant's genetic makeup (Kunwar and Acharya 2013). In Florida USA, *L. camara* can compete and hybridize with the endangered, indigenous species of *L. depressa,* contaminating the gene pool of rare plant (Anon, 2000).

Hydrological patterns, soil chemistry, soil water holding capacity and erodibility can be alter due to invasion of alien species. The decrease in plant biodiversity can result in change in soil chemistry, level of soil erosion, transformation of land and disruption in ecological processes and functioning (Crowling et al., 1997). Day et al., 2003 considered the invasion of *L. camara* are the cause of destruction or loss of pasture land in Queensland. Monospecific strands of *L. camara* can replace native vegetation by reducing the environmental quality and disrupting certain ecological function ultimately causing extinction of species. Certain ecological functions can be restored through restoration ecology but extinct species cannot be restored (Myers et al., 2000).

Invasive plant species release different chemical substances from their above and belowground parts into the soil by the process of leaching and exudation (Dayakar et al., 2009). These released chemical substances have the capacity to alter soil biophysical properties and ultimately alter plant diversity (Thapa et al., 2016. Soil microbial community has both positive and negative feedback the plants (Bonanoni et al., 2005). Negative feedback involves different pathogenic effect, production of different allelo-chemicals and bioactive substances whereas positive feedback involves mutual association between root and fungus and production of plant growth enhancing substances (Bias et al., 2006). Invasion of invasive species can modify soil microbial communities (Van der Putten et al., 2007).

Sundaram & Hiremath, (2012) reported the fourth fold increase in density of *L. camara* and decline in species richness, diversity and evenness of native species in the duration between 1997 to 2008 in India's Biligiri Rangaswamy temple wildlife sanctuary. This decrease in native plant diversity and increase in density of *L. camara* are mostly linked to competition for resources and space.

According to Simba et al. (2013), allelo-chemicals produced by *L. camara* potentially alter the nature of substances in which plant grow and also increase the competitive ability of the invasive species for nutrients uptake. Macro-nutrient like magnesium, calcium, potasium were found higher whereas the phosphorous and nitrogen were less in the *L. camara* invaded soil. High soil pH in the invaded sites of *L. camara* were recorded and is known to accelerate litter decomposition and help in nutrient availability (Simba et al., 2013). Bacteria and fungi present in the soil invaded by *L. camara* were responsible to change the nutrient cycle resulting in the competitive outcomes in their favor (Hawkes et al., 2005).

Invasive species show negative ecological impacts and affect biodiversity by impacting indigenous vegetation and food web associated with this vegetation. *L. camara* affects the indigenous plant species richness as well as invertebrates in the riparian habitats in the south Africa (Raphela & Duffy, 2022).

Ruwanza (2020), found that *L. camara* invasion at different cover conditions impact the species diversity, cover and composition of species in the Vhembe Biosphere, Limpopo Province of South Africa. It has become one of the problematic species and are responsible to transform the natural ecosystem.

Invasion of *L. camara* modified the plant community structure and also reduced the plant species richness and diversity significantly. Bhatta et al. (2020), found that the invasion of *L. camara* reduced the species richness of native plants by less than half on the Bardiya National Park.

2.5 Impact of *L. camara* on soil microbes

Fungi are the decomposers of organic debris in different ecosystem throughout the world. They play a crucial role in decomposition and nutrient cycling in the ecosystem. After the introduction of invasive species in a healthy ecosystem, invasive species disrupt the fungal mutualistic associations with the native plants. Moreover, invasion of invasive species even prevents the mutualistic associations from occurring by changing the soil nutrients dynamics, interrupting soil food webs or introducing plant pathogens (Ehrenfeld et al., 2005).

Pysek et al. (2012), reveals that the richness and abundance of soil biota increase due to the invasion of exotic species. The invasive species produce more leaf litter with lower C:N ratio compared to native species. Increase in quality and quantity of litter increases the availability of carbon in the soil, which could allow the establishment of diverse and abundant soil microbes community (Zhang, 2019).

Soli bacterial, and fungi play a vital role in nutrient cycling and organic matter turnover but introduction of invasive plant species can alter the activity and structure of soil microbe communities (Kourtev et al., 2002). Invasion of invasive species changed the soil chemistry and bacteria are very sensitive to the changes in the environment and alter the soil bacterial communities resulting in the changes in the whole ecosystem (Gaggini et al., 2018).

The spread of alien plant species significantly affects abundance and diversity of soil microbes including the plant symbionts, arbuscular mycorrhizal fungi (AMF) (Tanner and Gange, 2013). Niu et al. (2007), carried out study on alteration of soil microbial communities by *A. adenophora* in China. They found that *A. adenophora* invasion strongly increased the abundance of soil VAM and the fungi/bacteria ratio. Their results suggested that *A. adenophora* alters the soil community in such a way that favors itself and inhibits native plant which helps to promote the invasion. The soil characteristics and soil biota changed after *A. adenophora* invasion and helped in increasing available nutrients (N, P, K) and soil mutualists (VAM and fungi).

Invasive species accelerate the succession of soil microbial communities in their rhizosphere and promote microbial functions, which facilitate the invasion process

(Suding et al., 2013). Si et al. (2013), studied the change in the characteristics of soil microbial communities on different level of plant invasion and found that low degree of invasion of *W. trilobata* significantly increased the soil pH values. Richness of the soil fungal community increased on both low and high degrees of *W. trilobata* invasion but the soil bacterial community did not show any effects.

Invasive species modified the belowground soil microbe community. Balami et al. (2017), reported that *A. adenophora* altered the species composition, species richness and occurrence frequency of soil fungi. Lower species richness of saprophytic soil fungi and high occurrence frequency of pathogenic soil fungi is associated to *A. adenophora.* Wang et al. (2021), found that when the invasive plant species once replace native plants and occur at high density, they can modify fungal communities, increased taxonomical and functional similarities of fungal pathogens even at low plant density that may limit negative soil effects on invasive plants.

3. MATERIALS AND METHODS

3.1 Study area

3.1.1 Location

Dhading district lies between 80º17’ to 84º35’N longitude and 27º40’ to 28º17’E latitude. Its altitude ranges from 300m to 7110m above the sea level and covers an area of 1926 sq.km. The study was carried out in Dhunibesi municipality ward number 1 and 2 of Dhading district. Dhunibesi municipality is located at 27°46’N - 85°14’E and 27°76’N - 85°24’E coordinates. It covers an area of 98.64 sq.km. It is bounded by Chandragiri municipality, Nagarjun municipality, Tarkeswor municipality and Shivapuri National Park of Kathmandu in the east, Thakre Gaupalika of Dhanding in the west, Belkotgadi Municipality and Kakani Gaunpalika of Nuwakot in the north and Thaha municipality of Makwanpur in the south.

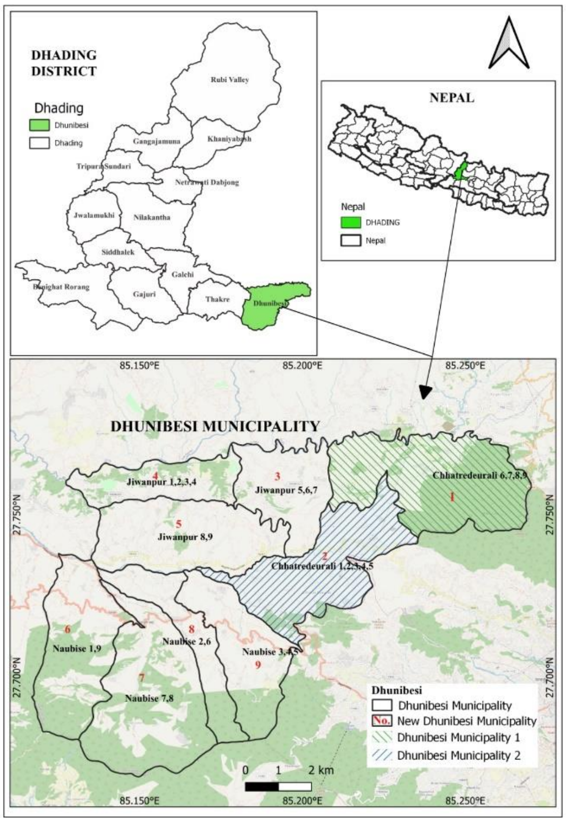


Figure 1: Administrative map of Nepal, Dhading district and Dhunibesi municipality showing study area. (Source: QGIS 3.4.8 with GRASS 7.6.1).

3.1.2 Climate

Dhunibesi municipality lies in the sub-tropical region of Nepal. The climatic data of Naubesi weather station for ten years (2011-2021) was obtained from the Department of Hydrology and Meteorology. The maximum average temperature was observed in the month of May (32.53ºC) and June (32.71ºC) and the average minimum temperature was observed in the month of January (7.53ºC). The average maximum precipitation was in July (408.80mm) and average minimum precipitation occurred in November (2.18mm). More than 90% rainfalls seen during May-September (fig 2). (DHM, 2021).

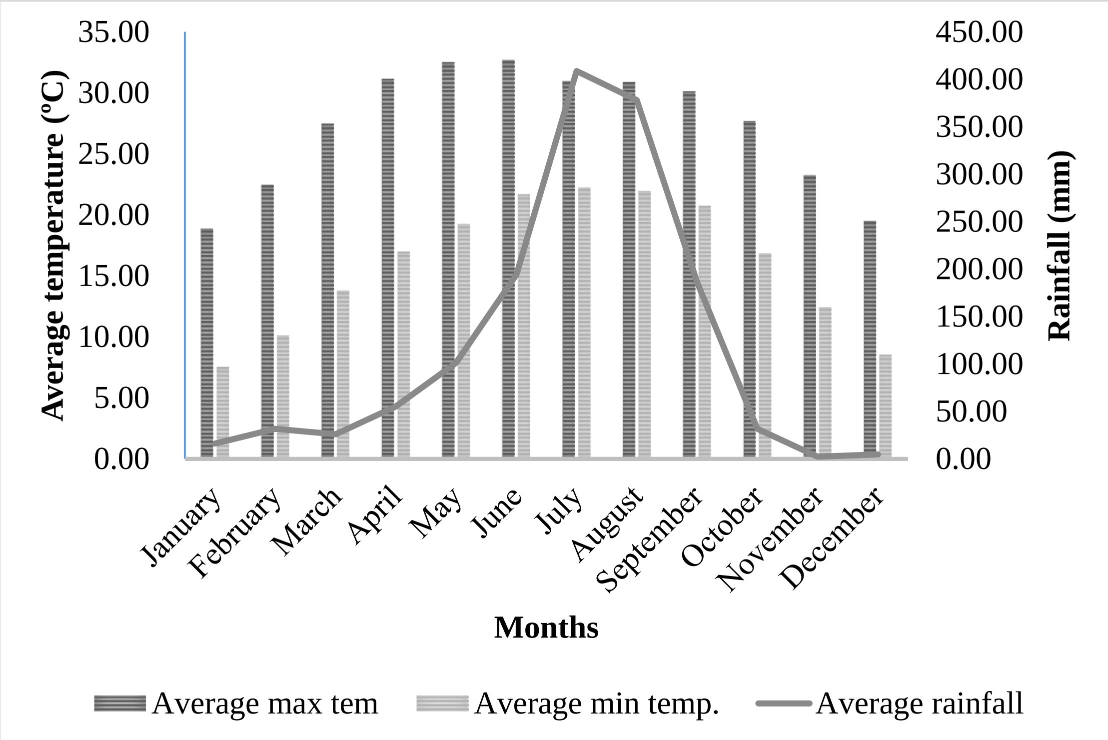


Figure 2: Variation in monthly average (minimum and maximum) temperature and precipitation of last 10 years (2011-2021) in Dhunibesi Station. (Source: Department of Hydrology and Meteorology (DHM, 2021).

3.1.3 Vegetation

Dhunibesi consists of sub-tropical types of vegetation. It is characterized by mixed broad leaves vegetation. The major observed trees species are *Schima wallichii, Pinus roxburghii*, *Castanopsis indica*, *Shorea robusta* etc. *Alnus nepalensis* is predominant in the degraded hill slopes. Other plants in the study area are *Colebrookea oppositifolia, Artemisia spp, Rubus ellipticus* etc. The observed invasive species of this area are

Lantana camara, Bidens pilosa, Ageratum haustonianum, Ageratina adenophora, Chromoleana odoratus etc.

3.1.4 Description of *Lantana camara*

L. camara is a perennial, woody shrubs with long weak pubescent branches with stout recurved prickles. On average, it grows upto a height of 3m. Roots; very stout and can give new shoots even after repeated cutting. Leaves; opposite, Leaf blade; ovate to oblong, rough-hairy with coarsely-serrated margin, emit a pungent scent when crushed or rubbed. Stem usually angular and roughly hairy. Flowers; Small, colourfull, in round flat-topped heads in axils of upper leaves. Calyx usually bilobed and triangular. Corolla 4-5 lobed, unequal, creamy, variation in color, tube cylindrical 5-8mm long. Fruit small, shining, blue-black when ripe.

Figure 3: *Lantana camara* shoots

3.2 Vegetation sampling

Vegetation sampling was done by the method followed by Mueller-Dombois and Ellenberg (1974). To establish areas with *Lantana camara* occurrence, a field survey was done. The study was under taken in the month of February and March of 2021. Stratified Random Sampling method was used with two categories; Invaded (*L. camara* cover greater than 10%) and non-invaded (*L. camara* cover with less than and equal to

10%). Total 100 sampling plots, each plot measuring 10×10m^2 was randomly laid with 50 plots in each category. For trees, 10m×10m square plot was used and DBH, height along with the number of seedling and sampling was recorded. For shrubs, three subplots of 5m×5m were laid and the plants were recorded along with its number and coverage. For herbs, three subplots of 1m×1m were laid and the plants were recorded along with its number and coverage. Invaded and non-invaded site was 50m apart. In each plot, an altitude, slope and aspect and the location from a global positioning system was recorded using a Geographical Positioning system (GPS) unit.

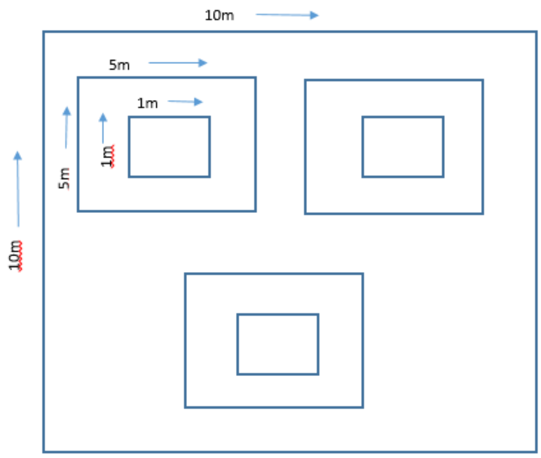


Figure 4: Plot design of vegetation sampling; 10m square plot for trees, 5m for shrubs and 1m for herbs

Identification of unidentifies plants were done with the help of local name, photographs and consulting standard literatures (Hara et. al 1966, Press et al., 1982, Malla et al.,1986, Stainton, 1988).

3.3. Vegetation analysis

Density, frequency, coverage and Importance value index were calculated from the data collected from the field following the method given by Zobel et al., (1987).

Frequency (F) and Relative frequency (RF)

Frequency is the proportion of sampling units containing the species. The frequency of the species was evaluated by presence and absence method, recorded from each plot.

Frequency and relative frequency were calculated separately for individual plant species by using the following formula:

$$Frequency(\%) = \frac{No.of\ \ quadrat\ \ in\ \ which\ \ individual\ \ species\ \ occured}{Total\ \ no.of\ \ quadrat\ \ sampled} \times 100\%$$

$$Relative\ \ frequency = \frac{Frequency\ \ of\ \ individual\ \ species}{Sum\ \ of\ \ the\ \ frequency\ \ of\ \ all\ \ species} \times 100\%$$

Density (D) and Relative density (RD):

Density is the number of individuals per unit area. Density of each species was estimated with the help of number of each species individual and calculated by the formula given below:

$$Density\left(\ /_{ha}\right) = \frac{Total\ \ no.of\ \ individual\ \ of\ \ a\ \ species\ \ in\ \ all\ \ plots}{Total\ \ no.of\ \ plots\ \ studied} \times \frac{10000}{Size\ \ of\ \ the\ \ plot}$$

Relative density of each species was calculated by comparing the density of individual species and total density of all species.

$$Relative\ \ density = \frac{Density\ \ of\ \ individual\ \ species}{Total\ \ density\ \ of\ \ all\ \ species} \times 100\%$$

Coverage (C) and Relative coverage (RC):

The coverage of species in percent was evaluated by visual estimation method, considering each plot as 100 percent (Zobel et al., 1987).

$$\text{Coverage} = \frac{\text{Total coverage of individual species}}{\text{Total number of plots studied}}$$

$$\text{Relative coverage} = \frac{\text{Coverage of individual species}}{\text{Total coverage of all species}} \times 100$$

Importance value index (IVI):

$$IVI = RFi + RDi + RCi$$

Where,

IVI= Importance Value Index

RFi= Relative Frequency of species i

RDi= Relative Density of species i

RCi= Relative Coverage of species i

Shannon-Weiner's diversity Index (H):

Species diversity was estimated by using the Shannon-wiener index (Shannon and Weaver, 1949) which was calculated by using the following formula

$$H = -\sum Pi.ln(Pi)$$

$$Equitability = \frac{H}{Hmax} = \frac{H}{lnN}$$

Where,

H= Species Diversity Index

Pi= Proportion of the species

Pi= ni/N

N= Sum of number of all species

ni= Sum of number of individual species

Simpson Diversity index (D);

Concentration of dominance and diversity were determined by using Simpson's index (Simpson, 1949) which is calculated by using following formula;

Concentration of dominance (λ)=$\sum pi^2$

Simpson's diversity index (D)= 1-λ

Where, Pi= Proportion of the species

Pi= ni/N

Similarity index;

To determine the similarity index in invaded and non-invaded areas, Jaccard similarity index (Jaccard, 1901) was used which is calculated by following formula;

$$\text{ISj} = \left(\frac{c}{a + b + c}\right) \times 100$$

Where, IS_j=Jaccard similarity index

a=Number of species only present in invaded plots

b=Number of species present only in non-invaded plots

c= Number of species common to the two stands

3.4 Soil Collection

The soil from the study plot was collected by using the method of Stohlgren et al. (1998). Five soil samples from the top 15cm of the ground were collected from the four corners and center of each plot. The soil samples from the same plot were thoroughly mixed and a composite sample was made. Soil of nearby 5 quadrats of same category were mixed thoroughly and a composite sample was made. Composite soil sample was packed in an air-proof polythene bag. Altogether 20 composite samples, 10 from invaded and 10 from non-invaded plots were collected and used to determine soil microbes.

3.5 Microbial culture, isolation and identification

Bacteria and fungi were isolated by using Nutrient agar and Potato Dextrose Agar (PDA) respectively. The media was prepared as per the instruction given in the media bottle. Serial dilution method (Benson, 2002) followed by pour plate technique were adopted for culturing and isolating soil microbes from all types of composite soil samples. 10gm of composite soil sample was mixed with 90ml of distill water to make 10^{-1} dilution. From 10^{-1} dilution, 1ml of mixture was transferred to 9ml of distill water to make 10^{-2} dilution. Similarly, serial dilution was performed up to 10^{-7} dilution. 1ml of mixture from 10^{-3}, $10^{-4,}$ $10^{-5,}$ 10^{-6} and 10^{-7} dilution were poured to sterile petri-dishes in triplicate. 10-15ml of sterile Nutrient agar for bacteria and Potato Dextrose Agar for fungi were poured in the set of petri-dishes. The content was mixed uniformly to distribute the organism. After solidification, the Nutrient agar plates were incubated at 37ºC for 72 hours and PDA plates at 28ºC for 7 days. The bacterial population were counted after 24 hours, 48 hours and 72 hours. The fungal population were counted in 4th, 5th, 6th and 7th days. The fungi were then observed by using electric microscopes by preparing a slide by cello-tape method. The total number of bacteria and fungi in the soil sample i.e Colony forming units (CFU) was calculated by using the formula given below.

$$\text{CFU/ml} = \left(\frac{\text{No. of colonies} \times \text{dilution factor}}{\text{Volume of sample}}\right)$$

3.6 Soil pH

pH of soil was determined with a 1:2 soil water suspension (Zobel et.al, 1987) using pH meter in laboratory of Botany Department, Amrit Campus. Soil pH of soil samples were measured by using digital glass electrode method. 5g of soil is mixed with 10ml distilled water which in the ration of 1:2. Thus prepared solution was stirred gently for and kept for few minutes. Then calibration of pH meter was done with buffer solution of 7 and 4 and pH values were noted down. Three replications of each sample were prepared.

3.7 Statistical Data Analysis

The field data were recorded in a tabular form in Microsoft Excel 2010. Different formulae were used to calculate different parameters. Thus, calculated data were used in SPSS software (SPSS Inc., Chicago, IL, USA) to find the significance difference of species richness, pH and microbe's population between invaded and non-invaded plots by independent sample t-test ($p<0.05$). The correlation between the parameters were calculated by using statistical software Past 4.03.

4. RESULTS

4.1 Effects of *L. camara* invasion on vegetation

4.1.1. Effects of *L. camara* invasion on species composition

A total of 159 species belonging to 73 families were recorded including *Lantana camara*, from the study area (Annex 1). Out of which 139 species were found in non-invaded areas, 103 species in *L. camara* invaded areas and 83 species were common to both. Hence, the number of species is lesser by 26.42% in invaded areas as compare to non-invaded areas. 19 species were recorded only from invaded sites and 57 species were recorded only from non-invaded sites (Appendix 1). Among all the species recorded, 90 species were herbs, 30 species were shrubs and 39 species were trees (Fig. 5).

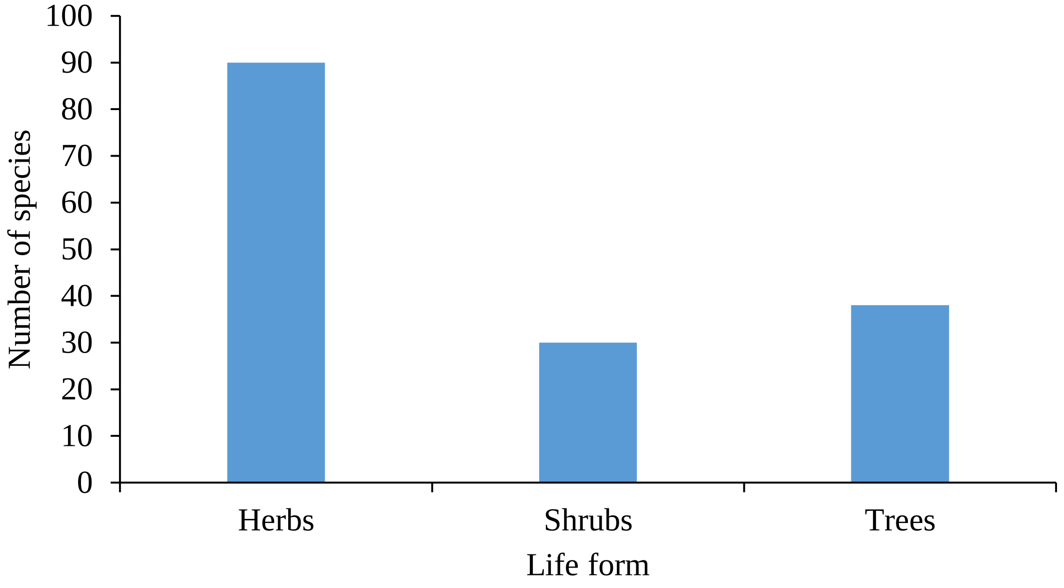


Figure 5: Graph showing the Species Composition of different life forms

In *L. camara* invaded areas 56 species of herbs, 22 species of shrubs and 25 species of trees were recorded whereas in non-invaded areas 84 species of herbs, 27 species of shrubs and 28 species of trees were recorded (fig. 6).

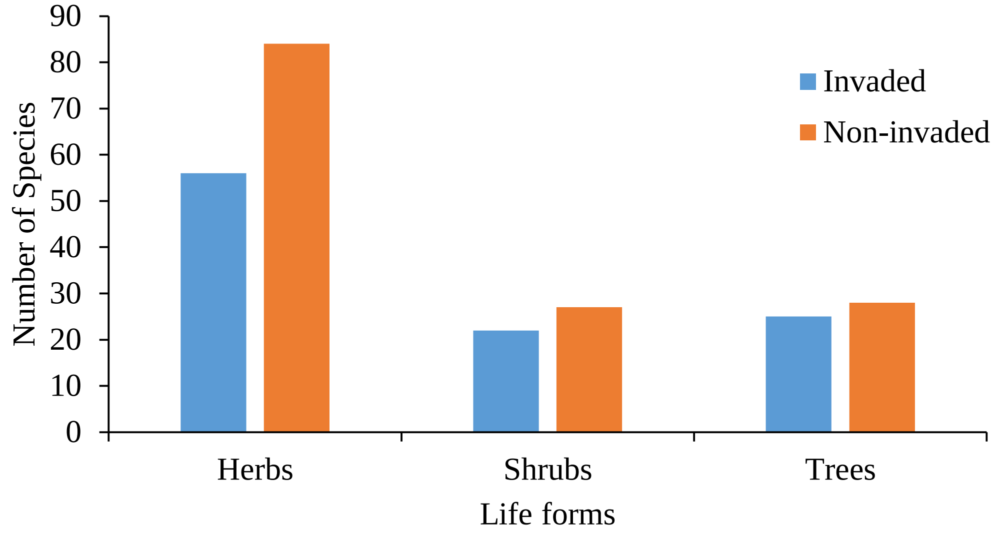


Figure 6: Graph showing the species composition in *L. camara* invaded and non-invaded areas.

The recorded plants belong to 73 families. Asteraceae family has the highest number of plants species i.e., 17 which is followed by Poaceae (12 species), Fabaceae (8 species), Rosaceae and Urticaceae (8 species). The list of plant along with its family was shown in appendix 1.

4.1.2 Effects of *Lantana camara* on species density

The overall density of the plants in invaded and non-invaded areas were found different. The mean density per hectare of the invaded areas was found to be lower i.e., 347293 than that of non-invaded areas i.e., 571444. The mean density of non-invaded areas was higher by 224151/ha.

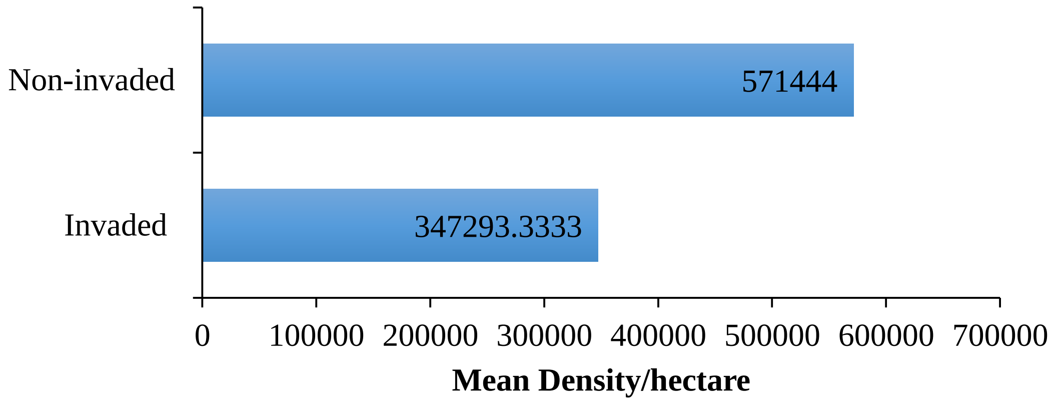


Figure 7: Mean density per hectare of plant species in invaded and non-invaded areas.

when the independent sample t test was done to find the significance difference in mean density of plants per hectare it was found that there is significance difference ($p<0.05$) in density per hectare at 95% level of confidence.

4.1.3 Effects of *Lantana camara* on herbs layer

Total of 90 species of herbs were recorded. Out of these 56 species were recorded in invaded areas of *Lantana camara*. Among these species, the invaded areas were mostly dominated by *Imperata cylindrica* (38.92), *Capillipedium parviflorum* (32.92), *Capillipedium assimile* (28.49), *Ageratina adenophora* (26.38), *Bidens pilosa* (24.86) followed by other species which is listed in the appendix 2 along with their IVI values.

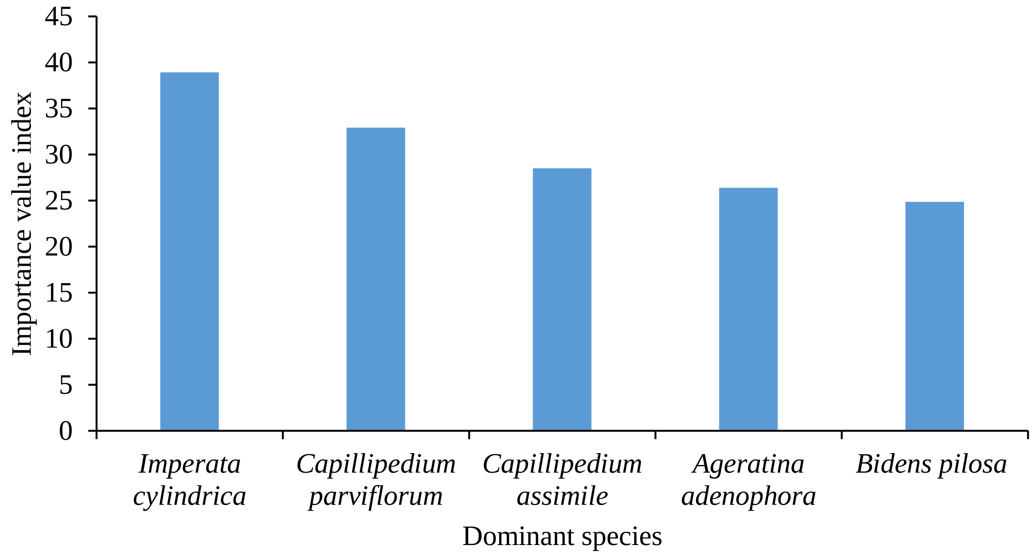


Figure 8: Importance value index of dominant herbs in invaded areas

In non-invaded areas total of 84 species were recorded. Among these, the dominant species along with its IVI are *Imperata cylindrica* (42.78), *Capillipedium assimile* (27.64), *Oxalis corniculata* (21.90), *Paspalum distichum* (18.63), *Ageratina adenophora* (17.44) and other species which is listed in appendix 3.

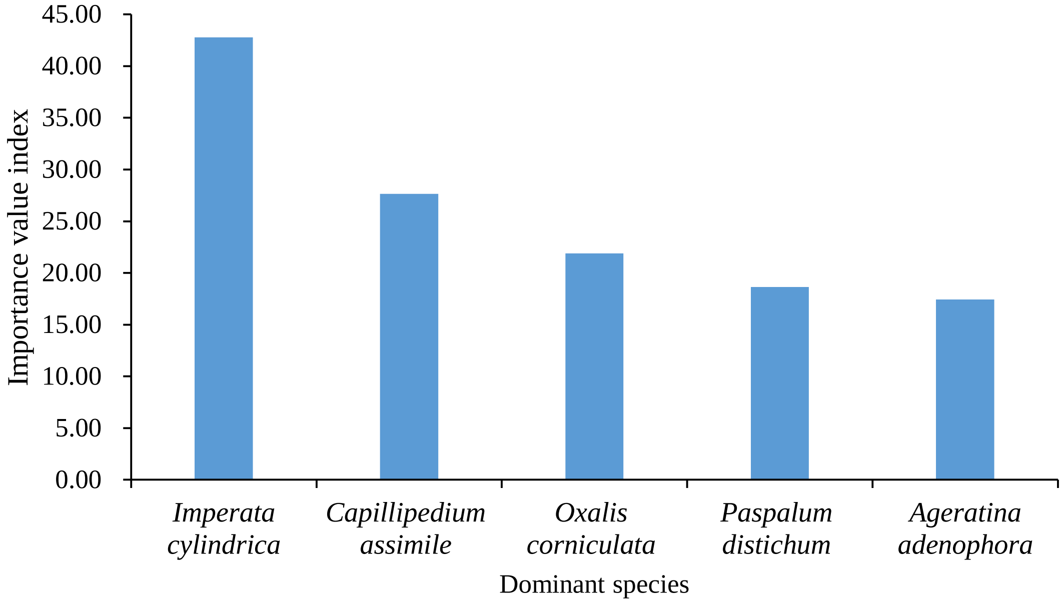


Figure 9: Importance value index of dominant herbs in non-invaded areas

4.1.4 Effect of *Lantana camara* on shrubs layer

Total of 30 shrubs species. Out of this, 22 species were found in invaded areas. The major dominant species are *Lantana camara, Artemisia indica, Colebrookea oppositifolia*, *Rubus ellipticus, Hypericum cordifolium* etc followed by other species which is listed in the appendix 4. *Lantana camara* has the highest IVI (159.11) which is followed by *Artemisia indica* with IVI value 42.55.

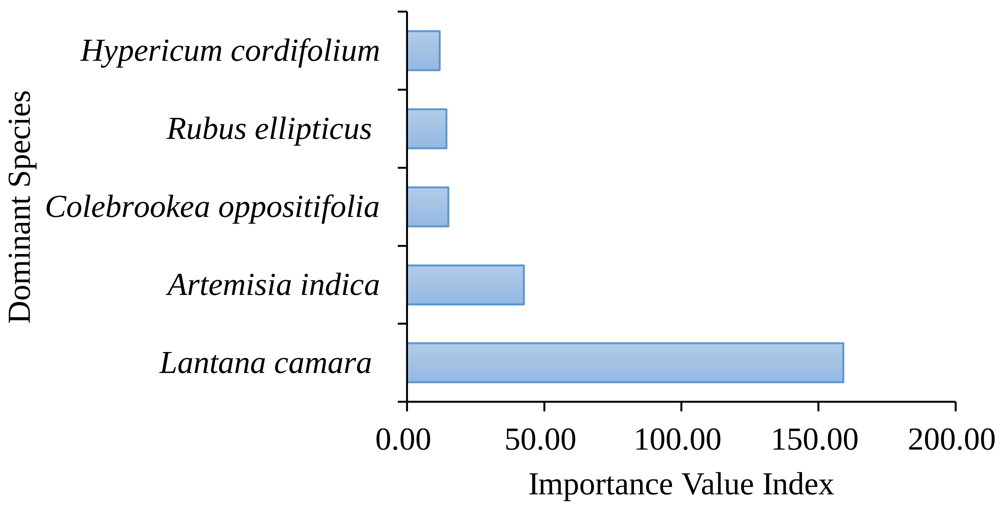


Figure 10: Importance value index of dominant shrubs in invaded areas

On the other hand, 27 shrubs species were recorded in non-invaded areas. *Artemisia indica, Lantana camara, Hypericum cordifolium, Colebrookea oppositifolia, Rubus ellipticus* etc were the dominant species with the highest IVI of *Artemisia indica* (60.69). The IVI of other species was listed in the appendix 5.

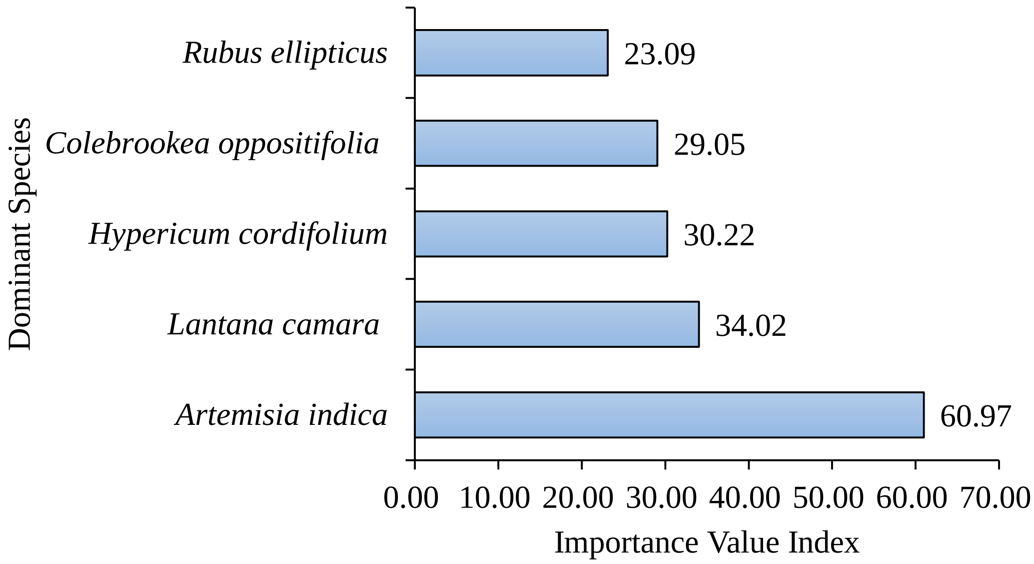


Figure 11: Importance value index of dominant shrubs in non-invaded areas

4.1.5 Effects of *Lantana camara* on species diversity

The indices of diversity, namely Simpson's index of diversity, Concentration of dominance, Shannon-Wiener index and evenness differed significantly among the invaded and non-invaded condition. The concentration of dominance was found to be 0.096 in invaded area and 0.065 in non-invaded area. The Simpson's diversity was found to be higher i.e., 0.935 in non-invaded area than that of invaded area i.e., 0.904. The mean Shannon-Wiener index in invaded areas were found to be lower i.e., 2.80 than that of non-invaded areas i.e., 3.198. The vegetation of non-invaded areas was more evenly distributed than that of invaded areas. The mean evenness of invaded areas was 0.7680 indicated that 76% of the plant communities had uniform distribution whereas the mean evenness for non-invaded areas was found 0.805 indicated that 80% of the plant communities had uniform distribution. Thus, the heterogeneity of the invaded study sites was reduced by only 4%. The mean values of Simpson's index of diversity, Concentration of dominance, Shannon-Wiener index and evenness were shown in table 1.

Table 1: Diversity indices of invaded and non-invaded areas

	PLOTS	Mean±SD(N=10)
Concentration of dominance	1	0.096±0.015
	2	0.065±0.015
Simpson's Diversity(D)	1	0.904±0.015
	2	0.935±0.015
Shannon-Wiener index	1	2.80 ± 0.103
	2	3.198±0.149
Evenness	1	0.768±0.041
	2	0.805±0.029

Where 1= Invaded areas; 2= Non-invaded areas

Independent sample t-test were done to find the significance difference in species diversity of both areas. At 95% level of confidence, the p value was found to be less than 0.05 which means that there was significance difference in species diversity indices in between invaded and non- invaded areas (table 2).

Table 2: Comparing diversity indices of invaded and non-invaded sites (t- test analysis).

Independent Samples Test					
	Levene's Test for Equality of Variances	t-test for Equality of Means			
	F	Sig.	t	df	Sig. (2-tailed)
Concentration of dominance	0.184	0.673	4.841	18	0.000

Diversity(D)	0.184	0.673	-4.841	18	0.000
H	1.874	0.188	-6.795	18	0.000
Evenness	0.602	0.448	-2.294	18	0.034

4.1.6 Similarity index

Out of 158 species recorded, 19 species were only found in invaded areas and 57 species were found in non-invaded areas. 82 species were found in both invaded and non-invaded areas. Species like *Alternanthera philoxeroides, Boenninghausenia sp, Fragaria vesca, Pteris vitata, Boehmeria nivea, ziziphus incurva, Careya arborea* etc were recorded only from the invaded sites whereas the species like *Agave* Sp., *Adiantum capillus-veneris, Argemone mexicana, Cirsium wallichii, Desmodium triflorum, Eulaliopsis binata, Dabregesica longifolia, Melaleuca viminalis* etc were only recorded from the non-invaded sites.

When the similarity index of plant communities of invaded and non-invaded area was calculated, it was found that invaded and non-invaded vegetation was 51.89% similar. Higher similarity was found in shrubs layer i.e., 63.33% which was followed by herbs i.e., 55.56% and Trees i.e., 34.21%. The Jaccard similarity index of different life forms and two communities were shown in table 3 below.

Table 3: Jaccard's similarity index of invaded and non-invaded sites

	IS_j(%)
Herbs	55.56
Shrubs	63.33
Trees	34.21
Total plant community	51.89

4.1.7 Frequency Rank Curve

Frequency rank analysis showed that *Ageratina adenophora* was the frequently occurred herb species in invaded areas which was followed by *Bidens pilosa*, *Oxalis corniculata*, *Paspalum sp.*, *Imperata cylindrica* and so on. *Gonostegia hirta*, *Dendrocalamus*, *Anaphalis busua*, *Dryopteris* were the least occurred species which was shown in fig 12. Similarly, *Lantana camara* frequently occurred shrubs species in invaded areas which was followed by *Artemisia indica*, *Rubus ellipticus* and so on. Species like *Inula cappa*, *Nyctanthes arbor-tristis*, *Pogostemon benghalensis* were the least occurred species as shown in fig 13. In case of tree species, *Schima wallichii* was the frequently occurred species which was followed by *Sapium insigne*, *Alnus nepalensis* and so on. The least occurred species were *Prunus domestica*, *Castonopsis indica*, *Diploknema butyracea*, *Phyllanthus emblica* etc as shown in fig 14.

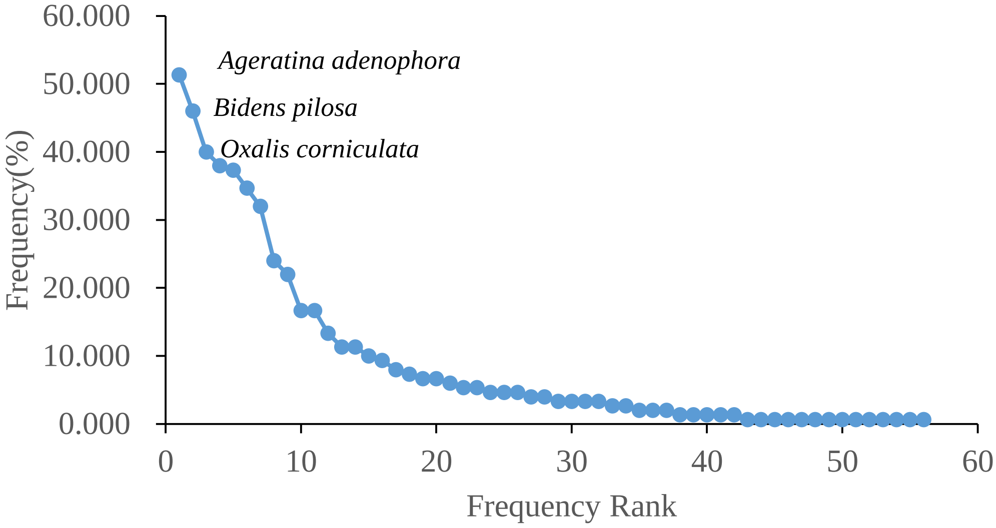


Figure 12: Frequency rank curve of Invaded herb species

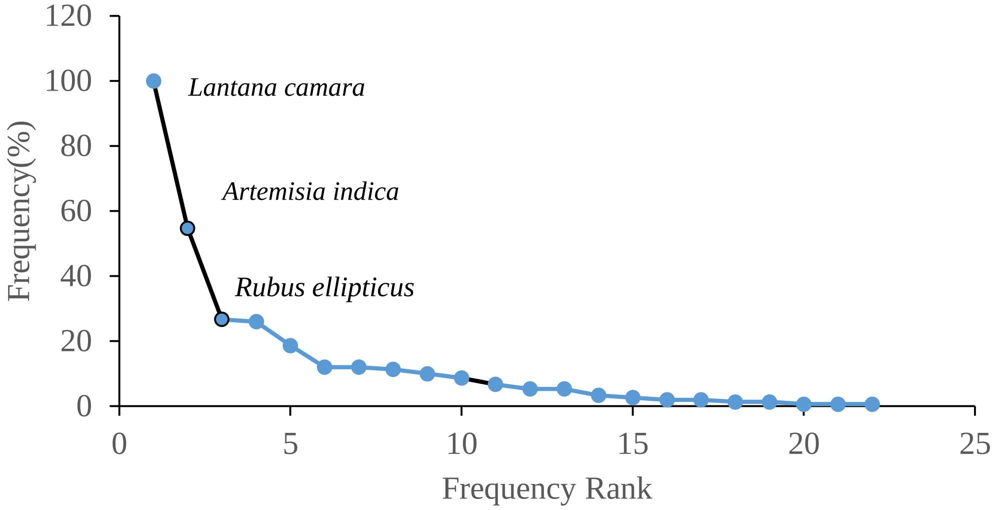


Figure 13: Frequency rank curve of Invaded shrubs species

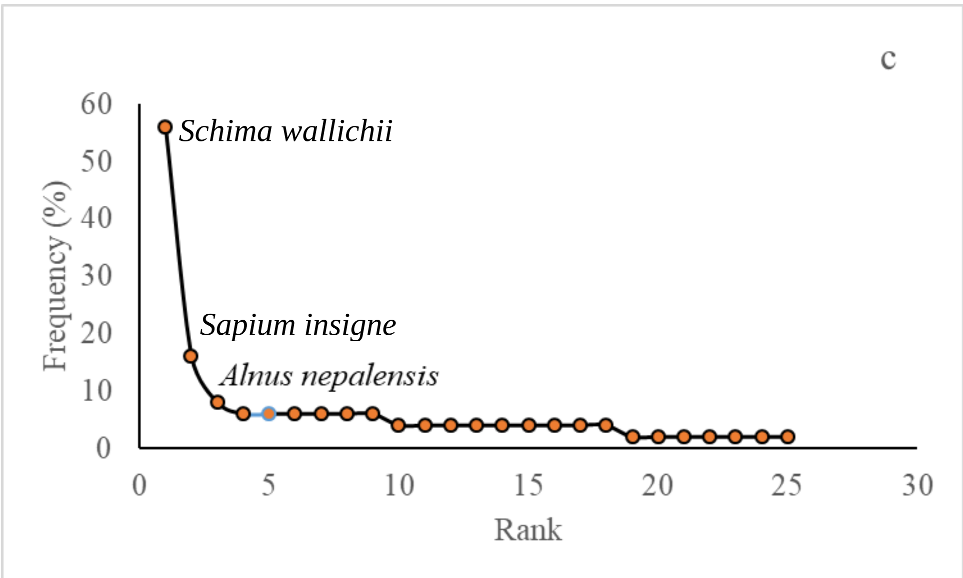


Figure 14: Frequency rank curve of invaded trees species

Similarly, in the case of non-invaded areas *Bidens pilosa* occurred more frequently which was followed by *Ageratina adenophora*, *Capillipedium assimile*, *Oxalis corniculata* and so on. Species like *Eranthemum pulchellum*, *Gentiana capitata*, *Adiantum capillus-veneris*, *Clematis Buchananiana etc* were the species having least frequency which was shown in fig 15. Similarly, in case of shrubs layer, *Artemisia indica* has high frequency of occurrence which was followed by *Lantana camara*, *Rubus ellipticus*, *Colebrookea oppositifolia* and so on. The least occurred shrub species were *Justicia adhatoda, Rhus chinensis, Clerodendrum chinensis* etc which was shown in fig 16. Tree species like *Schima wallichii*, *Litsea monopetala*, *Alnus nepalensis* have high frequency of occurrence whereas the species like *Wendlandia heynei, Citrus medica*, *Mangifera indica*, *Terminalia chebula*, *Engelhardia spicata* etc occurred least frequently in the non-invaded areas which was shown in fig 17 below.

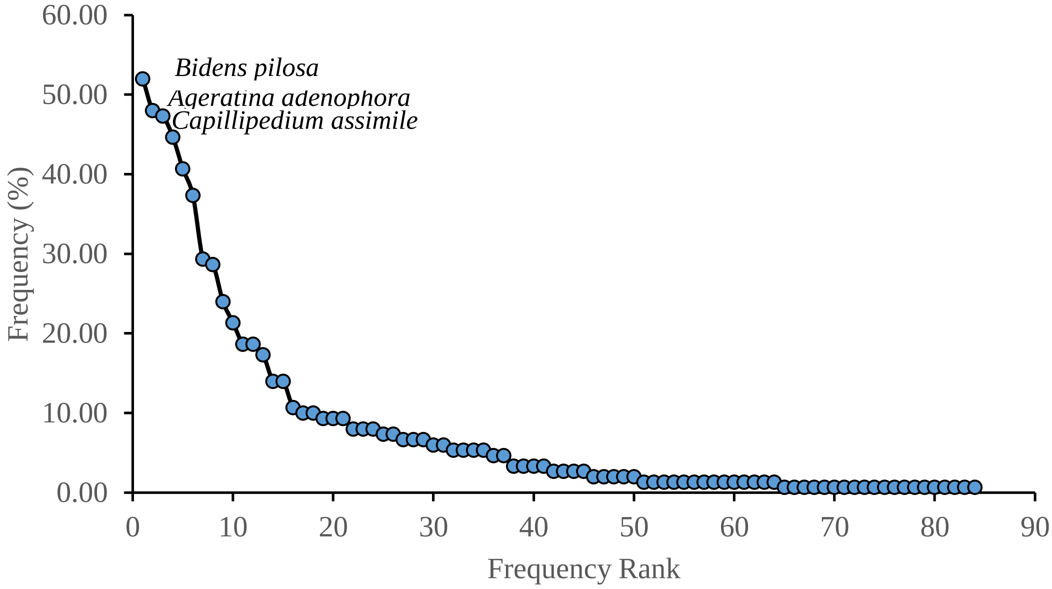


Figure 15: Frequency rank curve of non- invaded herb species

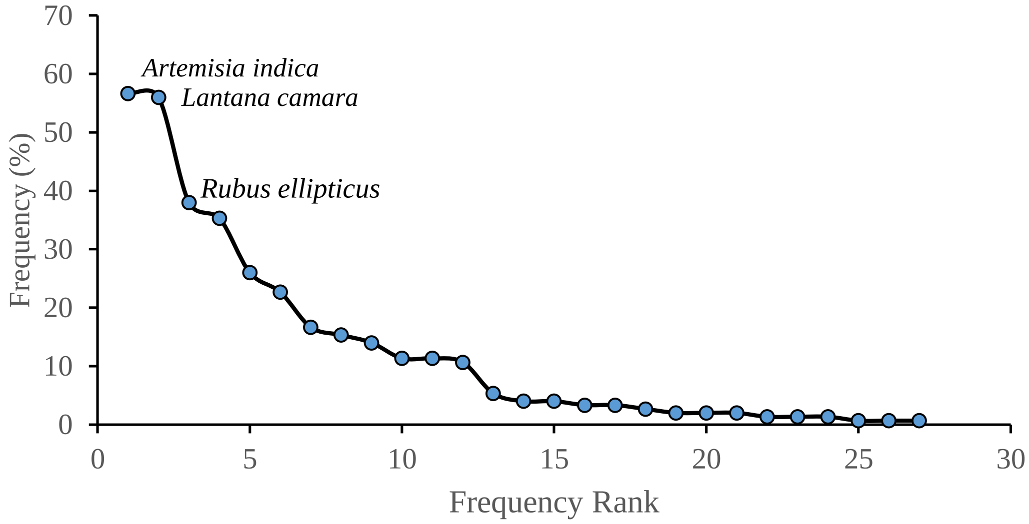


Figure 16: Frequency rank curve of non-invaded shrub species

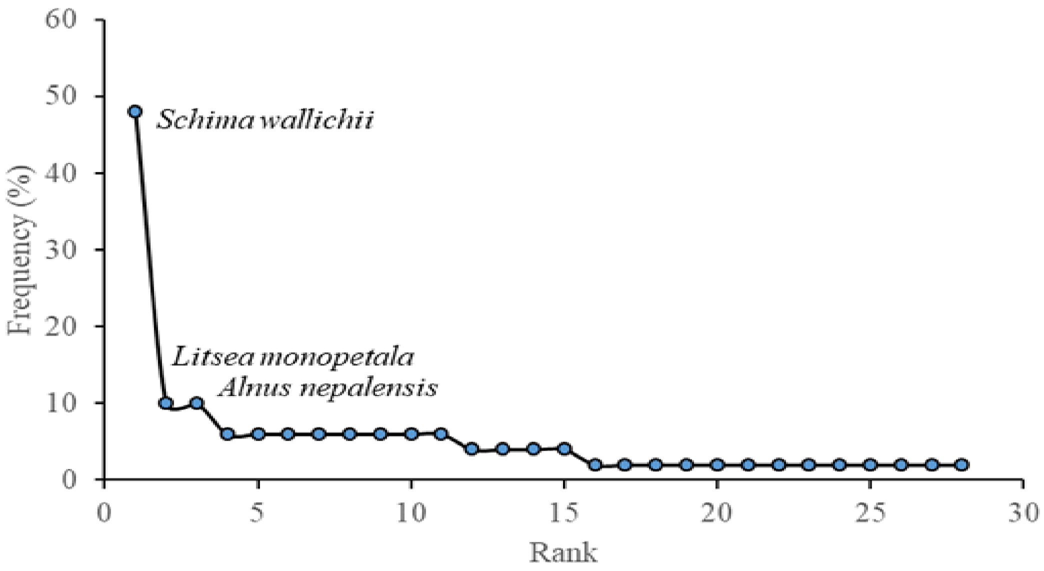


Figure 17: Frequency rank curve of non- invaded tree species

4.2 Effects of *Lantana camara* on soil pH

When the pH of the soil sample was measured, the pH of invaded areas was slightly high as compared to non-invaded areas. pH of invaded areas was 6.01 whereas pH of non-invaded areas was 5.717.

Table 4: soil pH of the invaded and non-invaded sites.

	Invaded/Non-invaded	Mean±SD
Soil pH	1	6.011±0.367
	2	5.717±0.298

Where 1= Invaded soil and 2= Non-invaded soil

When the independent sample t-test was done to find the significance difference on pH of soil, p value was found to be 0.65 which was greater than 0.05 at 95% of confidence interval percentage so, there was no significance difference in the pH of soil of invaded and non-invaded area.

4.2.1 Effect of pH on species diversity

The regression analysis showed a weak positive relationship between the pH and species diversity (H) (fig 18) on invaded sites. Hence the regression equation could be presented as $y = 0.1078x + 2.2157$, where y is species diversity and x is pH of soil. Here, $R^2 = 0.0568$ or 5% indicated that there was a weak positive relation between pH and species diversity. The pH of the soil ranges from 5.5 to 6.47. The diversity of plant species was less affected by soil pH.

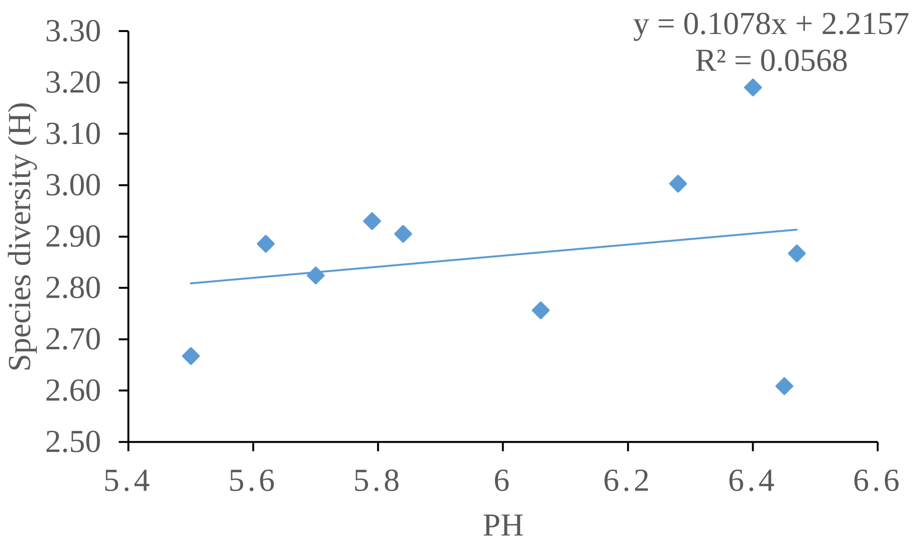


Figure 18: Relationship between pH and species diversity in invaded sites.

In non-invaded sites, the regression analysis showed a weak positive relationship between the pH and species diversity (H) (fig 19) on non-invaded sites. Hence the regression equation could be presented as $y = 0.3557x + 1.1088$, where y is species diversity and x is pH of soil. Here, $R^2 = 0.2393$ or 23% indicated that there was a weak positive relation between pH and species diversity. The pH of the soil ranges from 5.34 to 6.26. The diversity of plant species was affected by soil pH.

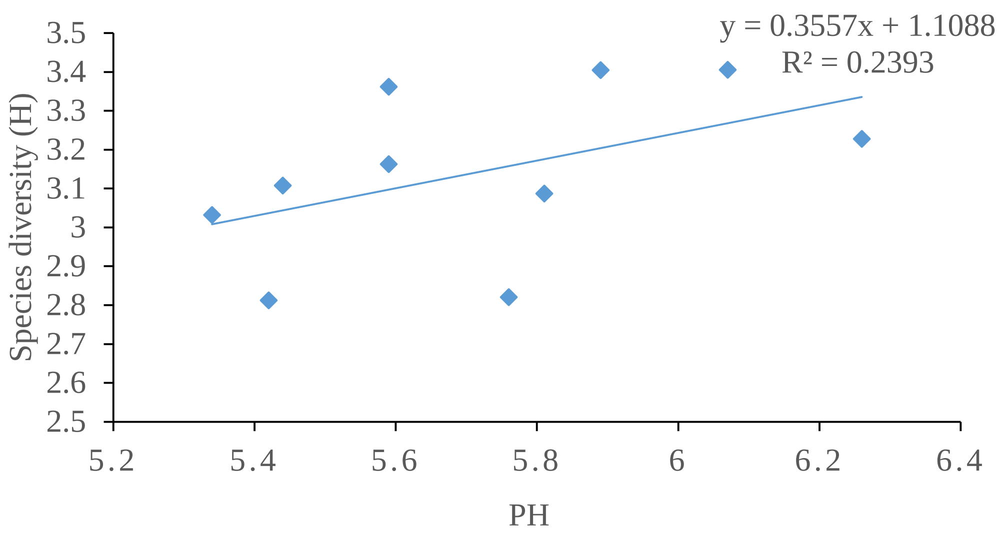


Figure 19: Relationship between pH and species diversity in non-invaded sites.

4.3 Effects of *L. camara* on Soil microbes

4.3.1 Effects of *Lantana camara* on bacterial population

At the fifth fold of dilution, the bacterial population or Colony Forming Units(CFU) were differed in invaded and non-invaded areas. The mean CFU/ml of soil sample in invaded and non-invaded area were 7663333 and 13450000. respectively. The bacterial population in non-invaded areas were higher by 5786666.66.

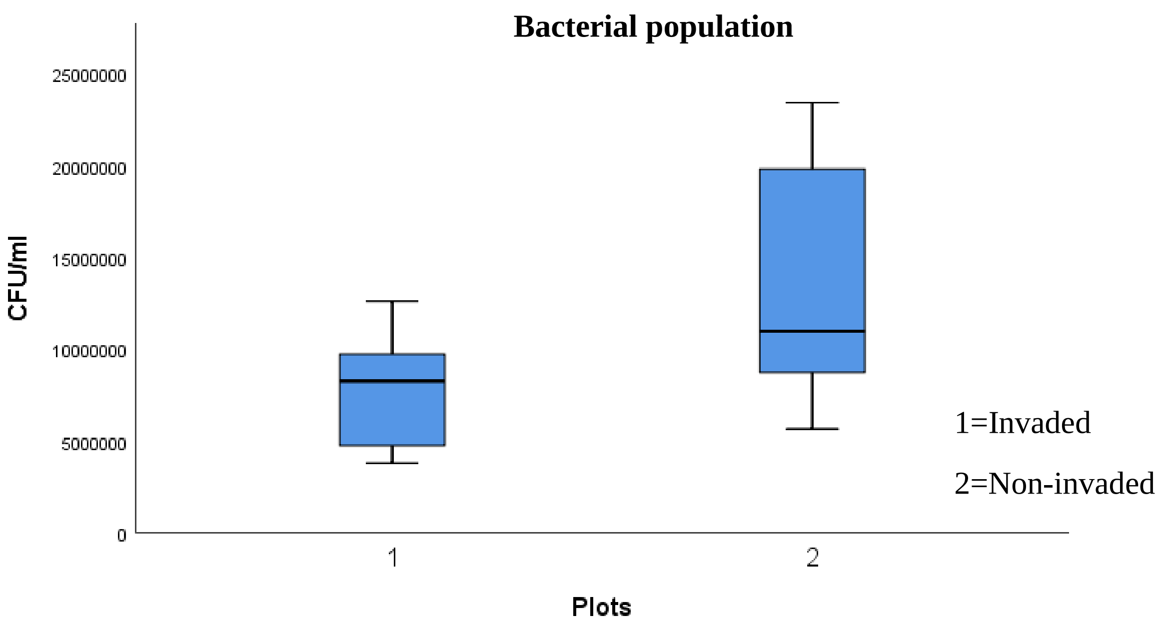


Figure 20: Bacterial population in invaded and non-invaded areas where 1. indicate invaded areas and 2. indicated non-invaded areas.

When independent sample t-test was done to find the significance difference in bacterial population in invaded and non-invaded areas, p value was found to be 0.003 which was less than 0.05. So, it was found that there was significance difference in bacterial population in invaded and non-invaded areas.

4.3.2. Effects of *Lantana camara* on fungal population

At the 5th fold of dilution, the fungal population was found higher in non-invaded plots. The population of fungus in invaded plots were 1310000 and the population were increased to 2553333 in non-invaded plots which was shown in figure 21. The mean CFU/ml of soil sample in non-invaded plots was found higher by 1243333.

1=Invaded

2=Non-invaded

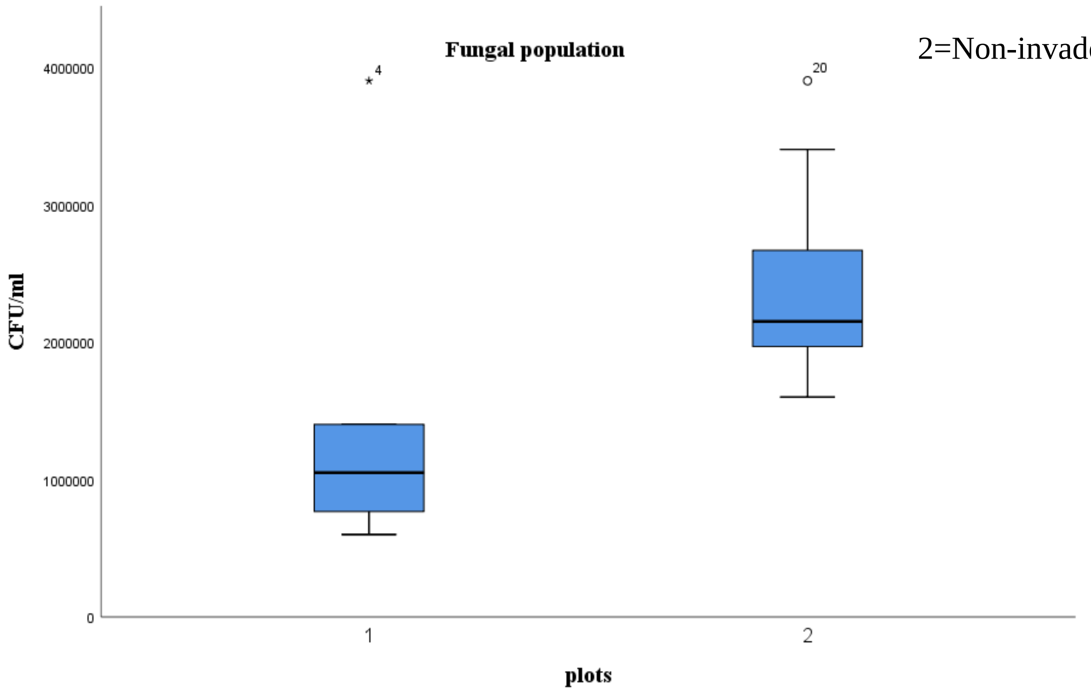


Figure 21: Fungal population in invaded and non-invaded areas where 1 indicate invaded areas and 2 indicate non-invaded areas.

When independent sample t-test was done to find the significance difference in fungal population in invaded and non-invaded areas, p value was found to be 0.003 which was less than 0.05. So, it was found that there was significance difference in fungal population in invaded and non-invaded areas.

4.3.3 Effects of *Lantana camara* on fungal species Richness

A total of 34 species of fungi were recorded from the soil. Twenty-six species belong to division Ascomycota, six species belong to Zygomycota, one species belongs to division Basidiomycota and one species remain unidentified. Species richness were found to be high in the soil of non-invaded i.e., 29 species than that of invaded soil i.e., 22 species (P=0.017). Out of the total species recorded, five species were found only in invaded soil, twelve species were found in non-invaded soil and seventeen species were common in both soil (Appendix 6).

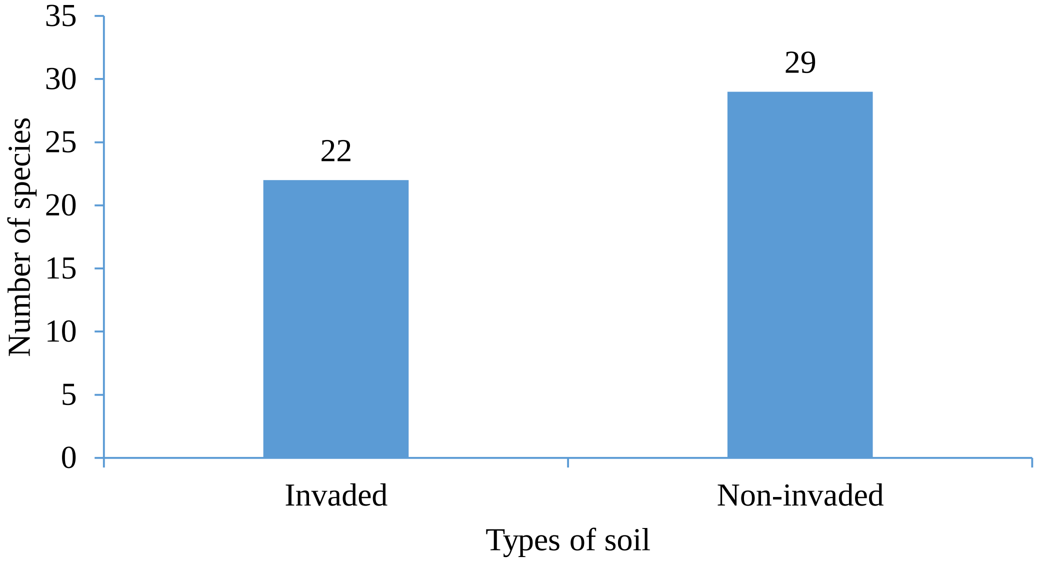


Figure 22: Species richness of fungal species present in study site

4.3.4 Frequency Rank curve of fungal species

The fungal species composition of invaded and non-invaded soil was found different. In the invaded soil, species like *Fusarium solani*, *Penicillium notatum*, *Trichoderma viridi* etc were occurred more frequently whereas the species like *Penicillium chrysogenum*, *Cunninghamella* Sp, *Absidia corymbifera etc* occurred less frequently which was shown in the fig 23 below.

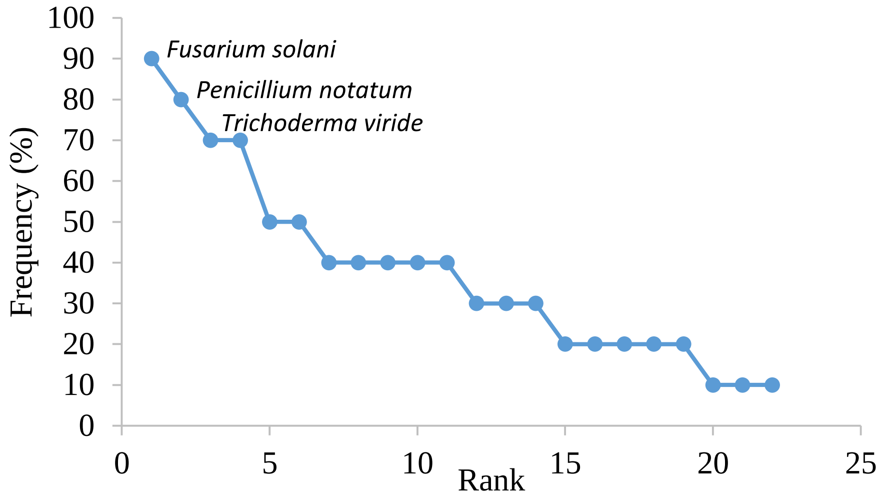


Figure 23: Frequency rank curve of fungi present in invaded soil

In the non-invaded the frequency of species were different. The species like *Trichoderma viridi*, *Penicillium notatum*, *Penicillium* Sp. etc were occurred more frequently whereas the species like *Phytopthora* Sp., *Lecanicillium fungicola, Scopulariopsis* Sp etc were occurred less frequently.

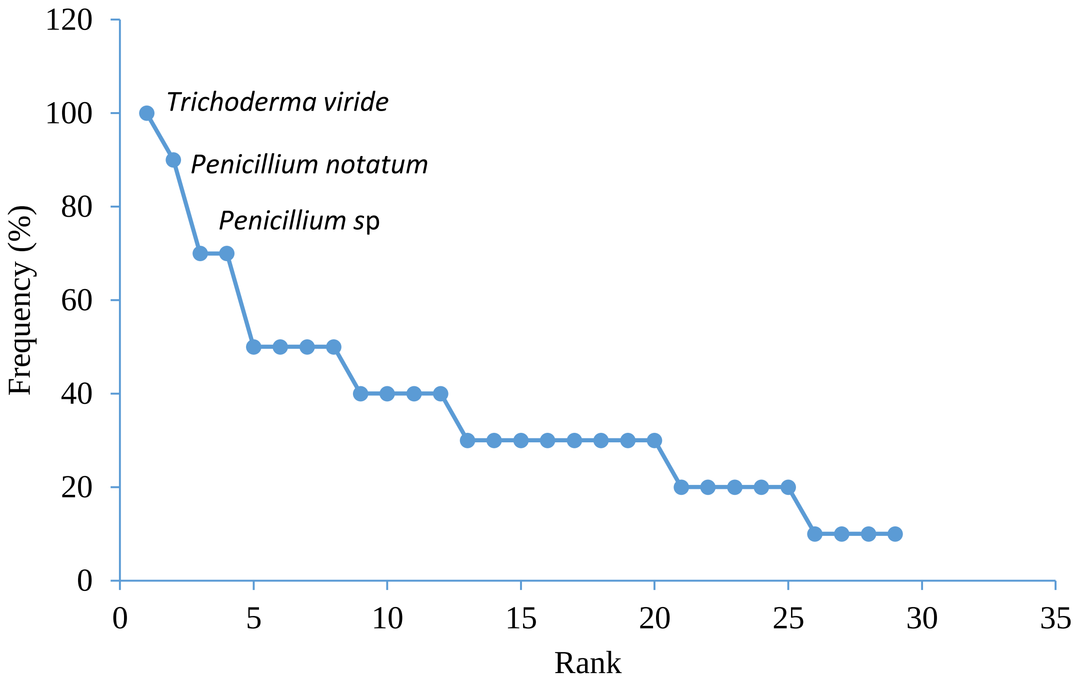


Figure 24: Frequency rank curve of fungi species of Non-invaded soil.

4.4 Correlation among the parameters

In the invaded sites, when the correlation was done between the parameters in invaded sites it was found that the evenness of the plant community and pH of soil had very weak negatively correlation (-0.18) whereas the pH and Shannon's diversity index had weak positive correlation i.e 0.24. Similarly, the bacterial population was negatively correlated with the parameters like Shannon’s diversity index (-0.17), plant species richness (0.39) and pH (-0.41) but the correlation was weak. Fungal population was also negatively correlate with soil PH (-0.29) i.e., weak correlation. But the other parameters were positively correlated but the correlation was not strong. Species richness and Shannon's index has the strong correlation (0.63) which is followed by correlation between Shannon index and Evenness (0.53) which was shown in the figure 25 given below.

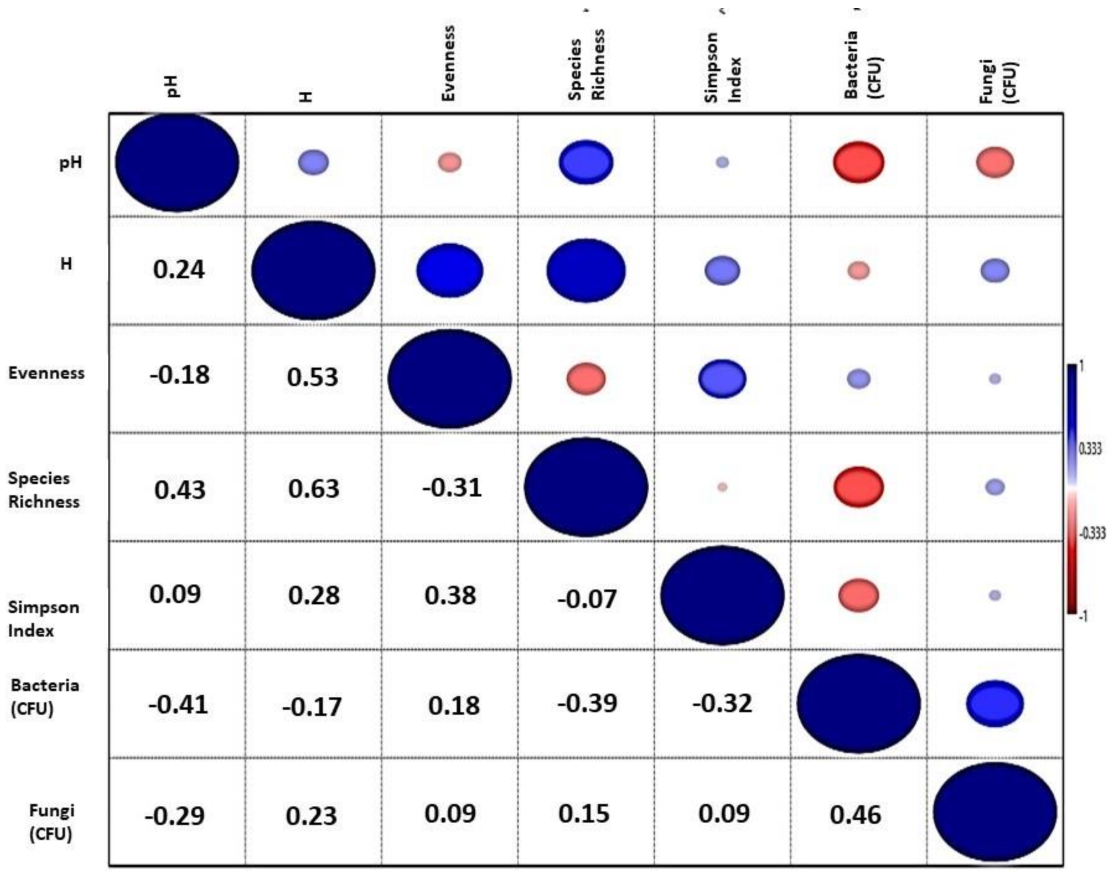


Figure 25: Correlation chart showing the correlation among the parameters of invaded sites

In the non-invaded sites the fungal population was negatively correlated with pH (-0.09), plant speciess richness (-0.47) and Bacterial population (-0.33). Similarly, the bacterial population was negatively correlated with pH (-0.11) and Simpson's index (-0.13). The plant species richness (0.36), Shannon's index (0.49), Simpson index (0.58) were strongly correlated with the soil pH. Parametres of plant species were positively correlated but the plants parameters and microbes parameters were negatively correlated which was shown in the figure 26 below.

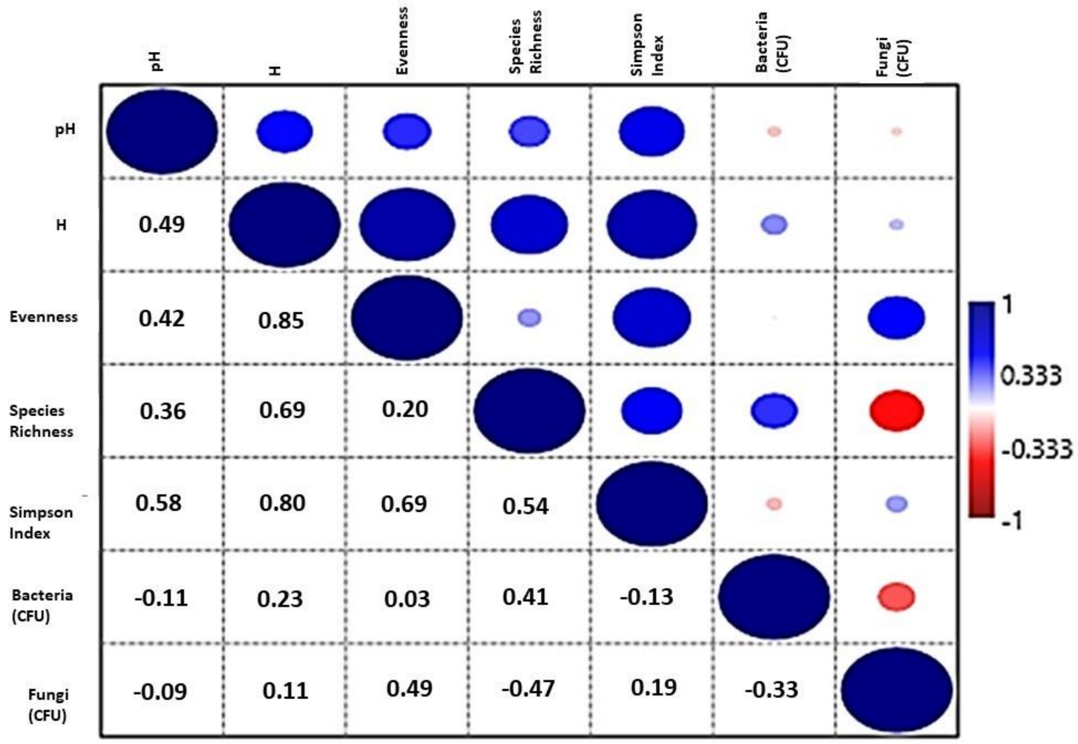


Figure 26: Correlation chart showing the correlation among the parameters of non-invaded sites.

5. DISCUSSION

This study aimed to study changes in plant species composition, diversity, frequency, soil pH and soil microbes in between the areas of *Lantana camara* invasion and non-invasion. Results of the study show that invasion of *L. camara* and decline in species composition, diversity, frequency, soil pH and microbes' diversity are related to each other.

5.1 Impacts of *Lantana camara* on species composition

Invasion of *L. camara* significantly change the species composition of plant species. During a study on the impact of *Lantana camara* invasion in Zimbabwe, Chatanga (2007) found that *Lantana camara* invasion reduce the species composition of all life form. The present study gives strong evidence to show that *L. camara* invasion affect the species composition. In the present study, in *L. camara* invaded areas the number of species were found less than the number of herbs, shrubs and trees in non-invaded areas. The species composition was changed in all growth form, herbs species most contributed to compositional changes. This observed variation on different life form may be due to different level of resource competition and allelopathic inhibition offered by the *L. camara* (Dobhal et al.,2010). This shift in species composition might be due to disturbance in the habitat that facilitates *Lantana* invasion which increases the capacity to suppress the native species by using the available resources and decreasing the space (Duggin and Gentle, 1998, Gooden et al., 2009).

Invasion of *L. camara* considerably declined the diversity and number of family (Vardien et al., 2012; Gantayet et al., 2014). Asteraceae, Poaceae, Fabaceae, Rosaceae etc were the families that contributed most of the species to the total flora in the study sites. Asteraceae was the dominant family in both invaded and non-invaded areas. This might be due to large number of species in this family that can grow in almost all terrestrial ecosystem (Funk et al., 2005). Presence of wide range of vectors like wind, animals, insects etc, small seed size increase the diversity of Asteraceae (Faegri and Van der Piji,1979). Presence of achene, pappus perched on the fruit, capitulum inflorescence, high abundance of secondary metabolites and bifurcate style that promotes outcrossing etc (Katinas et al., 2016, Mandel et al., 2017) may be the reason of high diversity of plants belonging to Asteraceae. The present result concurs with previous studies that showed with increasing *L. camara* cover, the increase in Fabaceae and Asteraceae species in the western Himalayan forests of India (Mandal & Joshi, 2015).

Growth and survival rates of a species are indicated by the density of a plant species (Dobhal et al., 2010). In the invaded areas, the overall number of species, the number of individuals per species and overall density were decreases. as compared to associated non-invaded ones. The density of non-invaded areas was higher by 224151/ha. There was significant difference ($p < 0.05$) in the density of plant species between invaded and non-invaded areas. This may be due to the thick monoculture of *L. camara* that change the micro-environment like light, pH and temperature under the *L. camara* coverage and also inhibit the germination and growth of other species (Sharma and Raghuvanshi, 2007).

In the present study, in the invaded sites the species like *Imperata cylindrica, Capillipedium parviflorum, Capillipedium assimile, Ageratina adenophora, Bidens pilosa* etc were dominant herbs with their high IVI values. Similarly, the shrubs species like *Lantana camara, Artemisia indica, Colebrookea oppositifolia, Rubus ellipticus, Hypericum cordifolium* etc were dominant in the invaded areas. In the non-invaded sites, the herbs species like *Imperata cylindrica*, *Capillipedium assimile*, *Oxalis corniculata*, *Paspalum distichum*, *Ageratina adenophora* etc were dominant and the shrubs species like *Artemisia indica*, *Lantana camara*, *Hypericum cordifolium*, *Colebrookea oppositifolia*, *Rubus ellipticus* etc were the dominant species. The dominant species in the invaded and non-invaded site were almost similar but the values of IVI decreased in the invaded site. The frequency of species was also decreased due to the invasion of *L. camara* as compared to the associated non-invaded ones. This result of decrease in frequency with increase in invasion is similar to the result of Dobhal et al., (2010). The invasive species like *A. adenophora, B. pilosa* etc occurred more frequently. This result suggests that co-occurrence of other alien plants with *L. camara* can benefit from the invasion process. Result of co-occurring of the other alien invasive plant species with *L. camara* was similar to the result of Joshi & Mandal, (2015), Ruwanza, (2020).

Species like *Ageratina adenophora, Bidens pilosa, Artemesia indica, Imperata cylindrica, Schima wallichii* occurred more frequently in both sites which suggest these species were able to tolerate the invasive effect of *L. camara* and also suggest that invasion of *L. camara* in the site does not replace or exclude total native species. thus, suggesting a potential refuge effect (Tererai et al., 2013).

5.2 Impact of *L. camara* on species diversity

Total species richness, Shannon-Wiener index, Simpson's diversity and evenness decreased significantly with the increase in *L. camara* invasion. These results show the pervasive threat posed by invasion of invasive species *L. camara* to native species diversity and composition. Results of this study was similar to the previous studies that have reported a decrease in species diversity and change in composition after *L. camara* invasion (Chatanga, 2007; Dobhal et al., 2010; Sundaram & Hiremath, 2012, Aravindhan & Rajendran, 2014; Ruwnza, 2020). Moyo (2004), also found a decrease in species richness and density with increase in invasion of *L. camara* in Zambezi/ Victoria Falls National park, Zimbabwe. Chatanga (2007), reported that *L. camara* impact negatively on the vegetation structure and composition and the decline in species diversity and richness may be due to the fact that *L. camara* reduces recruitment of native species and subsequently reduces their establishment. Aravindhan & Rajendran (2014), reported that invasion of *L. camara* led to degradation and decrease in native species richness, diversity, composition, and structure in the Velliangiri hills of India.

Similarly, Sundaram & Hiremath (2012), reported a significant decline in species richness, diversity and evenness with the increase in *L. camara* abundance in Biligiri Rangaswamy Temple wildlife sanctuary in India. This decrease in species diversity may because of competition from *L. camara.*

Decline in species diversity and composition due to invasion of *L. camara* may be due to several direct and indirect factors. Direct factors to decline species richness and diversity after the *L. camara* invasion can be linked to competition. Sharma et al. (2005), concluded that *L. camara* competes with the native flora for resources like nutrients, soil moisture sunlight etc. Sundaram & Hiremath (2012), also reported that *Lantana camara* compete with the native plants and tend to utilize the soil resources efficiently than other plants which help in expansion of *L. camara* and decline of species diversity. This competition between *L. camara* and other species is enhanced by the allelochemicals produce by *L. camara* that prevent and reduce the growth and establishment of other native species (Mason & French, 2008).

Habitat alteration (Sundaram & Hiremath, 2012) and changes in the physical structure of the invaded ecosystem (Mason & French, 2008) might be the indirect drivers to cause the species decline due to *L. camara* invasion. *L. camara* alters the litter and soil chemistry beneath its canopy due to its invasion which facilitate its invasion and native species displacement (Sharma & Raghubanshi, 2005). Shading may also be the cause of negative effects of *L. camara* invasion on species diversity which decline the native species germination and survival of underneath light demanding seedlings of other species (Vieira & Scariot, 2006).

Study done by Ghisalberti (2000), Sharma et al. (2005), French et al. (2009), Nel (2015) and Assefa & Molla (2021) highly marked the impacts of *L. camara* on native biodiversity and these impacts are due to the species invasive characters such as rapid vegetative growth, highly competitive ability, high seed production and proliferation throughout the year in ideal environmental conditions. Beside this, the allelochemicals present in the plant parts are responsible to impact the native plant species (Choyal and Sharma,2011).

Similarity index of plant communities of invaded and non-invaded sites were found to be 51.89% and its values in different life form ranges from 34.21% to 63.33%. Similarity index were found high in shrubs followed by herbs and trees have lower similarity index. The presence of some similar species of herbs, shrubs and trees in *L. camara* invaded sites and non-invaded sites seem to suggest that invasion of *L. camara* in the site does not replace or exclude total native species. thus, suggesting a potential refuge effect. However, with the increasing in intensity of *L. camara* invasion, coverage of such native species decreased. previous studies observed that presence of similar species in the both site is due to the result of shade tolerant species co-occurring with the invader (Tererai et al., 2013).

5.3 Impacts of *L. camara* on soil pH

The soil pH of invaded areas was slightly high as compared to non-invaded areas. The high pH in the soil of invaded site of *L. camara* invasion is consistent with the result reported by Chatanga (2007), Osunkonya and Perret (2011), Simba et al. (2013). However, Kourtev et al. (2002), Koutika et al. (2011), in their report showed both increases and decreases in soil pH due to the invasion of *L. camara.* Increase in the soil pH in the present study is not clear whether it is due to *L. camara* invasion or invasion favors the site with high soil pH. So, to find the exact pathway causing the increase in the invaded sites extensive study need to be done in its root chemistry and overall litter biomass. The higher soil pH in the soil of *L. camara* invasion is similar to those reported in India (Sharma et al., 2005) and the possible reason may be due to the preference of invasive species on high pH environments.

Previous study done by Fan et al. (2010), in China and Sharma and Raghubanshi (2009), also show the increase in pH with the increase in *L. camara* invasion. Bezabih et al. (2021), also reported the similar result in Wollo Floristic Region, Ethiopia. This high pH accelerates litter decomposition and regulate nutrient availability (Simba et al., 2013). Weidenhamer and Callaway (2010), stated that soil pH has a major role in controlling nutrient bio-availability.

5.4 Impact of *L. camara* on soil microbes

There is significant difference in the population of bacterial and fungi in the soil of invaded and non-invaded sites. The population were found to be higher in the non-invaded sites than that of invaded site. This result of decrease in bacterial population counting are confirmed by the findings of Piao et al., 2000; Fierer and Jackson, 2006). Variation in pH of invaded and non-invaded soil may attributed for the decrease in the bacterial population (Dar et al., 2012). Composition of the bacterial communities and soil pH are directly related (Rousk et al., 2010). This difference in the population of soil microbe might be due to the allelochemicals produced by the *L. camara.* Lauber et al. (2009), also reported the effect of soil pH on bacterial composition. But the finding of decrease in bacterial population due to invasion is not concurred with the finding published by Pysek et al. (2012), which reveals that increase of richness and abundance of soil biota due to invasion of exotic plant species.

Invasion of invasive species changes the structure of soil microbial communities (Kulmatiski, 2008). The species richness of fungi species was also different in the invaded and non-invaded sites. The species richness of soil fungi was lower in the soil of *L. camara* invasion as compared to the soil of non-invasion sites but the difference is insignificant. *Cladosporium* sp, *Microsporium gypseum*, *Aureobasidium* sp, *Fusarium solani* occurred only in the soil of *L. camara* invasion. *Fusarium solani, Penicillium notatum, Trichoderma viridi* are the species that occurred mostly in the invaded sites whereas the species like *Trichoderma viridi, Penicillium notatum, Penicillium sp, Fusarium oxysporium*, *Aspergillus niger* etc occurred mostly in the non-invaded sites. This result supports the result of Wolfe & Klironomos (2005), which shows that invasion of invasive species altered the soil biota. Shaukat & Siddiqui (2001), found the lower fungal diversity and equitability in *Lantana* amended soil but the species richness of fungi was increased.

Genera of *Penicillium*, *Aspergillus* etc are the common decomposers in the uninvaded soil (Fu-qiang et al. 2004). The frequency of these species decreased in the invaded sites of *L. camara* and this reduction of saprophytic fungi might be the reason for invasion of *L. camara.*

6. CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The present study has revealed that invasion of *Lantana camara* impact negatively on vegetation structure and composition. The highest numbers of species belong to family Asteraceae, followed by poaceae, Fabaceae. Density and frequency of species are remarkably lower in the invaded areas. IVI of the most of the dominant herb's species like *Imperata cylindrica, Capillipedium assimile, Oxalis corniculata* etc are reduce on moving from non-invaded sites to invaded sites. Similarly, in shrubs layer *A. indica* is the dominant species in non-invaded sites which is replaced by *L. camara* in invaded sites. These results show a change in species composition of *L. camara* invaded areas on increasing its invasion.

L. camara invasion reduces the species diversity, evenness and richness in the invaded sites. Species like *Agave* Sp., *Adiantum capillus-veneris, Argemone mexicana, Cirsium wallichii, Desmodium triflorum, Eulaliopsis binata, Dabregesica longifolia, Melaleuca viminalis* were replaced by the invasion of *L. camara.*

The soil parameter i.e., soil pH is higher in invaded sites as compared to invaded sites. But the changes in soil pH is insignificant. Invasion of *L. camara* also affects the soil microbe population. The population or CFU/ml of bacteria and fungi are significantly reduced in invaded sites. There is significant change in the species composition of fungi in invaded and non-invaded sites and fungal species richness were found higher in non-invaded sites. Among the species recorded, *Fusarium solani, Penicillium notatum, Trichoderma viridi* etc are occurred more frequently in invaded sites and the species like *Trichoderma viridi, Penicillium notatum, Penicillium* Sp. etc are occurred more frequently in non-invaded sites.

The present study has provided strong evidence that invasion of *L. camara* is reducing both above ground plants and underground fungal diversity and negatively affecting the areas of its occurrence.

6.2 Recommendation

Following recommendations have been suggested from the finding of present study;

- In present study, lower diversity in the invaded sites may suggest that *L. camara* invasion has positive role in decrease of plants and fungi diversity. However, as the present study was not focused to management of *L. camara*, it is recommended for the future researchers to start research work related to the methods of its management and control.
- Further studies should be carried out to find the reasen of replace of the species like *Agave* Sp., *Adiantum capillus-veneris, Argemone mexicana, Cirsium wallichii, Desmodium triflorum, Eulaliopsis binata, Dabregesica longifolia, Melaleuca viminalis* etc from the invaded sites.
- Further studies should be carried out to determine the changes in soil properties due to invasion.
- The rate at which *L. camara* invasion is occurring and expanding show the need for a monitoring and assessment of damage.

7. References

Abebe, F.B. (2018). Invasive *Lantana camara* L. shrubs in Ethiopia: Ecology, Threats, and suggested management strategies. *Journal of Agriculturl Science* 10(7).

Acchireddy, N.R. and Singh, M. (1984) Allelopathic Effects of *lantana (L. camara)* on Milkweed vine (Morrenia odorata). *Weed Science 32*:757-761.

Anon. (2000). National Strategy for Lantana Management. Queensland Department of Natural Resources, Brisbane.

Aravindhan, V., Rajendran, A., (2014). Impact of invasive species *Lantana camara* (L). on the vegetation of Velliangiri Hills, the southern Western Ghats, India. *Glob, J. Environ. Res. 8*(3)**:** 35-40.

Assefa, A.S. and Molla, E.L. (2021). Impact of invasive alien plant species, *Lantana camara,* on the species composition, richness and evenness of invaded plant communities in Sidama, Gamogofa and Gedio Zones, Ethiopia. *Research Square.* [https://doi.org/10.21203/rs.3.rs-943114/v1].

Ayesha E.P. (2006). Impact of *Lantana camara*, a major invasive plant, on wildlife habitat in Bandipur Tiger Reserve, southern India. *Nature Conservation Foundation, India*.

Balami, S., Thapa, L., B. and Jha, S. K. (2017). Effect of invasive species *Ageratina adenophora* on species richness and composition of saprophytic and pathogenic soil fungi. *Biotropia. 24*(3): 212-219.

Bansal, G.L., (1998). Allelopathic effects of *Lantana camara* on rice and associated weeds under the midhill conditions of Himachal Pradesh, India In: Olofsdotter, M., (Ed.), Workshop on Allelopathy in Rice. Proceedings of International Rice Research Institute, Manila, Philippines, 133-138.

Benson, H.J., (2002). Bacterial population counts. In: microbiological applications. New York (US): McGraw Hill Company. p. 87.

Bezabih. B., Gobezie, T., and Hassen, S., (2021). Impact of *Lantana camara* L. in plant diversity and Soil physiochemical characteristics in Wollo Floristic Region, Ethiopia. *Abyss. J. Sci.Technol. 6*(2):22-31.

Bhatt, Y.D., Rawat Y. S.& Singh, S. P., (1994). Changes in ecosystem functioning after replacement of forest by *Lantana* shrub-land in Kumaun Himalaya. *Journal of Vegetation Science. 5***:**67-70.

Bhatta, S., Joshi, L.R., Shrestha, B.B., (2020). Distribution and Impact of invasive alien plant species in Bardia National Park, Western Nepal. *Environmental conservation. 47.*

Bhattarai, K.R., Maren, I.E. and Subedi, S.C. (2014). Biodiversity and invasibility: distribution patterns of invasive plant species in the Himalayas, Nepal. *Journal of Mountain Science, 11:* 688-696.

Bias, H.P, Weir, T.L, Perry, L.G., Gilroy, S., Vivanco, J.M. (2006). The role of root exudates in rhizosphere interactions with plants and other organisms. *Annu Rev Plant Biol 57*:233-66.

Bonanomi, G., Giannino, F., Mazzoleni, S., Setala, H., (2005). Negative plant-soil feedback and species coexistence. *Oikos 111*(2):311-321.

Catford, J.A., Jansson, R., and Nilsson, C. (2008). Reducing redundancy in invasion ecology by integrating hypotheses into a single theoretical framework. *Diversity and Distribution. 15*(1); 22-40.

Chatanga, P., (2007). Impact of the invasive alien species *Lantana camara* (L). on native vegetation in Northern Gonarezhou National Park, Zimbawe. Master of Science Thesis. University of Zimbawe, Zimbabwe.

Choyal, R. and Sharma, S.K., (2011). Evaluation of Allelopathic effects of *Lantana camara* (Linn) on regeneration of *Pogonatum aloides* in culture media: *As. J. of Pla. Sci. and Rese.,1* (3)**:**41-48.

Clegg, S. (1999). Effect of Perennial Water on Soil, Vegetation and Wild Herbivore Distribution in Southern-eastern Zimbabwe. Unpublished MSc Thesis, University of Natal. Pietermaritzburg.

Crowling, R.M., Richardson, D.M. and Piece, S.M. (1997) Vegetation of Southern Africa. Cambridge University Press, Cambridge.

Dar, G.H., Nazir, R., Kamili, A., Bandh, S., (2012). A preliminary study of colony forming units of bacteria from the soils of Yusmarg Forest, Kashmir Valley India. *International Journal of current Research. 4*(12); 467-472.

Day, M., Wiley, C.J., Playford, J., and Zalucki, M.P. (2003) *Lantana*: Current Management Status and Future Prospects. ACIAR Monograph 102, 1-125.

Dayakar, B.V., Weir, T.L., Lelie, D.V., Vivanco, J.M., (2009). Rhizosphere chemical dialogues: plant microbe interactions. *Curr Opin Biotechnol.* 20:642–650.

Dobhal, P.K., Kohli, R.K., and Batish, D.R., (2010). Evaluation of the impact of *Lantana camara* L. invasion, on four major woody shrubs, along Nayar river of Pauri Garhwal, in Uttarakhand Himalaya: *Int. J. of Biodiv. and Cons*.;*2*(7): 155-161.

Dobremez, J.F. (1976). Le Nepal Ecologie et Phytogeography. Paris: Editiion du Centre National de la Recherche Scientifique, France

Duggin, J.A. and Gentle, C.B. (1998) Experimental Evidence on the Importance of Disturbance Intensity for Invasion of *L. camara* L. in Dry Rainforest Ecotones in North-eastern NSW, Australia. *Forest Ecology Management 109:* 279- 292.

Ehrenfeld J.G, Ravit B, Elgersma K. (2005). Feedback in the plant soil system. *Ann Rev Environ Resour 30*:75- 115.

Faegri, K. and Van der Piji, L. (1979). The principles of pollination ecology. Pergamon Press, Oxford, New York.

Fan, L., Chen, Y., Yuan, J., Yang, Z. (2010). The Effect of *Lantana* Invasion on the Soil Chemical, Microbial Properties and Plant Biomass accumulation in Southern China. *Geoderma* , *154*: 370-378.

Fierer, N. and Jackson, R. B. (2006). The Diversity and Biogeography of Soil Bacterial Communities. *PNAS 103*(3): 626-631.

French, G, B.K., Turner, P.J. and Downey, P.O. (2009). Impact threshold for an alien plant invader, *Lantana camara* L., on native plant communities. *Bio. Cons*., *142:* 2631-2641.

Fu-qiang, S., Xing-Jun, T., Zhong-Qi, L., Chang-Lin, Y., Bin, C., Jie-jie, H., Jing, Z., (2004). Diversity of filamentous fungi in organic layers of two forests in Zijin Mountain. *J For Res*. *15*(4):273-279.

Funk, V. A., Bayer, R. J., Keeley, S., Chan, R., Watson, L., Gemeinholzer, B., Schiling, E., Panero, J., Baldwin, B. G., Garcia-Jacas, N., Susanna, A. and Jansen, R. K. (2005). Everywhere but Antarctica: Using a supertree to understand the diversity and distribution of the Compositae. *Biologiske Skrifter 55*: 343-374.

Gaggini L, Rusterholz H, Baur B., (2018). The invasive plant *Impatiens glandulifera* affects soil fungal diversity and the bacterial community in forests. *Appl Soil Ecol*: *124*:335–43.

Gantayet, P.K., Adhikary, S.P., Lenka, K.C., and Padhy, B. (2014). Allelopathic Impact of *Lantana camara* on Vegetative Growth and Yield Components of Green Gram (*Phaseolus radiantus). International Journal of Current Microbiology and Applied Science 3*(7):327-335.

Gentle, C.B. and Duggin, J.A. (1998) Interference of Choricarpia leptopetala by *L. camara* with nutrient enrichment in mesic Forest on Central Coast of NSW. *Plant Ecology 136*: 205-211.

Ghisalberti, E.L., (2000). *Lantana camara* L. (Verbenaceae). *Fitoterapia 71:* 467-486.

Gooden, B., French. K., Turner, P.I., Downey, P.O. (2009). Impact Threshold for an alien plant invader, *Lantana camara* L. on native plant comunities. *Biol. conser*:*142*: 2631-2641.

Hara, H., (1966). The flora of eastern Himalaya: results of the botanical expedition to eastern Himalaya organized by the University of Tokyo 1960 and 1963. University of Tokyo Press, Tokyo.

Hawkes, C.V., Wren, I.F., Herman, D.J. (2005). Firestone, M.K; Plant invasion alters nitrogen cycling by modifying the soil nitrifying community. *Ecology Letters 8:* 976–985.

Heffernan, K.E. (1998) Managing Invasive Alien Plants in Natural Areas, Parks and Small Woodlands. Natural Heritage Technical Report 98 125. Virginia Department of Conservation and Recreation, Division of Natural Heritage. Richmond, Virginia.

Holmes, P.M., Richardson, D.M., Van-Wilgen, B.W. and Gelderblom, C. (2000) Recovery of South African Fynbos Vegetation Following Alien Woody Plant Clearing and Fire: Implications for Restoration. *Austral Ecology. 25:* 631-639.

Jaccard, P., (1901). Etude comparative de la distribution florale dans une portion des Alpes et des Jura. *Bulletin de la Societe Vaudoise des Sciences Naturelles. 37:*574-579.

Joshi, S. P., and Mandal, G., (2015). Change in physiochemical properties of soil encourages the invasion establishment and carbon dynamics of *Lantana camara* from Doon valley, Western Himalaya, India. *Asian Journal of Conservation Biology. 4:*62-75.

Katinas, L., Hernandez, M. P., Arambarri, A. M. and Funk, V. A. (2016). The origin of the bifurcating style in Asteraceae (Compositae). *Annals of Botany 117*: 1009-1021.

Kato-Noguchi, H., Kurniadie, D., (2021). Allelopathy of *Lantana camara* as an Invasive Plant. *Plants (Basel)*. *10*(5).

Kourtev, P., Ehrenfeld, J. and Haggblom, M. (2002). Exotic Plant Species Alter the Microbial Community Structure and Function in the Soil. *Ecology*. *83*: 3152-3166.

Kourtev, P., Ehrenfeld, J., Häggblom, M. (2003). Experimental analysis of the effect of exotic and native plant species on the structure and function of soil microbial communities. *Soil Biology and Biochemistry 35*: 895–905. DOI: 10.1016/s0038-0717(03)00120-2

Koutika LS, Rainey HJ, Dassonville N (2011). Impacts of *Solidago gigantea, Prunus serotina*, *Heracleum mantegazzianum* and *Fallopia javanica* invasions on ecosystems. *Appl. Ecol. Environ. Res. 9*(1):73- 83.

Klink, C.A. (1996) Germination and Seedling Establishment of Two Native and One Invading African Grass Species in the Brazilian Cerrado. *Journal of Tropical Ecology 12*(1)**:** 139-147.

Kunwar, R. M. and Acharya, R. P., (2013). Impact Assessment of Invasive Plant Species in Selected Ecosystems of Bhadaure Tamagi VDC, Kaski: An Ecosystem-based Adaptation in Mountain Ecosystem in Nepal. IUCN Nepal, Kupondole, Lalitpur, Nepal

Kulmatiski, A., Beard, K.H., Stevens, J.R., Cobbold, S.M., (2008) Plant-soil feedbacks: a meta-analytical review. *Ecol Lett 11:* 980–992.

Lamb, R. (1988). Ecological and perceptual changes to shrubland associated with lantana invasion. *Caring for Warringah's Bushland. Shire of Warringah, Sydney*.

Lauber, C.L., Hamady, M., Knight, R., and Fierer, N. (2009). Pyrosequencing-based assessment of soil pH as a predictor of soil bacterial community structure at the continental scale. *Appl Environ Microbiol*.*75*: 5111–5120.

Lowe, S., Browne, M., Boudjelas, S. and DePoorter, M. (2000). 100 of the World's Worst Invasive Alien Species: A Selection from the Global Invasive Species Database. The Invasive Species Specialist Group (ISSG), a specialist group of the Species Survival Commission (SSC) of the World Conservation Union (IUCN), New Zealand.

Lowe, S.M., Browne, P., Boudjelas, S. and De Poorter, M. (2004) Hundreds of World's Worst Invasive Alien Species. *BioSciences 280*: 252-254.

Macdonald, I.A.W., Theband, C., Strahm, W.A. and Strasberg, D. (1991) Effects of Plant Invasions on Native Vegetation Remnants on La Reunion (Mascarene Islands, Indian Ocean). *Environmental Conservation 18*(1): 31-46.

Malla, S. B.; Rajbhandari, S. B.; Shrestha, T. B.; Adhikari, P. M.; Adhikari, S. R. and Shakya P. R. (1986). Flora of Kathmandu Valley. Bull. Dept. Med. Plants Nepal No. 11. Department of Medicinal Plants, Thapathali, Kathmandu, Nepal.

Mandal, M., Joshi, S.P., (2015). Eco-physiology and habitat invasibility of invasive, tropical shrub (*Lantana camara)* in Western Himalayan forests of India. *Forest Science and technology. 11:* 182-196.

Mandel, J. R., Barker, M. S., Bayer, R. J., Dikow, R. B., Gao, T. G., Jones, K. E., Keeley, S., Kilian, N., Ma, H., Siniscalchi, C. M., Sunsanna, A., Thapa, A., Watson, L. and Funk, V. A. (2017). The compositae tree of life in the age of phylogenomics. *Journal of Systematics and Evolution. 55*(4): 405-410.

Mason, T.J., French, K., (2008). Management regimes for a plant invader differentially impact resident communities. *Biological Conservation, 136*: 246–259.

Mathakutha, R., Steyn, C., Roux, P.C., Chown, B.S., Daru, B. H., Ripley, B.S., Louw, A., Greve, M. (2019). Invasive species differ in key functional traits from native and non-invasive alien plant species. *Journal of Vegetation science, 30*(5): 994-1006).

Meffe, G.K., Caroll, C.R. and Contributors (1997) Principles of Conservation Biology, 2nd edition. Sinauer Associates, Inc. Sunderland, Massachisetts.

Mishra, A., (2015). Allelopathic properties of *Lantana camara*. *International Research Journal of Basic and Clinical Studies*. *3*(1); 13-28.

Moyo, G.H. (2004) Invasion of *L. camara* L. (Verbennacea) In the Upper Zambezi Riverine Vegetation Community of the Zambezi/Victoria Falls National Park. Msc Thesis. Tropical Resources Ecology Program, University of Zimbabwe.

Mueller-Dombois, D. and Ellenberg, H. (1974). Aims and Methods of Vegetation Ecology. John Wiley and Sons, New York.

Myers, N. Mittermeier, R.A. Mittermeier, C.G. da Fonseca, C.A.B. and Kent, J. (2000) Biodiversity Hotspots for Conservation Priorities. *Nature 403:* 853-858.

Nel, L. (2015). Effects of a highly invasive plant (*Lantana camara*) on an agricultural flower visitation network: Agricultural Science Thesis, Stellenbosch University, the Western Cape province of South Africa.

Niu, H.B., Liu, W.X., Wan, B.L., (2007). An invasive aster *(Ageratina adenophora)* invades and dominates forest understories in China: altered soil microbial communities facilitate the invader and inhibit natives. *Plant Soil. 294*:73-85.

Osunkonya, 0.0., Perret, C., (2011). *Lantana camara* L. (Verbenaceae) invasion effects on soil physicochemical properties. *Biol. Fertil. soils*. *47***:**349-355.

Piao, H.C., Hong, Y.T. and Yuan, Z.Y. (2000), Seasonal Changes of Microbial Carbon Related to Climated Factors in Soils from Karst Areas of Southwest China. *Biol. Fertil. 30:*294-297.

Press, J.R. in Hara, H., Chater, A.O. & Williams, L.H.J. (1982). An Enumeration of the Flowering Plants of Nepal. British Museum, London *.3*.

Pysek, P.V., Philip, E., Pergl, J., UrsSchaffner, M., Vila, M., (2012). Global assessment of invasive plant impacts on resident species, communities and ecosystems: the interaction of impact measures, invading species' traits and environment. *Glob Change Biol.18*:1725–37.

Raphela, T.D., and Duffy, K. (2022). The impact if *Lantana camara* on Invertebrates and plant species of the Groenkloof Nature Reserve, South Afica. *Zoo Stud 61:*e33.

Ratnayake, R.M.C.S. (2014). Why plant species become invasive? Conference: Naional Symposium on invasve alien species. At: Colombo. Srilanka. *1*.

Raphela, T.D. and Kevin, D., (2022). The impact of *Lantana camara* on invertebrates and plants species of the Groenkloof Nature Reserve, South Africa. *Zoo Stud. 61:*33.

Ricciardi, A., Neves, R.J. and Rasmussen, J.B., (1998). Impending extinction of North American fresh water mussels (Unionoida) following the zebra mussel (Dreissena polymorpha) invasion. *Journal of Animal Ecology 67*:613-619.

Richardson, D.M., Pysek, P. and Carlton, J.T. (2011). A Compendium of Essential concepts and terminology in invasive ecology. Chichester, UK.

Rousk, J., Baath, E., Brookes, P.C., Lauber, C.L., Lozupone, C., Caporaso, J.G., Knight, R. and Fierer, N. (2010), Soil Bacterial and Fungal Communities Across a pH Gradient in an Arable Soil. *The ISME Journal*, 1–12.

Royal Botanical Garden, Kew., (2017), State of the World's Plants.

Ruwanza, S. (2020). Effects of *Lantana camara* invasion on vegetation diversity and composition in the Vhembe Biosphere Reserve, Limpopo Province of South Africa. *Scientific African10.*

Sahu, A.K. and Panda, S. (1998) Population Dynamics of a Few Dominant Plant Species Around Industrial Complexes, in West Bengal, India. *Bombay Natural History Society Journal 95*:15-18.

Shannon, C.E., Weaver, W. (1949) The Mathematical Theory of Communication. *University of Illinois Press*, *Urbana*, IL. 1–117.

Sharma, G.P. and Raghubashi, A.S. (2005) Tree Population Structure, Regeneration and Expected Future Composition at Different Levels of *L. camara* L. Invasion in the Vindhyan Tropical Dry Deciduous Forest of India. *Australian Journal of Ecology 17*: 167-179.

Sharma, G.P., Raghubashi, A.S. and Singh, J.S. (2005). *L. camara* Invasion: An Overview. *Weed Biology and Management 5:* 157-165.

Sharma, G.P. and Raghubanshi, A.S., (2007). Effect of *Lantana camara* L. cover on local depletion of tree population in the Vindhyan tropical dry deciduous forest of India. *Appl. Ecol. Environ. Res.,* *5*(1): 109- 121.

Sharma, G., and Raghubanshi, A. (2009). *Lantana Invasion* Alters Soil Nitrogen Pool and Processes in the Tropical Dry Deciduous Forest of India. *Applied Soil Ecology*, *42:* 134- 140.

Sharma, L., Khare, A. & Siddiqui, M.A., (2017). Allelopathic Effect of Lantana Camara on Germination and Growth of Chickpea and Green Gram. *International Journal of Advanced Engineering, Management and Science (IJAEMS) 3*: 247-240.

Shaukat, S. and Siddiqui, I. (2001). Lantana camara in the Soil Changes the Fungal Community Structure and Reduces Impact of *Meloidogyne javanica* on mungbean. *Phytopathology Meditteranea, 40*: 245–252.

Shrestha, B. B. (2016). Invasive alien plant species in Nepal. In Eds.: Jha PK, Siwakoti M. and Rajbhandary. Central Department of Botany, Tribhuvan University, Kirtipur, Kathmandu. S. *Frontiers of Botany*. 269-284.

Shrestha, B.B., Budha, P.B., Pagad, S. & Wong, L.J. (2017). Global Register of Introduced and Invasive Species- Nepal, Invasive Species Specialist Group ISSG. Checklist Dataset https://doi.org/10.15468/4rokkr accessed via GBIF org.

Shrestha, B.B., Shrestha, K.K (2021). Invasions of alien plant species in Nepal; Patterns and Process. *Invasive Alien Species; Observations and Issues from around the world. 2:*168-183.

Si, C., Liu, X., Wang, C., Wang, L., Dai, Z., Qi, S. and Du, D. (2013). Different degrees of plant invasion significantly affect the richness of the soil fungal communities. *Plos One 8*(12).

Simba, Y. R., Kamweya, A. M., Mwangi, P. N. and Ochora, J. M. (2013). Impact of the Invasive shrub, Lantana camara L. on Soil Properties in Nairobi National Park, Kenya. *International Journal of Biodiversity and Conservation***,** *5*(12): 803-809.

Simberloff, D. and Holle, B.V., (2000). Positive interactions of nonindigenous species: Invasional meltdown? *Biological Invasion. 1***:** 21-32.

Simpson, E. H. (1949). The measurement of diversity. *Nature*, 163-88.

Singh, H.P., Batish, D.R., Dogra, K.S., Kaur, S., Kohli, R.K. and Negi, A. (2015). Negative effects of litter of invasive weed *Lantana camara* on structure and composition of vegetation in the lower Siwalik Hills, northern India. *Environmental Monitoring and Assessment 186*: 3379-3389.

Siwakoti, M., Shrestha, B. B., Devkota, A. et al. (2016). Assessment of the effects of climate change on the distribution of invasive alien plant species in Nepal. In: Building Knowledge for Climate Resilience in Nepal: Research Brief (eds. D.R. Bhuju, K. McLaughlin, J. Sijapati, et al.), 5–8. Kathmandu: Nepal Academy of Science and Technology.

Stainton, A. (1988). Flowers of the Himalaya: a supplement. Oxford University Press New Delhi.

Stinson, K., Campbell, S., Powell, J., Wolfe, B., Callaway, R. and Thelen, G. (2006). Invasive Plant Suppresses the Growth of Native Tree Seedlings by Disrupting Below Ground Mutualisms. *PloS Biology*, *4*: 727-731.

Stohlgren, T.J., Bull, K.A., Otsuki, Y., Villa, C.A. and Lee, M. (1998) Riparian Zones as Havens for Exotic Plant Species in the Central Grasslands. *Plant Ecology 138*: 113-125.

Sundaram, B., and Hiremath, A.J., (2012). *Lantana camara* invasion in a heterogeneous landscape: patterns of spread and correlation with changes in native vegetation. *Biol invasions 14:* 1127-1141.

Suding K.N, Harpole W.S, Fukami T, Kulmatiski A, MacDougall, A.S et al. (2013) Consequences of plant-soil feedbacks in invasion. *J Ecol 101*: 298–308. doi:10.1111/1365-2745.12057.

Tanner, R. A. and Gange, A. C. (2013). The impact of two non-invasive plant species on native flora performance: potential implications for habitat restoration. *Plant Ecology 214*: 423-432.

Thapa, L.B., Kaewchumnong, K., Sinkkonen, A., Sridith, K., (2016). Impacts of invasive *Chromolaena odorata* on species richness, composition and seedling recruitment of *Shorea robusta* in a tropical Sal forest, Nepal. *Songklanakarin J Sci Tech 38*(6):683-690.

Timberlake, J. and Musokonyi, C. (1994). Forest Conservation and Utilisation, Chirinda Forest: A Visitors Guide. Forestry Commission, Harare.

Tererai, F., Gaertner, M., Jacobs, S.M., and Richardson, D.M., (2013). Eucalyptus invasions in riparian forests; effects on native vegetation community diversity, stand structure and composition, *For. Ecol. Manag*; *29:* 84-93.

Tiwari, S., Adhikari, B., Siwakoti, M. and Subedi, K. (2005). An Inventory and Assessment of Invasive Alien Plant Species of Nepal. Kathmandu: IUCN Nepal

Kohli, R.K., Dogra, K.S., Batish, P.R, and Singh, H.P., (2004) "Impact of Invasive Plants on the Structure and Composition of Natural Vegetation of Northwestern Indian Himalayas" *Weed Technology, 18:*1296–1300.

Van der Putten, W. H., Kowalchuck, G.A., Brinkman, E.P., Doodeman, G.T.A, Van der Kaaij, R.M., Kamp, A.F.D, Veenendaal, E.M., (2007). Soil feedback of exotic savanna grass relates to pathogen absence and mycorrhizal selectivity. *Ecology*. *88:*978-88.

Vardien, W., Richardson, D.M., Foxcroft, L.C., and Thompson, G.D. , Wilson, J.R.U. and Le Roux, J.J. (2012). Review: Invasion dynamics of *Lantana camara* L. (sensu lato) in South Africa. *Sout. Afri. J. of Bot***,** *81:* 81-94.

Vieira, D.L.M., and Scariot, A., (2005). Principles of natural regeneration of tropical dry forest for restoration. *Restor. Ecol. 14*(1): 11-20.

Visteensaari, J., Johansson, S., Kaarakka, V. and Luukkanen, O. (2000) Is the Alien Tree Species Maesopsis eminii Engl. (Rhamnaceae) a Threat to Tropical Forest Conservation in the East Usambaras, Tanzania? *Environmental Conservation 27*(1): 76- 81.

Wang, R., Kang, X., Quan, G., Zhang, J (2015). Influence of *Lantana camara* on soil II. Effects of Lantana camara leaf litter on plants and soil properties. *Allelopathy Journal 35* (2)**:** 207-216.

Weidenhamer JD, Callaway RM (2010). Direct and indirect effects of invasive plants on soil chemistry and ecosystem functions. *J. Chem. Ecol. 36*:59-60.

Wolfe, B.E., Klironomos, J.N., (2005). Breaking new ground: soil communities and exotic plant invasion. *Bioscience 55(*6):477-487.

Yadav, K., Batish, D.R., Singh, H.P., Kohli, R.K., (2004). Allelopathic interference of *Lantana camara* L.: nature and dynamics of allelochemical release. *Bull. Environ. Sci., 1*: 69-72.

Yaduraju, N.T., Bhowmik, P.C. and Kushwaha, S. (2000). The Potential Threat of Alien Weeds to Agriculture and Environment. At the cross road of the New Millennium. (eds.) Jha, P.K., Karmacharya, S.B., Baral, S.R. and Lacoul, P. Ecological society (ECOS), Nepal, 229-234.

Zhang, P., Bo, L., Jihua, W., Hu, S., (2019) Invasive plants differentially affect soil biota through litter and rhizosphere pathways: a meta-analysis. *Ecol Lett; 22*:200–10.

Zobel, D.B., Jha, P.K., Behan, M.J., & Yadav, U.K.R (1987). A Practical Manual for Ecology. Ratana Book Distributor, Kathmandu, Nepal.

Appendices

Appendix 1: Species composition of study area

S.N	Name of species	Invaded	Non-invaded	Life form	Family
1	*Achyranthes aspera* L.	+	+	Herb	Amaranthaceae
2	*Acmella paniculata* (Wall. ex DC.) R.K.Jansen	+	+	Herb	Asteraceae
3	*Acmella uliginosa* (Sw.) Cass.	+	+	Herb	Asteraceae
4	*Adiantum capillus-veneris* L.	-	+	Herb	Pteridaceae
5	*Agave sp*	-	+	Herb	Asparagaceae
6	*Ageratina adenophora* (Spreng.) R.M.King & H.Rob.	+	+	Herb	Asteraceae
7	*Ageratum conyzoides* L.	+	+	Herb	Asteraceae
8	*Ageratum houstonianum* Mill.	+	+	Herb	Asteraceae
9	*Aleuritopteris bicolor* (Roxb.) Fraser-Jenk.	+	+	Herb	Pteridaceae
10	*Alternanthera philoxeroides* (Mart.) Griseb.	+	-	Herb	Amaranthaceae
11	*Anaphalis sp*	+	+	Herb	Asteraceae
12	*Argemone mexicana* L.	-	+	Herb	Papaveraceae
13	*Asparagus racemosus* Willd.	+	+	Herb	Liliaceae
14	*Barleria cristata* L.	-	+	Herb	Acanthaceae
15	*Bidens pilosa* L.	+	+	Herb	Asteraceae
16	*Blumea lacera* (Burm.f.) DC.	-	+	Herb	Asteraceae

17	*Boehmeria platyphylla* D.Don	-	+	Herb	Urticaceae
18	*Boenninghausenia sp*	+	-	Herb	Rutaceae
19	*Capillipedium assimile* (Steud.) A.Camus	+	+	Herb	Poaceae
20	*Capillipedium parviflorum* Stapf.	+	+	Herb	Poaceae
21	*Centella asiatica* (L.) Urb.	+	+	Herb	Apiaceae
22	*Chromolaena odorata* (L.) R.M.King & H.Rob.	+	+	Herb	Asteraceae
23	*Cirsium wallichii* DC.	-	+	Herb	Asteraceae
24	*Cissampelos pareira* L.	+	+	Herb	Menispermaceae
25	*Clematis buchananiana* DC.	-	+	Herb	Ranunculaceae
26	*Conyza bonariensis* (L.) Cronquist	+	+	Herb	Asteraceae
27	*Cynodon dactylon* (L.) Pers.	+	+	Herb	Poaceae
28	*Cyperus iria* L.	-	+	Herb	Cyperaceae
29	*Cyperus rotundus* L.	+	+	Herb	Cyperaceae
30	*Ocotea salicifolia* Nees	-	+	Herb	Urticaceae
31	*Dendrocalamus sp*	+	+	Herb	Poaceae
32	*Desmodium microphyllum* (Thunb.) DC.	+	+	Herb	Fabaceae
33	*Desmodium triflorum* Wall. ex Wight & Arn.	-	+	Herb	Fabaceae
34	*Dicranopteris linearis* (Burm.f.) Underw.	+	+	Herb	Gleicheniaceae
35	*Dioscorea deltoidea* Wall.	+	+	Herb	Dioscoreaceae

36	*Drepanostachyum falcatum* (Nees) Keng f.	+	-	Herb	Poaceae
37	*Drymaria diandra* Blume	+	+	Herb	Caryophyllaceae
38	*Dryoathyrium boryanum* (Willd.) Ching	+	+	Herb	Aspleniaceae
39	*Dryopteris filix-mas* (L.) Schott	+	+	Herb	Dryopteridaceae
40	*Eragrostis tenella* (L.) P. Beauv. ex Roem. & Schult.	-	+	Herb	Poaceae
41	*Eranthemum pulchellum* Andrews	-	+	Herb	Acanthaceae
42	*Eulaliopsis binata* (Retz.) C.E.Hubb.	-	+	Herb	Poaceae
43	*Euphorbia heterophylla* L.	-	+	Herb	Euphorbiaceae
44	*Fragaria indica* Andrews	-	+	Herb	Rosaceae
45	*Fragaria vesca* L.	+	-	Herb	Rosaceae
46	*Galinsoga parviflora* Cav.	-	+	Herb	Asteraceae
47	*Gentiana capitata* Buch.-Ham. ex D.Don	-	+	Herb	Gentianaceae
48	*Gentiana sino-ornata* Balf.f.	-	+	Herb	Gentianaceae
49	*Globba racemosa* Sm.	+	+	Herb	Zingiberaceae
50	*Gonostegia hirta* Miq.	+	+	Herb	Urticaceae
51	*Gynura angulosa* Hance	+	+	Herb	Asteraceae
52	*Heteropogon contortus* Beauv. ex Roem. & Schult.	-	+	Herb	Poaceae
53	*Hydrocotyle sibthorpioides* Lam.	-	+	Herb	Araliaceae

54	*Imperata cylindrica* (L.) P.Beauv.	+	+	Herb	Poaceae
55	*Lapsana sp*	-	+	Herb	Asteraceae
56	*Lepidium sativum* L.	+	+	Herb	Brassicaceae
57	*Lindenbergia indica* Kuntze	-	+	Herb	Orobanchaceae
58	*Lygodium flexuosum* (L.) Sw.	+	+	Herb	Lygodiaceae
59	*Lygodium japonicum* (Thunb.) Sw.	+	-	Herb	Lygodiaceae
60	*Mimosa pudica* L.	+	+	Herb	Fabaceae
61	*Mucuna pruriens* (L.)DC.	+	+	Herb	Fabaceae
62	*Nephrolepis cordifolia* (L.) C.Presl	+	+	Herb	Nephrolepidaceae
63	*Oxalis corniculata* L.	+	+	Herb	Oxalidaceae
64	*Oxalis latifolia* Kunth	+	+	Herb	Oxalidaceae
65	*Paspalum sp*	+	+	Herb	Poaceae
66	*Phyllanthus urinaria* L.	-	+	Herb	Phyllanthaceae
67	*Plantago major* L.	+	+	Herb	Plantaginaceae
68	*Polygonum persicaria* L.	+	+	Herb	Polygonaceae
69	*Pteridium sp*	-	+	Herb	Dennstaedtiaceae
70	*Pteris ensiformis* Burm.	-	+	Herb	Pteridaceae
71	*Pteris vittata* L.	+	-	Herb	Pteridaceae
72	*Rumex dentatus* L.	+	+	Herb	Polygonaceae
73	*Rungia pectinata* Nees	+	+	Herb	Acanthaceae
74	*Saccharum spontaneum* L.	+	+	Herb	Poaceae

75	*Senna tora* (L.)Roxb.	-	+	Herb	Fabaceae
76	*Smilax cordifolia* Humb. & Bonpl. ex Willd.	-	+	Herb	Smilacaceae
77	*Solanum nigrum* L.	+	+	Herb	Solanaceae
78	*Solanum virginianum* L.	+	+	Herb	Solanaceae
79	*Sonchus wightianus* DC.	-	+	Herb	Asteraceae
80	*Spermacoce alata* Aubl.	+	+	Herb	Rubiaceae
81	*Sphenomeris chinensis* (L.) Maxon	-	+	Herb	Lindsaeaceae
82	*Stellaria media* (L.) Vill.	-	+	Herb	Caryophyllaceae
83	*Stephania japonica* (Thunb.) Miers	+	+	Herb	Menispermaceae
84	*Taraxacum officinale* F.H.Wigg.	-	+	Herb	Asteraceae
85	*Themeda triandra* Forssk	+	+	Herb	Poaceae
86	*Triumfetta pilosa* Roth	+	+	Herb	Tiliaceae
87	*Urena lobata* L.	-	+	Herb	Malvaceae
88	*Urtica dioica* L.	+	+	Herb	Urticaceae
89	*Veronica persica* Poir.	+	+	Herb	Scrophulariaceae
90	*Vicia angustifolia* Reichard	-	+	Herb	Fabaceae
91	*Lantana camara* L.	+	+	Shrub	Verbenaceae
92	*Rhus javanica* L.	+	+	Shrub	Anacardiaceae
93	*Artemisia indica* Willd.	+	+	Shrub	Asteraceae
94	*Berberis aristata* DC.	+	+	Shrub	Berberidaceae
95	*Boehmeria nivea* Gaudich.	+	-	Shrub	Urticaceae

96	*Buddleja asiatica* Lour.	+	+	Shrub	Scrophulariaceae
97	*Catunaregam spinosa* (Thunb.) Tirveng.	+	-	Shrub	Rubiaceae
98	*Clerodendrum chinense* (Osbeck) Mabb.	+	+	Shrub	Lamiaceae
99	*Colebrookea oppositifolia* Sm.	+	+	Shrub	Lamiaceae
100	*Desmodium multiflorum* DC.	+	+	Shrub	Fabaceae
101	*Hypericum sp*	+	+	Shrub	Hypericaceae
102	*Inula cappa* (Buch. Ham. ex D.Don) DC.	+	+	Shrub	Asteraceae
103	*Justicia adhatoda* L.	+	+	Shrub	Acanthaceae
104	*Maesa chisia* D.Don	+	+	Shrub	Myrsinaceae
105	*Melastoma malabathricum* L.	+	+	Shrub	Melastomataceae.
106	*Nyctanthes arbor-tristis* L.	+	-	Shrub	Oleaceae
107	*Osbeckia nepalensis* Hook.	+	+	Shrub	Melastomataceae.
108	*Phyllanthus amarus* Schumach. & Thonn.	+	+	Shrub	Phyllanthaceae
109	*Pogostemon benghalensis* Kuntze	+	+	Shrub	Lamiaceae.
110	*Reinwardtia indica* Dumort	+	+	Shrub	Linaceae
111	*Rubus ellipticus* Sm.	+	+	Shrub	Rosaceae
112	*Woodfordia fruticosa* Kurz	+	+	Shrub	Lythraceae
113	*Dabregesica salcifolia*	-	+	Shrub	Urticaceae
114	*Debregeasia longifolia* (Burm.f.) Wedd.	-	+	Shrub	Urticaceae

115	*Hibiscus rosa sinensis* L.	-	+	Shrub	Malvaceae
116	*Jatropa sp*	-	+	Shrub	Euphorbiaceae
117	*Osyris wightiana* Wall. ex Wight	-	+	Shrub	Santalaceae
118	*Duranta sp*	-	+	Shrub	Verbenaceae
119	*Malvaviscus arboreus* Dill. ex Cav.	-	+	Shrub	Malvaceae
120	*vitex negundo* L.	-	+	Shrub	verbenaceae
121	*Litchi chinensis* Sonn.	+	+	Tree	Sapindaceae
122	*Alnus nepalensis* D.Don	+	+	Tree	Betulaceae
123	*Artocarpus heterophyllus* Lam.	-	+	Tree	Moraceae
124	*Bauhinia variegata* L.	-	+	Tree	Fabaceae
125	*Bombax ceiba* L.	+	+	Tree	Malvaceae
126	*Castanopsis indica* A.DC.	+	+	Tree	Fagaceae
127	*Celtis australis* L.	-	+	Tree	Cannabaceae
128	*Citrus medica* L.	-	+	Tree	Rutaceae
129	*Engelhardia spicata* Lechen ex Blume	+	+	Tree	Juglandaceae
130	*Ficus hispida* L.f.	+	+	Tree	Moraceae
131	*Ficus semicordata* Miq.	+	+	Tree	Moraceae
132	*Homalium napaulense* (DC.) Benth	+	+	Tree	Salicaceae.
133	*Litsea monopetala* (Roxb.) Pers.	+	+	Tree	Lauraceae
134	*Mangifera indica* L.	+	+	Tree	Anacardiaceae

135	*Melaleuca viminalis* (Sol. ex Gaertner) Byrnes	-	+	Tree	Myrtaceae
136	*Morus alba* L.	-	+	Tree	Moraceae
137	*Phyllanthus emblica* L.	+	+	Tree	Phyllanthaceae
138	*Picrasma javanica* var. *nepalensis* Blume	-	+	Tree	Simaroubaceae
139	*Pinus roxburghii* Sarg.	+	+	Tree	Pinaceae
140	*Psidium guajava* L.	+	+	Tree	Myrtaceae
141	*Pyrus pashia* Buch. Ham ex D.Don	-	+	Tree	Rosaceae
142	*Sapium insigne* (Royle) Trimen	+	+	Tree	Euphorbiaceae
143	*Schima wallichii* (DC.) Korth.	+	+	Tree	Theaceae
144	*Terminalia bellirica* (Gaertn.) Roxb.	-	+	Tree	Combretaceae
145	*Terminalia chebula* Retz.	-	+	Tree	Combretaceae
146	*Toona ciliata* M.Roem.	-	+	Tree	Meliaceae.
147	*Fraxinus floribunda* Wall.	-	+	Tree	Oleaceae
148	*Wendlandia heynei* (Schult.) Santapau & Merchant	-	+	Tree	Rubiaceae
149	*Ziziphus incurva* Roxb.	+	-	Tree	Rhamnaceae
150	*Careya arborea* Roxb.	+	-	Tree	Lecythidaceae
151	*Diploknema butyracea* (Roxb.) H.J.Lam	+	-	Tree	Sapotaceae
152	*Macaranga denticulata* Müll.Arg.	+	-	Tree	Euphorbiaceae

153	*Maesa macrophylla* Wall. ex A.DC.	+	-	Tree	Primulaceae
154	*Myrica esculenta* Buch. Ham. ex D.Don	+	-	Tree	Myricaceae
155	*Prunus cerasoides* D.Don	+	-	Tree	Rosaceae
156	*Prunus domestica* L.	+	-	Tree	Rosaceae
157	*Shorea robusta* C.F.Gaertn.	+	-	Tree	Dipterocarpaceae
158	*Streblus asper* Lour.	+	-	Tree	Moraceae
159	*Pyrus communis* L.	+	-	Tree	Rosaceae

Appendix 2: IVI of herbs of invaded sites

S.N	Name of species	RD	RF	RC	IVI
1	*Imperata cylindrica* (L.) P.Beauv.	14.77	7.071	17.088	38.929
2	*Capillipedium parviflorum* Stapf	9.288	6.566	17.073	32.926
3	*Capillipedium assimile* (Steud.) A.Camus	8.677	6.061	13.761	28.499
4	*Ageratina adenophora* (Spreng.) R.M.King & H.Rob.	8.006	9.722	8.661	26.39
5	*Bidens pilosa* L.	9.939	8.712	6.218	24.869
6	*Oxalis corniculata* L.	11.871	7.576	2.71	22.157
7	*Paspalum* sp	6.054	7.197	6.029	19.28
8	*Aleuritopteris bicolor* (Roxb.) Fraser-Jenk.	4.831	4.545	3.635	13.012
9	*Conyza bonariensis* (L.) Cronquist	3.964	4.167	1.637	9.767
10	*Mimosa pudica* L.	2.386	3.157	1.617	7.159
11	*Ageratum houstonianum* Mill.	2.09	3.157	1.812	7.059
12	*Chromoleana odorata* (L.) R.M.King & H.Rob.	1.124	2.146	3.077	6.348

13	*Oxalis latifolia* Kunth	2.82	1.894	0.804	5.518
14	*Dioscorea deltoidea* Wall.	0.71	1.768	1.906	4.383
15	*Ageratum conyzoides* L.	0.986	2.146	0.711	3.843
16	*Stephania japonica* (Thunb.) Miers	0.631	2.525	0.633	3.789
17	*Themeda triandra* Forssk	0.434	1.136	1.211	2.781
18	*Desmodium microphyllum* (Thunb.) DC.	0.67	1.515	0.461	2.646
19	*Cynodon dactylon* (L.) Pers.	0.789	1.01	0.617	2.416
20	*Cyperus rotundus* L.	0.592	0.884	0.826	2.302
21	*Asparagus racemosus* Willd.	0.355	1.263	0.656	2.274
22	*Centella asiatica* (L.) Urb.	0.966	1.01	0.226	2.203
23	*Drepanostachyum falcatum* (Nees.)Keng.	0.651	1.263	0.273	2.187
24	*Triumfetta pilosa* Roth	0.394	1.389	0.398	2.182
25	*Alternanthera philoxeroides* (Mart.) Griseb.	0.592	0.126	1.015	1.733
26	*Achyranthes aspera* L.	0.454	0.884	0.391	1.728
27	*Rungia pectinata* Nees	0.256	0.884	0.57	1.71
28	*Urtica dioica* L.	0.197	0.505	0.625	1.327
29	*Solanum virginianum* L.	0.177	0.758	0.375	1.31
30	*Acmella uliginosa* (Sw.) Cass.	0.414	0.631	0.242	1.288
31	*Gynura angulosa* Hance	0.158	0.758	0.177	1.092
32	*Fragaria vesca* L.	0.592	0.253	0.203	1.047
33	*Lygodium japonicum* (Thunb.) Sw.	0.158	0.631	0.25	1.039
34	*Drymaria diandra* Blume	0.454	0.379	0.164	0.996
35	*Solanum nigrum* L.	0.138	0.631	0.18	0.949

36	*Lygodium flexuosum* (L.) Sw.	0.138	0.505	0.297	0.94
37	*Polygonum persicaria* L.	0.316	0.253	0.344	0.912
38	*Saccharum spontaneum* L.	0.276	0.379	0.211	0.866
39	*Dryoathyrium boryanum* (Willd.) Ching	0.158	0.631	0.048	0.837
40	*Globba racemosa* Sm.	0.118	0.379	0.172	0.669
41	*Acmella paniculata* (Wall. ex DC.) R.K.Jansen	0.158	0.253	0.187	0.598
42	*Dicranopteris linearis* (Burm.f.) Underw.	0.158	0.126	0.312	0.596
43	*Boenninghausenia sp*	0.138	0.253	0.141	0.531
44	*Rumex dentatus* L.	0.158	0.126	0.234	0.518
45	*Spermacoce alata* Aubl.	0.177	0.253	0.047	0.477
46	*Anaphalis* Sp	0.158	0.126	0.187	0.471
47	*Nephrolepis cordifolia* (L.) C.Presl	0.158	0.126	0.156	0.44
48	*Dendrocalamus sp*	0.059	0.126	0.234	0.42
49	*Lepidium sativum* L.	0.099	0.126	0.141	0.365
50	*Dryopteris filix-mas* (L.) Schott	0.197	0.126	0.016	0.339
51	*Veronica persica* Poir.	0.158	0.126	0.031	0.315
52	*Mucuna pruriens* (L.)DC.	0.02	0.126	0.125	0.271
53	*Cissampelos pareira* L.	0.059	0.126	0.078	0.264
54	*Plantago major* L.	0.039	0.126	0.047	0.213
55	*Gonostegia hirta* Miq.	0.059	0.126	0.016	0.201
56	*Pteris vitata* L.	0.02	0.126	0.016	0.162

Appendix 3: IVI of herbs of non-invaded sites

S.N	Name of species	Relative Density	RF	RC	IVI
1	*Imperata cylindrica* (L.) P.Beauv.	18.42	6.49	17.87	42.78
2	*Capillipedium assimile* (Steud.) A.Camus	10.38	6.88	10.39	27.64
3	*Oxalis corniculata* L.	8.89	5.91	7.11	21.90
4	*Paspalum* sp	6.19	5.43	7.01	18.63
5	*Bidens pilosa* L.	5.42	7.56	4.95	17.93
6	*Ageratina adenophora* (Spreng.) R.M.King & H.Rob.	5.18	6.98	5.28	17.44
7	*Aleuritopteris bicolor*(Roxb.) Fraser-Jenk.	4.43	4.26	4.29	12.99
8	*Conyza bonariensis* (L.) Cronquist	2.67	4.17	2.62	9.46
9	*Mimosa pudica* L.	2.71	2.71	2.80	8.22
10	*Capillipedium parviflorum* Stapf.	2.73	2.52	2.71	7.96
11	*Ageratum houstonianum* Mill.	2.40	2.71	2.38	7.50
12	*Centella asiatica* (L.) Urb.	2.65	2.03	2.45	7.13
13	*Rungia pectinata* Nees	1.68	3.49	1.63	6.79
14	*Cynodon dactylon* (L.) Pers.	2.11	2.03	2.64	6.79

15	*Desmodium microphyllum* (Thunb.) DC.	1.64	3.10	1.72	6.46
16	*Mucuna pruriens* (L.)DC.	1.70	1.36	1.65	4.71
17	*Spermacoce alata* Aubl.	1.47	1.45	1.42	4.34
18	*Drymeria diandra* Blume	1.24	1.45	1.18	3.88
19	*Oxalis latifolia* Kunth	1.41	0.97	1.37	3.74
20	*Saccharum spontaneum* L.	1.31	1.07	1.28	3.65
21	*Heteropogon contortus* Beauv. ex Roem. & Schult.	0.88	1.36	0.85	3.09
22	*Themeda triandra* Forssk	0.95	0.97	0.92	2.84
23	*Cyperus rotundus* L.	0.68	0.97	1.02	2.67
24	*Fragaria indica* Andrews	1.10	0.48	1.07	2.66
25	*Ageratum conyzoides* L.	0.67	1.36	0.57	2.59
26	*Lindenbergia indica* Kuntze	0.63	1.16	0.61	2.41
27	*Dryoathyrium boryanum* (Willd.) Ching	0.57	1.16	0.56	2.30
28	*Sphenomeris chinensis* (L.) Maxon	0.72	0.78	0.75	2.24
29	*Agave sp*	0.18	0.39	1.58	2.15
30	*Stephania japonica* (Thunb.) Miers	0.29	1.55	0.25	2.09

31	*Gonostegia hirta* Miq.	0.42	1.07	0.41	1.90
32	*Gynura angulosa* Hance	0.35	1.16	0.38	1.89
33	*Anaphalis sp*	0.54	0.78	0.52	1.84
34	*Barleria cristata* L.	0.46	0.87	0.44	1.77
35	*Achyranthes aspera* L.	0.26	0.87	0.33	1.46
36	*Nephrolepis cordifolia* (L.) C.Presl	0.55	0.29	0.57	1.41
37	*Chromoleana odorata* (L.) R.M.King & H.Rob.	0.23	0.78	0.40	1.41
38	*Triumfetta pilosa* Roth	0.29	0.78	0.28	1.35
39	*Boehmeria platyphylla* D.Don	0.25	0.68	0.28	1.21
40	*Senna tora* (L.)Roxb.	0.36	0.48	0.35	1.20
41	*Dioscorea deltoidea* Wall.	0.22	0.68	0.26	1.16
42	*Lygodium flexuosum* (L.) Sw.	0.15	0.68	0.27	1.10
43	*Pteris ensiformis* Burm.	0.27	0.48	0.27	1.03
44	*Hydrocotyle sibthorpioides* Lam.	0.41	0.19	0.40	1.00
45	*Argemone mexicana* L.	0.38	0.19	0.36	0.93
46	*Polygonum persicaria* L.	0.29	0.29	0.24	0.82

47	*Acmella uliginosa* (Sw.) Cass.	0.35	0.10	0.34	0.79
48	*Stellaria media* (L.) Vill.	0.19	0.39	0.16	0.73
49	*Solanum virginianum* L.	0.08	0.48	0.11	0.68
50	*Dicranopteris linearis* (Burm.f.) Underw.	0.29	0.10	0.28	0.67
51	*Taraxacum officinale* F.H.Wigg.	0.23	0.19	0.23	0.66
52	*Acmella paniculata* (Wall. ex DC.) R.K.Jansen	0.13	0.39	0.13	0.64
53	*Rumex dentatus* L.	0.11	0.29	0.22	0.61
54	*Asparagus racemosus* Willd.	0.06	0.39	0.06	0.50
55	*Plantago major* L.	0.11	0.29	0.10	0.50
56	*Galinsoga parviflora* Cav.	0.08	0.29	0.09	0.46
57	*Veronica persica* Poir.	0.23	0.10	0.05	0.38
58	*Phyllanthus urinaria* L.	0.07	0.19	0.07	0.33
59	*Solanum nigrum* L.	0.07	0.19	0.07	0.33
60	*Gentiana capitata* Buch. Ham. ex D.Don	0.12	0.10	0.11	0.33
61	*Lapsana* Sp	0.06	0.19	0.06	0.31
62	*Smilax cordifolia* Humb. & Bonpl. ex Willd.	0.05	0.19	0.07	0.31

63	*Ocotea salicifolia* Nees	0.09	0.10	0.11	0.30
64	*Eulaliopsis binata* (Retz.) C.E.Hubb.	0.05	0.19	0.05	0.29
65	*Globba racemosa Smith*	0.05	0.19	0.05	0.29
66	*Urena lobata* L.	0.05	0.19	0.05	0.29
67	*Urtica dioca* L.	0.05	0.19	0.05	0.29
68	*Adiantum capillus-veneris* L.	0.09	0.10	0.09	0.28
69	*Eragrostis tenella* (L.) P. Beauv. ex Roem. & Schult.	0.09	0.10	0.09	0.28
70	*Cirsium wallichii* DC	0.04	0.19	0.03	0.26
71	*Sonchus wightianus* DC.	0.04	0.19	0.03	0.26
72	*Dryopteris filix-mas* (L.) Schott	0.04	0.10	0.11	0.25
73	*Euphorbia heterophylla* L.	0.02	0.19	0.02	0.23
74	*Dendrocalamus* Sp	0.05	0.10	0.05	0.19
75	*Pteridium* Sp	0.05	0.10	0.05	0.19
76	*Blumea lacera* (Burm.f.) DC.	0.04	0.10	0.06	0.19
77	*Cissampelos pareira* L.	0.04	0.10	0.03	0.17
78	*Desmodium triflorum* Wall. ex Wight & Arn.	0.04	0.10	0.03	0.17

79	*Lepidium sativum* L.	0.02	0.10	0.03	0.15
80	*Boehmeria platyphylla* D.Don	0.02	0.10	0.02	0.14
81	*Eranthemum pulchellum* Andrews	0.02	0.10	0.02	0.14
82	*Gentiana sino-ornata* Balf.f.	0.02	0.10	0.02	0.14
83	*Clematis buchananiana* DC.	0.01	0.10	0.01	0.12
84	*Cyperus iria* L.	0.01	0.10	0.01	0.12
85	*Vicia angustifolia L.*	0.01	0.10	0.01	0.12

Appendix 4: IVI of shrubs of Invaded sites

S.N	Name of species	RD	RF	RC	IVI
1	*Lantana camara* L.	51.13	31.65	76.34	159.11
2	*Artemesia indica* Willd.	19.88	17.3	5.38	42.55
3	*Colebrookea oppositifolia* Sm	4.04	8.23	2.7	14.96
4	*Rubus ellipticus* Sm	3.26	8.44	2.59	14.29
5	*Hypericum* Sp	4.27	5.91	1.69	11.86
6	*Boehmeria nivea* Gaudich.	2.79	3.16	2.18	8.14
7	*Berberis aristata* DC.	1.85	3.8	1.68	7.33
8	*Melastoma malabathricum* L.	2.35	3.8	1.12	7.27
9	*Woodfordia fruticosa* Kurz	1.95	3.59	1.65	7.18
10	*Buddleja asiatica* Lour.	2.15	2.74	1.2	6.09

11	*Catunaregam spinosa* (Thunb.) Tirveng.	1.08	2.74	0.4	4.22
12	*Osbeckia nepalensis* Hook.	1.18	1.69	0.41	3.27
13	*Clerodendrum chinense* (Osbeck) Mabb.	1.35	0.84	0.82	3.01
14	*Phyllanthus amarus* Schumach. & Thonn.	0.61	2.11	0.29	3
15	*Rhus javanica* L.	0.37	1.05	0.64	2.07
16	*Reinwardtia indica* Dumort	0.67	0.63	0.31	1.62
17	*Maesa chisia* D.Don	0.64	0.63	0.22	1.5
18	*Justicia adhatoda* L.	0.17	0.42	0.19	0.78
19	*Desmodium multiflorum* DC.	0.13	0.42	0.03	0.59
20	*Nyctanthes arbor-tristis* L.	0.17	0.21	0.06	0.44
21	*Inula cappa* (Buch.-Ham. ex D.Don) DC.	0.1	0.21	0.03	0.34
22	*Pogostemon benghalensis* Kuntze	0.07	0.21	0.04	0.32

Appendix 5: IVI of shrubs of non-invaded sites

S.N	Name of species	RD	RF	RC	IVI
1	*Artemisia indica* Willd.	28.576	15.9774	16.4164	60.9697
2	*Lantana camara* L.	9.609	15.7895	8.6179	34.0166
3	*Hypericum sp*	10.239	7.3308	12.6472	30.2167
4	*Colebrookea oppositifolia* Sm.	7.385	9.9624	11.7045	29.0522
5	*Rubus ellipticus* Sm.	6.546	10.7143	5.8320	23.0923
6	*Melastoma malabathricum* L.	6.001	6.3910	7.3454	19.7369
7	*Osyris wightiana* Wall. ex Wight	5.917	3.1955	9.3890	18.5011
8	*Woodfordia fruticosa* Kurz	4.616	4.6992	5.8416	15.1567

9	*Osbeckia nepalensis* Hook.	3.777	4.3233	2.5834	10.6833
10	*Buddleja asiatica* Lour.	3.357	3.0075	2.9497	9.3142
11	*Berberis aristata* DC.	2.014	3.9474	2.9613	8.9228
12	*phyllanthus amarus* Schumach. & Thonn.	1.637	3.1955	1.0835	5.9155
13	*Pogostemon benghalensis* Kuntze	1.637	1.5038	1.4267	4.5669
14	*Clerodendrum chinense* (Osbeck) Mabb.	1.469	0.9398	1.9279	4.3364
15	*Justicia adhatoda* L.	1.091	1.1278	1.5809	3.7997
16	*Rhus javanica* L.	1.217	1.1278	1.4460	3.7907
17	*vitex negundo* L.	0.713	0.5639	1.4460	2.7232
18	*Malvaviscus arboreus* Dill. ex Cav.	0.504	0.9398	0.8290	2.2724
19	*Reinwardtia indica* Dumort	1.175	0.7519	0.3181	2.2449
20	*Duranta sp*	0.336	0.3759	0.8868	1.5985
21	*Dabregesica salcifolia*	0.168	0.5639	0.3277	1.0595
22	*Desmodium multiflorum* DC.	0.294	0.5639	0.1350	0.9926
23	*Maesa chisia* D.Don	0.252	0.3759	0.2121	0.8398
24	*Debregeasia longifolia* (Burm.f.) Wedd.	0.168	0.1880	0.4820	0.8378
25	*Hibiscus rosa sinensis* L.	0.126	0.3759	0.1928	0.6946
26	*Inula cappa* (Buch.-Ham. ex D.Don) DC.	0.252	0.1880	0.0964	0.5361
27	*Jatropa sp*	0.042	0.1880	0.1928	0.4227

Appendix 6: Species composition of fungi

S.N	Name of species	Invaded	Non-Invaded	Division
1	*Absidia corymbifera*	+	+	Zygomycota
2	*Acremonium* sp	-	+	Ascomycota
3	*Actimucor* sp	-	+	Zygomycota
4	*Alternaria alternata*	+	+	Ascomycota
5	*Aspergillus flavus*	-	+	Ascomycota
6	*Aspergillus niger*	+	+	Ascomycota
7	*Aureobasidium* sp	+	-	Ascomycota
8	*Bipoparis* sp	-	+	Ascomycota
9	*Botyrtis* sp	-	+	Ascomycota
10	*Chaetomium globosum*	+	+	Ascomycota
11	*Cladosporium* Sp	+	-	Ascomycota
12	*Colletotrichum gloeosporioides*	-	+	Ascomycota
13	*Cunninghamella* sp	+	+	Zygomycota
14	*Curvularia* sp	-	+	Ascomycota
15	*Fusarium oxysporium*	+	+	Ascomycota
16	*Fusarium solani*	+	-	Ascomycota
17	*Gliocladium* sp	+	+	Ascomycota
18	*Lecanicillium fungicola*	+	+	Ascomycota
19	*Microsporium gypseum*	+	-	Ascomycota

20	*Microsporium* sp	-	+	Ascomycota
21	*Mucor* sp	+	+	Zygomycota
22	*Paecilomyces* sp	+	+	Ascomycota
23	*Penicillium chrysogenum*	+	+	Ascomycota
24	*Penicillium notatum*	+	+	Ascomycota
25	*Penicillium* Sp	+	+	Ascomycota
26	*Phytopthora* Sp	+	+	Zygomycota
27	*Rhizoctonia* sp	+	+	Basidiomycota
28	*Saksenaea* sp	-	+	Zygomycota
29	*Scopulariopsis* sp	+	+	Ascomycota
30	*Staphylotrichum* sp.	-	+	Ascomycota
31	*Trichoderma* sp	-	+	Ascomycota
32	*Trichoderma viridi*	+	+	Ascomycota
33	Unknown sp	+	-	-
34	*Verticillium fungicola*	-	+	Ascomycota

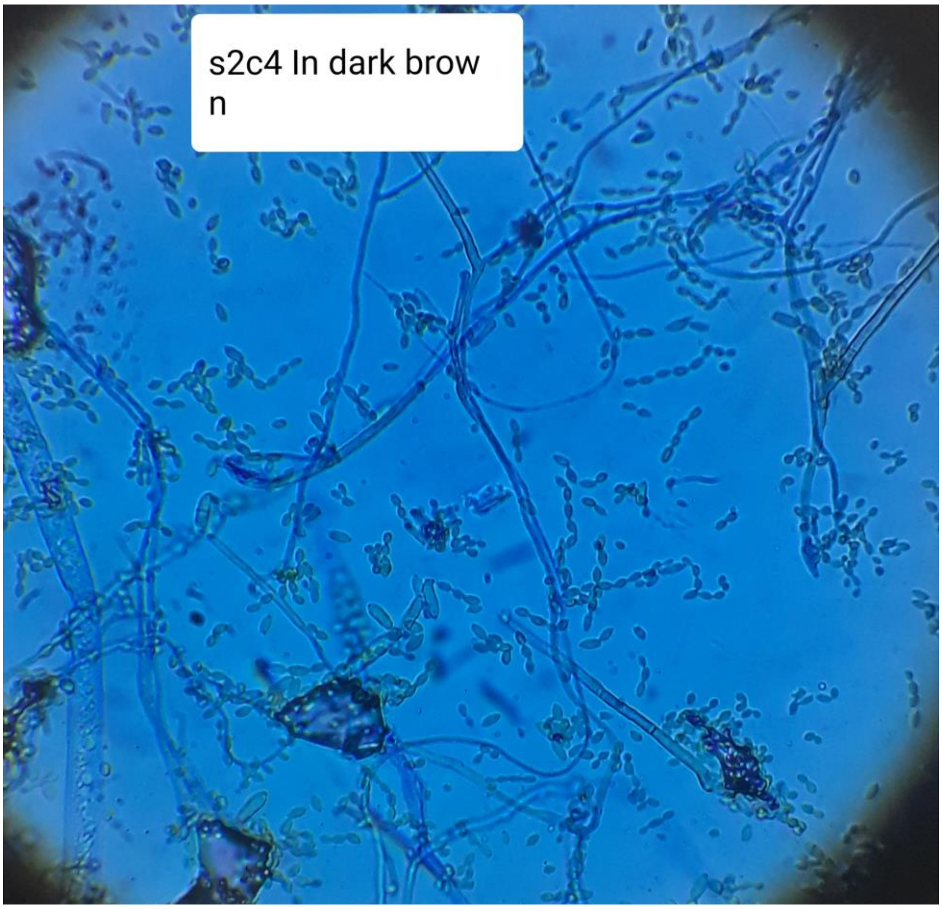
Photos of Field

Data collection during field visit

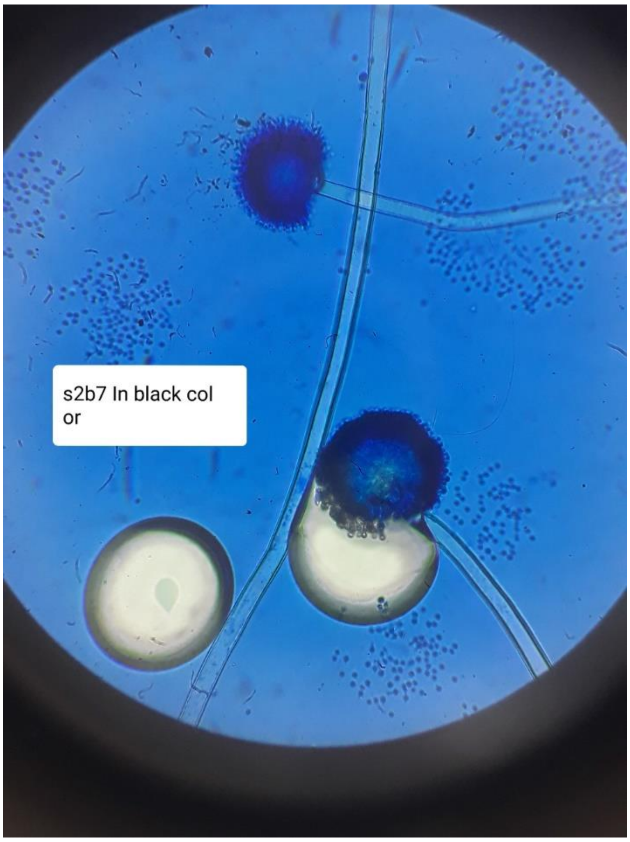
Area cover by *Lantana camara*

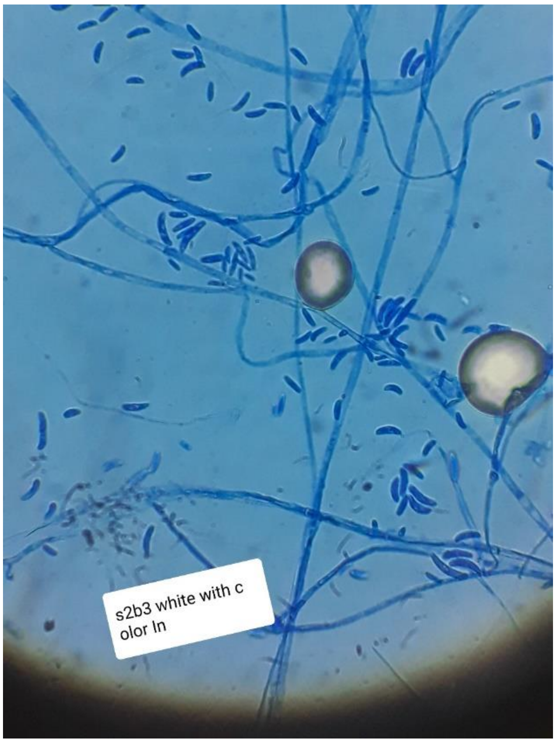
Plates of fungal colony

Isolation of fungi



Cladosporius sp





Fusarium sp

Aspergillus niger