

**Distribution of Major Invasive Alien Plant
Species and Impact Assessment of
Ageratina adenophora (Spreng.) K. & R. in
Kailash Sacred Landscape, Uttarakhand**

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**FOR
THE AWARD OF THE DEGREE OF
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IN
FORESTRY
(FOREST ECOLOGY AND ENVIRONMENT)**



BY

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Research Center



**भारतीय वन्यजीव संस्थान
Wildlife Institute of India**

Year 2022

**Distribution of Major Invasive Alien Plant Species and Impact Assessment
of *Ageratina adenophora* (Spreng.) K. & R. in Kailash Sacred Landscape,
Uttarakhand**



By

Alka Chaudhary

Under the supervision of

**Dr. B.S. Adhikari
(Supervisor)**

**Dr G.S. Rawat
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**भारतीय वन्यजीव संस्थान
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DECLARATION

I, Alka Chaudhary (Enrolment no. 16PhD408) hereby declare that the thesis entitled “Distribution of Major Invasive Alien Plant Species and Impact Assessment of *Ageratina adenophora* (Spreng.) K. & R. in Kailash Sacred Landscape, Uttarakhand” submitted by me to Forest Research Institute (Deemed to be) University, Dehradun (FRI), for the award of the Degree of Doctor of philosophy in forestry (Forest Ecology and Environment), is a record of original research work carried out by me under the supervision of Dr. B.S Adhikari and Dr. G.S. Rawat wildlife institute of India, Dehradun. The thesis has been duly checked through ‘URKUND’, a plagiarism detection tool approved by FRI Deemed to be University and the thesis has plagiarism to acceptable limits. No part of this thesis has been submitted for any other degree/diploma of the same Institution where the work is carried out or to any other Institution and it fulfils all the requirements of the ordinance governing the award of Ph.D. Degree of F. R.I. Deemed to be University, Dehradun.



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4. The Topic of research approved by the FRI University: “**Distribution of major Alien Invasive Plants and Impact Assessment of *Ageratina adenophora* (Spreng.) K. & R. in Kailash Sacred Landscape, Uttarakhand.**”
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P.T.O

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(Alka Chaudhary)

List of Abbreviations

S.no	Abbreviations	Full form
1	<i>A. adenophora</i>	<i>Ageratina adenophora</i>
2	<i>A. conyzoides</i>	<i>Ageratum conyzoides</i>
3	AUC	Area Under the Curve
4	DEM	Digital Elevation Model
5	<i>E. adenophorum</i>	<i>Eupatorium adenophorum</i>
6	FRI	Forest Research Institute
7	GCMs	Global Climate Models
8	GIS	Geographic Information System
9	GPS	Global Positioning System
10	HWC	Human Wildlife Conflict
11	IAPs	Invasive Alien Plant Species
12	ICIMOD	International Centre for Integrated Mountain Development
13	IHR	Indian Himalayan Region
14	IMD	Indian metrological department
15	IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
16	IPCC	Intergovernmental Panel on Climate Change
17	IUCN	International Union for Conservation of Nature and Natural Resources
18	KRI	Knowledge Richness Index
19	KSI	knowledge sharing index
20	KSL	Kailash Sacred Landscape
21	KSLCDI	Kailash Sacred Landscape Conservation and Development Initiative
22	KSL-India	Kailash Sacred Landscape- India
23	<i>L. camara</i>	<i>Lantana camara</i>
24	LULC	Land Use Land Cover
25	masl	Metres above sea level
26	<i>MaxEnt</i>	Maximum Entropy

27	MoEF&CC	Ministry of Environment, and forests and Climate Change
28	NAPCC	National Action Plan on Climate Change
29	NMHS	National Mission on Himalayan Studies
30	NTFPs	Non-Timber Forest Products
31	<i>P. hysterophorus</i>	<i>Parthenium hysterophorus</i>
32	PAs	Protected areas
33	PC	Principal Components
34	PCA	Principal Component Analysis
35	PFD	Pithoragarh Forest Division
36	<i>Q. floribunda</i>	<i>Quercus floribunda</i>
37	<i>Q. lanuginosa</i>	<i>Quercus lanuginosa</i>
38	<i>Q. leucotrichophora</i>	<i>Quercus leucotrichophora</i>
39	<i>Q. semicarpifolia</i>	<i>Quercus semicarpifolia</i>
40	RFC	Relative frequency of Citation
41	ROC	Receiver Operation Characteristic
42	RPCs	Representative Concentration Pathways
43	<i>T. bellirica</i>	<i>Terminalia bellirica</i>
44	TAR	Tibet Autonomous Region
45	USIDCL	Uttarakhand State Infrastructure Development Corporation Limited
46	WII	Wildlife Institute of India

EXECUTIVE SUMMARY

Invasive Alien Plant Species (IAPs) rank among the top three threats to global biodiversity, the other two being unsustainable harvest of various species from the wild and habitat degradation and loss. Invasive species, coupled with unsustainable resource use and climate change have seriously affected livelihoods of millions around the globe. Rapid spread of invasive alien species affects natural habitats, regeneration potential of native species and affects productivity of forests and grassland habitats. Changes in climatic conditions and land use practices favour introduction and spread of IAPs. The Himalayan region, one of the global biodiversity hotspots, is quite vulnerable due to climate change and other abiotic and biotic drivers of change including rapid spread of IAPs. Some of the most obnoxious IAPs in this region includes *Ageratina adenophora*, *Lantana camara*, *Parthenium hysterophorus* and *Ageratum conyzoides*. During the past few decades increasing anthropogenic pressures such as unabated linear infrastructure development, uncontrolled tourism, livestock grazing, agricultural expansion and extraction of non-timber forest products (NTFPs) have led to degradation of wildlife habitats and spread of a large number of invasive species. One of the major causes of spread of IAPs in the Himalayan region is climate change. Therefore, an urgent need was felt to study implications of climate and environmental change on distribution and abundance of major invasive alien species in the Himalayan region along with the impact assessment and management of such species. Will be highly helpful to the management authority to hinder their future growth across the elevational gradients of the landscape.

Chapter 1: Deals with General introduction of the study, gives background of the study, Review of literature, current trends of research on IAPs in the country and Himalayan region, knowledge gaps, problem statement and objectives of the study.

The study was conducted to assess the spread, distribution, impact of invasion in Indian part of Kailash Sacred Landscape (KSL) characterized by interspersion of human habitations, extensive forests managed by the state Forest Department and local community institutions (Van Panchayats). The objectives of the study were: (i)

1. To model spatial distribution of selected plant invasive species using distribution modeling technique.
2. To assess the impacts of IAPs on native flora and relationship with habitat parameters.
3. To analyze peoples' perception towards the spread of IAPs in KSL – India landscape.
4. Experimental trials on eco-restoration of habitats and prediction of future spread for better management.

Chapter 2: Provides comprehensive description of the study area covering biophysical features, climate, human habitations, land use and land cover. The extensive study area (7,212 km²) lies between 30.0815° N Latitudes and 80.3659° E Longitudes located in District Pithoragarh, Uttarakhand (Western Himalaya). This area is interspersed with human habitation (0.89%), Reserve Forest (63%), Van Panchayat (11.10%) and unclassified forest/fallow fields and agriculture land (25.04%). Intensive study was conducted in four developmental Blocks, viz. Bin, Berinag, Gangolihat and Didihat. The study was conducted during September 2014 to October 2018.

Chapter 3: The present study deals with the patterns and trends of invasion by *Ageratina adenophora* in lower-mid elevation ranges of KSL (i.e., intensive study area). Extensive surveys were conducted to map the species in each season and habitat type. Sites with high biotic pressure and open forest canopy were the most suitable habitats for its growth. A negative correlation was found between distribution and altitude. The highest invasion was recorded in between 1700 – 1800m elevation gradient, between 20° and 30° slope positions and at North (33.33%), whereas, the lowest invasion was recorded between 700 – 800m in South-East directions (3.70%). Several other parameters such as distance from the disturbance site such as road, villages or settlements, drainage and soil texture were also found to be affecting the distribution pattern of this species. Interestingly results reveal that the alien plants also start competing among themselves after reaching their threshold level.

Chapter 4: Deals with Probability distribution modeling of *Ageratina adenophora* and *Lantana camara* in the KSL-India landscape. Intensive field surveys were conducted to collect the presence of *A. adenophora* ($n = 567$) and *L. camara* ($n = 120$) along an altitudinal gradient between 300 and 3000 m a.s.l. We performed Principle Component Analysis to nullify the multi-collinearity effects of the environmental predictors following *MaxEnt* species distribution model in the current and future climatic scenarios for both the species. All current and future model precision (i.e. Area Under the Curve; AUC) for both species was higher than 0.81. It is predicted that under the current rate of climate change and higher emission (i.e. RCP8.5 pathway), *A. adenophora* will spread 45.3% more than its current distribution and is likely to reach up to 3029 m a.s.l. Whereas, *L. camara* will spread 29.8% more than its current distribution range and likely to reach up to 3018 m a.s.l.. Among the 19 bio-climatic variables selected precipitation of wettest month was found to be the most important variable for the distribution of *Ageratina adenophora*, followed by annual mean temperature and elevation,

however, elevation was the most important factor followed by precipitation seasonality and aspect in the distribution of Lantana.

Chapter 5: Deals with people's perception and knowledge on invasive alien plant species in two watersheds of the landscape. A total of 701 randomly selected household in 45 villages were surveyed through questionnaire surveys in two watersheds of Kailash Sacred Landscape (KSL-India) viz. Chandak-Aunla Ghat (329) Hat-Kalika: (372) to know their view on the issues associated with invasive plant species and attitudes towards their management. The knowledge, perception, use and management strategies of different IAPS were analysed. Only 39% of females and 27% males had the knowledge of IAPS. The respondents cited a total of 14 different IAPS in the study area, out of which *Ageratina adenophora* had the highest Relative Frequency of Citation (RFC) value whereas, informants of Hat-Kalika showed a low richness of knowledge and sharing with the members of their families in comparison to Chandak-Aunla Ghat. Most respondents in the study area perceived IAPs negatively and rated biological invasion and habitat loss as the major environmental problems. Most of the respondents (70%) agreed that controlling IAPs is necessary to conserve the environment and protect biodiversity. Restoration, eradication, education and information were reported to be the major management strategies. Our findings have implication for stakeholders and policymakers for the management of IAPs as it highlights that informal education activities helped in raising public awareness about the invasive species.

Chapter 6: Deals with the effect of *Ageratina adenophora* invasion on native plant species richness, Diversity and composition. The present study was carried out in in four blocks (Bin, Berinag, Gangolihat and Didihat) of Pithoragarh district of Uttarakhand state of India which is a part of Kailash Sacred landscape. Four different ecosystem types were sampled during the survey viz. roadside, pine forest, oak-mixed forest and Deodar forest. To assess the impacts of invasion by *Ageratina adenophora* on species richness, diversity and composition of resident plant communities a total of 276 pair of vegetation sampling plots of 1 sq meter and 5 sq. meter plots were laid among which 276 plots had *Ageratina adenophora* invasion (uncontrolled) and 276 were controlled plots not invaded by *Ageratina adenophora*. The uninvaded plots by *Ageratina adenophora* were selected to be in close vicinity of the invaded sampling plots with habitat parameters identical as diligently as possible. All herbs in 1X1m and shrub, seedlings and saplings in 5X5m plants species were recorded, their covers were estimated and used as importance values for calculating the Shannon diversity index, evenness and Sørensen index of similarity between invaded and uninvaded vegetation. Among all the 180 plant species

recorded from the sampling plots 29 plants species were identified as invasive. Results reveals that with maximum spread around roadsides, grasslands followed by forest fringes of pine, oak mixed and deodar the density of *Ageratina adenophora* was maximum (200-1644 ind ha⁻¹) among all other invasive plants in the sampled invaded plots. Biodiversity indices in both shrubs and herbs covers were recorded higher in control site than in infested site. The dominance of *Ageratina adenophora* was higher in the herbaceous layer. It strongly competes with the native plant species forming homogenous stand in the landscape due to its high rate of proliferation. Open canopies and moist areas and forest fringes were the most favourable site for invasion of *Ageratina adenophora*.

Chapter 7: This chapter deals with the Native plant community response to alien plant invasion after removal in three different forest types (Chir pine, Banj Oak and Deodar) of KSL India. The study was carried out in Gokerneshwergad watershed, part of Kailash Sacred Landscape (KSL) in Pithoragarh district of Uttarakhand. The objective of our research was to estimate plant community recovery after the removal of *Ageratina adenophora*. Within each forest type we randomly placed three (10X10m) observational plot which we monitored monthly for 13 months. Data was collected from the selected sites before and after removal of invader species *Ageratina adenophora* and the marked plots in each site were monitored.

Therefore, it is crucial to quantify and predict these effects. Our results show that in all the three type of forests (i.e., Oak, Deodar and Pine forests) *Ageratina adenophora* almost shows the same kind of regeneration pattern after complete removal. In absence of any other competitor alien species, it again regenerate in the evacuated area if not monitored and eradicated on regular basis. For monitoring the spread of alien invasive plant species only removal can lead to secondary invasion by other widely distributed alien invasive plans which can speedily proliferate in that area. Therefore, restoration of the invaded site with the native species, having some uses value eg. Fodder, fuel, medicinal, fruit, etc. The selection of species for restoration of the degraded habitat should be based on the habitat suitability of the species, natural history of the area, and in consultation with scientific local communities.

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1.1 General Introduction

Non-native or exotic species that occur outside of their natural suited ranges and dispersal potential are known as alien species. International Union for Conservation of Nature and Natural Resources (IUCN, 2000) defines Invasive Alien Plant Species (IAPs) as species established in natural or semi-natural ecosystems or habitat, an agent of change that threatens native biological diversity. Whether intentionally or unintentionally introduced to different parts of the world, invasive plant species can cause significant economic, environmental, and social losses (Anderson, 2005). Plant diversity is under threat worldwide and is rapidly dwindling (Dogra et al., 2009). Invasive species can ruin natural pasture, replace native trees, and limit rangeland grazing ability in locations where they proliferate (Admasu, 2008). Furthermore, invasive alien plants reduce rangelands' ability to support livestock and wildlife and significantly reduce biodiversity (Richardson & Van Wilgen, 2004). Also, increased biomass associated with plant invasions leads to more severe fires, which harm vegetation, soil and cause excessive erosion.

Invasion of alien invasive plant species has overtaken habitat loss as the second most serious hazard to plant diversity (Hobbs & Humphries, 1995). It may be due to invasive species have many important adaptation techniques as compared to native plants as faster rates of growth and biomass production compared to native species, high reproductive efficiency, including the production of a large number of seeds, higher efficient dispersal, competitive ability, rapid establishment, vegetative reproduction, and several other factors that help them adapt to new habitats (Sharma et al., 2005; Simberloff et al., 2005) and a broader range of tolerance (Walther et al., 2009; IUCN, 2013). The management of Invasive Alien Plant Species is becoming a global problem due to their uncontrolled proliferation. Altering climate and anthropogenic factors accelerate the growth of Invasive Alien Plant Species (IAPs) (Xiong et al., 2007; Dukes & Mooney 1999; Mack et al., 2001) as they favour the area where they are not limited by climatic constraints (Hellmann et al., 2008) Change in climatic conditions may upsurge the opportunities for their invasion and spread (Hellmann et al., 2008; Thapa et al., 2018). Understanding how ecosystems and landscapes will be stimulated and react to changing climatic circumstances (Tylianakis et al., 2008) since IAPs have become a global problem. They stretched their boundaries from lower to higher altitudes in

the Himalayas and have become a major topic of concern. (Kohli et al., 2006; Sekar 2012). Climate change has also stimulated many noxious weeds proliferation in the higher regions (Xu et al., 2009). Himalaya being the youngest mountains on earth, are very well known for their vast biodiversity, due to which they become one of the best sites for the study of climate change on the planet. It has been observed that species of higher elevations are predicted to shift higher (Pathak et al. 2019). A few invasive alien plant species that were previously restricted to lower areas are now shifting to higher altitudinal regions of the Himalaya (Telwala et al., 2013). Approximately half of the alien species in the Himalaya are intentionally introduced. (Sekar et al., 2012), and others came through trade and grain imports. Except for a few studies, mostly on specific locations, studies on invasive plants and their invasions still lack in India (Myers et al., 2000; Reddy, 2008; Singh et al., 2010) ecological status (Saxena, 1993; Bhatt et al., 1994; Negi & Hajra, 2007; Sharma & Raghubanshi, 2012; Jaryan et al., 2013; Adhikari et al., 2015) comprehensive studies on invasive species and plant invasions are still missing except a few studies (Singh et al., 2010; Reddy, 2008; Myers et al., 2000).

Climate change may increase the opportunities for introducing and spreading Invasive Alien Plant Species (Kriticos et al., 2003; Masters & Norgrove, 2010; IUCN, 2017). Despite the recognition of the impacts caused by invasive plants worldwide (Mooney & Hobbs, 2000), Many countries throughout the world, such as Asia and neighbouring regions, still have very rudimentary or no knowledge on introduced plant taxa and plant invasions (Corlett, 1988; Enomotto, 1999).

Alien plant invasions threaten a national ecological crisis with enormous social and economic repercussions in India, which has four of the world's most important 'biodiversity hotspots.' About 40% of the plant species are alien in the Indian flora, out of which 25% are invasive. A few prominent invasive alien species are *Ageratina adenophora*, *Lantana camara*, *Ageratum conyzoides*, *Parthenium hysterophorus*, *Mikania micrantha*, *Galinsoga parviflora*, *Argemone mexicana* and many more on the thrust to achieve the status of Invasive Alien Species (IAPs).

With the growing worldwide attention to the negative impacts of IAPs, better effort to control and eradicate them is required. This has basically been deemed an environmental issue (e.g. McDonald & Butz, 1998, Chandrasekaran & Swamy 2002), and at times harmonizing with economic one (e.g. Toledo et al., 2002; le Maitre et al. 2002; Turpie, 2004).

For conserving biodiversity and sustaining human livelihoods by minimizing the extent and harmful impact of invasive alien species, insight into the local community is important for environmental management and conservation. The importance of human views of wildlife (flora and fauna) and the environment is gradually being recognised. Invasive species have a significant socio-economic impact in addition to being a danger to biodiversity and ecosystem services. As a) they decrease the productivity from forestry, agriculture, and fisheries; b) impact on water quality; c) cause degradation of the land; d) Impasse transport route and supplement to the spread of disease; e) They also decrease the efficacy of growth investments by, for example, entangling industrial pipelines, clogging irrigation canals and damaging hydroelectric systems; f) passing modification in community structure (Gordon, 1998).

Both positive and negative native–alien richness relationships can happen across the same landscape, depending on the plant commune and the examined primary human and environmental ascent. Change in human habitation, which is often perplexed with changes in the environment, can result in high alien and low native species richness in areas dominated by native species. In the highly human-modified areas conquered by alien species, both native and alien species may be retorting to similar underlying gradients. This study shows how invasive plants are affecting the Himalayan ecosystem and affecting social life. Evaluating how locals recognize the issue of invasive alien species (IAPs) is a vital precondition for learning communication strategies (Dassonville et al., 2008). Such studies are frequent in biological invasions (Vanderhoeven et al., 2011; Andreu et al., 2010; Gagliardi et al., 2007) These studies can contribute to recognizing information breaches and preventive actions to implement for reducing introductions of invasive plants accidentally. The utmost successful and cost-effective method to preventing biological invasion is tackling them at a very initial stage. This demand awareness of the threats they pose, preventive measures to stop new invasions and control of those species that have already invaded the ecosystems. *Ageratina adenophora*, *Lantana camara*, *Parthenium hysterophorus*, and *Bidens pilosa* are some of the most widely disseminated and documented invasive plant species globally. *Ageratina adenophora* belongs to the Asteraceae family and is native to Mexico and Costa Rica of Central America (Datta et al., 2017). It was reported in India after 1498 (Biswas, 1934). Whereas, *Lantana camara* (family: Verbenaceae), a native of South American tropical (Holm et al. 1977) forest also known as wild sage, is considered globally as the most troublesome invasive species (Sundarapandian et al., 2015)

as it negatively affects the biodiversity of the invaded regions (Sharma & Raghubanshi, 2005). The major cause of the spread of these IAPs is pre-adaptation, inherent superiority and an empty niche lead to a strong invasion, as also supported by Morris (2007). Another reason is the availability of wasteland and space is found to be free from the native species encroached by invasive as revealed from the study areas because these species can use the resources more proficiently which are not used by natives species, and thereby generate a new environmental niche in the community, this complies with the empty niche hypothesis (Hierro et al., 2005).

The community's livestock and livelihood issues are most affected by the invasive that decreases forage quality and quantity, such as unpalatable grass, *Oxalis*, *Sonchus*, *Tridax*, *Ageratum*, *Parthenium*, etc. avoided by the cattle (Tambe & Rawat, 2009).

Therefore, an urgent need was felt to study the implications of climate and environmental change on the distribution and abundance of major invasive alien species in the Himalayan region and the impact assessment and management of such species.

1.2 Present Study

The spread of Invasive alien plant species is a global issue that is one of the key causes of global change. Plant invasion research has surged in popularity around the world. However, such investigations in the Indian Himalayan Region (IHR) are insufficient and have not been carried out systematically. The lack of scientific observation on several elements of plant invasion outlined in IHR is expected to exacerbate the problem of invasion control in the region. Under a changing climate, this scenario would deteriorate even further. Invasive alien species are spreading at greater altitudes in the Himalayas. Evidence from published studies suggests that with the development of tourism and the expansion of road networks that travel through forests, numerous alien species in the IHR have begun to invade forests and even alpine habitats. These shreds of evidence point to the possibility of alien species invading the previously invasion-resistant higher Himalaya, especially in the context of rising temperatures and human perturbations. Keeping this in perspective, the current study looked into the spread of IAPs, their influence on native biodiversity, local people in the landscape, and the management of these IAPs.

1.3 Objectives and Research Questions

1. To investigate the current pattern of invasion by major IAPs in the study area and to model the spatial distribution of selected plant invasive species using distribution modelling technique.
2. To assess the impacts of IAPs on native flora and relationship with habitat parameters.
3. To analyze peoples' perception towards the spread of IAPs in KSL – India landscape.
4. Experimental trials on eco-restoration of habitats and prediction of future spread for better management.

1.4 Research Questions

1. What are the patterns of distribution and bioclimatic variables associated with IAPs and areas which are more vulnerable to invasive alien plants spread in various parts of the Pithoragarh district?
2. Do IAPs have any relationship with [soil/temperature/moisture/ nutrient poor site/slope/altitude/biomass/ carbon sequestration]?
3. How does the pattern of socio-economic groups vary in terms of the spread and management of IAPs?
4. Does the eco-restoration of habitats can be useful for the management of IAPs?

Ecosystems infested by *Ageratina adenophora*



Plate 1.1. Different ecosystems infested by *Ageratina adenophora* in KSL, India

1.5 Organization of the thesis

Chapter one comprises a general introduction, rationale, objective and literature review.

Chapter two covers the introduction and the description of the study area, including location, topography, climate, geology and vegetation, fauna, local community and land use practices.

Chapter three deals with the Pattern of invasion of *Ageratina adenophora* in the pilot site of the landscape-KSL-India.

Chapter four deals with the objective first Probability distribution modelling of two major invasive alien species, *Ageratina adenophora* and *Lantana camara*, in the KSL-India landscape.

Chapter five deals with Knowledge and perception about invasive alien plant species in two watersheds of Kailash Sacred Landscape, Pithoragarh, Uttarakhand and their management.

Chapter six deals with objective three, which depicts the impact of *Ageratina Adenophora* invasion on native plant species richness, diversity, and composition and assesses the distribution of dominant invasive alien plant species in the study area.

Chapter seven deals with objective four. Which focuses on the Native plant community response to alien plant invasion after removal in three different forest types and suggests recommendations for managing invasive plant species in the study sites.

1.6 Biological invasion at the global level

Alien species invasion has now been identified as a global issue and is one of the major causes of global alteration (Millennium Ecosystem Assessment 2005). Since the mid-twentieth century, the study on plant invasion has expanded exponentially worldwide and had become the subject of intensive management and research initiatives (Kennedy et al., 2002). Invasions occur when organisms are introduced, either deliberately or inadvertently, outside their natural or historical range and effectively spread in their new atmosphere (Sharma et al., 2005). Invaders can dramatically alter the species make-up and functionality of native habitats by competition, predation, and habitat modification (Ehrenfeld 2003; Yurkonis et al., 2005; Dogra et al., 2010), which results in loss of biodiversity and degradation of ecosystem services (Tylianakis et al., 2008). The spread of invasive alien species has been correlated to land-use change and global climate change (Walther et al., 2009; Shrestha et al., 2019). When pooled with climate change, this rise in exotic plant cover is causing irreversible biodiversity loss (Myers 1993; Hulme 2009). Invasive plants are to blame for global environmental trends, habitat loss, species extinction, and the destruction of ecological systems vital to human well-being (Mooney, 2005; Herron et al., 2007, Pejchar & Mooney, 2009). Invasive plants have the greatest effect on global biodiversity, second only to forest fragmentation, and are a significant global concern.

Furthermore, the economic consequences of introduced species are immense, although they are not well understood (Jeschke & Strayer 2005; Pimentel et al., 2005; Van Kleunen et al., 2010), no robust methods for understanding impacts have been developed (Parker et al., 1999). Various invasive plants, for example, have been shown to reduce local plant species diversity (Vila et al. 2006; Powell et al. 2011), reduce habitat productivity and alter nutrient cycling rates (Liao et al. 2008; Ehrenfeld 2010), and thus have an effect on ecosystem resources and human well-being (Pejchar & Mooney, 2009). Although there are an increasing number of research concentrating on the effects of alien plants, we still lack large quantitative syntheses of how impacts vary depending on recipient habitat traits and invaders characteristics (Levine et al., 2003). To reduce the impact of invasive plants on biodiversity and habitats, a significant increase in intervention is

required (Tittensor et al., 2014), which requires globally coordinated methods to prioritise, monitor, and regulate them (McGeoch et al., 2016). Biological invasions may occur across various routes, most of which are linked to commerce and transportation (Hulme et al., 2008). The growing amount of trade and extension of transportation networks will continue to encourage invasive plants to spread outside their native ranges (Seebens et al., 2015). Therefore, to slow the pace of new incursions, cross-border strategy and cooperation are necessary. Also, for assessing transboundary and trading relationship risks, accurate information on alien species distributions is needed (Essl et al., 2015). It is essential to implement an effective invasive species management strategy. Many areas worldwide, such as Asia and neighbouring countries, still have only rudimentary knowledge on naturalised plant taxa and plant invasions (Corlett, 1988; Pyšek 2004; Thuiller, 2005). As a result, there was an urgent need to investigate the consequences of the spread and abundance of large invasive aliens due to climate and environmental change species in the Himalayan region and the evaluation and management of their effect on a species.

1.7 Invasion in the Indian Himalayan Region

Due to its unique and rich habitats, the Himalaya is one of the world's 36 biodiversity hotspots. A significant portion of this hotspot is found in India's Himalayan region, known for its rich forest biome (Singh 2014; Negi et al. 2018). This region provides goods and various ecosystem services to millions of people both within and beyond its geographical borders. According to the National Action Plan on Climate Change (NAPCC), the Himalayan region is crucial for India's ecological security. The NAPCC, on the other side, stresses the region's high susceptibility to anthropogenic behaviours and environmental perturbations, such as climate change and biological invasion (Palni & Rawal 2013; Negi et al., 2019; Sharma et al., 2016). Since the mid-twentieth century, study on plant invasion has expanded exponentially worldwide (Lowry et al., 2013). IHR research, on the other hand, has remained constrained in scale and scope. However, only a few studies (Khuroo et al., 2012; Sekar, 2012) have made this topic common in the area in the last decade. However, the bulk of these experiments do not offer a complete picture of the case. India is also suffering from harmful consequences, and its ecosystem is in jeopardy due to biological invasion (Khuroo et al., 2012). The Indian subcontinent is particularly vulnerable to biotic invasion due to its diverse climatic and environmental conditions. In India, the most recent inventory identified 1,599 species belonging to 842 genera in 161 families, accounting for 8.5 percent of the total Indian vascular

flora (Khuroo et al., 2012). In contrast, according to Khuroo et al. (2007), the alien flora of Kashmir Himalaya alone consists of 571 belonging to 352 genera and 104 families, with the Amaranthaceae and Chenopodiaceae having the highest percentage of alien plant species 83 and 72, respectively. At the same time, 190 invasive alien species belonging to 112 genera in 47 families were recorded in the Indian Himalayas (Sekar et al., 2012). Most studies suggested that these species originated in America and Europe and are mainly herbaceous. Invasive organisms are fostering the homogenization of the natural ecosystems in Kashmir, in the western Himalaya, according to Dar et al. (2020).

Similarly, Priyanka and Joshi (2013) recorded that, as a result of increased warming, most western Himalaya's southern and western regions will be suitable for the distribution of *Lantana camara* in the future. According to Kosaka et al. (2010) and Bhattarai et al. (2014), road construction has aided plant invasion in India's mountainous areas. The distribution pattern of invasive plants along roadsides varies depending on altitude. Bhattarai et al. (2014) discovered a positive relationship between invasive species and tree species diversity and a negative relationship with elevation. Invasive species have been spreading across the region's protected areas, posing a threat to animal habitat and food availability (Murphy et al., 2013; Lamsal et al., 2018). This means that, as a result of past and potential environmental change, such as accelerated warming, landslides, forest fires and tourism, the Himalayan region is similarly vulnerable to species invasion.

1.8 Impact of Invasive Alien Plant Species

The invasion of alien plant species has increased rapidly throughout the world in the twenty-first century and is responsible for the homogenization of floras, posing a significant threat to biodiversity and the ecological integrity of native habitats and ecosystems (Booth et al., 2003; Hulme, 2003). Invasive species have far-reaching effects on the habitats they invade, such as reducing indigenous species diversity, altering soil nutrient composition, altering forest fire cycles, and reducing the productivity of invaded ecosystems. It also threatens endangered or threatened plant species worldwide (Pimentel et al., 2005). Disruptions of natural environments offer excellent conditions for Invasive Alien Plant Species to develop themselves. The occurrence of alien plants has risen in places where humans have interfered, such as construction and forest fragmentation (Higgins et al., 1996). Alien species that can quickly reach high densities will have tremendous establishment success and dominate invaded populations to exclude indigenous

species (Kolar & Lodge, 2001). In addition, dominant invasive species with accelerated colonisation are more likely to affect biodiversity (Callaway & Ridenour, 2004) negatively. Studies of previous introductions show that the impacts of invasive species are dynamic and can permanently change community structure (Holway et al., 2002; Carlton, 2003). Invasive alien species endanger native/indigenous plant populations worldwide, particularly where such communities are breached (D'Antonio et al., 2001). However, only a few foreign plant species seem to be capable of invading undisturbed native plant populations (Rejmanek, 1989). *L. camara*, *A. conyzoides*, *P. hysterophorus*, *Ageratina adenophorum*, are well-known alien invaders in India, posing a threat to local plant populations oscillating from plains to hills. Invasive plants like *Ageratum conyzoides*, *Eupatorium odoratum* *Eupatorium adenophorum*, *Lantana camara*, *Parthenium hysterophorus*, and *Mikania micrantha* have wreaked havoc on terrestrial habitats. In contrast, *Eichhornia crassipes*, *Ipomoea* spp., and *Salvinia molesta* have wreaked havoc on marine ecosystems (Batish et al., 2011). Aside from that, several other reports are available that detail the invasive flora of a specific region or area. Kohli et al. (2004, 2006) offered details on the status of invasive plants in the north-western Himalayan region, stating that three invasive weeds present in this region - *Ageratum conyzoides*, *Lantana camara*, and *Parthenium hysterophorus* - have caused significant harm to the fragile biodiversity. The establishment of invasive species and diminishing biodiversity are due to various factors, including vulnerable soil, anthropogenic activity, tourism, deforestation, rapid urbanization, and aboriginals' livestock-dependent lifestyles, such as that of the Gaddi or Gujjar populations (Kohli et al., 2006). Khuroo et al. (2007) found 571 alien species in the Kashmir Himalayas, divided into 352 genera and 104 families, with roots in Europe, Asia, and Africa. Negi & Hajra (2007) observed 308 woody and 128 exotic herbaceous species in the Doon Valley of the northwestern Himalayas, many of which are invasive and have caused cultural, socioeconomic, and health problems. Despite extensive ecological research (Kohli et al., 2006; Bhatt et al., 2011; Bajpai & Inderjit, 2013; Mandal & Joshi, 2015), few attempts have been made to investigate the effect on indigenous biodiversity, habitats, or well-being of humans (Kosaka et al., 2010), Plant diversity loss (Kohli et al., 2004; Dogra et al., 2009), habitat destruction (Dobhal et al., 2011), and biodiversity loss (Bawa et al., 2007). However, a complete picture of the effects of Invasive Alien Plant Species on biodiversity and the ecosystem is still missing (Chaudhary et al. 2019).

1.9 Management of Invasive alien plant species

Plant invasion management in the Himalayas has been mainly generic, focusing on agriculture, horticulture, and freshwater lakes (McDougall et al., 2011). Climate and habitat conditions are thought to affect the altitudinal distribution of alien species in mountainous areas (Haider et al., 2010). Because of the rough and steppe mountain terrains, alien species that want to establish themselves in the highlands quickly flourish and become impossible to maintain and monitor (McDougall et al., 2011). It's critical to consider Invasive Alien Plant Species' biogeography, life cycle, weed history, and habitat to monitor them and determine their invasive potential (Daehler, 2003), which helps a species to be classified as invasive or non-invasive. In the Indian Himalaya, *Lantana camara*, a well-established invasive alien species in the area, was successfully eradicated in Corbett National Park, Uttarakhand, India, using the cut root stock system in conjunction with manual removal (Love et al., 2009). Restoration of the degraded ecosystems with native grass species was undertaken to discourage re-invasion or secondary invasion by other invasive species, and the findings were fruitful (Babu et al., 2009). Burning the invaded locality has been introduced as a management method in some regions. Still, it may not be a safe practice because the target invasive species may grow further after burning the infested locality (Dobhal et al., 2009). Carbon addition to soil may be thought of as a means of managing invasive alien plants (Rashid & Reshi 2010). Thus, before attempting eradication, systematic research on the ecological function of dominated invaders is needed. The adverse effects of IAPs are now well known, and multiscale (local, state, national, and international) programmes are being initiated in many parts of the world to reduce current and potential effects. Identifying risks, monitoring of pathways, early warning, quick response, avoidance, and restoration are all critical. A detailed understanding of their ecology, morphology, phenology, reproductive biology, physiology, and phytochemistry is needed to monitor invasive species effectively. The permanence of financing constraints makes invasive species control expensive and labor-intensive (Larson et al. 2011), and thus has become a barrier to invasive species management. With shifting climatic conditions, it is expected to raise invasion rates in the coming years (Hellmann et al. 2008), more effort should be made to address the issue. Only when invasive species are eradicated at an early stage of proliferation are they considered successful (Zanden et al. 2010; Khuroo et al. 2010).

When a well-established invasive species is eradicated, another previously suppressed non-native species may invade that area (Caut et al., 2009). Biological protection of invasive species by using co-evolved natural enemies has long been regarded as a stable, environmentally sustainable, and cost-effective management technique (Messing & Wright 2006). It is a single approach that can be used alone or in conjunction with other management options. It is often highly competitive and cost-efficient (Moran et al., 2005). In 1916, attempts were made in India to manage *Lantana camara* infestations scientifically by introducing pests of the genus (Muniappan and Viraktamath 1986). Various experiments have been performed since then (Khan 1944) to monitor the plant by various pests (*Lantanophaga pusillidactyla*, *Ophiomyia lantanae*, *Teleonemia scrupulosa*, etc.) whose host is *Lantana camara* (Kumar, 2015). The magnitude of the harmful impacts of introduced natural enemies on populations of non-target/native animals, on the other hand, is of greater concern (Zimmermann et al., 2000; Louda et al., 2005). After learning about the advantages and potential costs of introducing biocontrol organisms, management plans should be developed more systematically to resolve the risk. To deter further invasion, routine surveillance of these areas is needed. Effective management steps are expected to monitor invasive plants at the unprecedented pace they are growing in India and worldwide. There are different approaches to deal with those already established and those who can be troublesome but are not a threat right now. Above all, preventative measures are critical, and they require close attention at all levels to prevent the spread of invasive species.



2.1 Kailash Sacred Landscape-India: An introduction

The present study was conducted out in Kailash Sacred Landscape (KSL)-India (Lat N 29° 30 N to 30° 44 and Long E 80° 24 E to 82°), which is a culturally rich, ecologically diverse and geographically fragile transboundary landscape adjoining far-western Nepal and Tibet Autonomous Region (TAR) of China. This landscape is mountainous, remote, with steep topography, high spatial heterogeneity, and difficult access. Of the total extent of the landscape, being 31000 km², nearly 7100 km² falls within the Indian Territory.

Kailash Sacred Landscape (KSL) has its conservation significance because of its rich biodiversity unique bio-cultural area. Site of ethnicity, intermixing and cultural assimilation and is revered by -Buddhism, Hinduism, Bon, Jainism and Sikhism and all five different religion have their religious belief in sacred mount Kailash. KSL is one of the seven transboundary landscapes identified in the Hindu Kush Himalayan region for its biological, ecological, cultural and spiritual values.

The Indian part of KSL covers a 7,120 sq km area predominantly represented by the Pithoragarh district (6,818 sq km) with an altitudinal range from 212 to 6851 masl. KSL-India predominates in pristine natural ecosystems, from grasslands to moist subtropical broadleaf to temperate oak forests, sub-alpine conifers, and high-alt birch forests. At the same time, broad alpine pastures range from >3000-3500 masl beside agroecosystems in lower reaches, which is mainly represented by community-managed *Van Panchayat* forests and agroecosystems besides the embedded patches of natural ecosystems and corridors. Numerous rivers, tributaries and springs have intersected mixed forests. They face enormous environmental challenges, including fragmentation of natural habitats and degradation (Zomer & Oli, 2011). The KSL-Indian landscape has wildlife protected areas and a source of six rivers of the region *viz.* Gori, Dhauli, Kuti yangti, Kali, Saryu, and Ramganga traverse through the sacred landscape. The total area Area under these rivers, their tributaries and streams is 11.34 km² which represents 0.16% area of the landscape.

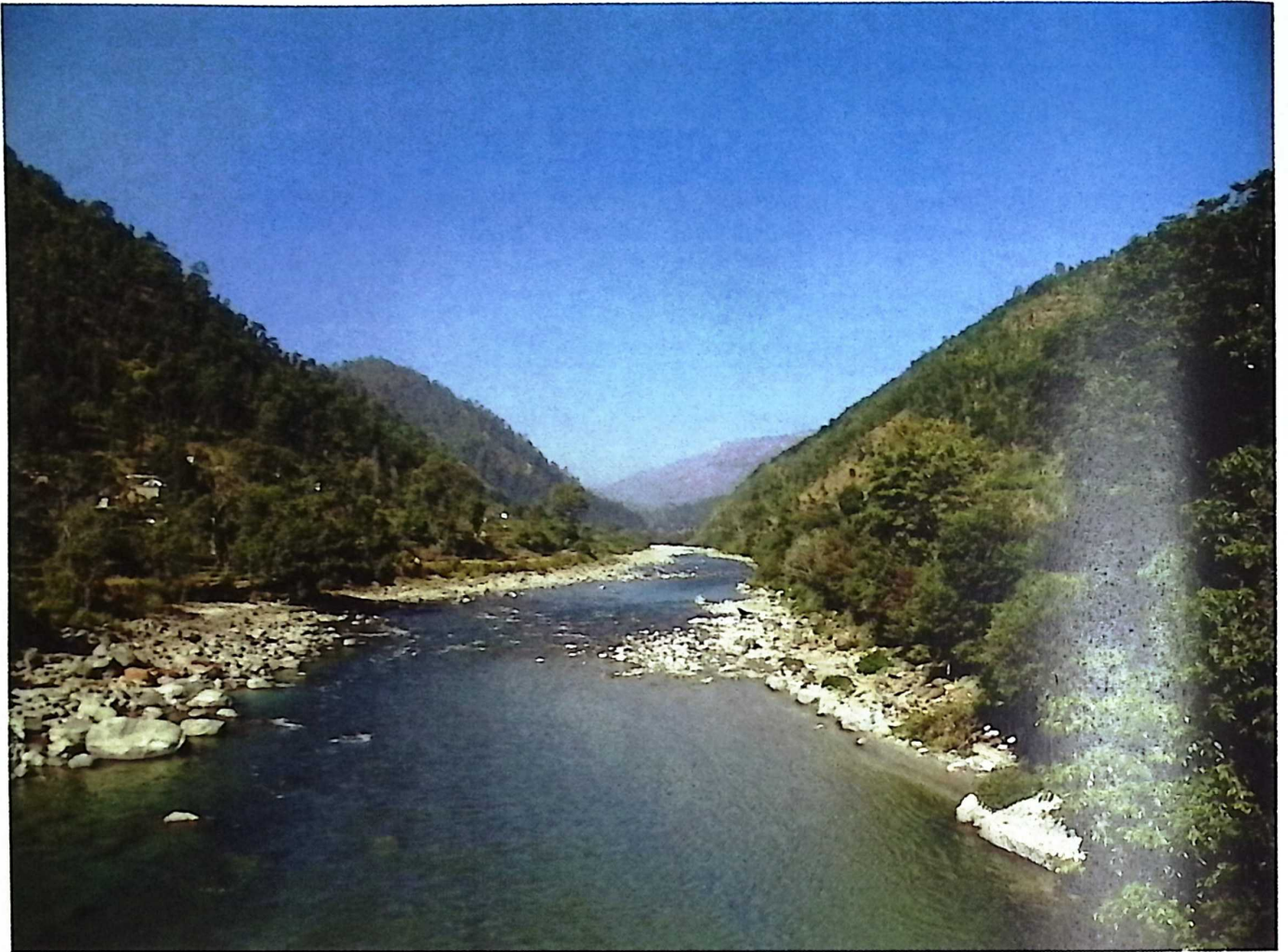


Plate 2.1. A view of Kailash sacred landscape- India

The study was conducted exclusively in Pithoragarh district, eastern Kumaon ($29^{\circ} 30' - 29^{\circ} 45'$ Latitude and $79^{\circ} 50' - 80^{\circ} 25'$ Longitude). This area is part of the Kailash Sacred Landscape (Figure 2.1). The Pithoragarh district has seven forest ranges, viz. Askot, Berinag, Dharchula, Pithoragarh, Didihat, Munshiyari and Gangolihat (Table 2.1). Further, all these forest ranges include eight watersheds areas viz. Gori Ganga (2275.90 km^2), Dhauli (1355.70 km^2), Kutti (939.10 km^2), Ramganga Purvi (1359.21 km^2), Dharchula (233.60 km^2), Godigad (327.54 km^2), Lower Saryu (105.10 km^2) and Jhulaghat (527.85 km^2) (Table 2.2). Out of seven forest ranges, two forest ranges, the Pithoragarh range and Gangolihat range, were part of the pilot site to study Invasive Alien Plant Species under the project KSLCDI (Plate 3; Figure 2.1).

Forests under KSL-India fall in two categories - protected areas (PAs) and non-protected areas. KSL-India embraces only one legally designated PA, *i.e.* Askot Wildlife Sanctuary. However, the non-PA category of forests comprises reserved and protected forests under the control of

Uttarakhand, State Forest Department. KSL India also includes highly interspersed small forest fragments falling under two broad categories: (a) civil / soyam forests and (b) community forests. Both these categories are under the control of the Revenue Department. For nearly nine decades or so, the latter category of community forests has been managed by the communities and is referred to as 'Community Forests' or 'Van Panchayat Forests'.

Table 2.1 Forest ranges of KSL-India

S. No.	Forest Range	Total area in km ²
1	Askot	423.82
2	Dharchula	2398.64
3	Didihat	485.94
4	Gangolihat	341.33
5	Munsyari	2642.98
6	Pithoragarh	462.44
7	Berinag	267.44

The dynamic ecosystems and biodiversity in the landscape provide a natural habitat for many endangered plant and animal species and provide deific ecosystem services to the local community.

The KSL-India, in the past several decades, has experienced changes mainly on account of forest management practices, expansion of agriculture and its intensification, infrastructure development, growing tourism and invasion of Invasive Alien Plant Species. As the landscape is culturally rich, ecologically diverse, and geographically fragile, IAPs spread rapidly and have become a threat to the entire landscape. These selected sub- watersheds have been taken as pilot sites, demonstrating that these are also not untouched by this outbreak and to what extent they are affected.

About 29% area of the Pithoragarh Forest Division (PFD) is covered by different Forest types Chandran (2012). Himalayan Temperate Banj Oak (*Q.leucotrichophora*) Forest predominate the

entire landscape as it covered 708.67 sq km or 9.96% of the overall landscape or 33.27% of the forested area. Himalayan temperate Moru Oak (*Q. floribunda*) Forest covered an area of 2,989.89 sq km and represented 14.05% of the forested tract. Himalayan Temperate Kharsu Oak (*Q. semicarpifolia*) Forest covered 56.60% sq km area and represented just 2.66% of the forested tract. *Q. lanuginosa* occurred only to a small extent, and these forest types have not been separated from the other three types of Oak.

Table 2.2 Sub-watersheds of KSL-India

S. No.	Sub-Watershed	Total area in km ²
1	Gori Ganga	2275.90
2	Dhaulti	1355.70
3	Kutti	939.10
4	Ramganga	1359.21
5	Dharchula	223.60
6	Godigad	327.54
7	Lower Saryu	105.85
8	Jhulaghat	527.85

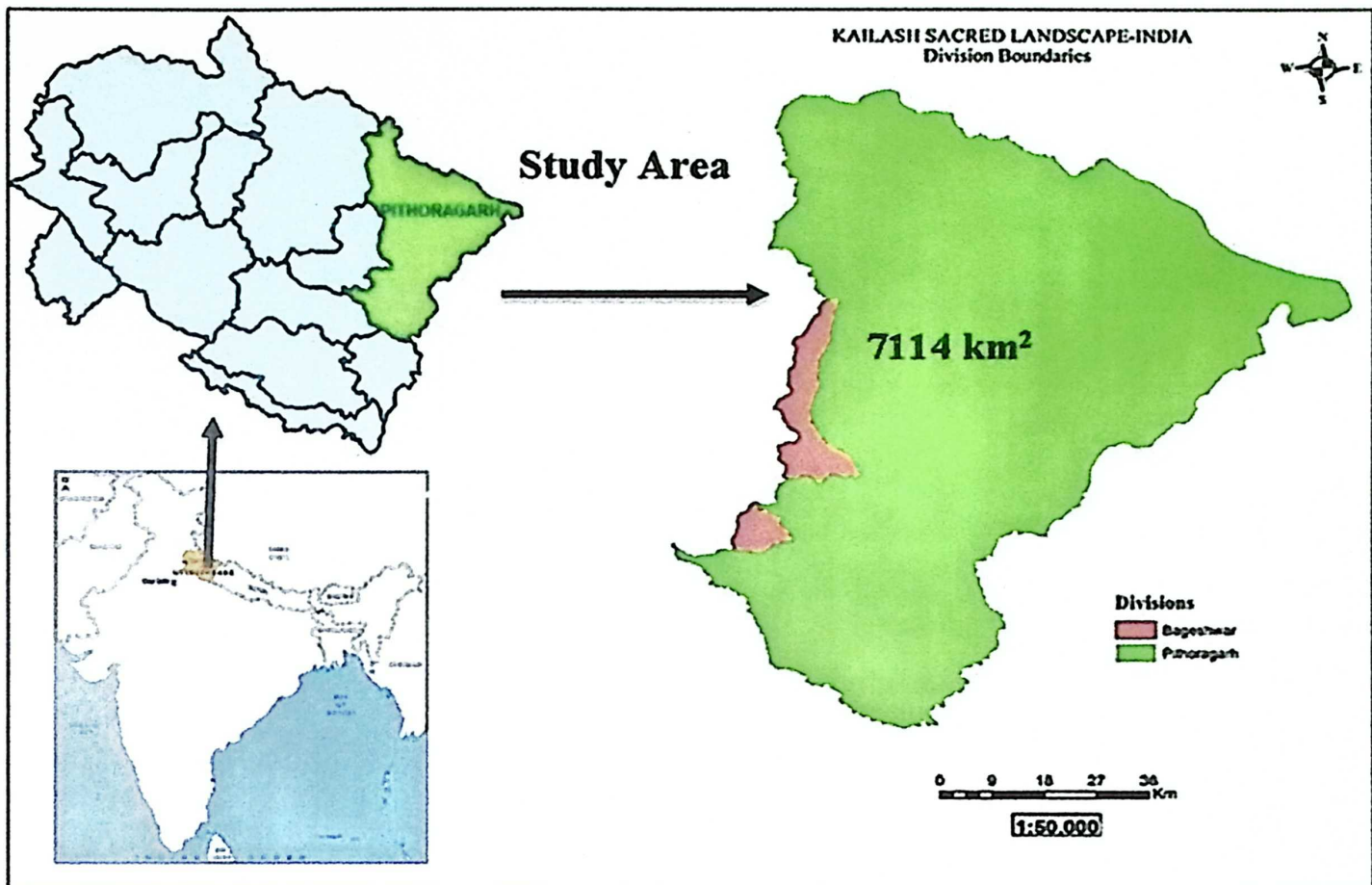


Figure 2.1. Map showing study area of KSL-India

The current study was conducted in two sub-watersheds in the district's southern region, namely Chandak-Aunla Ghat and Hat-Kalika. In Bin block, the Chandak-Aunla Ghat (29°37'0.36" N, 80° 9'42.05" E) covers an area of 23.23 km² at an elevation of 607 to 2119 masl. Temperate broadleaf (Oak) and Sub-tropical Temperate Conifer (Chir Pine) are the major forest types in the area. There are 12 Gram Panchayats and 28 revenue villages, accommodating 1,774 households with an overall population of 7534 (3676 male and 3858 female). Hat-Kalika watershed (29°39'-22.99' N and 080°03'- 38.93'E) encompassing an area of 36.68 km² supports Temperate Broad Leaf mixed conifer (Banj-Oak-Chir Pine) and Sub-tropical/Temperate Conifer (Chir Pine) forests at an elevation 625 -2150 masl.

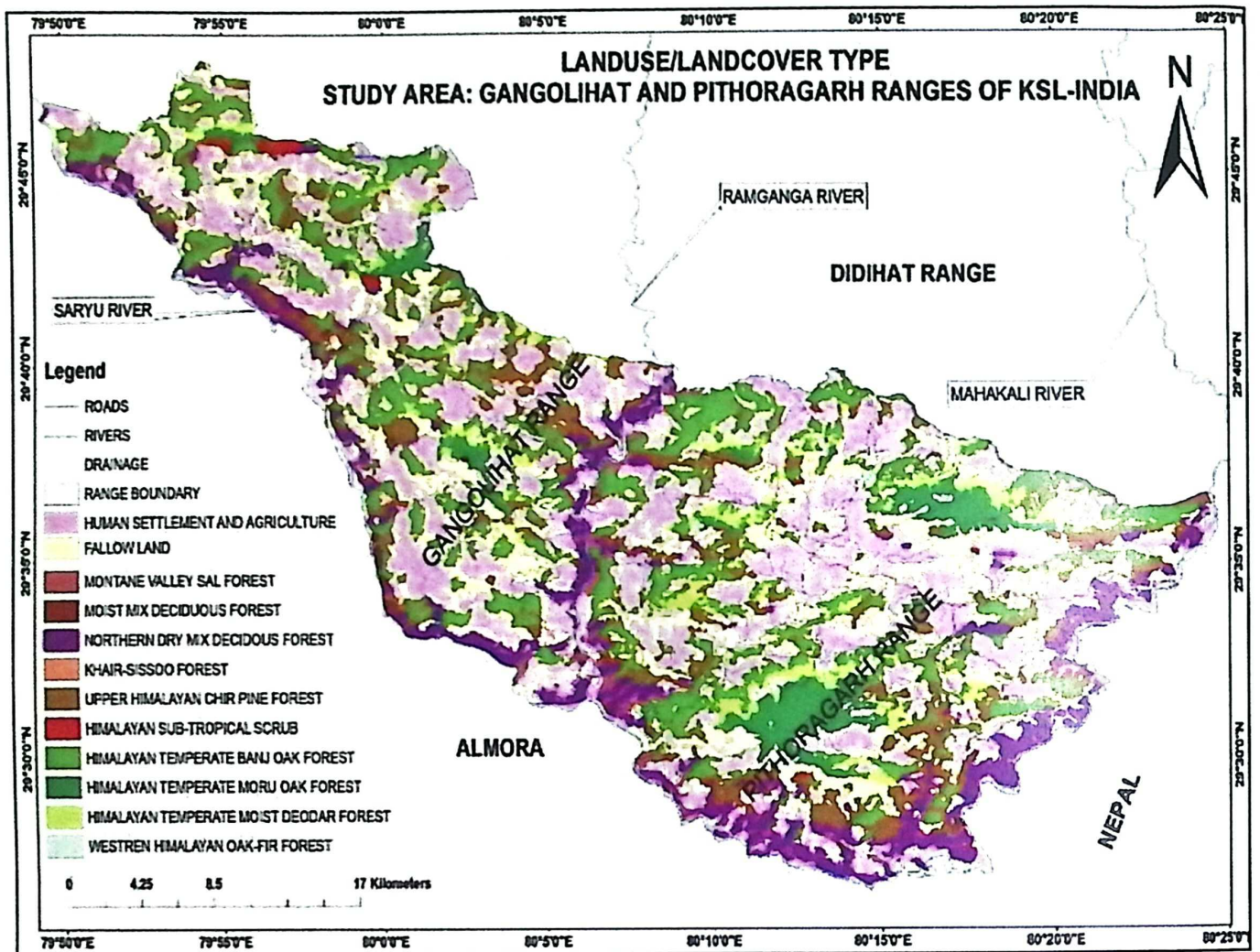


Figure 2.2. Map showing Land use and Land cover types in the intensive study site of KSL-India



Plate 2.2. Human habitation in the pilot site: Bans-Maitoli

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Wildlife Institute of India, D. Deh
विज्ञान सं. WFI/3336 (WFI/3336)
पुस्तक सं. 11-4-2025
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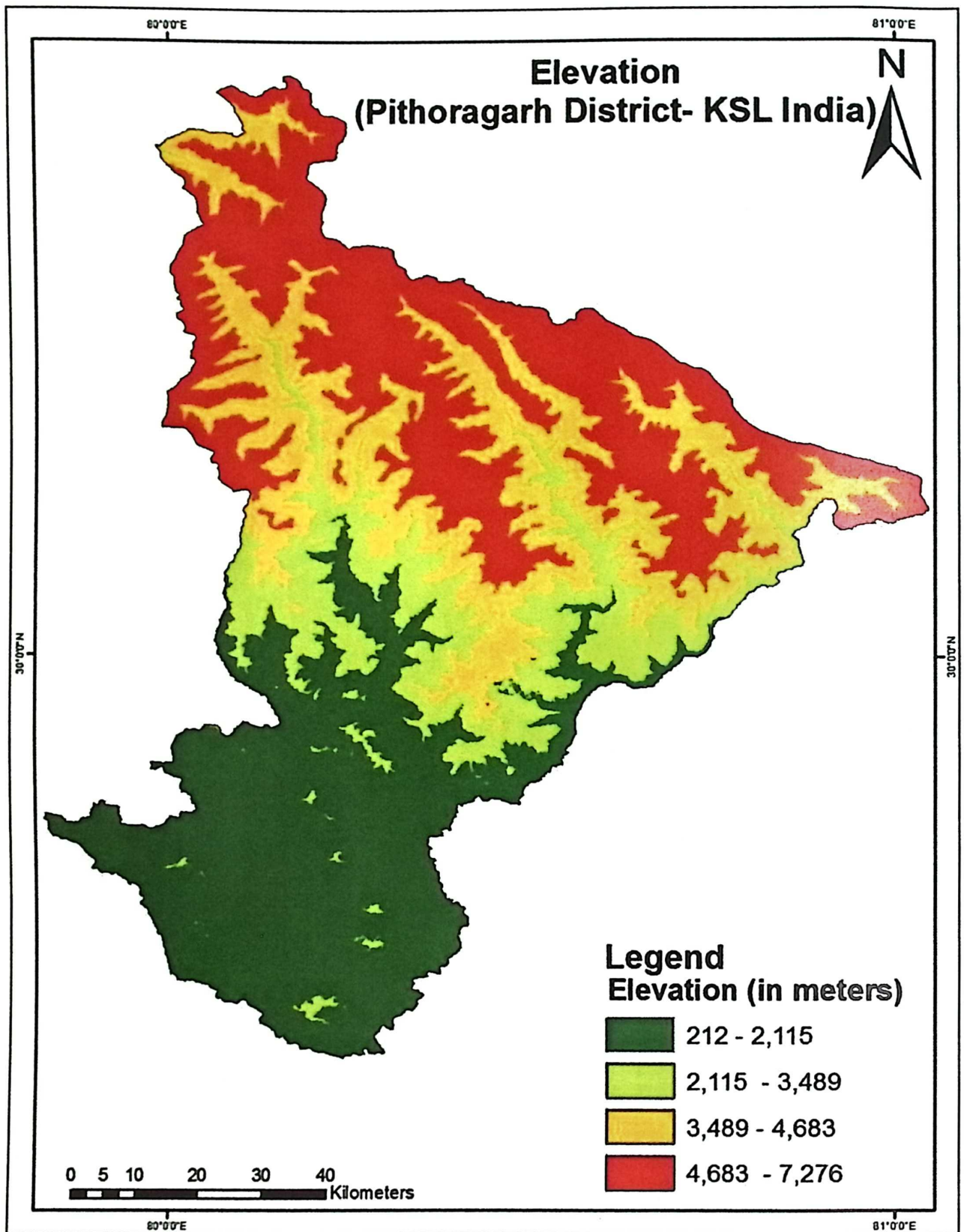


Figure 2.3. Map of KSL-India showing elevation zone

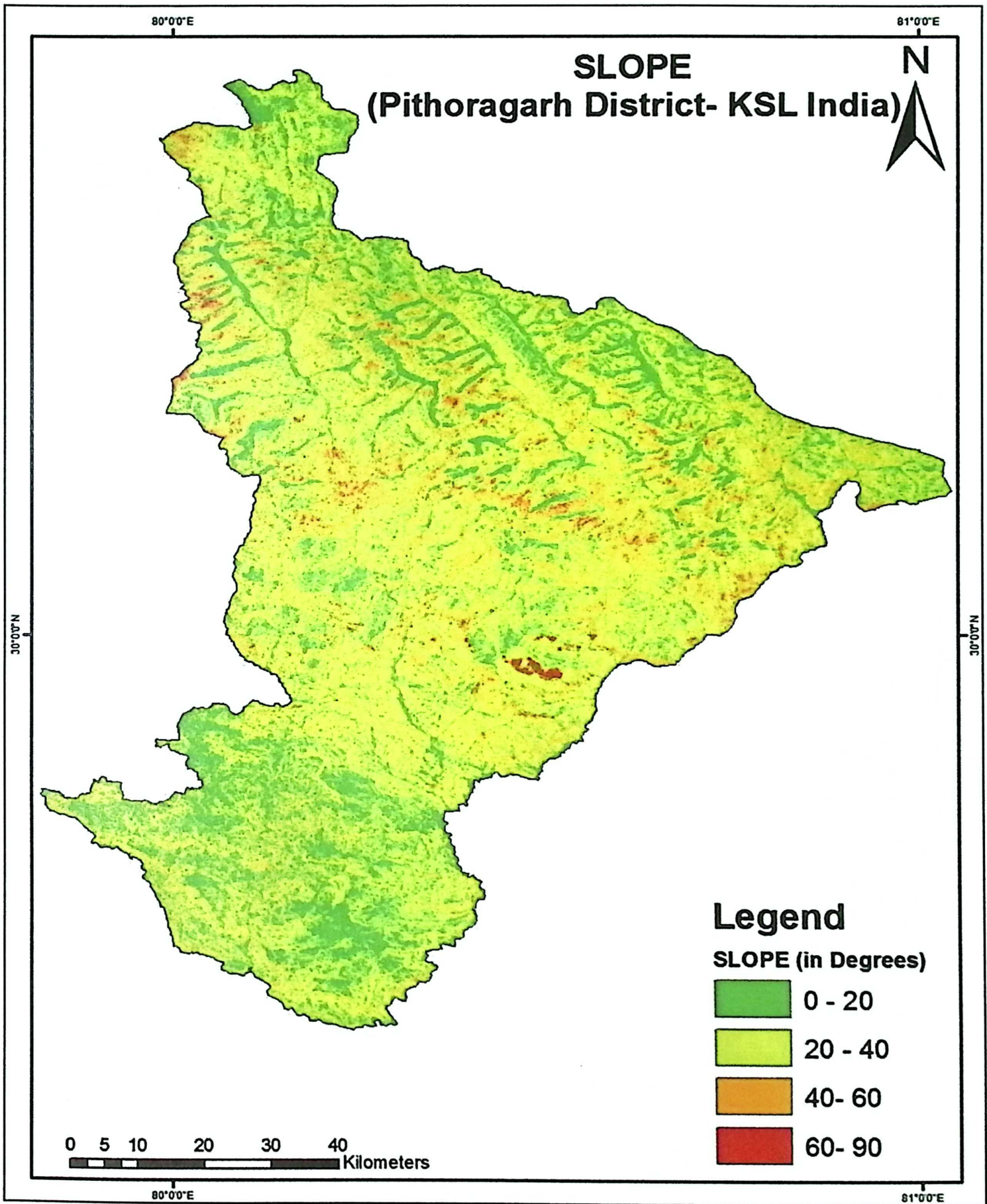


Figure 2.4. Map of KSL-India showing slope characteristics

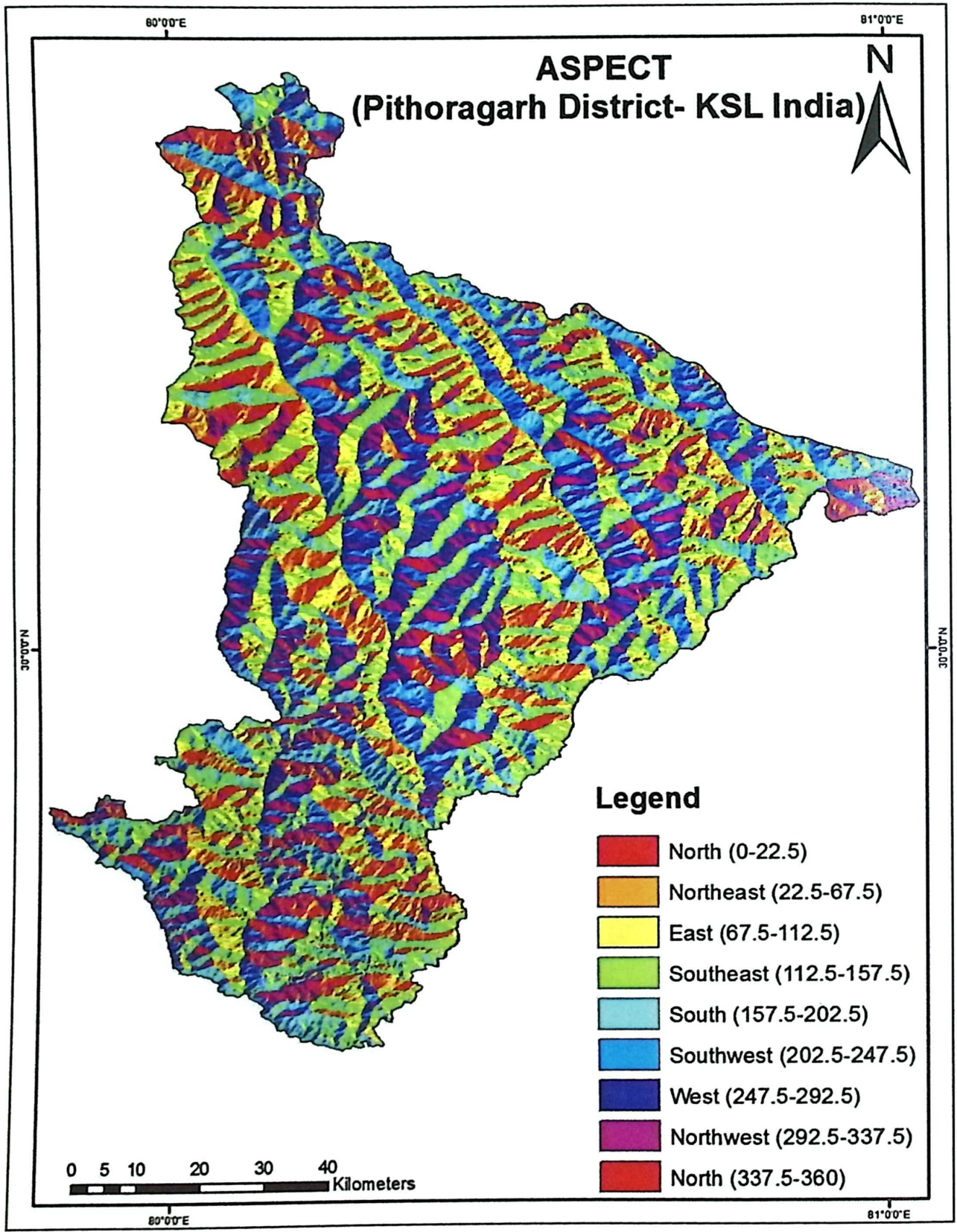


Figure 2.5. Map of KSL-India showing different Aspect

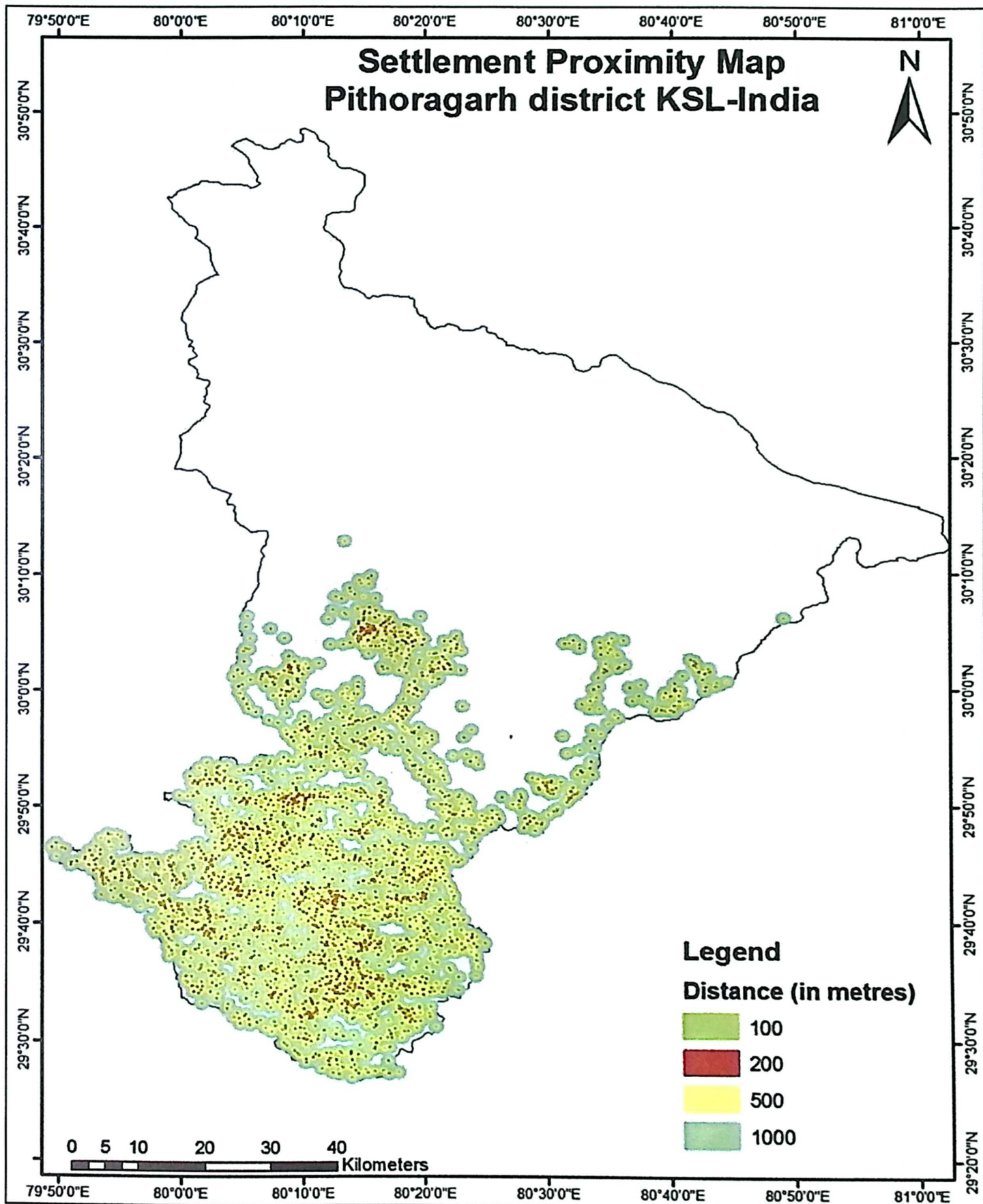


Figure 2.6. Map of KSL-India showing distribution of human settlement

2.2 Biophysical features

Primarily the area covers three major physiographic zones viz., Trans Himalayan zone in the North (occupies > 40%), followed by the Greater Himalayan zone towards the south, and the southern-most Lesser Himalayan zone (most inhabited zone), which forms 40% of the target area (Figure 2.5).

The study area shows significant variation in altitude, which ranges from < 300 m to peaks ranging > 7000 m above mean sea level (Figure 2.3). The slope category classes reveal that a small portion of the area has plain or minimal inclination (< 2%). In general, slopes of 20° – 40° are common in the area. However, steeper slopes (41-60°) are more common towards higher altitudes or narrow river valleys (Figure 2.4). The landscape harbours various snow covers and glaciers, which together cover nearly 10% (2,000 km²) of the landscape. The geography of the study area is undulating with an interspersed of different types of forests, alpine pastures, fallow land, and agricultural fields.

Diverse forests predominate the landscape. The forest types vary from moist subtropical broadleaf to temperate oak forests, sub-alpine conifers, high altitude birch forests, alpine meadows and grasslands (Figure 2.7).

In recent past decades, the landscape witnesses the rapid development of roads, infrastructure and tourism. Because of such rapid development, the landscape has experienced habitat degradation, decreasing agricultural areas, loss of traditional knowledge, and migration from villages to cities (Joshi & Rawat, 2021). These mountain communities suffer from the constraints imposed by their remoteness, which comprise restricted infrastructure and transportation, poor health facilities and education, and high levels of migration by the locals for labour employment (Zomer & Oli, 2011). These landscapes also exhibit great variability in geological and physiographic forms. In the southern part (Greater and Lesser Himalayan zones), the climate in the study area is mainly governed by the monsoon whereas, in the extreme North (Trans Himalayan zone), it is ruled by a rain-shadow zone (cold desert environment). An increase in minimum temperature has been observed in all the locations; however, rainfall does not fluctuate much between the years. The climate in the landscape is primarily governed by the monsoon in the southern part (Greater and Lesser Himalayan zones) and by the rain-shadow zone (cold desert conditions) in the extreme north (Trans Himalayan zone). An increase in minimum temperature has been observed in all the locations; however,

rainfall does not fluctuate much between the years (Figure 2.2). Furthermore, the understanding impact of climate change on native biodiversity like Pithoragarh district is important.

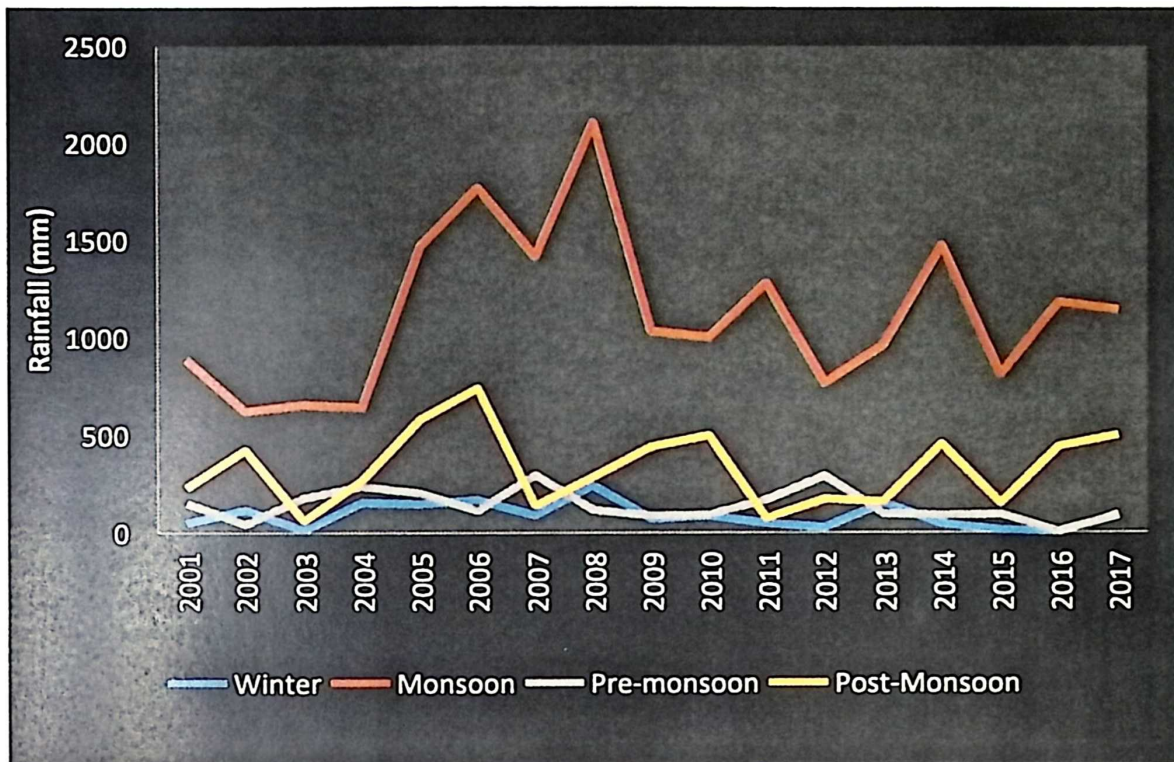


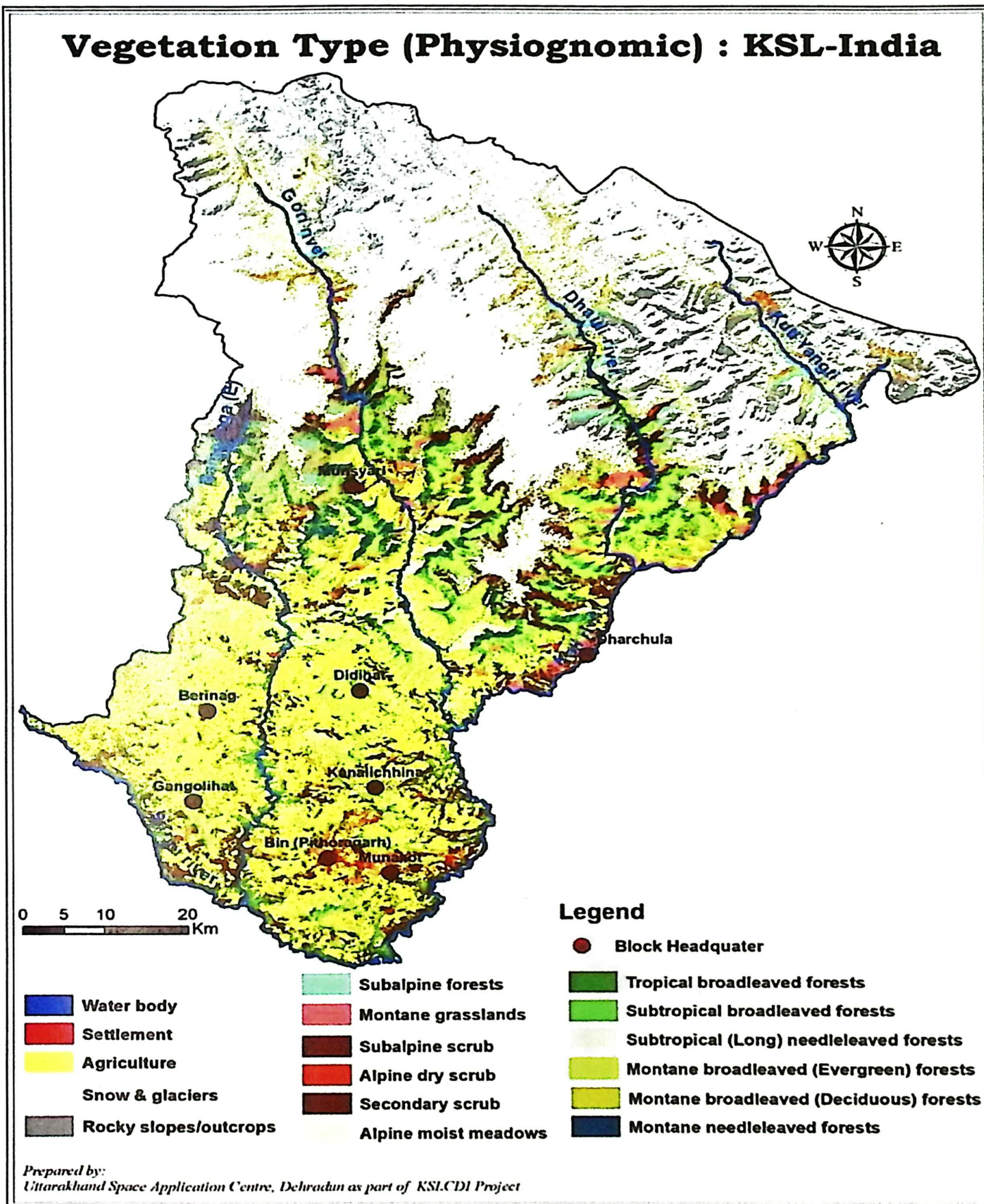
Figure 2.7. Year-wise rainfall in KSL-India during 2000-2017 (Source IMD: <http://www.indiawaterportal.org/disclaimer>)

2.3 Forest types and floral diversity

Covering an area of 2,766 km² forests in KSL-India provides timber, fodder, fuel wood, and several non-timber forest products to sustain the lives and livelihoods of local inhabitants. Major forest zones in KSL-India are Tropical-Subtropical Forest, Subtropical-Temperate, Temperate-Subalpine, and Alpine forests and shrubs (Dhar et al., 1997). The arid alpine zone falls under KSL-India lying to the North, which is incredibly harsh climatic conditions in the middle of the tree line and snowline areas of this area, which remains under snow for 4 - 6 months the temperature goes several degrees below zero during the winter season. The sub-alpine belt harbours species of flora from both regions. Species of flora and found in this region can be used as indicators for monitoring the changes in the habitat conditions and climate. Several important species are *Rhododendron barbatum*, *Triosteum himalayanum*, *Angelica glauca*, *Piptanthus nepalensis*, *Calanthe tricarinata*, *Syringa emodi*. Under this region, the Warm Temperate Zone is characterized by inter-montane valleys and low hills dominated by Banj oak (*Quercus leucotrichophora*) and Chir pine (*Pinus roxburghii*) forest patches where the temperature falls 2°C to 3°C during winter months. Vegetation in this belt depending upon the geology, soil and frequency of forest fire. Sub-tropical zones are low-elevation warm

valleys, the climate of this zone is similar to the tropics during summer except having a short winter season when the minimum temperature may drop to 8-10°C. This zone is connected with the Bhabar belt of Uttarakhand through corridors along the Sharada Basin (the lower stretch of Kali), which exhibits close affinities of the flora of Bhabar like *Shorea robusta*, *Terminalia chebula* and *T. bellirica* (Singh et.al, 1984; Dhar et al., 1997; Rawat 1998).

Figure 2.8. Map of KSL-India showing the land use and land cover type



2.4 Faunal Diversity

These rich habitats in the landscape support around 349 faunal species, including birds, mammals, fishes, reptiles and amphibians, documented so far in KSL-India, comprising 193 birds, 38 mammals, 19 reptiles and nine amphibians (Feasibility Report, 2010). The distinctive faunal elements in this area embrace endanger snow leopard (*Panthera uncia*), tiger (*Panthera tigris tigris*), common leopard (*Panthera pardus*), jungle cat (*Felis chaus*), leopard cat (*Prionilurus bengalensis*), Asiatic black bear (*Ursus thibetanus*), Himalayan weasel (*Mustela sibirica*), red fox (*Vulpes vulpes*), yellow-throated marten (*Martes flavigula*), Himalayan palm civet (*Paguma larvata*), Himalayan tahr (*Hemitragus jemlahicus*), Himalayan serow (*Capricornis thar*), musk deer (*Moschus leucogaster*), blue sheep (*Pseudois nayaur*), sambar (*Rusa unicolor*), Himalayan goral (*Naemorhedus goral*), wild pig (*Sus Scrofa*), barking deer (*Muntiacus muntjak*), rhesus macaque (*Macaca mulata*), Assamese macaque (*Macaca assamensis*), grey langur (*Semnopithecus entellus*), pikas (*Ochotona* spp.), flying squirrel (*Hylopetes alboniger*), and few pheasants Tibetan snowcock (*Tetraogallus tibetanus*), Himalayan monal (*Lophophorus impejanus*), satyr tragopan (*Tragopan satyra*), snow partridge (*Lerwa lerwa*), hill partridge (*Arborophila torqueola*), black francolin (*Francolinus francolinus*), kalij pheasant (*Lophura leucomelanos*) (Sathyakumar, 1993).

2.5 Land cover / Land use of KSL-India

The types of land use/cover in the Indian part of KSL are Barren land, Waterbody, Human settlement, Agriculture land, Range Land, Forest cover and Glacier & Snowbound areas. The most extensive land cover category of KLS-India is forest cover (including scrub cover), which covers 2,766 km² i.e. 38.85% of the landscape. The second most extensive land cover category is snow and glacier cover, covering 2,000 km² i.e. 28.08% of the landscape. Mountain and alpine grasslands cover 971.63 km² i.e. 13.64%, agriculture land covers 717.89 km² i.e. 10.08%, buildup areas cover 60.35 km² i.e. 0.84% and water bodies covers 39.82 km² i.e. 0.54% of the landscape. Under forest, the area covered by different vegetation classes are mountain broadleaved (evergreen) 726.10 km², tropical broadleaved forests 53 km², Subtropical (long) needle-leaved forests 659 km², montane broadleaved (deciduous) forests 49.03 km² and subalpine forests cover 154.09 km² (Table 2.3).

2.6 Human habitations and socio-cultural features

Human habitation, including District Headquarter (Pithoragarh), towns, villages, and their agro-ecosystems covered 1,252.73 sq km area, representing 17.6% area of the landscape

(Table 1.). During the last few decades, the KSL-India landscape witnessed increasing in human settlement. The total buildup area in KSL-India is 60.35 km². Human settlement is increased more in the district and block headquarter across the landscape.



Plate 2.3. Human habitations

Human habitations and human density are distributed with varying concentrations. The settlement concentration is more in the southern portion of the landscape, primarily represented by moderate altitude. Human settlements are also present in deep interior Himalayan valleys in the upper part of the landscape, and most of the villages in upper valleys are seasonal migrants. More than 2500 settlements and more than 1600 revenue villages are there in the landscape. The distribution of these villages and human settlements is depicted in figure 2.3.

Table 2.3 Area statistics of various vegetation types (physiognomic) in KSL-India

Major Categories	Vegetation (Physiognomic) Types	Area (km²)
Forest	Tropical broadleaved forests	53.06
	Subtropical broadleaved forests	54.57
	Subtropical (long) needleleaved forests	658.73
	Montane broadleaved (Evergreen) forests	726.10
	Montane broadleaved (Deciduous) forests	49.03
	Montane needleleaved forests	195.43
	Subalpine forests	154.09
Scrub	Secondary scrub	496.51
	Subalpine scrub	206.11
	Alpine dry scrub	172.65
Grassland	Montane grasslands	297.92
	Alpine moist meadows	673.71
Other Classes		
Agriculture		717.89
Habitation		60.35
River		39.82
Snow & glaciers		2000.00
Rocky outcrops		563.95
Total		7120

2.7 Farming systems and agriculture

The main occupation in KSL-India is agriculture, and the total area of agricultural land in the landscape is 717.89 km² (Table 2.3). In particular, the traditional mountain agricultural systems is practised here, with staple crops ranging from rice and maize to highland buckwheat, barley, potatoes and amaranth, and tightly integrated with transhumance and other livestock systems, are magnificently tuned and adapted for subsistence within the steep topography and highly variable climatic conditions. Widespread collection of non-timber forest products, non-livestock rangeland products, aromatic and medicinal plants, notably *yarsagumba* (*Ophiocordyceps sinensis*), and their transboundary trade, are likewise important livelihood activities for mountain communities. These mountain communities suffer from the constraints imposed by their inaccessibility, including restricted infrastructure and transportation, poor health and educational facilities, and high levels of local labour occupation. Limited livelihood options, together with economic impacts associated with changes in lifestyle due to modernization, regional economic integration, and globalization, put the landscape, mountain communities, and its biodiversity at threat (Zomer & Oli, 2011). Systematic and constant monitoring of the most appropriate habitats and strict patrolling of the alpine and Krummholtz zone state can efficiently reduce the destructive effects of existing anthropogenic activities such as unsustainable resource extraction for resident use and unsupervised livestock foraging (Bashir *et al.*, 2014).



Plate 2.4. View of the study site

The most predominant form of livelihood for indigenous people in the KLS-India is agriculture farming (Plate 2.4). The landscape is also the part of identified probable Agricultural Biodiversity Heritage Site in India (i.e., the western Himalayan region) where the ancient local

inhabitants have explored diverse forms of productive interaction with nature, resulting in the cultivation of the largest number of plant species under diverse farming/production system (Singh, 2010). The different cultural communities, enormous land heterogeneity, and different climate conditions contributed to extreme diversification in agriculture farming in the landscape and the wide range of altitudes. Unique micro-climatic conditions, inaccessibility, marginality have favoured the maintenance of the rich genetic diversity in the landscape (KSLCDI feasibility report 2010). The agricultural area is more prevalent in the southern part of the landscape, as the northern part of the landscape has rugged topography and harsh climatic conditions. The community follows the traditional system of carved out of hills slope which forms small and fragmented terraced fields for agriculture practice in in the landscape. Most of the agricultural land is rain-fed areas (Figure 2.7), whereas villages near streams and rivers have an irrigation system, where two crops are taken in one year. The farmers of the landscape have a strong knowledge base for the selection of suitable crops.

During the post India's independence, the countrywide agenda of self-sufficiency in food through the 'green revolution' program brought into extensification and intensification of agricultural activities and resulted in the expansion of agro-ecosystems in the whole landscape. The last four to five decades witnessed rapid round development throughout the landscape through the road network and urbanization development. Soon, like most mountainous landscapes in the Himalayan states of the country, KSL-India is also expected to witness the rapid development of infrastructure and tourism. In a nutshell, the rapidity of ecological alterations experienced by the Indian landscape and the universal natures of socio-economic forces have not only prejudiced the whole landscape, but most of the associated elements and ecosystems have been prominently transformed. These sustained human-mediated changes in memorable history have resulted in different spatial patterns and heterogeneity in the landscape. An increase in the area of invasive species increased forest extraction throughout the residual matrix, and even greater poaching pressure has been pronounced. In several instances, these have resulted in deleterious influences on species of concern.

3.1 Introduction

Biological invasions are one of the most pressing environmental issues of the present time, owing to their high ecological and economic costs (Pimentel et al., 2001). Invasive plant species can cause important economic, environmental and social losses, either introduced deliberately or accidentally to different parts of the world (Anderson, 2005). The plant diversity worldwide faces various threats and is reducing very rapidly (Dogra et al., 2009). Local studies have shown that invasive plant species can directly or indirectly affect the food security of local residents. After the habitat loss, the invasion of alien plant species has become the second-highest threat to plant diversity (Hobbs, 1995) in the new regimes. It may be due to invasive species have many important adaptation techniques as compared to native plants as faster rates of growth and biomass production compared to native species, high reproductive efficiency including production of a large number of seeds, higher efficient dispersal, competitive ability, rapid establishment, vegetative reproduction, and several other factors that help them adapt to new habitats (Simberloff, 2005; Sharma et al., 2005) and a broader range of tolerance (Walther et al., 2009; IUCN, 2013).

Tackling or preventing biological invasions at a very early stage is considered the most proficient and cost-effective method (Brunelet et al., 2011). Therefore, awareness of the dangers they pose, protective actions to stop new invasions and control of these hazardous invasive species that have already invaded the natural ecosystems should be made. Some of the widely spread and documented invasive plant species all over the world are *Ageratina adenophora*, *Lantana camara*, *Parthenium adenophorus* and *Bidens pilosa*. Himalaya being the youngest mountains on earth, are very well known for their vast biodiversity, due to which they become one of the best sites for the study of climate change on the earth. As per (Sekar et al., 2012), about 50% of the alien species are intentionally introduced in the Himalaya and others came through trade and gain imports. In India, the studies on invasive plants and their invasions are still missing, except for a few studies, mainly on the specific locations listing (Myers et al., 2000; Reddy, 2008; Singh KP, 2010; Sekar et al., 2012) ecological status (Sharma & Raghubanshi, 2012; Adhikari & Tiwary, 2015; Bhatt, et al., 1994; Negi & Hajra, 2007). Climate change may increase the opportunities for introducing and spreading Invasive Alien Plant Species (Sun et al., 2020; Abatzoglou et al., 2011; Masters &

Norgrove, 2010; IUCN, Invasive alien species and climate change, 2017). Despite the recognition of the impacts caused by invasive plants worldwide (Mooney & Hobbs, 2000), there are still many regions in the world where basic information on naturalized plant taxa and plant invasions is only superficial or completely lacking like in Asia and neighbouring regions (Corlett, 1988; Enomotto, 1999). Therefore, an urgent need was felt to study the implications of climate and environmental change on the distribution and abundance of major invasive alien species in the Himalayan region and the impact assessment and management of such species.

3.2 Study area

The study was carried out in the Gokerneshwergad watershed, a part of Kailash Sacred Landscape (KSL) in Pithoragarh district of Uttarakhand state, India (Fig. 01). The topography of the study area is hilly with an interspersion of different types of forests, agricultural fields, fallow land ranging from 600 to 2200masl. The climate is normally moderate and warm. When compared with winter, the summers have much more rainfall. The average temperature is 25 °C. The rainfall here averages 1263 mm. (USIDCL 2012). The total area of the watershed under study was calculated using Arc GIS and was 31.93 Km².

3.3 Methods

The site was chosen after a thorough reconnaissance of the area depending on the abundance of alien plant specie in the Gokerneshwer gad watershed, i.e. *Ageratina adenophora* popularly known as *Eupatorium adenophorum*. Exhaustive field surveys were conducted from January to April 2016 to record the maximum patches of invasion by *Ageratina adenophora* in adjoining areas of 20 villages in Gokerneshwer gad watershed covering forests and fallow lands, agricultural lands and grasslands. Principal Component Analysis (PCA, Jolliffe, 2002) using software R (version 3.1.1) was used for the multivariate data analysis and the estimation of the variables correlation structure and inter-relationship amongst them. It also shows the influence of exploratory variables on the objects (sampling plots or sites). The environmental matrix variables considered were slope, distance from the village, distance from the road, distance from drainage, altitude, LULC, Aspect and soil texture.

The invasion of *Ageratina adenophora* was also discussed with the local communities. Based on the group discussions, patches in each village were identified and classified on the basis of the population intensity of selected species such as dense, moderate or sparse. Following the participatory mapping of species-specific, a rapid ecological assessment was carried out in 41 different patches 229 random quadrates of 1x1m² were laid in the identified patches in the

watershed. The number of individuals of *Ageratina adenophora* and its clumps was recorded in each plot. The density of *Ageratina adenophora* was calculated following the method proposed by Misra (1968).

3.4 Results and Discussion

The interpretation was also made based on the correlation matrix and loadings of principal components biplot and factor loading. The graphic presentation of the biplot gives a clear frame to understand the influence of variables on the species, sites and interrelationship among the exploratory variables.

All the exploratory variables were treated with Principal Component Analysis to extract the factors of significant contribution to variations, and PCA identified four components. The variables (variance \geq 1) viz. altitude, distance from village, aspect and soil texture were found as principal components responsible for the invasion of the plant species. **Table 3.1** shows the results of component analysis by PCA.

Table 3.1: Results of component analysis by PCA.

Variable	Component 1	Component 2	Component 3	Component 4
	Altitude	Distance from village	Aspect	Soil texture
Slope	-0.210	0.563	-0.315	0.216
Distance from village	0.221	0.573	0.414	0
Distance from road	-0.519	0	0.282	0.237
Distance from drainage	-0.458	0	0.303	-0.170
Altitude	0.526	0	-0.112	-0.232
LULC	0.363	0.293	0.365	0.357
Aspect	-0.126	0.434	-0.577	-0.184
Soil texture	0	-0.261	-0.282	0.807

Significant habitat factor of component 1 consists of Altitude. Component 2 comprised of distance from the village, whereas Aspect was the main factor of component 3 and Soil texture for component 4. The core topographic factors that influence the distribution and patterns of vegetation in mountain regions are Elevation, slope and aspect (Titshall *et al.*, 2000). Therefore, topographic factors such as aspect, elevation and slope of the region were created from the digital elevation model. Euclidean distance from road and water source was prepared in Arc GIS-L1, and cover types, important geological layers such as soil textures were prepared. Several other parameters such as distance from the disturbance site and watershed and land cover type were also found to be important that control the distribution and pattern of *Ageratina adenophora*. The results of the current study are illustrated as follows:

The area of invasion was least in Godiyagaon (485 m²), followed by Bhurmuni village (613 m²) whereas, the maximum invasion was recorded in Dhuryee (5370 m²). The maximum density of *Ageratina adenophora* was recorded in Jajroli (203/m²) followed by Mostmanu (230.83/m²). In terms of the density of *Ageratina adenophora*, the lowest value was recorded in Bhurmuni (62.25/m²). Out of 41 patches surveyed, maximum patches were recorded in Bichcot, Jagtar and Naini villages (04). In contrast, the lowest number of patches were recorded in Malliseem, Sinchora, Sintoli, DhoogaBhool, Bhurmuni, Mostmanu, Sanghar, Jajroli, GodiyaGaon (01 each).

Table 3.2: *Ageratina adenophora* invasion in different villages of Gokerneshwer-gad watershed

S.No	Village	Average patch area (m ²)	No. of patches	Total area of invasion (m ²)	Density (plants/m ² ± SD)
1	Malliseem	713	1	713	114.75 ± 59.72
2	Dhuryee(Bhanar)	537.9 ± 505.25	2	5370	186.94 ± 186.14
3	Bichcot (Bhanar)	419 ± 371.28	4	3345	91.25 ± 64.59
4	Sankatiya	248.66 ± 286.97	3	1492	114.66 ± 79.48
5	Sinchora	712	1	712	70 ± 31.82
6	Sintoli	621	1	621	168.25 ± 65.37
7	Jagtar	623.4 ± 357.17	4	3117	102.71 ± 31.25
8	Kantye	462.33 ± 502.47	3	2774	141.5 ± 66.82
9	DhoogaBhool	1889 ± 347.89	1	3778	150.5 ± 55.09
10	Bhurmuni	204.33 ± 63.06	1	613	62.25 ± 15.43
11	Naini (Dumali)	736.4 ± 646.06	4	3682	136.43 ± 60.98

12	Ratwali	582.16 ± 570.06	2	3493	167.2 ± 74.63
13	Bans	582.75 ± 429.05	3	2331	113.64 ± 68.67
14	Gurura	318.16 ± 370.60	2	1909	78.33 ± 34.11
15	Mostmanu	928.66 ± 159.76	1	2786	230.83 ± 93.29
16	Sanghar	289.6 ± 80.31	1	1448	175.08 ± 56.83
17	Chera Village	1768.75±1638.94	2	7075	199.41 ± 70.83
18	Digitoli	378.77 ± 311.20	3	3401	130.31 ± 75.57
19	Jajroli	567 ± 467.10	1	5429	203 ± 145.72
20	Godiya Gaon	485	1	485	248

Density of *Ageratina adenophora* was also calculated in different ecosystems of the study area (Table 3.3). As per our study, the maximum density of *Ageratina adenophora* in fallow land was recorded in Godiya Gaon, which was 248/m² whereas the minimum density was recorded in Bichcot village, which was 95.87/m². In case of invasion in agriculture land, the maximum density was recorded in Chera village (196.75/m²), whereas, the minimum was recorded from Jagtar village (70.5/m²). Chera village has maximum (200.7/m²) invasion of *Ageratina adenophora* in terms of density in forest whereas; minimum (62.7/m²) was recorded in Bhurmuni village.

Table 3.3: Density of *Ageratina adenophora* in the different ecosystem (village wise) of Gokerneshwer-gad watershed

S.No	Village	The density of <i>Eupatorium</i> (plants/m ²)			
		Agriculture land	Forest	Grassland	Fallow land
1	Malliseem	114.75 ± 59.72	-	-	-

2	Bhanar	194.2 ± 184.06	-	159.75 ±220.30	-
3	Bichcot	86.62 ± 47.35	-	-	95.87±81.55
4	Sankatiya	103 ± 112.89	-	-	120.5 ± 65.94
5	Sinchora	-	70 ± 31.82	-	-
6	Sintoli	-	168.25 ± 65.37	-	-
7	Jagtar	70.5 ±13.43	-	-	108.08 ± 30.30
8	Kantye	96.25 ± 4.64	-	-	164.125 ±72.47
9	DhoogaBhool	-	-	-	150.5 ±55.09
10	Bhurmoni	-	62.25 ±15.43	-	-
11	Naini (Dumali)	156 ±62.22	-	-	112.27 ± 68.36
12	Ratwali	-	140.33 ± 48.47	-	167.2 ± 74.63
13	Bans	-	-	64.25 ± 29.18	133.4 ± 70.78
14	Gurura	-	81.6 ± 42.34	92.5 ± 49.41	-
15	Mostmanu	-	-	230.83 ±103.88	-
16	Sanghar	-	-	-	175.08 ±56.83
17	Chera Village	196.75 ± 48.70	200.7 ± 82.83	-	-
18	Digitoli	-	-	-	130.31 ± 75.57

19	Jajroli	-	-	-	203 ±145.72
20	GodiyaGaon	-	-	-	248

The density of patches and area of spread by *Ageratina adenophora* in different ecosystems are listed in table 3.4. Fallow lands have a maximum area of invasion, followed by Agricultural land and grassland. But highest patch density was observed in most of the grasslands and agricultural lands of the Gokerneshwer-gad watershed.

Table 3.4: Density and area of *Ageratina adenophora* invasion in the different land cover of Gokerneshwer-gad watershed

S.No	Land cover type	The total area of invasion (m ²)	Density (plants/m ² ± SD)
1	Fallow land	29950	135.12 ± 76.38
2	Agriculture	7993	144.69 ± 129.94
3	grassland	3895	159.58 ± 124.14
4	forest	968	132.2571 ± 74.11

The region's topographic factors (aspect, elevation and slope) were created from a digital elevation model. Euclidean distance from road and water source was prepared in Arc GIS-L1, and cover types, important geological layers such as soil textures were also prepared. Several other parameters, such as distance from the disturbance site and watershed and the land cover type, were also important to control the distribution and pattern of *Ageratina adenophora*. The results of the current study are illustrated as follows:

The area of invasion was least in Godiyagaon (485 m²), followed by Bhurmuni village (613 m²) whereas, the maximum invasion was recorded in Dhyuree (5370 m²). The maximum density of *Ageratina adenophora* was recorded in Jajroli (203/m²), followed by Mostmanu (230.83/m²), and the lowest value (62.25/m²) was recorded in Bhurmuni (Fig. 3.1). Out of 41 patches surveyed, maximum patches were recorded in the boundaries of Bichcot, Jagtar and Naini villages (04) whereas, the lowest number of patches were recorded in Malliseem, Sinchora, Sintoli, DhoogaBhool, Bhurmuni, Mostmanu, Sanghar, Jajroli, GodiyaGaon (01 each).

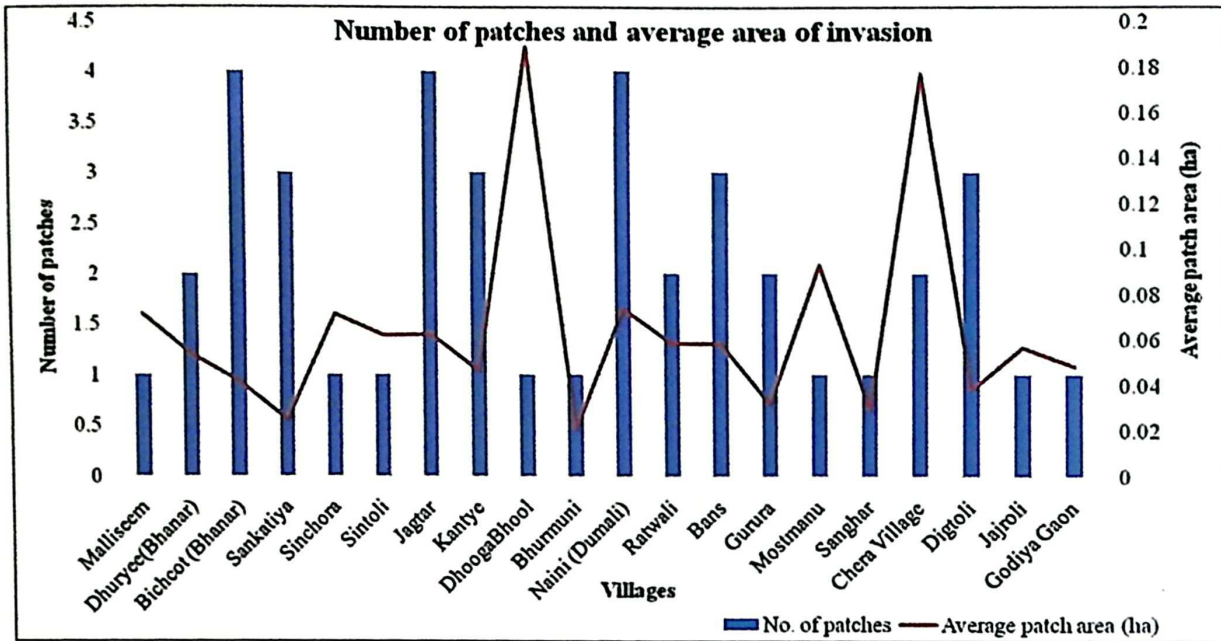


Fig. 3.1: *Ageratina adenophora* invasion in different villages of Gokerneshwer-gad watershed. The density of *Ageratina adenophora* was also calculated in different ecosystems of the study area. As per our study, the maximum density of *Ageratina adenophora* in the fallow land was recorded in Godiya Gaon ($248/m^2$), whereas the minimum density was recorded in Bichcot village, which was $95.87/m^2$. In case of invasion of agricultural land, the maximum density was recorded in Chera village ($196.75/m^2$), whereas the minimum was recorded from Jagtar village ($70.5/m^2$). Chera village has a maximum ($200.7/m^2$) invasion of *Ageratina adenophora* in terms of density in the forest, whereas; minimum ($62.7/m^2$) was recorded in Bhurmuni village (Fig. 3.2).

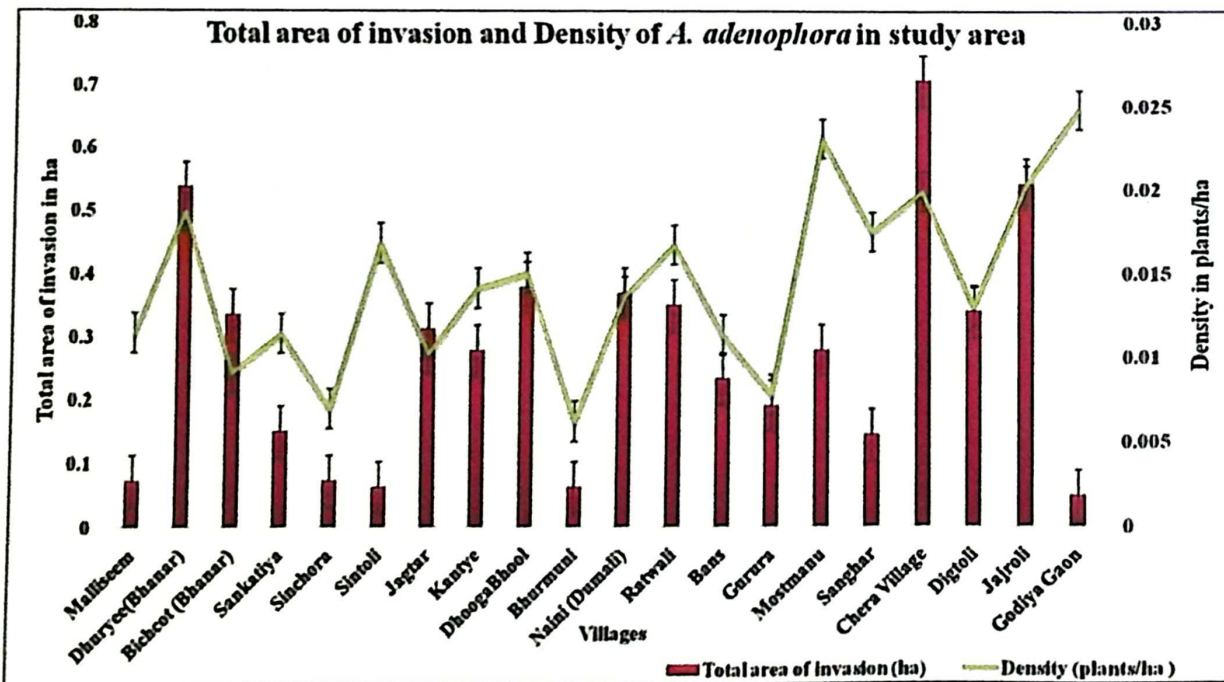


Fig. 3.2: Density of *Ageratina adenophora* in different ecosystems (village wise) of Gokerneshwer-gad watershed

In terms of area, fallow lands had a maximum area of invasion followed by Agricultural land and grassland whereas the highest patch density was observed in most of the grasslands and agricultural lands of the Gokerneshwer-gad watershed. The various ecological parameters which affected the distribution of *Ageratina adenophora* were as follows:

1. Slope: Slopes of landforms control the amount of rainwater accumulation. Within this region, the maximum presence of *Ageratina adenophora* was observed between 20° and 30° slope positions as it requires moderate slope steepness for more stability.

2. Distance from road: The distance from the road was inversely proportional to the growth of the *Ageratina adenophora* invasion in the study area. It was also reported (Tyser & Worley, 1992; Parendes & Jones, 2000; Watkins et al., 2003) that roads were contributing to the spread of exotic plants in several ecosystems. In the current study, too highest invasion (41.39%) was observed at surrounding roads. The intensity of invasion reduced as the distance from the roads increased. Our results were also in line with Kosaka et al. (2010) and Bhattarai et al. (2014), who reported that road construction facilitated plant invasion in mountainous regions of India and Nepal and the distribution pattern of invasive plants along roadsides varied with altitude.

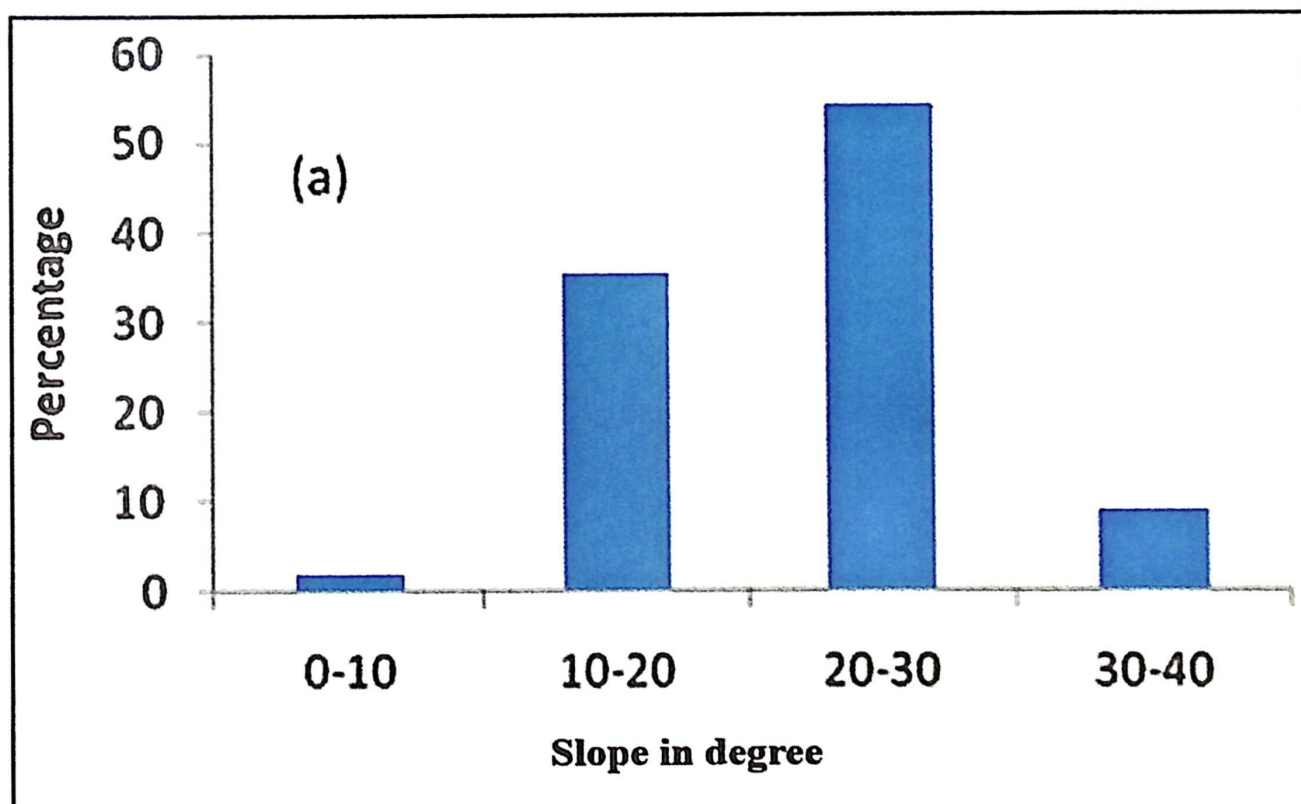


Fig. 3.3: *Ageratina adenophora* distribution with respect to slope.

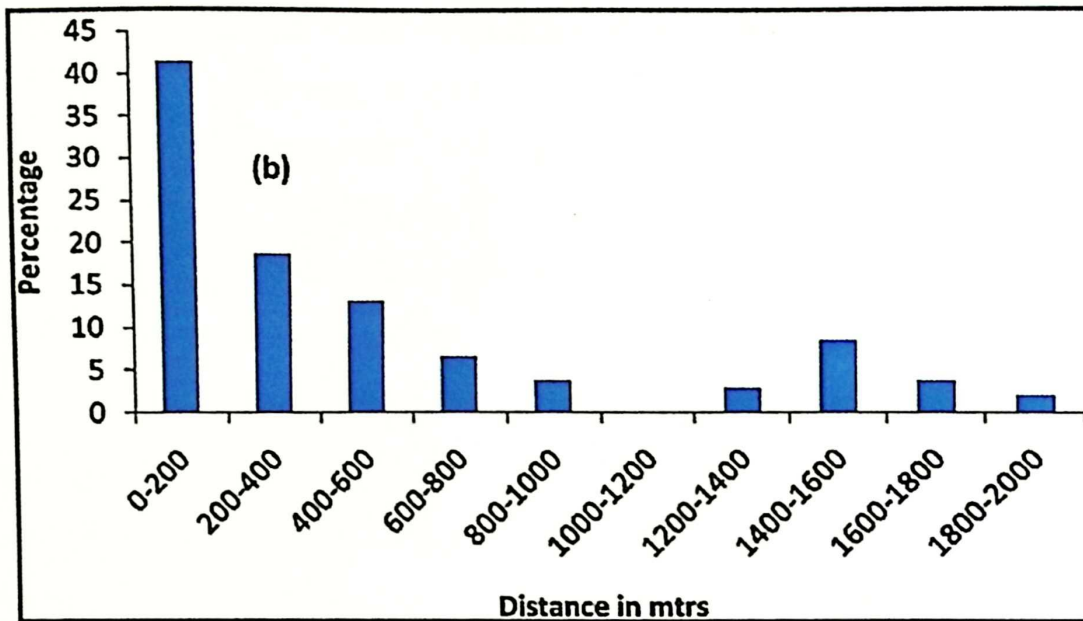


Fig. 3.4: *Ageratina adenophora* distribution with respect to road

3. Land use cover type: The accomplishment of invasive alien plants is due to the nonexistence of natural competitors, the opportunistic habit of anthropogenic disturbances and their allelopathic competitive approaches. (Kunwar, 2003). The presence of *Ageratina adenophora* was recorded in four different types of land cover type's viz. grassland, forest, agriculture and fallow land. The maximum occurrence was recorded in fallow land (69.97%) followed by grassland (18.67%), agriculture (9.10%) and forest (2.26%).

4. Distance from water source: Invasive plants have a major impact on catchment hydrology: 30-70% lower water runoff is reported from watershed areas with dense stands of alien species (Geldenhuys, 1986), our results supported this as *Ageratina adenophora* presence (82%) was recorded maximum near most of the water bodies (secondary and tertiary tributaries).

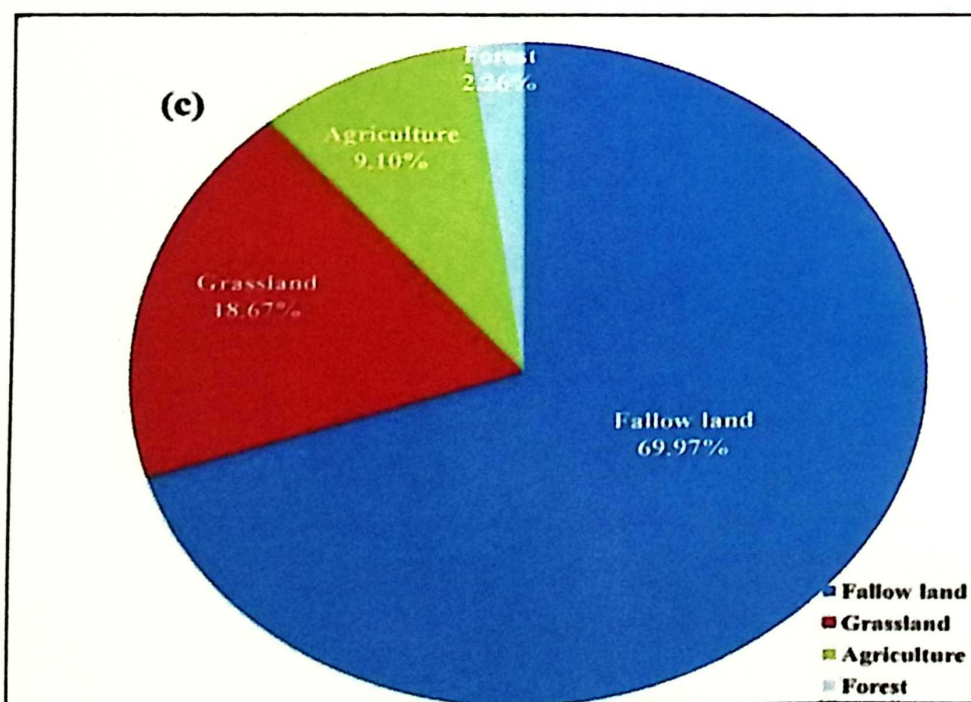


Fig.3.5: Distribution of *Ageratina adenophora* with respect to LULC

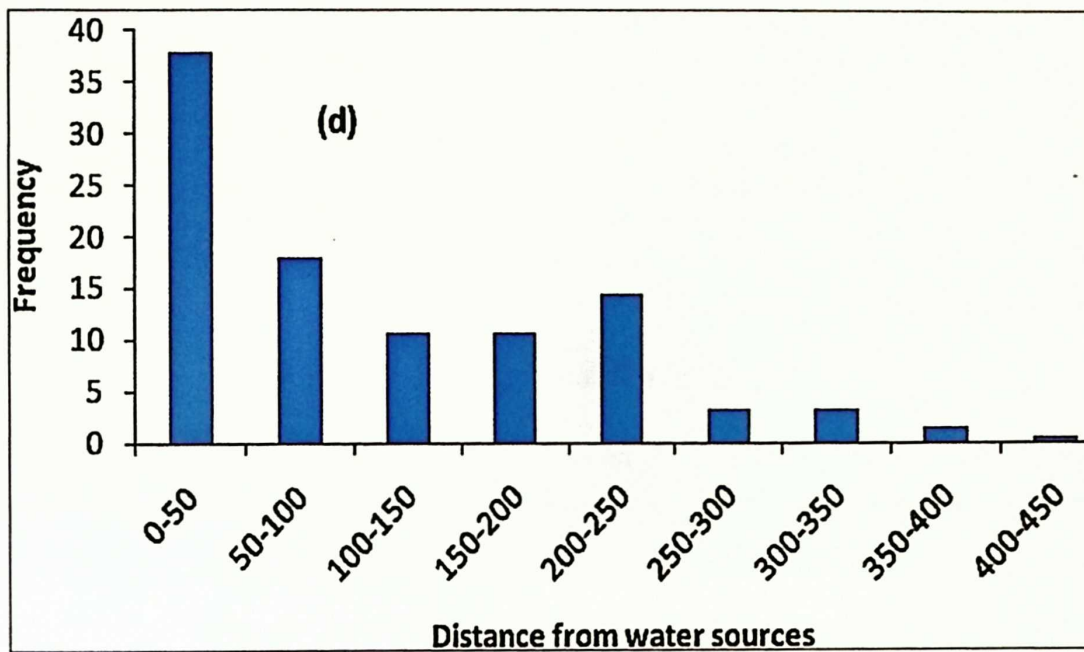


Fig 3.6: Distribution of *Ageratina adenophora* with respect to distance from the water source

5. Elevation: Elevation determines the microclimate and thus, large-scale spatial distribution and patterns of vegetation (Busing et al., 1992). The relationship was further confirmed when the distribution and altitude maps were superimposed by GIS. It was observed that the highest Eupatorium invasion was in between 1700 – 1800m elevation gradient (16.66%) and the lowest presence detected between 700 – 800m (3.70%).

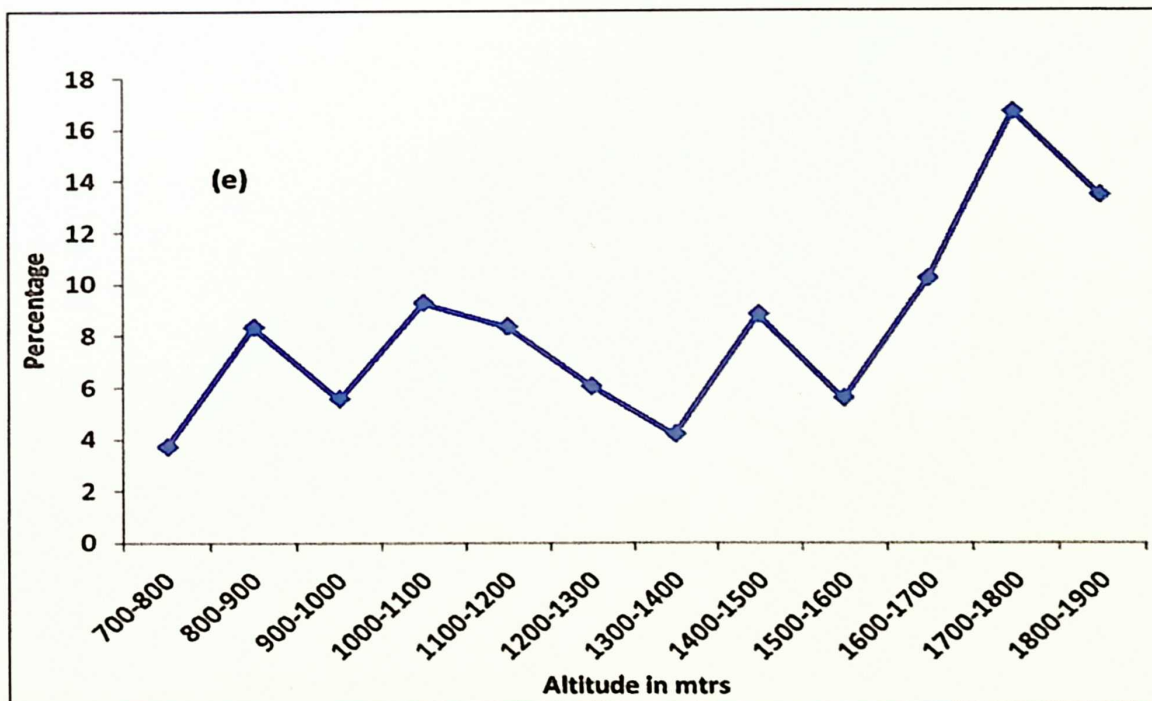


Fig. 3.7: *Ageratina adenophora* distribution with altitude

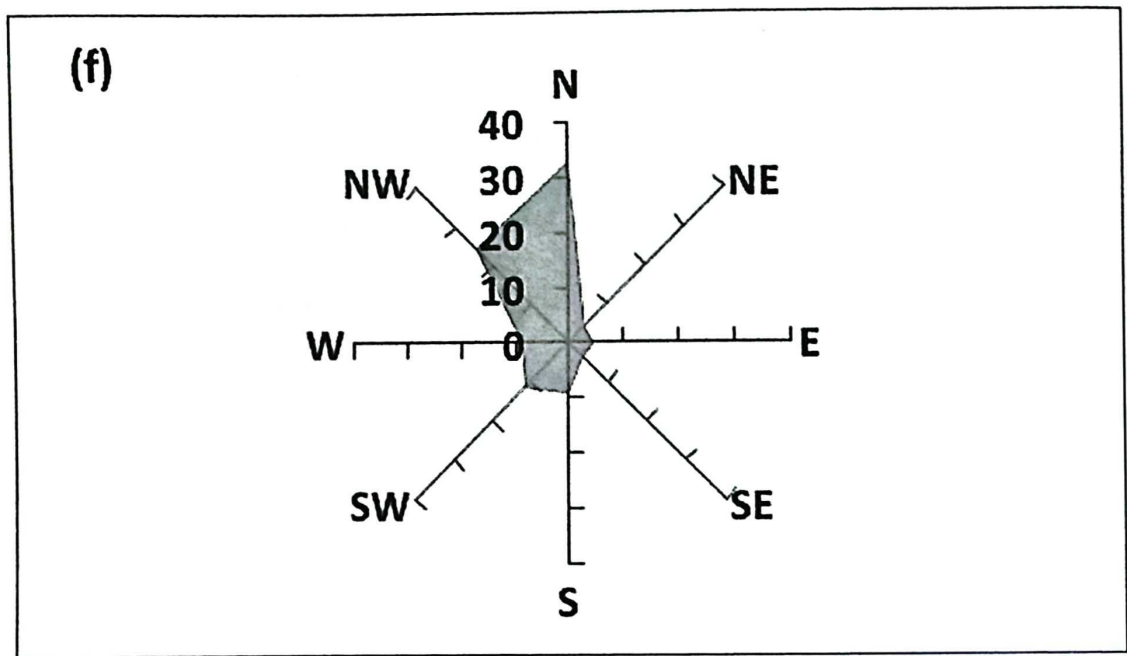


Fig 3.8: *Ageratina adenophora* distribution with respect to aspect

6. Aspect: A community strongly affected by aspect, and this appears in the species distribution at special aspects. *Ageratina adenophora* was recorded highest at North (33.33%) followed by North West (24.53%), South-West (11.57%), South (9.25%), West (8.79%), at East (4.62%), North East (4.16%) South East (3.70%). Most of *Ageratina adenophora* was concentrated on North and North-West direction, which gives the species more sheltered conditions.

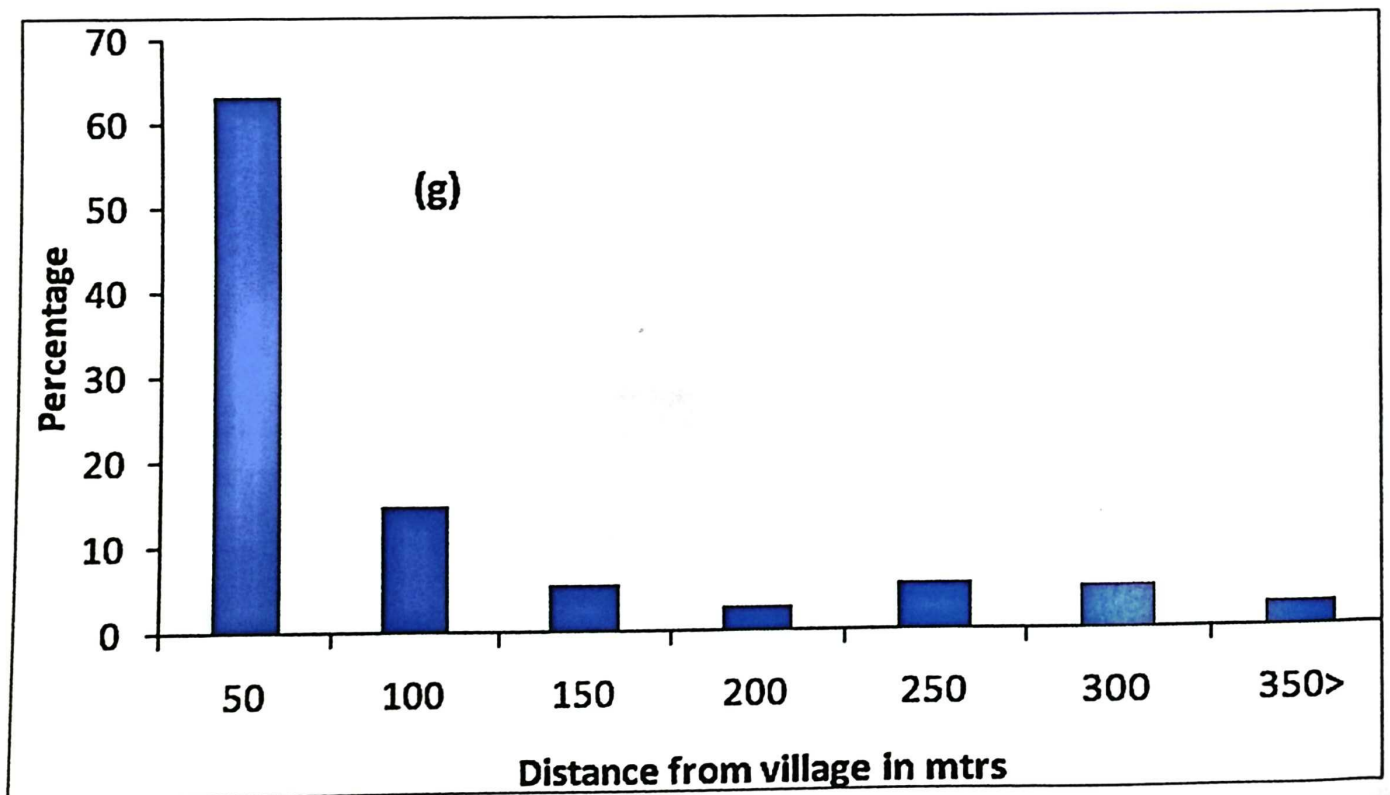


Fig 3.9: *Ageratina adenophora* distribution with respect to distance from the village.

7. Distance from the village: During the study, it was noticed that the abundance and occurrence of *Ageratina adenophora* were inversely proportional to the distance from the village or disturbance site. As we move away from the villages, less density and abundance of *Ageratina adenophora* was recorded. Both "natural" and direct human disturbances are known to promote invasive exotic species (Hobbs and Huenneke, 1992; Lozon and MacIsaac, 1997; D'Antonio et al., 1999). Thus it could be concluded that the disturbance or anthropogenic activities are favourable for the distribution of *Ageratina adenophora*.

The number of clumps of *Ageratina adenophora* was found to be negatively correlated with the digital elevation (DEM) thus altitude plays an important role in the distribution of this alien plant species and the number of clumps was negatively correlated with the mean number of plants per clump indicating that more the density of clumps lesser is the number of plants per clump in an area. Thus, it may also be said that after acquiring an area, the species is competing to itself.

A very interesting correlation was found between the environmental and ecological variables with the total clumps, total plants and mean number plants per clump of *Ageratina adenophora* in the study area (Table 3.5).

Table 3.5: Correlation between various factors and variables responsible for the distribution of *Ageratina adenophora*

	Slope	Altitude	Distance from village	Distance from road	Aspect	Distance from drainage	Soil texture	LULC	Clumps	Total Plants	Mean No. of Plants/Clump
Slope	1	-0.345	0.120	0.238	0.176	0.074	0.044	-0.020	0.081	0.061	0.041
Altitude	-0.345	1	0.343	-0.674	-0.178	-0.187	0.152	0.102	-0.165	-0.133	-0.107
Distance from village	0.120	0.343	1	-0.080	0.003	-0.112	-0.209	0.294	0.011	0.001	-0.005
Distance from road	0.238	-0.674	-0.080	1	0.121	0.495	0.094	-0.250	0.004	0.146	0.208
Aspect	0.176	-0.178	0.003	0.121	1	-0.057	-0.047	0.134	0.058	0.010	-0.035
Distance from Drainage	0.074	-0.187	-0.112	0.495	-0.057	1	0.097	-0.157	-0.156	-0.098	0.035
Soil texture	0.044	0.152	-0.209	0.094	-0.047	0.097	1	-0.262	-0.140	0.009	0.036
LULC	-0.020	0.102	0.294	-0.250	0.134	-0.157	-0.262	1	-0.028	0.012	-0.012
Clumps	0.081	-0.165	0.011	0.004	0.058	-0.156	-0.140	1	1	0.320	-0.237
Total Plants	0.061	-0.133	0.001	0.146	0.010	-0.098	0.009	0.012	0.320	1	0.779
Mean No. of Plants/Clump	0.041	-0.107	-0.005	0.208	-0.035	0.035	0.036	-0.012	-0.237	0.779	1

In bold, significant values (except diagonal) at the level of significance $\alpha=0.050$ (two-tailed test).

The PCA results show a negative correlation between the clumps of *Ageratina adenophora* and altitude, indicating that the number of clumps of *Ageratina adenophora* decreases with an increase in altitude. In contrast, it also decreases with an increase in distance from drainage and soil texture (Fig. 3.10). A negative correlation of clumps to mean the number of plants per clump was also found, suggesting that as the number of clumps increases in an area, the mean number of plants per clump decreases, which further indicates that the alien reaches a threshold level plants start competing among themselves. Similarly, a positive correlation was found between total clumps and total *Ageratina adenophora* plants in the study area, suggesting more the number of clumps more is the number of plants of this alien species, which is obvious. On the other hand, a positive correlation was found between the mean number of plants per clump and distance from road and village/settlements suggesting that this plant species prefer to remain in clumps as it moves away from the disturbance sites. The total number of clumps also increased with the decline in distance from the drainage, suggesting that these species prefer habitats that are moist to dry habitats. Thus the availability of water sources is also one of the important factors in the distribution of this alien plant species, although it does not require more fertile land to grow as a negative correlation was found between the total number of clumps of this plant species and soil texture.

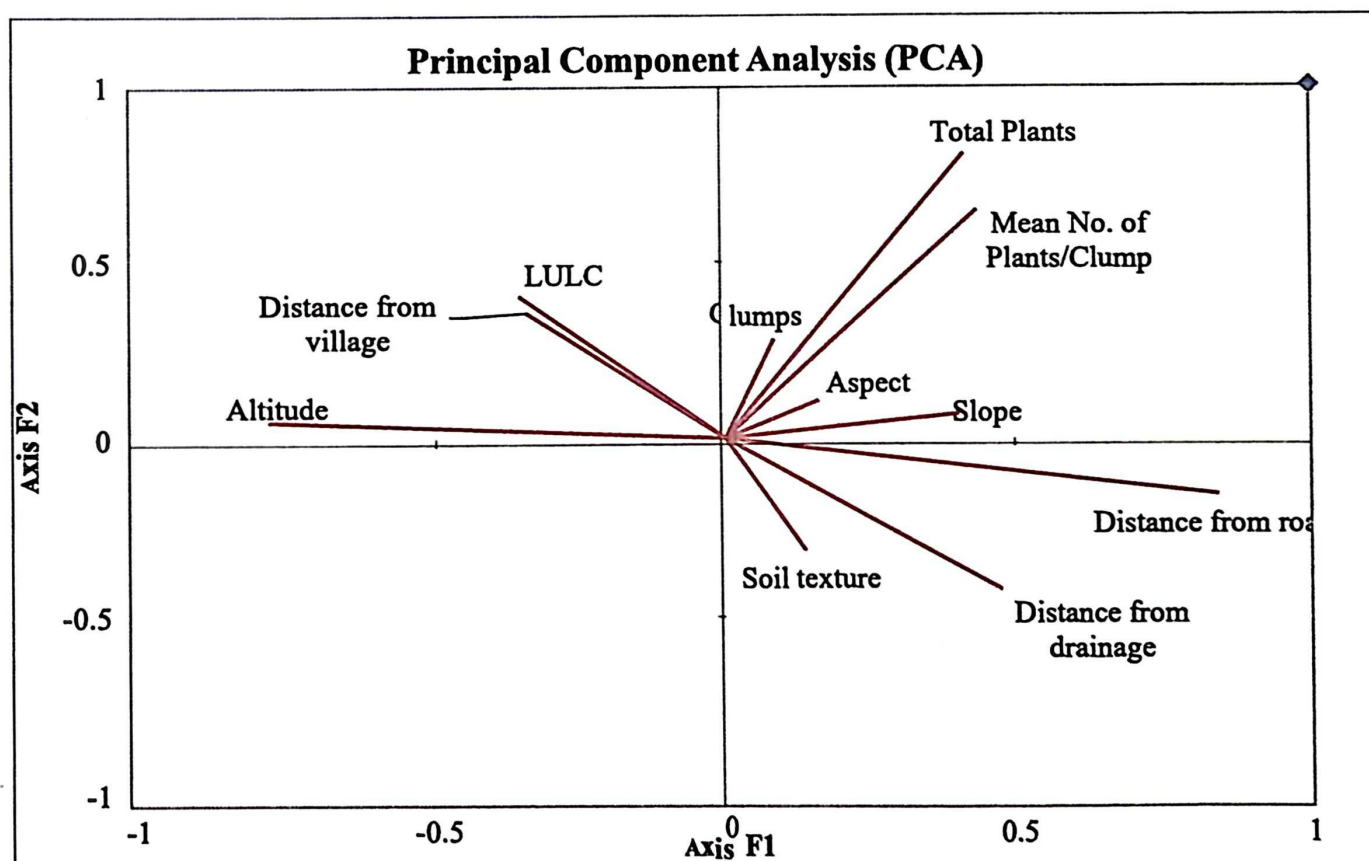


Fig. 3.10: Factors responsible for distribution and invasion of *Ageratina adenophora*

3.5 Conclusion

Plant invasions in the new areas cause huge economic and ecological imbalance by altering native community composition, depletion of species diversity, thus affecting the ecosystem process.

Open areas, forest fringes and degraded fallow lands were more vulnerable to invasion by *Ageratina adenophora* in Gokerneshwer-gad micro-catchment. The increased incidence of invasion at higher elevations poses a major threat to the local biological diversity of the region. The results indicate that environmental variables viz., altitude, soil texture, distance from road and village/settlement, and a water source show a high correlation with the abundance of *Ageratina adenophora*. Areas that have high anthropogenic pressure and are degraded and disturbed are easily invaded by *Ageratina adenophora*. This species readily inhabits such habitats, and their presence is greater in ecosystems under high anthropogenic pressure.

Some profound mitigation techniques and measures are required to check the further distribution of this alien species in the western Himalayan region. The additional distribution of this alien species in the Himalayan region may cause a severe threat to the local biodiversity and a change in the area's ecosystem process, causing loss of vital ecosystem services.

Chapter 4 Invasibility and prediction of future spread by major invasives

4.1 Introduction

Invasive alien plant species (IAPs) rank among the top three threats to global biodiversity. The other two are the unsustainable harvest of various species from the wild and habitat degradation and loss (Early et al. 2016). Invasive species, coupled with unsustainable resource use and climate change, have seriously affected the livelihoods of millions of people in the south and southeast Asia (IPBES 2018). The rapid spread of invasive alien species affects natural habitats, the regeneration potential of native species, and the productivity of forests and grassland habitats (Rai and Singh 2020). The spread of alien species is particularly challenging in terrestrial ecosystems across the world. Changes in climatic conditions and land use practices favour the introduction and spread of IAPs in most parts of the world (Vila and Weiner 2004; Hellmann et al. 2008; Thapa et al. 2018). Therefore, it is vital to assess the current extent and future scenarios of invasion for various IAPS (Kohli et al., 2004; Tylianakis et al., 2008; Sekar, 2012).

The Himalayan region, one of the global biodiversity hotspots, is quite vulnerable due to climate change and other abiotic and biotic drivers of change, including the rapid spread of IAPS. Some of the most obnoxious IAPs in this region include *Lantana camara*, *Mikania micrantha*, *Chromolaena odorata*, and *Ageratina eupatoria* (Pathak et al. 2019). During the past few decades, increasing anthropogenic pressures such as unabated linear infrastructure development, uncontrolled tourism, livestock grazing, agricultural expansion and extraction of non-timber forest products (NTFPs) have led to the degradation of wildlife habitats and spread of a large number of invasive species (Babu et al., 2009). It is estimated that the Indian Himalayan region has over 600 IAPs species and nearly 50% of them are said to have escaped from agriculture and accidental introduction (Sekar 2012). One of the major causes of spread of IAPs in the Himalayan region is climate change. It has been observed that plant species of higher elevation are projected to shift higher. A few IAPs previously limited to the lower elevations are now shifting towards the higher altitudes in the Himalaya (Telwala et al., 2013; Shrestha et al., 2018).

As a signatory to Convention on Biological Diversity, India has set its National Target in alignment with Aichi Biodiversity Targets. Accordingly, India's Biodiversity Strategy and Action Plan aims to identify the priority species of IAPs as well as their invasion pathways so

that appropriate management strategies could be formulated. It is realized that a very few baseline studies have been conducted on the current extent and spread of even common species in the Himalayan region. Anthropogenic pressures coupled with climate change makes complex the future prediction of species spread. Several authors, e.g., Oli & Zomer (2011); Taylor et al. (2012), Goncalves (2014); Uddin et al. (2015) and Mungi et al. (2018) have opined that the IAPS, which were earlier limited to the lower areas are likely to shift towards the higher elevations in the Himalaya. This calls for the validation of earlier models as well as multi-locational studies. In this paper, we present a case study on two IAPS, viz., *A. adenophora* and *L. camara* at a landscape level within Indian part of Kailash Sacred Landscape, hereafter referred to as Kailash Sacred Landscape (KSL) –India. The chapter deals with the potential current spread of these species in KSL–India and predicts their invasion in future climate change scenarios.

4.2 Study Area

The study was carried out in KSL – India that is located between 29°26'35" to 30°35'13" N and 80°01'24"- 81°02'44" E. Administratively, KSL-India falls entirely within District Pithoragarh in the state of Uttarakhand and is characterized by the heterogeneous landscape, wide altitudinal range (ca. 800 to over 7000 m a.s.l.), diverse topography and rich biodiversity (Oli and Zomer, 2011). This area is contiguous with far-western Nepal and Tibet Autonomous Region (TAR) of the Peoples' Republic of China. The study area is spread over 7,120 km² area (Figure 4.1).

KSL – India has the predominance of diverse natural ecosystems from grasslands to moist sub-tropical broadleaved to temperate oak forests, sub-alpine conifers, high altitude birch forests, while extensive alpine pastures occur in areas >3000 to 4000 m a.s.l beside agro-ecosystems in lower reaches (Singh et al., 2011; Singh et al., 2018). The diverse habitats cater to numerous indigenous flora and fauna. Forests in KSL – India fall into two categories - Protected Areas (PAs) and non-protected areas. KSL – India includes only one legally designated PA (*i.e.* Askot Wildlife Sanctuary), which provides important ecosystem services for the region. However, the non-PA category of forests includes reserve forests and protected forests under the control of the State Forest Department of Uttarakhand managed for an extended period for the production of timber and non-timber forest products (NTFPs). KSL – India also includes highly interspersed small forest fragments falling under two broad categories, *i.e.* civil/soyam forests and community forests, under the control of the Revenue

Department of the State Government. For nearly nine decades or so, the latter category of community forests has been managed by the local communities and is referred to as 'Community Forests' or 'Van Panchayat Forests'. This community forest serves as the primary source of livelihood to locals. The KSL – India has experienced a considerable change during recent decades in terms of land use and land cover, along with the development of infrastructure and patterns of natural resources used by the local communities (Singh et al. 2018; Negi et al. 2018).

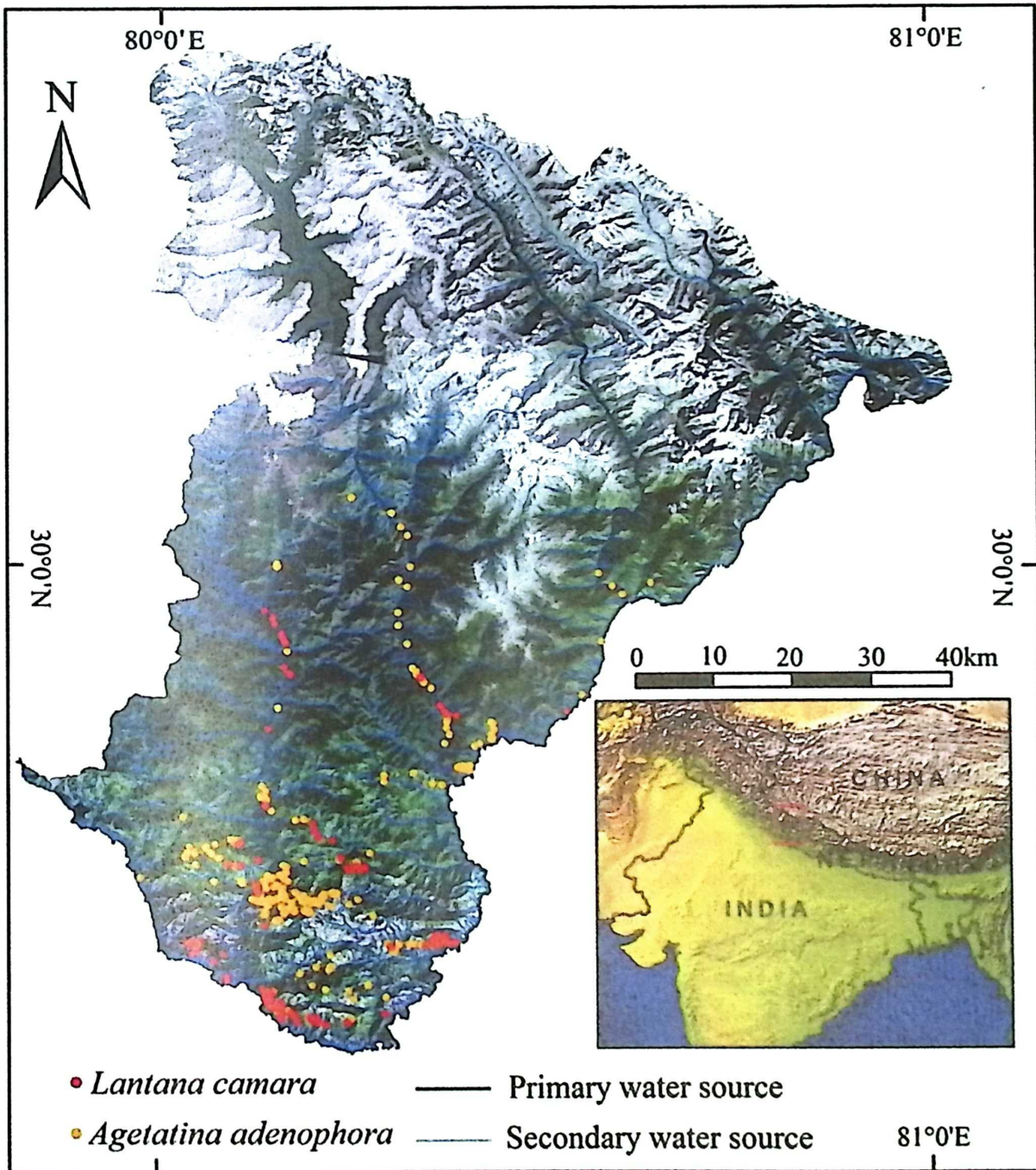


Fig 4.1. Geographical location of the study area with sampling locations of *Lantana camara* and *Ageratina adenophora*.

4.3 Methods

4.3.1 Species presence

After the extensive vegetation survey and local consultation with experts, two most widely spread IAPS were selected for the present study, i.e. *Ageratina adenophora* (Asteraceae) and *Lantana camara* (Verbenaceae). *A. adenophora* is a native of Central America (Datta et al. 2017) and distributed worldwide (Cronk and Fuller 1995). *L. camara*, native to Tropical America (Holm et al. 1977), is considered one of the most troublesome invasive species worldwide (Kohli et al. 2006). *A. adenophora* is a perennial, semi-shrubby herbaceous plant that produces many tiny seeds dispersed by wind and human activities (Sang et al. 2010). Its ubiquitous property to invade diverse habitats, such as roadsides, riverbanks, forest edges, crop fields, wastelands, and rubbish dump edges, makes it fit to invade various ecosystems. *L. camara* is one of India's most widely distributed IAPs (Sundaram et al. 2012), resistant to fire and can regrow if burnt (Hiremath and Sundaram 2005). It reproduces primarily by seeds as well as through coppice and prefers to grow in degraded habitats.

Though the species selected for the study are known to affect the wildlife habitats and native vegetation negatively, they are also known to have a few minor uses to local communities. Leaves of *A. adenophora* are used for cattle bedding (Shrestha 1989), or its leaf paste is applied to cuts and wounds (Joseph & Kharkongor, 1981). The wood of *L. camara* is used as fuel (Sharma et al., 1988), a source of food for birds (Corlett 1998; Aruna & Balasubramanian, 2017) and nectar for butterflies and moths (Day et al., 2003) as it flowers and fruits throughout the year.



Plate 4.1. Field data collection

4.3.2 Presence record

We recorded *A. adenophora* and *L. camara* presence between 400 and 2500 m a.s.l from different ecosystems including agricultural lands, grasslands, fallow lands and forests (e.g. Sal, Chir pine, Bang-Oak, Deodar and mixed), proximity to major road networks and naturally occurring drainages (*i.e.* *Saryu*, *Gori* and *Kali* rivers) in different parts of the landscape during four consecutive years (2014 to 2017). A total of 400 and 250 presence locations for *A. adenophora* and *L. camara* were recorded using handheld Garmin N72 GPS. Of these, 80% of locations were used for probability distribution modelling and the rest 20% were used to evaluate the model performance.

4.3.3 Selection of Environmental and bioclimatic variables

We used two-time periods (“current” and “2050”) environmental data to model the *A. adenophora* and *L. camara* current and future distribution in KSL – India. A total of 22 environmental variables were used for probability distribution modelling in each time period. We retrieved the standard 19 bioclimatic variables for WorldClim version 2 (Fick & Hijmans 2017). These are the average for the years 1970-2000 with a spatial resolution of 30 seconds (~1 km²). These variables are considered as current bioclimatic variables. We also retrieved 19 bioclimatic variables with a spatial resolution of 30 seconds (~1 km²) for the year 2050

(average for 2041-2060). These are the climate projections as per the Intergovernmental Panel on Climate Change (IPCC) 5th assessment report from Global Climate Models (GCMs) for one Representative Concentration Pathways (RCPs). The data was downscaled and calibrated using WorldClim 1.4 as baseline 'current' climate (Hijmans et al., 2005, Fick and Hijmans, 2017). These bioclimatic data are also the most recent GCM climate projections that have already been considered in the IPCC fifth assessment report.

We also considered four major static topographic factors for both the “current” and “2050” time frames. These are elevation (ASTER, Digital elevation data from Advanced Space-borne Thermal Emission and Reflection Radiometer), slope, aspect, Euclidian distance from water channels and euclidian distance from major roads. These variables were assumed to be constant across the entire study period. The details of all the variables used in this study are provided in Table 4.1.

4.3.4 Pair-wise Pearson correlations and Principal Component Analysis

We checked for multi co-linearity with pair-wise correlations for both “current” and “2050” environmental data sets to avoid spurious model calibrations (Guisan & Thuiller 2005). It is common practice to retain only predictors with pair-wise correlation $< |.7|$. (Aguirre-Gutiérrez et al. 2013). To nullify the correlation structure of the variables and inter-relationship among them, we implemented the Principal Component Analysis (PCA; Jolliffe 2002, Cruz-Cárdenas et al. 2014). The PCA reduces the number of orthogonal predictors, each of which is the linear combination of 24 original environmental variables. All the exploratory variables were subjected to PCA to extract the factors of significant contribution using *prcomp* function and used the *predict* function in R version 3.3.3 (R Core Team 2018). Furthermore, we obtained 24 Principal Components (PC) in raster format. For both “current” and “2050” data sets, the first six PCs accounted for 99% of the variability and were chosen for further multivariate species distribution modelling (Table 4.1).

4.3.5 MaxEnt species distribution modelling

Maximum Entropy (*MaxEnt*) distribution modelling was implied to identify the current and future invasion for both *A. adenophora* and *L. camara* in KSL – India. *MaxEnt* is a machine learning algorithm that is widely used for species distribution modelling that uses presence-only data (Phillips et al. 2006; Elith et al. 2011) to predict the potential distribution of a

particular species in the current as well as future climatic scenarios (Loarie et al. 2008; Remya et al., 2015).

The occurrence data from the field was collected for both *A. adenophora* (n = 567) and *L. camara* (n = 120). One thousand background points were drawn randomly across the KSL – India by considering the pseudo-absence of both species. We generated four main *MaxEnt* models (two for each species) using the six PCA derived explanatory variables for both ‘current’ and ‘2050’ years.

We implemented k-fold cross-validation (Peterson et al. 2011) to build each main *MaxEnt* model. Firstly, we used standard k-fold cross-validation in our randomly partitioned approach. In our k-fold cross-validation approach, the occurrence localities were divided randomly into 10 bins, where each bin constitutes an equal proportion of sample size (Boyce et al. 2002; Lehmann et. 2002). Then, each model was developed iteratively, using (k – 1) bins for model calibration in each iteration, with the remaining fold retained for evaluation. This is repeated until all the folds were utilized at least once for model evaluation. *MaxEnt* produces a model based on a series of ‘features’, such as a linear, hinge, quadratic, product, threshold and discrete; we used all except for discrete, as all of our explanatory variables were continuous (Phillips & Dudík 2008). In the ‘feature’ functions, we set the beta multiplier as 0.5 (medium) that affect the smoothness of the model output. We have opted for the clamping function in each model as the function is strongly suggested for projecting future species distributions by both Elith et al. (2010) and Webber et al. (2011).

As we set the models *via* k-fold cross-validation (k = 10), for each dataset, we used the respective evaluation localities to calculate Area Under the Curve (AUC) of the Receiver Operation Characteristic (ROC), which is a measure of the overall discriminatory ability of the model or to precisely evaluate model performance by plotting its model sensitivity graph (Peterson et al. 2008). We averaged those values from each sub-models of each main model and represented the averages for each of the four main *MaxEnt* models. The AUC score closer to 1 indicates that the model had accurately predicted the habitat, while a value ≤ 0.5 indicates the low accuracy of the model (Hanley & McNeil 1982).

Binary habitat invasion maps for the ‘current’ and future ‘2050’ were prepared by using the threshold of maximum training sensitivity plus the specificity logistic threshold. The threshold approach of ‘*Maximum training sensitivity + specificity*’ is a more reliable, restrictive and conservative approach to understand the potential distribution of a species. This particular threshold approach is popular for either presence/absence or presence-only data (Liu et al., 2005). We used ‘*dismo*’ package (Hijmans et al. 2017) in R (R Core Team 2017) along with a

source file developed by Feng et al. (2017) to build all *MaxEnt* models as well as to evaluate their performance.

4.3.6 Invasion across the elevation gradient

To check the future spread of *A. adenophora* and *L. camara*, we extracted all elevational range values from a 30m resolution digital elevation model (ASTER) using the threshold polygons generated from *MaxEnt* main models. Elevational gradients that fall within the distribution ranges were re-classified into multiple classes considering 100 m a.s.l intervals. Area invaded by both species in each elevational class were compared between current and 2050 year using paired sample t-test. The distributions of elevational class vs invaded areas of both *A. adenophora* and *L. camara* were plotted separately for the current year and 2050 year to visually assess their spread pattern across the elevational classes.

4.4 Results and Discussion

The pair-wise Pearson correlations were generally higher ($r > |0.70|$) for most of the variables (Figure 4.2.). We could not use these variables directly in *MaxEnt* as they showed high correlation, which avoids the overprediction of suitability in *MaxEnt* models. However, PCA transformed the 24 environmental variables (each for ‘current’ and ‘2050’) into a composite set of 24 components that are orthogonal and un-correlated to each other. Six out of 24 components demonstrated the cumulative proportion of variance > 0.99 for both current and 2050 years (Table 4.1). The first six PCs, each from the ‘current’ and ‘2050’, were represented in Figures 4.1 and 4.2.

Table 4.1. Representation of the first seven principal components derived from all 24 original environmental variables and the proportion of variance in environmental variables explained by each principal component and their cumulative proportion of variance.

Principal components	The “current” year		Year 2050	
	Proportion of Variance	Cumulative Proportion	Proportion of Variance	Cumulative Proportion

PC1	0.98890	0.98890	0.98880	0.98880
PC2	0.00810	0.99700	0.00810	0.99700
PC3	0.00276	0.99979	0.00277	0.99973
PC4	0.00013	0.99992	0.00015	0.99988
PC5	0.00007	0.99998	0.00008	0.99996
PC6	0.00001	0.99999	0.00003	0.99999
PC7	0.00000	1.00000	0.00000	1.00000

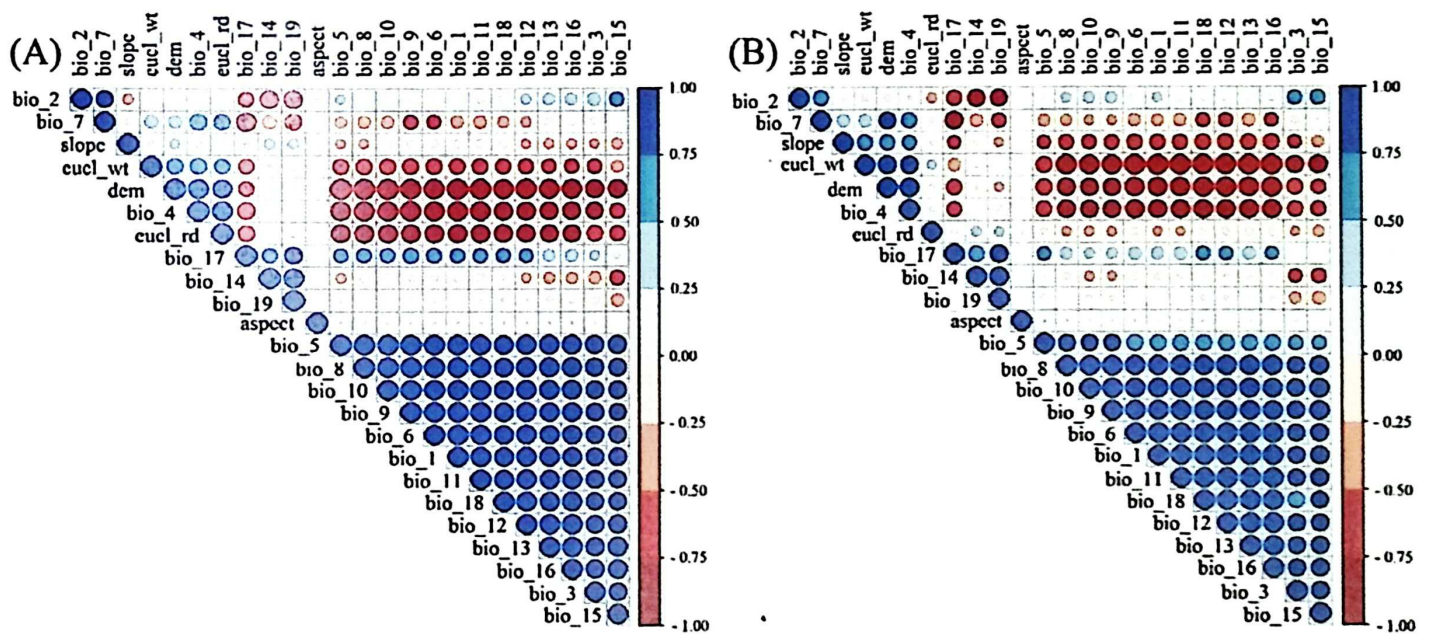


Figure 4.2.: Representation of Pearson correlation matrix for environmental data of the “current” year (A) and year 2050 (B).

Both training and test area under ROC curve (AUC) values were > 0.81 for both species under the ‘current’ and future ‘2050’ climatic conditions (Figure 4.3., Table 4.2). The current occurrence locations of *A. adenophora* and *L. camara* where 95.06% and 92.5% respectively fall within their most climatically suitable current distribution ranges. The relative percent contribution of all PCs from both ‘current’ and year ‘2050’ are presented in Table 4.3, and all response curves associated with the above MaxEnt model predictions were given in Figure 4.3.

Table 4.2. The area under the receiver operating curve (AUC) score of MaxEnt models for both *Ageratina adenophora* and *Lantana Camara*.

Species	The “current” year		Year 2050	
	Test AUC	Training AUC	Test AUC	Training AUC
<i>Ageratina Adenophora</i>	0.81	0.82	0.81	0.82
<i>Lantana Camara</i>	0.93	0.93	0.92	0.93

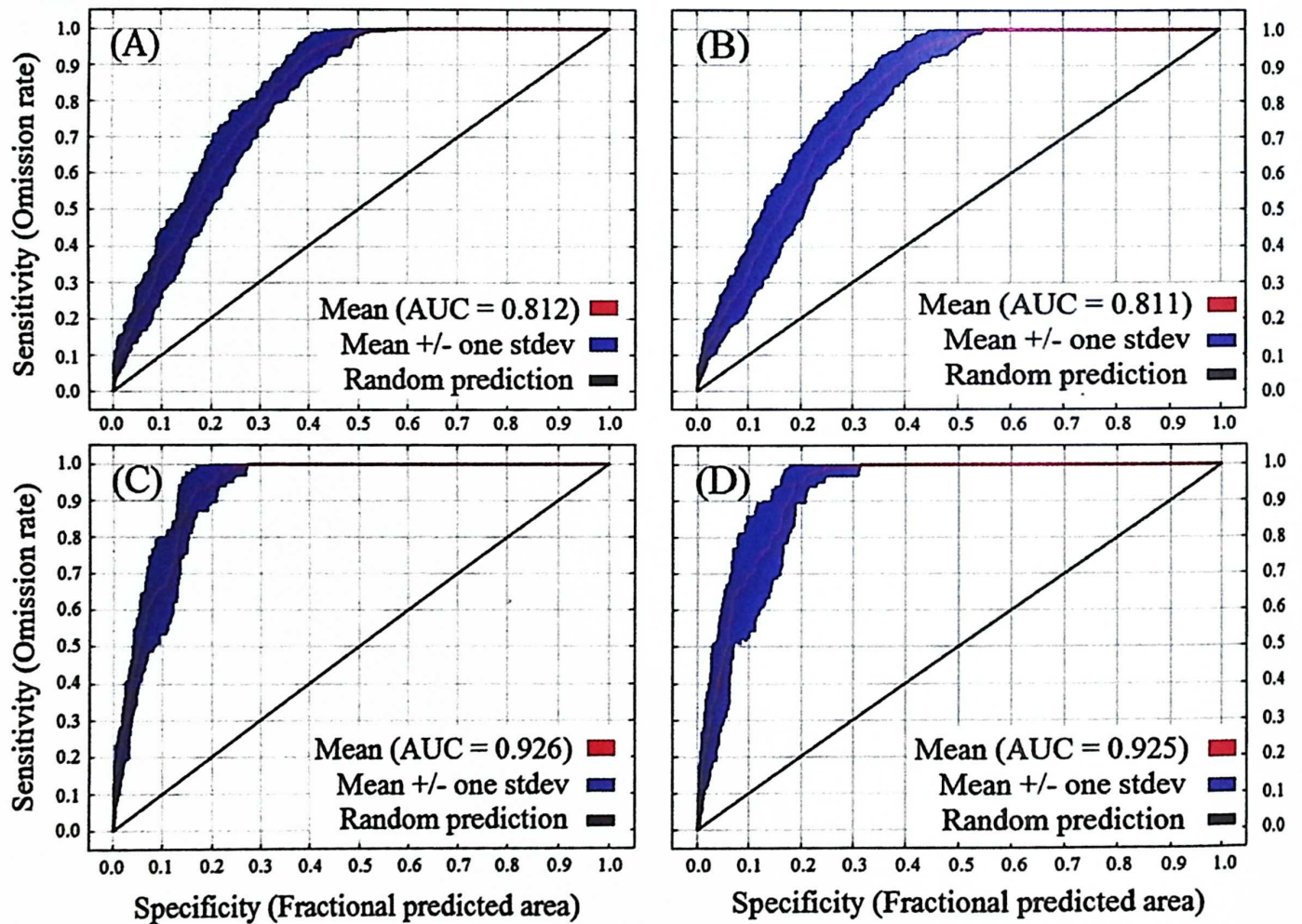


Figure 4.3.: Receiver operating characteristic (ROC) curve for the predicted distribution *MaxEnt* models averaged over the ten replicate runs: *Ageratina adenophora* (the “current” year – A; the year 2050 - B) and *Lantana camara* (the “current” year – C; the year 2050 - D).

Table 4.3. Relative contributions of each principal component are used in all the *MaxEnt* models.

	Contribution of <i>Ageratina adenophora</i> (%)		Contribution of <i>Lantana camara</i> (%)	
	The “current” year	Year 2050	The “current” year	Year 2050
PC1	83.00	86.10	62.8	65.2
PC2	00.00	00.10	0.1	0.2
PC3	01.10	02.40	9.1	15.6
PC4	04.60	04.60	2.1	1.1
PC5	07.30	05.40	16.7	15.8
PC6	04.00	01.50	9.1	2.2

The current and future distributions of the *A. adenophora* and *L. camara* along the elevational gradient of KSL – India are determined by the RCP 8.5 pathway projections for 2050 (Figure 4.4(A)- 4.4 (B)).

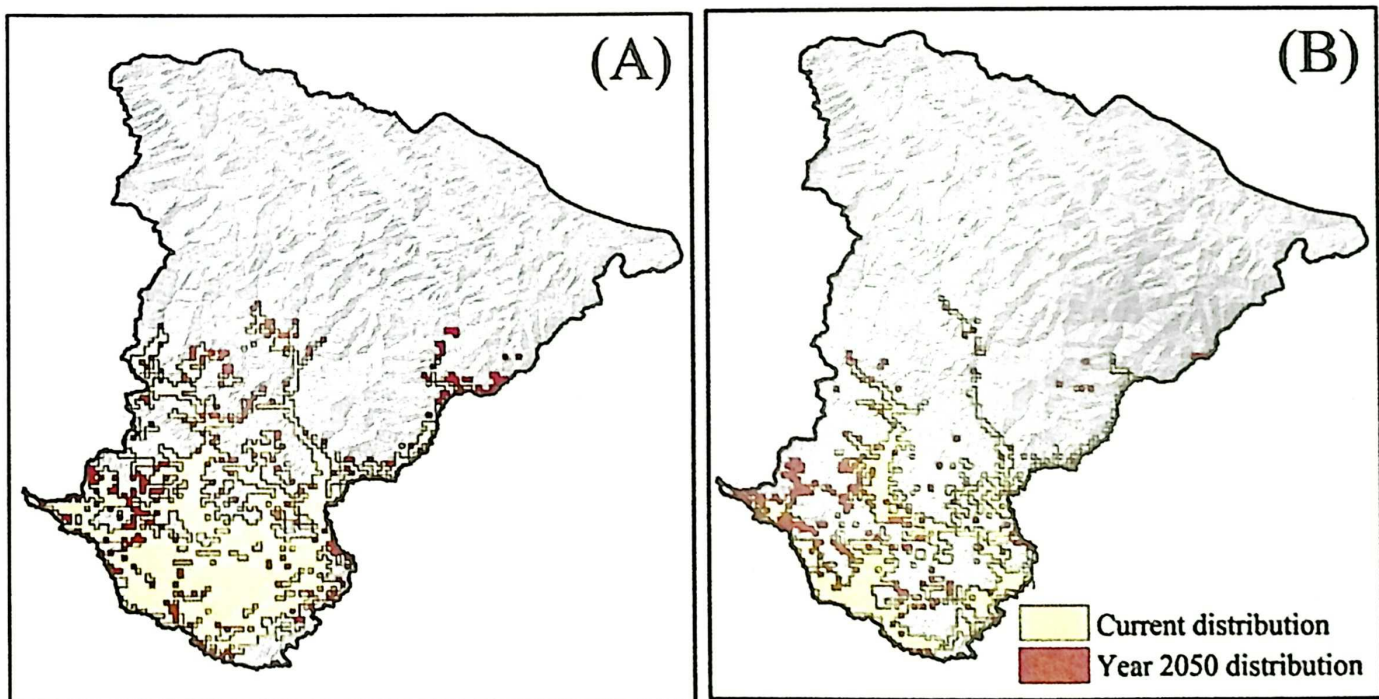


Figure 4.4.: Predicted distribution *MaxEnt* models averaged over the ten replicate runs. Orange and Red polygons represent maximum training sensitivity + specificity logistic threshold for

the distribution of (A) *Ageratina adenophora* and (B) *Lantana camara* in the “current” and year 2050.

The current distribution of *A. adenophora* ranges between 212 - 2616 m a.s.l, where the *L. camara* was distributed mostly below 2045 m a.s.l. The potential area that is currently vulnerable to invasion by *A. adenophora* and *L. camara* extends to 1403.7 km² and 1053.1 km², respectively. If the climate change continues to follow the higher emission RCP 8.5 pathway, by 2050, invasion of *A. adenophora* will reach up to 3029 m a.s.l, whereas *L. camara* will invade up to 3018 m a.s.l. Both *A. adenophora* and *L. camara* will spread across the landscape occupying 2039.7 km² and 1366.5 km² areas, respectively. The area invasion by *A. adenophora* ($t = -7.61$, $df = 28$, $p \leq 0.05$) and *L. camara* ($t = -2.70$, $df = 28$, $p \leq 0.05$) will significantly increase by 2050 year in across all designated elevational class (Figure 4.5.).

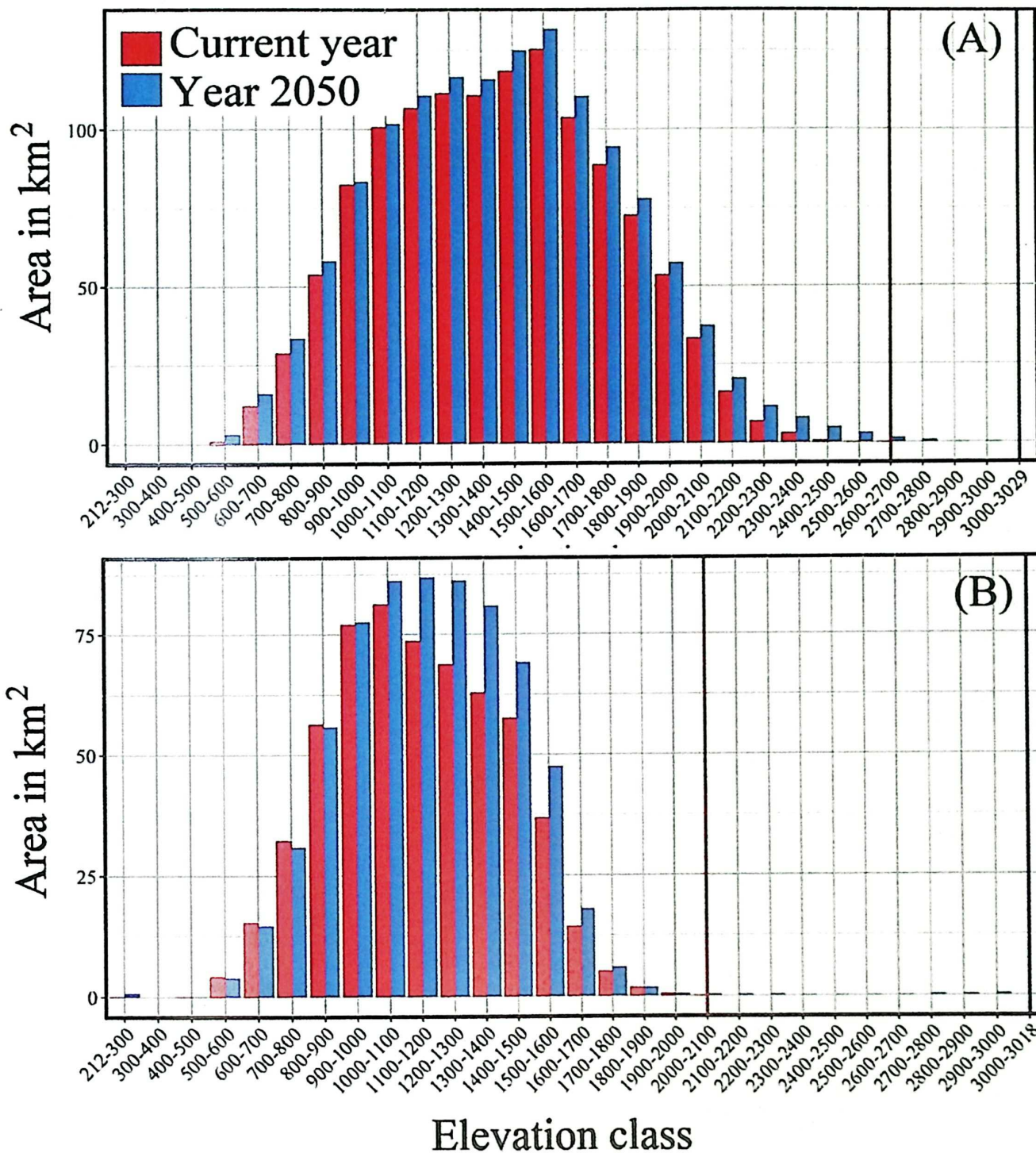


Figure 4.5.: The predicted spread (in Km²) of *Ageratina adenophora* (A) and *Lantana camara* (B) in different elevational classes of KSL – India during the current year and the year 2050.

Plant invasions is the emerging area of science that impacts on substantial economic and ecological imbalance by altering native plant community composition (Gordon 1998) and depleting native plant species diversity (Hejda et al. 2009), thus affecting ecosystem processes (Weidenhamer 2010; Crooks 2002; Dukes and Mooney 2004). The lower and mid ecosystems in the mountains are more vulnerable to invasion by exotic plant species due to the altering

climate change and increasing anthropogenic pressure (Priyanka & Joshi 2013). These plant species also exceeded their ranges and many of them have become abundant at higher elevations (Alexander et al. 2016; Pauchard et al. 2009). The increased incidence of invasion in the high-altitude ecosystems (Thapa et al. 2018) poses a significant threat to the native biological diversity of the region and it is expected to expand in the future (Mungi et al. 2018). The use of new and robust methods, especially combining PCA and *MaxEnt* species distribution modelling will reduce the chance of overpredicting species distribution maps.

This study demonstrated an increasing (both vertical and horizontal) trend of plant invasion in KSL – India. Altering climatic conditions and mostly increased temperature have provided favourable conditions for the invasion and spread of these species in the KSL-India. Joshi et al. (2018) already demonstrated that *L. camara* occurrence was recorded widely in dry and exposed slope, forest fringes and deep forests throughout their study sites in the Indian butter tree (*Diploknema butyracea*) forest, which is one of the economically, spiritually and culturally significant trees in the region with its great importance for local livelihood. Looking forward, *L. camara* might also affect the regeneration of such economically important trees in the area. Elevation was the most crucial factor in the current and future distribution. It appeared that in future, both of these IAPS would colonize more vigorously in the landscape where currently they are not present. This invasion of both species is likely to happen if climate change continues to follow the higher emission RCP 8.5 pathway. Furthermore, *L. camara* will spread within a similar altitudinal range where it is currently absent. According to Singh et al. (2016), *A. adenophora* prefers north-facing moist slopes along roadsides, forest fringe, cliffs, near water bodies, including agricultural and degraded lands and sub-tropical and warmer temperate landscapes. It also invades natural habitats, Deodar, Banj oak- Chir pine and mixed forests, degraded grassland areas and sometimes invading pure stands of pristine temperate broadleaved oak (*Quercus leucotrichophora*) forest representing climax vegetation between 1000 – 3500 m a.s.l in KSL – India. Our study also showed a similar trend, as this species will reach 968 m a.s.l higher than its current distribution range.

Our predictive models also depicted high infestation and expansion in the present climatic scenario by *A. adenophora* and *L. camara* in the lower parts of KSL – India in western Himalaya. The MaxEnt model also predicted that the landscape provides more suitable conditions for the infestation of *A. adenophora* as compared to *L. camara*, even at its current climatic condition. Both the species will expand their habitats with the increase in temperature and human activity in the landscape. Our study demonstrated similar results as compared to

previous studies (Reese et al. 2005; Hernandez et al. 2006; Wisz et al. 2008), but in a more robust and spatially explicit manner.

4.4.1 Comparative distribution and threat

Lantana occurrence was recorded in abundant lands and in dry and exposed slope, forest fringes, and deep forests throughout the study sites. Sal forest cheura (Indian butter tree) Cheura is one of the economically important and has a mystical and cultural significance along with livelihood association of the Van-Rajis (Himalayan communities) which are amongst the most ancient primitive vulnerable tribes (PVTs) of India with inhabitants of about 700 in Uttarakhand. Cheura is indigenous to the sub-Himalayan tracts of India, Nepal Bhutan and China (Brandis 1906) altitude ranging from 300 to 1500 meters which is a suitable habitat for *Lantana*. Elevation was the most important factor in the distribution of *Lantana* as with the decrease in elevation and increase in anthropogenic activities (fire landslide roads and landslide), the distribution of *lantana* increases. In comparison, *Ageratina adenophora* prefers north-facing moist slopes along roadsides, forest fringe, cliffs, near water bodies, roadside, including agricultural and degraded lands and sub-tropical and warmer temperate regions of the landscape. It also invades natural habitat. Deodar oak-pine grasslands are degraded and is invading in pure stands of pristine forests or the temperate broadleaved oak (*Quercus* spp.), representing climax vegetation between 1000 - 3500 m (Singh et al., 2016) of the KSL as well as mixed forests in the landscape.

4.4.2 Comparing with other studies

The model depicts high infestation of *Ageratina adenophora* and *Lantana camara* in the lower parts of the landscape. Both the species show a vigorous expansion in the present climatic scenario of the landscape in the western Himalayas. The *maxent* model predicts that the landscape provides more suitable conditions for the infestation of *Ageratina adenophora* as compared to *Lantana camara*. Both the species are expanding their habitat with the increase in temperature and human activity in the landscape.

This study shows similar results with earlier studies that stated that increasing sample size model performance escalates whereas variability in predictive accuracy descends (Reese et al., 2005; Hernandez et al., 2006 Wisz et al., 2008). (Thapa et al. 2018) does not show the distribution of these two invasive species in the lower part of the landscape where the invasion rate is high by both the species in the landscape which may be due to less sampling points and topographic factors as the points were laid near the boarded of the two countries.

4.5 Conclusion

In the future, these species are expected to invade deeper inside the forest and other natural ecosystems, causing loss of native biodiversity and a decline in ecosystem services of the study area. The predicted results from modelling suggest that in the future, the KSL landscape will be largely affected by the gregarious presence of *Ageratina adenophora* and *Lantana camara*. Our study also highlights the potentially vulnerable area for the invasion of *Ageratina adenophora* and *Lantana camara* in the KSL-India. In the future, the dispersal range of these invasive species will magnify vertically and horizontally to the north and south aspect of KSL-India. The further distribution of these alien species may cause a serious threat to the local biodiversity and a change in the pristine ecosystem process of the area. Our model predicted and identified probable hotspots for invasion. Most of the range extension of the IAPS will be in the three-forest type's viz., lower temperate, temperate forest, temperate conifer forest. This will put these pristine ecosystems under the intimidation of resource scarcity. Identification and long-term monitoring of degraded habitat and eco-restoration of degraded habitats by the native fodder species, along with capacity building and awareness generation among local communities, should be made to mitigate the impact in future. The locals require action research to manage the van panchayats and the forest department to manage the reserve forests in the KSL- India landscape. Intervention at lower altitudes should be initiated to stop the infestation of these invasive plants at higher landscape regions. Distribution maps can be useful for community awareness and formulation of appropriate long-term management strategies for IAPs invasion from hotspots and areas at risk of becoming climatically suitable for invasion under future climatic scenarios. The map, therefore, can be used for risk mitigation enforcement by field managers.

Chapter 5 Local knowledge and perception about invasive alien plant species

5.1 Introduction

The importance of human views of nature and the environment for environmental management and conservation is increasingly recognised. Humans play a crucial role in influencing and adapting to environmental change processes (Christie et al., 2017).

Understanding people's perceptions are important to understand behaviour better and developing effective management strategies to preserve, protect, and improve biodiversity, ecosystem services, and human well-being. Biological invasions are widely heralded as the second important agent after habitat destruction for species endangerment and extinction (Wilcove et al., 1998). Invasive alien species modifies habitat (Tripathi et al., 1981; Kandwal et al., 2009); aquatic or terrestrial (Gordon 1998), influences ecosystem services (Charles & Dukes, 2008), replace fodder grasses and other medicinal plants (Bughani & Rajwar, 2005), favours other alien species over endemic species (Dobhal et al., 2011), predate native species (Manchester et al., 2000), inhibit seed germination (Bhardwaj et al., 2014), decrease in the nutrient content of the soil (Bhatt et al. 1994) and cause homogenization of natural habitats (Dar & Reshi 2015). Being a threat to biodiversity and ecosystem services, invasive species have a significant socio-economic effect as they decrease the economic gain from forest (Larson 2007), agriculture (Wijeratne, 2015) and fisheries (Cambray, 2003), deteriorate water quality (Chamier et al., 2012), cause habitat fragmentation (Raghubanshi and Tripathi, 2009), and contribute to the spread of disease (Mack & Smith 2011). The Himalaya is a repository of unique and threatened floral and faunal diversity (Sharma et al., 2016). It plays an important role in fulfilling the daily needs of the inhabitants, like fuel, fodder, timber, agricultural implements, edible fruits and medicinal plants (Samant, 2006; Badola 2010; Bhat et al., 2013; Aryal et al., 2018) and is extremely vulnerable to climate change, anthropogenic pressure along with biological invasion (Adhikari et al. 2015; Negi et al. 2018, Mungi, 2018; Thapa et al. 2018). Two hundred ninety-seven (297) invasive plant species have invaded the Indian Himalayan region dominated by genera *Ipomoea*, *Solanum*, *Cassia*, *Indigofera*, *Corchorus*, *Datura*, *Euphorbia*, *Physalis*, *Blumea*, *Chenopodium* and *Opuntia* (Sekar 2012, Sekar et al., 2015, Pathak et al., 2019). Kailash Sacred Landscape (KSL) is in the western part of Himalaya and spreads over an area of 31000 km² nearly 7100 km² falls within Indian Territory (Zomer and Oli, 2011)) predominantly represented by Pithoragarh district (6,818 sq km)

with an altitudinal range from 212 to 6851 masl. It is a fragile ecosystem with diverse habitats; grassland, moist sub-tropical broad-leaved forest, temperate oak forest, sub-alpine conifers, high altitude birch forest, alpine pastures, along with agro-ecosystem (Hussain et al. 2018). Invasive Alien Species was highlighted to impact tree regeneration, forage production in rangeland, native forage species, non-timber forest product habitat, and the cost of crop production in Nepal (Shrestha et al. 2018) and KSL India (Chaudhary et al. 2019).

In the Indian part of KSL, studies on invasive species are restricted to determine status and distribution, impacts, and management strategies (Lamsal et al. 2018, Thapa et al. 2018, Chaudhary et al. 2019). Understanding the social and cultural perspectives in research on invasive species and considering biological invasions as social-ecological phenomena is crucial for successful management, both socially and ecologically (Kueffer 2013). However, studies on knowledge and perception about IAPs are rudimentary in Kailash Sacred Landscape (Mandal and Joshi 2014, Paudel 2015, Shrestha et al. 2018). The present study was conducted with the aim to 1) determine the magnitude to which locals perceive plants invasion as a problem 2) determine knowledge perceive impacts and management of IAPS in two watersheds of Kailash Sacred Landscape. This will aid in the avoidance and mitigation of conflicts, the implementation of prioritisation strategies, the improvement of stakeholder participation platforms, and the implementation of control measures.

5.2 Study area

The present study was carried out in Kailash Sacred Landscape (KSL)-India, Pithoragarh (30.0815° N, and 80.3659° E) in the western Himalayas is located in the north-eastern part of Uttarakhand state of India (Fig. 1). Tibet bounds the district on the north, Nepal on the east, District Champawat on the south, and Chamoli on the west. The whole of the area of the district sprawls in the ragged terrain of the mystic Himalayas with an elevation ranging between 350 m and 7000 masl. The district's temperature largely depends upon the aspect and elevation that range between 30.3⁰ C and -1.7⁰ C. Precipitation is in the form of snowfall in the northern portion of the district during rainfall (1296.6 mm) in the southern part of the district. Six rivers viz., Saryu, Ramganga, Gawri, Kali, Dhauli and Kuti pass from the district. The district has 205,299 hectares of forest which are represented by moist sub-tropical broad-leaved, temperate oak forest, sub-alpine conifers, high altitude birch forest and alpine pastures (ICIMOD KSL India Feasibility Report 2010). The total population of Pithoragarh is about 483,439 (Census 2011). The district has been identified as a part of ecologically diverse, biologically rich and culturally significant Kailash Sacred Landscape (KSL). The current chapter deals with research

in two sub-watersheds, Chandak-Aunla Ghat and Hat-Kalika, in the southern section of the Pithoragarh district, which is part of the Kailash Sacred Landscape (KSL)-India. Chandak-Aunla Ghat (29°37'0.36" N and 80° 9'42.05" E) at an elevation ranging between 607 and 2119 masl encompasses an area of 23.23 Km² in Bin block. The chief forest types in the area are Temperate broadleaf (Oak) and Sub-tropical Temperate Conifer Chir Pine. There are 12 Gram Panchayats and 28 revenue villages, accommodating 1,774 households with an overall population of 7534 (3676 male and 3858 female). Hat-Kalika watershed (29°39'-22.99' N and 080°03'- 38.93'E) encompassing an area of 36.68 km² supports Temperate Broad Leaf mixed conifer (Banj- Oak, Chir-Pine) and Sub-tropical/Temperate Conifer (Chir-Pine) forests at an elevation 625 -2150 masl.

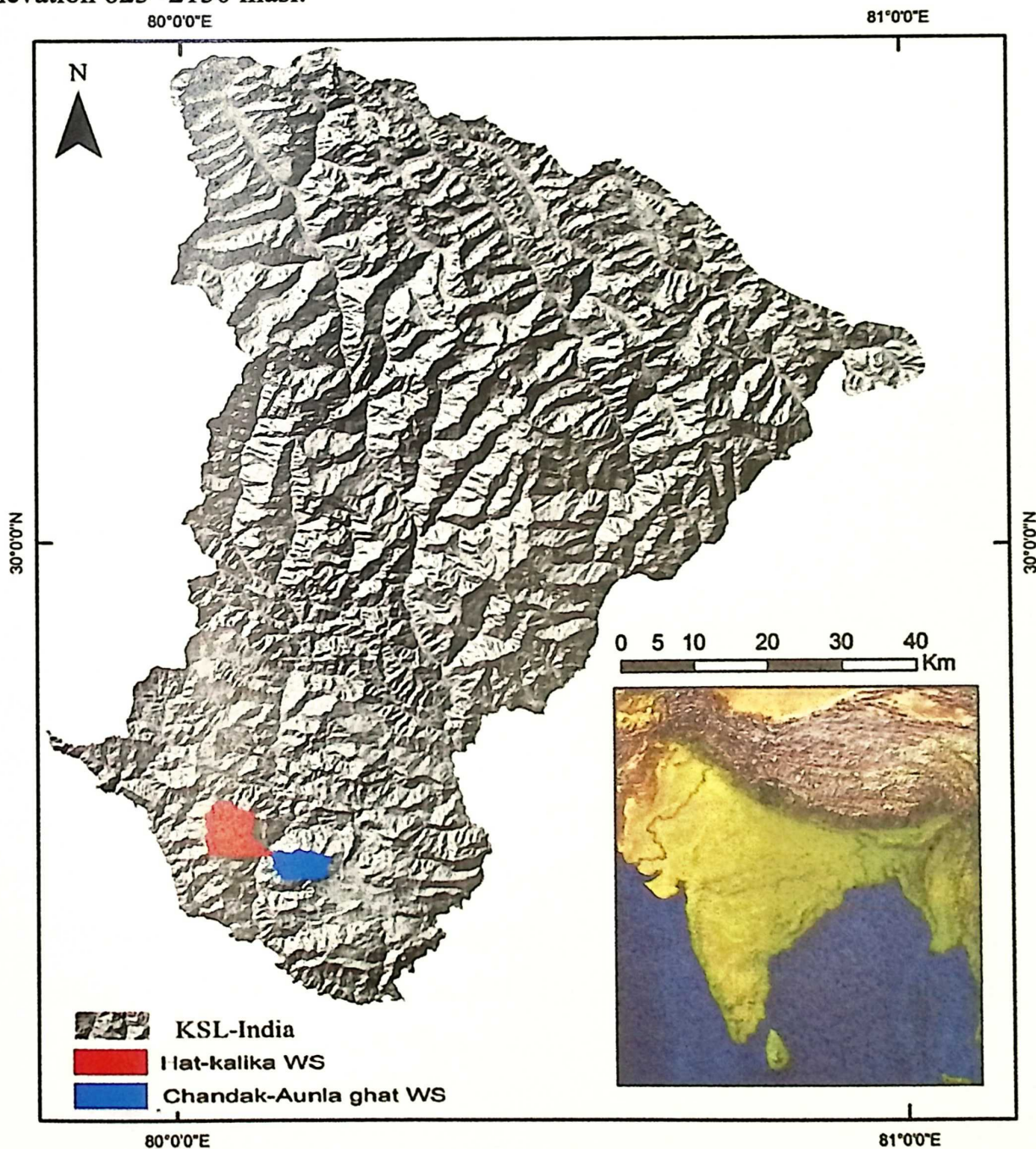


Figure 5.1. Map showing the study sites.

5.3 Methodology

Between April 2016 and June 2018, 701 randomly chosen families in 45 villages were questioned to determine their knowledge and perception of invasive alien plant species (Chandak-Aunla Ghat: 329, Hat-Kalika: 372). Questions regarding existing invasive plant species, the introduction of AIP's, establishment, spread, impacts, usage and management measures were asked to adult males (30-90 years), females (25-75 years) and Students (>18 years) using semi-structured open-ended questions. A vegetation survey supplemented the surveys to determine the presence of invasive alien plant species.

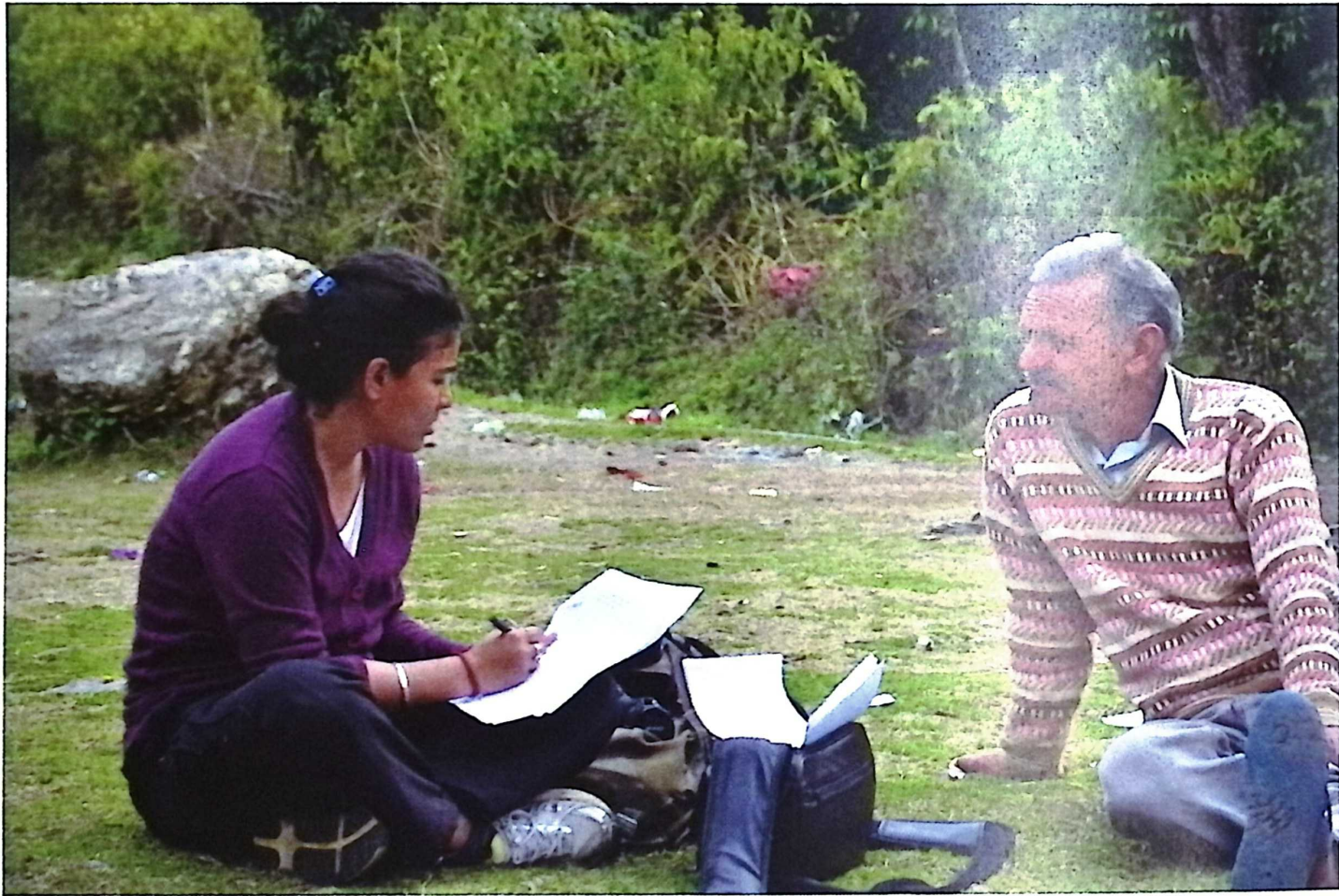


Plate 5.1. Questionnaire survey with the locals

5.3.1 Data Analysis

To determine the most known invasive alien plant species and knowledge richness about the invasive species, two quantitative index; Relative frequency of Citation (RFC) (Vitalini et al. 2013) and Knowledge Richness Index (KRI) (Araújo et al., 2012), were used.

The formulas for calculating both indices are as follows:

$$RFC = FC_i / N$$

$$KRI = 1 / \sum J^2$$

$$J^2 = FC_i / FC_n$$

Where,

FC_i = number of informants mentioning the i^{th} invasive alien plant species,

N = total number of informants participating in the survey,

FC_n - Total record of invasive alien species (S_i) cited by the community.

The value of RFC range between 0 and 1, 0 reflect respondents have no knowledge, and 1 indicate better knowledge of invasive alien plants species. The KRI values range from 0 to infinity, where lower values indicate a higher knowledge of Invasive Alien Plant Species and vice-versa.

5.4 Results

5.4.1 Knowledge about IAPs

With an average knowledge of 2.7 ± 0.03 species, the respondents reported a total of 14 species of IAPs plants in the study area (Chandak-Aunla Ghat: 14 species, Hat-Kalika: 9 species) (range 1-5 IAPs). More than half the respondents in watersheds (58%) were aware of IAPs. However, the knowledge was found to be more in Chandak-Aunla Ghat (82%) than Hat-Kalika (37%). Our outcomes showed that 99% of respondents were familiar with at least one IAPs. The awareness was observed more in females (49%) than males (37%) and students (12%) (Fig 5.2.). *Ageratina adenophora* was the most cited IAPs (RFC: 0.51) and it was followed by *Lantana camara* (0.17) and *Ageratum conyzoides* (Table 5.1). The Knowledge Richness Index (KRI) of the study area was recorded to be 0.03 and it was more in Chandak-Aunla Ghat (0.05) than Hat-Kalika, which indicates that the informants of Hat-Kalika showed a low richness of knowledge and sharing with the members of their families in comparison to Chandak-Aunla Ghat (Table 5.2). Further, females have a higher knowledge of IAPs in both Chandak-Aunla Ghat and Hat-Kalika.

Respondents having knowledge of IAPS

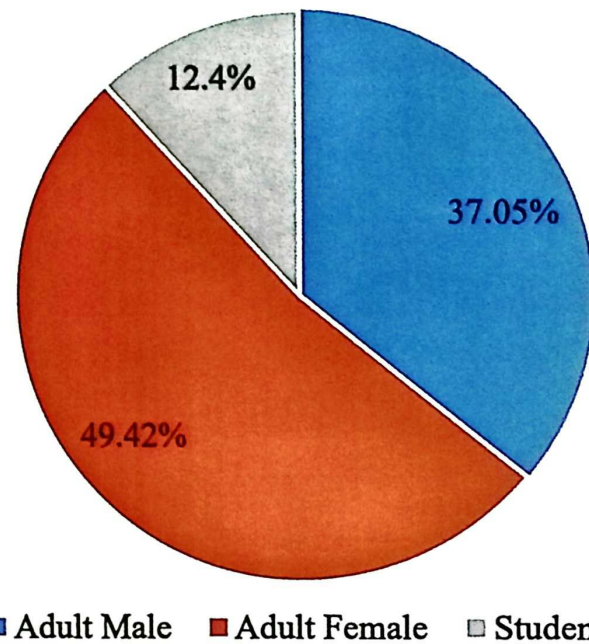


Figure 5.2.: Percentage of male, female and Students having knowledge of IAPs in Pithoragarh, Uttarakhand

Table 5.1: Relative frequency of citation of various Invasive Alien plant species in two watersheds of Pithoragarh, Uttarakhand

Invasive Alien Plant Species	Family	Life form	Chandak-Aunlaghat Watershed	Hat-Kalika Watershed
<i>Calotropis procera</i>	Asclepiaceae	Perennial woody shrub	0.01	0.00
<i>Conyza sumatrensis</i>	Asteraceae	Annual herb	0.02	0.00
<i>Erigeron bonariensis</i>	Asteraceae	Herb	0.02	0.00
<i>Xanthium strumarium</i>	Asteraceae	Annual herb	0.08	0.26

<i>Ipomoea carnea</i>	Convolvulaceae	Shrub	0.11	0.02
<i>P. hysterothorus</i>	Asteraceae	Annual herb	0.11	0.01
<i>Erigeron karvinskianus</i>	Asteraceae	Perennial herb	0.12	0.11
<i>Sonchus asper</i>	Asteraceae	Annual or biennial herb	0.18	0.00
<i>Solanum viarum Dunal</i>	Solanaceae	Bushy, prickly herbaceous perennial	0.24	0.00
<i>Bidens pilosa</i>	Asteraceae	Herbaceous annual herb	0.35	0.09
<i>Oxalis latifolia</i>	Oxalidaceae	Perennial herb	0.42	0.52
<i>Ageratum conyzoides</i>	Asteraceae	Annual herbaceous weed	0.44	0.34
<i>Lantana camara</i>	Verbenaceae	Woody shrub	0.52	0.54
<i>A. Adenophora</i>	Asteraceae	Perennial shrub	0.57	0.47

Table 5.2: Knowledge richness Index among various groups in Pithoragarh, Uttarakhand

Groups	Chandak-Aunlaghat	Hat-Kalika	Pithoragarh
Male	0.14	0.27	0.09
Female	0.11	0.16	0.06
Students	0.49	0.85	0.31
Overall	0.05	0.09	0.03

5.4.2 Perception about impact IAPs

Respondents in Chandak-Aunla Ghat rated biological invasion as a major environmental problem, while of Hat-Kalika believed habitat loss as a major environmental problem (Fig 5.3.). Most respondents in the study area perceived IAPs negatively (99%). In Chandan-Aunla, respondents perceived native species loss (19.8%), an increase in a wildfire (18.5%), and a decrease in the water table (15.2%) as the effect of invasive species. The major perceived negative impact of IAPs in Hat-Kalika includes native species loss (15.4%), decrease in the water table (14.6%) and change in ecosystem stability (Fig 5.4.).

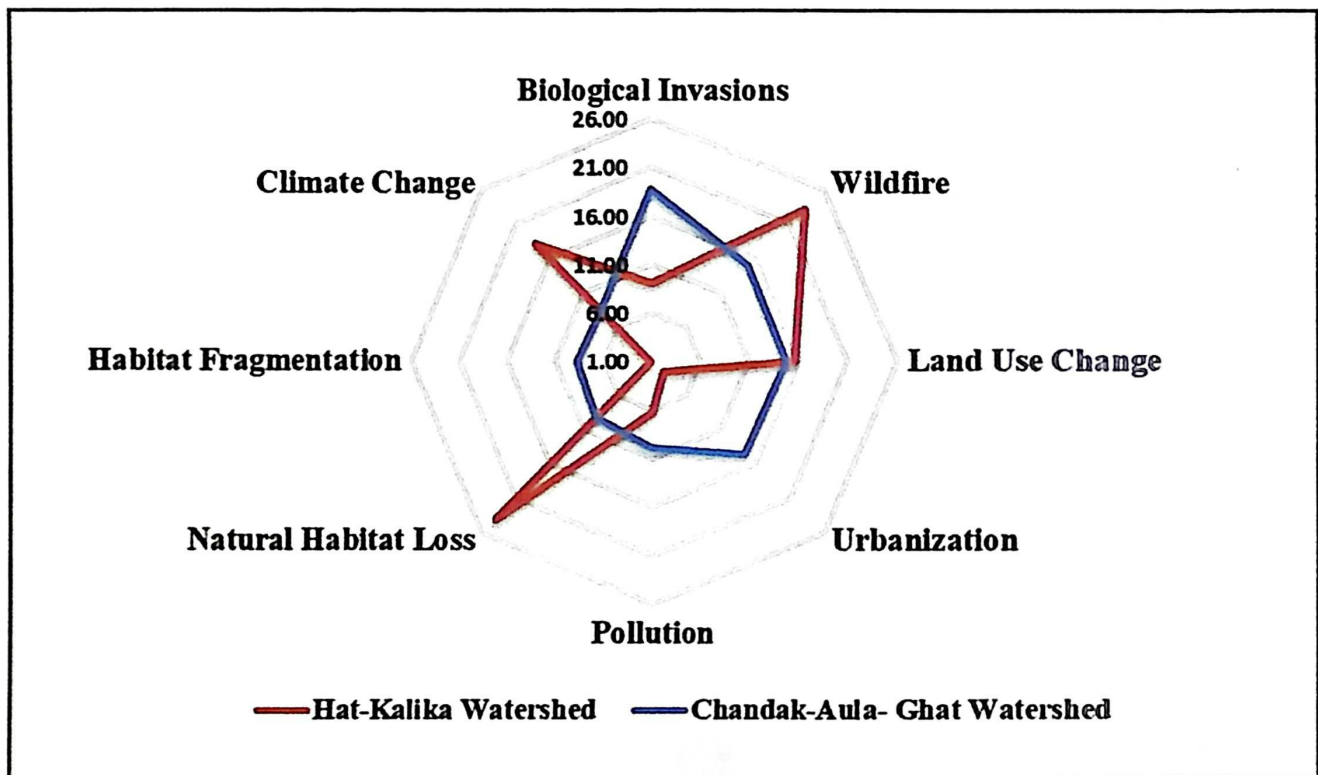


Figure 5.3.: Perception of the people to various environmental problems in Pithoragarh, Uttarakhand

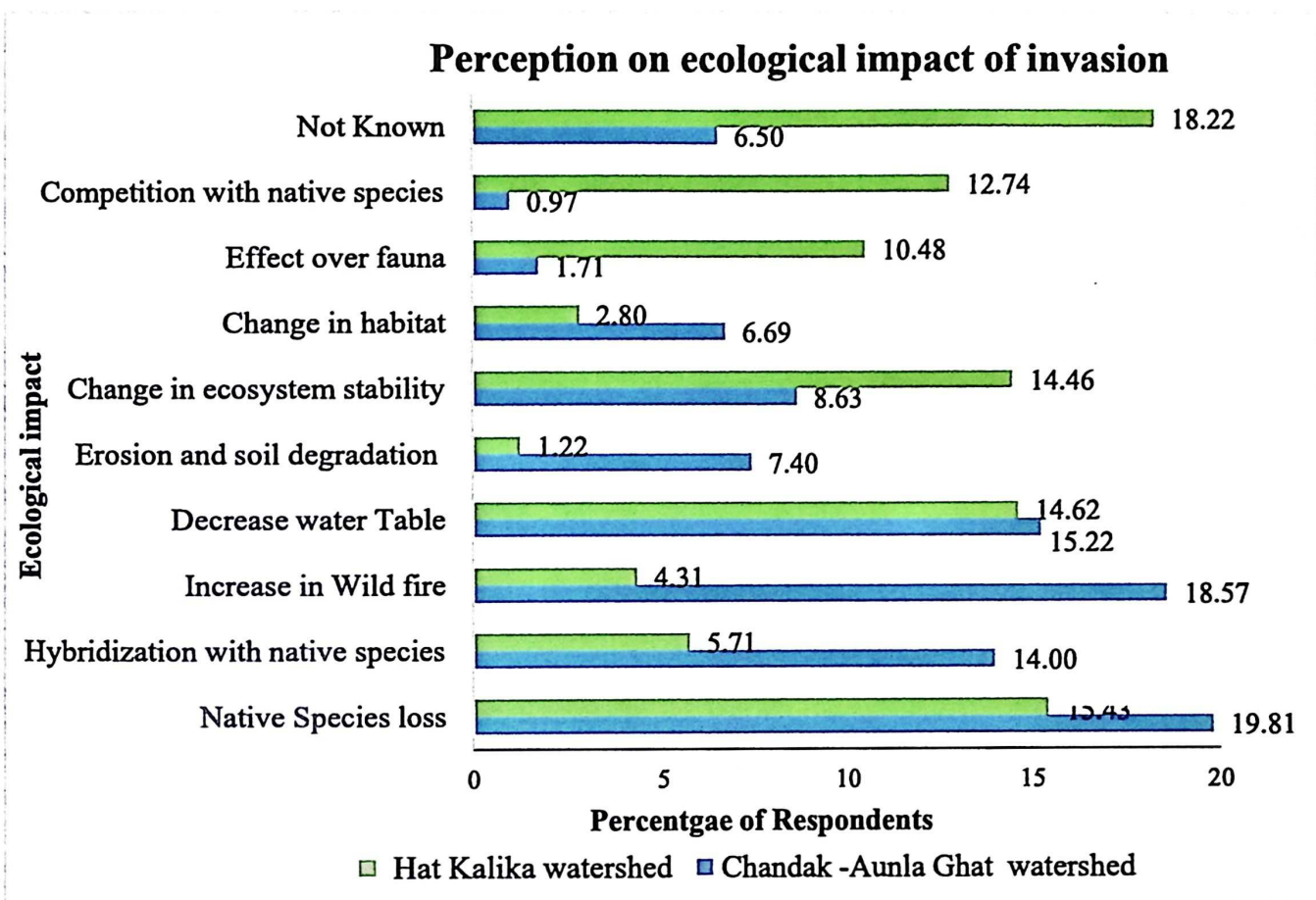


Figure 5.4.: Perception of respondents on the ecological impact of invasion

5.4.3 Use and perceived management of *Ageritina adenophora*

Although most respondents perceived IAPs negatively, many still recognise the importance of *Ageritina adenophora* (50%). The provision for blood clotting was the most common perceived use (25.8%), followed by the bedding of animals (12%) and grazing by goats (Fig 5.5.). Managing of IAPs was perceived positively in the study area, and 70% of the respondents agreed that management of IAPs is compulsory to conserve the environment and protect biodiversity. Most respondents in Chandak-Aunla Ghat perceived restoration (40%) and eradication (27%) as a major management strategy for IAPs. In Hat-Kalika, on the other hand, the respondent saw eradication (35%) and education and information (22%) as the best ways to manage IAPs (Fig 5.6.).

Overall use percentage

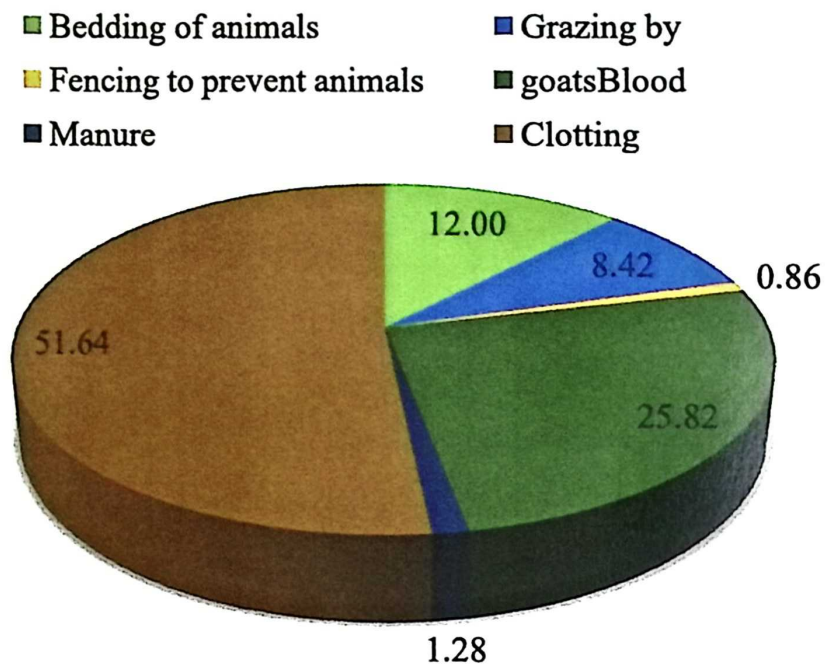


Figure 5.5.: Various uses of *Ageritina adenophora* by respondents in Pithoragarh, Uttarakhand

Perception about management strategies

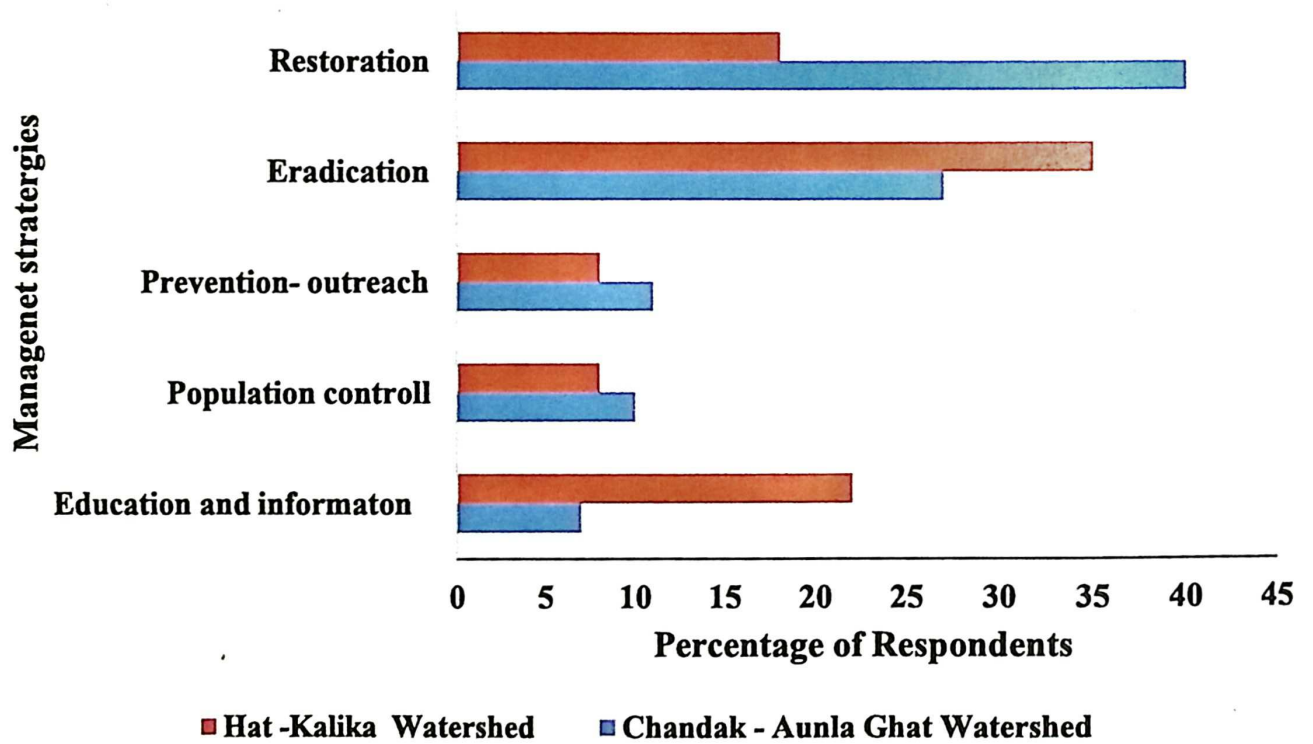


Figure 5.6.: Management strategies for invasive alien plants species in Pithoragarh, Uttarakhand

Table 5.3: Knowledge and perception of people towards the invasive alien species of KSL

Knowledge and Perception	Watershed	
	Chandak-Aunla Ghat Watershed	Hat-Kalika Watershed
KNOWLEDGE		
Priority for biological invasion	High	Medium
Priority for management	81%	36%
No. of Invasive Alien Plant Species reported	14	9
Major Invasive Alien Plant Species		
<i>Ageratina adenophora</i>	31.5%	65.00%
<i>Lantana camara</i>	25.0%	10.89%
<i>Ageratum conizoids</i>	10.8%	6.00%
<i>Parthenium histophorus</i>	0.9%	7.59%
Year of invasion	20 years	10 years
Knowledge richness index (KRI)		
Management activities		
Uprooting	51.67%	10.48%
Burning	36.47%	5.38%
Cutting	9.12%	3.76%
Impact of invasion		

Economic	25.00%	1.21%
Human health	24.85%	30.44%
Social	24.77%	13.31%
Ecological	24.47%	22.78%
<i>Use of invasive plants</i>		
Medicinal value	50.24%	21.41%
Bedding	26.41%	2.14%
Feeding	18.84%	0.2%
Manure	2.51%	0.8%
No use	1.39%	58.60%
Fencing	0.61%	1.22%
PERCEPTION		
<i>Major ecological impacts</i>		
Species loss	19.76%	15.43%
Hybridization with native species	18.97%	3.76%
Increase in fire hazard	18.91%	2.31%
decrease water quality	13.98%	14.62%
<i>Environmental problem</i>		
Biological invasions	18.79%	7.99%
Wildfire	15.03%	23.92%

Land use change	14.85%	3.99%
Urbanization	14.48%	3.89%
Natural habitat loss	9.1%	40.10%
Climate change	8.4%	18.10%
<i>Management and Strategies</i>		
Management required	80%	55%
<i>Management strategies</i>		
restoration	60.2%	22.1%
eradication	25.8%	12.7%
education and information activities	5.6%	55.18%
Impact of invasion in their watershed		
Loss of agriculture	30.14%	22.58%
Loss of grass and fodder	26.88%	41.40%
Degrade and deplete water quality	19.60%	4.57%
Degrade soil quality	10.72%	8.87%
Health problem	12.6%	11.56%

5.5 Discussion

About 40% of the species in the Indian flora are alien, of which 25% are invasive (Raghubanshi et al., 2005). The reported IAPs species in Kailash sacred landscape is about 4%, and 7.3% of IAPs found in Himalaya and Uttarakhand, respectively (Sekar et al. 2012, Pathak et al., 2019). Of the 14 IAPs, *Ageratina adenophora*, *Lantana camara* and *Ageratum conyzoides* were the

most cited IAPs species in both the watershed. *Lantana camara*, *Ageratina adenophora* and *Ageratum conyzoides* are widely distributed and more rapidly proliferating alien plant species in Uttarakhand (Pathak et al., 2019). Among all the IAPs mentioned by respondents, *Ageratina adenophora* had the highest RFC value. *Ageratina adenophora* is an aggressive, rapidly spreading IAPs, have recently been reported at an elevation ranging between 2800 and 3000 m in Uttarakhand (Pathak et al., 2019). A high abundance of *A. adenophora* suppresses the growth of the seedlings of native canopy trees (Fu et al., 2018). Hence, the high citation value of the *Ageratina adenophora*, *Lantana camara* and *Ageratum conyzoides* implies that such species have invaded the area, posing a severe threat to the unique plant diversity and medicinal plants under future climate change scenario.

Respondents in Chandak-Aunla Ghat were more aware of the IAPs than Hat-Kalika. Hence our results support Reis et al. (2013), highlighting informal education activities that help in raising public awareness. Consequently, our findings have implications for policymakers for the management of IAPs. People are much more aware of the species that have been the subject of awareness programmes, indicating such efforts could be effective and should be used in policymaking. It is important to note that the knowledge richness was higher among females than males. This could be related to the involvement of females in agriculture and participation in the awareness programmes regarding the management of IAPs. Males usually remain outside the town for various occupations, such as the army, tourism, business, labour, etc. Interestingly, students (irrespective of gender) had the highest value for KRI in both Chandak-Aunla Ghat and Hat-Kalika (0.49 and 0.85, respectively) and hence the least knowledge richness on IAPs. This could be due to the change in the traditional social practices as a lesser number of the younger generation now participate in agro-pastoral practices. We found respondents perceived IAPs negatively in both watersheds of Pithoragarh and are responsible for various environmental hazards.

The knowledge sharing index was also found to be higher among females, followed by males and students. The KSI value was also recorded maximum among females (16.67), among which females of Chandak-Aunla Ghat (9.09) shared more knowledge with their community members followed by females Hat-Kalika (6.25). The students showed less interest in sharing the knowledge with their colleagues due to their lesser interest.

5.6 Conclusion

The present study highlights the importance of public awareness and participation in the management of IAPs can further bring a change in the management of IAPs in the study area. Only few participants had prior knowledge of IAPs due to their related occupation (as women had more knowledge than men due to their more involvement in agricultural practices) or personal curiosity (very less knowledge among students), the results reveals the need of awareness programmes in the study area and they need to know the tentative threats of the IAPs to their ecosystems. Public participation is to be ensured in eradication and restoration programmes in the study area. The participation of the students in the activities is also of utmost importance as it would help mitigate the impacts. The results revealed that the students had the least knowledge related to IAPs and their management. This may be due to their less interest in their traditional agricultural-based livelihood activities and further in managing their croplands and ecosystems. Special workshops should regularly be done in schools and colleges for awareness and scientific knowledge sharing on IAPs, which would help in reducing the future impacts.

Although women of Himalayan hills have the sophistication to manage a multiplicity of roles to adaption and survival in fragile Himalayan ecosystems, very few studies have been carried out concerning gender and biodiversity management. Literature review reveals that an enormous gap exists between the field of biodiversity management and gender. The gender issues and approaches need to be explored and documented. Active participation of local women in IAPs management planning and policy making by considering their traditional knowledge and culturally held perceptions can help control the further invasion of alien plants in the study area. Capacity building of local people, especially the females, through regular workshops and orientation programmes can help the scientific management of the invasive plant species and further ensuring their role in conservation and management activities.



Chapter 6 Impact of *Ageratina adenophora* invasion on native vegetation

6.1 Introduction

Biological invasion is one of the significant reasons for disruption in the biodiversity of the native species in most countries across the world (Pimentel et al., 2000; Simberloff, 2011; Bellard et al., 2012). Its impacts will increase even further under future climatic conditions (Paini et al., 2016; Early & Sax, 2014). The Convention on Biological Diversity (1992) considered biological invasion as primary drivers of biodiversity disruption, second only to habitat destruction and ecosystem degradation (Vitousek et al., 1996; Kowarik, 2003; Pauchard et al., 2009; Reddy, 2012). In recent decades, bio-invasion has enhanced considerably due to climatic changes, anthropogenic emissions, and land use land cover (LULC) changes (McDougall et al., 2011; Muhlfeld et al., 2014). The existing unique landscapes, ecosystems, and biota of Kailash Sacred Landscape (KSL) flourish due to diverse climatic, topographic, geological, and altitudinal variations (Shrestha et al., 2012). The KSL-India is fragile and sensitive to altering the climate and is undergoing an annual rise in temperature (IGES, ICIMOD 2013; Zomer et al., 2014). Plant invasions in mountain areas due to enhanced trade, tourism, and other anthropogenic activities can severely alter native floral species composition inducing prolonged negative impacts and biodiversity changes permanently (Alexander et al., 2016; Fei et al., 2014).

In the past few decades, invasions studies have gathered more attention globally, so many studies were initiated to map the spread of invasive species, measure economic and biological impacts, and develop effective and economical management methods (Kohli et al., 2006; Kosaka et al., 2010; Bhattarai et al., 2014).

In national-level evaluation and mapping, the plant species considered in this study is reported as 'invasive' (Tiwari, 2005; Shrestha, 2016). Still, during shifting climate, the growth of the study of the Invasive Alien Plant Species in the KSL area was underexplored, particularly in the transboundary areas, which serve as the study's motivation. The study serves as the ideal information for understanding the present distribution and calculating the future spread of invasive alien plant species (IAPs), which may pose severe biodiversity pressures in the future. Harsh environmental conditions, rugged terrain, and political sensitivities have limited the systematic monitoring, lacking historical bioclimatic data. The region has a severe lack of

scientific knowledge about invasive specie's influence on the native biodiversity. Therefore, in the KSL area, there is an urgent requirement felt for regional collaboration for informed decision-making, vulnerability and risk mapping, appropriate biodiversity and conservation management, and a holistic methodology while developing climate change adaptation policies (Zomer et al., 2014). Developing active adaptation approaches to cope with climate change and its impacts is essential to identify the factors influencing species distribution in ecological research (Aguirre-Gutiérrez et al., 2013; Royle et al., 2012).

Ageratina adenophora mostly invades forests and shrublands (Bisht et al., 2016; Shrestha et al., 2018). The present study reports the influence of biological invasion in four blocks (i.e., Bin, Berinag, Gangolihat, and Didihat) of Pithoragarh district, Uttarakhand in India forms a part of the KSL region.

The objective of this chapter was to assess the impacts of invasion by *Ageratina adenophora* on species richness, biodiversity, and composition concerning native plant communities and assess the distribution of dominant invasive alien plant species in the study area.

Intensive field surveys were conducted in four different ecosystems, viz. along the roadsides, Pine-Oak Forest, mixed forest, and Deodar Forest. For 276 pairs of vegetation sampling plots, in each ecosystem, an intercomparison of uncontrolled plots (where an intensive invasion of *Ageratina adenophora* is present) and control plots (where any intensive invasion of *Ageratina adenophora* is absent) is performed. The uninvaded plots by *Ageratina adenophora* were selected to be in the adjacent area of the invaded sampling plots with the habitat parameters identical as diligently as feasible. Significant herbs and grasses were identified and recorded in 1m × 1m plots, whereas 5m × 5m plots were laid to record significant shrub species, seedlings, and saplings. Plant species covers were assessed and recorded as essential standards for computing the Shannon diversity index, evenness and Sørensen index to calculate the similarity between invaded and uninvaded sampling plots. The invasion of any area by alien plants causes a severe threat to the native biodiversity. It is restricted to the change in species composition and ecosystem services and affects the local people's livelihood as the rural livelihood's sustenance relies entirely on the forest goods. Therefore, the management of invasive plants through action research to conserve local biodiversity is essential as this species' occurrence indicates possible future changes in composition, diversity, ecosystem structure, and functioning of the pristine ecosystems of the Himalaya.

6.2 Method

6.2.1 Sample sites

The present study was carried out to study the impact of invasion in four blocks (Bin, Berinag, Gangolihat and Didihat) of Pithoragarh district, Uttarakhand - India, part of Kailash Sacred Landscape. To access the impacts of invasion by *Ageratina adenophora* on species richness, diversity and composition of resident plant communities, intensive field surveys were conducted between 2017-2019 in four different ecosystems viz. roadside, pine forest, oak-mixed forest and Deodar Forest of KSL-India.

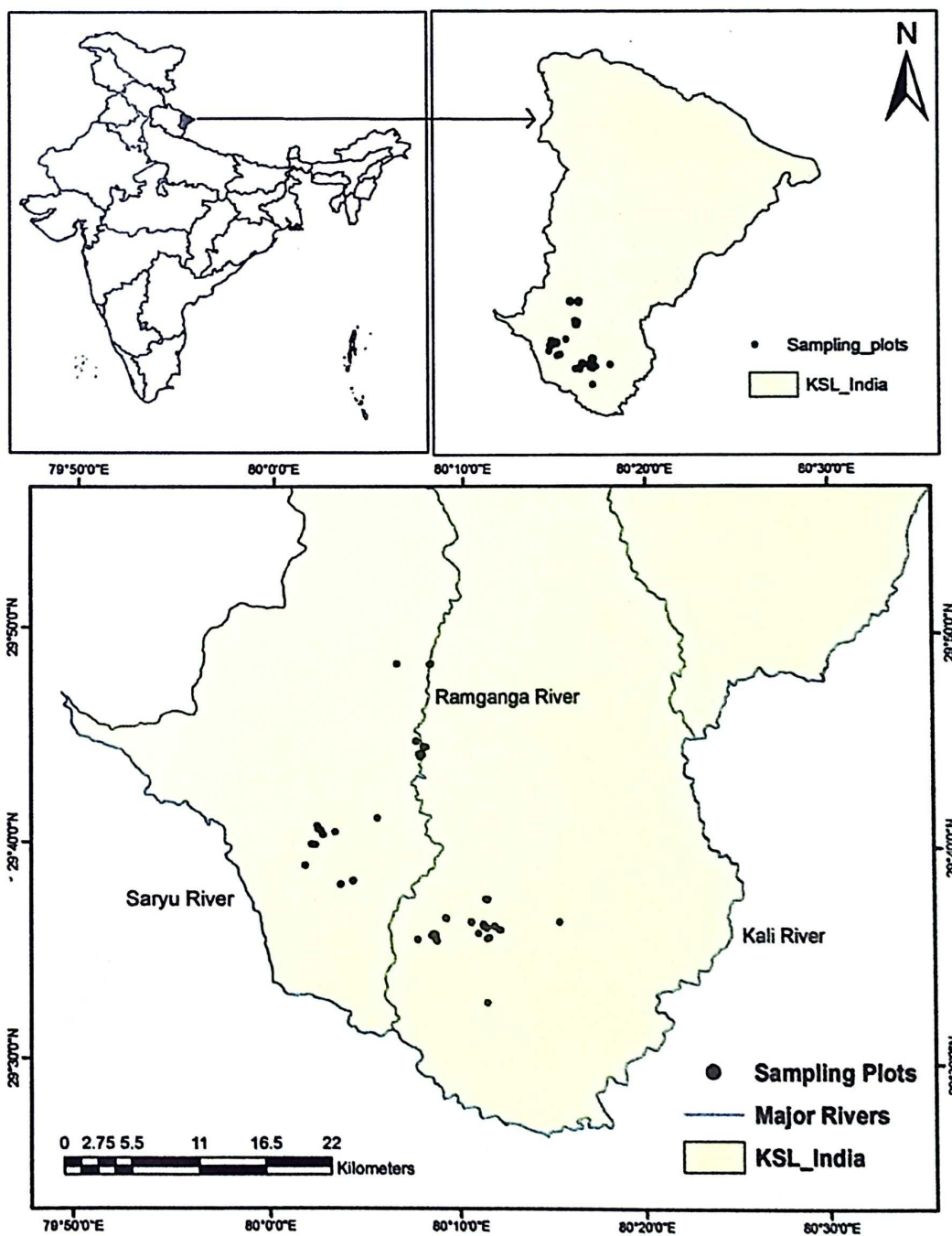


Figure 6.1.: Map showing the study site

A Total of 276 pair of vegetation sampling plots was placed. In each ecosystem, one plot of the pair was placed where there is intense invasion of *Ageratina adenophora* ('uncontrolled plots') to describes the associated changes in species Composition and diversity in these invaded plant communities and the second plot was laid in adjacent vegetation, where the invasion by *Ageratina adenophora* is absent ('controlled plots') (Hejda et.al, 2009). Out of which 78 plots were laid in the pine forest, 67 in the dominant oak forest, 70 plots were laid adjacent roadside and 61 sampling plots were laid in deodar forest. The uninvaded plots by *Ageratina adenophora* were selected to be in close vicinity of the invaded sampling plots with habitat parameters identical as diligently as possible. Herbs and grasses were identified and recorded in percentage in each sampled plot 1m*1m, whereas 5m*5m plots were laid to record shrub, seedlings and saplings to calculating the Shannon diversity index, evenness and Simpson index to calculate the similarity between invaded and uninvaded sampling plots. The number of individuals of *Ageratina adenophora* and its clumps was recorded in each plot.



Plate 6.1. Deodar forest



Plate 6.2. Banj-Oak forest



Plate 6.3. Chir-Pine forest

In a few vegetation plots, very few *Ageratina adenophora* occurred in the uninvaded plot, which could not have induced any alterations to species composition and vegetation structure.

Species diversity, richness, and similarity were studied in 276 pair plots of the four different ecosystems of the KSL-India Landscape.



Figure 6.4. Quadrat of 1mX1m

The Shannon diversity index, species richness, and species dominance were calculated to understand the variation in herbs and shrubs community among the vegetation quadrates in the landscape's Deodar, Chir-pine, Oak and Roadside ecosystem. The information on herb and shrub species structure can provide baseline information for conserving the biodiversity of the three different forests in this area.

6.2.2 Identification

The plant species verified in all laid plots in the study site were documented and identified with the help of taxonomists from WII and the Botanical Survey of India. Plant communities composition were identified as native, invasive plants and alien non-invasive. Indigenous plants were identified from the information existing in the literature (Uniyal et al., 2007) and the region of species was confirmed with the assistance of herbaria of Forest Research Institute, Dehradun, and Botanical Survey of India, Dehradun (BSD). The Invasive Alien Plant Species were distinguished from the printed literature [Negi et al. 2007; Reddy, 2008; Singh et al. 2010] and non-native plants were identified as invasive or alien non-invasive (alien for short) plants according to (Saxena 1991, Mooney and Hobbs 2000; Pandey 2000; Negi and Hajra 2007, sekar at al, 2012)

6.2.3 Statistical analysis

Similarity Analysis (ANOSIM) was performed between the groups to estimate differences in vegetation communities (Clarke 1993). When significant differences among vegetation plots was identified using ANOSIM, then similarity percentage (SIMPER) (Clarke 1993) with Bray Curtis dissimilarity metric (Bray, 1957) was run to observe the differences among plots and which features contribute to it. PAST v3.05 (Hammer 2001) was used to perform SIMPER.

6.2.4 SIMPER analysis

The Bray Curtis dissimilarity metric categorizes the percentage involvement between time 1 and 2 of each family. Similarity percentage analysis of the family differences between time 1 and time 2. The first column categorizes the family described by that row, the second column shows average Bray Curtis dissimilarity between time 1 and time 2 for that family, the third column shows the % dissimilarity explained by that family, the fourth column tallies the cumulative Bray Curtis dissimilarity metric for the family thus far represented in the table. The last three columns show mean abundance at time 1, mean abundance at time 2, and change in mean abundance, respectively.

6.2.5 Community diversity metrics

Shannon-Wiener's species diversity index (H') [McArt et al. 2012], Simpson's dominance index (D') [Pe'ru and Dole'dec S (2010)], and Shannon-Wiener's evenness index (J') (Gonza'lez-Sanso'and Aguilar C, 2010) were used to test the community effects on the compositions by the invader community *Ageratina adenophora*. The equations for calculating the above indices are as follows: (1) $H' = -\sum [(P_i) \ln (P_i)]$; (2) $D' = 1/\sum (P_i)^2$; and (3) $J' = H' / (\ln S)$. S is the number of species in each plot, and P_i is the ratio of the cover of species i to the total cover of all species in each plot. (Li P-X et al., 2011).

6.3 Results and discussion

Among all the 180 plant species recorded from the sampling plots, 29 plants species were identified as invasive in the sampled plots. Our results showed reduced species richness, diversity and evenness in invaded plots by *Ageratina adenophora*. It strongly competes with the native plant species forming a homogenous stand in the landscape.

The overall average dissimilarity between the community in the Deodar forest is 95.4 Percent and the major species contributing to the dissimilarity were *Fragaria indica* (10.43%) *Origanum vulgare* (8.601%) *Randita tetrasperma* (4.816%).

The overall average dissimilarity between the community in Oak forest is 96 Percent and the major species contributing to the dissimilarity were *Origanum vulgare* (11.62%), *Pyracantha crenulata* (5.504%) *Myrsine sp* (5.244%) *Fragaria indica* (5.232%).

The overall average dissimilarity between the community in pine forest is 94.6 Percent and the major species contributing to the dissimilarity were *Fragaria indica* (9.93%) followed by *Rubus ellipticus* (6.5%) *Artemisia vulgaris* (4.81%) *Oxalis corniculata* (4.22%) *Pyrus pashia* (4.15%) and *Berberis* (3.81%).

The overall average dissimilarity between the community in a pine forest is 95.39 Percent and the major species contributing to the dissimilarity were *Fragaria indica* (10.35%) *Artemisia vulgaris* (6.26%) *Oxalis corniculata* (5.90%) *Clinopodium umbrosa* (5.74%) *Erigeron* (4.36%).

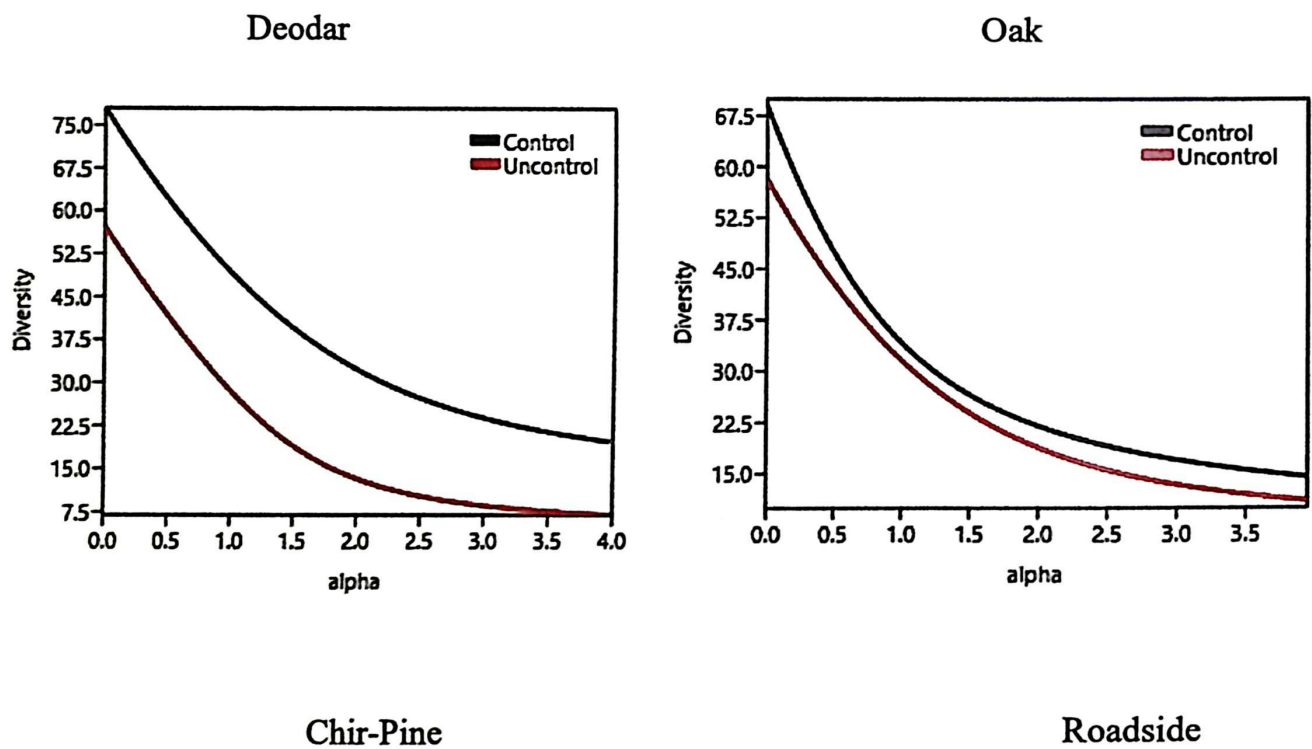
Table: 6.1. Alien invasive plants identified in the study area

S.no.	Name of the Species	Family	Nativity	Life Form	Habit
1	<i>Alternanthera sessilis</i>	Amaranthaceae	Trop. America	herb	Perennial
2	<i>Bidens pilosa</i>	Asteraceae	Trop. America	herb	Annual
3	<i>Amaranthus spinosus</i>	Amaranthaceae	Trop. America	herd	Annual
4	<i>argemone mexicana</i>	Papaveraceae	S. America	herb	Annual
5	<i>Ageratum conyzoides</i>	Asteraceae	Trop. America	herb	Annual
6	<i>Calotropis procera</i>	Asclepiadaceae	Trop. Africa	shrub	Perennial
7	<i>Cannabis sativa</i>	Cannabaceae	Central Asia	herb	Perennial
8	<i>Cassia alata</i>	Caesalpiniaceae	S. America	shrub	Perennial
9	<i>Lantana camara</i>	Verbenaceae	Trop. America	shrub	Perennial
10	<i>Oxalis corniculata</i>	Oxalidaceae	Europe	herb	Perennial
11	<i>Parthenium hysterophorus</i>	Asteraceae	N. America	herb	Annual

12	<i>Solanum nigrum</i>	Solanaceae	Trop. America	herb	Annual
13	<i>Solanum hispidum</i>	Solanaceae	Peru	shrub	Perennial
14	<i>Solanum viarum</i>	Solanaceae	Trop. America	herb	Perennial
15	<i>Sonchus asper</i>	Asteraceae	Mediterranean	herb	Annual
16	<i>Xanthium strumarium</i>	Asteraceae	Trop. America	herb	Annual
17	<i>Ageratina adenophora</i>	Asteraceae	Mexico	shrub	Annual
18	<i>Euphorbia hirta</i>	Euphorbiaceae	Trop. America	herb	Tiliaceae
19	<i>Datura stramonium</i>	Solanaceae	Trop. America	herb	Perennial
20	<i>Corchorus tridens</i>	Tiliaceae	Trop. Africa	herb	Annual
21	<i>Ipomoea purpurea</i>	Convolvulaceae	South America	climber	Annual
22	<i>Indigofera trita</i>	Fabaceae	Trop. Africa	shrub	Perennial
23	<i>Mimosa pudica</i>	Mimosaceae	Brazil	herb	Perennial
24	<i>Erigeron karvinskianus</i>	Asteraceae	Mexico	herb	Perennial
25	<i>Alternanthera philoxeroides</i>	Amaranthaceae	South America	herb	Perennial
26	<i>Senna occidentalis</i>	Fabaceae	America	shrub	Annual
27	<i>Senna tora</i>	Fabaceae	Central America	herb	Annual
28	<i>Ipomoea carnea</i>	Convolvulaceae	Tropical America	shrub	Perennial
29	<i>Oxalis latifolia</i>	Oxalidaceae	Central America	herb	Perennial

Our results demonstrated that invaded plots had reduced species richness, diversity and evenness. A decrease in species number at the plot scale indicated less resemblance between invaded and uninvaded plots and a clear reduction in the total species number at the landscape level. The maximum number of species appeared in control plots of pine forest (83), followed by deodar (78), roadside (71) and Banj-Oak (69). While the maximum number of species in uncontrolled plot was recorded in roadside (63) and Chir-Pine forest (63) and the minimum was recorded in oak (58) and deodar forest (57).

In the Deodar forest, the diversity was recorded at 3.89 ± 0.24 individuals m^{-2} in controlled plots, whereas 3.341 ± 0.18 individuals m^{-2} was recorded in uncontrolled plots. In Oak Forest, the diversity was recorded at 3.54 ± 0.20 individuals m^{-2} in controlled plots, whereas 3.45 ± 0.16 individuals m^{-2} was recorded in uncontrolled plots. Whereas in the pine forest, the diversity was recorded 3.56 ± 0.56 individuals m^{-2} in controlled plots, whereas 3.27 ± 0.33 individuals m^{-2} was recorded in uncontrolled plots. In the case of diversity in roadside sampling plots, the diversity was recorded 3.48 individuals m^{-2} in controlled plots, whereas 3.27 ± 0.33 individuals m^{-2} was recorded in uncontrolled plots.



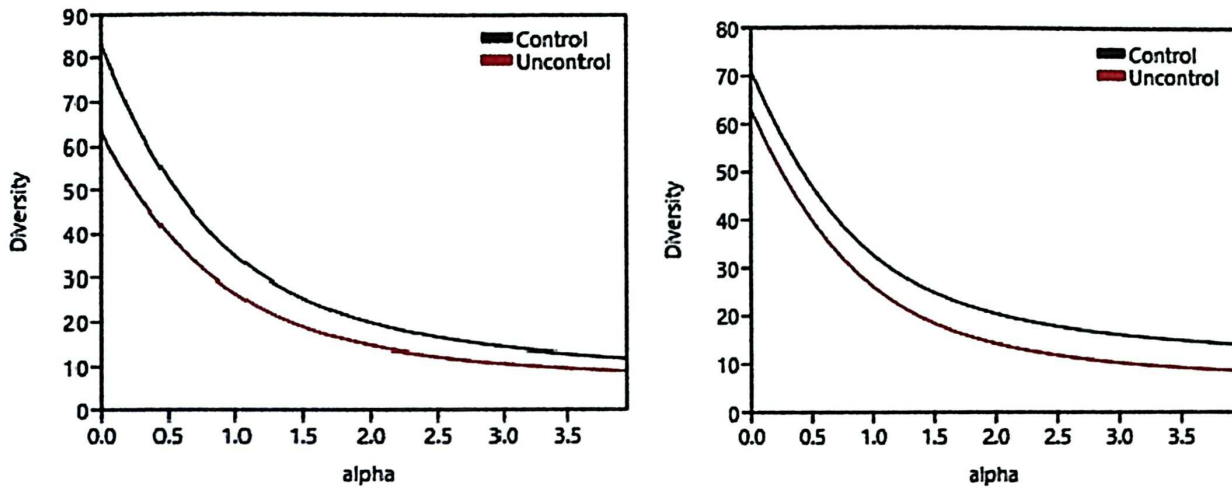


Figure 6.5.: Diversity indices in different ecosystems

The Margalef richness was recorded in deodar forest was 10.36 in controlled sites where as 8.84 in uncontrolled sites of the plots laid. Whereas, in oak forest, it was recorded 9.725 in controlled plots and 8.93 in uncontrolled plots. In pin forest, the richness was recorded at 11.46 in controlled sites and 9.034 in uncontrolled sites. The recorded richness in controlled sampling plots along the roadside was 9.61 and 9.014 in uncontrolled plots.

Ageratina adenophora had a maximum density of 487/m² in the infested site, recorded in the deodar forest.

Table 6.2: Deodar forest:

Biodiversity indices	control	Uncontrol
Total number of species	78	57
Individuals	1688	566
Dominance_D	0.03115	0.07585
Simpson_1-D	0.9688	0.9242
Shannon diversity index	3.893	3.341
Evenness_e^H/S	0.629	0.4953
Margalef richness	10.36	8.835

Table 6.3: Banj oak forest:

Biodiversity indices	Control	Uncontrol
Taxa_S	69	58
Individuals	1088	591
Dominance_D	0.04541	0.05316
Simpson_1-D	0.9546	0.9468
Shannon diversity index	3.537	3.456
Evenness_e^H/S	0.4979	0.5463
Margalef	9.725	8.932

Table 6.4: Chir-pine forest:

Biodiversity indices	Control	Uncontrol
Taxa_S	83	63
Individuals	1279	956
Dominance_D	0.05027	0.06826
Simpson_1-D	0.9497	0.9317
Shannon diversity index	3.556	3.273
Evenness_e^H/S	0.4218	0.4188
Margalef	11.46	9.034

Table 6.5: Roadside forest:

Biodiversity indices	Control	Uncontrol
Taxa_S	71	63
Individuals	1457	971
Dominance_D	0.04886	0.07015
Simpson_1-D	0.9511	0.9298
Shannon diversity index	3.485	3.261
Evenness_e^H/S	0.4594	0.414
Margalef	9.61	9.014

The present study reflects *Ageratina adenophora* high rate of proliferation with the maximum density of *Ageratina adenophora* invasion in deodar forest (259.3/m²) followed by roadside (218.4/m²) pine (177/m²) and oak forest (156.43/m²). This invasive species indicates potential future changes in native species compositional and diversity in forests of Himalaya (Negi 2016). Other major Invasive Alien Plant Species recorded in the infested sites were and *Ageratum conyzoides*, *Bidens pilosa*, *Lantana camara*, *Erigeron karvinskianus* and *Parthenium hysterophorus*.

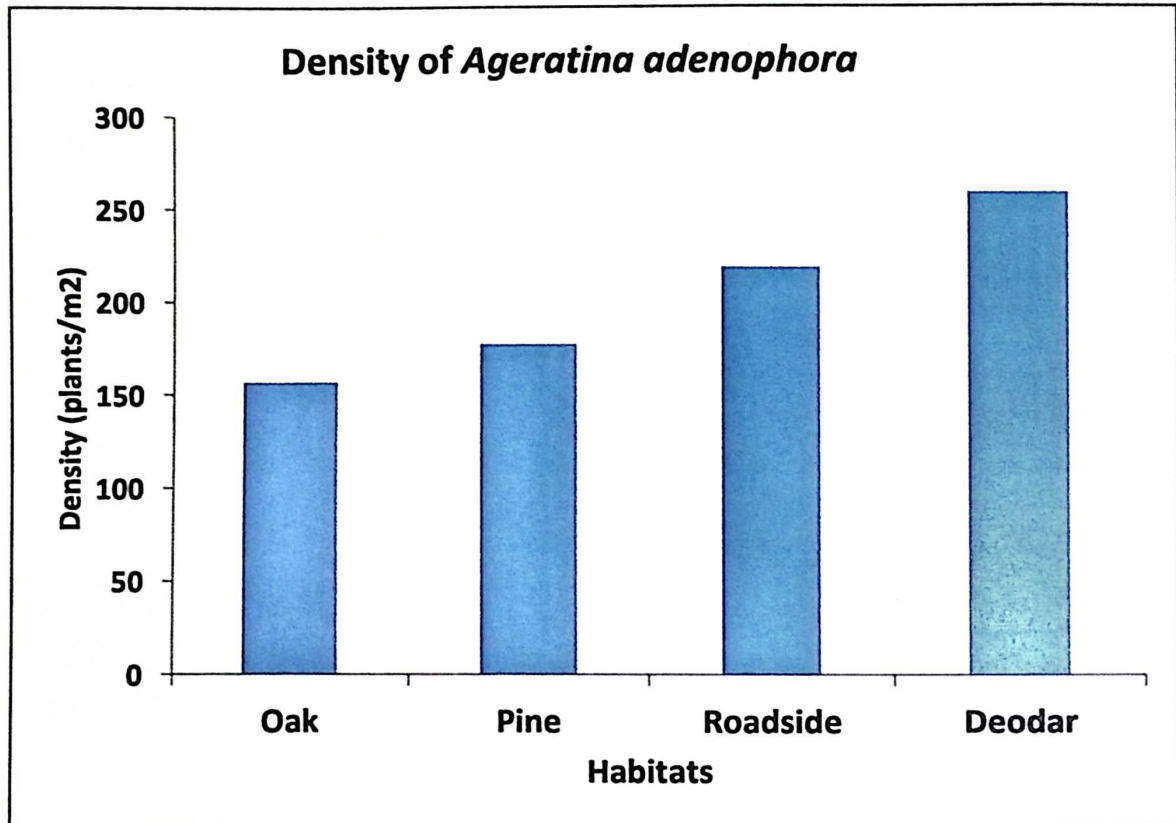


Figure 6.6. Showing the density of *Ageratina adenophora* in different habitats

There was a significant difference amongst the diversity (You compared ex. Diversity, richness or abundance) between the control and uncontrolled plots ($t=2.112$, $P<0.05$) in Oak forest and the deodar forest ($t=4.128$, $p<0.05$). This may be because *Ageratina adenophora* occupies moist environments such as forest fringes of Banj-oak and Deodar forest. It is an exceptionally aggressive competitor, particularly in moist and shaded conditions (Auld & Martin 1975; Zheng et al. 2009; Heystek 2011). Also, these sites have high anthropogenic pressure, which favours the growth of this species.

Where as the diversity indices did not differ significantly between controlled and uncontrolled plots along the road side and pine forest of the study area as pine needles do not decompose easily and release allelochemicals inhibiting grass and other understorey plants to grow, making the soil more acidic (Anderson, 1965, Federer and Tanner, 1966 and Anderson et al., 1969, Gupta 2007). Where as degraded habitats due to low nutrients do not support more vegetation.

The occurrence of *Ageratina adenophora* caused a reduction in the native understorey of shrubs, herbs and species by 20–37%, showing a strong influence on native plant species of the study site.



Figure 6.7. Infestation of *Ageratina adenophora* in Pine forest of KSL-India.



Figure 6.8. Infestation of *Ageratina adenophora* in Deodar forest of KSL-India.

Table 6.6: SIMPER analysis identifying % contribution of each species in Deodar forest to the Bray Curtis dissimilarity metric between mean 1 and Mean 2

Taxon	Av. Dissimilarity	Contribution %	Cumulative %	Mean 1	Mean 2
<i>Fragaria indica</i>	9.646	10.43	10.43	2.66	2.28
<i>Origanum vulgare</i>	7.953	8.601	19.03	2.43	0.845
<i>Randia tertrasperma</i>	4.453	4.816	23.85	1.34	0.345
<i>Artemisia vulgaris</i>	3.362	3.635	27.48	1.14	0.241
<i>Berberis aristata</i>	2.72	2.942	30.43	0.741	0.345
<i>Galium rotundifolium</i>	2.63	2.844	33.27	1.22	0
<i>Rubus elipticus</i>	2.457	2.657	35.93	0.828	0.121
<i>Pyracantha crenulata</i>	2.233	2.415	38.34	0.569	0.224
<i>Symplocos chinensis</i>	2.222	2.403	40.74	0.862	0.103
<i>Hedra nepalensis</i>	2.119	2.292	43.04	0.552	0.19
<i>Maesa indica</i>	2.108	2.28	45.32	0.362	0.483
<i>Strobilanthes alatus</i>	1.986	2.148	47.46	0.655	0
<i>Leucas lanata</i>	1.966	2.127	49.59	0.845	0.069
<i>Viola canescans</i>	1.871	2.023	51.61	0.655	0.207
<i>Boenninghausenia albiflora</i>	1.695	1.833	53.45	0.603	0.121

<i>Teucrium</i>	1.654	1.788	55.24	0.672	0
<i>Reinwardtia indica</i>	1.634	1.767	57	0.328	0.276
<i>Urtica dioica</i>	1.533	1.658	58.66	0.534	0.121
<i>Smilax aspera</i>	1.438	1.555	60.22	0.19	0.293
<i>Anaphalis triplinervis</i>	1.417	1.533	61.75	0.466	0.121
<i>Blumea mollis</i>	1.417	1.532	63.28	0.534	0
<i>Ajuga bracteosa</i>	1.299	1.405	64.69	0.431	0.069
<i>Myrsine africana</i>	1.29	1.396	66.08	0.31	0.259
<i>Plantago major</i>	1.269	1.373	67.45	0.448	0

Table 6.7: SIMPER analysis identifying % contribution of each species in Oak forest to the Bray Curtis dissimilarity metric between mean 1 and Mean 2

Taxon	Av. Dissimilarity	Contribution %	Cumulative %	Mean 1	Mean 2
<i>Origanum vulgare</i>	10.85	11.62	11.62	2.13	1.2
<i>Pyracantha crenulata</i>	5.139	5.504	17.12	1	0.19
<i>Myrsine africana</i>	4.896	5.244	22.36	1.11	0.177
<i>Fragaria indica</i>	4.885	5.232	27.6	1.3	0.671
<i>Pyrus pesia</i>	4.229	4.529	32.13	0.641	0.392
<i>Rubus ellipticus</i>	4.201	4.499	36.62	0.703	0.392
<i>Randia tetrasperma</i>	3.629	3.887	40.51	0.375	0.354

<i>Anaphalis triplinervis</i>	3.371	3.611	44.12	0.578	0.139
<i>Reinwardtia indica</i>	3.264	3.496	47.62	0.953	0.0253
<i>Ajuga bracteosa</i>	3.252	3.483	51.1	0.625	0.152
<i>Berberis aristata</i>	2.754	2.95	54.05	0.391	0.266
<i>Strobilanthes alatus</i>	2.598	2.782	56.83	0.484	0.0506
<i>Ainsliaea aptera</i>	2.308	2.472	59.31	0.531	0.203
<i>Oxalis corniculata</i>	2.187	2.343	61.65	0.625	0.0253
<i>Potentilla indica</i>	1.669	1.788	63.44	0.406	0.152
<i>Valeriana wallichii</i>	1.479	1.584	65.02	0.219	0.165
<i>Coriaria nepalensis</i>	1.443	1.545	66.57	0.125	0.114
<i>Sida acuta</i>	1.437	1.539	68.1	0.297	0.0759
<i>Bulbifera dioscorea</i>	1.293	1.384	69.49	0.281	0.101
<i>Plectranthus rugosus</i>	1.261	1.35	70.84	0.0781	0.329
<i>Hedera nepalensis</i>	1.177	1.261	72.1	0.156	0.0633
<i>Murraya koenigii</i>	1.143	1.224	73.32	0.172	0.0759
<i>Blumea mollis</i>	1.082	1.159	74.48	0.219	0
<i>Galium rotundifolium</i>	0.9686	1.037	75.52	0.0781	0.19

Table 6.8: SIMPER analysis identifying % contribution of each species in Pine forest to the Bray Curtis dissimilarity metric between mean 1 and Mean 2

Taxon	Av. Dissimilarity	Contribution %	Cumulative %	Mean 1	Mean 2
<i>Fragaria indica</i>	9.933	10.56	10.56	0.192	1.97
<i>Rubus ellipticus</i>	6.505	6.916	17.48	0.321	0.549
<i>Artemisia vulgaris</i>	4.812	5.116	22.59	0.218	0.385
<i>Oxalis corniculata</i>	4.225	4.492	27.08	0.0641	1.01
<i>Pyrus pashia</i>	4.152	4.414	31.5	0.231	0.275
<i>Berberis aristata</i>	3.814	4.054	35.55	0.205	0.264
<i>Myrsine africana</i>	3.771	4.009	39.56	0.218	0.187
<i>Anaphalis adnata</i>	3.194	3.395	42.96	0.154	0.132
<i>Clinopodium umbrosa</i>	2.988	3.177	46.13	0.154	0.264
<i>Pyracantha crenulata</i>	2.796	2.973	49.11	0.141	0.176
<i>Erigeron karvinskianus</i>	2.739	2.912	52.02	0.0385	0.989
<i>Leucas lanata</i>	2.323	2.47	54.49	0.141	0.242
<i>Valeriana wallichii</i>	2.14	2.275	56.76	0.0641	0.22
<i>Bidens pilosa</i>	2.121	2.255	59.02	0.0385	0.56
<i>Origanum vulgare</i>	1.947	2.07	61.09	0.154	0.0879
<i>Ajuga bracteosa</i>	1.912	2.033	63.12	0.141	0.0659

<i>Blumea mollis</i>	1.901	2.021	65.14	0.115	0.0659
<i>Centella asiatica</i>	1.84	1.957	67.1	0.0513	0.286
<i>Cirsium wallichii</i>	1.494	1.588	68.69	0.0641	0.0879
<i>Murraya koenigii</i>	1.44	1.531	70.22	0.0385	0.154
<i>Galium rotundifolium</i>	1.314	1.397	71.62	0.0641	0.121
<i>Geranium nepalense</i>	1.304	1.386	73	0.0256	0.154
<i>Scutellaria elliptica</i>	1.239	1.318	74.32	0.0128	0.385
<i>Solanum xanthocarpum</i>	1.09	1.159	75.48	0.0513	0.033

Table 6.9: SIMPER analysis identifying % contribution of each species in Roadside forest to the Bray Curtis dissimilarity metric between mean 1 and Mean 2

Taxon	Av. Dissimilarity	Contribution %	Cumulative %	Mean 1	Mean 2
<i>Fragaria indica</i>	10.35	10.85	10.85	2.3	2.47
<i>Artemisia vulgaris</i>	6.262	6.565	17.41	1.66	0.132
<i>Oxalis corniculata</i>	5.908	6.193	23.6	1.09	1.22
<i>Clinopodium umbrosa</i>	5.745	6.022	29.63	1.68	0.316
<i>Erigeron karvinskianus</i>	4.361	4.571	34.2	0.829	1.18
<i>Rumex hastatus</i>	4.356	4.567	38.77	1.17	0.0132

<i>Pyracantha crenulata</i>	3.931	4.121	42.89	0.697	0.211
<i>Rubus ellipticus</i>	3.166	3.319	46.21	0.276	0.697
<i>Pyrus pesia</i>	2.857	2.995	49.2	0.382	0.421
<i>Leucas lanata</i>	2.677	2.806	52.01	0.526	0.289
<i>Berberis aristata</i>	2.357	2.471	54.48	0.263	0.395
<i>Reinwardtia indica</i>	2.306	2.418	56.9	0.724	0.171
<i>Ajuga bracteosa</i>	2.191	2.297	59.19	0.526	0.0789
<i>Bidens pilosa</i>	1.823	1.911	61.1	0.171	0.671
<i>Centella asiatica</i>	1.713	1.796	62.9	0.395	0.342
<i>Origanum vulgare</i>	1.711	1.793	64.69	0.461	0.105
<i>Desmodium triflorum</i>	1.564	1.639	66.33	0.868	0
<i>Geranium nepalense</i>	1.464	1.535	67.87	0.263	0.224
<i>Murraya Koenigii</i>	1.424	1.493	69.36	0.184	0.184
<i>Myrsine africana</i>	1.225	1.284	70.65	0.0526	0.224
<i>Taraxacum officinale</i>	1.212	1.27	71.92	0.263	0
<i>Valeriana wallichii</i>	1.174	1.231	73.15	0.105	0.263
<i>Anaphalis triplinervis</i>	1.147	1.203	74.35	0.0263	0.237
<i>Urtica dioica</i>	1.129	1.184	75.53	0.211	0.0789

6.4 Conclusion

Sites with high anthropogenic pressure and degraded habitats (fallow lands) are more vulnerable to invasion by Invasive Alien Plant Species as related to well-managed habitats and ecosystems. The habitats that support more diverse communities are tremendously competitive and easily repel invasion (Crawley, 1987). For example, monocultures of an invasive alien plant species result from direct competition with the native flora. The disturbed and fragmented forest understories are at a higher risk of biological invasion than the undisturbed ones. Human and livestock population dependency on the forests sets heavy pressure on forests increasing forest fragmentation in the landscape. Roads, anthropogenic pressure, and climate change have facilitated the invasion of *Ageratina adenophora*, resulting in forming homogenous stands in lower parts of the landscape.

Biodiversity indices such as diversity, species richness and evenness were documented higher in control plots than infested sites by *Ageratina adenophora*. Decrease in grass cover and seedling of oak and *Pyrus pashia*, *Berberis asiatica* and *Pyracantha* and herbs *Artemisia vulgaris*, *Ajuga bracteosa*, *Origanum vulgare* and other native species reveals study that it is affecting the indigenous plant diversity. Hence, the spread of invasive plant species should be monitored by implementing appropriate conservation methods and strategies. Deteriorating plant diversity of the infested sites must be restored by adopting appropriate conservation measures. Our outcomes will not only offer managers immediate essential information about invasive plant *Ageratina adenophora* effects but will also add to our wider understanding of its effects on native plant communities. The depletion of native plant species is troublesome from both the perspectives of ecological and socio-economical and requires serious attention of policymakers and forest managers of that area.

Chapter 7 Native plant community response to alien plant invasion after removal in three different forest types

7.1 Introduction

One of the major threats to species diversity around the world is Biological invasion. It has been affecting biodiversity globally at various scales (Davis 2003; Mack et al. 2000). They alter the native community, ecosystem structure, functioning and dynamics of an ecosystem. Infiltration of invasive exotic plants in the forested ecosystems may disrupt the ecosystem process and functioning by displacing native indigenous plant species (Collier et al., 2002, Huebner 2003). Invasive species cause major effects on their habitats, like they influence native species diversity, soil nutrient structure, altering forest fire cycles, and proficiency of invaded ecosystems. Threatened or endangered plant species around the biosphere face threats due to Biological invasion (Pimentel et al., 2005). Research on the restoration of invaded indigenous communities has attracted much attention (Hartman & McCarthy 2004; Mason & French 2007) due to its adverse effect on natural and managed habitats (Mack et al. 2000). In invaded ecosystems, management strategies comprise the elimination of Invasive Alien Plant Species to decrease their population magnitude or eliminate them entirely if possible (Price & Weltzin 2003; Holmes et al. 2005). Successful removal of Invasive Alien Plant Species requires both effective removal and then restoration of the indigenous plant community back to its historical function and composition (Zavaleta et al. 2001; Hulme 2006). For effective management and control of invasion, valuation of the extent of their impacts is also mandatory (Stinson et al., 2007). Therefore, understanding the accomplishment of invasive alien plants management would include comparative studies, observational and experimental, which will assess the impacts of invasion of the invader species ensuing native species accumulation after its removal.

The management of invasive alien plant species is a current challenge for environmental and ecological restoration of degraded habitats (Kettenring et al., 2011, Pearson et al., 2016) with the main aim is recovering the features of an ecosystem that were predominant before the invasion, such as increasing biodiversity and re-establishing ecological functions (Perterra et al., 2013).

The retrieval of community structure and ecosystem functioning are barely attained or even estimated (Prior et al. 2018) and the results of invasive alien plant species management is

exceptionally unpredictable. It has been observed that after the removal of dominant Invasive Alien Plant Species, other non-native plants species occupy that area which is also known as a secondary invasion (D'Antonio et al. 2017; Kuebbing et al. 2015). For the better management and restoration of a habitat invaded by IAPs, both elimination of Invasive Alien Plant Species and re-establishment of native plant communities is essential (Hulme 2006). In few imperative studies, the amputation of IAPs has been directed to certain effective consequences underneath certain conditions (Cuevas and Zalba, 2010; Galloway et al., 2017) but could not clear which particular condition favoured fruitful or ineffective restoration results. To know the invasive plant's impact on plant communities, it is important to pool observation and experimental approaches, which will assist the precise understandings of results and will lead to the right conclusions and decisions for the control and management of Invasive Alien Plant Species. Therefore, the objective of the study research was to estimate plant community recovery after the removal of *Ageratina adenophora*.

7.2 Study area

The study was conducted in two watersheds, Gokerneshwergad watershed and Chandak-Aunla Ghat watershed part of Kailash Sacred Landscape (KSL) in Pithoragarh district of Uttarakhand state, India (Fig. 01). Gokerneshwergad watershed (Chandak-Aunla Ghat watershed) consists of 12 Gram Panchayats and 28 Revenue Villages. It has 12 Gram Panchayats and 28 Revenue Villages, which accommodate 1,774 households overall population 7534 (3676 male and 3858 female) as per the 2011 census. Total 73% people are literate, among them 80% male and 62% females. The major forest in this area is Temperate Broad Leaf (Oak) and Sub-tropical Temperate Conifer of (Chir Pine), which is 54.6% of total land area, followed by agriculture which is 31.1%.

The land use in these watersheds is dominated by farming with dispersed human settlements. The heritage trade and pilgrimage route of Sacred Mount Kailash passes through this watershed.

The study area was selected as a pilot site for intervention under the Kailash Sacred Landscape Conservation and Development Initiative project, India. The topography of the study area is hilly with an interspersed of different types of forests, agricultural fields, fallow land ranging from 600 to 2200m. Sal (*Shorea robusta*), Oak (*Quercus leucotrichophora*), Chir Pine (*Pinus roxburghii*) and are the major forest types in the area. The weather is often moderate and warm. Summers receive significantly more rainfall than winters. 25 °C is the average temperature.

The average annual rainfall in this area is 1263 mm.. The total area of the watershed under study was calculated using Arc GIS and was found to be 23.23 sq. Km.

7.3 Methods

The invasion of *Ageratina adenophora* was examined, which is presently the most problematic invasive species in the region. The site was chosen after an extensive reconnaissance investigation of the depending on the presence of alien plant species in the Gokerneshwer gad watershed, i.e. *Ageratina adenophora* in different forest types. Intensive field surveys were conducted from January to April 2017 to September 2018 to record the maximum patches of invasion by *Ageratina adenophora* in adjoining areas of 20 villages in the Gokerneshwer gad watershed covering different forest types. Based on the survey conducted, three sites were selected for monitoring—Oak forest in Chana Pande village, Pine forest in Gurura village and Deodar forest near Mostamanu. By experimentation on invaded communities supplemented by observation of uninvaded plant communities, we assessed *Ageratina adenophora* impact on native biodiversity and assessed plant community reaction to its elimination and discussed the efficiency of removal techniques. We laid ecological monitoring plots in three different forest types oak, deodar and pine of pilot site Bans Maitoli of KSL –India from 2016-2017.

We randomly placed three (10m*10m) observational plots within each forest type, which we monitored monthly for 13 months.

Data was collected from the selected sites before and after removal of invader species *Ageratina adenophora* and the marked plots in each site were monitored. At three different field sites, we applied common removal treatment and compared native plant species responses before and after removing *Ageratina adenophora* from the monitoring plots where invasion occurred.

Four 1m x 1m quadrat plots were marked at the corners and one 1m x 1m quadrat was marked at the centre in each 10*10 m plot to collect herb and shrub data in the laid plots.

The number of individuals of *Ageratina adenophora* and its clumps were recorded in each to evaluate the effect of removal of invasive herb *Ageratina adenophora* on native community structure and secondary invasion varied with environmental conditions. All sites were historically covered by forest but have been subjected to various anthropogenic pressures like fodder and fuelwood collection; grazing and study sites were located 4 km apart.



Plate 7.1. Permanent plot to monitored *Ageratina adenophora*

7.5 Data analysis

7.5.1 Calculating plant diversity

The Shannon diversity index, species richness, and species dominance were calculated to understand the variation in herbs and shrubs community among the vegetation quadrates in deodar, pine, oak forest of the selected sites.

To calculate the diversity of the plant species, the most frequently used index (Kent and Coker, 1992), the Shannon index (H'), was performed. Species richness index was calculated as the number of species observed in the sampled plot. This index takes both species richness and species abundance into the analysis (Heuserr, 1998).

Calculated as:

$$H' = - \sum_{i=1}^s p_i \ln p_i$$

Where, s equals the number of species and p_i is the relative cover of i th species (Whittaker, 1972; Pielou, 1975).

In addition, the Simpson index (D) and the evenness index (E=Evenness) are considered as a metric for species dominance and a metric for spread evenness, respectively (Magurran, 1988). The Simpson index is defined as:

$$D = \sum P_i^2$$

Whereas, the evenness index (E) is calculated as:

$$E = \frac{H'}{H_{max}} = \frac{-\sum_{i=1}^s p_i \ln p_i}{\ln s}$$

The natural logarithm of the total number of species is Hmax.

All diversity indices were calculated using PAST v3.05 (Hammer 2001)

7.6 Results and discussion

Removing any alien or native species from an ecosystem can have diverse consequences, which may be desired or undesired. Therefore, it is crucial to quantify and predict these effects. Our results show that in all the three types of forests (i.e., Oak, Deodar and Pine forests), *Ageratina adenophora* almost shows the same kind of regeneration pattern after complete removal (Fig. 7.1.). In the absence of any other competitor alien species, it again regenerates in the evacuated area if not monitored and eradicated regularly. The rate of regeneration does not depend on the type of native species. Overall, the *Ageratina adenophora* tend to increase in ascending order (Fig. 7.2.).

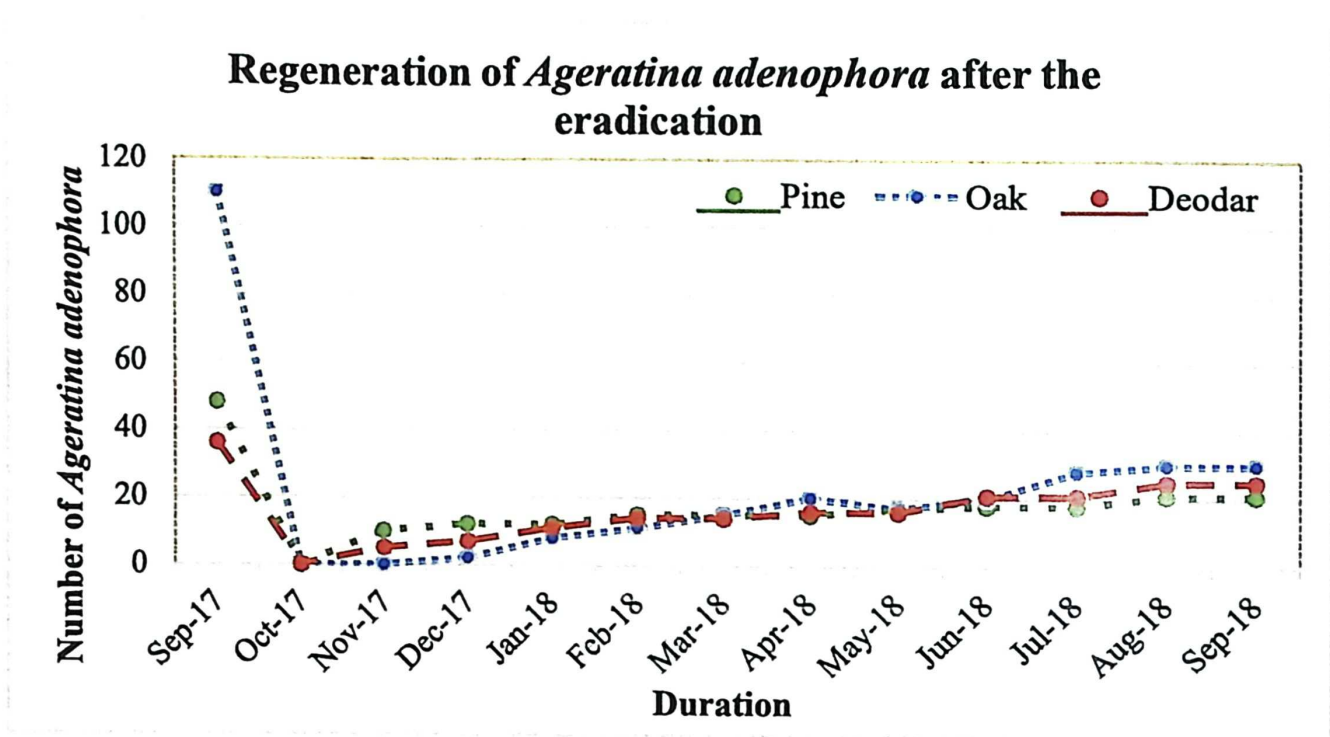


Figure 7.1. Number of *Ageratina adenophora* plants before and after eradication in different types of forests

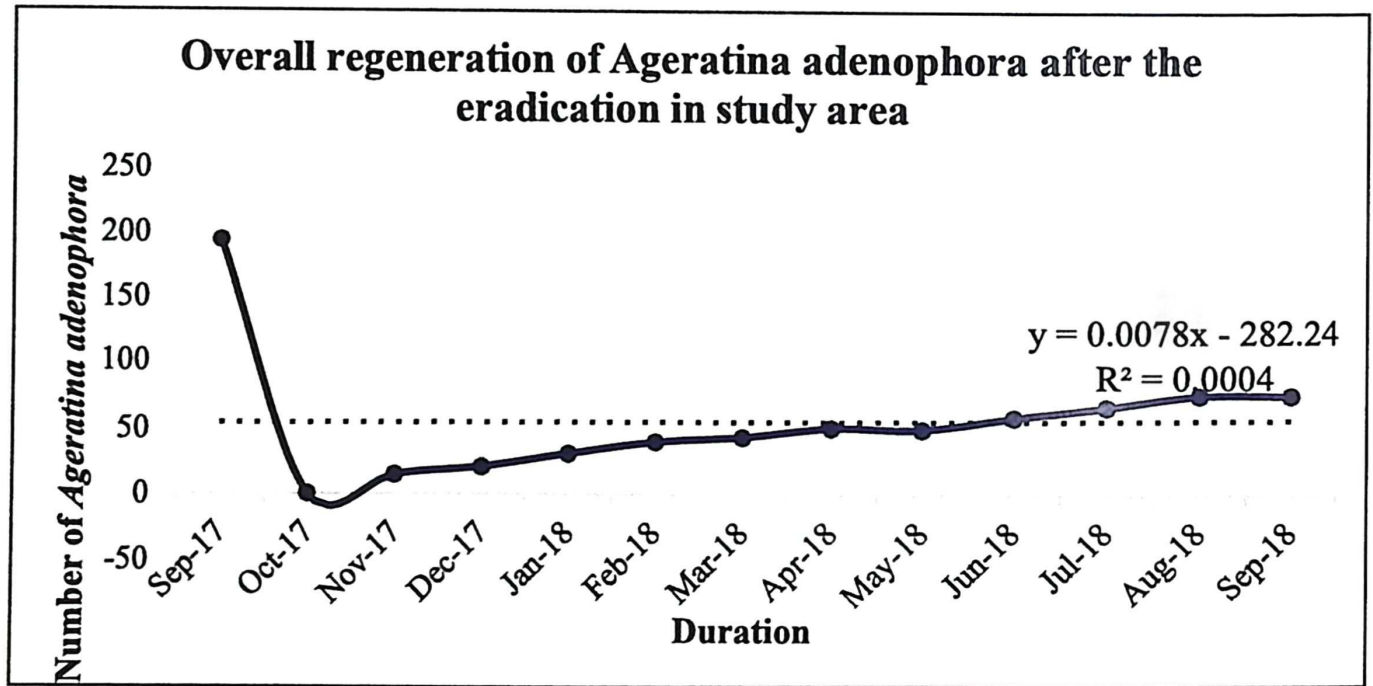


Figure 7.2. Overall number of *Ageratina adenophora* plants before and after eradication in forest

7.6.1 Impact of eradication of *Ageratina adenophora* from Deodar forest

Invasive alien plant species may prohibit the growth of other plants in the area in which they have invaded. Eradication of invasive species from different forest types may have a different impact on different forest types. In the Deodar forest, it was found that the overall number of individuals (N) of plants increased at the site after the eradication of *Ageratina adenophora* (Fig. 7.3.). The Shannon Diversity (H) also increased after eradication (Fig. 7.4.). This shows that the eradication of invasive plant species could increase plant diversity in an area. However, the invasive species returned to the area within two months and recovered upto 69% within one year. Moreover, the increase in diversity may cause a decline in total grass cover.

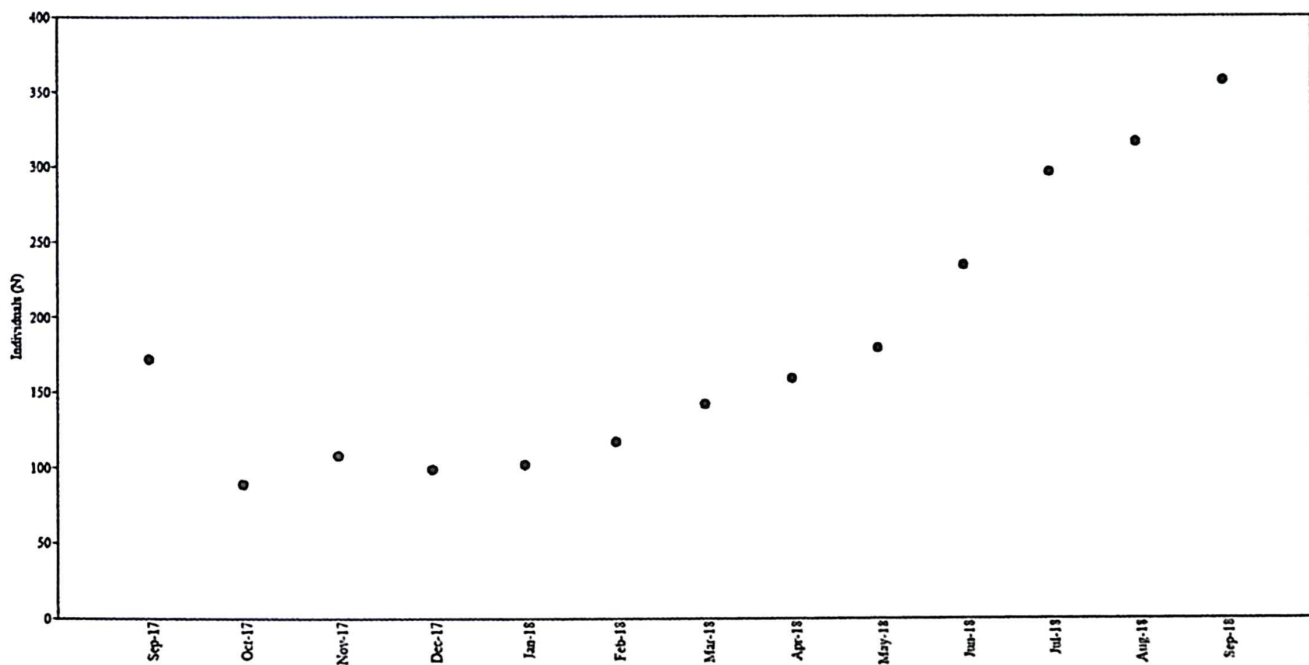


Figure 7.3. Number of individuals (N) of plants before and after eradication of *Ageratina adenophora* from Deodar forest

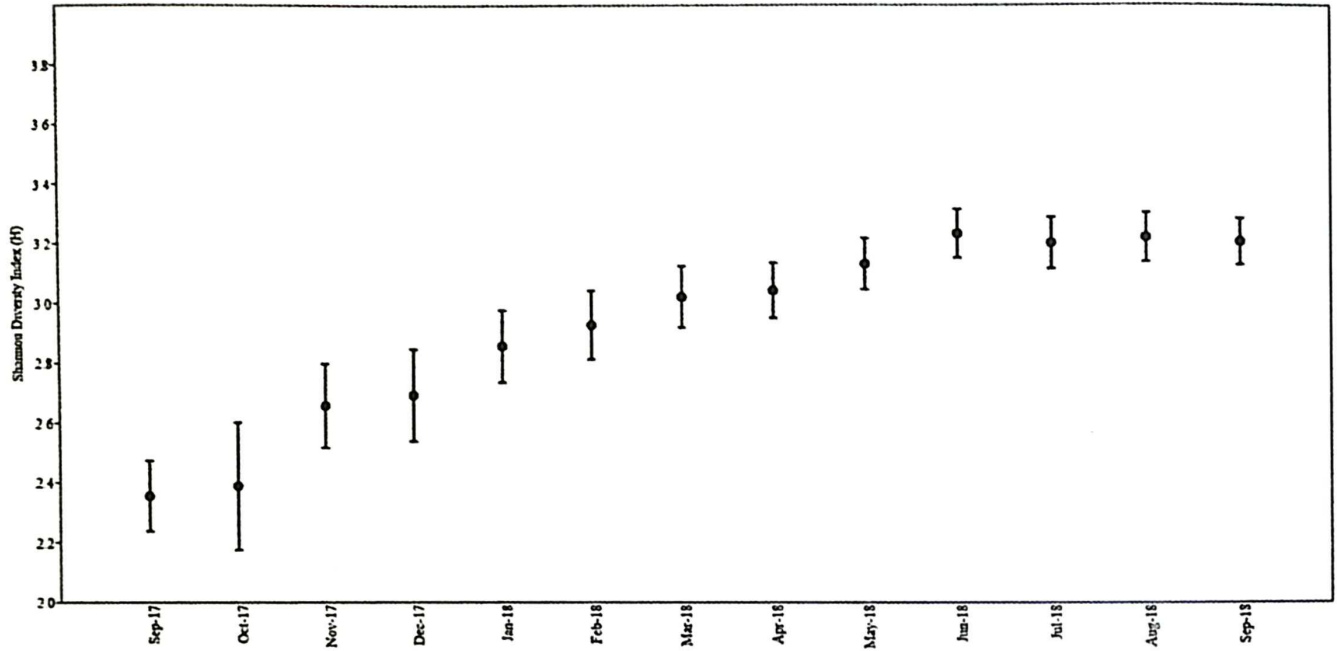


Fig. 7.4. Shannon Diversity index of the Deodar forest site before and after eradication of *Ageratina adenophora*

The richness was also calculated and it was found that too increased in the study area (Fig. 7.5.). In comparison, the evenness (Fig.7.6.) tends to increase in the starting few months and later decreases along with the increase in the number of invasive species. Thus, from these results, it is evident that although the complete eradication of any invasive species from the Deodar forest could result in an increase in diversity and richness, it would not cause any major difference in evenness as the invasive species could again invade the area of eradication if not monitored regularly and regular eradication programmes are not run.

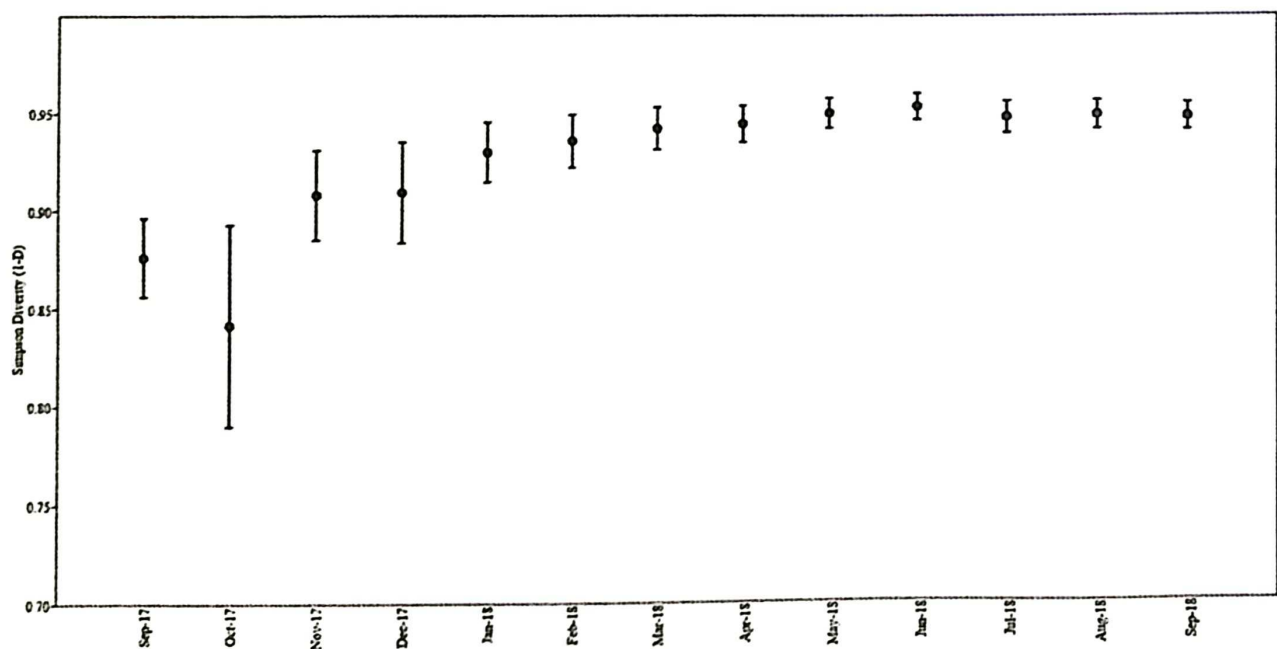


Figure 7.5. Richness of the Deodar forest site before and after eradication of *Ageratina adenophora*

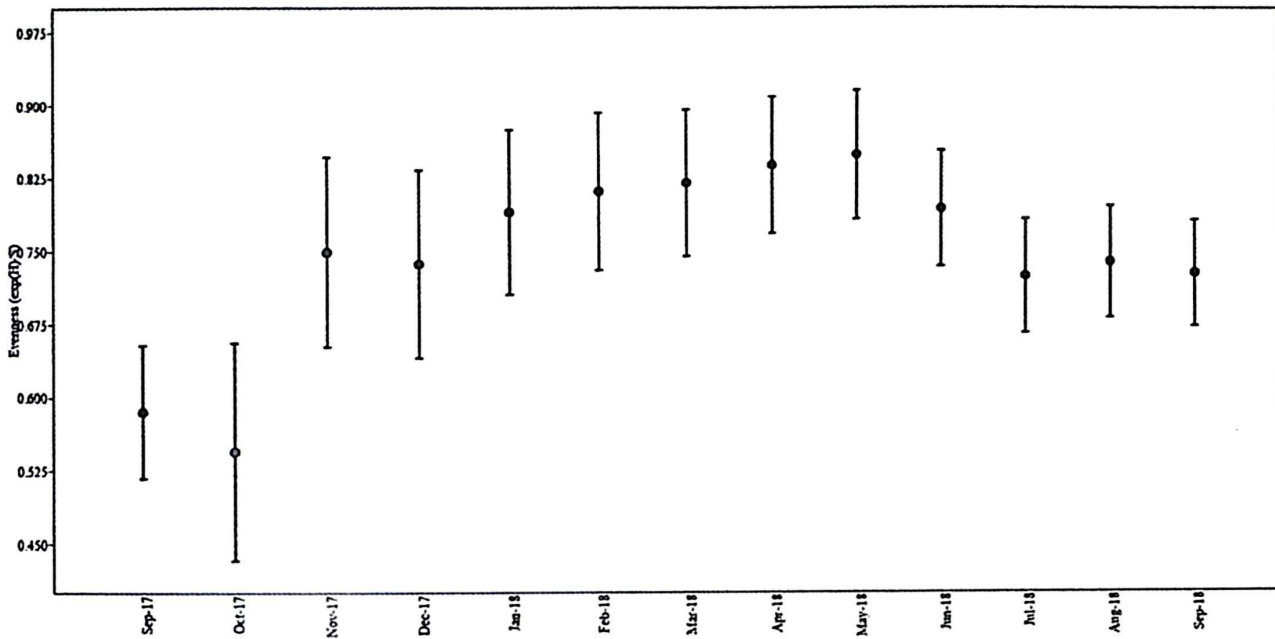


Figure 7.6. Evenness of the Deodar forest site before and after eradication of *Ageratina adenophora*

7.6.2 Impact of eradication of *Ageratina adenophora* from Pine forest

The number of individuals varied in various seasons in the pine forest. After the eradication of *Ageratina adenophora*, the number of individuals declined initially but increased during monsoon months (Fig. 7.7.). Although there was an increase in the Shannon diversity (Fig. 7.8.), it was less compared to the Deodar forest. Results further reveal that about 44% of the invasive plant population recovered within one year after the eradication.

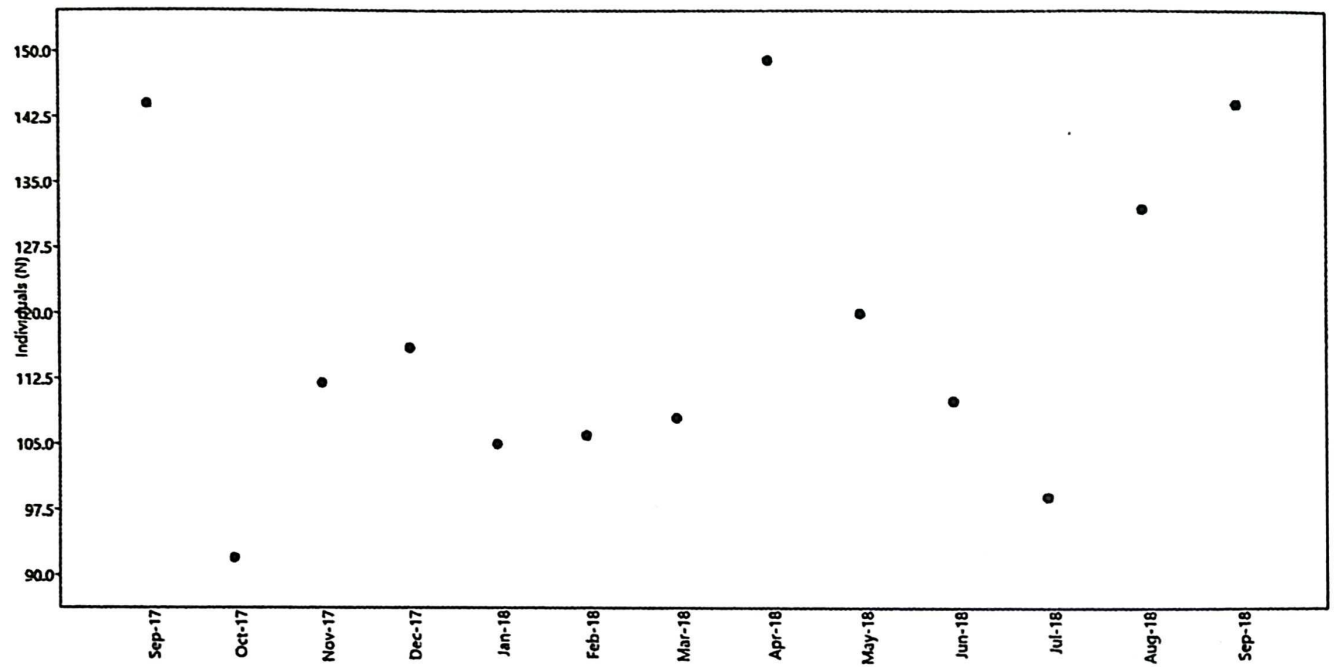


Figure 7.7. Number of individuals (N) of plants before and after eradication of *Ageratina adenophora* from Pine forest

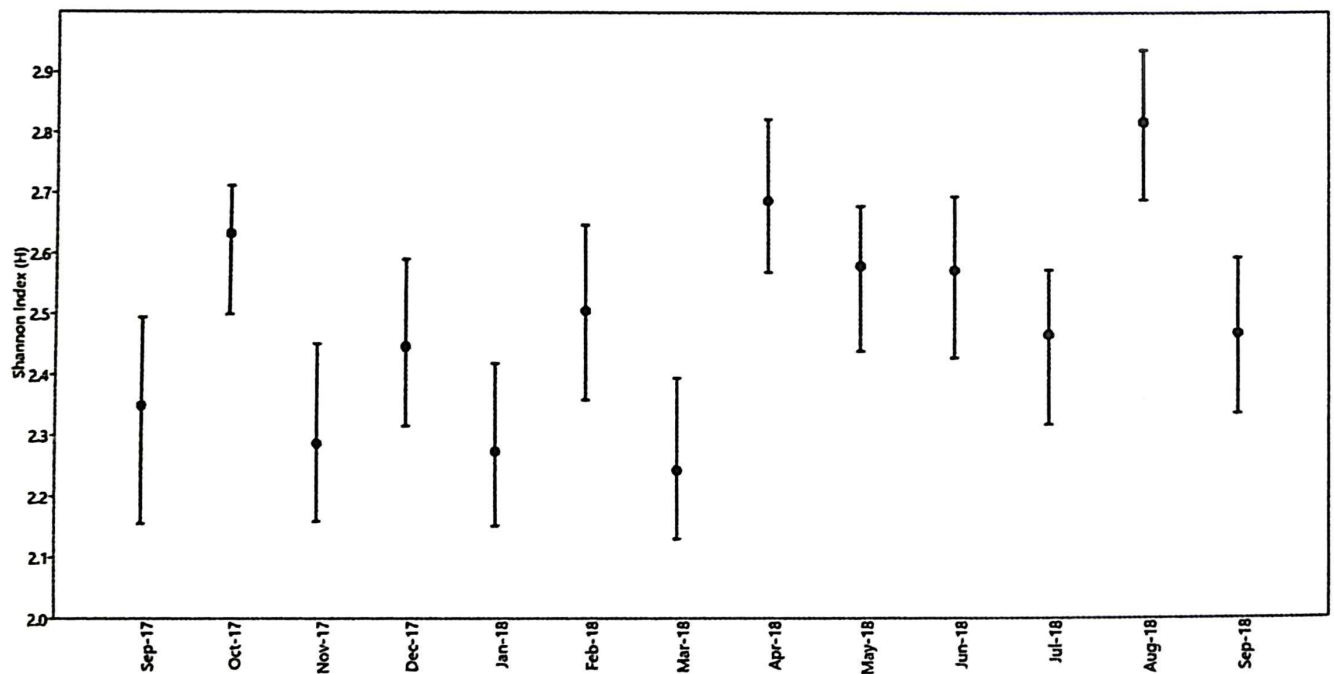


Figure 7.8. Shannon Diversity index of the Pine forest site before and after eradication of *Ageratina adenophora*

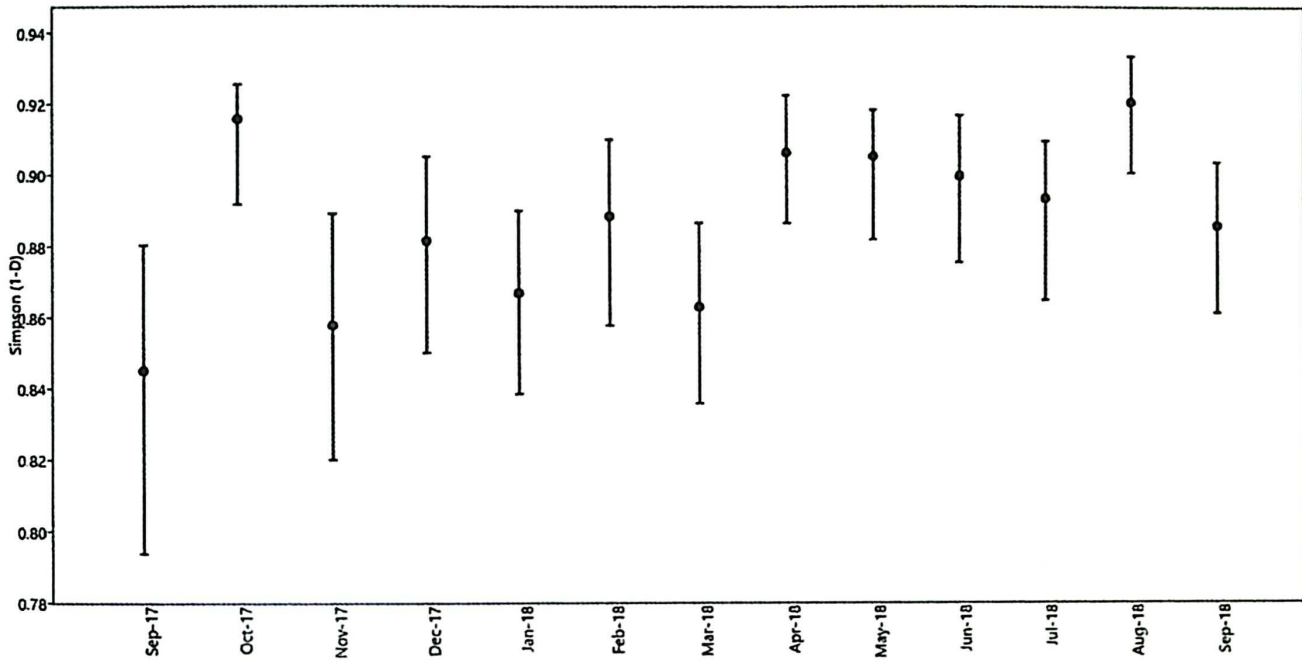


Figure 7.9. Richness of the Pine forest site before and after eradication of *Ageratina adenophora*

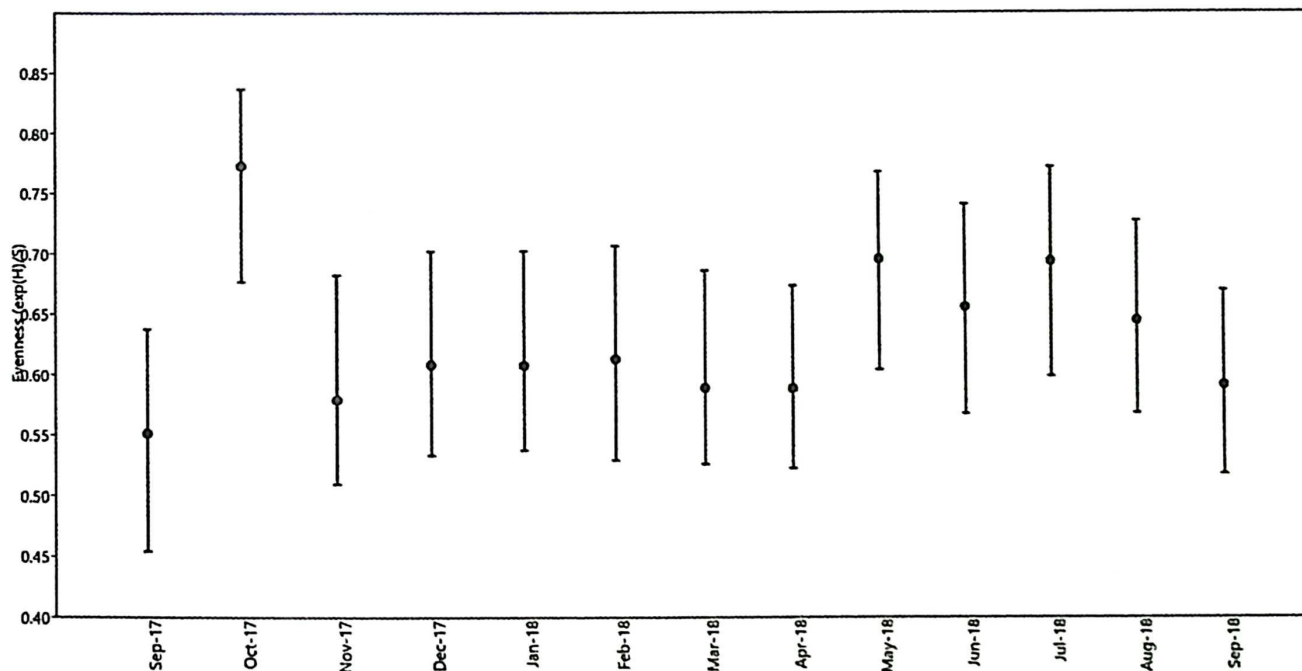


Figure 7.10. Evenness of the Pine forest site before and after eradication of *Ageratina adenophora*

7.6.3 Impact of eradication of *Ageratina adenophora* from Oak forest

The number of individuals of other species increases in various seasons in the oak forest (Fig. 7.11.). Results further reveal that about 27% of the invasive plant population recovered within one year (Fig. 7.12.). Although there was an increase in the Shannon diversity (Fig. 7.13.), the same level of evenness is maintained. Grass cover also increased by 19% in oak forests. Also,

removing *Ageratina adenophora* has led to Secondary invasion by *Ageratum conizoides* and *Bidens pilosa* in the oak forest. (Grosholz. 2005; Johnson et al., 2009; Green et al. 2011;) the number of native species *Ajuga bracteosa* and *Artemisia vulgaris* increased with the removal of *Ageratina adenophora* in the oak forest. An increase in oak seedlings was observed.

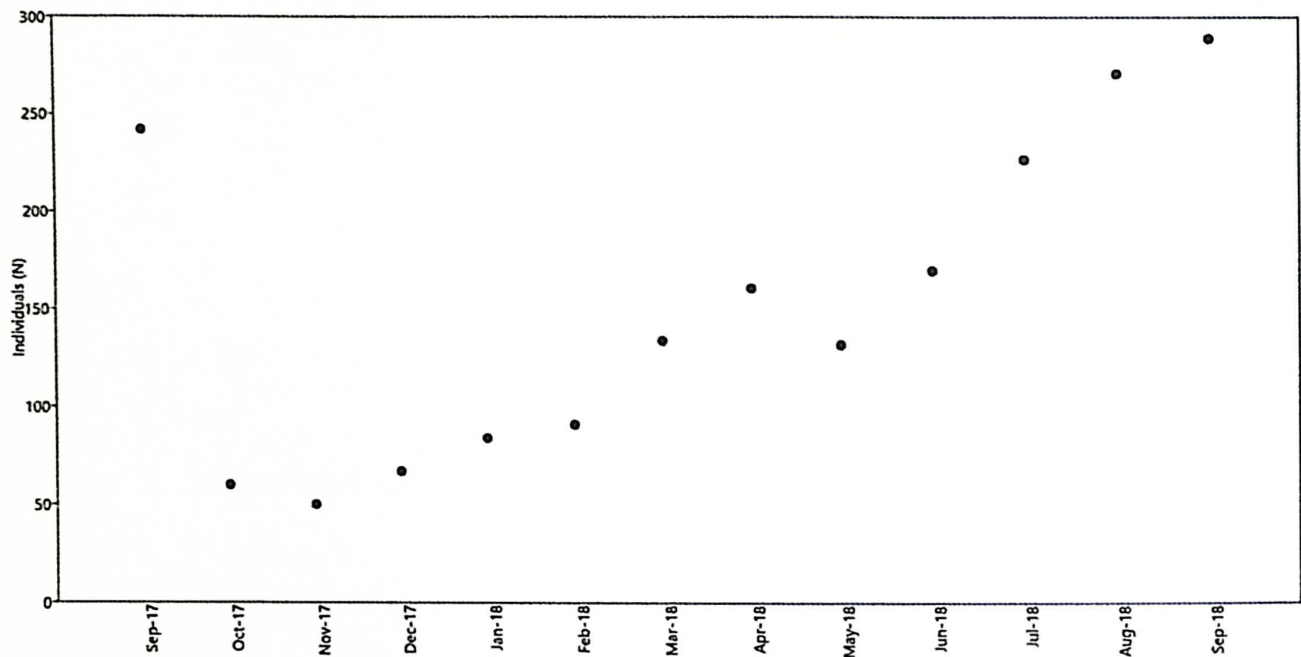


Figure 7.11. Number of individuals (N) of plants before and after eradication of *Ageratina adenophora* from Oak forest

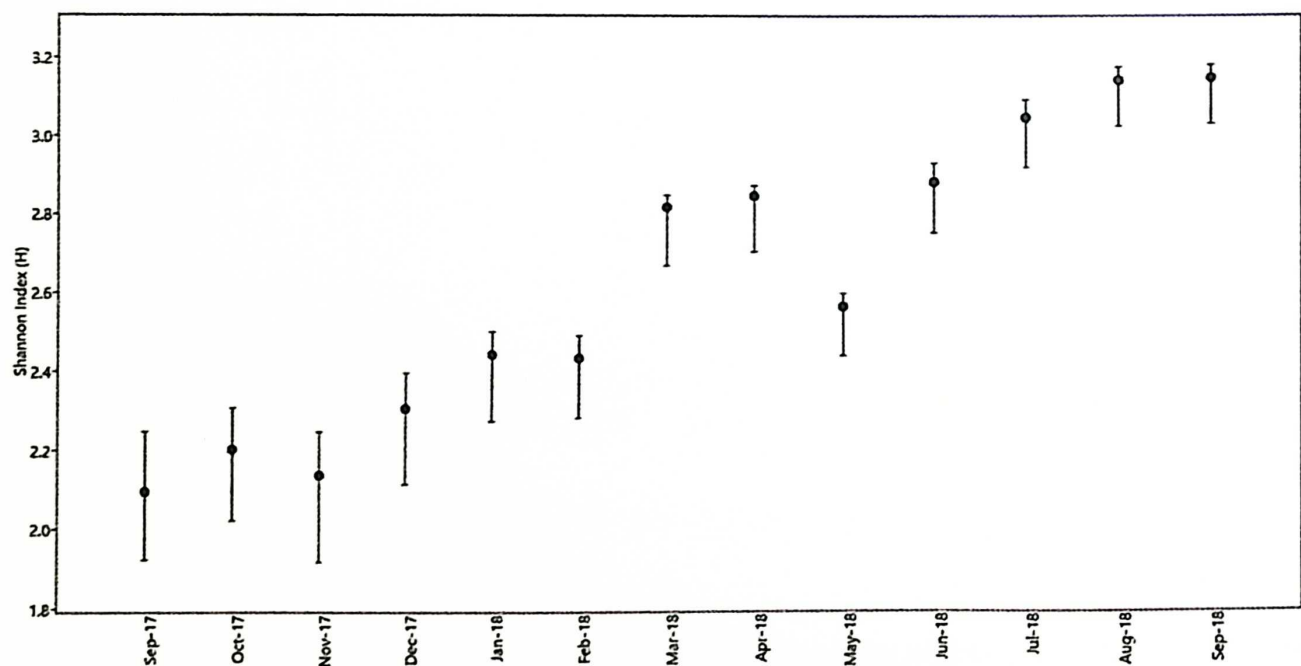


Figure 7.12. Shannon Diversity index of the Oak forest site before and after eradication of *Ageratina adenophora*

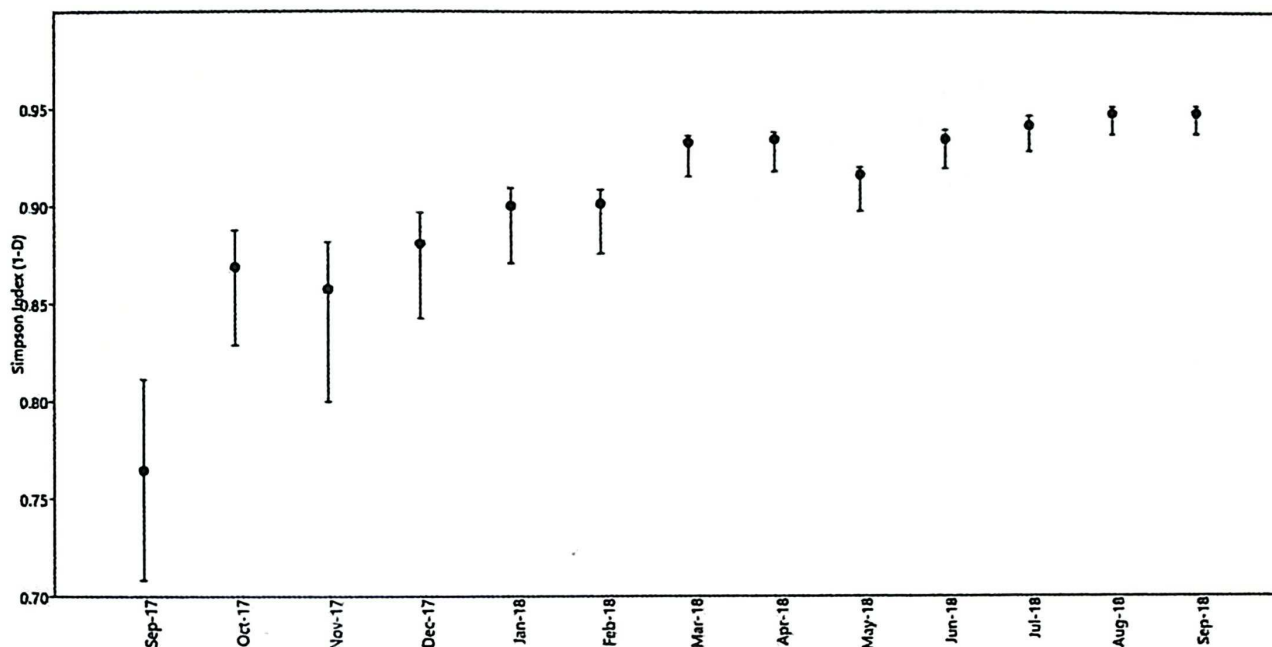


Figure 7.13. Richness of the Oak forest site before and after eradication of *Ageratina adenophora*

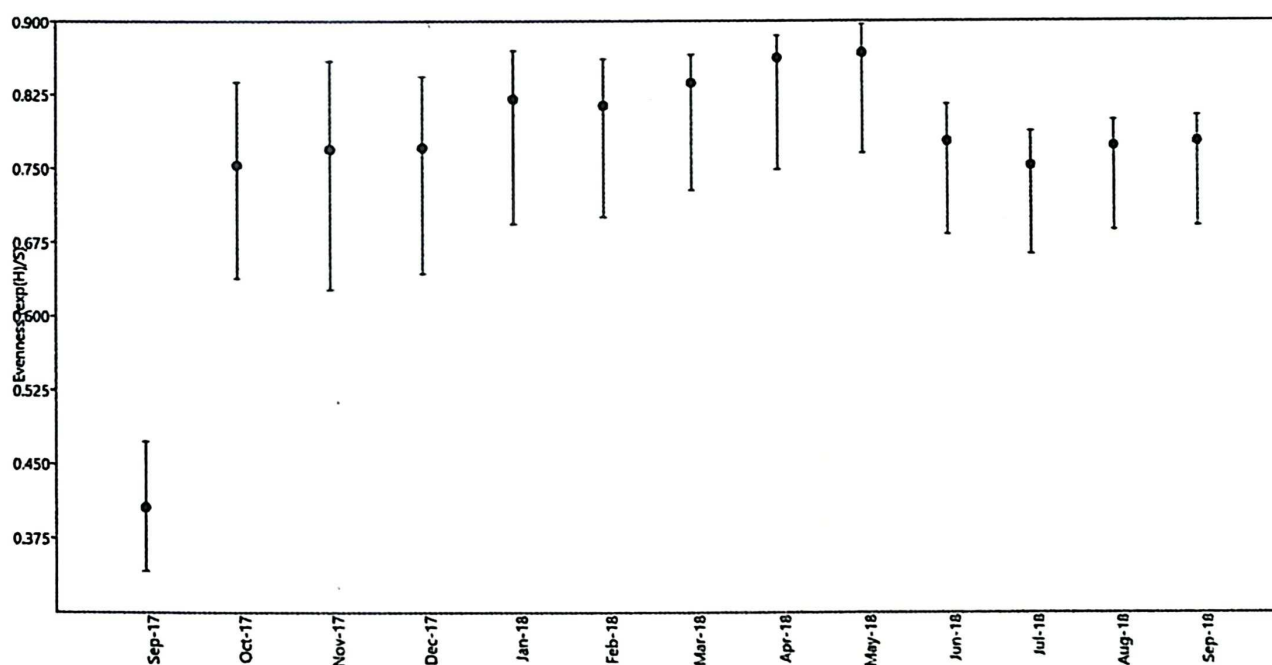


Fig. 7.14. Evenness of the Oak forest site before and after eradication of *Ageratina adenophora*

The regeneration of *Ageratina adenophora* was higher in deodar forest followed by Pine and Oak. This may be due to high anthropogenic pressure in selected deodar sites as Invasive Alien Plant Species species growth is being accelerated due to anthropogenic perturbations, which potentially facilitate the access and spread of invasive alien plant species. (Rai, 2015; Vaz, 2017; Young and Larson, 2011).

7.7 Conclusion

To control and manage invasive plant species, regular monitoring and effective management is required. Vegetation structure of forest also exposed that local forests have high density and frequency of native species while forest fringes have more invasive alien species such as *Ageratina adenophora* and *Lantana camara*, which are rigorously penetrating inside the forest. Invasive species in the naturally important broadleaf forest may affect the regeneration of native species by modifying soil characteristics and competition. Deterioration in vegetation & soil quality may affect the status of provisioning as well as regulating services. *Ageratina adenophora*, *Lantana camara*, *Ageratum conyzoides*, *Parthenium hysterophorus* and *Erigeron karvinskianus* are speedily proliferating and widely distributed invasive alien plant species in the study area. Studies have shown that with rising temperature and anthropogenic disturbances, these species are also documented in higher elevations (Dobhal et al., 2011; Khanduri et al., 2017). With the intensification in tourism, anthropogenic disturbances and rapidly increasing road linkages that pass through forests have increased the invasion of Invasive Alien Plant Species even in alpine habitats of the IHR (Pathak 2019).

To monitor the spread of invasive alien plant species, only removal can lead to secondary invasion by other widely distributed invasive alien plants that can speedily increase in that area. Therefore, restoration of the invaded site with the native species has some uses value, e.g., fodder, fuel, medicinal, fruit, etc. (Bisht et al., 2016). The selection of species for restoration of the degraded habitat should be based on the habitat suitability of the species, the natural history of the area, and in consultation with local scientific communities. The nursery was developed in the Bans-Maitoli pilot site to maintain the gene bank and propagated indigenous fodder species to restore the degraded forest ecosystems and provide planting material for the identified sites. A total of 500 saplings of broom grass (*Thysanolaena maxima*) were planted for eco-restoration in the Jhuli area by BMC and Mahila Mangal Dal (women self-help group) member's weed-infested grassland and fallow lands. Two reserve forests were also identified for habitat improvement in the Bans-Maitoli pilot site. The plantation of wild edible plants and fodder grass was carried out by forest officials, BMC members, and local community members. The results indicate that this species prefers and occupies such habitats which are degraded, disturbed and the habitats where the anthropogenic pressure is much higher than other habitat types in any ecosystem and does not require much fertile land to invade. Further, the distribution of this invasive alien plant species will magnify and may cause a serious threat to the local biodiversity and a change in the pristine ecosystem process of the area, causing loss

of vital ecosystem services. Therefore, active conservation and management approaches are required to check the further distribution of this alien species in the western Himalayan region and to mitigate the growth and impact of invasion on different ecosystems.

7.8 Recommendations

- Intervention through Participatory action research for restoration with the help of the Biodiversity Management Committee (BMC) and village-level support was carried out. *Ageratina adenophora* was uprooted from nearby water resources for proper recharge, maintaining the purity in the Bans-Maitoli pilot site. Two sites representing these habitats were taken up by the BMC of Bans-Maitoli to manage *Ageratina adenophora* and its replacement by native fodder grasses and is used for compost. Two sites representing these habitats were taken up by the BMC of Bans-Maitoli for management and replacement by native fodder grasses (*Thysanolaena maxima*)
- A nursery should be developed to propagate indigenous fodder species, including hill bamboo and broom grass, to provide planting material for the identified sites. For habitat restoration, 500 saplings of broom grass (*Thysanolaena maxima*) was brought from Gori Valley and planted in this nursery with the help of forest officials and BMC members.
- Also, BMC and Mahila mangal dal participated in the plantation of native fodder species and multipurpose tree species in weed-infested grassland and infested fallow lands.

Plate 7.2. Awareness about invasive alien species and their spread



Before and after the removal of *Ageratina adenophora* from invaded grassland



Before



After

Plate 7.3. Removal of *Ageratina adenophora* from the different infested sites of the pilot village

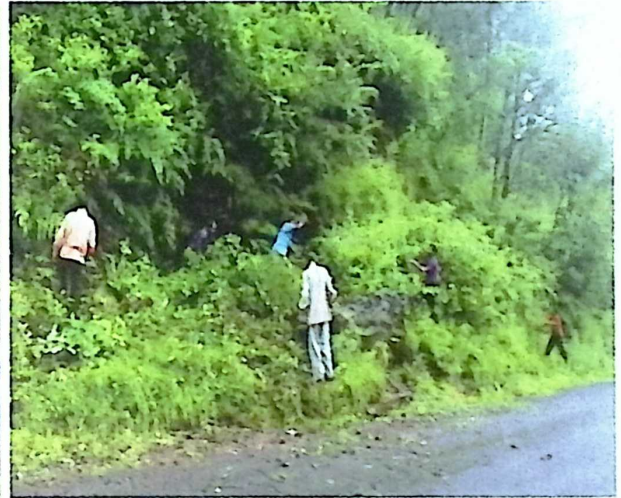
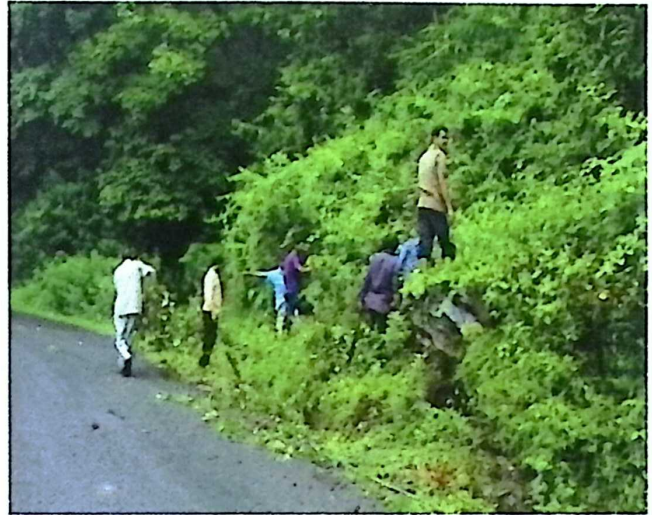


Plate 7.4. Plantation of native fodder species and multipurpose tree species by BMC and Mahila mangal dal



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Probability Distribution Modeling of *Ageratina adenophora* and *Lantana camara* in Kailash Sacred Landscape, Uttarakhand

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ABSTRACT: Biological invasion has become one of the major causes of economic and environmental damage. The Himalayan region, one of the biodiversity hotspots is rapidly getting invaded by alien invasive species this study aims to understand the pattern of invasion by *Ageratina adenophora* (Kala Bansa) and *Lantana camara*. Intensive field surveys were conducted to record the invasion by major invasive plants across agricultural lands, fallow lands, forests and grasslands of Kailash sacred landscape—India situated in district Pithoragarh of Eastern Uttarakhand in Western Himalaya. Site selection was carried out on the basis of intensive reconnaissance surveys at different altitudinal gradients. MaxEnt modeling was done to predict potential distribution of these two alien invasive plants. The models were calibrated using data from observations and geographic distribution records and then a combined model was prepared to get the approximate area under invasion in the landscape. The average model was chosen among 5 replicates on the bases of AUC value (94 ± 0.01 for *Eupatorium* and 94 ± 0.006 for *Lantana*). Among the 19 bio-climatic variables selected precipitation of wettest month was found to be the most important variable for the distribution of *Ageratina adenophora*, followed by annual mean temperature and elevation, however, elevation was the most important factor followed by precipitation seasonality and aspect in the distribution of *Lantana*. ©2018

KEYWORDS: *Invasive species; Kailash Sacred Landscape; Ageratina adenophora; Principal component analysis; MaxEnt.*

INTRODUCTION

The plant diversity around the world is facing various threats and is reducing very rapidly (Dogra *et al.*, 2009). Invasive species are a major threat to the Earth's biodiversity because they often dramatically affect the structure and functioning of ecosystems. Altering Climate and anthropogenic factors accelerates the growth of Alien invasive plants as they favor the area where they are not limited by climatic constrains. Change in climatic conditions may increase the opportunities for their introduction and spread (Mooney, 2000). Due to which they have spread their horizons from lower to higher altitudes in Himalaya. In areas where they spread, invasive can destroy natural pasture, displace native trees, and reduce grazing potential of rangelands (Admasu, 2008). The invasion of alien plant species has become the second highest threat to plant diversity in the new regimes after the habitat loss (Hobbs & Humphries, 1995). It may be due to invasive species has faster rates of growth and biomass production compared to native species, higher competitive ability, high reproductive efficiency including production of a large number of seeds, efficient dispersal, vegetative reproduction, rapid establishment, other traits that help them adapt to new habitats (Simberloff *et al.*, 2005; Sharma *et al.*, 2005) and broader range of tolerance (Walther *et al.*, 2009; IUCN Report, 2013). Some of the widely spread and

documented invasive plant species all over the world are *Ageratina adenophora*, *Lantana camara*, *Parthenium adenophorum* and *Bidens pilosa*. It is widely accepted fact that preventing biological invasions or tackling them at a very early stage is the most efficient and cost-effective approach (Brunel *et al.*, 2011). This demand awareness of the threats they pose, preventive measures to stop new invasions and control of those species that have already invaded the ecosystems. Distribution maps can be useful tool for community awareness and formulation of appropriate long-term management strategies for AIP species invasion from hotspots and areas which are at risk of becoming climatically suitable for invasion under the future climatic scenarios.

LITERATURE REVIEW

Himalaya being the youngest mountains on earth is very well known for their vast biodiversity due to which they become one of the best sites for study of climate change on the earth. It has been observed that species of higher elevations are projected to shift higher, due to which few invasive alien plant species which were earlier limited to the lower areas are now shifting towards the higher altitudinal areas of Himalaya (Telwala *et al.*, 2013). About 50% of the alien species are deliberately introduced in the Himalaya and others came through trade and grain imports (Sekar *et al.*, 2012). There are still many regions in the world where basic information on naturalized plant taxa and plant invasions is only superficial or completely lacking like Asia and neighboring regions (Corlett, 1988;

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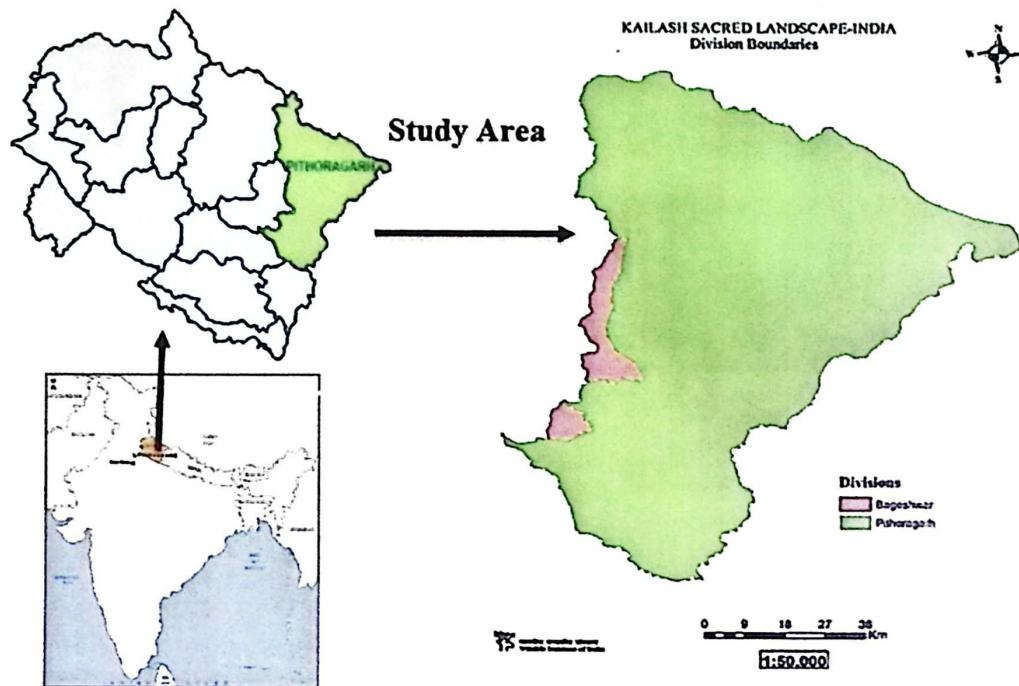


Figure 1: Map showing the study area.

Enomotto, 1999). Therefore, an urgent need was felt to study implications of climate and environmental change on distribution and abundance of major invasive alien species in the Himalayan region along with the impact assessment and management of such species.

MaxEnt (Phillips *et al.*, 2006) has been used to model the potential distribution of invasive species (Pawar *et al.*, 2007; Thomas *et al.*, 2010; Roger *et al.*, 2015; Adhikari *et al.*, 2015; Choudhury *et al.*, 2016; Qin *et al.*, 2016; Mungi *et al.*, 2018) and is being used in the current study.

MATERIALS AND METHODS

Study Area

The present investigation will be conducted mainly for two major invasive alien species *viz.*, *Ageratina adenophora* and *Lantana camara* in Pithoragarh district of Kumaon region, Uttarakhand which falls under Kailash Sacred Landscape (KSL). This landscape is mountainous, remote with steep topography, high spatial heterogeneity, and difficult to access. Of the 31,000 km² KSL area, nearly 7114 km² falls within the Indian territory, that too mainly in Pithoragarh district (96%) followed by Bageshwar (4%). The Indian part of KSL (*ref.* Fig. 1) is culturally rich, ecologically diverse and geographically fragile but with high rates of poverty and facing enormous environmental challenges including fragmentation of natural habitats and degradation (Zomer & Oli, 2011). The KSL-India predominates in diverse

forest (from moist subtropical broadleaf to temperate oak forests, sub-alpine conifers, high altitude birch forests, while extensive alpine pastures in area >3000–3500 m asl). These forests have been intersected by numerous rivers, tributaries and springs. Human habitation includes district headquarter (Pithoragarh), towns, and villages along with their agro-ecosystems covered 1252.73 km² area and represented 17.6% area of the landscape.

Site selection was conducted based on the intensive reconnaissance survey of the KSL-India depending on the availability of the alien plant species, *i.e.* *Ageratina adenophora* (*Eupatorium adenophorum*) and *Lantana camara*. Intensive field surveys were conducted to record the distribution, Geographical coordinates and patch size of these two invasive species using GPS to study the patterns and extent of invasion, presence/absence, abundance and general cover in four major eco-systems *viz.*, forest, fallow land, agricultural and grassland. Colonies with different population intensity of selected species such as dense, moderate and sparse were identified and each was sampled.

The bio-climatic variables and DEM (slope aspect and elevation) of the study area were directly downloaded from the WorldClim and MODIS websites, respectively. We used Maximum Entropy (MaxEnt) distribution modelling, for analysis of data obtained. It is a habitat distribution/probability distribution model which uses presence only data to predict potential distribution of a particular species. MaxEnt model was calibrated using data from observations and geographic distribution records to get the approx area under invasion in Kailash Sacred Landscape.

RESULTS

A potential distribution model was developed with MaxEnt. 25 runs were performed for model, building replicates were taken, and the average model was chosen on the basis of AUC value (for *Ageratina adenophora*: 94 ± 0.01 and *Lantana camara*: 94 ± 0.006). A total of 19 bio-climatic variables were considered including the topographic variables (slope aspect and elevation). The maximum probability of occurrence of *Ageratina adenophora* and *Lantana camara* is shown with red colour in Figure 2, and the least probability of occurrence in green colour in KSL-India landscape.

Different variables were found to be responsible for distribution of the two alien plant species. The most important bio-climatic variable which was responsible for the distribution of *Ageratina adenophora* was found to be precipitation of wettest month (bio_13), followed by annual mean temperature (bio_1) and elevation (DEM; Table 1), whereas in case of *Lantana camara*, the elevation (DEM) was found to be the most important factor responsible for the distribution of the species, followed by precipitation seasonality (bio_15) and aspect, respectively. DEM (elevation) was found to be the most important factor for invasion of *Lantana camara* (35.5%), whereas it contributed only 12% in case of *Ageratina adenophora*. Similarly,

Table 1: Percentage contribution of *Ageratina adenophora* and *Lantana camara* with respect to different variables

<i>Ageratina adenophora</i>		<i>Lantana camara</i>	
Variables	Percentage Contribution	Variables	Percentage Contribution
bio_13	21.4	DEM	35.5
bio_1	12.6	bio_15	31.2
DEM	12	aspect	5.1
bio_8	11.5	bio_2	4.8
bio_6	10	bio_13	3.9
bio_19	7.5	bio_8	3.9
bio_17	5.9	bio_14	3.6
Aspect	3.1	Slope	3.5
bio_12	2.4	bio_18	2.7
bio_14	2.2	bio_19	1.8
bio_2	2	bio_17	1
bio_4	1.7	—	—
bio_11	1.6	—	—
bio_5	1.3	—	—
bio_10	1	—	—
bio_16	1	—	—

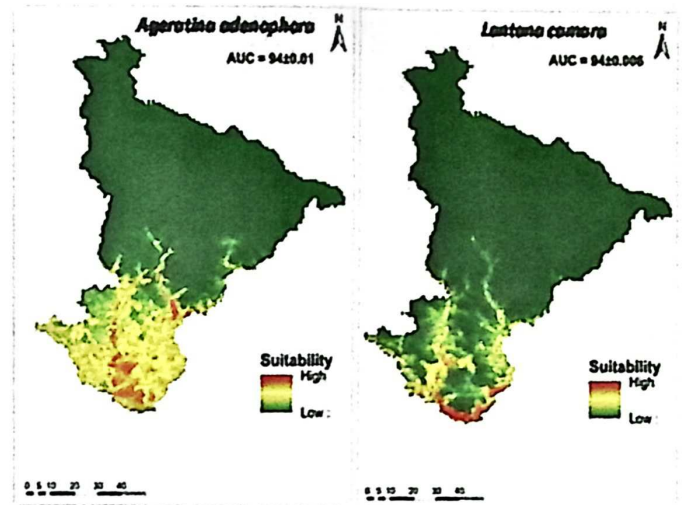


Figure 2: Distribution map of *Ageratina adenophora* and *Lantana camara* through MaxEnt modeling in KSL-India.

bio_13 (precipitation of wettest month) was found to be the most affecting environmental variable for distribution of *Ageratina adenophora* (21.4%), whereas it was found to be contributing only 3.9% in case of *Lantana camara*. Thus, it is evident from our results that the degree of impact of eco-climatic variables varies with species, indicating both the species have different habitat and microclimatic preferences. Our results also suggest that the 80.9% of invasion was dependent on seven variables for *Ageratina adenophora*, whereas only five factors were mainly contributing (80.5%) towards the distribution of *Lantana camara*. When compared with the forest density map, open forests were more vulnerable to invasion followed by moderate and dense forests of the landscape.

DISCUSSION

Our results indicate that open areas adjoining forest fringes are more vulnerable to the growth of both the alien invasive plant species and their distribution is influenced by many eco-climatic factors such as elevation, temperature, precipitation and water bodies along with the anthropogenic disturbance such as roads, settlements and degraded lands which greatly facilitates the invasion of invasive species. Elevation, aspect, and slope are the three main topographic factors that control the distribution and patterns of vegetation in mountain areas (Titshall *et al.*, 2000). The dominating variables which were responsible for the distribution of *Ageratina adenophora* were precipitation, followed by annual mean temperature and elevation. The invasion of *Ageratina adenophora* requires low temperature and high precipitation (Sun *et al.*, 2004; Tereraia & Wood, 2014),

and it has also been reported that invasive plants have a major impact on catchment hydrology (Geldenhuys, 1986); we also recorded the maximum presence (82%) of *Ageratina adenophora* near water bodies (secondary and tertiary tributaries). The annual mean temperature is also important bio-climatic variable as the suitability of habitat of *Ageratina adenophora* increases with increase in annual mean temperature.

Elevation was found to be the most dominant factor followed by precipitation seasonality and aspect for the distribution of *Lantana camara*. The species preferred disturbed micro-habitats either naturally (land-slides and flood sites) or anthropogenic disturbed sites (Mungi *et al.*, 2018) and was found that the intensity of invasion was directly proportional to increase in temperature, whereas inversely proportional to the elevation. Among this elevation was found to be the more dominant limiting factor as the distribution was recorded between 600 and 1700 m asl only. Our results suggest that *Ageratina adenophora* and *Lantana camara* compete with the native species and are capable of excluding native species from any micro-habitat. The invasion of exotic plant species in any ecosystem reduces the biodiversity and alters important ecosystem functions and services (Houlahan & Findlay, 2004). It was observed during the study that the exotic species had a significant negative effect on the native plant community. One reason could be the poor competitive ability of the native species (Gaston, 1994).

CONCLUSION

Plant invasions in the new areas cause huge economic and ecological imbalance by altering native community composition, depletion in species diversity, thus affecting ecosystem process. The increased incidence of invasion in high altitudinal ecosystems possesses a major threat to indigenous biological diversity of the region. Alien invasive species prefers and occupies such habitats which are degraded, disturbed and the habitats where the anthropogenic pressure is much higher than other habitat types in any ecosystem. Some serious mitigation techniques and measures are required to check the further distribution of this alien species in the western Himalayan region. The further distribution of this alien species may cause a serious threat to the local biodiversity and a change in ecosystem process of the area. The results of the present study show the present distribution scenario of two major alien invasive plants in Kailash Sacred Landscape. Red colour shows the area where there is maximum probability of occurrence of *Ageratina adenophora* and *Lantana camara* in KSL-

India landscape. It was observed that the highest invasion of *Ageratina adenophora* was in between 1700 and 1800 m asl elevation gradient and the lowest presence detected between 700 and 800 m asl. *Ageratina adenophora* was recorded highest at Northern aspect which gives the species more sheltered conditions whereas in case of *Lantana camara* its distribution increased with increase in temperature and decrease in elevation. The average model performance may not lose any place where there is high probability of invasion, therefore, the distribution map of alien invasive plants can be used by risk managers for monitoring the spread of these invasive plant and eco-restoration of degraded ecosystems.

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Patterns of invasion by crofton weed (*Ageratina adenophora*) in Kailash sacred landscape region of western Himalaya (India)

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Abstract

Invasion of alien species in high altitude ecosystems is a potent threat to the species diversity as well as it can cause severe environmental and economic issues. The invasion of alien plant species can be facilitated by many eco-climatic factors. The present study was conducted to assess patterns and trends of invasion by *Ageratina adenophora* in major land use and land cover types; in Gokerneshwergad watershed of Kailash Sacred Landscape (KSL) in western Himalaya. Extensive surveys were conducted to map the species in each season and habitat type. Sites with high biotic pressure and open forest canopy were the most suitable habitats for its growth. A negative correlation was found between distribution and altitude. The highest invasion was recorded in between 1700 – 1800m elevation gradient, between 20° and 30° slope positions and at North (33.33%), whereas, the lowest invasion was recorded between 700 – 800m in South-East directions (3.70%). Several other parameters such as distance from the disturbance site such as road, villages or settlements, drainage and soil texture were also found to be affecting the distribution pattern of this species. Interestingly results reveal that the alien plants also start competing among themselves after reaching their threshold level.

Key Words: *Invasive alien species, watershed, Kailash Sacred Landscape, biodiversity, Himalaya*

Introduction

Invasive alien species are those which become established in natural or semi-natural ecosystems or habitats, an agent of change and threaten native biological diversity (IUCN, Guidelines for the prevention of biodiversity loss caused by alien invasive species, 2000). Invasive plant species can cause important economic, environmental and social losses, either introduced deliberately or accidentally to different parts of the world (Anderson, 2005). Plant diversity around the world is facing various threats and is reducing very rapidly (Dogra *et al.*, 2009). Local studies have shown that invasive plant species can directly or indirectly affect the food security of residents. In areas where they spread, invasive can destroy natural pasture, displace native trees, and reduce the grazing potential of rangelands (Admasu, 2008). After the habitat loss, the invasion of alien plant species has become the second-highest threat to plant diversity (Hobbs and Humphries, 1995) in the new regimes. It may be due to invasive species have many important adaptation techniques as compared to native plants as faster rates of growth and biomass

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production compared to native species, high reproductive efficiency including production of a large number of seeds, higher efficient dispersal, competitive ability, rapid establishment, vegetative reproduction, and several other factors that help them adapt to new habitats (Sharma *et al.*, 2005; Simberloff *et al.*, 2005) and broader range of tolerance (Walther, *et al.*, 2009; IUCN, 2013). Preventing or tackling biological invasions at a very early stage is considered as the most efficient and cost-effective approach (Brunel, *et al.*, 2013). This demand awareness of the threats they pose, preventive measures to stop new invasions and control of those species that have already invaded the ecosystems. Some of the widely spread and documented invasive plant species all over the world are *Ageratina adenophora*, *Lantana camara*, *Parthenium hysterophorus* and *Bidens pilosa*. Himalaya being the youngest mountains on earth are very well known for their vast biodiversity due to which they become one of the best sites for the study of climate change on the earth. It has been observed that species of higher elevations are projected to shift higher, due to which few invasive alien plant species which were earlier limited to the lower areas are now shifting towards the higher



altitudinal areas of Himalaya (Telwala *et al.*, 2013). About 50% of the alien species are intentionally introduced in the Himalaya (Sekar and Manikandan, 2012) and others came through trade and gain imports. In India the studies on invasive plants and their invasions is still missing, except a few studies, mainly on the specific locations listing (Myers *et al.*, 2000; Reddy, 2008; Singh *et al.*, 2010; Sekar and Manikandan, 2012) ecological status (Jaryan and Singh, 2013; Sharma *et al.*, 2012; Adhikari and Tiwary, 2015; Saxena, 1993; Bhatt *et al.*, 1994; Negi and Hajra, 2007) comprehensive studies on invasive species and plant invasions are still missing except a few studies (Singh *et al.*, 2008; Myers *et al.*, 2000). Climate change may increase the opportunities for introduction and spread of alien invasive plants (Kriticos *et al.*, 2010; IUCN, 2017). Despite the recognition of the impacts caused by invasive plants worldwide (Mooney and Hobbs, 2000), there are still many regions in the world where basic information on naturalized plant taxa and plant invasions is only superficial or completely lacking

like Asia and neighbouring regions (Corlett, 1988; Enomotto, 1999). Therefore, an urgent need was felt to study implications of climate and environmental change on distribution and abundance of major invasive alien species in the Himalayan region along with the impact assessment and management of such species.

Study area

The study was carried out in Gokerneshwergad watershed, a part of Kailash Sacred Landscape (KSL) in Pithoragarh district of Uttarakhand state, India (Fig. 01). The topography of the study area is hilly with an interspersed of different type of forests, agricultural fields; fallow land ranging from 600 to 2200m. The climate is mild and generally warm. The summers have much more rainfall when compared with winter. The average temperature is 25 °C. The rainfall here averages 1263 mm. (USIDCL 2012). The total area of the watershed under study was calculated using Arc GIS and was found to be 31.93 Km².

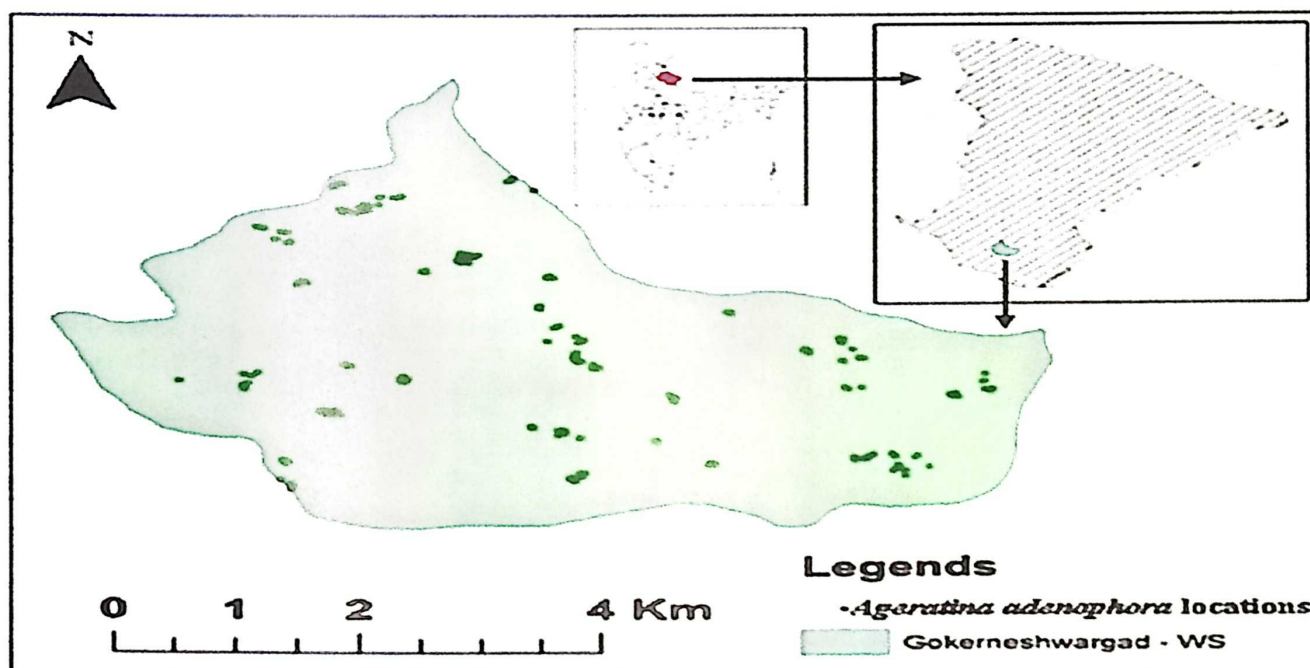


Fig 1. Study area and distribution map of *Ageratina adenophora* at Gokerneshwergad watershed of KSL-India

Materials and Method

Site selection was conducted based on the intensive reconnaissance survey of the Gokerneshwergad watershed depending on the availability of the alien

plant species, i.e. *Ageratina adenophora* (Syn. *Eupatorium adenophorum*). Intensive field surveys were conducted during January to April 2016 to record the maximum patches of invasion by



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Ageratina adenophora in adjoining areas of 20 villages in Gokerneshwer gad watershed covering forests, fallow lands, agricultural lands and grasslands.

The invasion of *Ageratina adenophora* was also discussed with the local communities and based on the group discussions patches in each village were identified and classified based on the population intensity of selected species such as dense, moderate or sparse. Following the participatory mapping of species-specific, a rapid ecological assessment was carried out in 41 different patches. 229 random quadrates of 1x1m² were laid in the identified patches in the watershed. The number of individual of *Ageratina adenophora* and its clumps were recorded in each plot. The density of *Ageratina adenophora* was calculated following the method proposed by Misra (Misra, 1968).

Results and Discussion

Elevation, aspect, and slope are considered the three main topographic factors responsible for the distribution and patterns of vegetation in mountain areas (Titshall, O'Connor and Morris, 2000). Therefore, these topographic factors (aspect, elevation and slope) of the region were created from a digital elevation model. Euclidean distance from road and water source was prepared in Arc GIS-L1, and cover types, important geological layers such as soil textures were also prepared. Several other parameters such as distance from the disturbance site and watershed and land cover type

were also found to be important that control the distribution and pattern of *Ageratina adenophora*. The results of the current study are illustrated as follows:

The area of invasion was least in Godiyagaon (485 m²) followed by Bhurmuni village (613 m²) whereas, the maximum invasion was recorded in Dhyuree (5370 m²). The maximum density of *Ageratina adenophora* was recorded in Jajroli (203/m²) followed by Mostmanu (230.83/m²), and the lowest value (62.25/m²) was recorded in Bhurmuni (Fig 2). Out of 41 patches surveyed; maximum patches were recorded in the boundaries of Bichcot, Jagtar and Naini villages (04) whereas, the lowest number of patches were recorded in Malliseem, Sinchora, Sintoli, Dhooga Bhoor, Bhurmuni, Mostmanu, Sanghar, Jajroli, Godiya Gaon (01 each).

The density of *Ageratina adenophora* was also calculated in different ecosystems of the study area. As per our study, the maximum density of *Ageratina adenophora* in the fallow land was recorded in GodiyaGaon (248/m²), whereas, the minimum density was recorded in Bichcot village, which was 95.87/m². In case of invasion of agriculture land, the maximum density was recorded in Chera village (196.75/m²), whereas, the minimum was recorded from Jagtar village (70.5/m²). Chera village has a maximum invasion of *Ageratina adenophora* (200.7/m²) in terms of density in forest whereas; minimum (62.7/m²) was recorded in Bhurmuni village (Fig 3).

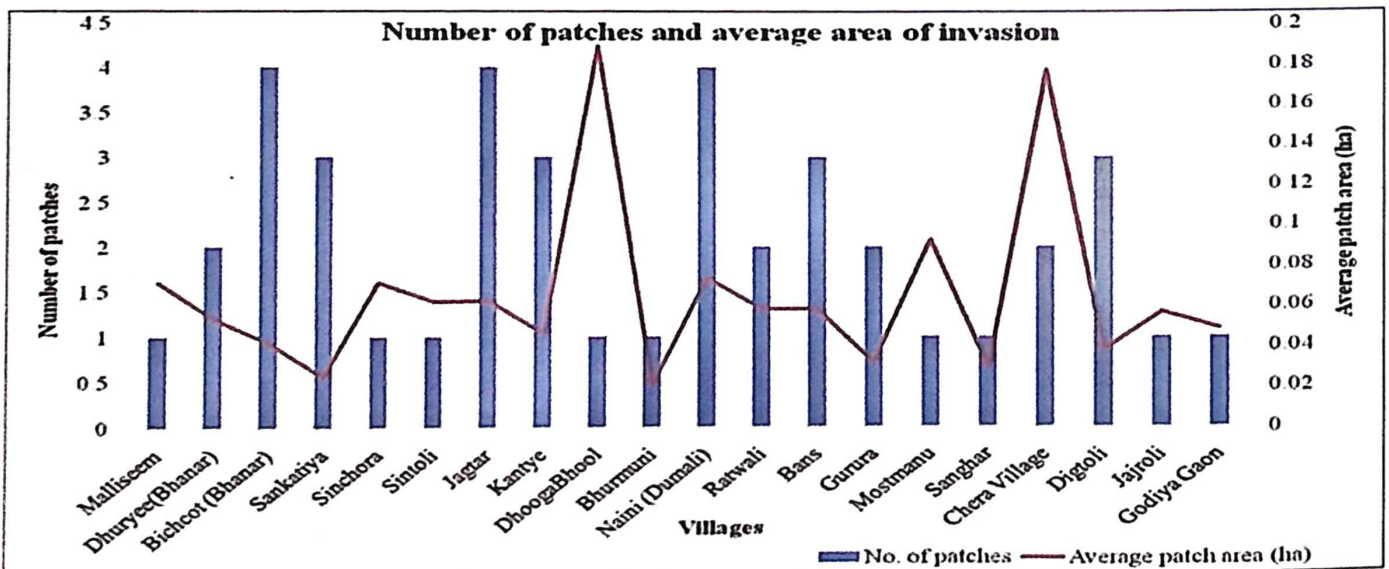


Fig 2. *Ageratina adenophora* invasion in different villages of Gokerneshwer-gad watershed



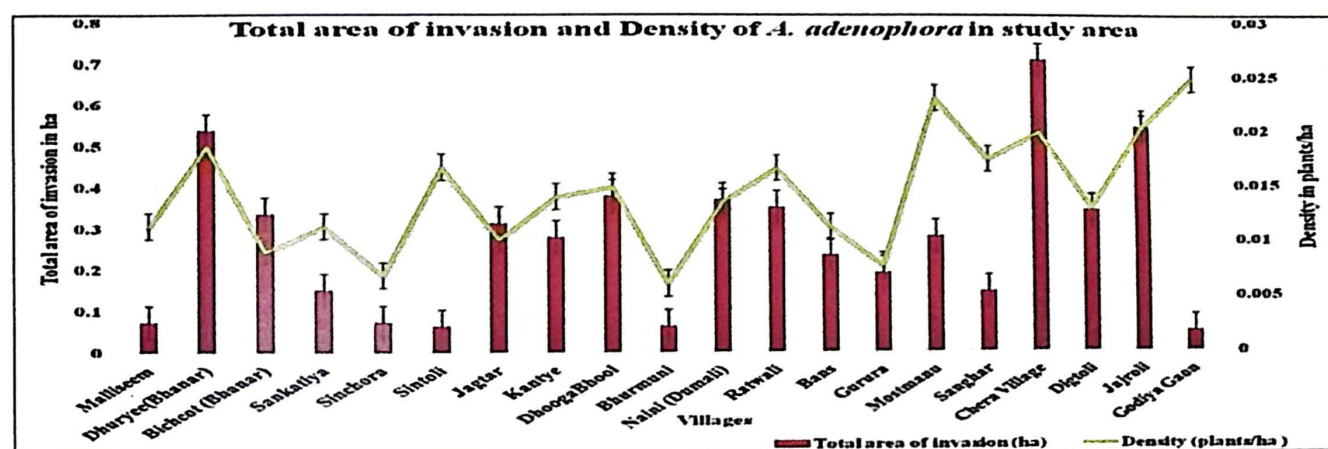


Fig 3. Density of *Ageratina adenophora* in different Ecosystem (village wise) of Gokerneshwer-gad watershed

In terms of area, fallow lands had a maximum area of invasion followed by Agricultural land and grassland whereas, highest patch density was observed in most of the grasslands and agricultural lands of Gokerneshwer-gad watershed. The various ecological parameters which affected the distribution of *Ageratina adenophora* were as follows:

- Slope:** Slopes of landforms control the amount of rainwater accumulation. Within this region, the maximum presence of *Ageratina adenophora* was observed between 20° and 30° slope positions (Fig 4) as it requires moderate slope steepness for more stability. Slope (Titshall *et al.*, 2000) has also been reported to be one of the important parameters for invasive species distribution.
- Distance from road:** The results suggest that the distance from the road was inversely proportional to the growth of *Ageratina adenophora* invasion in the study area as the highest invasion (41.39%) was observed at roadsides (Fig 5). Similar patterns were also observed by various other workers in other ecosystems (Tyser and Worley, 1992; Parendes and Jones, 2000; Watkins *et al.*, 2003). Our results were also in line with (Kosaka, *et al.*, 2010) and (Bhattarai *et al.*, 2014), who reported that plant invasion in mountainous regions of India and Nepal was facilitated by road construction and the distribution varied with altitude.
- Land use cover type:** The maximum occurrence of *Ageratina adenophora* (Fig 6) was recorded in the fallow land (69.97%) followed by grassland (18.67%), agriculture (9.10%) and forest (2.26%). The success of invasive alien plants is due to their opportunistic exploitation of anthropogenic disturbances, the absence of natural enemies, and frequently, higher dispersal rate and competitive ability, (Kunwar, 2003; Simberloff *et al.*, 2005; Sharma *et al.*, 2005; Simberloff *et al.*, 2005; Simberloff *et al.*, 2005).
- Distance from water source:** Invasive plants have a major impact on catchment hydrology, (Geldenhuys, 1986) reported 30-70% lower water runoff from watershed areas with dense stands of alien species this was also supported by our results (Fig 7) as maximum presence of *Ageratina adenophora* (82%) was recorded near the water bodies (secondary and tertiary tributaries).
- Aspect:** A community strongly affected by aspect and this appears in the species distribution at special aspects. *Ageratina adenophora* was recorded highest at North (33.33%) followed by North-West (24.53%), South-West (11.57%), South (9.25%), West (8.79%), East (4.62%), North-East (4.16%) and lowest invasion was recorded in South-East (3.70%). Most of *Ageratina adenophora* was concentrated on the North and North-West direction, which gives the species more sheltered conditions (Fig 8).



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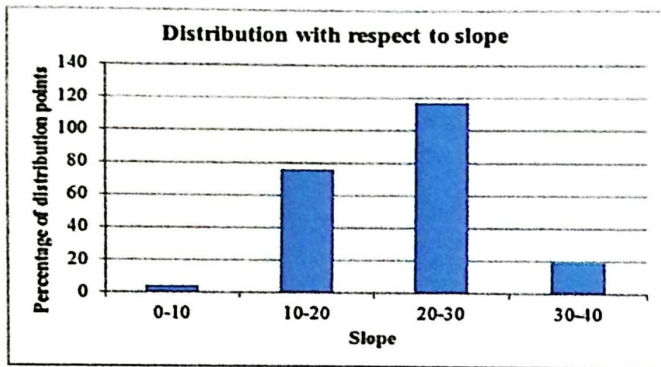


Fig 4. *Ageratina adenophora* distribution with respect to slope.

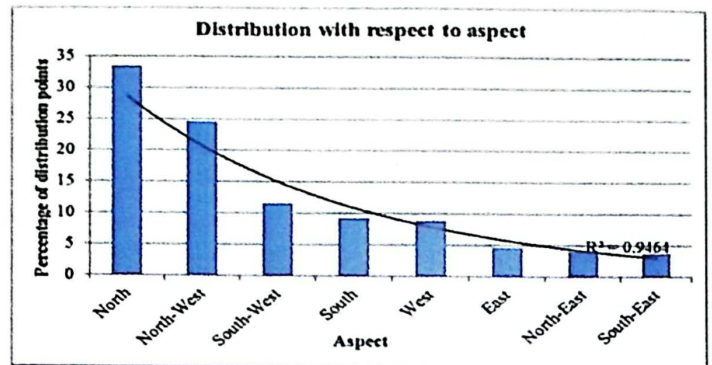


Fig 8. *Ageratina adenophora* distribution with respect to the aspect.

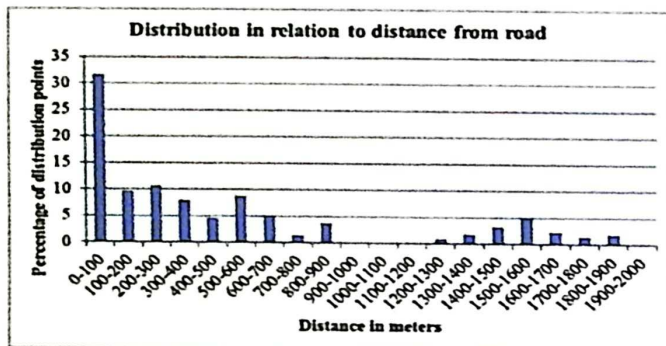


Fig 5. *Ageratina adenophora* distribution with respect to distance from the road.

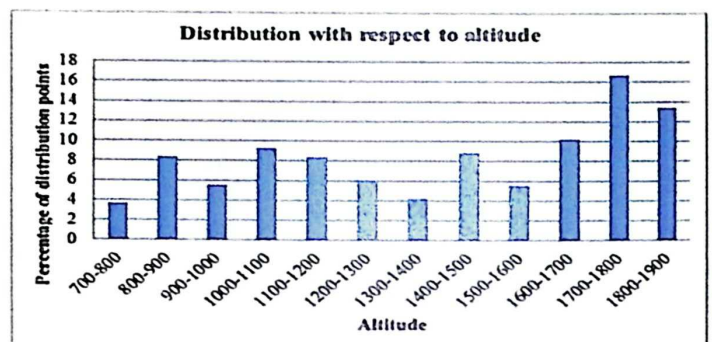


Fig 9. *Ageratina adenophora* distribution with respect to altitude.

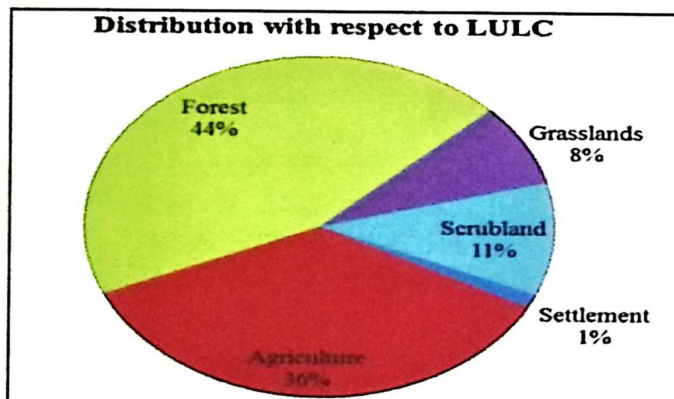


Fig 6. Distribution of *Ageratina adenophora* with respect to LULC.

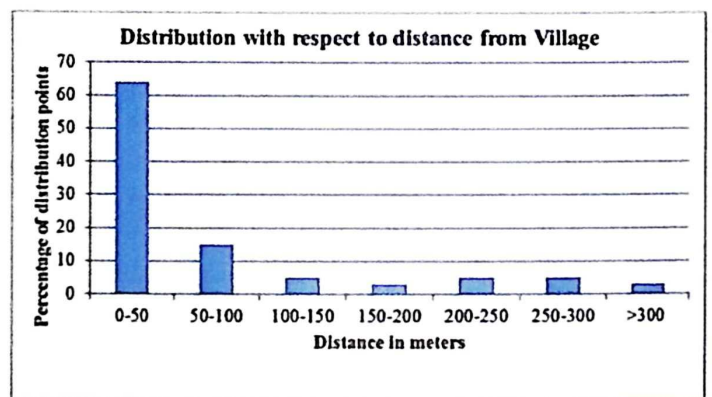


Fig 10. *Ageratina adenophora* distribution with respect to distance from the village

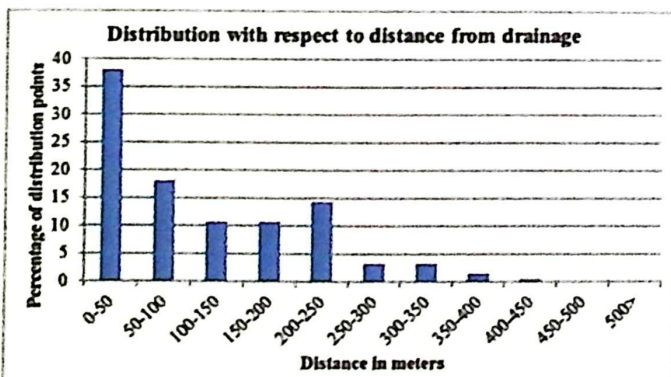


Fig 7. Distribution of *Ageratina adenophora* with respect to distance from the water source.

6. **Elevation:** An elevation determines the microclimate of an area; thus, it also determines the large-scale spatial distribution and patterns of vegetation (Busing *et al.*, 1992). The relationship was further confirmed when the distribution and altitude maps were superimposed by GIS. It was observed that the highest *Ageratina adenophora* invasion (16.66%) was in between 1700 – 1800m elevation gradient and the lowest presence (3.70%) detected between 700 – 800m (Fig 9).



7. **Distance from the village:** During the study, it was noticed that the abundance and occurrence of *Ageratina adenophora* were inversely proportional to the distance from the village or disturbance site. As we moved away from the villages, less density and abundance of *Ageratina adenophora* was recorded (Fig. 10). Both natural and direct anthropogenic disturbances are known to promote invasion of exotic species (Hobbs and Huenneke, 1992) (Lozon and MacIsaac, 1997); (D'Antonio *et al.*, 1999). Thus it could be concluded that the disturbance or anthropogenic activities are favourable for the distribution of *Ageratina adenophora*.

The number of clumps of *Ageratina adenophora* was found to be negatively correlated with the digital elevation (DEM) thus altitude plays an important role in distribution of this alien plant species and number of clumps was negatively correlated with mean number of plants per clump indicating that more the density of clumps lesser is the number of plants per clump in an area. Thus it may also be said that after acquiring an area, the species is competing to itself. A very interesting correlation was found between the environmental and ecological variables with the total clumps, total plants and mean number plants per clump of *Ageratina adenophora* in the study area (Table 1).

The PCA shows a negative correlation between the clumps of *Ageratina adenophora* and altitude, indicating that the number of clumps of *Ageratina adenophora* decreases with increase in altitude whereas it also decreases with increase in distance from drainage and soil texture (Fig 11). A negative correlation of clumps to mean number of plants per clump was also found suggesting that as the number of clumps increase in an area, the mean number of plants per clump decreases which further indicates that after reaching a threshold level the alien plants start competing among themselves. Similarly, a positive correlation was found between total clumps and total *Ageratina adenophora* plants in the study area. On the other hand, a positive correlation was also found between the mean number of plants per clump and distance from road and village/settlements suggesting that this plant species prefer to remain in clumps as it moves away from the disturbance sites. The total number of clumps also increased with the decline in distance from the drainage suggesting that this species prefer habitats which are moist to dry habitats. Thus availability of water source is also one of the important factors in distribution of this alien plant species although it does not require more fertile land to grow as a negative correlation was found between total number of clumps of this plant species and soil texture.

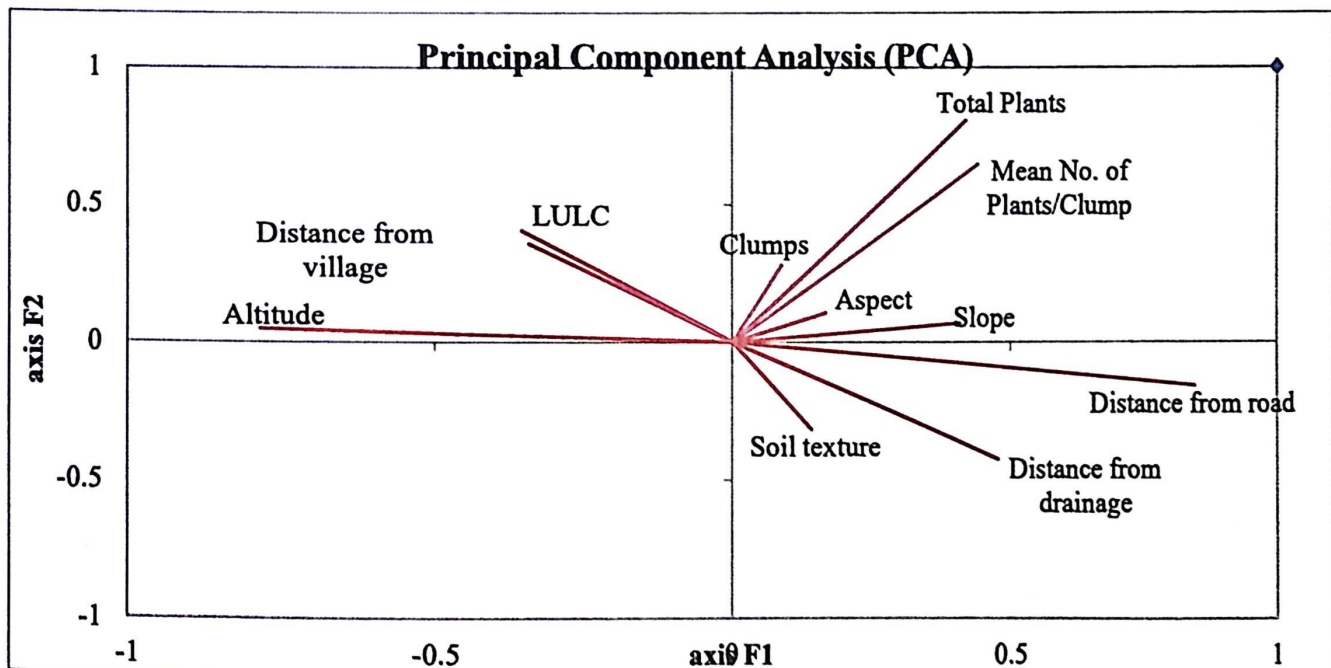


Fig 11. Factors responsible for distribution and invasion of *Ageratina adenophora*



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Table 1. Correlation between various factors and variables responsible for the distribution of *Ageratina adenophora*

	slope	Altitude	Distance from village	Distance from road	Aspect	Distance from drainage	Soil texture	LULC	Clumps	Total Plants	Mean No. of Plants/Clump
Slope	1	-0.345	0.120	0.238	0.176	0.074	0.044	-0.020	0.081	0.061	0.041
Altitude	-0.345	1	0.343	-0.674	-0.178	-0.187	0.152	0.102	-0.165	-0.133	-0.107
Distance from village	0.120	0.343	1	-0.080	0.003	-0.112	-0.209	0.294	0.011	0.001	-0.005
Distance from road	0.238	-0.674	-0.080	1	0.121	0.495	0.094	-0.250	0.004	0.146	0.208
Aspect	0.176	-0.178	0.003	0.121	1	-0.057	-0.047	0.134	0.058	0.010	-0.035
Distance from Drainage	0.074	-0.187	-0.112	0.495	-0.057	1	0.097	-0.157	-0.156	-0.098	0.035
Soil texture	0.044	0.152	-0.209	0.094	-0.047	0.097	1	-0.262	-0.140	0.009	0.036
LULC	-0.020	0.102	0.294	-0.250	0.134	-0.157	-0.262	1	-0.028	0.012	-0.012
Clumps	0.081	-0.165	0.011	0.004	0.058	-0.156	-0.140	-0.028	1	0.320	-0.237
Total Plants	0.061	-0.133	0.001	0.146	0.010	-0.098	0.009	0.012	0.320	1	0.779
Mean No. of Plants/Clump	0.041	-0.107	-0.005	0.208	-0.035	0.035	0.036	-0.012	-0.237	0.779	1

In bold, significant values (except diagonal) at the level of significance $\alpha=0.050$ (two-tailed test)

Conclusion

Plant invasions in the new areas cause huge economic and ecological imbalance by altering native community composition, depletion of species diversity thus affecting the ecosystem process. The increased incidence of invasion in high altitudinal ecosystems possesses a major threat to the indigenous biological diversity of the region. The results indicate that four environmental variables viz. altitude; soil texture, distance from disturbance site such as road and village/settlement as well as a water source as the distance from nearest drainage, play a major role in the distribution and invasion of *Ageratina adenophora*. This species prefers and occupies such habitats which are degraded, disturbed and the habitats where the anthropogenic pressure is much higher than other habitat types in any ecosystem and does not require much fertile land to invade. Some serious mitigation techniques and measures are required to check the further distribution of this alien species in the western Himalayan region as this species was recorded up to an elevation of about 2100 masl. The further distribution of this alien species in the Himalayan region may cause a serious threat to the local biodiversity and a change in ecosystem process of the area causing loss of vital ecosystem services.

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Patterns of invasion by crofton weed (*Ageratina adenophora*) in Kailash sacred landscape

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RESEARCH ARTICLE

Ageratina adenophora and *Lantana camara* in Kailash Sacred Landscape, India: Current distribution and future climatic scenarios through modeling

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Abstract

The Himalayan region is one of the global biodiversity hotspots. However, its biodiversity and ecosystems are threatened due to abiotic and biotic drivers. One of the major biotic threats to biodiversity in this region is the rapid spread of Invasive Alien Species (IAS). Natural forests and grasslands are increasingly getting infested by IAS affecting regeneration of native species and decline in availability of bio-resources. Assessing the current status of IAS and prediction of their future spread would be vital for evolving specific species management interventions. Keeping this in view, we conducted an in-depth study on two IASs, viz., *Ageratina adenophora* and *Lantana camara* in the Indian part of Kailash Sacred Landscape (KSL), Western Himalaya. Intensive field surveys were conducted to collect the presence of

A. adenophora ($n = 567$) and *L. camara* ($n = 120$) along an altitudinal gradient between 300 and 3000 m a.s.l. We performed Principal Component Analysis to nullify the multi-collinearity effects of the environmental predictors following *MaxEnt* species distribution model in the current and future climatic scenarios for both the species. All current and future model precision (i.e., Area Under the Curve; AUC) for both species was higher than 0.81. It is predicted that under the current rate of climate change and higher emission (i.e., RCP 8.5 pathway),

A. adenophora will spread 45.3% more than its current distribution and is likely to reach up to 3029 m a.s.l., whereas, *L. camara* will spread 29.8% more than its current distribution range and likely to reach up to 3018 m a.s.l. Our results will help in future conservation planning and participatory management of forests and grasslands in the Kailash Sacred Landscape-India.

Introduction

Invasive alien species (IAS) rank among the top three threats to global biodiversity, the other two being unsustainable harvest of various species from the wild and habitat degradation and

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loss [1]. Invasive species, coupled with unsustainable resource use and climate change have seriously affected the livelihoods of millions of people in south and south-east Asia [2]. The rapid spread of invasive alien species affects natural habitats, regeneration potential of native species and affects the productivity of forests and grassland habitats [3]. The spread of alien species is particularly challenging in terrestrial ecosystems across the world [4–6]. Changes in climatic conditions and land use practices favour the introduction and spread of IAS in most parts of the world [7–9]. Therefore, it is vital to assess the current extent and future scenarios of invasion for various IAS [10–12].

The Himalayan region, one of the global biodiversity hotspots, is quite vulnerable due to climate change and other abiotic and biotic drivers of change including the rapid spread of IAS. Some of the most obnoxious IAS in this region includes *Lantana camara*, *Ageratina adenophora*, *Parthenium hysterophorus*, and *Ageratum conyzoides* [13]. During the past few decades increasing anthropogenic pressures such as unabated linear infrastructure development, uncontrolled tourism, livestock grazing, agricultural expansion and extraction of non-timber forest products (NTFPs) have led to the degradation of wildlife habitats and the spread of a large number of invasive species [14]. It is estimated that total 297 IAS species belong to 65 families were reported in the IHR [13]. One of the major causes of the spread of IAS in the Himalayan region is climate change [15]. It has been observed that plant species of higher elevation are projected to shift higher, due to which a few IAS previously limited to the lower elevations are now shifting towards the higher altitudes in the Himalaya [15,16].

As a signatory to Convention on Biological Diversity, India has set its National Target in alignment with Aichi Biodiversity Targets. Accordingly, India's Biodiversity Strategy and Action Plan aim to identify the priority species of IAS as well as their invasion pathways so that appropriate management strategies could be formulated. It is realized that very few base-line studies have been conducted on the current extent and spread of even common species in the Himalayan region. Anthropogenic pressures coupled with climate change make complex the future prediction of species spread. Several authors [e.g., 15,17–21]; have opined that the IAS which were earlier limited to the lower areas are likely to shift towards the higher elevations in the Himalaya. This calls for the validation of earlier models as well as multi-location studies. In this paper, we present the findings of a case study on two IAS, viz., *A. adenophora* and *L. camara* at a landscape level within the Indian part of Kailash Sacred Landscape–India, hereafter referred as KSL–India. The major objectives of the study were to predict the potential current spread of these species in KSL–India and predict their invasion in future climate change scenarios.

Materials and methods

Study area

The study was carried out in KSL–India that is located between 29°26'35" to 30°35'13" N and 80°01'24" to 81°02'44" E. It is characterized by heterogeneous landscape, wide altitudinal range (ca. 800 to over 7000 m a.s.l.), diverse topography and rich biodiversity [17]. This area is contiguous with far-western Nepal and Tibet Autonomous Region (TAR) of China. The study area is spread over 7,120 km² (Fig 1).

KSL–India has the predominance of diverse natural ecosystems from grasslands to moist sub-tropical broadleaved to temperate oak forests, sub-alpine conifers, high altitude birch forests, while extensive alpine pastures occur in areas >3000 to 4000 m a.s.l. beside agro-ecosystems in lower reaches [22,23]. The diverse habitats cater to numerous indigenous flora and fauna. The forests in KSL–India falls into two categories—Protected Areas (PAs) and Non-Protected Areas. KSL–India includes only one legally designated PA (i.e. Askot Wildlife

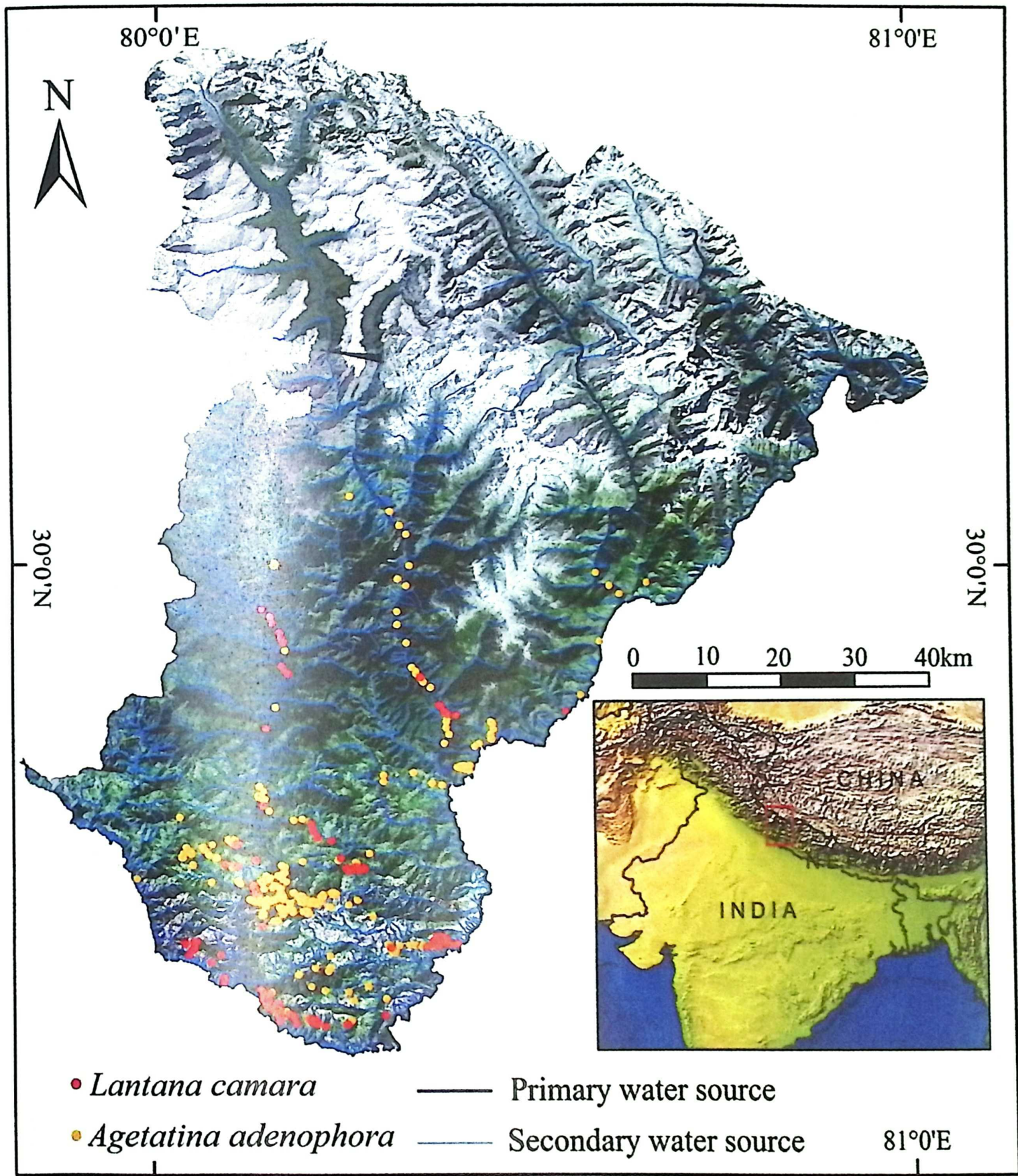


Fig 1. Geographical location of the study area with sampling locations of *Lantana camara* and *Ageratina adenophora*.

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Sanctuary) which provides important ecosystem services for the region. However, the non-PA category of forests includes reserve forests and protected forests under the control of the State Forest Department of Uttarakhand, managed for an extended period for the production of timber and non-timber forest products (NTFPs). KSL–India also includes highly interspersed small forest fragments falling under two broad categories, *i.e.*, civil/soyam forests and community forests are under the control of the Revenue Department of the State Government. The latter category of community forests, for nearly nine decades or so, has been managed by the local communities and is referred to as ‘Community Forests’ or ‘Van Panchayat Forests’. This community forest serves as the primary source of livelihood for locals. The KSL–India has experienced a considerable change during recent decades in terms of land use and land cover, along with the development of infrastructure and patterns of natural resources used by the local communities [23,24].

Species presence

After the extensive vegetation survey and consultation with experts, the two most widely spread IAS, *i.e.*, *Ageratina adenophora* (Asteraceae) and *Lantana camara* (Verbenaceae) were selected for the present study. *A. adenophora* is native of Central America [25] and distributed worldwide [26]. *L. camara*, native to Tropical America [27] is considered to be one of the most troublesome invasive species worldwide [28]. *A. Adenophora*, a perennial, herb produces a large number of tiny seeds which are dispersed by wind and human activities [29]. Its ubiquitous property to invade diverse habitats, such as roadsides, riverbanks, forest edges, crop fields, wastelands, and rubbish dump edges makes it fit to invade various ecosystems. *L. camara* is one of the most widely distributed IAS in India [30], resistant to fire and can regrow if burnt [31]. It reproduces primarily by seeds as well as through coppice and prefers to grow in degraded habitats.

Though, the species selected for the study are known to negatively affect the wildlife habitats and native vegetation, they are also known to have a few minor uses to local communities. Leaves of *A. adenophora* are used for cattle bed [32], or its leaf paste is applied to cuts and wounds and leaves are also have the properties of antimicrobial activity, antipyretic activity, wound healing, antioxidant activity, analgesic activity, anti-tumor activity, insecticidal activity, antiviral activity, anti-inflammatory activity, and larvicidal activity [33,34]. The wood of *L. camara* is used as fuel [35,36], a source of food for birds [37–39] and nectar for butterflies and moths [40,41] as flowering and fruiting happens throughout the year.

Presence record

We recorded *A. adenophora* and *L. camara* presence between 300 and 2500 m a.s.l. covering a wide range of habitats including agricultural lands, grasslands, fallow lands and forests, proximity to major road networks and naturally occurring drainages in different parts of the landscape during 2014 to 2017. A total of 567 and 120 presence locations for *A. adenophora* and *L. camara*, respectively were recorded using handheld Garmin N72 GPS (Supplementary Information). Of these, 80% locations were used for probability distribution modeling and the rest 20% were used to evaluate the model performance. The study was conducted outside the protected area and no Schedule-I or -II species were used in the study.

Selection of environmental and bioclimatic variables

We used two-time periods (“current” and “2050”) environmental data to model the *A. adenophora* and *L. camara* current and future distribution in KSL–India. A total of 22 environmental variables were used for probability distribution modeling in each period. We retrieved

standard 19 bioclimatic variables for WorldClim version 2 [42]. These are the average for the years 1970–2000 with a spatial resolution of 30 seconds (~1 km²). These variables are considered as current bioclimatic variables. We also retrieved 19 bioclimatic variables with a spatial resolution of 30 seconds (~1 km²) for the year 2050 (average for 2041–2060). These are the climate projections as per the Intergovernmental Panel on Climate Change (IPCC) 5th assessment report from Global Climate Models (GCMs) for one Representative Concentration Pathways (RCPs). However, we used RCP 8.5. Because, out of several IPCC climate change scenarios, RCP 8.5, generally taken as the basis for worst-case climate change scenario among all (viz., RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5.) [43–45]. The data were downscaled and calibrated using WorldClim 2 as baseline 'current' climate [42,46]. These bioclimatic data are also the most recent GCM climate projections that have already been considered in the IPCC fifth assessment report.

We also considered four major static topographic factors for both the "current" and "2050" time frame. These are elevation (ASTER, Digital elevation data from Advanced Spaceborne Thermal Emission and Reflection Radiometer), slope, aspect, Euclidian distance from water channels and Euclidian distance from major roads. These variables were assumed to be constant across the entire study period. The details of all the variables used in this study are provided in Appendix 1 in S1 Appendix.

Pair-wise Pearson correlations and principal component analysis

We checked for multi co-linearity with pair-wise correlations for both "current" and "2050" environmental data sets to avoid spurious model calibrations [47]. It is common practice to retain only predictors with pair-wise correlation $< |0.7|$ [48]. To nullify the correlation structure of the variables and inter-relationship among them, we implemented the Principal Component Analysis [PCA; 49,50]. The PCA reduces the number of orthogonal predictors each of which is the linear combination of 24 original environmental variables. All the exploratory variables were subjected to PCA to extract the factors of significant contribution using *prcomp* function and *predicting* the function of R version 3.3.3 [51]. Furthermore, we obtained 24 Principal Components (PCs) in raster format. For both "current" and "2050" data sets, the first six PCs accounted for 99% of the variability and were chosen for further multivariate species distribution modeling (Table 1).

MaxEnt species distribution modeling

Maximum Entropy (*MaxEnt*) distribution modeling was implied to identify the current and future invasion for both, *A. adenophora* and *L. camara* in KSL–India. *MaxEnt* is a machine learning algorithm that is widely used for species distribution modeling that uses presence-only data [52,53] to predict the potential distribution of a particular species in the current as well as future climatic scenarios [54,55].

The occurrence data from the field was collected for both *A. adenophora* ($n = 567$) and *L. camara* ($n = 120$). One thousand background points were drawn randomly across the KSL–India by considering the pseudo-absence of both species. We generated four main *MaxEnt* models (two for each species) using the six PCA derived explanatory variables for both the 'current' and '2050' year.

We implemented k-fold cross-validation [56] to build each main *MaxEnt* model. Firstly, we used standard k-fold cross-validation in our randomly partitioned approach. In our k-fold cross-validation approach, the occurrence localities were divided randomly into 10 bins, where each bin constitutes an equal proportion of sample size [57,58]. Then, each model was developed iteratively, using $(k - 1)$ bins for model calibration in each iteration, with the

Table 1. Representation of the first seven principal components derived from all 24 original environmental variables along with the proportion of variance in environmental variables explained by each principal component and their cumulative proportion of variance.

Principal components	The “current” year		Year 2050	
	Proportion of Variance	Cumulative Proportion	Proportion of Variance	Cumulative Proportion
PC1	0.98890	0.98890	0.98880	0.98880
PC2	0.00810	0.99700	0.00810	0.99700
PC3	0.00276	0.99979	0.00277	0.99973
PC4	0.00013	0.99992	0.00015	0.99988
PC5	0.00007	0.99998	0.00008	0.99996
PC6	0.00001	0.99999	0.00003	0.99999
PC7	0.00000	1.00000	0.00000	1.00000

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remaining fold retained for evaluation. This is repeated until all the folds were utilized at least once for model evaluation. *MaxEnt* produces a model based on a series of ‘features’, such as linear, hinge, quadratic, product, threshold and discrete; we used all except for discrete, as all of our explanatory variables were continuous [59]. In the ‘feature’ functions, we set the beta multiplier as 0.5 (medium) that affects the smoothness of the model output. We have opted for the clamping function in each model as the use of the function is strongly suggested for projecting future species distributions [60,61].

As we set the models *via* k-fold cross-validation ($k = 10$), for each dataset, we used the respective evaluation localities to calculate Area Under the Curve (AUC) of the Receiver Operation Characteristic (ROC), which is a measure of the overall discriminatory ability of the model or to precisely evaluate model performance by plotting its model sensitivity graph [62]. We averaged those values from each sub-models of each main model and represented the averages for each of the four main *MaxEnt* models. The AUC score closer to 1 indicates that the model had accurately predicted the habitat, while a value $\diamond 0.5$ indicates the low accuracy of the model [63]. We also calculate other model evaluation matrices such as kappa max (kappa), true positive rate (TPR), true negative rate (TNR), and True skill statistics (TSS) using the ‘*dismo*’ package in R [64].

Binary habitat invasion maps for the ‘current’ and future ‘2050’ were prepared by using the threshold of maximum training sensitivity plus the specificity logistic threshold. The threshold approach of ‘*Maximum training sensitivity + specificity*’ is a more reliable, restrictive and conservative approach to understand the potential distribution of a species. This particular threshold approach is one of the popular methods either for presence/absence or presence-only data [65]. We used ‘*dismo*’ package in R [64] along with a source file developed to build all *MaxEnt* models [66] as well as to evaluate their performance.

Invasion across the elevation gradient

To check the future spread of *A. adenophora* and *L. camara*, we extracted all elevational range values from a 30 m resolution digital elevation model (ASTER) using the threshold polygons generated from *MaxEnt* main models. Elevation gradients that fall within the distribution ranges were re-classified into multiple classes considering 100 m a.s.l. intervals. Area invaded by both species in each elevation class was compared between current and 2050 year using paired sample t-test. The distributions of elevation class vs. invaded areas of both *A. adenophora* and *L. camara* were plotted separately for the current year and 2050 to visually assess their spread pattern across the elevation classes.

Results

The pair-wise Pearson correlations were generally higher ($r > |0.70|$) for most of the variables (Fig 2). We were not able to use these variables directly in *MaxEnt* as they showed high correlation, and this avoids the overprediction of suitability in *MaxEnt* models. However, PCA transformed the 24 environmental variables (each for ‘current’ and ‘2050’) into a composite set of 24 components that are orthogonal and un-correlated to each other. Six out of 24 components demonstrated the cumulative proportion of variance > 0.99 for both the ‘current’ and the year ‘2050’ (Table 1). The first six PCs each from the ‘current’ and ‘2050’ were represented in Appendices 2–3 in S1 Appendix.

Both training and test area under ROC curve (AUC) values were > 0.81 for both species under the ‘current’ and future ‘2050’ climatic conditions (Fig 3, Table 2). Other model evaluation statistics were provided in Appendix 4 in S1 Appendix. The current occurrence locations of *A. adenophora* and *L. camara* were 95.1% and 92.5%, respectively falls within their most climatically suitable current distribution ranges. The relative percent contribution of all PCs from both the ‘current’ and the year ‘2050’ are presented in Table 3, and all response curves associated with the above *MaxEnt* model predictions were given in Appendix 5 in S1 Appendix. The current and future distributions of the *A. adenophora* and *L. camara* along the elevation gradient of KSL–India are determined by the RCP 8.5 pathway projections for 2050 (Fig 4A and 4B).

The current distribution of *A. adenophora* ranges between 212–2616 m a.s.l., while *L. camara* distributed mostly below 2045 m a.s.l. The potential area that is currently vulnerable to invasion by *A. adenophora* and *L. camara* extends to 1403.7 km² and 1053.1 km², respectively. If the climate change continues to follow the higher emission RCP 8.5 pathway, by 2050, invasion of *A. adenophora* would reach up to 3029 m a.s.l., whereas, *L. camara* will invade up to 3018 m a.s.l. Both *A. adenophora* and *L. camara* will spread across the landscape occupying an area of 2039.7 km² and 1366.5 km², respectively. The area invasion by *A. adenophora* ($t =$

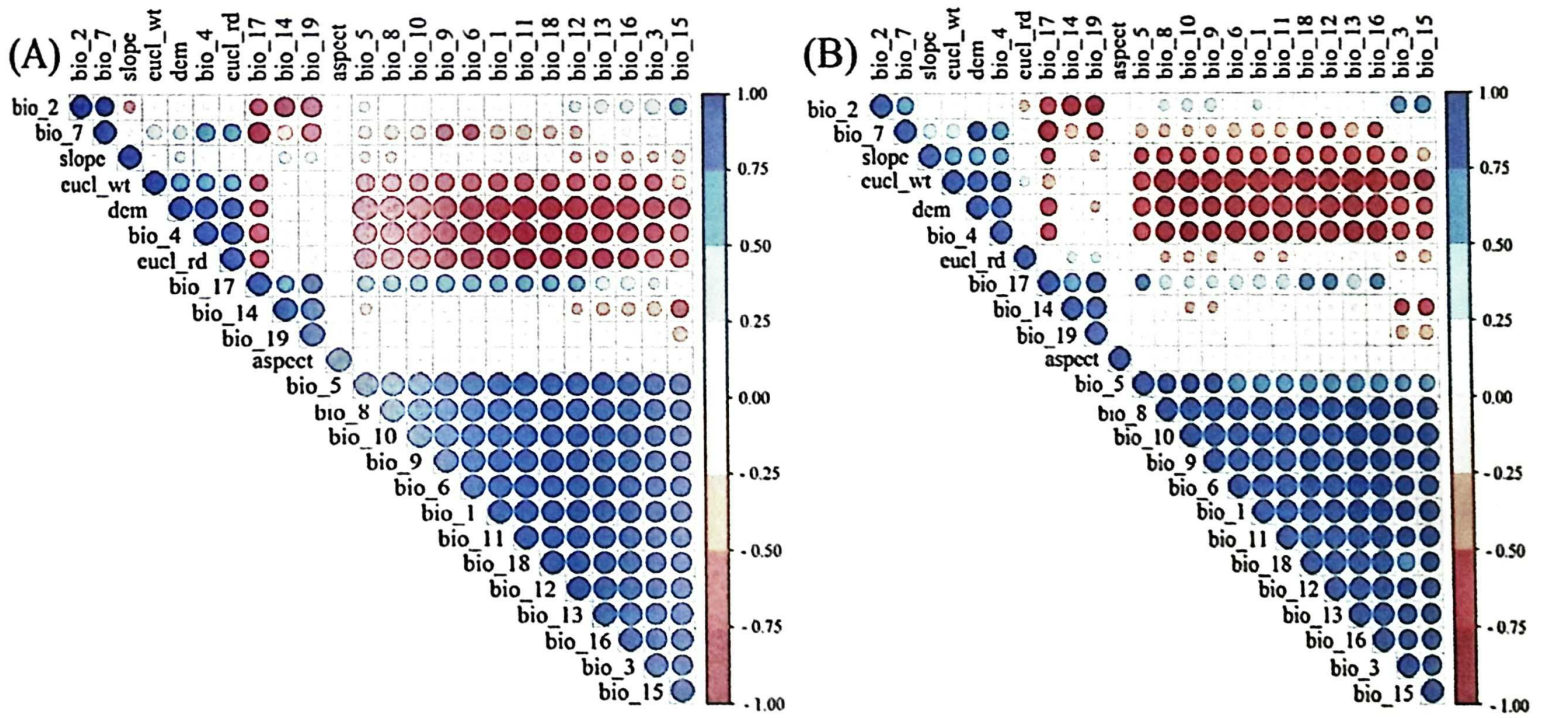


Fig 2. Representation of Pearson correlation matrix for environmental data of the “current” year (A) and year 2050 (B).

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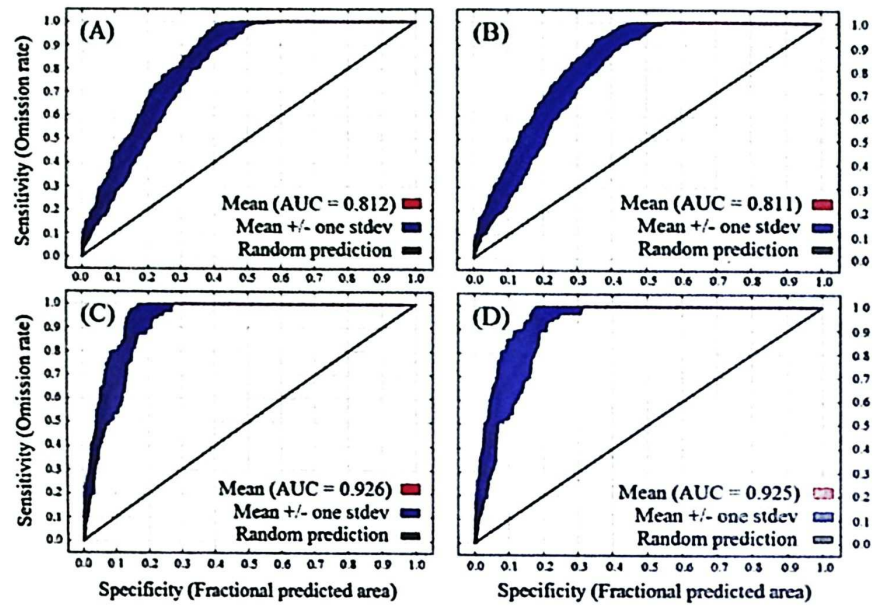


Fig 3. Receiver operating characteristic (ROC) curve for the predicted distribution *MaxEnt* models averaged over the ten replicate runs: *Ageratina adenophora* (the “current” year–A; year 2050 –B) and *Lantana camara* (the “current” year–C; year 2050 –D).

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-7.61, $df = 28$, $p < 0.05$) and *L. camara* ($t = -2.70$, $df = 28$, $p < 0.05$) will significantly increase by year 2050 across all designated elevation class (Fig 5).

Discussion

Plant invasion is the emerging area of science that impacts substantial economic and ecological imbalance by altering native plant community composition [67] and depleting native plant species diversity [68] thus affecting ecosystem processes [69–71]. The lower and mid ecosystems in the mountains are more vulnerable to invasion by exotic plant species due to the altering climate change and increasing anthropogenic pressure [72]. These plant species also exceeded their ranges and many of them have become abundant at higher elevations [73,74]. The increasing incidence of invasion in the high-altitude ecosystems [9] poses a significant threat to the native biological diversity of the region and it is expected to expand in the future [21]. Using principal components as input variables in *MaxEnt* enhances the prediction of good habitat suitability [50,75]. Alien species that seek to establish themselves in mountains easily proliferate and become difficult to sustain and manage due to the rugged and steppe mountain terrains [76]. It is important to detect potential invaders and take preventative action, since this is the most cost-effective way to restrict the spread of IAPS to new locations. This demonstrated an increasing (both vertical and horizontal) trend of plant invasion in KSL–India. Altering climatic condition and mostly increased temperature has been providing favourable conditions for the invasion and spread of these species in the KSL–India.

Table 2. The area under the receiver operating curve (AUC) score of *MaxEnt* models for both *Ageratina adenophora* and *Lantana camara*.

Species	The “current” year		Year 2050	
	Test AUC	Training AUC	Test AUC	Training AUC
<i>Ageratina adenophora</i>	0.81	0.82	0.81	0.82
<i>Lantana camara</i>	0.93	0.93	0.92	0.93

<https://doi.org/10.1371/journal.pone.0239690.t002>

Table 3. Relative contributions of each principal component (PC) are used in all the *MaxEnt* models.

PC	Contribution of <i>Ageratina adenophora</i> (%)		Contribution of <i>Lantana camara</i> (%)	
	The "current" year	Year 2050	The "current" year	Year 2050
PC1	83.00	86.10	62.8	65.2
PC2	00.00	00.10	0.1	0.2
PC3	01.10	02.40	9.1	15.6
PC4	04.60	04.60	2.1	1.1
PC5	07.30	05.40	16.7	15.8
PC6	04.00	01.50	9.1	2.2

<https://doi.org/10.1371/journal.pone.0239690.t003>

The presence of *L. camara* was recorded widely in forest and scrublands [77,78]. Looking forward, *L. camara* might also affect the regeneration of native biodiversity in the area. It appeared that in the future both of these IAS would colonize more vigorously in the landscape where currently they are not present. This invasion of both species is likely to happen if climate change continues to follow the higher emission RCP 8.5 pathway. Furthermore, *L. camara* will spread within a similar altitudinal range where it is currently absent. These species have already spread in mountains and along rivers and roadside [79]. *A. adenophora* presence between 2800 to 3000 m a.s.l. [13], which suggest that the spread of this species in higher regions of western Himalaya can cause a potential threat to the native biodiversity in the alpine and subalpine zone.

Our study also showed a similar trend, as this species will reach 968 m a.s.l. higher than its current distribution range. Our predictive models also depicted high infestation and expansion in the present climatic scenario by *A. adenophora* and *L. camara* in the lower parts of KSL—

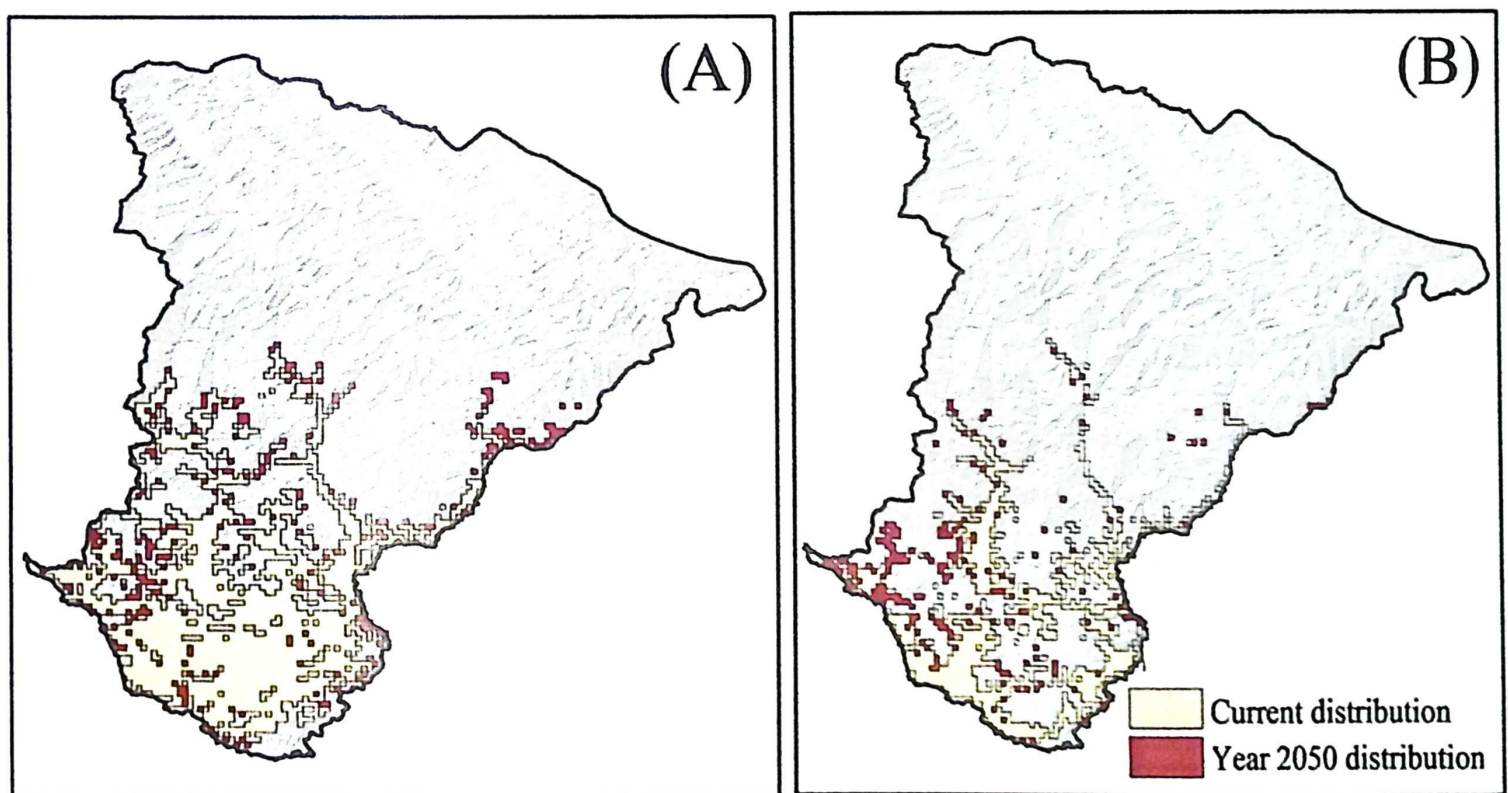


Fig 4. Predicted distribution *MaxEnt* models averaged over the ten replicate runs. Orange and Red polygons represent maximum training sensitivity + specificity logistic threshold for the distribution of (A) *Ageratina adenophora* and (B) *Lantana camara* in the "current" and year 2050.

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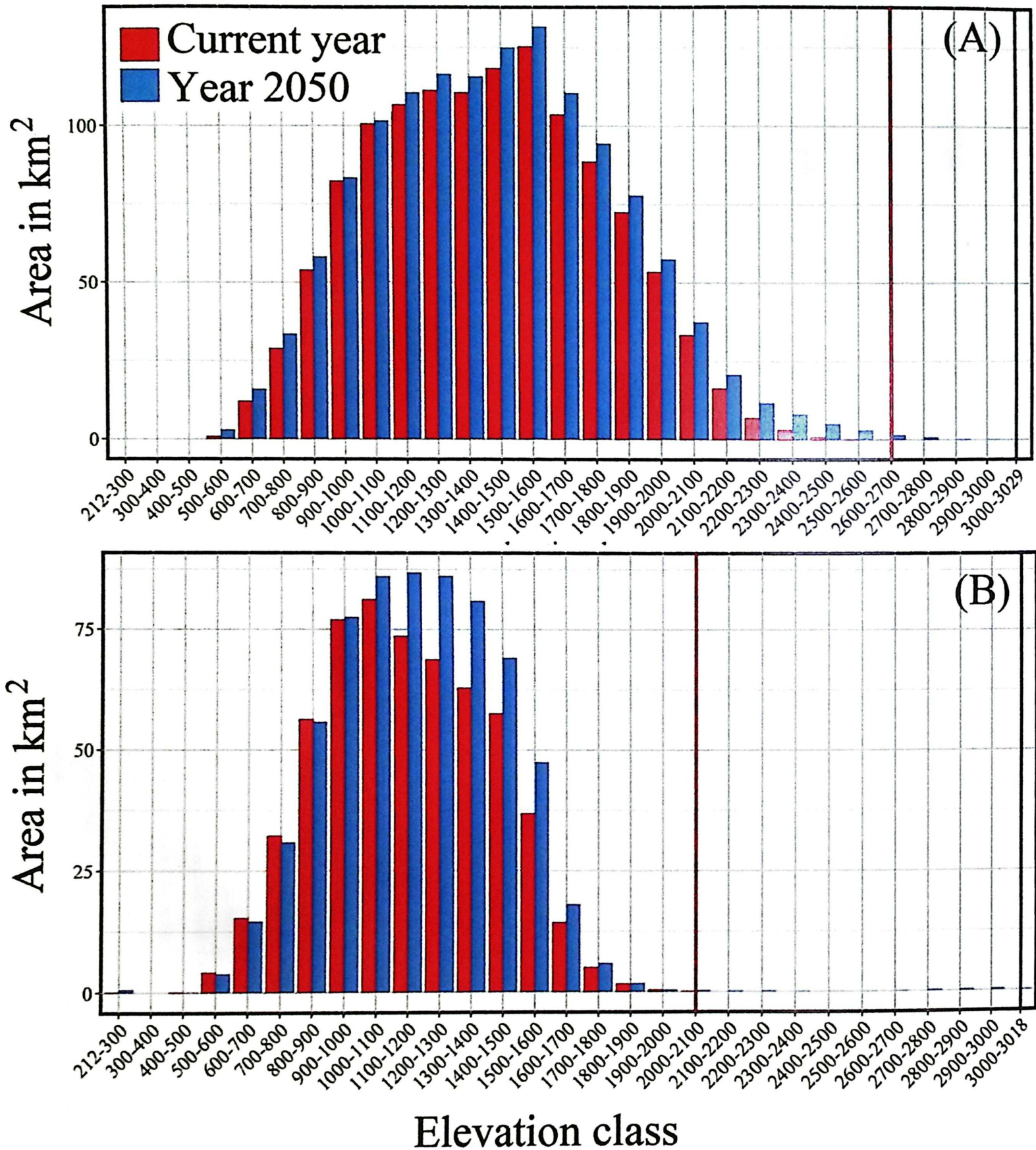


Fig 5. The predicted spread (in Km²) of *Ageratina adenophora* (A) and *Lantana camara* (B) in different elevation classes of KSL-India during the current year and the year 2050.

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India in western Himalaya. The *MaxEnt* model also predicted that the landscape provides more suitable conditions for the infestation of *A. adenophora* as compared to *L. camara* even at its current climatic condition. Both the species will expand their habitats with the increase in temperature and human activity in the landscape. Our study demonstrated similar results as compared to previous studies [80–82], but in a more robust and spatially explicit manner.

Our study has come up with a current pattern of distribution and established future scenarios of invasion by two highly obnoxious IAS within KSL–India. The distribution maps generated in this exercise would be of much help in further conservation planning and participatory management of forest/grassland management. The findings of our study can be used in the identification of vulnerable areas and important localities which are likely to be infested by these species. Habitat restoration and community-based monitoring at a local scale involving Biodiversity Management Committee (BMC) would be one of the logical steps forward.

Supporting information

S1 Appendix.
(DOCX)

S1 Data.
(RAR)

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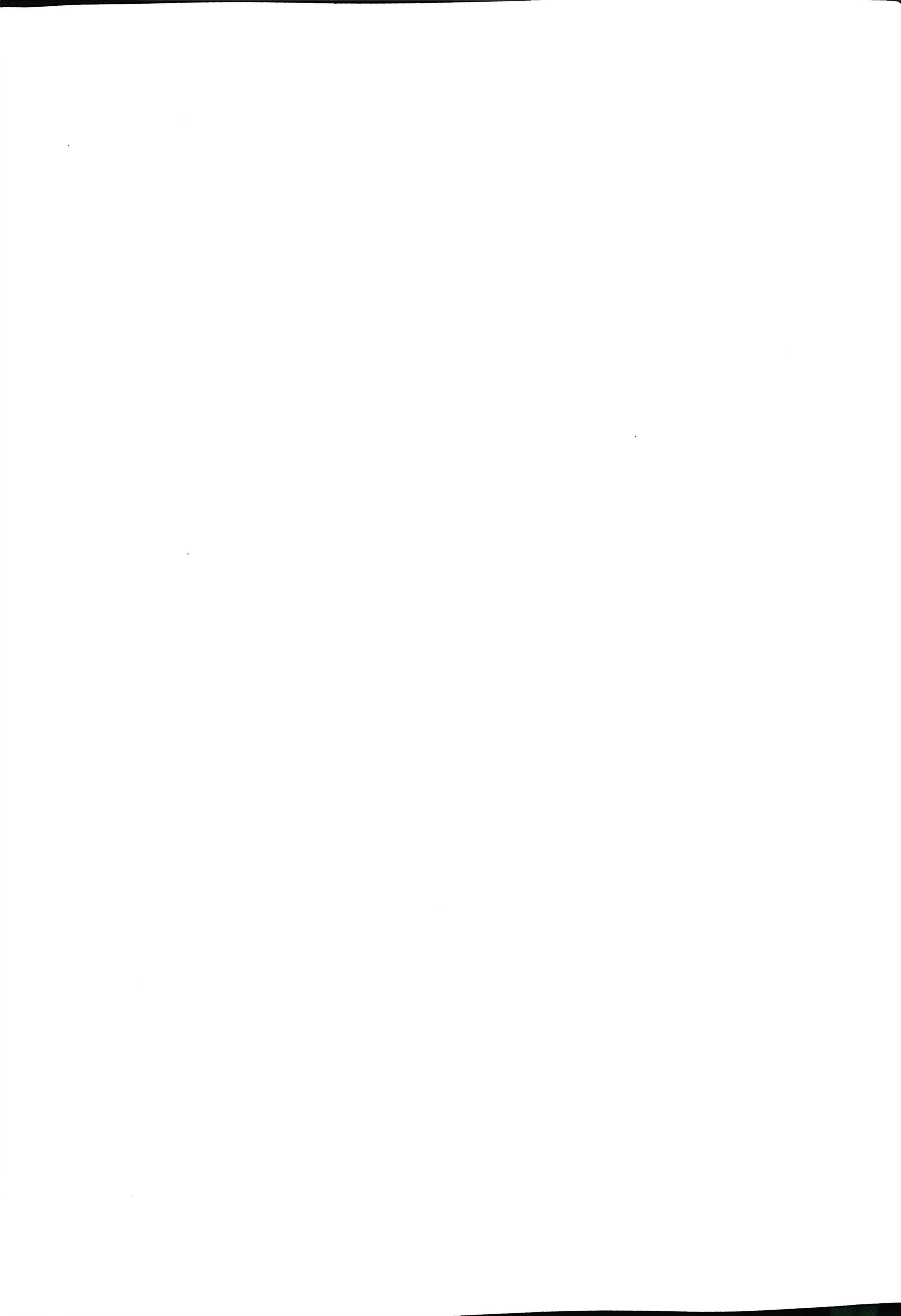
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Perception and knowledge of community people on invasive Alien Plantspecies in Chandak-Aunla Ghat and Hat-Kalika watersheds of Kailash sacred landscape - India: A case study

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ABSTRACT

Invasive alien plant species (IAPS) are considered the second most important agent after habitat destruction for species endangerment and extinction. Though dozens of alien invasive plant species (IAPS) occur in the Indian Himalayan region, information on distribution and perceived impact is lacking in the western Himalaya. In the present study, 701 randomly selected households in 45 villages were surveyed through questionnaire surveys in Chandak-Aunla Ghat (329) and Hat-Kalika (372) watersheds in Kailash Sacred Landscape (KSL-India) to know their view on the issues associated with the IAPS and attitudes towards their management. The knowledge, perception, use and management strategies of different IAPS were analyzed. Only 39% of females and 27% of males had knowledge of IAPS. The highlights of the study are: i) *Ageratina adenophora* had the highest Relative Frequency of Citation value among 14 major IAPS in the study area, ii) informants of Hat-Kalika showed low richness of knowledge and sharing with their family members as compared to Chandak-Aunla Ghat, iii) respondents perceived IAPS negatively and rated biological invasion and habitat loss as major environmental problem, iv) the major management strategies identified were restoration, eradication, community education and information, and v) perception and level of knowledge sharing on invasive species among age classes and gender have implications for stakeholders and policymakers in management of IAPS.

83. Introduction

Alien species are non-native or exotic organisms that occur outside their natural adapted ranges and dispersal potential. International Union for Conservation of Nature and Natural Resources (IUCN, 2000) defines Alien Invasive Plant Species (IAPS) as species that become established in natural or semi-natural ecosystems or habitat, an agent of change that threatens native biological diversity. They are widely considered as the second most important agent after habitat destruction for species endangerment and extinction (Wilcove et al., 1998). Alien invasive species modify habitat (Tripathi et al., 1981; Kandwal et al., 2009) -aquatic or terrestrial (Gordon, 1998), influence ecosystem services (Charles and Dukes, 2008), replace fodder grasses and other medicinal plants (Bughani and Rajwar, 2005), favours other alien species over native species (Dobhal et al., 2011), predate native species (Manchester and Bullock, 2000), inhibit seed germination (Bhardwaj et al., 2014), alter nutrient content of the soil (Bhatt et al., 1994) and cause homogenization of natural habitats (Dar and Reshi, 2015).

Being a threat to biodiversity and ecosystem services, invasive species have a significant socioeconomic effect as they decrease the economic gain from the forest (Larson, 2007), agriculture (Wijeratne, 2015) and fisheries (Cambray, 2003), deteriorate water quality (Chamier et al., 2012), cause habitat fragmentation (Raghubanshi and Tripathi, 2009), and contribute to the spread of disease (Mack and Smith, 2011). The Himalaya is a repository of unique and threatened floral and faunal diversity (Sharma et al., 2016), which plays a vital role in fulfilling the daily needs of the inhabitants, like fuel, fodder, timber, agricultural implements, edible fruits and medicinal plants (Samant et al., 2006; Badola et al., 2010; Aryal et al., 2018; Bhat et al., 2013). Himalaya is highly vulnerable to climate change, anthropogenic pressure, and biological invasion (Adhikari et al., 2015; Negi et al., 2018; Mungi et al., 2018; Thapa et al., 2018). A total of 297 invasive plant species have invaded the Indian Himalayan region dominated by genera *Ipomoea*, *Solanum*, *Cassia*, *Indigofera*, *Corchorus*, *Datura*, *Euphorbia*, *Physalis*, *Blumea*, *Chenopodium* and *Opuntia* (Sekar et al., 2015; Pathak et al., 2019).

Kailash Sacred Landscape (KSL) spreads over an area of 31,000 km², of which ca. 7100 km² falls within the Indian Territory in west Hi-

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malaya (Zomer and Oli, 2011), predominantly represents Pithoragarh district (6818 km²) with an altitudinal range from 212 to 6851 m asl. It is a fragile ecosystem with diverse habitats; grassland, moist sub-tropical broadleaved forest, temperate oak forest, sub-alpine conifers, high altitude birch forest, alpine pastures, along with agro-ecosystem (Hussain et al., 2018). IAPS are reported to impact tree regeneration, forage production in rangeland, native forage species and habitat of non-timber forest products, and crop production costs in Nepal (Shrestha et al., 2018) and in KSL-India (Chaudhary et al., 2019).

Studies on invasive species in the Indian part of KSL are restricted to determine the status and distribution, impacts, and management strategies (Lamsal et al., 2018; Thapa et al., 2018; Chaudhary et al., 2019; 2021). Understanding the social and cultural perspectives in research on IAPS and considering biological invasions as social-ecological phenomena is crucial for successful management, both socially and ecologically (Kueffer et al., 2013). However, studies on knowledge and perception about IAPS are rudimentary in the KSL (Mandal and Joshi, 2014; Paudel, 2015; Shrestha et al., 2018). The present study was conducted to know the extent to which people perceive plants' invasion as a problem, and to know the knowledge of perceived impacts and management of IAPS in Chandak-Aunla Ghat and Hat-Kalika watersheds of Kailash Sacred Landscape.

84. Study area

Invasion of exotic species is among the most significant global problems experienced by natural ecosystems (Sharma et al., 2005). The reported IAPS species in Kailash Sacred Landscape is about 4%, and 7.3% of IAPS found in Himalaya and Uttarakhand, respectively (Sekar et al., 2012; Pathak et al., 2019). Therefore, the present study was carried out in Kailash Sacred Landscape (KSL)-India, Pithoragarh (30.0815° N Lat. and 80.3659° E Long.) in the western Indian Himalaya. Pithoragarh is located in the north-eastern part of Uttarakhand state of India (Fig. 1). Tibet bounds the district on the north, Nepal on the east, the district Champawat on the south and Chamoli on the west. The area of the district sprawls in the rugged terrain of the mystic Himalaya with an elevation ranging between 350 m and 7000 m asl and the annual temperature ranges between 30.3 to -1.7 °C. The precipitation is in the form of snowfall in the northern portion of the district and in

the form of rainfall in the southern part of the district. Pithoragarh district abounds in rivers, and some of the major rivers of the district are Saryu, Ramganga, Gori, Kali, Dhauri and Kuti. The district has 205,299 hectares of forest represented by moist Sub-tropical broadleaved, Temperate oak forest, Sub-alpine forest represented by conifers and high altitude birch and Alpine pastures (Oli and Zomer, 2010). The total human population of Pithoragarh is 483,439 (Census, 2011). The district has been identified as an ecologically diverse, biologically rich and culturally significant Kailash Sacred Landscape (KSL).

The present study was carried out in two sub-watersheds, i.e. Chandak-Aunla Ghat and Hat-Kalika, located in the southern portion of the district. Chandak-Aunla Ghat (29°35' N- 29°39' N Lat. and 080°06'- 80°13' E Long.) with an elevation ranging between 607 and 2119 m asl encompassing an area of 23.23 km² in Bin block. Banj oak (*Quercus leucotrichophora*) and Chir pine (*Pinus roxburghii*) forms the principal forest types in the watersheds. There are 12 Gram Panchayats and 28 revenue villages accommodating 1774 households with an overall population of 7534 (3676 males and 3858 females; Census of India, 2011). Hat-Kalika watershed (29°36'-29.42' N Lat. and 080°02'- 80°13' E Long.) encompassing an area of 36.68 km², supports Temperate broadleaved-mixed conifer (Banj oak and Chir pine) and Sub-tropical/Temperate conifer (Chir pine/Cedar) forests at an elevation 625-2150 m asl. The watershed includes 45 villages. The total population of the watershed is 13,465 people, with males accounting for 48% of the population and females for 52%. In the watershed, 61.6% of the population is literate (females 52.2% and males 70.3%). Agriculture performed on terraced farms and

forest resources are the main sources of income for the majority of people. The forest vegetation spans from subtropical Sal (*Shorea robusta*) to Temperate Banj oak (*Quercus leucotrichophora*) forests, with a variety of forest species in between.

85. Methods

A stratified systematic sampling method was adopted, and a total of 701 (20% of the total) selected households (Chandak-Aunla Ghat: 329, Hat-Kalika: 372) in 45 villages were surveyed between April 2016 and June 2018 through semi-structured questionnaires to assess the level of people's knowledge and their perception regarding alien invasive plant species (IAPS). Every third house was surveyed, and to reduce household selection bias, the first house visited was determined by a random method (Joshi and Rawat, 2021). Interviews were conducted between 0900 and 1500 h of the day in Hindi language. Starting from one end, the central path of the village was followed, and questionnaire surveys were carried out on both sides of the path till another end of the village was reached. Questions regarding existing IAPS, their introduction, establishment, spread, impacts, usage and management measures were asked to adult males, females and students (>18 years of age). A vegetation survey supplemented the household surveys to determine the presence of IAPS. A Prior Informed Consent (PIC) was acquired after providing full information about the study's objectives. All the respondents were informed about their rights to refuse to answer any question and to withdraw from the survey at any time.

• Data analysis

To measure the knowledge richness about the IAPS known to the respondents, two quantitative indexes, Relative Frequency of Citation (RFC; Vitalini et al., 2013) and Knowledge Richness Index (KRI; Araujo et al., 2012), were used. The formulae used for assessing both the indices are as below:

$$RFC = \frac{FC_i}{N} \quad (1)$$

$$KRI = \sum J_i \quad (2)$$

$$J_i = \frac{FC_i}{FC_n} \quad (3)$$

Where,

FC_i = number of informants mentioning the i^{th} IAPS,

N = total number of informants participating in the survey,

FC_n = Total record of IAPS (S_i) cited by the community.

The value of RFC range between 0 and 1; 0 reflects respondent has no knowledge, and 1 indicates better knowledge of the IAPS. The KRI values range from 0 to infinity, where lower values indicate a higher knowledge of the IAPS and vice-versa (Araujo et al., 2012).

86. Results and discussion

• Knowledge about IAPS

The respondents reported a total of 14 species of IAPS in the study area (Chandak-Aunla Ghat: 14 species, Hat-Kalika: 9 species) with an average knowledge of 2.7 ± 0.03 species. A maximum of 5 species and a minimum of 1 species of IAPS were reported from any respondent. More than half of the respondents (58%) in both the watersheds were aware of IAPS and knew that IAPS could affect the local vegetation structure. The knowledge related to IAPS was recorded more in Chandak-Aunla Ghat (82%) than Hat-Kalika (37%). Survey results indicate that 99% of respondents were familiar with at least one IAPS. The level of awareness was observed more in females (39%) than males (27%). Only a few participants had prior knowledge of IAPS due to their related occupation (as women had more knowledge than men due to their involvement in

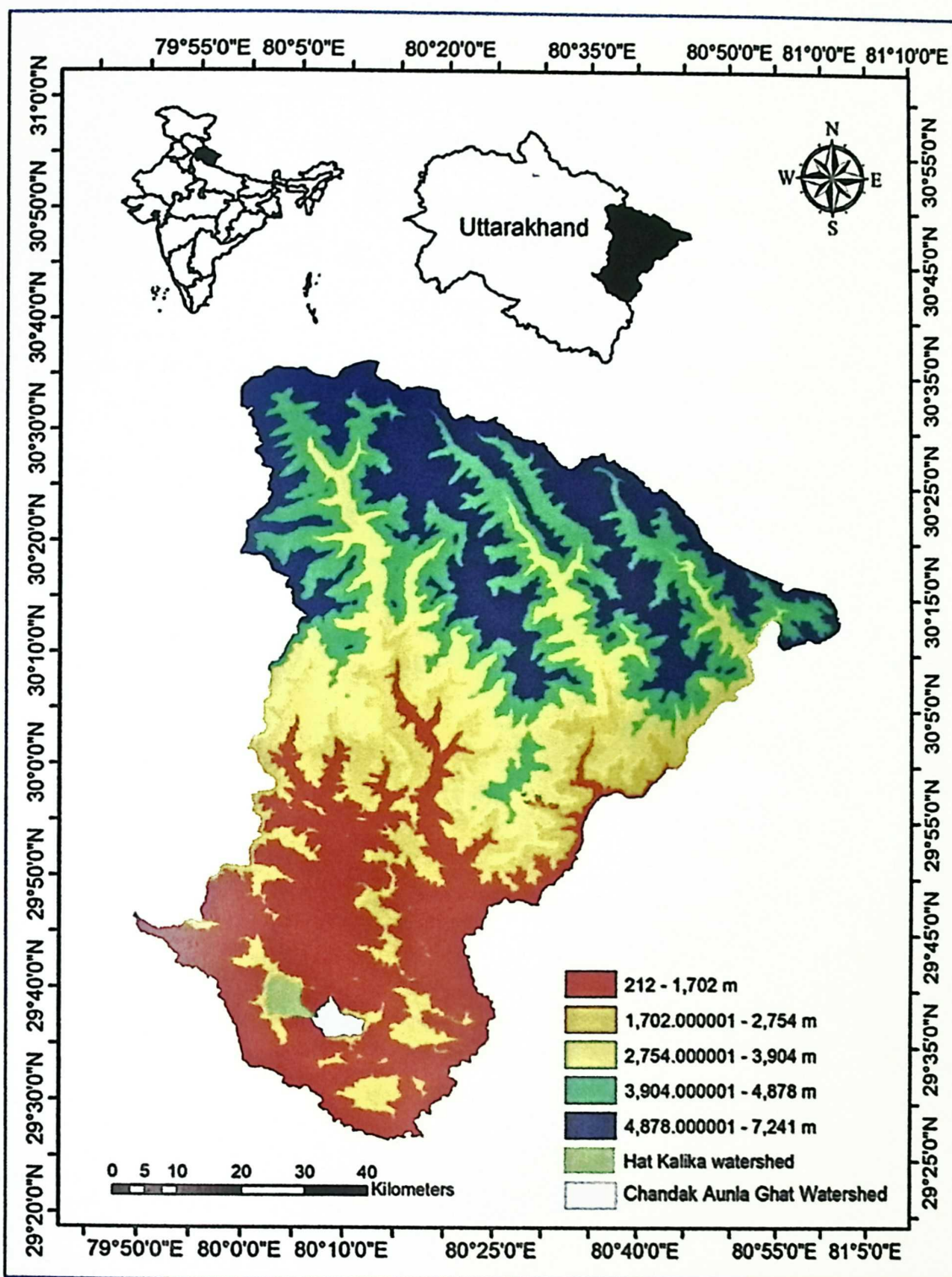


Fig. 1. Location of micro-watersheds in Pithoragarh district, Uttarakhand.

agricultural practices) or personal curiosity (very less knowledge among students). The results revealed that the students had the least knowledge related to IAPS and their management. This may be due to their least interest in traditional agricultural based livelihood activities and further in managing their croplands and ecosystems. Therefore, there is a need to organize awareness programmes for the local community to know the probable threats of IAPS to their ecosystems. The eradication of IAPS and restoration of habitats may be ensured by the involvement of public participation as well as college students. The involvement of NSS students at regular interval would be of immense help to curb the proliferation of IAPS.

Ageratina adenophora was the most cited IAPS (RFC: 0.51), and it was followed by *Lantana camara* (0.17) and *Ageratum conyzoides* (Table 1). The Knowledge Richness Index (KRI) of the study area (Table 2) was

recorded to be 0.03, and the KRI was recorded lower in Chandak-Aunla Ghat (0.05) than in Hat-Kalika (0.09). This indicates that the Hat-Kalika informants showed a low richness of knowledge and shared less information with their family members than Chandak-Aunla Ghat. The higher the value of KRI, the lesser the richness of knowledge as per the index (Araujo et al., 2012). Further, females have a higher knowledge of IAPS in Chandak-Aunla Ghat and Hat-Kalika than male respondents.

• Perception about impact of IAPS

Respondents in Chandak-Aunla Ghat rated biological invasion as a major environmental problem, while of Hat-Kalika believed that habitat loss was a major ecological problem (Fig. 2). Most respondents in the study area perceived IAPS negatively (99%). In Chandan-Aunla Ghat re-

Table 1
Relative frequency of citation of various IAPS in two watersheds of Pithoragarh, Uttarakhand.

Alien invasive plants	Family	Life form*	Chandak-Aunla Ghat Watershed	Hat-Kalika Watershed
<i>Ageratina adenophora</i> (Spreng.) R.M. King & H. Rob.	Asteraceae	PS	0.57	0.47
<i>Ageratum conyzoides</i> L.	Asteraceae	AH	0.44	0.34
<i>Bidens pilosa</i> L.	Asteraceae	AH	0.35	0.09
<i>Coryza sumatrensis</i> (Retz.)	Asteraceae	AH	0.02	0.00
<i>Erigeron bonariensis</i> L.	Asteraceae	PH	0.02	0.00
<i>Erigeron karvinskianus</i> DC.	Asteraceae	PH	0.12	0.11
<i>Ipomoea carnea</i> Jacq.	Convolvulaceae	S	0.11	0.02
<i>Lantana camara</i> L.	Verbenaceae	WS	0.52	0.54
<i>Oxalis latifolia</i> Kunth	Oxalidaceae	PH	0.42	0.52
<i>Parthenium hysterophorus</i> L.	Asteraceae	AH	0.11	0.01
<i>Solanum viarum</i> Dunal	Solanaceae	PH	0.24	0.00
<i>Xanthium strumarium</i> L.	Asteraceae	AH	0.08	0.26

* PS: Perennial shrub, AH: Annual herb, PH: Perennial herb, H: Herb, S: Shrub, WS: Woody shrub.

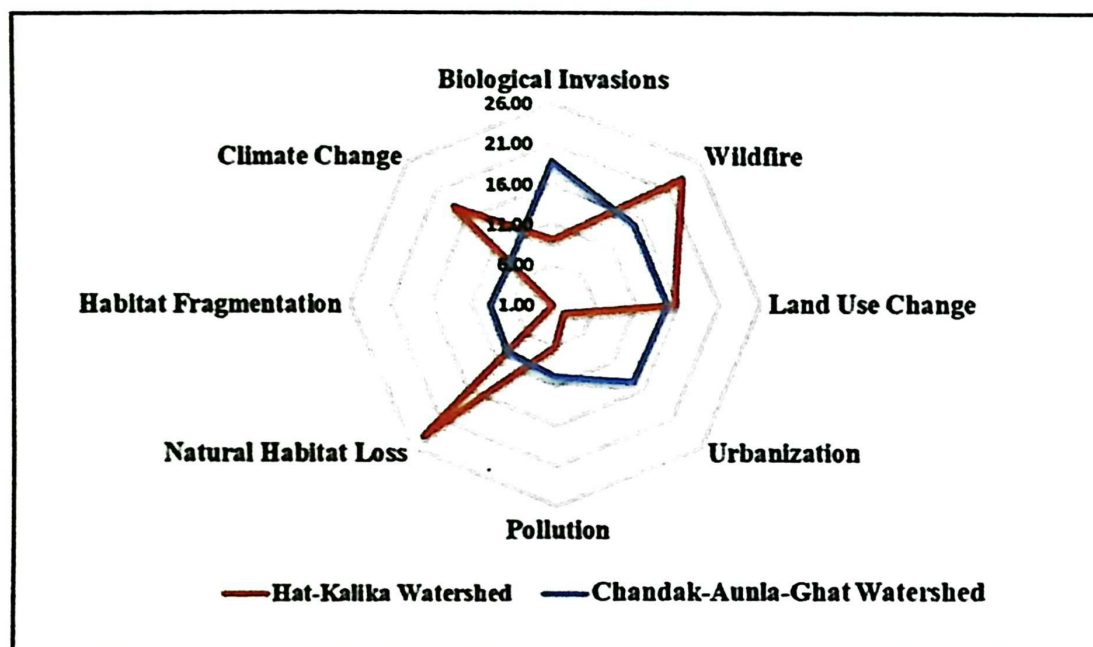


Fig. 2. Peoples' perception to various environmental problems in studied watersheds.

Table 2
Knowledge Richness Index (KRI) and Knowledge Sharing Index (KSI) among various groups in the study area.

ik-Aunla Ghat	ika	Study area
KSI		

7.14

11

spondents perceived native species loss (19.8%), an increase in wildfire (18.5%), and a decrease in the water table (15.2%) as the effect of invasive species. The major perceived negative impact of IAPS in Hat-Kalika includes native species loss (15.4%), decrease in the water table (14.6%) and change in ecosystem stability (Fig. 3).

Use and management of *Ageratina adenophora*

Ageratina adenophora is identified as the most problematic IAPS in the study area from a preliminary survey with the highest RFC value. Therefore, during the survey, questions about the management options of *A. adenophora* were posed to see if locals are managing it at their level. Survey results showed that about 50% of respondents considered *A. adenophora* to be the most harmful alien invasive plant species. Invasive plant species which have been part of the landscape for generations can have numerous commercial and non-market uses (Shackleton et al.,

2011). The provision for blood clotting was the most common perceived use (25.8%) of this IAPS, followed by the bedding of animals (12%) and grazing by goats (Fig. 4).

Among 14 IAPS in the study area, *Ageratina adenophora*, *Lantana camara* and *Ageratum conyzoides* were the most cited IAPS species in both the watershed. All these three species are widely distributed and rapidly proliferating IAPS in Uttarakhand (Pathak et al., 2019). Managing IAPS in the study area was perceived positively, and 70% of respondents agreed that controlling IAPS is necessary to conserve the environment and protect biodiversity. Most respondents in Chandak-Aunla Ghat perceived restoration (40%) and eradication (27%) as major management options for IAPS. On the contrary, eradication (35%), community education and information (22%) were believed to be the best ways for managing IAPS in Hat-Kalika by respondent (Fig. 5). *A. adenophora* is aggressive, rapidly spreading IAPS, which have recently been reported at an elevation ranging between 2800 and 3000 m in Uttarakhand (Pathak et al., 2019). A high abundance of *A. adenophora* suppresses the growth of the seedlings of native canopy trees (Fu et al., 2018). Hence, the high citation value of the *A. adenophora*, *Lantana camara* and *Ageratum conyzoides* implies that such species have invaded the area, posing a severe threat to the native plant diversity. The dominance of similar IAPS was also observed by Shrestha et al. (2019) in Chitwan-Annapurna landscape as per community perception and identified uprooting of IAPS as one of the major control measures. They also identified IAPS as a major threat to native biodiversity, reduced agricultural production and regeneration of forest-forming species.

The respondents in Chandak-Aunla Ghat were more cognizant of the IAPS than Hat-Kalika. It could be due to the awareness program on IAPS

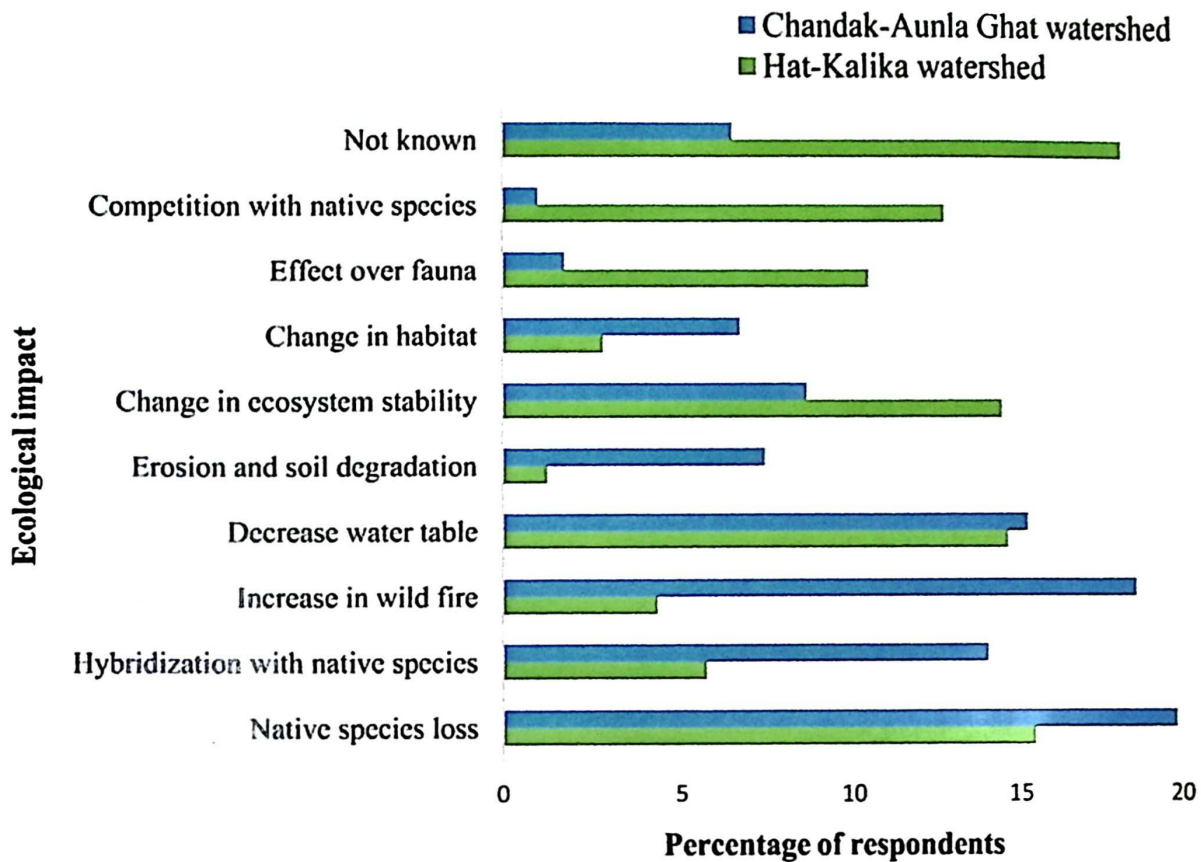


Fig. 3. Perception of respondents on ecological impacts of IAPS in studied watersheds.

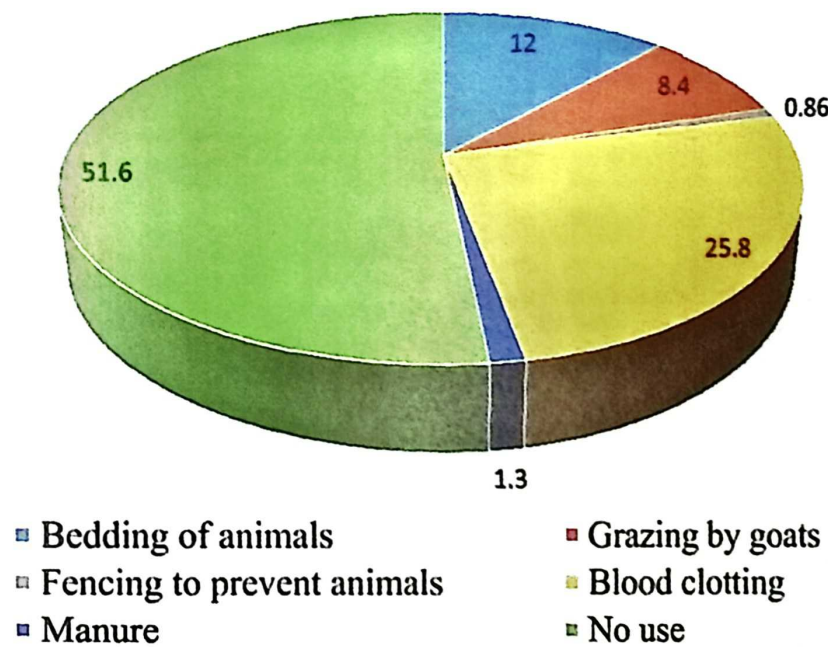


Fig. 4. Uses of *Ageratina adenophora* by respondents in study area.

and their impacts, conducted in the Chandak-Aunla Ghat area by the Wildlife Institute of India under the Kailash Sacred Landscape Conservation and Development Initiative (KSLCDI) project between 2014 and 2016. Hence, our results highlight informal education activities that help raise public awareness and align with other studies (Reis et al., 2013; Waliczek et al., 2017). Consequently, our findings imply for policymakers for the management of IAPS. People are much more conscious

of the species that have been the subject of awareness programmes, indicating such efforts could be effective and should be used in policy-making. It is important to note that the knowledge richness was higher among females than males. This could be related to the involvement of females in agriculture and participation in the awareness programmes regarding the management of IAPS. Males usually remain outside the town for various occupations such as the army, tourism, business, labor

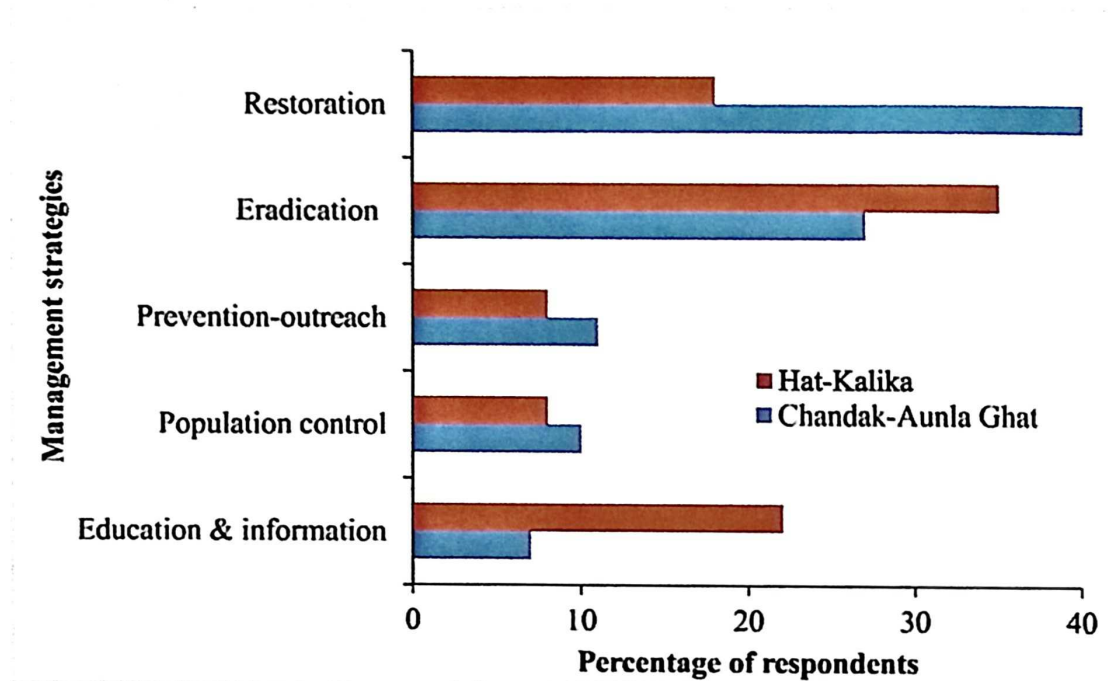


Fig. 5. Management strategies for IAPS in different watersheds

etc. Interestingly, students (irrespective of gender) had the highest value for KRI in both Chandak-Aunla Ghat and Hat-Kalika (0.49 and 0.85, respectively) and hence the least knowledge richness on IAPS. This could be due to the change in the traditional social practices as a lesser number of the younger generation now participate in agro-pastoral practices. We found respondents perceived IAPS negatively in both watersheds of Pithoragarh and are responsible for various environmental hazards.

The knowledge sharing index was also higher among females, followed by males and students. The KSI value was also recorded as maximum among females (16.7), among which females of Chandak-Aunla Ghat (9.1) shared more knowledge with their community members, followed by females of Hat-Kalika (6.3). The students showed less interest in sharing the knowledge with their colleagues due to their lesser interest.

87. Conclusion

The present study highlights the importance of public awareness and participation in the management of IAPS in the study area. Although women of Himalayan hills have the sophistication to manage a diversity of roles to adaptation and survival in the fragile Himalayan ecosystem, significantly few studies have been carried out concerning gender and biodiversity management. The gender issues and approaches need to be explored and documented. Active participation of local women in IAPS management planning and policymaking by considering their traditional knowledge and culturally held perceptions can help control the further invasion of alien plants in the study area. Capacity building of local people, particularly the females, through regular workshops and orientation programmes, can help the scientific management of the invasive plant species and further ensure their role in conservation and management activities.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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