1. INTRODUCTION

1.1 Background

Biological invasions have become a global problem and are included as a major part of research in ecological and environmental studies. Biological invasions are defined as the introduction, establishment and spread of invasive species outside their native range (Richardson & Pyšek, 2006) and they are recognized as a major threat to the economy, environment, natural resources, agriculture and recreation worldwide (Vitousek *et al.* 1997; Mack *et al.* 2000 and Pimentel *et al.* 2005). Large parts of the world are currently dominated by human modified ecosystems that often comprise a greater biomass of introduced species than native (Vitousek *et al.* 1997). Besides human actions, several other factors contribute to successful invasion by alien plants. Some basic factors related to successful invasion include the invaded area's climate, the environment's disturbance regime, and the competitiveness of the native species.

Many plant species are transported by humans intentionally or accidentally from one geographic region to others for various purposes like nurseries, botanical gardens, medicinal, horticulture or as contaminants in commercial products. After certain time period these alien species transported by man become naturalized and form a part of existing landscapes and ecosystems. Many of them form a basic source of livelihood and behave like native species and could be manageable. These alien species do not turn into invasive. However, some of the aliens colonize unmanageably outcompeting native species and such species are called invasive alien plant species (IAPS). Alien species are thus the non-native or exotic organisms that occur outside their natural adapted ranges and dispersal potential placing constraints on environmental conservation, economic growth and sustainable development (Raghubanshi *et al.* 2005*)*. The Global Invasive Species Programme has defined IAS as "IAS are organisms that have been moved from their native habitat to a new location where they cause significant harm to the environment, economic systems or human health" (*http://www.gisp.org).*The IAPS can successfully colonize in both disturbed as well as natural habitats due to their faster growth rate, high biomass production, efficient seed dispersal mechanism, high reproductive efficiency, rapid colonization, vegetative propagation as an alternative mode of reproduction, wider geographical range and phenotypic plasticity. Allelopathy exhibited by many of the invasive plants (e.g.

Parthenium hysterophorus, Hyptis suaveolens, Lantana camara) in the new environment as a defense and adaptive strategy provides further advantage to these aliens over the natives (Bais *et al.* 2003; Callaway & Ridenour 2004; Singh *et al.* 2008). All invasive plant species are aggressive competitors with the ability to significantly reduce diversity of native plant and animal species. Nepal's biographic settings along with variation in geographical and climatic conditions favour the introduction and growth of several alien plant species making our country more vulnerable to biological invasion. Many invasive alien plant species in Nepal are unintentionally introduced. An inventory carried out during 2002-2003 reported that over 166 alien species are naturalized in Nepal and are potential invaders (Tiwari *et al.* 2005). Among them 21 alien plant species have been considered as problematic invasive alien plant species.

Disturbed and unattended habitats like residential, industrial or agricultural, roadways etc are prone to invasions as compared to well-managed ecosystems and habitats. Invasive alien plant species pose a threat to native/indigenous plant communities globally, especially where these communities are disturbed (D'Antonio *et al.* 2001), as disturbance decreases competition and increases the probability of invasion. Most of the IAPS occurring in Nepal are of neo-tropical origin (Bhattarai *et al.* 2014) and mostly introduced through India due to open border, direct road connection and geographical continuance in contrast to natural barriers in the North. Invasive alien plants readily colonize disturbed areas and habitat edges, such as transportation corridors. Roads as dispersal corridors facilitate plant invasion by dispersing plant propagules of IAPS into new areas mediated by vehicles and humans (Christen & Matlack 2009; Sullivan *et al.* 2009). The land adjacent to roadways tends to be ideal habitat for invasive plants because of its high level of disturbance and abundant sunlight and nutrients. Land use change brought about by humans is also a form of disturbance favoring plant invasion. Ecosystems vary in their natural susceptibility to invasion which is further increased by land use change as a result of anthropogenic disturbance. Land use change makes ecosystems more vulnerable to biological invasion by changing resource availability, altering disturbance regime and changing propagule pressure (Davis *et al.* 2000; Hobbs 2000).

Over recent decades many developing countries have become potential sources and recipients of IAPS to and from other countries of the world as a result of globalization associated with expansion in trade, transport and travel. And our country also reflects the same scenario. In Central Nepal too, the problem of invasion facilitated by road expansion and land use change is one of the major environmental problem. The construction of roads has led to the loss of natural habitats and opening of disturbance corridors providing suitable habitats to the establishment and spread of IAPS. Our country has a long history of introduced plant species (Bhattarai *et al.* 2014) but still there is a lack of comprehensive study of IAPS distribution and their potential impacts in Nepal. Therefore, biological invasion in Nepal appears as an unsolved but serious environmental problem. The aim of this research work is to address these gaps to some extent by analyzing diversity and distribution pattern of IAPS along roadside vegetation in Central Nepal. The regional inventory of such IAPS would provide necessary information related to the impacts of biological invasions and may act as a foundation to design appropriate management strategies. Roadsides as frequently disturbed habitats act as suitable habitats and dispersal corridors for IAPS and are suitable to study such variation in invasion. And a promising way to understand the varying interaction of these factors is to study the distribution pattern of IAPS occurring in roadside communities along elevational gradient.

1.2 Justification of the study

The establishment and spread of IAPS represents a serious environmental problem and considerable effort is required to minimize it. The uncontrolled spread of species from one geographic region to other, introduced either intentionally or accidentally by man is considered to pose one of the most serious threats to native biodiversity conservation and has significant socio-economic, health and ecological impacts (Vitousek *et al.* 1997). Different IAPS are entering to our country from neighboring countries i.e., mostly from India due to open border transportation and high dependency for food and commodities import. Such invasive alien plant species can transform the structure and species composition of ecosystems by suppressing or excluding native species either directly by out-competing them for resources or indirectly by changing the way nutrients are cycled through the systems. Therefore, the negative impacts associated with the invasion of IAPS necessities that their establishment and spread into new areas should be minimized. And for the management of IAPS detail information linked with species distribution pattern is needed. An inventory at national level is preferred for such applications. But, survey carried out at regional level may also act as a stepping stone for national level assessment of IAPS distribution. The study of distribution of individual species may be useful for the management of IAPS through impact classification based on available data and also to develop species-specific strategies for invasion prevention. The government of Nepal has recently formulated NBSAP, 2014 and has expressed interest on IAPS management through some strategies. The major strategy is to carry out nation-wide survey and research of five most problematic species. Therefore, the regional inventory of IAPS carried out in Central Nepal may provide necessary information related to the impacts of biological invasions and act as a foundation to design appropriate management strategies. Roadside communities were preferred for this study because most of the IAPS are concentrated to road verges as they serve as conduits for the dispersal of IAPS (Christen & Matlack 2009; Sullivan *et al.* 2009). Roads act as dispersal corridors facilitating invasion to adjacent communities and the construction and maintenance of roads create safe areas for invasive alien plant species to germinate and establish by removing native species. Since plant invasion is directly associated with disturbance, roads as the areas with high human- mediated disturbance will serve as source areas for invasive species. The study of IAPS distribution along elevation gradient can provide information on effects of both biotic and abiotic factors limiting invasion. Thus, such type of study may be useful to design management strategies for monitoring the further spread of IAPS into new geographical regions and controlling the impacts associated with them.

1.3 Hypothesis

Following research hypothesis were designed for this study:

- Species richness of IAPS decreases with increase in elevation.
- Abundance of IAPS varies with land use types.
- Species having long residence time has wider distribution than those having short residence time.

1.4 Objectives

The general objective of this research is to conduct an ecological survey of invasive alien plant species along roadside vegetation in Central Nepal. The specific objectives of this research are:

- To know the diversity of invasive alien plant species along roadside vegetation in Central Nepal.
- To prepare spatial distribution map of individual IAPS.
- To analyze the factors governing the distribution pattern of IAPS.

1.5 Limitations

The present research had following limitations:

- This study, carried out during the monsoon rainy season could not assess some road sections due to natural disasters (landslide, erosion) and heavy rainfall.
- Wetland dependent IAPS were partially included in our research as only few wetlands were present along roadsides. Species like *Pistia stratoites* was not included in map preparation due to inadequate data. *Leersia hexandra* was not included in our study due to identification problem in its vegetative stage.
- Land use classification was based on the nature of our data only. Therefore, the relationship between land uses and the species richness of IAPS may be considered preliminary.
- High altitude districts could not be explored due to the lack of road connection and accessibility.

2. LITERATURE REVIEW

2.1 Biological Invasions

Invasive alien plant species are rapidly hunting the native biota all over the world. Invasive alien species are introduced to different geographic regions through various agents of dispersal. Invasion by IAPS are considered as a significant component of human caused global environment change, resulting in a significant loss in the economic value, biological diversity and functioning of invaded ecosystem (Vitousek *et al.* 1997; Mooney& Hobbs 2000; Mack *et al.* 2000; Pimentel *et al.* 2001). Biological invasions are defined as the introduction, establishment and spread of species outside their native range (Richardson & Pyšek 2000). This phenomenon now operate on a global scale and will undergo rapid increase in coming years due to interactions with other global changes such as globalization of markets, explosive rise in global trade, travel, tourism, expansion of road network and exchange of goods (Hobbs 2000). Biological invasions may be human- induced invasions or natural invasions. The human-induced invasions in the new habitats are quick and increasing rapidly with globalization. The impact of natural invasion is almost similar to that of human-mediated invasions but such invasion mostly depends upon the dispersal ability of the invading plants themselves. The sources of natural invasions are humans, birds, animals, insects, wind, water, vehicles etc. Basically IAPS has to pass through three different phases for biological invasions- introduction, colonization and naturalization to invade the host ecosystem (Mack *et al.* 2000). Successful invasions occur when species introduced outside their native range by anthropogenic means establish self-sustaining populations and spread into new areas (Richardson et al. 2000; Richardson& Pyšek 2006). Biological invasion is mainly influenced by three factors; propagule pressure, biological traits of IAPS and invisibility (Londsale1999). IAPS have life history traits like fitness homeostasis, smaller seed size and weight for efficient dispersal, allelopathy, vegetative reproduction as an alternative mode of reproduction, phenotypic plasticity, persistent seed bank and successful colonizers of disturbed habitat (Kohli *et al.* 2006; Grice 2006). Dispersal of IAPS have major role in biological invasion and roads as dispersal corridors promote invasion to adjacent areas (Christen & Matlack 2009; Sullivan *et al.* 2009). The disturbed nature of roads acts as source areas for biological invasion.

Biological invasion have significant impacts on ecosystems and economy (Vitousek *et al.*1997) as they affect the distribution, abundance and reproduction of many native species (Sala *et al.* 1999). IAPS have both beneficial and harmful impacts. As a part of beneficial impacts they contribute to biodiversity enrichment, can act as a source of livelihood and have medicinal value too. But, it is estimated that as many as 50% of IAPS in general can be classified as harmful (Richardson *et al.* 2000). Based on a study conducted in the rangelands of Northern Himalayas, India Kohli *et al.* (2006) found that invasion by *Parthenium hysterophorus*, *Ageratum conyzoides* and *Lantana camara* significantly decreased species richness in the invaded area. The estimated annual losses due to IAPS in various countries have been estimated to be about US$ 30 billion in USA (Pimentel *et al.* 2005), US$ 12 billion in Europe and US$ 15 billion in China (Xu *et al.* 2006). The total economic loss in Australia is estimated to be between $ 3554 million and $ 4532 million (Sinden *et al.* 2004). But in the context of Nepal studies about the extent of IAPS spread and their impacts on ecosystems and economy is yet to be explored.

2.2 Origin and Distribution of IAPS

The movement of species by humans beyond natural dispersal barriers is a still accelerating process, resulting from globalization and disturbance of natural ecosystems. Different IAPS has invaded and continues to invade new regions at an alarming rate exerting strong impacts on ecosystems and human welfare (Mooney *et al.* 2005; Pimentel *et al.* 2005). The openness of a country's economy and the composition of its trade routes enhance the vulnerability of nations to biological invasions (Perrings *et al.* 2002; Taylor & Irwin 2004). Over recent years, many developed and developing countries have become potential sources and recipients of IAPS to and from other countries of the world and Asian countries like China, India, Nepal, Bangladesh, Pakistan etc are also at risk of biological invasions (Weber & Li 2008). Many IAPS have been introduced in Nepal via different pathways across various ecosystems including wetlands, forests, grasslands, rangelands, cropland, roadways etc. Most of the IAPS are accidentally introduced in Nepal from neighboring country i.e. India due to open border linkage, direct road connection and high dependency for basic requirements (Tiwari *et al.* 2005). Majority of the IAPS in Nepal are of neo-tropical origin (South America) (Bhattarai *et al.* 2014). Many alien species have been introduced and have become invasive species in Europe and are supposed to have greater impacts on native biodiversity (European Environment Agency 2007). In Europe the share of American species in the alien flora is 34.8% (Lambdon *et al.* 2008). In Australia, 429 weeds have been declared as noxious or under some form of legal control which are destructive, injurious to public health, recreational and wildlife properties (AWS 2006).The entry of IAPS into India has occurred through different pathways over time. India’s colonial past and historical trade relations have led to the plant introduction by British, Portuguese, Spanish, French, and from the Middle East and Central Asian countries (Pandey 2000). Among the 225 IAPS in India, more than half (52%) are of South American origin while others are from Africa (16%), Asia (16%), Europe (9%), North America (4%) and Australia (2%) with few (1%) cryptogenic (Khuroo *et al.* 2011). During recent decades, the expanding economy of India has resulted large infrastructure development projects that have led to the loss of natural habitats and opening of disturbance corridors, favoring the spread and establishment of many IAPS (Sharma *et al.* 2005). China’s rapid economic development in the 20th century, including explosive growth in trade and transportation systems is increasing the pathways for the introduction and spread of IAPS among regions within China and the introduction of new IAPS to China from other countries (Yan *et al.* 2001). There are about 270 IAPS in China, originated across the world most of them are agricultural weeds and are mainly distributed in disturbed habitats such as wastelands, roadsides and arable fields (Weber *et al.* 2008). Based on the number of published studies, the most notorious invaders in China are 13 clonally-growing perennials from the Americas followed by 18 accidentally introduced annuals (Huang *et al.* 2010). In China 58% of IAPS have their origin from the Americas (Wu *et al.* 2008), followed by those with European (14%), Asian (13%), African (9%) origins and about 4% from the Mediterranean, the Pantropics and Oceania origins (Jiang *et al.* 2011).

IAPS are not uniformly distributed across different ecosystems. The spread of IAPS to new range is limited by propagule pressure, abiotic factors and biotic interactions with competitors, consumers and mutualists and all these factors may vary with environmental gradients of latitude and elevation (Hallet 2006). Across elevation gradients, many factors change simultaneously at smaller scales (Becker *et al.* 2005). Therefore research along elevation gradients is a valuable approach to analyze limiting factors of plant invasion. Several studies have found a strong decrease in non-native plant species richness at the highest elevations, although patterns at lower and middle elevations vary among regions (Pauchard *et al*. 2009).

2.3 Dispersal of IAPS

Invasive alien species have been introduced in a variety of ways and the means and routes by which they are introduced are called invasion pathways (Singh *et al.* 2008). These invasion pathways serve as dispersal corridors for the spread of IAPS across the globe with the aid of different vectors. A species can be introduced to a new locality in many ways either accidentally or intentionally. The intentional movement of species includes a multitude of vectors like importation of ornamental plants, crop species, biocontrol, medicinal plants, fodder etc whereas accidental transportation includes the movement of species as contaminants within commercial products (Lockwood *et al.* 2007). Seed dispersal is an important determinant of plant distributions (Lockwood *et al.* 2007). Naturalized plant species disperse their populations over considerable distances to become invasive. Invasive plants encroach into uninfested areas by various vectors like humans, vehicles, wind, water, insects, animals etc (Sorensen 1986).

Dispersal refers to the movement of seeds away from the parent plants by various physical methods. The ability to disperse away from the area of introduction into novel areas is critical for a plant to become a successful invader (Singh *et al.* 2008). Plants can disperse by means of vegetative propagation or dispersal of their seeds. The seeds of plants including invasive alien species are primarily dispersed long distances by humans, animals, water, birds, wind etc. Plants have many different adaptations or pre-adaptations for dispersal by these vectors (Rejmanek 2011). Human dispersal either intentional or accidental is more common in invasive plants than in native species and is often the most significant driver of invasions (Richardson & Pyšek 2006). In addition to human dispersal, seed dispersal by vertebrate animals is responsible for the success of many invaders into both disturbed and undisturbed habitats (Rejmanek 2011). Disturbance typically results in an increase in resource availability due to a decline in resource use by plants that were killed by disturbance and increase in resource supply rates through plant decomposition, thereby increasing susceptibility to invasion (Davis *et al.* 2000). Hulme *et al.* (2008) identified three general mechanisms through which non-native species may enter a new region: importation as or with a commodity, arrival with a transport vector and dispersal by the species themselves either along infrastructure corridors (e.g. roads, canal) or unaided. Accelerating human trade, transport and travel have dramatically increased the spread of IAPS across different ecosystems (Vitousek *et al.* 1997; Mack *et al.* 2003). The number of seeds an introduced plant produces may be an important factor in its invasion success, with a greater number of seeds resulting in a greater number of colonization opportunities and hence greater chance of successful establishment and spread into new area. Roadways represent the major source of IAS and help in the long-distance dispersal of these species via vehicular transport (Von der Lippe & Kowarik 2007). The construction and maintenance of roads create safe areas for IAPS to germinate and establish by removing native species and adding new layer of soil suitable for invasion (Londsale & Lane 1994). Routine maintenance and construction activities along transportation corridors can also play a significant role in the spread of invasive plants by dispersing or introducing seeds and other viable plant materials. Along roadsides IAPS find low competitive environment relative to the dense native vegetation and usually receives higher amount of sunlight, rainfall and soil nutrients favouring invasion (Parendes & Jones 2000).

2.4 Community Invasibility

Invasibility is defined as the susceptibility of an environment to the colonization and establishment of new non-native or alien species. It can be quantified as the probability of establishment per arriving propagule (Davis *et al.* 2000). A community's invasibilty varies not only in time but from species to species. The ability of colonizers to become established in a new community depends on the existence of available resources (Davis *et al.* 2000) and other site attributes of the new environment, such as the presence or absence of particular predators and pathogens (Shea & Chesson 2002) and the extent to which the physical conditions of the native environment match those of the new environment (Kolar & Lodge 2001). Ecosystems vary in their natural susceptibility to invasion. Urban-industrial areas, habitats suffering from periodic disturbance, harbors, lagoons, estuaries and the fringes of water bodies, where the effects of natural and anthropogenic disturbances are often linked, are also particularly vulnerable to invasions (Kowarik 1999). Disturbance-mediated susceptibility to invasion seems particularly pronounced in fertile/eutrophic environments (Burke & Grime 1996). Deserts, semi-deserts, tropical dry forests and woodlands, artic systems and pelagic marine systems appear to be least susceptible to invasions while mixed island systems, road networks, lake, river, canals and near-shore marine systems appear to be most susceptible to invasions (Heywood 1995). Similarly, systems with low natural diversity (especially if they are without existing predators or competitors) seem to be more vulnerable to invasion than with high natural diversity (Rejmanek 1999). But, susceptibility also depends on land use type, disturbance level, travel and tourism activities etc. Disturbance caused by any natural or human-mediated events can provide the opportunity for IAPS to colonize new habitat. Habitat fragmentation, habitat conversion and agricultural disturbance increases invasibilty of a community (Williamson 1999). The construction of roads facilitate invasion by IAPS to adjacent communities. A large number of IAPS occur in places disturbed by human activity such as in urban environments, on agricultural land and by road sides (Leszon 1997). Different theories have been proposed to explain the variability in invasiveness between different plant communities. Davis *et al.* (2000) theorise that invasibility is a result of fluctuations in resource availability while Thompson *et al.* (2001) recognize that invasibility is a product of change in availability of resources, either through increase or reduction of resources.

2.5 IAPS in Nepal

The diverse bioclimatic zones of Nepal ranging from tropical to alpine favor the introduction and establishment of many IAPS from different regions of the world. The country has a list of over 166 species of naturalized alien plant species (Tiwari *et al.* 2005). Among them, 21 species have been considered important with various levels of impacts on biodiversity and ecosystems i.e., 6 IAPS posing high risk, 3 IAPS having medium risk, 7 IAPS posing low risk and 5 IAPS with insignificant risk. Different IAPS have been introduced in Nepal both intentionally and accidentally. Nepal as a part of Indian sub-continent has a long history of introduced plant species. However, knowledge base on IAPS in Nepal is limited and there is no any specific institution responsible for IAPS which makes biological invasions as unsolved but serious environmental problem (Tiwari *et al.* 2005). In the 20th century, the country's economic development including growth in trade and transportation systems multiplied the avenues of introduction and spread of invasive species in Nepal (Kunwar 2003). Occurrence of *Chromolaena odorata*, one of the most widely distributed and problematic IAPS in Nepal was reported as early as in 1825 while the other problematic IAPS were mostly reported during 1950s and 1960s by foreign botanical explorers (Tiwari *et al.* 2005). *Ageratina adenophora* and *Chromolaena odorata* are the most widely distributed IAPS in forest ecosystem; these species are particularly common in degraded and secondary forests with relatively low tree canopy. In recent decades, *Mikania micrantha* has been rapidly expanding from eastern Nepal to westward in forests and wetlands of Tarai and Siwalik range (Tiwari *et al.* 2005). Similarly, *Parthenium hysterophorus* has been also expanding its distribution from urban areas and grasslands to forest ecosystems including the habitats of endangered mammals (Shrestha 2012; Shrestha *et al.* 2015). It appears that richness of IAPS and their abundance have been increasing in Nepal. However, a detail survey of IAPS across the landscape and ecosystems to evaluate their impact on native species and ecosystem is still lacking. IUCN-Nepal carried out inventory of IAPS in 16 districts during 2002-2003 representing tropical, sub-tropical and temperate regions of the country (Tiwari *et al.* 2005) A few species such as *Chromolaena odorata* (Norbu 2004; Joshi *et al.* 2006), *Ageratina adenophora* (Joshi 1982; Chettri 1986; Kunwar 2003), *Mikania micrantha* (Sapkota 2007; Siwakoti 2007; Basnet 2011; Rai *et al.* 2012; Rai & Rai 2013) and *Parthenium hysterophorus* (Joshi 2005; Maharjan 2006; Karki 2009; Timsina *et al.* 2011; Paudel 2011; KC 2012, Pokhrel 2012; Maharjan *et al.* 2014; Shrestha *et al.* 2015) invading forest and grassland ecosystems have been studied to some extent in Nepal, while the remaining other species with potential significant impact on various ecosystems have not been examined. *Ageratina adenophra, Chromolaena odorata, Lantana camara* and *Eichhornia crassipes* were first introduced as ornamental plants in Nepal and they are now well established and dominant in forest, farmland, wetland and wasteland (Tiwari *et al.* 2005). *Mikania micrantha* is considered the most problematic terrestrial invasive plants in the tropical parts of Nepal (Poudel *et al.* 2005). *Mikania micrantha* invasion has been a serious problem in the forests and grasslands of the Chitwan National Park, the Koshi Tappu Wildlife Reserve and many other areas in the Tarai, Siwalik and Middle Mountains (Murphy *et al.* 2013; NBSAP 2014). *Parthenium hysterophorus* has emerged as a major threat in recent years particularly in the tropical and sub-tropical fallow lands and roadside areas and more recently invading into cropping systems (Shrestha *et al.* 2015). Invasion of *Eichhornia crassipes* is a major threat to tropical and sub-tropical wetlands of Nepal like Phewa Lake in Pokhara and Beeshazari Lake in Chitwan (NBSAP 2014).

2.6 Management of IAPS

Monitoring, control and eradication programs are required to reduce the impact of introduced species on agriculture, ecosystems and society. Eliminating or reducing the spread and establishment of invasive plants requires a proactive approach, in which there are two key elements. First, new introductions, especially those that occur due to human activities, must be avoided to the maximum extent possible. Second, there must be an emphasis on early detection and eradication of new populations (Perron 2008). A variety of well-known methods can be used as measures to control alien invasive species and their spread. These vary from administrative (national and international cooperation and coordination, database management, legislation regarding quarantine and so on), to mechanical (including digging up root systems, slashing and chopping), to chemical (utilizing acceptable and tested herbicides) and to biological (making use of plant specific insects or pathogens to damage and control aliens). Among them biological control, using specialist insect herbivores and plant pathogens, can be a self-sustaining, cost effective and low-risk tool for the management of invasive weeds (Singh *et al.* 2008). Control of invasive alien weeds infesting large areas, using mechanical or chemical control, can be extremely difficult and costly. Classical biological control offers a complete or partial solution to some alien weed problems by introducing host-specific natural enemies of the weed from its original native range. Biological control of *Ageratina adenophora* using gall fly *Procecidochares utilis* has been carried out throughout world including Nepal. Introduction of the gall fly into India and its eventual movement into Nepal has resulted in some reduction in vigor, growth, and density of the plant; however, the heavy incidence of parasitism has reduced the efficiency of *Procecidochares utilis* (Sankaran, 1973). It was successful in Hawaii, USA, and elsewhere (Bess & Haramota 1972) however, this technique has not yet been successful in Nepal (Kunwar 2003). Leaf feeding beetle *Zygogramma bicolorata* has been emerging as a real hope for the biological control of *Parthenium hysterophorus* in Asia including Nepal. Both larva and adults of *Zygogramma bicolorata* feed voraciously on the leaves of *Parthenium* weed reducing the plant vigor and flower production (Shrestha *et al.* 2010). Uprooting, cleaning, weeding, ploughing, control grazing, hoeing, digging, mowing, flooding and burning are some of the common traditional practices. Alternative use of IAPS such as bio-briquette (e.g. *Lantana camara*, *Chromolaena odorata*), organic manure (*Ageratina adenophora*, *Eichhornia crassipes*), ropes, baskets and handicraft are increasing in Nepal at local level.

Nepal formulated its first Biodiversity Strategy (NBS) 2002 which recognized the introduction of alien species as one of the major threats to biodiversity in Nepal (NBS 2002). Nepal in its Fourth National Report to CDB had set a target to prepare management plans by 2010 for preventing three major alien species (*Eichhornia crassipes, Mikania micrantha* and *Parthenium hysterophorus*) that threatens ecosystems, habitats or species (MFSC 2009). But due to data gap and lack of effective implementation of designed strategies practically at national level all these plans remained as such as. And the problem of biological invasion remained as a serious but neglected field. Again Nepal had made a strong commitment to manage IAPS of different ecosystems in the Fifth National Report to CBD to fulfill the goals set up in Aichhi Biodiversity Conservation Targets (MFSC 2014). As a next step to conserve biodiversity Nepal has formulated National Biodiversity Strategy and Action Plan 2014-2020 (NBSAP) with some strategies for invasive species management. The first strategy of NBSAP is to enhance knowledge and understanding of IAS through nation-wide survey and research on at least five most problematic IAPS by 2020 (NBSAP 2014). The next strategy is to control the invasion and spread of IAPS through effective quarantine policy and early detection of IAPS. Proper implementation of these strategies may solve the problem of IAPS in Nepal in future.

3. MATERIALS AND METHODS

3.1 Study Area

The survey of IAPS along road network in Central Nepal was conducted between June and July of 2013. Nepal's rich biodiversity is a reflection of its unique geographic location along with its altitudinal and climatic variation. Geographically, Nepal is located at a latitude of 26°02' to 30°27' N and the longitude of 80°04' to 88°22' E and occupies an area of 147,181 sq km. Stearn (1960) using climatological, floristic and ecological data proposed a broad categorization of Nepal into three geographic regions: Western Nepal (corresponding to the Karnali River System from the western boundary of Nepal to 83°E longitude), dominated by Western Himalayan Flora; Eastern Nepal (corresponding to the Koshi River System from the Eastern boundary of Nepal to 86°30'E longitude), dominated by an Eastern Himalayan flora and Central Nepal (between 83° and 86°30' E) comprising an intermediate zone between these two floras. The climate of Nepal falls within the monsoon system of Indian sub-continent, with dry periods in the winter and wet periods in the summer. More than 80% of the rainfall occurs during the four summer months (June – September). The country receives average annual rainfall of around 1,600 millimeters (NBSAP 2014). The annual precipitation ranges from165 millimeters in the rain shadow areas of the northern Himalayas (Upper Mustang) to 5,500 millimeters in the Pokhara Valley in western Nepal. Lumle, in Central Nepal receives maximum rainfall ranging from 4000-5000 mm annually. The country can be divided into five major physiographic zones extending from east to west namely the Tarai, Siwalik, Middle Mountains, High Mountains and High Himal (LRMP 1986 as cited in NBSAP 2014). The Tarai plain makes up less than one-third of the total area but has the largest cultivated area, economically valuable forests, and dense human population. The rest of the topography is rugged made up of hills, mountains and inner-mountain valleys. Middlle Mountains has sub-tropical to temperate monsoonal climate and has the greatest diversity of ecosystems and species in Nepal due to the great variety of terrain types and climatic zones. The High Himal zone, located above 4,000 m, comprises subalpine and alpine climates and associated vegetation types. Above 5,500 m, the Himalayas are covered with perpetual snow and no vegetation.

Central Nepal, the study area of present research encompasses major cities like Kathmandu, Lalitpur, Pokhara, Narayanghat, Birgunj, Hetauda, Butwal, Bhairahawa etc with dense population and high commercial activities. The road network of this region is expanding rapidly and includes highways, main roads, secondary roads and trails. For this study, the 'main road' includes the road linking highway and district headquarters, and the 'secondary road' includes access roads to villages and small urban areas from highway, main road or district headquarter. The altitudinal range of our study area varied from70 to 2600 m. The total length of road covered during our survey was approximately 2074.05 km. Our study included some major highways of Nepal *(source:www.dor.gov.np/national-highways.php)* i) Mahendra Highway (partly) (East to West; 1027.67 km) ii) Tribhuvan Highway (Tripureshwor to Birgunj; 159.66 km) iii) Araniko Highway (Kathmandu to Kodari border112.83km) iv) Prithvi Highway (Naubise to Pokhara; 173.43 km) vi) BP Highway (Jaleshwor to Dhulikhel; 198 km) vii) Siddhartha highway (Sunauli border to Pokhara; 181.22 km). Our survey was also conducted along some regional roads (Feeder roads) which include *(source: www.dor.gov.np/feeder-roads.php):*

- Nawalpur- Malangwa Road (26.63 km)
- Narayanghat- Mugling Road (36.16 km)
- Chandranigapur- Gaur road (44.14 km)
- Bardaghat- Pratappur- Surajpur Road (23.05 km)
- Gorusinge_ Sandhikharka Road (69.13 km)
- Chanauta - Krishnanagar Road (20.06 km)
- Birgunj - Kalaiya Road (11.66 km)
- Bhainse – Bhimphedi Road (12 km)
- Palung – Kulekhani - Balaju by pass Road (20.57 km)
- Kathmandu – Trisuli - Dhunche Road (118.26 km)
- Balkhu – Dachinkali Road (16.39 km)
- Banepa – Panauti Road (9.54 km)
- Dolalghat - Chautara Road (25.11 km)
- Lamosangu – Tamakoshi –Ramechhap Road (124.92 km)
- Tamakoshi –Jiri Road (38.03 km)
- Malekhu – Dhading Road (17.50 km)
- Anbukhaireni – Gorkha Road (24.69 km)

- Dumre – Besisahar Road (43.69 km)
- Pokhara – Baglung – Beni Road (90 km)
- Bartung – Tansen – Ridi – Tamghas Road (80.20 km)
- Bhairahawa – Lumbini Road (22.78 km)
- Lumbini – Taulihawa Road (24.55 km)
- Chuharwa – Siraha – Madar Road (26.66 km)

Other main roads and secondary roads connecting to different districts of Central Nepal were also surveyed. Road network of this region generally pass through different protected areas like Parsa Wildlife Reserve, Chitwan National Park, Langtang National Park, Gaurishankar Conservation Area, Annapurna Conservation Area, Shivapuri Nagarjun National Park etc. Economical activities like business, tourism, trade, construction of infrastructure, agriculture are mainly flourishing due to extension of road network in Central Nepal along with dispersal of many IAPS. Roads networks are serving as connectors to different ecosystems increasing their vulnerability to biological invasion.

Human population is not uniformly distributed across these geographic regions. There is high population density in Tarai and valleys of Siwalik and Middle mountain while hills have moderate and mountains have low population density. The population of Tarai is 50.2%, Hills is 43.1% and Himalayan region is only 6.7% (CBS 2011). Among the five development regions of Nepal, Central development region (36.45%) has highest population whereas Far-Western Development region (9.63%) has lowest population. Kathmandu, the major city of Central Nepal has highest population density (4408 person/km^2) whereas Manang has lowest population density (3persons/km^2) (CBS 2011). Kathmandu is the most urbanized district in the country. Bhaktapur (53%), Kaski (52%), Lalitpur (48%), Chitwan (27%) and Sunsari (25%) are other districts with significant proportion of its population living in urban areas (CBS 2001). And all these districts except Sunsari lie in Central Nepal resulting in greater urban population density in Central Nepal. Central Nepal encompasses major industrial estates such Balaju Industrial estate, Patan Industrial estate, Hetaunda Industrial estate, Birgunj Industrial estate, Bhairahawa Industrial estate, Pokhara Industrial estate etc. Birgunj is an important trading centre in Central Nepal linked with India. This zone is linked with India in the south and with China to the north.

The major entry points on the southern border from India include Birgunj, Sunauli, Gaur, Malangwa, Jaleshwor and Bhairahawa and on the northern border from China include Rasuwagadhi (Rasuwa), Lomanthang (Mustang), and Tatopani (Sindhupalchok).

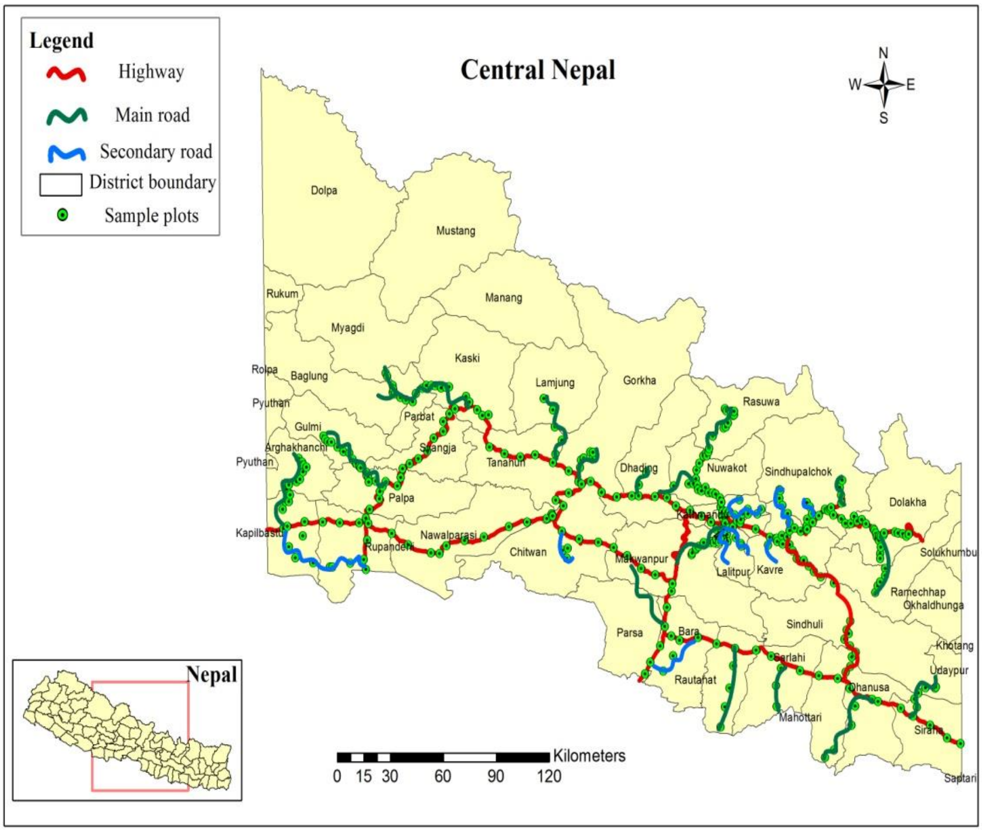


Figure 1: Map of Study Area (Source: GIS Unit,POOP,NEP/95/008,2001); accessed on September 21, 2014.

3.2 Survey of IAPS

For the purpose of survey the list of most problematic invasive alien plant species prepared by Tiwari et al. (2005) was used (Table 1). An ecological survey of these invasive alien species was carried along road network of Central Nepal between June and July of 2013. This period encompasses peak appearance of annuals since rainfall takes place mostly from June in this region. During our survey road network was taken as a reference considering that abundance of IAPS will be higher in roadside vegetation. This approach has been also used earlier by (Kosaka *et al.* 2010; Wabuyele *et al.* 2014) for the distribution of invasive plant species. The survey of IAPS followed systematic sampling method through systematic location of sample plots along the road at an interval of 10 km in plain and of 5 km in hilly areas. At every specified distance, a 10 × 10 m^2 plot was defined along the sides of the road. To avoid biasness in selection of plot location relative to the road (i.e., right or left side of the road) lottery method was used in case of plain areas whereas for hilly region upslope (i.e. above the road) was considered for sampling. At each plot, IAPS encountered within the plot, their phenophase (vegetative, flowering, fruiting or senescence) of each individual species, presence or absence of biocontrol agents, order of dominancy of IAPS in terms of cover and land use type were recorded along with surrounding IAPS. For dominancy order, IAPS having highest cover was regarded as first dominant followed by the second and third with decreasing cover. The cover of IAPS was determined by visual estimation. Those species were then arranged in descending order of dominancy based on the level of invasion within each plot. IAPS occurring outside the sample plots i.e. at about 50 m from each plot were noted as surrounding invasive alien plant species in our study. Latitude, longitude and elevation were recorded for each plot using Global Positioning System (GPS) whereas slope and aspect were measured using a clinometer. The distances of the plots to the road ranged from 1 to 15 meters depending upon the locality and accessibility. The field data sheet used during our survey has been attached in Appendix I. All together 340 roadside plots were sampled along the major road networks in Central Nepal. All accessible highways, main roads and secondary roads of Central Nepal were surveyed to the extent possible.

Table 1: Invasive alien plant species (IAPS) considered in the present research

SN	Name of IAPS	Family	Common name	Native range
1	*Ageratina adenophora* (L.) King & Robinson	Asteraceae	Crofton weed	Central America (Mexico)
2	*Ageratum conyzoides* L.	Asteraceae	Billy goat weed, chick weed	South America
3	*Alternanthera philoxeroides* (Mart.) Griseb.	Amaranthaceae	Alligator weed	Central America
4	*Amaranthus spinosus* L.	Amaranthaceae	Spiny pigweed	Tropical America
5	*Argemone mexicana* L.	Papaveraceae	Mexican prickly poppy	Tropical America
6	*Bidens pilosa* L.	Asteraceae	Beggar's stick	Tropical America
7	*Cassia occidentalis* L.	Fabaceae (Leguminosae)	Coffe senna, coffee weed	Tropical America
8	*Cassia tora* L.	Fabaceae (Leguminosae)	Sicklesena	South America
9	*Chromolaena odorata* (Spreng) King & Robinson	Asteraceae	Siam weed; chromolaena	Tropical America, Jamaica, West Indies
10	*Eichhornia crassipes* (Mart.) Solms.	Pontederiaceae	Water hyacinth	South America
11	*Hyptis suaveolens* (L.) Poit.	Lamiaceae (Labiatae)	Wild spikenard, Chan	Tropical America
12	*Ipomoea carnea Jacq. ssp. fistulosa* (Mart. ex Choisy) D.F. Austin	Convolvulaceae	Shrubby morning glory	South America
13	*Lantana camara* L.	Verbenaceae	Lantana	West Indies
14	*Mikania micrantha* Kunth	Asteraceae	Mile-a-minute	Central and South America
15	*Mimosa pudica* L.	Fabaceae (Leguminosae)	Sensitive plant, sleeping grass	Tropical America
16	*Oxalis latifolia* Humb.	Oxalidaceae	Purple wood sorrel, broad-leaf wood sorrel	Central and South America
17	*Parthenium hysterophorus* L.	Asteraceae	Bitter weed, Carrot grass, False ragweed, Fever few	Mexico, West Indies, Central and South America
18	*Xanthium strumarium* L.	Asteraceae	Rough cockle-Bur	America

3.3 Data Analysis

From our survey data, the frequency of each individual IAPS was calculated according to Zobel *et al.* (1987) using the following relation:

$$\text{Frequency (\%)} = \frac{\text{No of sample plots with individual IAPS} \times 100}{\text{Total no of plots sampled}}$$

Likewise, the frequency of only dominant species was also calculated in the same manner. During this process, the frequency of IAPS only up to third dominant order was included. The dominant order was determined based on percentage of cover within the plot by visual estimation. To know the distribution pattern of IAPS along elevation gradient, regression analysis was done (SPSS 16). The total number of species encountered within a sample plot of 100 m^2 was regarded as species richness. Before doing regression, the normality of our data (species richness, elevation) was tested (Shapiro Wilk normality test) but our data was not normally distributed. Our data did not show normal distribution even after logarithmic and square root transformations. Then, average species richness of each 100m asl elevation band was calculated. The elevation gradients between 100 and 2600 m asl were divided into 26 elevation zones (100 m asl) and average species richness of each band was obtained. Regression analysis was performed to know the pattern of distribution of IAPS along elevation gradient for this data after normality test. Here quadratic regression models offered the best fit with highest coefficient of determination. During regression analysis, average species richness was considered as response variable and elevation as predictor variable. Information like year of record of individual IAPS in Nepal, IAPS's country of origin and distribution range was obtained from Tiwari *et al.* (2005).To access the relationship between frequency of IAPS and year of record of each IAPS in Nepal linear regression analysis was performed. Here, year record means first reported date in Nepal which was obtained from Tiwari *et al.* (2005). The relationship between maximum elevation limit and minimum residence time was simply represented by scatter diagram only. Here, maximum elevation limit of each species was the highest elevation reached by individual in Central Nepal as per the record of our field data. Residence time means time since first record in Nepal for each species and this value was obtained by noting the first reported date through available literature Tiwari *et al.* (2005) and subtracting it with present date (i.e. 2013).

This gave the value of residence time in years for each species. Similar method was adopted by Alexander *et al.* (2011) to obtain the minimum residence time of each species during study of IAPS distribution along an elevation gradient in Czech Republic. The mean values of species richness across different land use types was compared using ANOVA followed by Duncan homogeneity test as the data was normally distributed with equal variance. For this analysis we identified five categories of land use type namely Forest, Shrubland, Grazing and Fallow land, Agricultural land and Wetland based on the nature of our data. Agricultural land included both cultivated and abandoned type whereas wetland included swamps, marshes and areas with continuous water logged condition. And shrubland means areas covered by shrubby vegetation and with secondary succession. Grazing and fallow land included areas used for waste deposition, grazing, public fallow lands and grasslands. Further, the calculation of percentage occurrence in different land use for each individual IAPS was also done. For this following relation was adopted:

For *Chromolaena odorata*, as an example

Total sample plots in agricultural land= x

Number of plots in agricultural land with *Chromolaena odorata* = x_1

Percentage of occurrence of *C. odorata* in agricultural land $= \frac{X1}{X} \times 100$

In the same way percentage of occurrence of this species in other four land use types was obtained. Likewise, similar calculation was done for other IAPS too. The GPS reading obtained from the field survey were incorporated into Arc GIS version 10 to prepare spatial distribution map of individual IAPS. While preparing the distribution maps of individual IAPS, data recorded as surrounding species were also included. A geographic distribution map based on the number of invasive alien plant species was prepared according to the distribution information listed in our detailed database. The elevational range of each IAPS was graphically represented. Elevational range in our data refers to the minimum and maximum elevation limit of each species obtained during our survey. To know the district wise distribution of IAPS in Central Nepal, present distribution data of each species was complied and compared with the most comprehensive report on IAPS for Nepal i.e. Tiwari *et al.* 2005.

4. RESULTS

4.1 Frequency of Invasive Alien Plant Species

Altogether 18 invasive alien plants species (IAPS) were recorded during an inventory along the road network in Central Nepal. Among them *Bidens pilosa* (58%) had the highest frequency followed by *Ageratina adenophora* (43%) and *Chromolaena odorata* (36%) (Figure 2). Eight of these IAPS had frequency >20%.

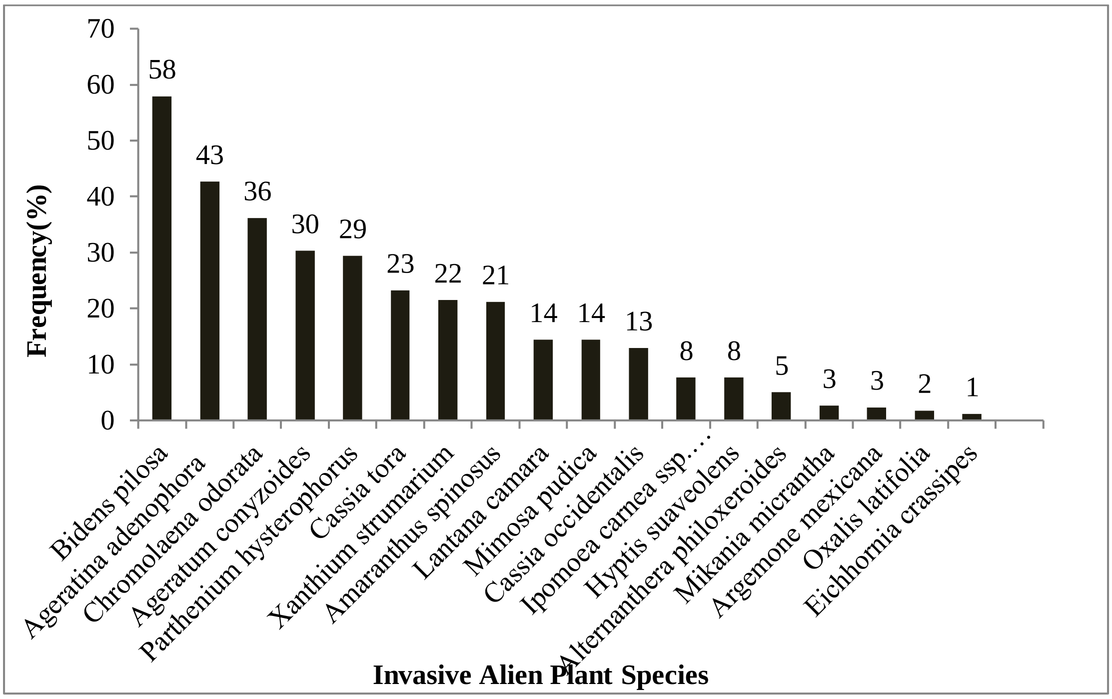


Figure 2: Frequency (%) of different invasive alien plant species in roadside vegetation in Central Nepal.

4.2 Frequency of Dominant Invasive Alien Plant Species

The IAPS showed great variation in their abundance. Based on the frequency of first dominant species, *Ageratina adenophora* was the most dominant in 29% of the sample plots followed by *Parthenium hysterophorus*, *Chromolaena odorata* and *Bidens pilosa* whereas species like *Argemone mexicana*, *Cassia occidentalis* and *Oxalis latifolia* were the most dominant only in a few sample plots (Figure 3). *Bidens pilosa* was the most frequent as the second and third dominant species; it was second dominant species in 29% of the plots and third dominant in 21 % (Figure 4 and 5).

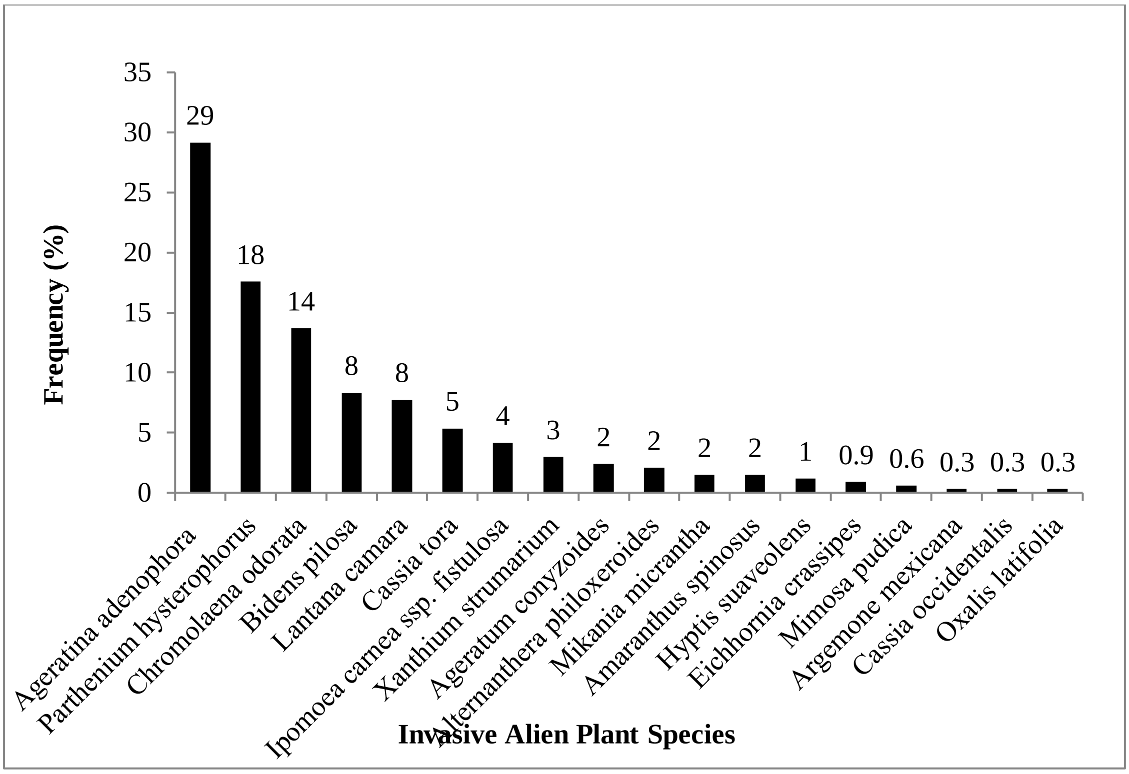


Figure 3: Frequency (%) of the species which was the most dominant species.

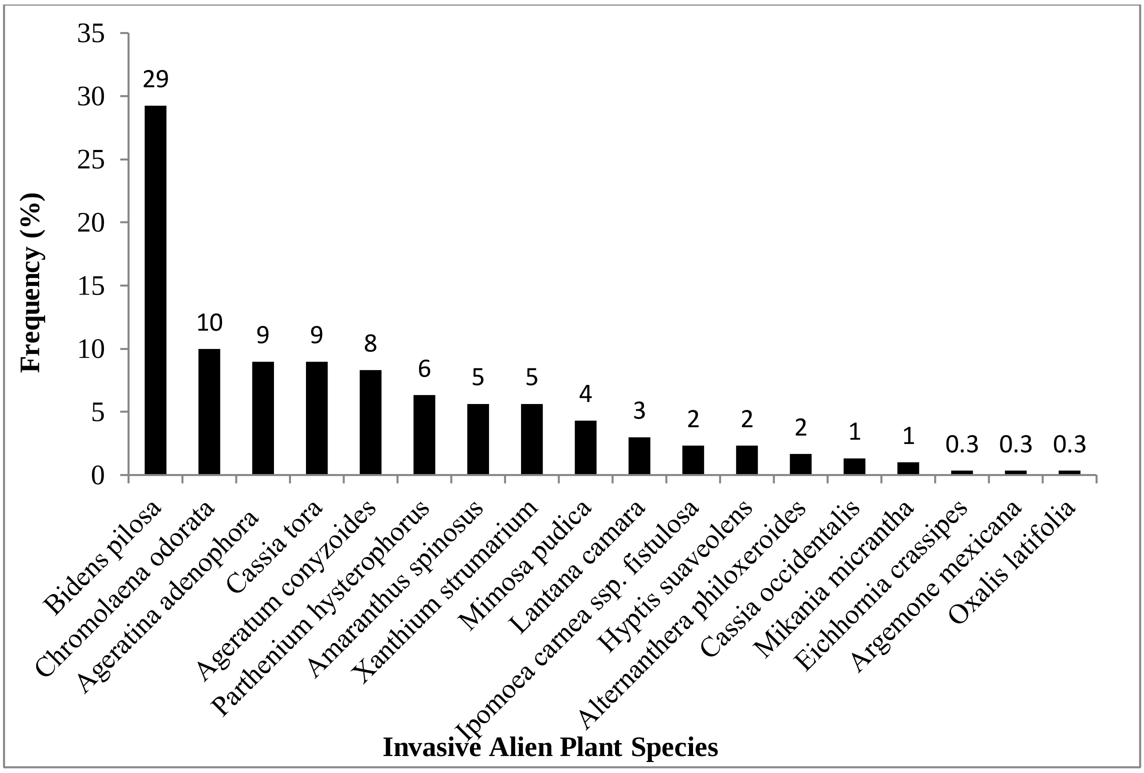


Figure 4: Frequency (%) of the species which was the second most dominant.

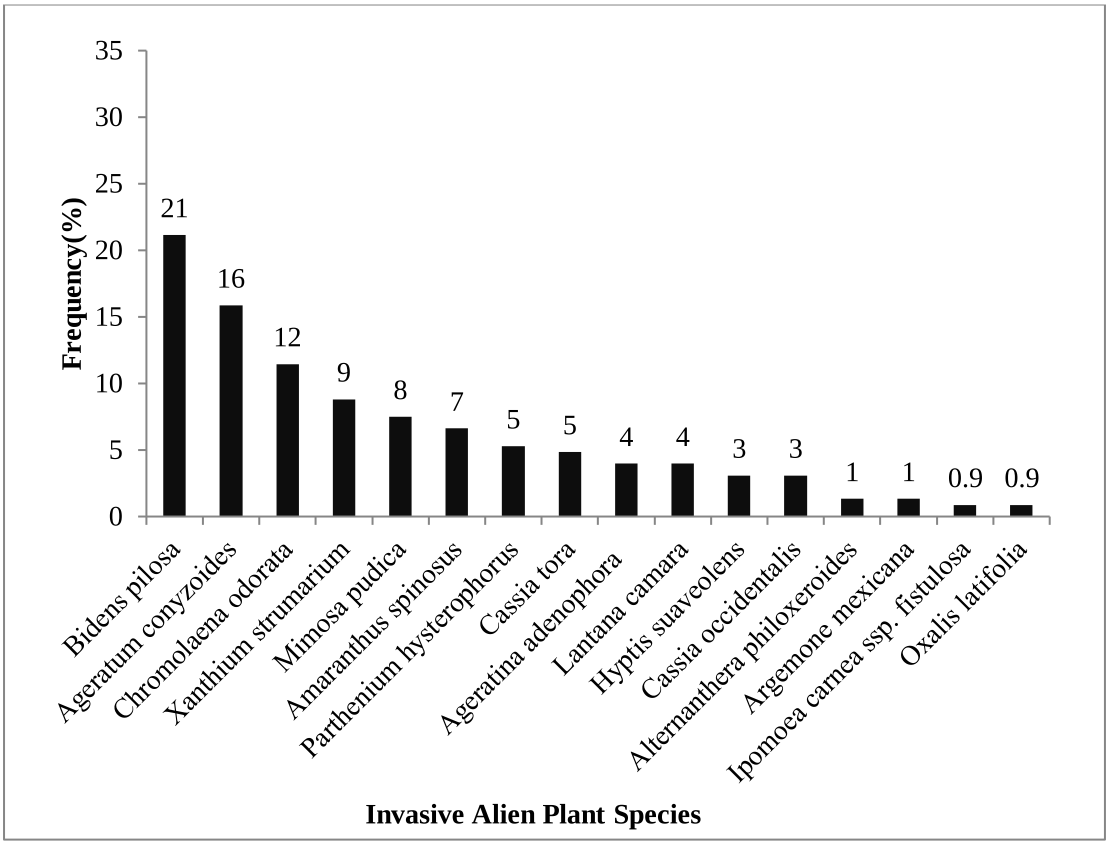


Figure 5: Frequency (%) of the species which the third most dominant.

4.3 Invasive Alien Plant Species Richness along Elevation Gradient

The IAPS richness showed statistically significant unimodal pattern of distribution with elevation (Figure 6). It increased with increasing elevation up to 600m asl and then decreased gradually with increasing elevation. Maximum species richness occurred between 400-600m asl.

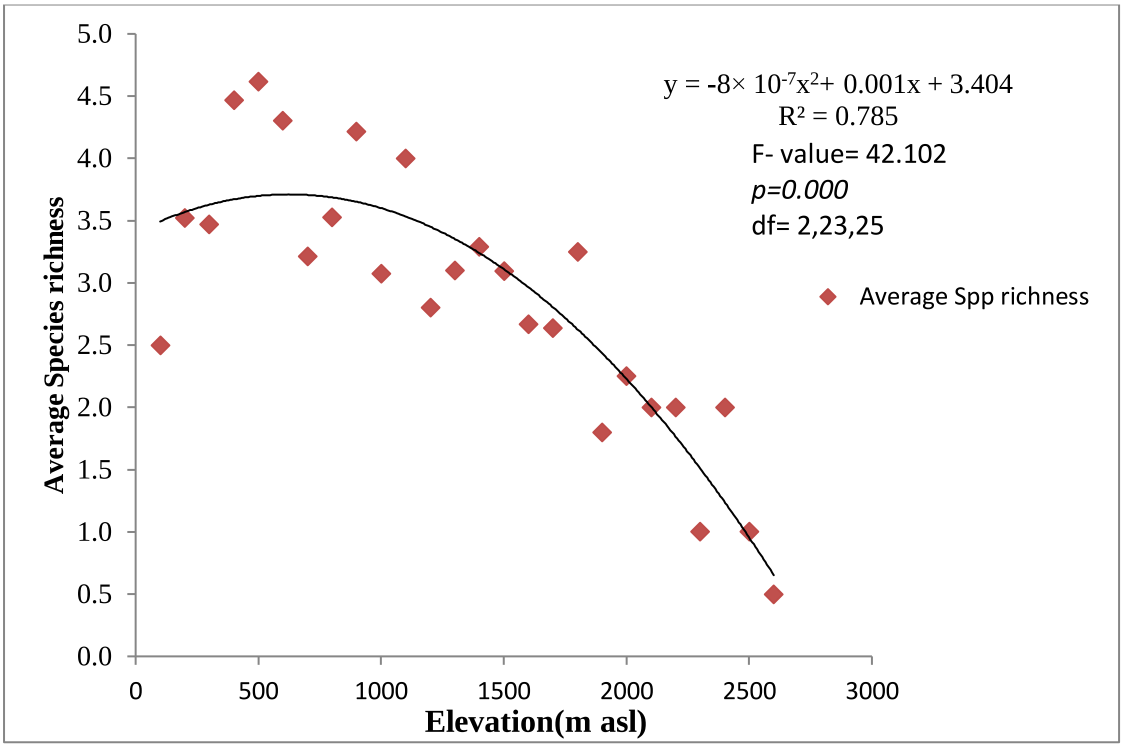


Figure 6: Relationship between average invasive plant species richness (number/100 m^2) and elevation (m) asl. The fitted line was obtained by quadratic regression model. Each point represents average species richness of IAPS in sample plots of different elevation bands.

4.4 Invasive Alien Plant Species Richness across Land Use Types

Among the different land use types, grazing and fallow land had the highest IAPS richness followed by agricultural land, shrubland, forest and wetland. Species richness of IAPS across different land use types was statistically significant ($p \leq 0.05$). The mean species richness in forest, wetland and shrubland was significantly different from the species richness of grazing and fallow land but there was no significant difference in species richness of agricultural land and grazing and fallow land. Species richness of IAPS was the lowest in wetland (Figure 7).

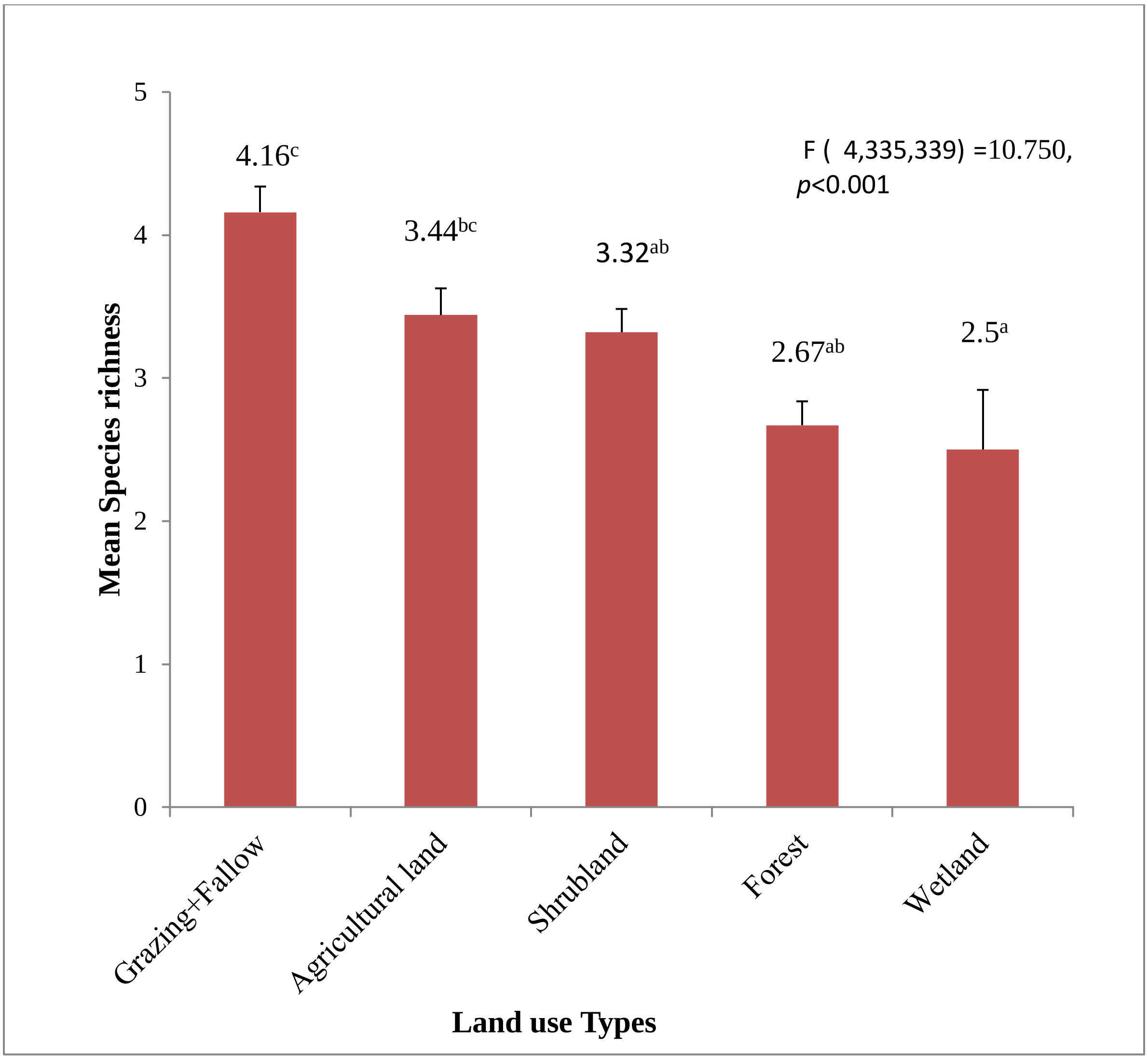


Figure 7: Species richness of invasive alien plant species across different land use types. The vertical error bars represent the standard error. The mean values were compared by ANOVA followed by Duncan homogeneity test. The values with same alphabet are not significantly different at p=0.05.

4.5 Distribution of IAPS across Different Land use types

The IAPS were not uniformly distributed across different land use types (Table 1). Grazing and fallow land was mostly invaded by many of these IAPS in comparison to other land use types.

Table 2: Percentage of occurrence across different land use types.

Name of IAPS		Percentage of occurrence in different land use types				
	Total no of presence Plots	Agricultural land (%)	Forest (%)	Grazing+Fallow land (%)	Shrubland (%)	Wetland (%)
Ageratina adenophora	181	18	28	19	35	0
Ageratum conyzoides	139	24	26	23	27	0
Alternanthera philoxeroides	20	30	5	55	5	5
Amaranthus spinosus	113	20	16	44	19	2
Argemone mexicana	11	46	0	46	9	0
Bidens pilosa	223	20	19	29	31	1
Cassia occidentalis	83	18	19	40	22	1
Cassia tora	110	20	22	39	17	2
Chromolaena odorata	156	15	33	28	23	1
Eichhornia crassipes	9	0	0	22	11	68
Hyptis suaveolens	66	9	27	33	29	2
Ipomoea carnea ssp. *fistulosa*	44	14	11	41	9	25
Lantana camara	92	16	21	29	30	3
Mikania micrantha	15	13	27	47	7	7
Mimosa pudica	77	20	23	29	25	4
Oxalis latifolia	12	42	8	17	33	0
Parthenium hysterophorus	112	13	11	54	20	3
Xanthium strumarium	113	21	9	42	25	4

4.6 Relationship between Frequency and Year of Record of Different IAPS

IAPS introduced earlier had higher frequency than IAPS with recent introduction. When the frequency of IAPS and year of record was graphically represented negative linear relationship was obtained (Figure 8).

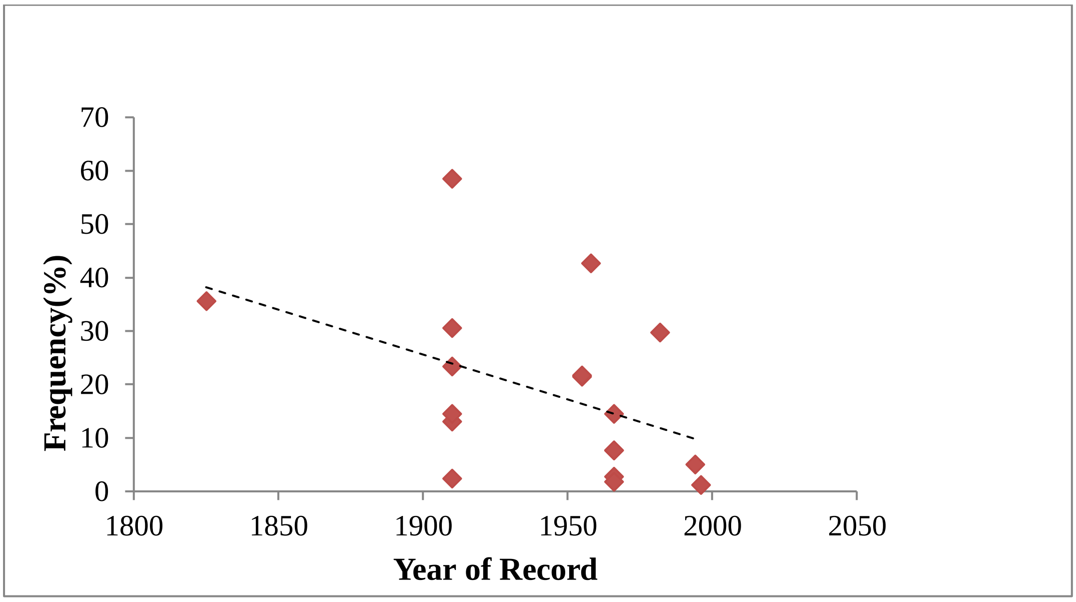


Figure 8: Relationship between frequency (%) and year of record of IAPS. The fitted line was obtained by linear regression model. Each point represents frequency value of IAPS.

4.7 Relationship between Elevational limit and Minimum Residence Time of IAPS

There was no significant relationship between elevational limit and minimum residence time of IAPS. The scatter plot showed the maximum elevation reached by different IAPS (Figure 9). Among these IAPS, *Ageratina adenophora* was found at highest elevation followed by *Bidens pilosa*. But many of the IAPS had elevation limit between 1500-2000m asl except few. *Mikania micrantha* was the only species having elevation limit below 500m asl.

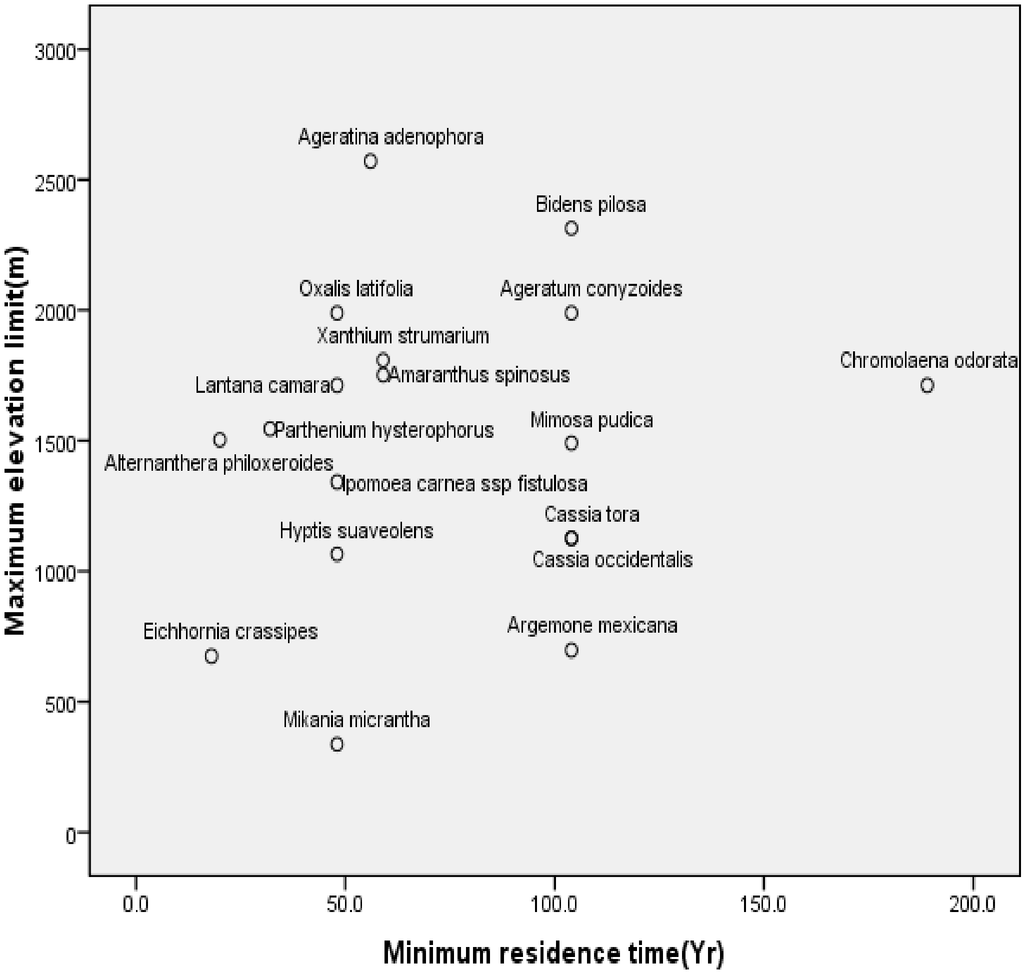


Figure 9: Scatter plot showing the relationship between minimum residence time and maximum elevation reached by different IAPS. Each point represents the upper elevation limit of distribution of the respective species.

4.8 Elevational Range of Different IAPS:

Most of the IAPS introduced in Nepal have spread to different ecological regions with varying altitudinal range. Invasive alien plant species showed their occurrence from tropical to temperate region along road network in Central Nepal. Some species were confined to tropical region only (e.g.; *Eichhornia crassipes, Mikania micrantha, Argemone mexicana*); some were present in both tropical and sub-tropical region whereas few species were found from tropical to temperate region (e.g.; *Bidens pilosa, Ageratina adenophora*). The altitudinal range of each species is shown below (Figure 10).

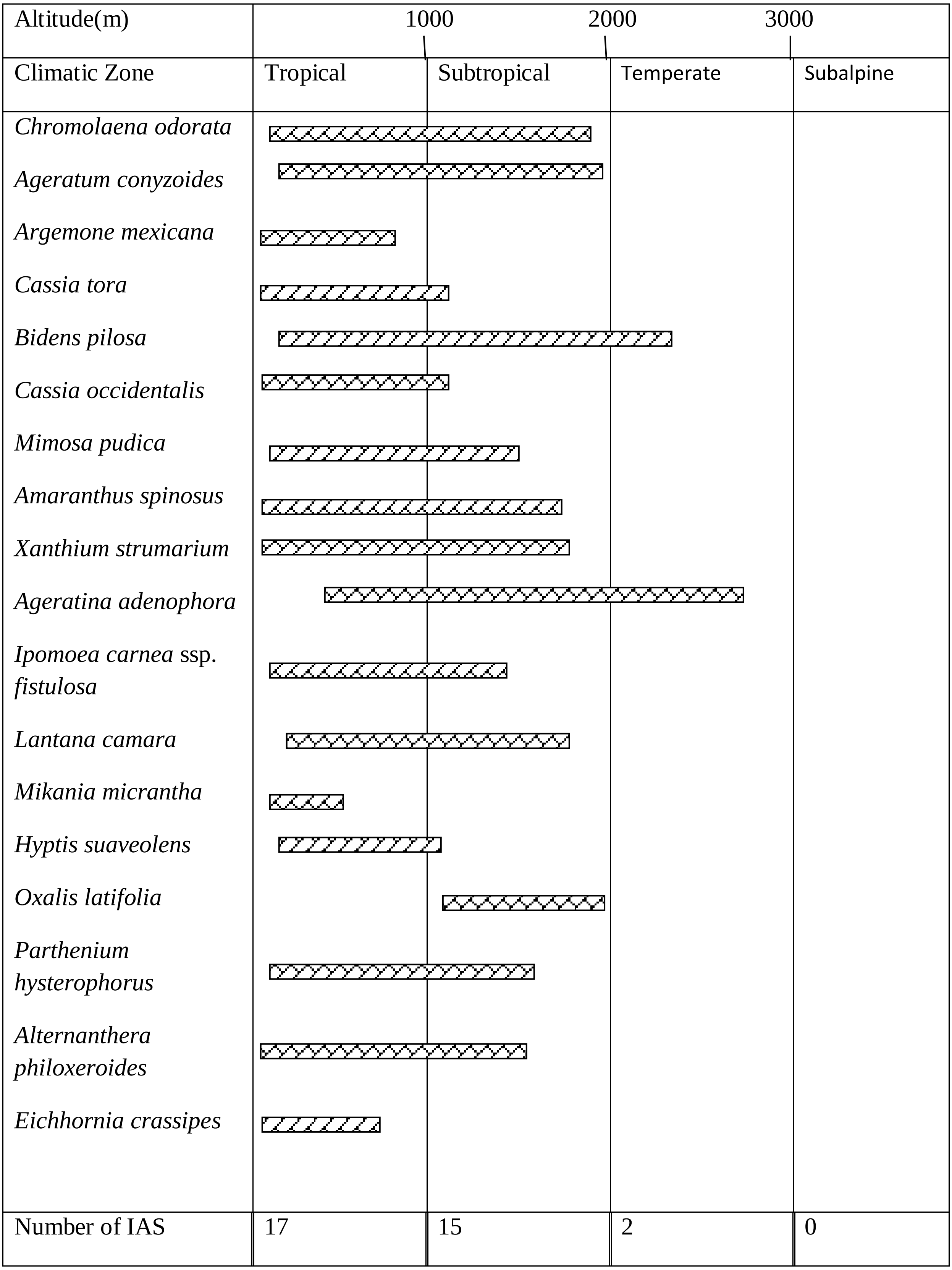


Figure 10: Altitudinal range of invasive alien plant species found along road network of Central Nepal.

4.9 Distribution of IAPS

Invasive alien plant species were found in all four physiographic regions except High Himal region in Central Nepal. But Middle mountains had greater IAPS richness in comparison to others. IAPS were mostly confined to those areas with high population density, industrial and commercial activities and extensive road network.

4.9.1 Distribution of *Chromolaena odorata*

Chromolaena odorata was found in most of the districts but mostly dominant in districts of tropical climate. This species was mostly found in Tarai, Siwalik and Middle mountains of Nepal (Figure 11). *C. odorata* was common along forest edges, open canopy forests and shrublands and less frequent in wetland. The plant have been encroaching the interior of the forest of some protected areas where forest canopy was open. This species was found across different land use types (Table 2). This species was absent in most of the sample plots in Tarai though this region was climatically suitable for its growth. In the present survey *C. odorata* was found from 105-1750m asl in Central Nepal.

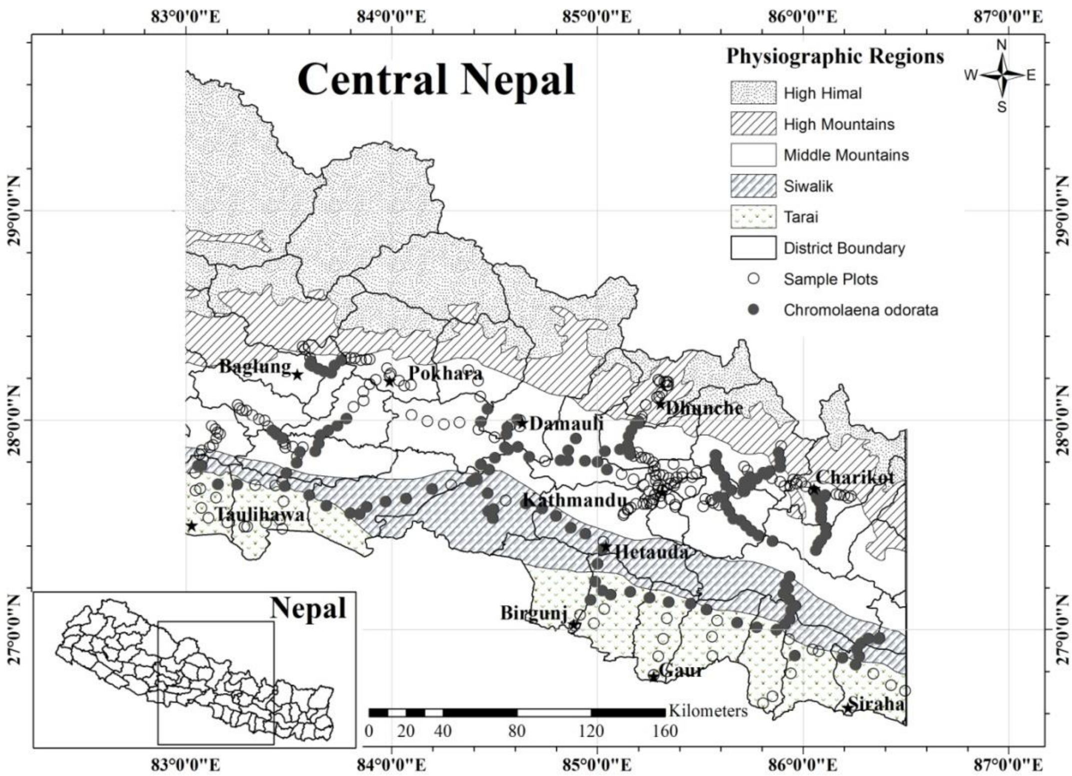


Figure 11: Geographic distribution of *Chromolaena odorata* in Central Nepal.

4.9.2 Distribution of *Ageratum conyzoides*

Ageratum conyzoides was mainly found in roadside agricultural lands, forest edges, grazing and fallow lands and shrubland (Table 2). This species was more commonly found in hilly areas as compared to Tarai region in Central Nepal. The plant was most dominant in Middle mountains as compared to other physiographic regions. The dense population of it was found mainly in Kathmandu, Pokhara, Damauli etc (Figure 12). Though, *A. conyzoides* is a problematic agricultural weed it was frequently found in shrubland and forest which were disturbed by human activity. Degraded forest with open canopy was being invaded by this species. In the present survey *A. conyzoides* was found from 180-2000m asl in Central Nepal.

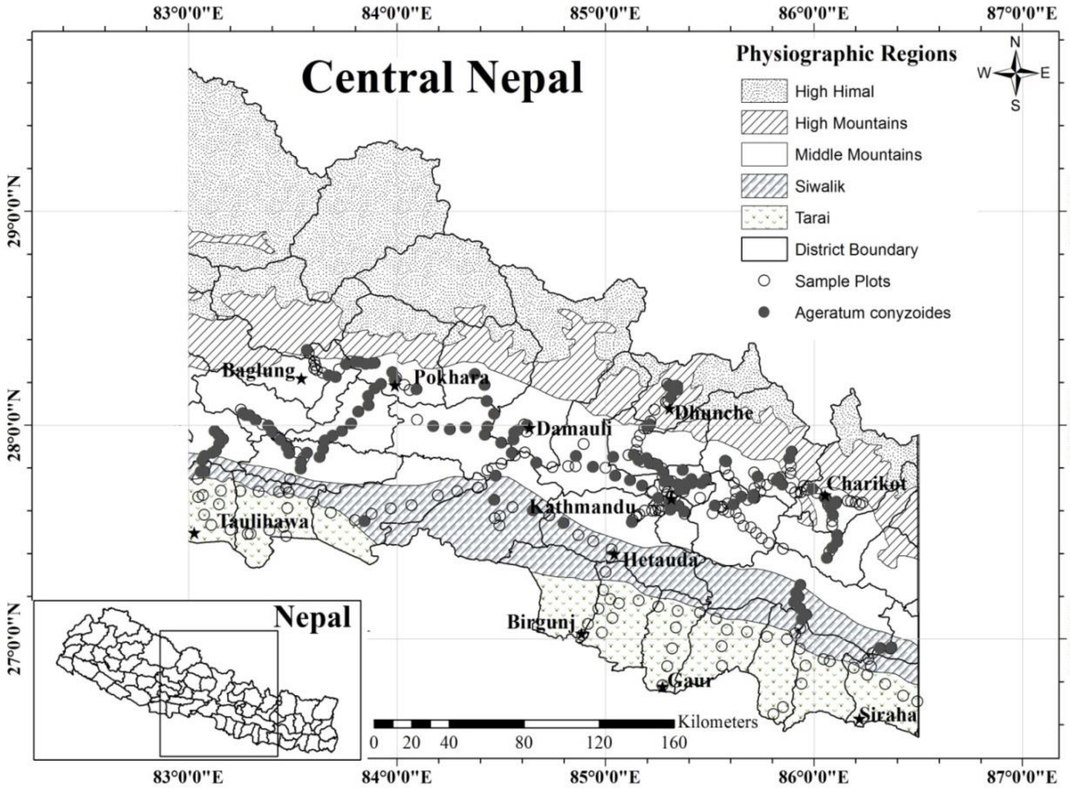


Figure 12: Geographic distribution of *Ageratum conyzoides* in Central Nepal.

4.9.3 Distribution of *Argemone mexicana*

Argemone mexicana was mainly found in agricultural land, grazing and fallow land and shrubland (Table 2). This species was common in agricultural and fallow lands along roadsides in Central Nepal and mostly present in hot and humid areas only i.e., confined to tropical region only (Figure 13). This species was mainly confined to Tarai and Siwalik region except at few places in other physiographic regions. In the present survey this species was found from 65-700m asl in Central Nepal.

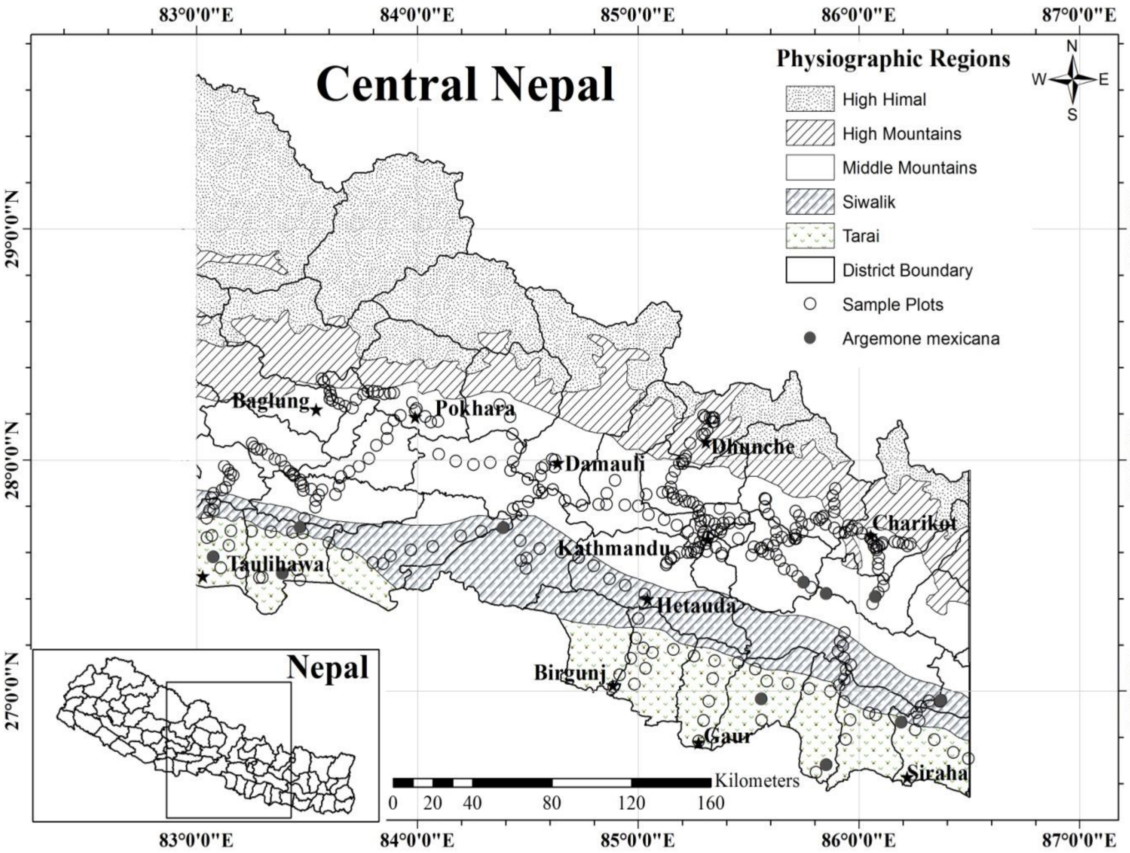


Figure 13: Geographic distribution of *Argemone mexicana* in Central Nepal.

4.9.4 Distribution of *Cassia tora*

Cassia tora was one of the major invasive weed in Central Nepal and was mainly found in grazing and fallow lands, shrubland, agricultural land and sometimes in wetland too (Table 2). This species was common in grazing and fallow land as compared to other land use types of warm and dry areas. *Cassia tora* was almost uniformly distributed in three physiographic regions namely Tarai, Siwalik and Middle mountains (Figure 14). In the present survey *Cassia tora* was found from 75-1150m asl in Central Nepal.

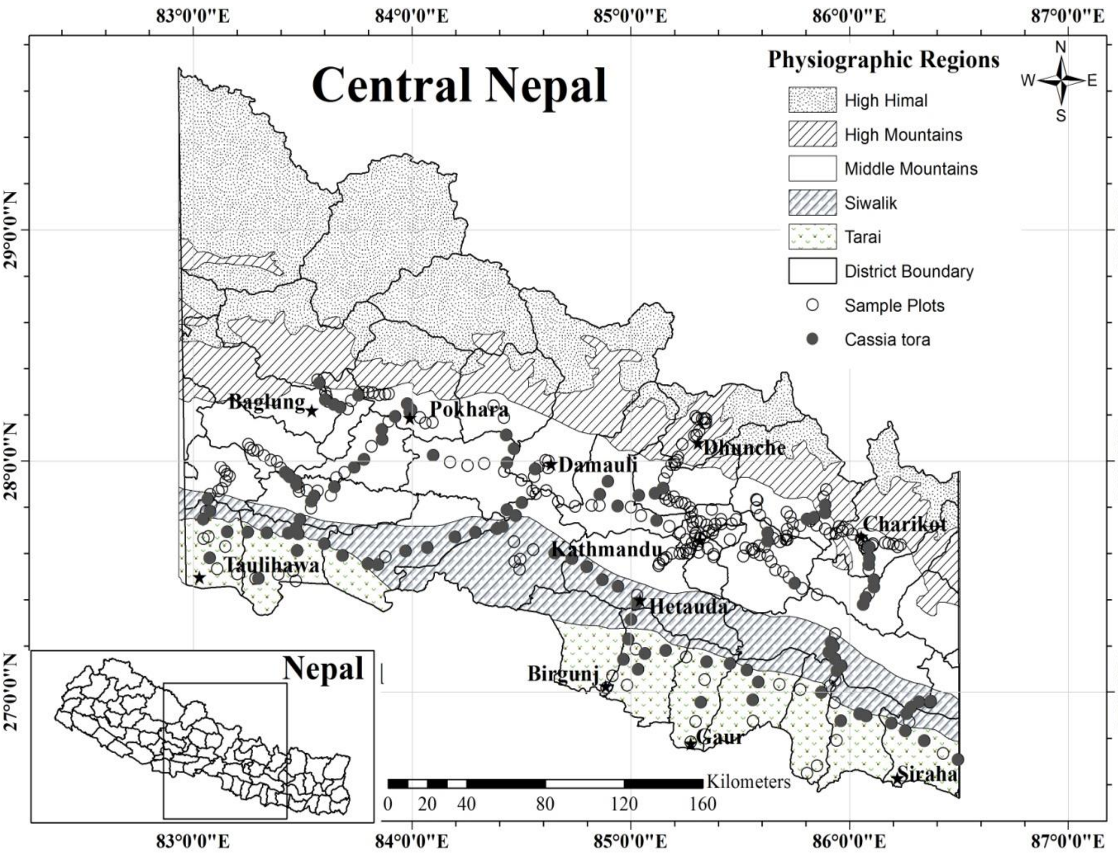


Figure 14: Geographic distribution of *Cassia tora* in Central Nepal.

4.9.5 Distribution of *Bidens pilosa*

Bidens pilosa was mainly found in agricultural lands, forest, grazing and fallow land, shrubland and in some cases in wetlands too (Table 2). It was most common in shrubland and grazing and fallow land. This species was mostly found in Middle mountains of Nepal along roadside communities (Figure 15) and almost absent in Tarai region. *Bidens pilosa* had wider geographic range spreading from tropical to temperate zones of Nepal. In the present survey *Bidens pilosa* was found from 130-2350m asl in Central Nepal.

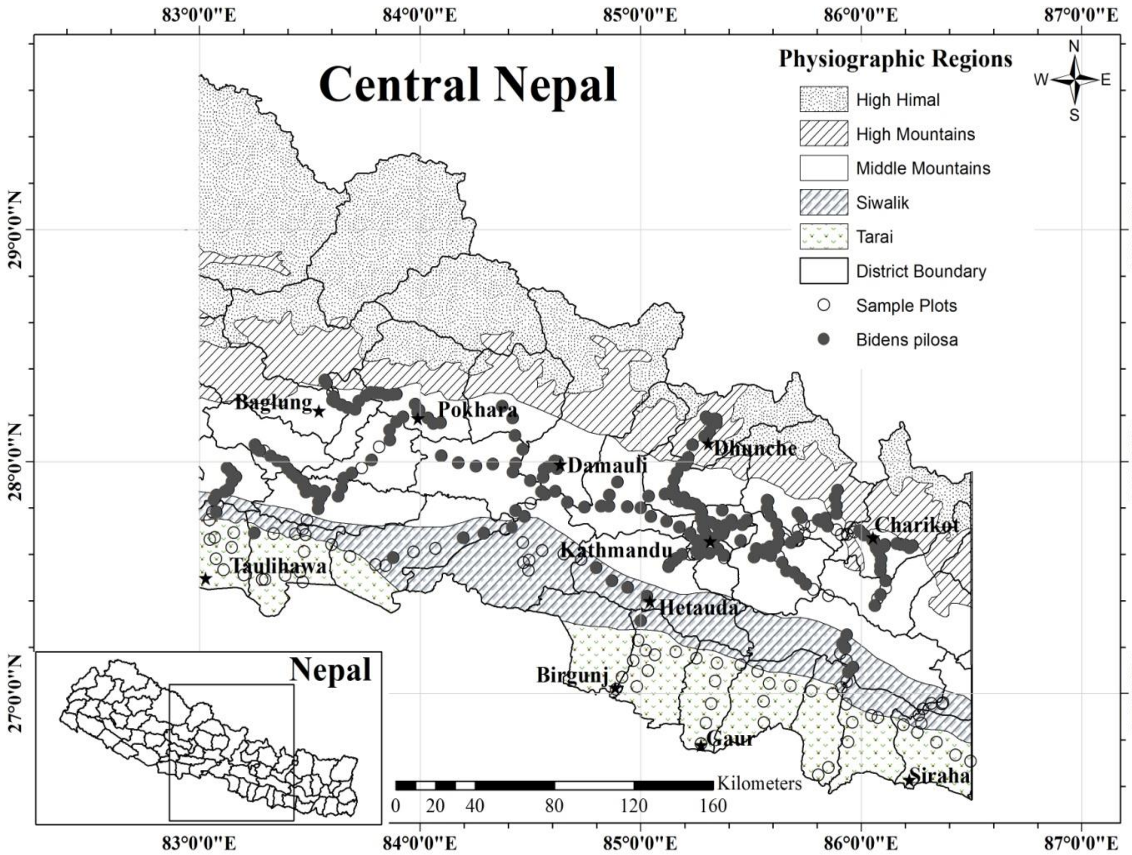


Figure 15: Geographic distribution of *Bidens pilosa* in Central Nepal.

4.9.6 Distribution of *Cassia occidentalis*

Cassia occidentalis was mainly found in agricultural land, forest margins, shrubland, grazing and fallow land and in wetland too (Table 2). But this species was most common in grazing and fallow land as compared to other land use types. Considering the physiographic distribution of this species, it was commonly found in Middle mountains of Nepal (Figure 16) and prefers to grow on hot and humid climate. In the present survey *Cassia occidentalis* was found from 75-1150m asl in Central Nepal.

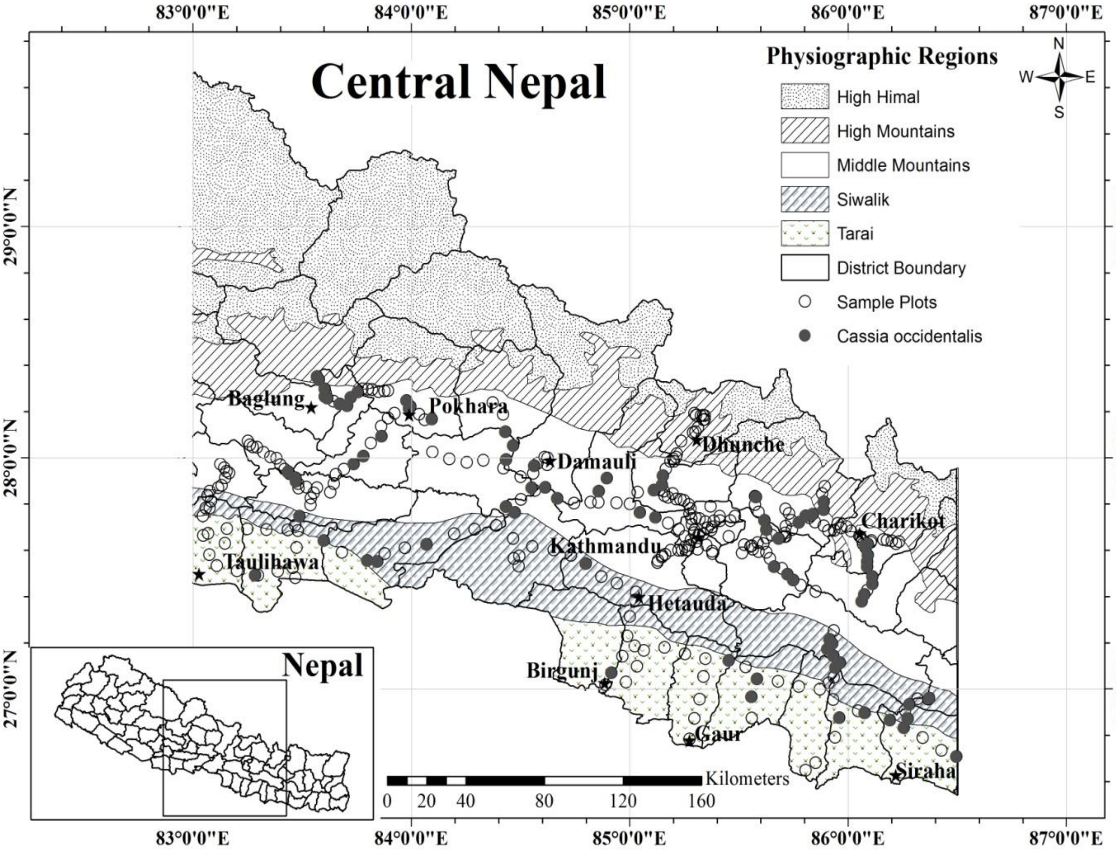


Figure 16: Geographic distribution of *Cassia occidentalis* in Central Nepal.

4.9.7 Distribution of *Mimosa pudica*

Mimosa pudica was mainly found in abandoned agricultural lands, forest margins, grazing and fallow lands, shrubland and wetlands (Table 2). It was commonly found in grazing and fallow land and less frequent in wetland. This species was common in transitional zones of Siwalik and Middle mountains of Nepal (Figure 17) and prefers to grow on moist fallow and agricultural lands. In the present survey *Mimosa pudica* was found from 80-1500m asl in Central Nepal.

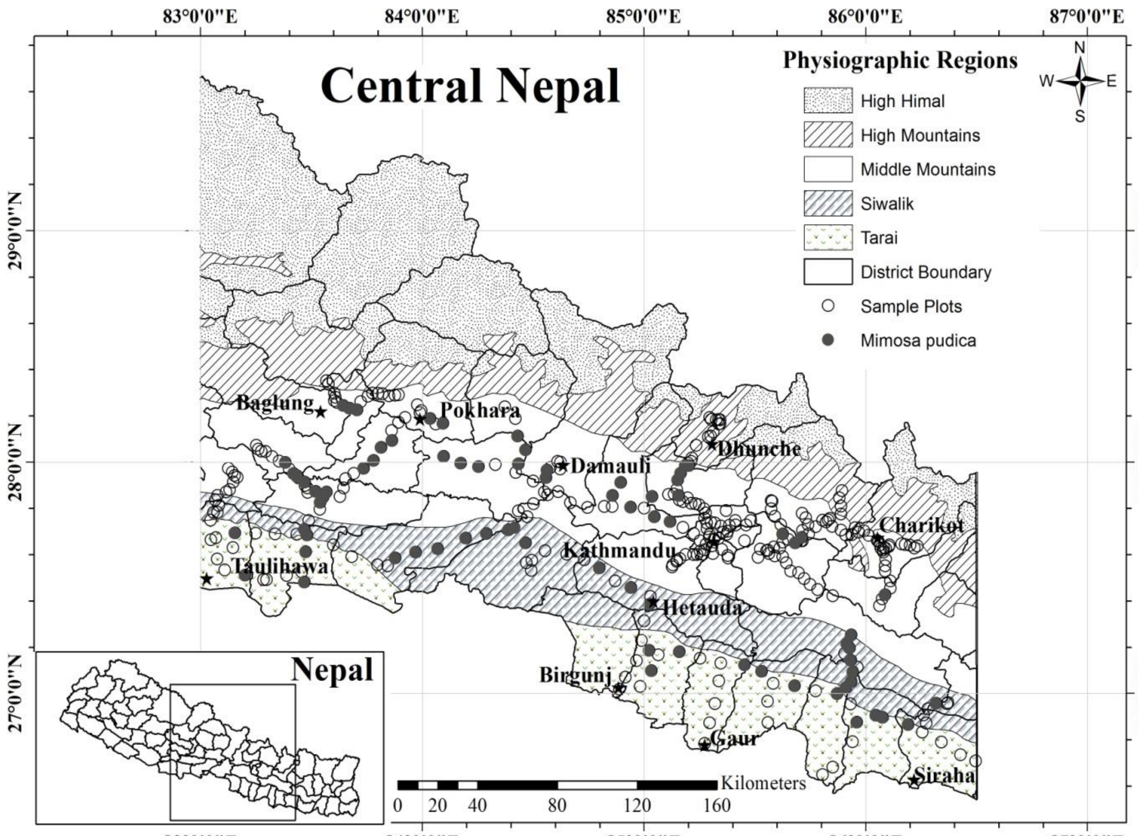


Figure 17: Geographic distribution map of *Mimosa pudica*.

4.9.8 Distribution of *Amaranthus spinosus*

Amaranthus spinosus, a major invasive weed in Central Nepal was mainly found in agricultural lands, forest margins, grazing and fallow land, shrubland and wetland too (Table 2). Almost half of the sample plots (44%) with *A. spinosus* were in grazing and fallow land. Considering the physiographic regions of Nepal it was commonly found in Middle mountains (figure 18). This species was common in waste lands of roadsides. In the present survey *Amaranthus spinosus* was found from 70-1750m asl in Central Nepal.

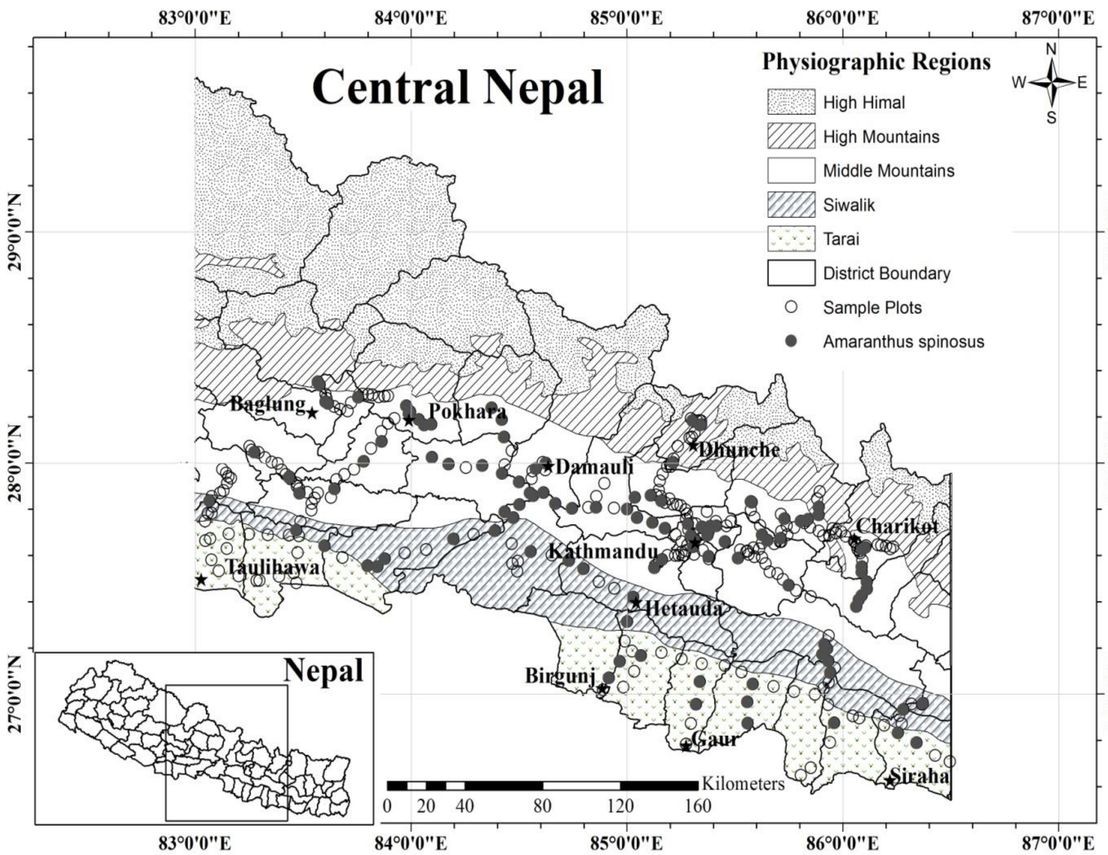


Figure 18: Geographic distribution of *Amaranthus spinosus* in Central Nepal.

4.9.9 Distribution of *Xanthium strumarium*

Xanthium strumarium was a common IAPS in roadside vegetation. This species was mainly found in abandoned agricultural lands, forest margins, grazing and fallow land, shrubland and wetland too (Table 2). Almost half (42%) of sample plots with *X. strumarium* were present in grazing and fallow land. Considering the physiographic distribution of this species, it was commonly found in Middle mountains of Nepal (Figure 19). This species had been mostly invading in tropical and subtropical regions of Nepal. In the present survey this species was found from 70-1810m asl in Central Nepal.

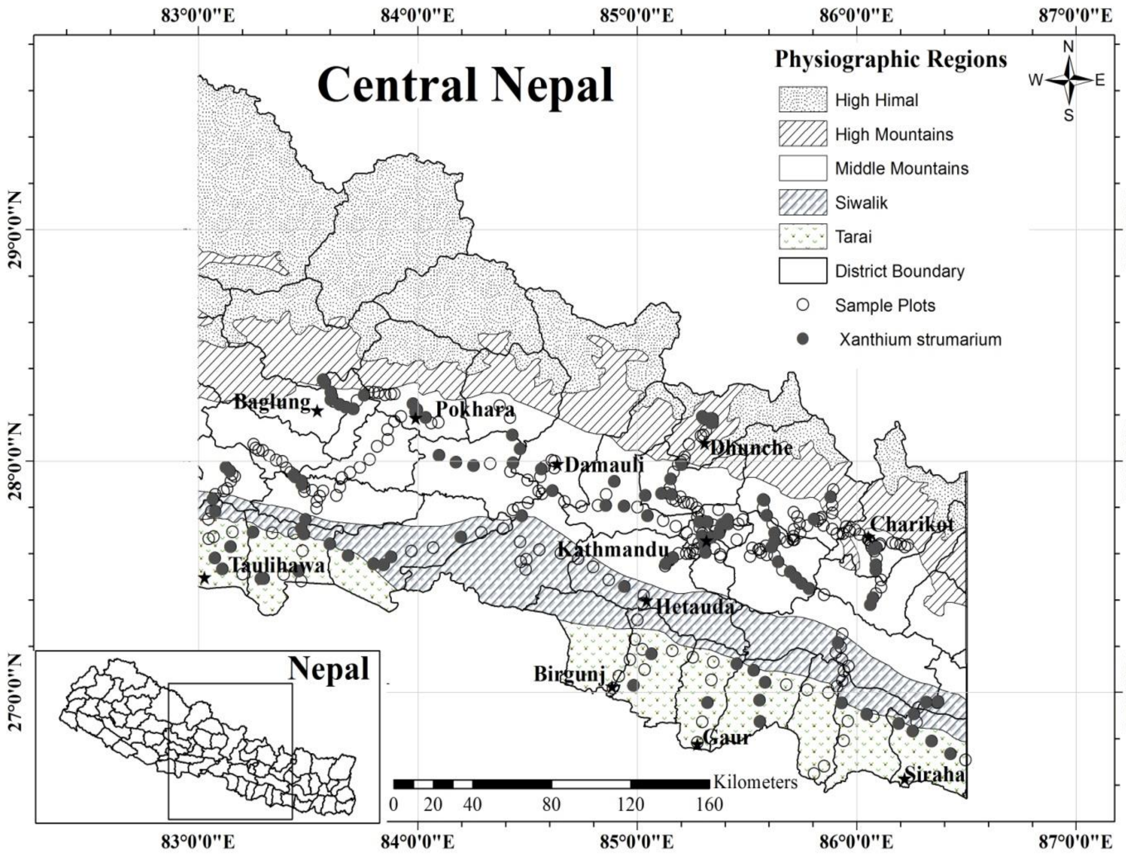


Figure 19: Geographic distribution of *Xanthium strumarium* in Central Nepal.

4.9.10 Distribution of *Ageratina adenophora*

Ageratina adenophora was a common IAPS in roadside vegetation of Central Nepal. This species was found invading in abandoned agricultural lands, forest, grazing and fallow land and shrubland (Table 2). It was common in shrubland and forest. Considering the physiographic distribution, this species was commonly found in Middle mountains of Nepal (Figure 20). This plant had wider geographical range spreading from tropical to temperate zones. This species was highly spreading in disturbed forest of moist areas and as a pioneer species in landslide sites along road network of Central Nepal. But this species was absent in Tarai region. In the present survey *Ageratina adenophora* was found from 395-2600m asl in Central Nepal.

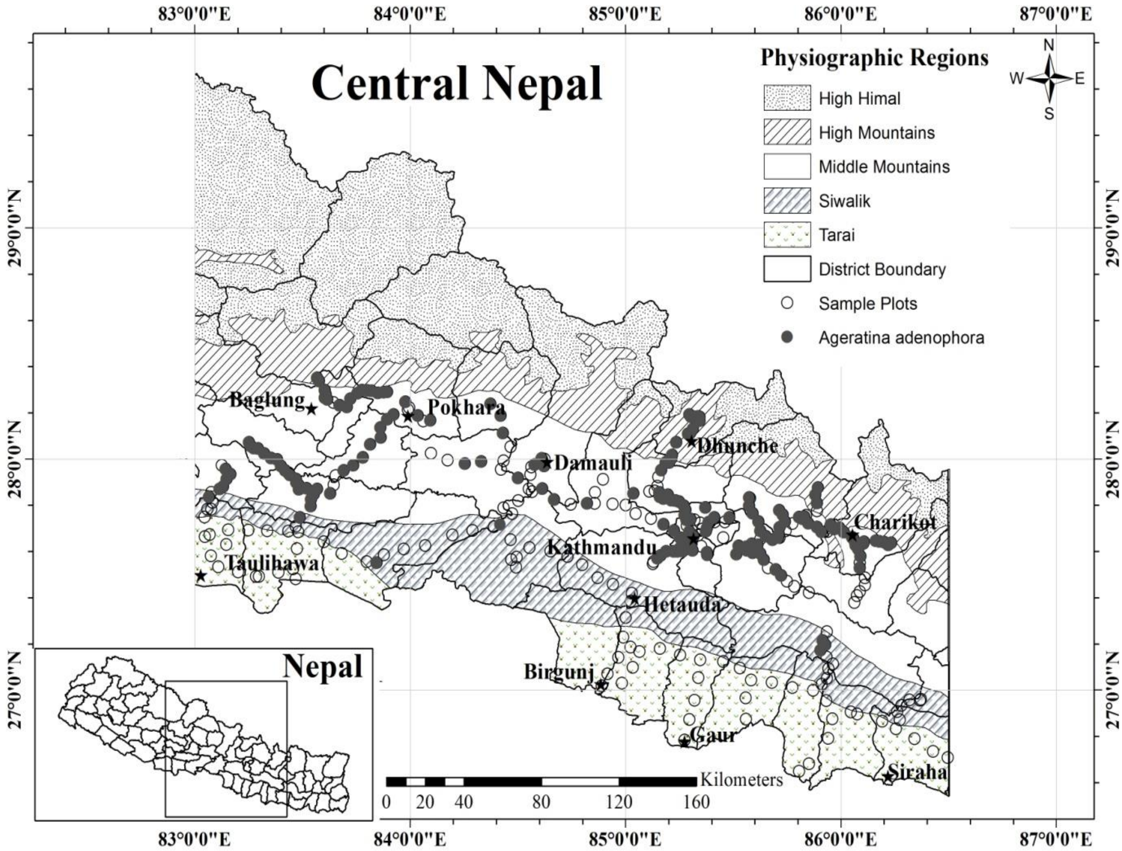


Figure 20: Geographic distribution of *Ageratina adenophora* in Central Nepal.

4.9.11 Distribution of *Ipomoea carnea* ssp. *fistulosa*

Ipomoea carnea ssp. *fistulosa* was mainly found in margins of agricultural lands and forest, grazing and fallow land, shrubland and wetland (Table 2). It was present in 41% of the sample plots in grazing and fallow land. Considering the physiographic distribution of this species, it was dominant in Tarai region of Nepal (Figure21). This species was found in different land use types in Middle mountains too due to human-mediated transport for controlling soil erosion and landslides. In most of the places it was planted for controlling flood and landslide. The species was more frequent in the western part of Tarai in central Nepal. In the present survey this species was found from 70-1350m asl in Central Nepal.

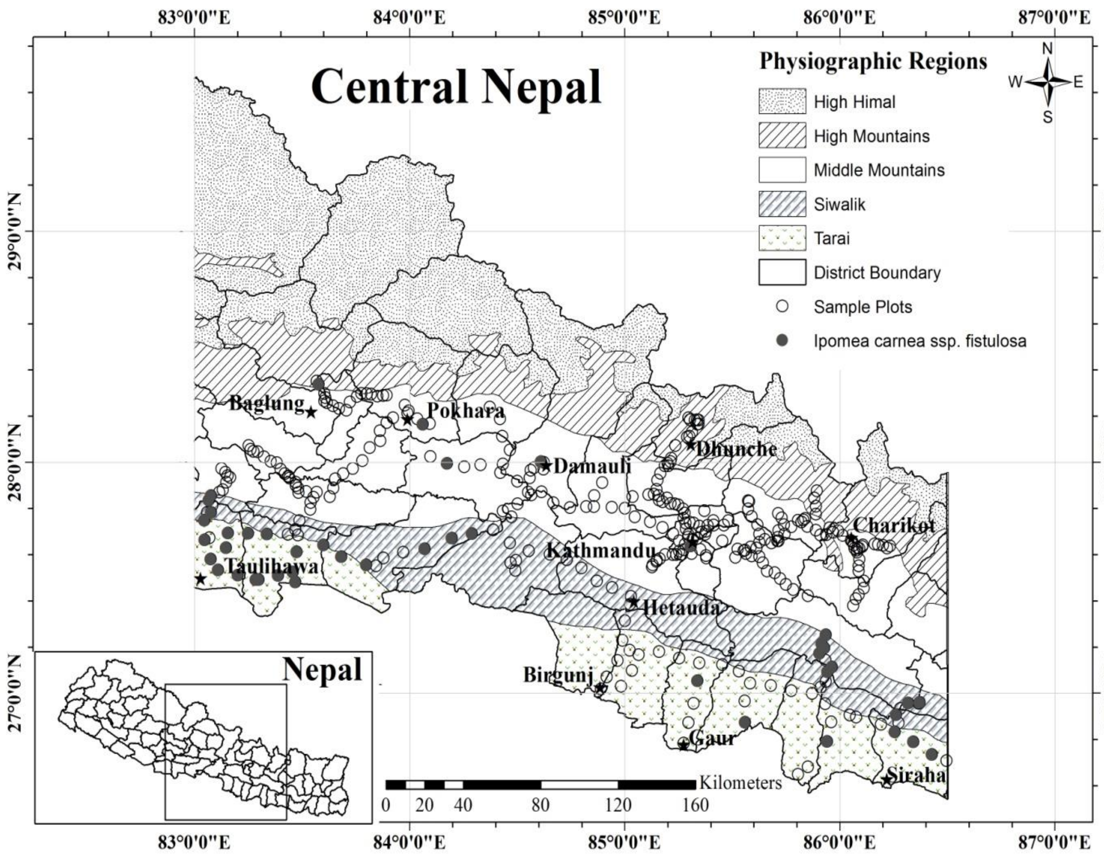


Figure 21: Geographic distribution of *Ipomoea carnea* ssp. *fistulosa* in Central Nepal.

4.9.12 Distribution of *Lantana camara*

Lantana camara was mainly found in margins of agricultural land, forest, grazing and fallow land, shrubland and in wetland too (Table 2). This species was common in shrubland and grazing and fallow land but rare in wetland. Considering the physiographic distribution of this species, it was common in Middle mountains of Nepal (Figure 22) mostly concentrated around Kathmandu area. The plant was mainly found in tropical and tropical regions. *L. camara* was less common in Tarai region. In the present survey *Lantana camara* was found from 107-1720m asl in Central Nepal.

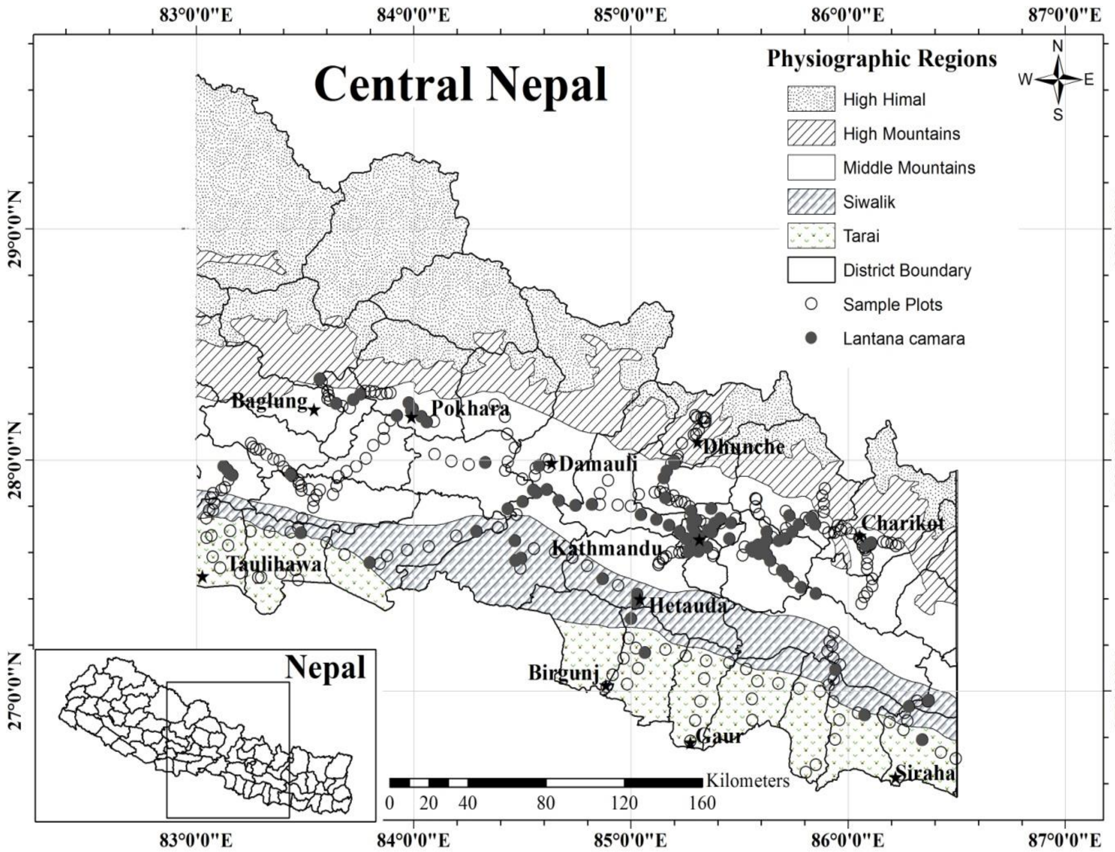


Figure 22: Geographic distribution of *Lantana camara* in Central Nepal.

4.9.13 Distribution of *Mikania micrantha*

Mikania micrantha was present in almost half (47%) of the sample plots of grazing and fallow land. This speicies was mainly found in forest, grazing and fallow land, abandoned agricultural land, shrubland and wetland too (Table 2). Considering the physiographic distribution of this species, it was common in Siwalik region (Figure 23). Chitwan National Park of Central Nepal had been highly invaded by this species and was found spreading along Prithivi highway too. This species was confined to tropical region only. In the present survey *Mikania micrantha* was found from 70-350m asl in Central Nepal.

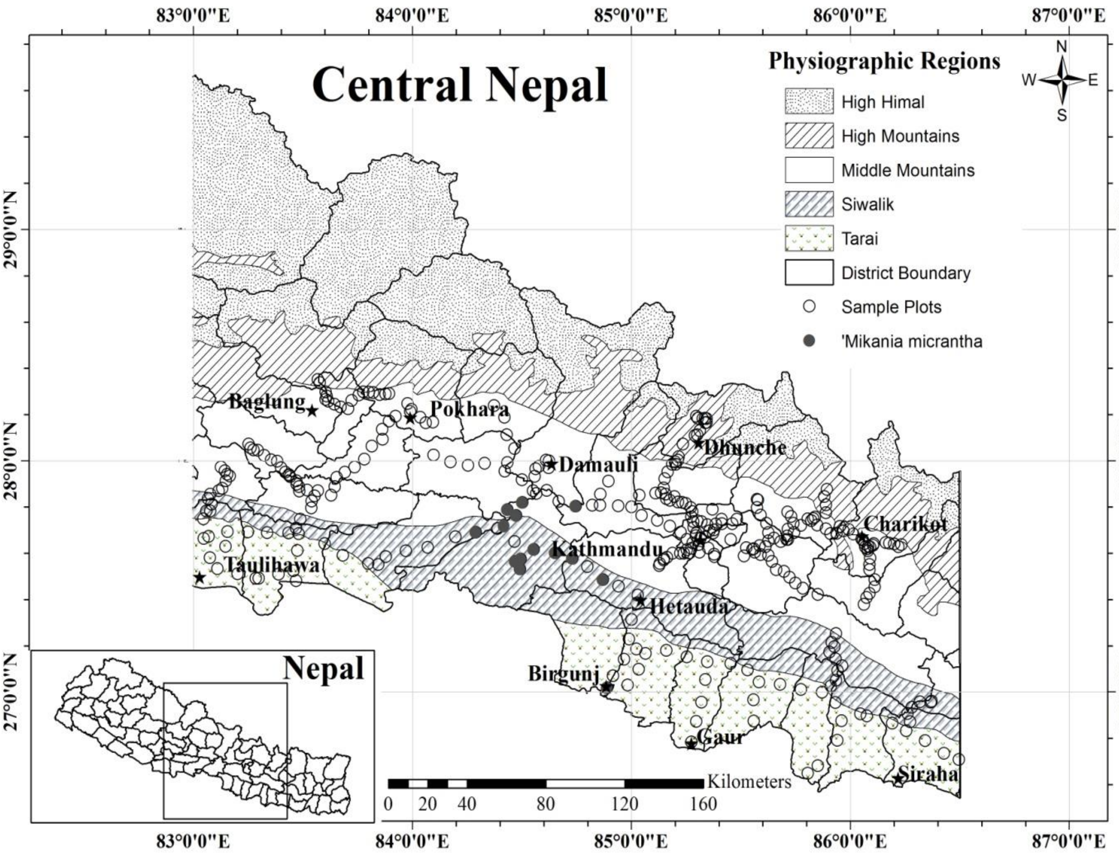


Figure 23: Geographic distribution of *Mikania micrantha* in Central Nepal.

4.9.14 Distribution of *Hyptis suaveolens*

Hyptis suaveolens was common in grazing and fallow land in Central Nepal. This species was also found in shrubland, forest margins, agricultural land and wetland (Table 2). Considering the physiographic distribution of this species, it was equally distributed in Siwalik and Middle mountains (Figure 24). In the present survey *Hyptis suaveolens* was found from 105-1100m asl in Central Nepal.

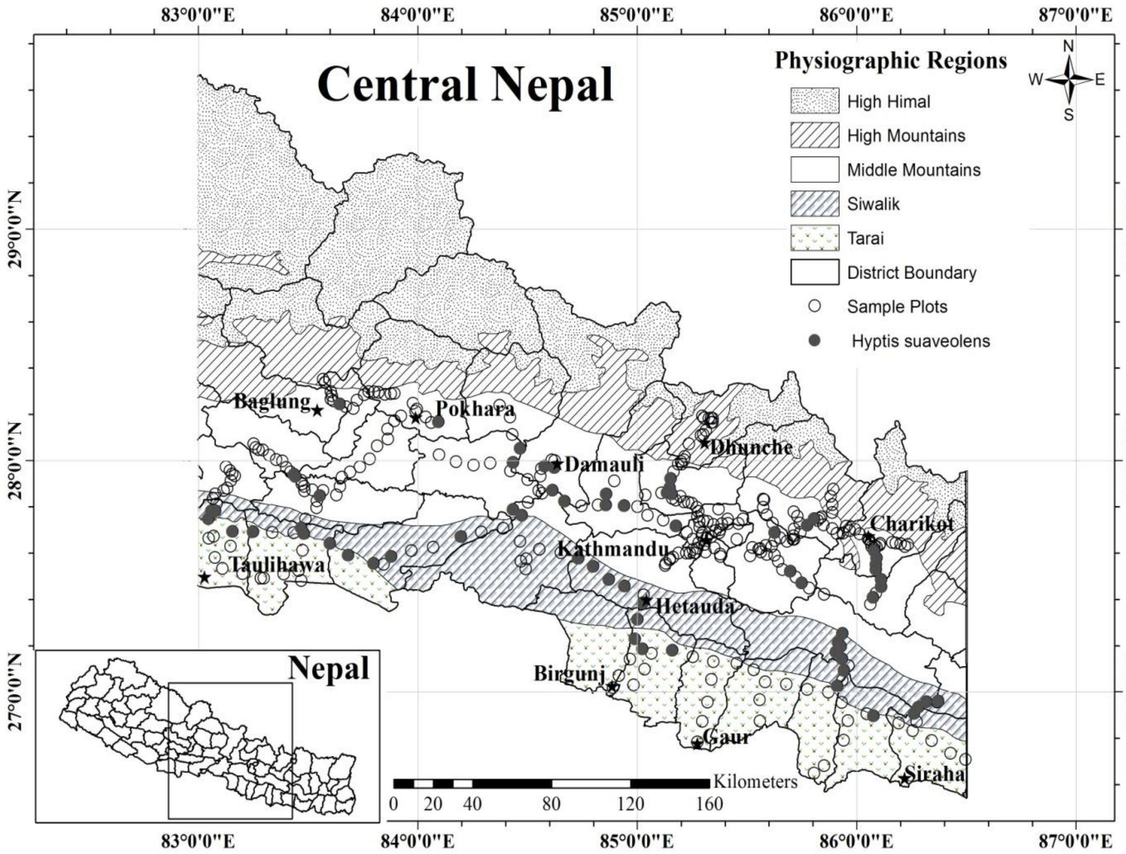


Figure 24: Geographic distribution of *Hyptis suaveolens* in Central Nepal.

4.9.15 Distribution of *Oxalis latifolia*

Oxalis latifolia was found in agricultural land, forest, grazing and fallow land, shrubland (Table 2). This species was present in half of the sample plots (41%) in agricultural land of roadside in Central Nepal. It was not found in wetland. Considering the physiographic distribution of this species, it was mostly found in Middle mountains (Figure 25). This species was found in subtropical region of Nepal. In the present survey *Oxalis latifolia* was found from 1100-2000m asl in Central Nepal.

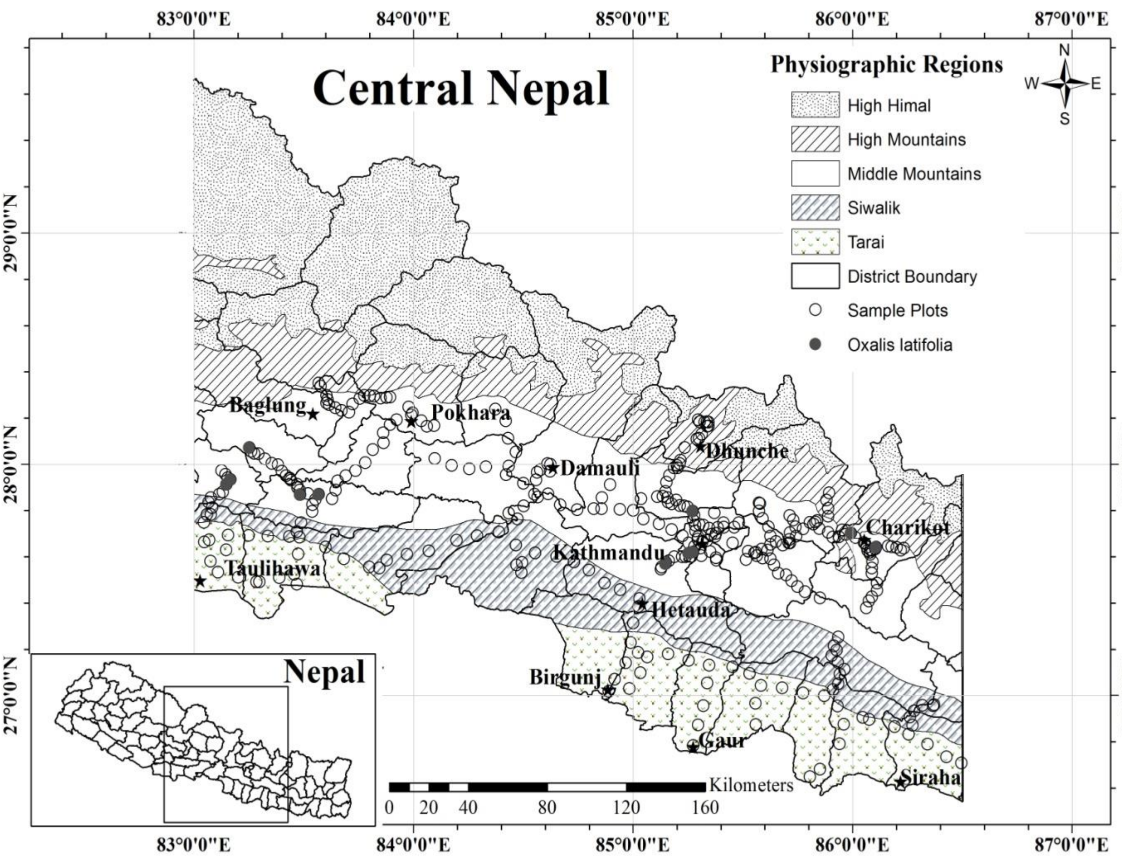


Figure 25: Geographic distribution of *Oxalis latifolia* in Central Nepal.

4.9.16 Distribution of *Parthenium hysterophorus*

Partheniuum hysterophorus was found in margins of agricultural land and forest, grazing and fallow land, shrubland and wetland (Table 2). *P. hysterophorus* showed its occurrence in 54% of sample plots in grazing and fallow land. Considering the physiographic distribution of this species, it was uniformly distributed in Tarai, Siwalik and Middle mountains and also found to be spreading in High mountains too (Figure 26). The places with extensive road network like Kathmandu, Pokhara, Butwal, Hetunda, Chitwan, Birgunj were highly invaded by this species. It was common in tropical and subtropical areas in Central Nepal. In the present survey *Parthenium hysterophorus* was found from 70-1600m asl in Central Nepal.

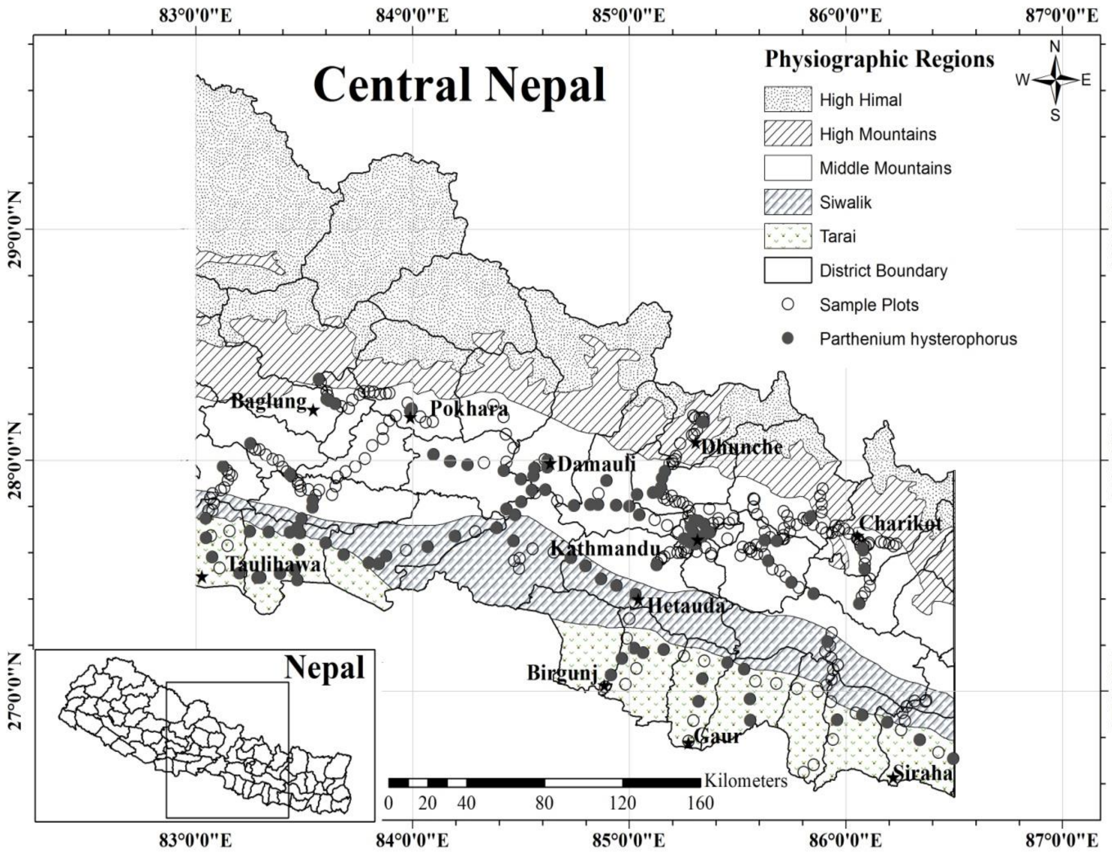


Figure 26: Distribution of *Parthenium hysterophorus* in Central Nepal.

4.9.17 Distribution of *Alternanthera philoxeroides*

Alternanthera philoxeroides was found in abandoned agricultural land, grazing and fallow land, shrubland and wetland (Table 2). It was common in grazing and fallow land. Considering the physiographic distribution of this species, it was mostly found in Middle mountains (Figure 27). This species was common in Kathmandu valley of Central Nepal. In the present survey this species was found from 65-1500m asl in Central Nepal.

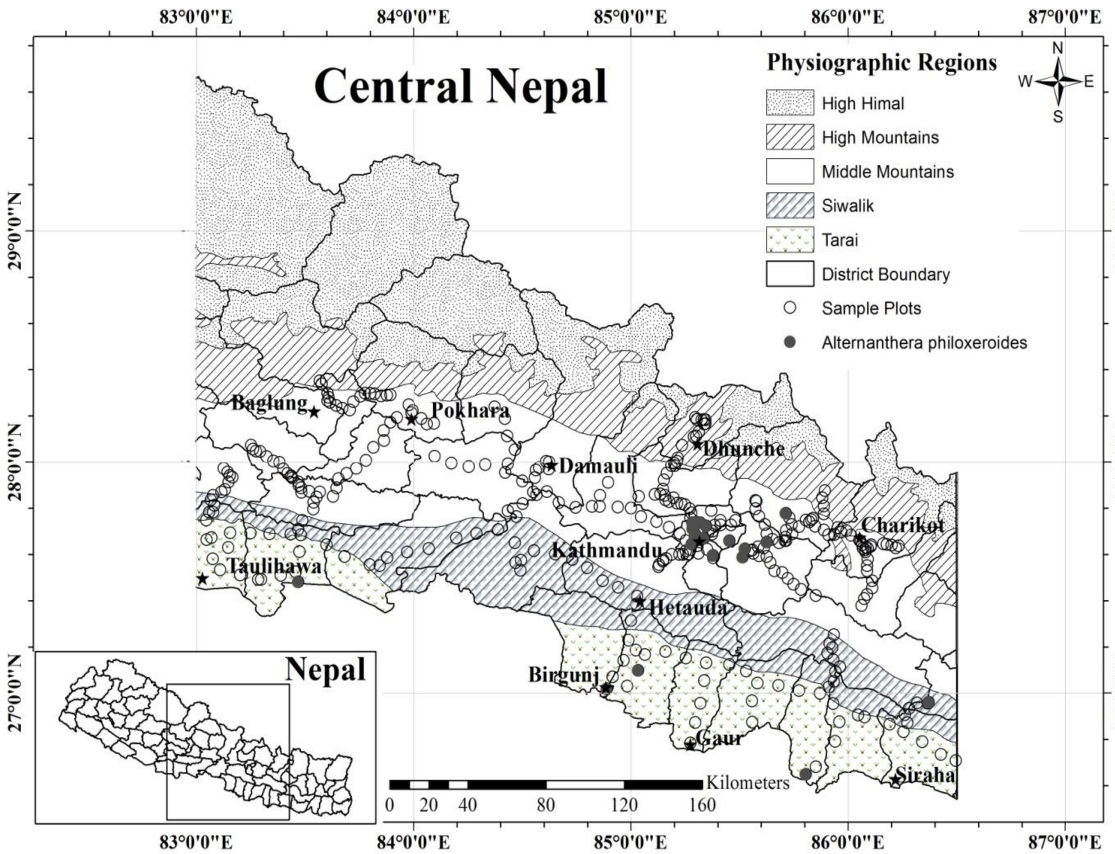


Figure 27: Geographic distribution of *Alternanthera philoxeroides* in Central Nepal.

4.9.18 Distribution of *Eichhornia crassipes*

Eichhornia crassipes was the dominant species of some wetlands in Central Nepal. This species was also found in grazing and fallow land, shrubland (Table 2). Considering the physiographic distribution of this species, it was mostly present in Tarai (Figure 28). This species was dominant in marsh and swamp areas logged with waste in Tarai along roadside in Central Nepal. In the present survey this species was found from 65-700m asl in Central Nepal.

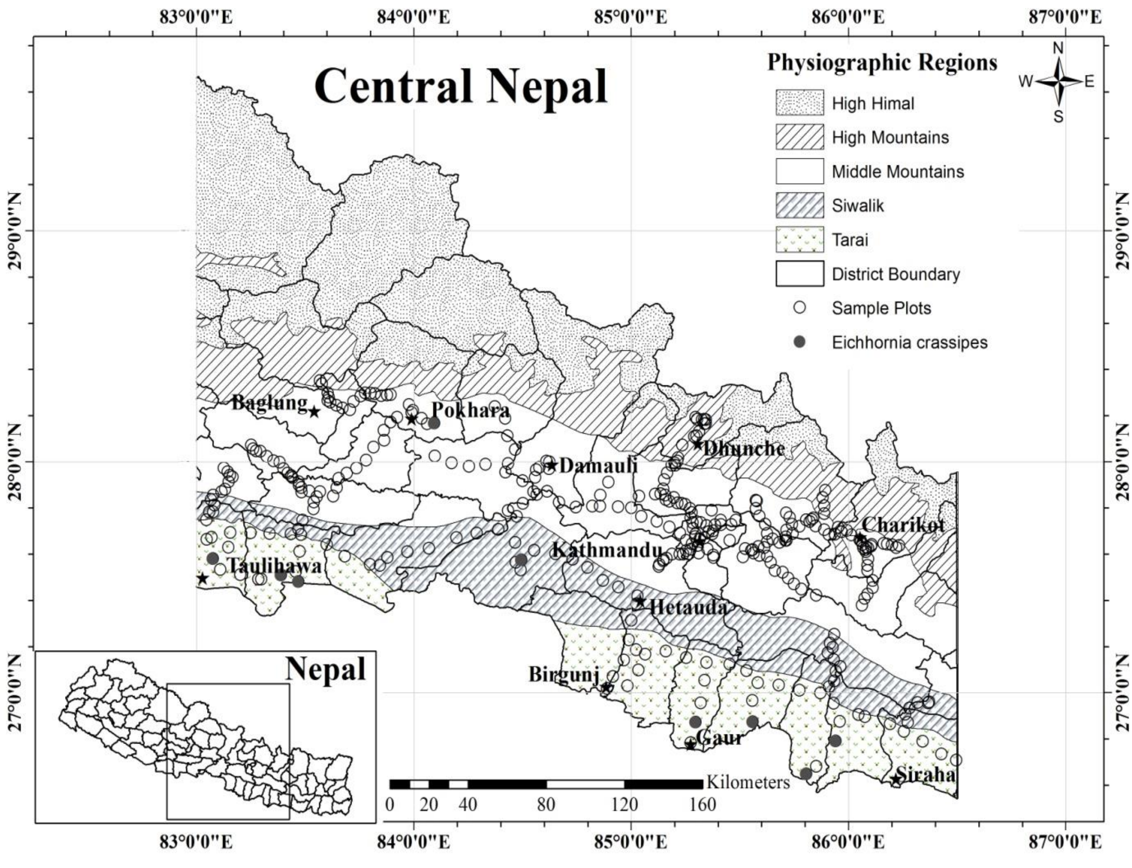


Figure 28: Geographic distribution of *Eichhornia crassipes* in Central Nepal.

4.10 Biological control agents

In roadside vegetation of Central Nepal only two biological control agents were found (i.e *Procecidochares utilis* for *Ageratina adenophora* and *Zygogramma bicolorata* for *Parthenium hysterophorus*).

4.10.1 Distribution of *Procecidochares utilis*

Procecidochares utilis, a biocontrol agent for *Ageratina adenophora* was present in a wide range of habitats but this was common in species growing in shrubland (42%) and less common in species growing in grazing and fallow land (12%) (Table 2). But, this insect was not found so effective in controlling the spread of *Ageratina adenophora* in Central Nepal. Biocontrol agent was mostly found in Middle mountains in comparison to other physiographic regions (Figure 29). In the present survey this species was found from 400-2570m asl (Dolakha) in Central Nepal.

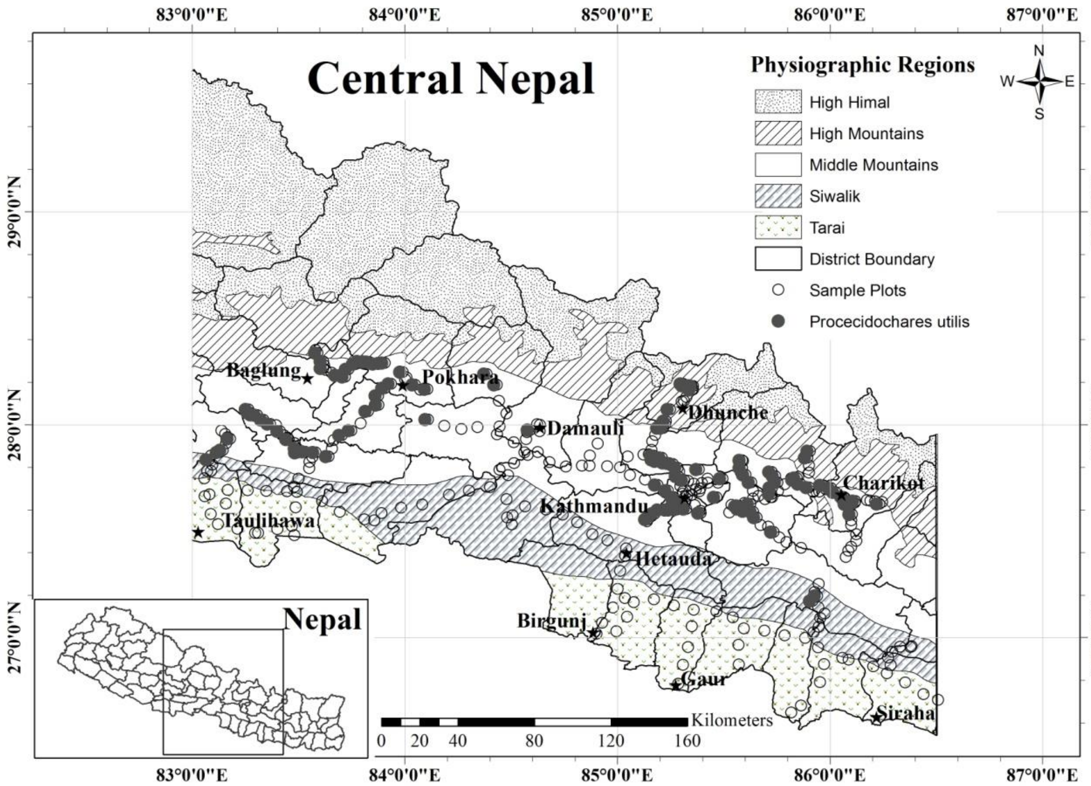


Figure 29: Geographic distribution of *Procecidochares utilis* in Central Nepal.

4.10.2 Distribution of *Zygogramma bicolorata*

Zygogramma bicolorata, a beetle feeding on leaves of *Parthenium hysterophorus* used as biocontol agent was common in species growing in grazing and fallow land (56%) and less in species growing in wetlands (2%) (Table2). This beetle was found effective in controlling further spread of *P. hysterophorus* in some places. Considering the physiographic distribution of this biocontrol agent in roadside vegetation in Central Nepal, it was present frequently in species of Tarai and Siwalik region (Figure 30) and spreading in species occurring in Middle mountains too. The present distribution of this species in Central Nepal was 75-1330m asl in Central Nepal.

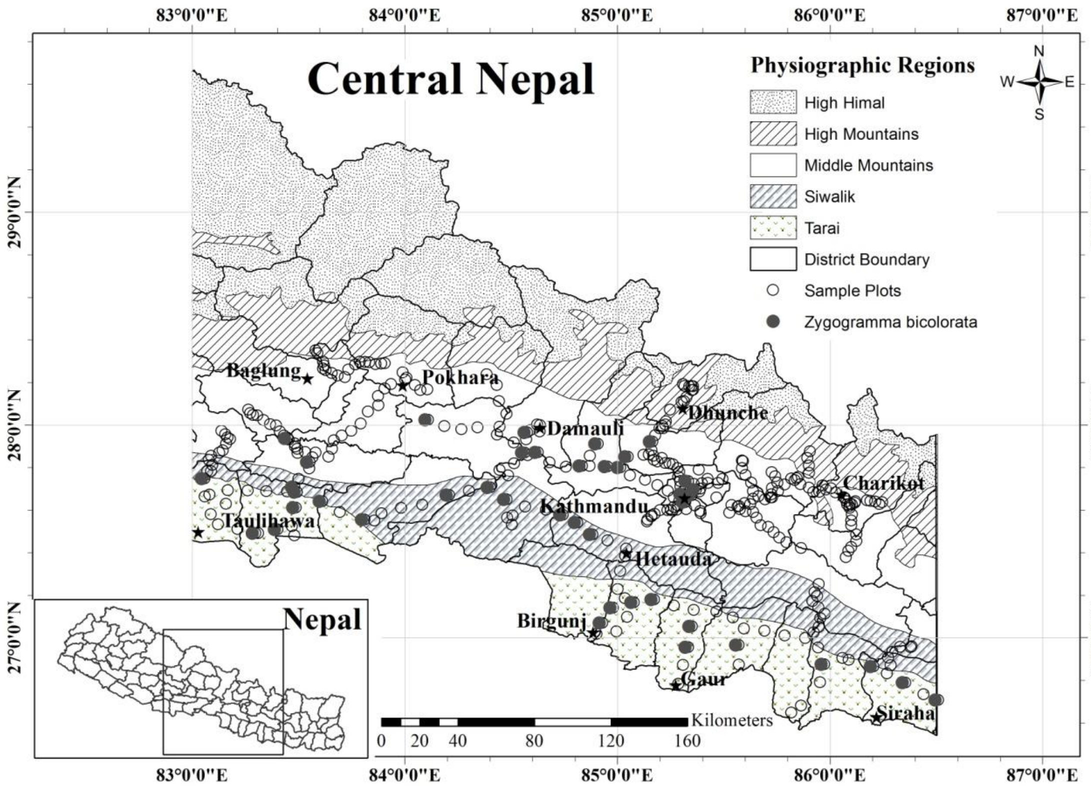


Figure 30: Geographic distribution of *Zygogramma bicolorata* in Central Nepal.

4.10 Species Richness Pattern of IAPS along Road Network in Central Nepal.

Major cities of Central Nepal like Kathmandu, Butwal, Pokhara, Chitwan, Hetaunda etc linked by extensive road network had higher species richness of IAPS as compared to other places. But, IAPS were spreading rapidly on newly constructed road network too. Considering the physiographic regions, Middle mountains holds higher richness of IAPS as compared to other regions (Figure 31).

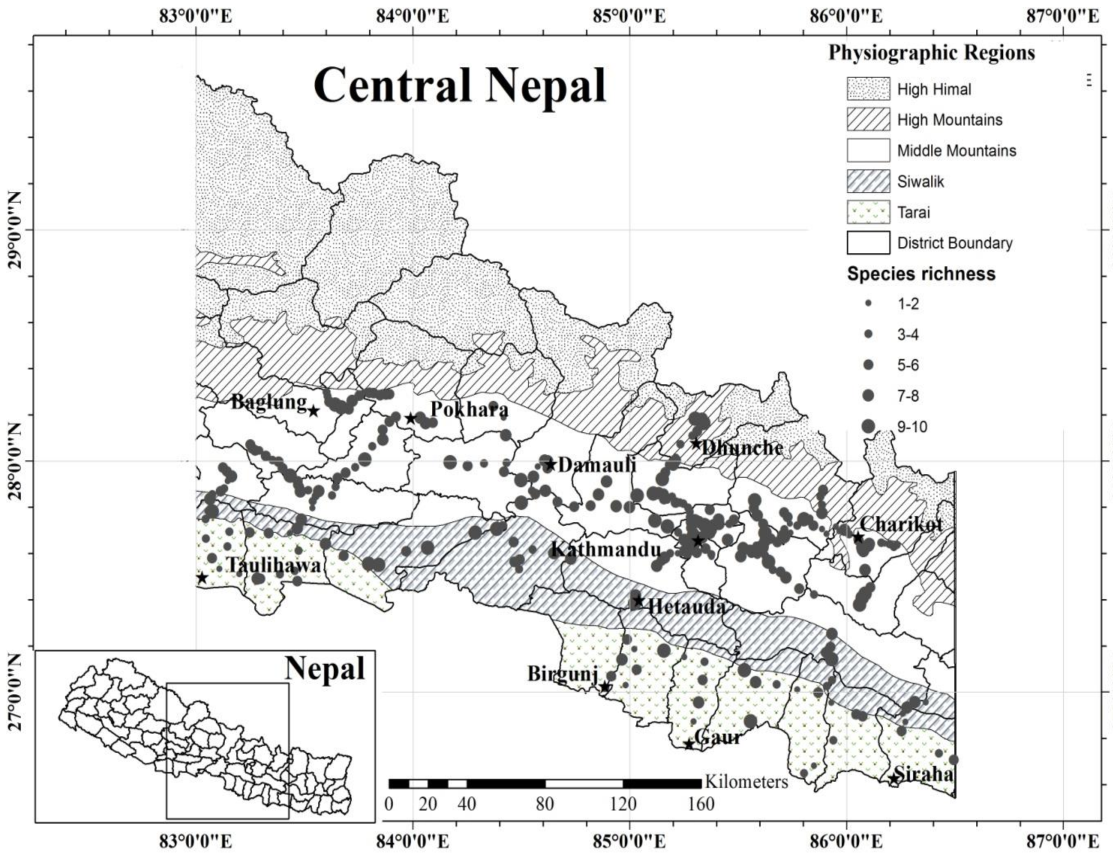


Figure 31: Species richness pattern of IAPS along road network in Central Nepal. The increasing size of the given symbol signifies the increasing number IAPS richness.

4.11 Comparison with earlier reports

IAPS were found in some additional districts of Central Nepal (Table 3) as compared to the previous report on IAPS by Tiwari et al. (2005). Few species like *Parthenium hysterophorus, Ageratum conyzoides, Cassia tora, Amaranthus spinosus, Mimosa pudica, Xanthium strumarium, Cassia occidentalis, Lantana camara* etc were present in all of the districts sampled. Among these IAPS, *Parthenium hysterophorus, Hyptis suaveolens* and *Xanthium strumarium* were reported in more than 15 additional districts.

Table 3: No of districts with particular IAPS. Out of 36 districts in Central Nepal only 34 districts were covered during our survey.

SN	Name of IAPS	No of districts with IAPS		Total districts
		Tiwari *et al.* 2005	Addition from the present study (2013)	
1	*Ageratina adenophora*	19	6(32%)	25
2	*Ageratum conyzoides*	30	4(13%)	34
3	*Alternanthera philoxeroides*	11	3(27%)	14
4	*Amaranthus spinosus*	31	2(7%)	33
5	*Argemone mexicana*	13	3(23%)	16
6	*Bidens pilosa*	18	12(67%)	30
7	*Cassia occidentalis*	27	4(15%)	31
8	*Cassia tora*	20	14(70%)	34
9	*Chromolaena odorata*	18	12(67%)	30
10	*Eichhornia crassipes*	14	1(7%)	15
11	*Hyptis suaveolens*	13	16(123%)	29
12	*Ipomoea carnea* ssp. *fistulosa*	11	12(109%)	23
13	*Lantana camara*	27	4(15%)	31
14	*Mikania micrantha*	9	2(22%)	11
15	*Mimosa pudica*	28	4(14%)	30
16	*Oxalis latifolia*	21	1(5%)	22
17	*Parthenium hysterophorus*	17	17(100%)	34
18	*Xanthium strumarium*	17	16(94%)	33

* Values inside the parentheses indicate the percentage of additional districts for respective IAPS in comparison to earlier report.

5. DISCUSSION

5.1 Frequency of invasive alien plant species

The vegetation along roadside was invaded by diverse invasive alien plant species (IAPS). Among the 18 IAPS recorded in the present study, their frequency varied from 58% (*Bidens pilosa*) to 1% (*Eichhornia crassipes*) (Figure 2). This variation in frequency of IAPS may be related to life history-traits of IAPS, residence time and bioclimatic origin of each species. IAPS with wider geographical range and efficient dispersal mechanism (e.g. *Ageratina adenophora, Bidens pilosa, Parthenium hysterophorus, Chromolaena odrata, Lantana camara* etc) were present in most of the sample plots leading to higher frequency. Some IAPS had attained wide distributions whereas others remained localized which may be related to invasiveness of particular species, pathway of introduction and residence time. *Ageratina adenophora, Chromolaena odorata, Mikania micrantha, Eichhornia crassipes,* and *Lantana camara* are regarded as invasive in tropical regions but not in temperate regions (Weber 2003). This could be reason for limited distribution of some tropical species like *M. micrantha, E. crassipes, Argemone mexicana* (Figure 10). *A. adenophora* and *B. pilosa* had higher elevation range varying from 395-2570m asl and 130-2320m asl respectively as compared to other IAPS. This may be the reason for their higher frequency. *C. odorata* had the longest residence time among 18 IAPS but had lower frequency than *A. adenophora, B. pilosa.* This might be due to habitat preference of *C. odorata* i.e. it prefers to grow in open, hot and humid places but does not thrive on cold and shaded conditions (Wu & Xu 1992 as cited in Lu *et al.* 2008). It is cold sensitive and dies at temperature below 0°C but can tolerate high temperature. In contrast, *A. adenophora* could survive in the temperature range from -11.5- 35°C (Zhao & Ma 1989 as cited in Lu *et al.* 2008). *Eichhornia crassipes* is the most problematic IAPS in wetlands of tropical regions of Nepal (Tiwari *et al.* 2005; NBSAP 2014). However it turned out to be least frequent IAPS in the present study which is mainly because of the low representation of wetland habitats in the survey.

Species introduced earlier had higher frequency than those introduced later (Figure 8). *Ageratina adenophora* was the most dominant species in 30% of the sample plots followed by *Bidens pilosa* (29%) and *Parthenium hysterophorus* (18%). *A. adenphora* was the most dominant species in roadside communities along elevational gradient (ca. 132- 3660m) in Darjeeling Himalaya, India (Moktan & Das 2013) which is similar to our result. The higher dominancy of *A. adenophora* and *B. pilosa* could be due their greater residence time, wider geographic range and good dispersal ability. Each plant of *A. adenophora* can produce 100,000 achenes per season and dense stands can contribute up to 60,000 viable seeds /m^2 (Muniappan *et al.* 2009). And these seeds are easily dispersed by wind, water, livestock and vehicles to long distances increasing its dispersal and spread. Likewise the seeds of *B. pilosa* are easily dispersed by man, animals and vehicles as they stuck easily on these agents and are light. Another species *P. hysterophorus* is an extremely prolific seed producer with up to 30,000-40,000 seeds per plant and with enormous seed bank (Joshi 1991) and suppress other species due to its stronger allelopathic effects. Seeds of this species are easily dispersed to long distances due to smaller seed size and light. These species were found in diverse type of habitats in tropical to subtropical regions including some parts of temperate regions which resulted in higher dominancy of these species. Species with greater residence time develop genetic adaptation to changing environmental conditions and dispersed to distant places (Sakai *et al.* 2001). *P.hysterophorus* was the third dominant species in roadside communities of Central Nepal. This may be related to high seed production capacity, persistent seed bank, efficient dispersal mechanism and allelopathy (Joshi 1991; Navie *et al.* 1996). This species is an aggressive colonizer of disturbed habitats, able to germinate, grow and flower over a wide range of temperatures and photoperiods (Evans 1987). And most of the roadside habitats where this species was dominant i.e. grazing and fallow land (Table 2) were highly disturbed by human activity which further facilitated its spread and colonization often forming monocultures. Vehicle movement, including transport of construction machinery and road works, agriculture products, livestock, and water movement are thought to be the main means of seed dispersal of this species in Central Nepal (Shrestha *et al.* 2015).

5.2 Invasive alien plant species richness pattern

Invasive alien plant species richness along roadside vegetation in Central Nepal showed a statistically significant ($p \leq 0.05$) unimodal relation with elevation (Figure 6). Similar unimodal relation has been also reported for naturalized plant species along elevation gradient in Nepal (Bhattarai *et al.* 2014). But maximum richness of naturalized plant species was found at 1100m asl in that study which was different from our peak (600m asl). Likewise, during a survey of roadside non-native flora along an elevation gradient on Tenerife Island, both Mediterranean and Temperate invasive alien plant species showed unimodal pattern of distribution with an increase of non-native species richness from low to mid-elevations followed by a decrease of the species richness from mid to high elevations (Haider 2011). Similar was the pattern of distribution of IAPS along elevational gradient for both Gran Canaria and Tenerfire islands (Arevalo *et al.* 2005); IAPS showed a unimodal, relationship with elevation. The higher IAPS richness at lowlands might be due to a combination of high propagule pressure and the introduction of plant species adapted to low elevation conditions and dispersed either intentionally or accidentally by humans. Most of the IAPS introduced in Nepal are of neo-tropical origin (Bhattarai *et al.* 2014) and might be unable to complete their lifecycle at higher elevation with low temperature. This may be related to greater IAPS richness at lower elevation with tropical climate. The general decrease in IAPS richness with increasing elevation is probably due to directional ecological filtering, where species are introduced in to low elevations and spread to higher elevations (Alexander *et al.* 2011). The result of the ecological filtering is that only species with broad environmental tolerances establish and survive across the gradient from low to high elevations (Alexander *et al.* 2011). Species introduced into disturbed habitats at low elevations are progressively filtered out by the increasingly harsh climatic conditions along an elevational gradient. Similar conditions may also apply to IAPS of Central Nepal as most of them were introduced via lowland introduction pathway. IAPS richness decreased with increasing elevation because only few invaders possess the necessary adaptations to succeed under extreme environmental conditions. *Lantana camara*, a common weed of shrubland, fallow land and forest seldom occurs where temperature frequently falls below 5˚C (Day *et al.* 2003) as prolonged freezing temperatures kill aerial woody branches and cause defoliation. *Mikania micrantha* a problematic weed in some of the protected areas in Central Nepal requires open, fertile, moist, hot and humid places for best growth so confined to lowlands mostly in Siwalik and Tarai region. And *Ageratum conyzoides* a common weed of fallow and agricultural land requires an optimum temperature of 20 to 25˚C for germination and mostly found in mid hills of Nepal. *Chromolaena odorata* is cold sensitive and dies at temperature below 0˚C (Wu & Xu

1992 as cited in Lu *et al.* 2008). Hence its distribution is mostly restricted to lower altitudes only. This species is better able to tolerate high temperatures (≥40°C) so mostly invades hot, humid and dry places with open canopy as it appears sterile in stressful environment (Joshi *et al.* 2006). In contrast to these species *Ageratina adenophora* could survive in the temperature range (-11.5 to 35°C) (Zhao & Ma 1989 as cited in Lu *et al.* 2008). This could be the reason for wider geographical range of *Ageratina* as compared to other IAPS and was present at highest altitude.

Despite this many other factors like level of anthropogenic disturbance, propagule pressure, habitat properties and biological traits of the invading species might be responsible for variation in species richness pattern of IAPS along elevation gradient. Most of the lowland areas in Central Nepal linked by extensive road network were disturbed; some areas were used for agriculture, some for settlement and some as industrial and urban areas whereas land abandonment was also a common phenomenon. Travel, trade and transport were acting as vectors for the dispersal of IAPS resulting high propagule pressure of different IAPS. Lowland area of Central Nepal is productive which includes plain areas and is land linked with India. The open border with high transboundry activities such as import of food, plants and other commodities may be responsible for the accumulation of greater number of invasive species in lowlands. Lowlands where productive habitats were found had been used for farming and urban development and public fallow lands for waste disposal. Therefore, human land use was usually more intensive at lower elevation. Such activities further exposed terrestrial systems to disturbance and resulted in colonization of different IAPS. In contrast, high elevation areas were less exposed to anthropogenic disturbance due to lower population density and less commercial activities as the population density of Tarai is higher in comparison to Hills and Himalayan region (CBS 2011). This situation led to decline in species richness of IAPS at higher elevation. The dispersal and spread of IAPS was mostly dependent on human activities in Central Nepal. There was slight decrease in species richness at an elevation below 100 m asl. And this may be due to availability of well managed agricultural fields and densely populated urban areas i.e. no space for further colonization. In well managed agricultural field continuous weeding, thinning and pruning contributed for the prevention of invasion. Roads generally pass through agricultural land and dense forest within protected areas in lower elevation areas which might be responsible for lower species richness of IAPS at such elevations. Some species (e.g. *Chromolaena odorata*) were seldom found in agricultural land use.

5.3 Comparison of IAPS richness across land use types

Habitat disturbance, an inevitable consequence of modern land use change makes ecosystems more vulnerable to invasive species that are transported either intentionally or accidentally by humans (Moore 2000). Land use change may facilitate plant invasion by causing fluctuations in levels of resources i.e. soil nutrients, light, water etc that persist for some period of time (Davis *et al.* 2000). A statistically significant ($p \leq 0.05$) difference in species richness across different land use types was obtained (Figure 7). This variation could be due to the difference in availability of unexploited resources by resident species, competitive ability of invasive species, allelopathic interactions and effect of natural enemies or the disturbance regime (Grime 1979; Ridenour & Callaway 1991; Mack *et al.* 2000; Davis *et al* 2000). Such characteristics provide a competitive advantage to IAPS over the native when disturbance occurs. Disturbance through land use transformation causes change in availability of resources either by delivering resources to the system or by decreasing their consumption by removing resident vegetation. The reason for higher species richness in grazing and fallow land may be due to the opportunistic behavior of IAPS. They can utilize the available resources efficiently when they get chance to colonize in disturbed or exposed habitats through rapid growth and dispersal. Most of the fallow lands along roadside in Central Nepal were used for solid waste deposition, vehicle parking, storage of construction materials and grazing. And deposition of waste and parking of vehicles had acted both as vector and source areas for plant invasion (Personal observation). The continuous deposition of waste added resources to the system and leaving public land fallow also resulted in accumulation of resources due to absence of resident vegetation whereas parking of vehicles played a vital role in dispersal of IAPS. Such habitats exhibit higher levels of plant invasion as a result of higher propagule pressure and higher disturbance levels than other natural or semi-natural habitats. Furthermore, grazing also results in addition of resources through reduction in competition from resident vegetation as most of the IAPS are less palatable to grazers and have allelopathic effects (Bais *et al.* 2003; Singh *et al.* 2008). All these phenomena results in accumulation of unused resources in grazing and fallow land and facilitated the growth and spread of IAPS. Davis *et al.* (2000) hypothesized that the presence of unused resources in an environment will increase the vulnerability of particular area to invasion. Hence, the occurrence of high species richness in grazing and fallow land is consistent with the theory of fluctuating resource availability (Davis *et al.* 2000) and the concept of resource opportunity in fluctuating environment (Shea & Chesson 2002). High vulnerability of grazing and fallow land to IAPS was also reported by IUCN (2013) in Panchase area of Kaski district, Central Nepal. Agricultural lands also harbored greater species richness of IAPS after grazing and fallow land in comparison to shrubland, forest and wetland in roadside communities of Central Nepal. This might be the result of land abandonment as most of the cultivable lands near roadsides were left barren for the purpose of housing, infrastructure development and for urbanization. Such factors had contributed to the spread and establishment of many IAPS. Land abandonment can lead to drastic disturbance changes and thereby provide new opportunities for biological invasion. Invading species are particularly successful in areas with high levels of human activity such as urban centers, agricultural fields and roadways (Christen & Matlack 2006). But, IAPS abundance was low in well managed agricultural lands due to continuous weeding which prevented them from being established. The lower species richness in wetland is expected because 15 of the IAPS included in the survey were primarily terrestrial.

5.4 Distribution of IAPS

Most of the IAPS found in Central Nepal were accidentally introduced except few species like *Ipomoea carnea* ssp. *fistulosa*, *Lantana camara* etc. At many locations, local people informed that *I. carnea* ssp. *fistulosa* was planted as ornamental plant and for control of soil erosion at landslide whereas *Lantana camara* was used for ornamental value and fencing. *Ageratina adenophora,* was a major invasive plant in Central Nepal .Invasive alien plant species were spreading rapidly in most of the ecosystems along roadsides. Most of the species were confined to the lowlands whereas only few species were present at higher elevation. Road network had acted both as corridor and vector for the distribution of invasive species into adjacent ecosystems and new locations. The construction of new roads had opened windows of opportunities for IAPS to reach into a new geographical region which was further supported by human disturbance. Considering the physiographic distribution of IAPS in Central Nepal, Middle mountains were richer than Siwalik and Tarai regions. The major cities like Kathmandu, Lalitpur, Hetaunda, Pokhara, Chitwan, Damauli, Butwal, Bhairahawa etc were becoming source areas for invasion (Figure 29). This might be the result of extensive road network in such urban areas to support the need of growing population density through high commercial activities. An increase in invasive plant species abundance with nearness to urban centers has been observed by Arevalo *et al.* (2005). The greater richness of IAPS in urban areas may be due to greater movement of people from different places, extensive road connectivity with many districts, high commercial activities and greater transportation of commodities. All these activities help in the dispersal and spread of different invasive plant species. Vehicles were one of the major vectors facilitating the spread of IAPS along road verges contributing in long-distance dispersal of seeds in urban areas. Increased human traffic and commercial activities facilitates and increases plant invasion through disturbance. The accidental or intentional introduction of IAPS takes place mostly in human-disturbed areas like residential, industrial, agricultural, fallow lands and roads and their naturalized population produce propagules that spread into adjacent areas (Pimentel *et al.* 2005; Mack *et al.* 2000). This might be the reason for the accumulation of most of the IAPS in human-made environment of major cities. Most of the developmental works concentrate in urban areas in Nepal which further increases the vulnerability of such areas to invasion. The construction and maintenance of roads create safe areas for invasive alien plant species to germinate and establish, by removing native species. *Parthenium hysterophorus*, an aggressive colonizer of disturbed fallow lands along roadsides was mostly found spreading through road construction and maintenance equipments like soil excavator and bulldozer, fodder and animal transportation in Central Nepal (Personal observation). This species was dominant in roadside grazing and fallow lands but present in diverse land use types. Tiwari *et al.* (2005) also reported that this species is an aggressive colonizer of natural and man-made ecosystems, grassland habitats, open woodlands, river banks, flood plains, open fields of settlement areas, roadsides, crop fields, and watering points. Though the climatic conditions of Tarai region was suitable for the growth and spread of *Chromolaena odorata*, this species was less common in this region. This might due to intensive agricultural system there and dense forest canopy in well managed protected areas of Tarai. *Xanthium strumarium* was a common weed of fallow land, shrubland and agricultural land. Kaur *et al.* (2014) also reported that *Xanthium* is a heat-loving and drought resistant plant growing along roads, waste lands, dumps, river banks and crops. Along the roadsides, alien invasive species of plants find lower competition relative to the dense native vegetation, and usually receive higher amounts of light and water (Parendes & Jones 2000). Therefore most of IAPS were being dispersed via roads to adjacent ecosystems and from lowlands especially from Tarai to highlands. This may be due to road network connection between the transition zones. The open border of our country linked by road networks with India have been further increasing the vulnerability of lowlands to invasion raising the chance of new introductions of alien species and increasing the propagule pressure of already introduced plants. Most of the IAPS found in Central Nepal were either intentionally or accidentally introduced from sourthern corridors of Tarai via India which is evident from the high concentration of IAPS in southern borders at lower elevation like Bhairahawa. Birgunj, Gaur etc. *Lantana camara, Chromolaena odorata* and *Mikania micrantha* have been established in Nepal via the plains of north-east India (Tiwari *et al.* 2005). *Ageratina adenophora* and *Parthenium hysterophorus* were accidentally transported to Nepal via India through commercial routes due to land-linked border of Nepal.

IAPS were found in all districts surveyed in Central Nepal. If we compare our present survey data with previous one (Tiwari *et al.* 2005), most of the IAPS were found in some additional districts. This indicates that the problem of invasion is expanding in Central Nepal and timely action is needed to prevent further spread. Government of Nepal had already made commitment on managing the problem of invasion via different strategies and plans. But all these remained as it was due to the lack of proper planning, implementation and data gap. The major constraint to address the problems of IAPS in Nepal was absence of comprehensive survey and research at national level about the distribution of IAPS. NBSAP (2014) will probably help to manage this problem at national level. The reason for the spread of IAPS into different districts might due to increasing human activities coupled with growing population, development of infrastructures, commercial activities, urbanization etc. coupled with expanding road networks among different districts.

6 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Invasive alien plant species were spreading rapidly along road corridors in Central Nepal. Among the 18 species of IAPS recorded, *Ageratina adenophora* was the most abundant species followed by *Bidens pilosa, Parthenium hysterophorus, Chromolaena ododrata, Cassia tora, Ageratum conyzoides* etc. IAPS were found along the elevation range from 65 m asl to 2600 m asl in Central Nepal and had unimodal relation with elevation with maximum richness at 600m asl. Therefore, our hypothesis stating IAPS richness decreases with increasing elevation was rejected. The higher species richness at this elevation (i.e., 500-600m) might be due to a combination of high propagule pressure and the introduction of IAPS of tropical origin which is further aided by human disturbance. Land use changes had significant impact on biological invasion which has further increased the susceptibility of biological communities to plant invasion. Grazing and fallow lands were found highly invaded by IAPS due to greater availability of resources favorable for disturbance-resistant, ruderals and highly competitive species. This variation in species richness across these land use types supported our hypothesis that abundance of IAPS varies with land use types. Most of the IAPS present in Central Nepal are of neo-tropical origin so mostly confined to lowlands contributing for greater species richness in lowlands. Tropical region had greater number of IAPS than sub-tropical and temperate region. Middle mountains had higher concentration of IAPS among other physiographic regions of Nepal. Old-established invasive species have higher frequency than recent introductions. Residence time, dispersal and disturbance were the important factors determining the elevational distribution of many IAPS. The dispersal of IAPS via expanding road networks seems to be central in shaping invasion success of individual species whereas anthropogenic disturbance, propagule pressure and climate are all factors explaining pattern of variation in IAPS richness. Therefore, the increasing importance of human-modified ecosystems and establishment of transportation corridors would facilitate plant invasion increasing the opportunities for the accumulation of IAPS in areas with greater human activities as well as to new geographical regions. Disturbance created by road development and maintenance would also increase the susceptibility of roadside and adjacent communities to invasion.

The information related to the distribution and abundance of IAPS at regional level, as presented in this work may be useful to develop management strategies for controlling biological invasions and raise public awareness at community level. The negative impacts associated with road network extension necessitates that the ecological impacts of road construction needs to be minimized to the extent possible. The rapid spread and establishment of IAPS into new areas and ecosystems should be controlled on time to minimize their impacts.

6.2 Recommendations

- The uncontrolled spread of IAPS from one geographic region to others either intentionally or accidentally by man is considered to pose most serious impacts on native biodiversity, ecosystem functioning, socio-economic aspects, human health and other natural systems at both regional and national level. So, an inventory of IAPS considering various types of ecosystems and land use on a national scale needs to be carried out to document information related to their ecology and biology.
- Roads are basic infrastructure for the regional development in one hand and dispersal vectors for IAPS on the other hand. Therefore the construction and maintenance activities must be done in ecologically and biologically sustainable manner to prevent invasion.
- Human-modified ecosystems are more vulnerable to invasion in comparison to natural ecosystems. So, disturbance should be minimized to the extent possible.
- Comprehensive IAPS control and management plan for Nepal is required to deal with the problem of IAPS in Nepal.

References

Alexander J, Kueffer C, Daehler C, Edwards P, Pauchard A, Seipel T & Consortium M. 2011. Assembly of non-native floras along an elevational gradients explained by directional ecological filtering. *Proceedings of the National Academy of Science of the United States of America* **108**: 656-661.

Alexander JM, Naylor B, Poll M, Edwards PJ & Dietz H. 2009. Plant invasions along mountain roads: the altitudinal amplitude of alien Asteraceae forbs in their native and introduced ranges. *Ecography* **32**: 334-344.

Alpert P, Bone E & Holzapfel C. 2000. Invasiveness, invasibility and the role of environmental stress in the spread of non-native plants. *Perspectives in Plant Ecology, Evolution and Systematics* **3**: 52-66.

Arévalo JR, Delgado JD, Otto R, Naranjo A, Salas M & Fernández-Palacios JM. 2005. Distribution of alien vs. native plant species in roadside communities along an altitudinal gradient in Tenerife and Gran Canaria (Canary Islands). *Perspectives in Plant Ecology, Evolution and Systematics* **7**: 185-202.

Arteaga MA, Delgado JD, Otto R, Fernandez-Palacios JM & Arevalo JR. 2008. How do alien plants distribute along roads on oceanic islands? A case study in Tenerife, Canary Islands. *Biological Invasions* **11**: 1071-1086.

Bais HP, Vepachedu R, Gilroy S, Callaway RM & Vivance JM. 2003. Allelopathy and exotic plant invasion: from molecules and genes to species interactions. *Science* **301**: 1377-1380.

Barbosa NPU, Fernandes GW, Carneiro MAA & Junior LAC. 2010. Distribution of non-native invasive species and soil properties in proximity to paved roads and unpaved roads in a Quartzitic mountainous grassland of South Eastern Brazil (rupestrian fields). *Biological Invasions* **12**: 3745-3755.

Basnet B. 2011. *Impact of Mikania micrantha Invasion on Species Richness and Composition: A Case of Chitwan National Park, Nepal* [MSc Thesis]. Central Department of Botany, Tribhuvan University, Kathmandu, Nepal.

Becker T, Dietz H, Billeter R, Buschmann H & Edwards PJ. 2005. Altitudinal distribution of alien plant species in the Swiss Alps. *Perspectives in Plant Ecology, Evolution and Systematics* **7**: 173-183.

Bess HA & Haramoto FH. 1972. Biological control of *pamakani* (*Eupatorium adenophorum)* in Hawaii by a Tephritid gall fly, *Procecidochares utilis*: status of the weed, fly and parasites of the fly in 1966-71 versus 1950-57. *Proceedings of the Hawaiian Entomological Society* **21**: 165-178.

Bhattarai KR, Maren IE & Subedi SC. 2014. Biodiversity and invasibility: distribution patterns of invasive plant species in the Himalayas, Nepal. *Journal of Mountain Science* **11**: 688-696.

Bhowmik PC & Sarkar D. 2005. *Parthenium hysterophorus* L.: Its world status and potential management. In: *Proceedings of the second International Conference on Parthenium Management*, 5-7 December 2005. University of Agricultural Science, Banglore. Pp 1-6.

Burke MJW & Grime JP. 1996. An experimental study of plant community invisibility. *Ecology* **77**: 776-790.

Caley P, Groves RH & Barker R. 2008. Estimating the invasion success of introduced plants. *Diversity and Distributions* **14**: 196-203.

Callaway RM & Aschehoug ET. 2000. Invasive plants versus their new and old neighbours: a mechanism for exotic invasion. *Science* **290**: 521-523.

Callaway RM & Ridenour WM. 2004. Novel weapons: invasive success and the evolution of increased competitive ability. *Frontiers in Ecology and the Environment* **2**: 436-443.

CBS. 2012. *Environmental Statistics of Nepal*. Central Bureau of Statistics , Kathmandu. Available online at: http://cbs.gov.np/wp-context/uploads/2012/03/environment-book-final.pdf (accessed on November 29, 2014).

Christen DC & Matlack GR. 2006. The role of roadsides in plant invasions: a demographic approach. *Conservation Biology*. **20**: 385-391.

Christen DC & Mat lack GR. 2009. The habitat and conduit functions of roads in the spread of three invasive plant species. *Biological Invasion* **11**: 453-465.

Chytry M, Jarosik V, Pysek P, Hajek O, Knollova I, Tichy L & Danihelka J. 2008. Separating habitat invasibility by alien plants from the actual level of invasion. *Ecology* **89**: 1541-1553.

Crawley MJ. 1987. What makes a community invasible? In*: Colonization, Succession and Stability* (Eds.) Gray AJ, Crawley MJ, Edwards PJ. The 26th Symposium of the British Ecological Society. Blackwell Scientific Publications, London, UK. Pp. 429-453.

Davis MA, Grime PJ & Thompson K. 2000. Fluctuating resources in plant communities: a general theory of invasibility. *Journal of Ecology* **88**: 528-534.

Day MD, Broughton S & Hannan-Jones MA. 2003. Current distribution and status of *Lantana camara* and its biological control agents in Australia with recommendations for further biocontrol introductions into other countries. *Biocontrol* **24**: 63-76.

Dogra KS, Sood SK, Dobhal PK & Sharma S. 2010. Alien plant invasion and their impact on indigenous species diversity at global scale: A Review. *Journal of Ecology and the Natural Environment* **2**: 175-186.

Elton CS. 1958. *The Ecology of Invasions by Animals and Plants.* Methuen, London.

European Environment Agency .2007. *Europe's Environment: The Fourth Assessment.* European Environment Agency. Copenhagen, Denmark.

Evans HC. 1997. *Parthenium hysterophorus*: A review of its weed status and the possibilities for biological control. *Biocontrol News and Information* **18**: 89-98.

Forman R. & Alexander L. 1998. Roads and their major ecological effects. *Annual Review of Ecology and Systematics* **29**: 207-231.

Fuentes N, Ugarte E, Kuhn I & Klotz S. 2010. Alien plants in southern South America. A framework for evaluation and management of mutual risk of invasion between Chile and Argentina. *Biological Invasions* **12**: 3227-3236.

Gasso N, Sol D, Pino J, Dana ED, Lloret F, Sanz-Elorza M, Sobrino E, & Vila M. 2009. Exploring species attributes and site characteristics to assess plant invasions in Spain. *Diversity and Distributions* **15**: 50-58.

Grice AC. 2006. The impacts of invasive plant species on the biodiversity of Australian rangelands. *The Rangeland Journal* **28**: 1-27.

Haider S, Alexander J, Dietz H, Trepl L, Edwards PJ & Kueffer C. 2010. The role of bioclimatic origin, residence time and habitat context in shaping non native plant distributions along an altitudinal gradient. *Biological Invasions* **12**: 4003-401.

Hejda M, Pysek P, & Jarosik V. 2009.Impact of invasive plants on the species richness, diversity and composition of invaded communities. *Journal of Ecology* **97**: 393-403.

Heywood V. (Ed). 1995. *Global Biodiversity Assessement.* Cambridge University Press. UK.

Hobbs RJ & Huenneke L. 1992. Disturbance, diversity, and invasion: implications for conservation. *Conservation Biology* **6**: 324-337.

Hobbs RJ. 2000. Land use change and invasion: *In Invasive Species in a Changing World*, (Eds.) Mooney HA & Hobbs RJ. Island Press, Washington DC.

Hodkinson, DJ & Thompson K. 1997. Plant dispersal: the role of man. *Journal of Applied Ecology* **34**: 1484-1496.

Huang QQ, Qian C, Wang Y, Jia X, Dai XF, Zhang HHF. Peng SL & Wang GX. 2010. Determinants of the geographical extent of invasive plants in China: effects of biogeographical origin, life cycle and time since introduction. *Biodiversity Conservation* **19**: 1251-1259.

Hulme PE. 2009. Trade, transport and trouble: managing invasive species pathways in an era of globalization. *Journal of Applied Ecology* **46**: 10-18.

Hulme PE, Bacher S, Kenis M, Klotz S, Kuhn I, Minchin D, Nentwig W, Olenin S, Panov V, Pergl J, Pysek P, Roques A, Sol D, Solarz W & Vila M. 2005. Grasping at the routes of biological invasions: a framework for integrating pathways into policy. *Journal of Applied Ecology* **45**: 403-414.

Inderjit. 2005. Plant invasions: habitat invasibility and dominance of invasive plant species. *Plant and Soil* **277**: 1-5.

Jiang H, Fan Q, Li JT, Shi S, Li SP, Liao WB & Shu WS. 2011. Naturalization of alien plants in China. *Biodiversity Conservation* **20**: 1545-1556.

Joshi C, Leeuw JD, Andal J, Skidmore AK, Lekhak HD, Duren IC & Norbu N. 2006. Indirect remote sensing of a cryptic forest understorey invasive species. *Forest Ecology and Management* **225**: 243-256.

Karki D. 2009. *Ecological and Socioeconomic Impact of Parthenium hysterophorus L. Invasion in Two Urban Areas in Nepal* [MSc Thesis]. Central Department of Botany, Tribhuvan University, Kathmandu, Nepal.

Kaur B, Kour R, Bhatia S & Sharma KK. 2014. Diversity of invasive alien species of Jammu district (Jammu and Kashmir). *International Journal of Interdisciplinary and Multidisciplinary Studies* **1**: 214-222.

KC J. 2012. *Plant Species Composition and Soil Seedbank in Parthenium hysterophorus L. Invaded Grassland of Hetaunda Central Nepal* [Msc Thesis]. Central Department of Botany, Tribhuvan University, Kathmandu, Nepal.

Khuroo AA, Reshi ZA, Rashid I & Dar GH. 2011. Towards an integrated research framework and policy agenda on biological invasions in the developing world: A case study of India. *Environmental Research* **111**: 999-1006.

Khuroo AA, Reshi ZA, Malik AH, Weber E, Rashid I & Dar GH. 2011. Alien flora of India: taxonomic composition, invasion status and biogeographic affiliations. *Biological Invasions* **14**:99-113

Khuroo AA, Weber E, Malik AH, Reshi ZA & Dar GH. 2011. Altitudinal distribution patterns of the native and alien woody flora in Kashmir Himalaya, India. *Environmental Research* **111**: 967-977.

Kohli RK, Batish DR, Singh HP & Dogra KS. 2006. Status, invasiveness and environmental threats of three tropical American weeds (*Parthenium hysterophorus L., Ageratum conyzoides L., Lantana camara L.*) in India. *Biological Invasions* **8**: 1501-1510.

Kolar CS & Lodge DM. 2001. Progress in invasion biology: predicting invaders. *TRENDS in Ecology and Evolution* **16**: 199-204.

Kosaka Y, Saikia B, Mingki T, Tag H, Riba T & Ando K. 2010. Roadside distribution patterns of invasive alien plants along an altitudinal gradient in Arunachal Himalaya, India. *Mountain Research and Development* **30**: 252-258.

Kunwar RM. 2003. Invasive alien plants and *Eupatorium*: biodiversity and livelihood. *Himalayan Journal of Science* **1**: 129-133.

Lockwood JL, Hoopes MF & Marchetti MP. 2007. *Invasion Ecology*. Blackwell Publishing, Malden, USA.

Londsale WM & Lane LA. 1994. Tourist vehicles as vectors of weed seeds in Kakadu National Park, Northern Australia. *Biological Conservation* **69**: 277-283.

Londsale WM. 1999. Global patterns of plant invasions and the concept of invasibility. *Ecology* **79**: 2694- 2705.

LRMP. 1986. *Land Utilization Report. Land Resources Mapping Project (LRMP),* Kenting Earth Sciences Limited, Government of Nepal and Government of Canada.

Lu P, Sang WG & Ma KP. 2008. Differential responses of the activities of antioxidant enzymes to thermal stresses between two invasive *Eupatorium* species in China. *Journal of Integrative Plant Biology* **50**: 393-401.

Lundgren M, Christine R, Small J & Dreyer GD. 2004. Influence of land use and site characteristics on invasive plant abundance in the Quinehaug Highlands of southern New England. *Northeastern Naturalist* **11**: 313-332.

MacDougall AS & Turkington R. 2005. Are invasive species the drivers or passengers of change in degraded ecosystems? *Ecology* **86**: 42-55.

Mack RN, Simberloff D, Londsale WM, Evans H, Clout M & Bazzaz FA. 2000. Biotic invasions: Causes, epidemiology, global consequences and control. *Ecological Applications* **10**: 689-710.

Mack R. 2003. *Global Plant Dispersal, Naturalization and Invasion: Pathways, Modes, and Circumstances*. Washington, Island Press.

Maharjan S, Joshi S, Shrestha BB, Devkota A & Jha PK. 2014. Life history traits and invasion success of *Parthenium hysterophorus* L. in Kathmandu Valley, Nepal. *Nepal Journal of Science and Technology* **15**: 31-38.

Manier DJ, Aldridge CL, O'Donnell M & Schell SJ. 2014. Human infrastructure and invasive plant occurrence across rangelands of Southwestern Wyoming, USA. *Rangeland Ecology & Management* **67**: 160-172.

McDougall KL, Khuroo AA, Loope LL, Parks CG, Pauchard A, Reshi ZA, Rushworth I & Kueffer. 2011. Plant invasions in mountains: global lessons for better management. *Mountain Research and Development* **31**: 380-387.

McKinney ML. 2006. Urbanization as a major cause of biotic homogenization. *Biological Conservation* **127**: 247-260.

McNeely JA, Mooney HA, Neville LE, Schei PJ & Waage JK (Eds.). 2001. *Global Strategy on Invasive Alien Species*. IUCN in collaboration with the Global Invasive Species Programme, Cambridge, UK.

MFSC. 2002. *Nepal Biodiversity Strategy*. Government of Nepal, Ministry of Forests and Soil Conservation (MFSC), Kathmandu.

MFSC. 2009. *Nepal Fourth National Report to the Convention on Biological Diversity,* Ministry of Forests and Soil Conservation (MFSC), Kathmandu.

MFSC. 2014. *Nepal National Biodiversity Strategy and Action Plan 2014-2020.* Government of Nepal, Ministry of Forests and Soil Conservation (MFSC), Kathmandu.

MFSC. 2014. *Nepal Fifth National Report to the Convention on Biological Diversity,* Ministry of Forests and Soil Conservation (MFSC), Kathmandu.

Ministry of Health and Population. 2011.*Nepal Population Report*. Government of Nepal, Ministry of Health and Population, Population Division, Ramshahpath, Kathmandu.

Moktan S & Das AP. 2013. Diversity and distribution of invasive alien plants along the altitudinal gradient in Darjiling Himalaya, India. *Pleione* **7**: 305-313.

Moore PD. 2000. Alien Invaders. *Nature*. **403**: 492-493.

Moravcova L, Pyšek P, Jarosik V, Havlickova V & Zakravsky P. 2010. Reproductive characteristics of neophytes in the Czech Republic: traits of invasive and non-invasive species. *Preslia* **82**: 365-390.

Mortensen D, Rauschert E, Nord A & Jones B. 2009. Forest roads facilitate the spread of invasive plants. *Invasive Plant Science and Management* **2**: 191-199.

Murphy ST, Subedi N, Jnawali SR, Lamichhane BR, Upadhyay GP, Kock R & Amin R. 2013. Invasive mikania in Chitwan National Park, Nepal: the threat to one-horned rhinoceros *Rhinoceros unicornis* and factors driving the invasion.*Oryx* **47**: 361-368.

Navie SC, McFadyen RE, Panetta FD & Adkins SW. 1996. The biology of Australian weed *Parthenium hysterophorus* L. *Plant Protection Quarterly* **11**: 76-87.

Norbu N. 2004. *Invasion Success of Chromolaena odorata in the Terai of Nepal* [Msc Thesis]. International Institute for Geo-information. Science and Earth Observation, the Netherlands.

Parendens LA & Jones JA. 2000. Role of light availability and dispersal in alien plant invasion along roads and streams in the H.J. Andrews Experimental Forest, Oregon. *Conservation Biology* **14**: 64-75.

Pauchard LA & Alaback PB. 2004. Influence of elevation, landuse, and landscape context on patterns of alien plant invasions along roadsides in protected areas of South-Central Chile. *Conservation Biology* **18**: 238-248.

Paudel A. 2011. *Germination Response of Fallow Land Plant Species of Central Nepal to Allelopathic Effect of Parthenium hysterophorus L.* [MSc Thesis]. Central Department of Botany, Tribhuvan University, Kathmandu.

Perrings C, Mooney HA & Williamson M. 2010. *Bioinvasions and Globalization: Ecology, Economics, Management & Policy*. Oxford University Press, Oxford, U.K.

Perron C. 2008. *Best Management Practices,* New Hampshire Department of Transportation, Bureau of Environment (http://www.nh.gov/dot/bureau/environment/document.htm) (accessed on 20 Oct, 2014).

Pimental D, Zuniga R & Morrison D. 2005. Update on the environmental and economic costs associated with alien invasive species in the United States. *Ecological Economics*. **52**: 273-288.

Pokhrel K. 2013. *Phenology and Response of Clipping in Relation to Invasiveness of Parthenium hysterophorus L.*[MSc Thesis]. Central Department of Botany, Tribhuvan University, Kathmandu, Nepal.

Pollnac F, Seipel T, Repath C & Rew LJ. 2012. Plant invasion at landscape and local scales along roadways in the mountainous region of the Greater Yellowstone Ecosystem. *Biological Invasions* **14**: 1753-1763.

Poudel A, Baral HS, Ellison C, Subedi K, Thomas S & Murphy S. 2005. *Mikania micrantha Weed Invasion in Nepal*: *A Summary Report*. The First National Workshop for Stakeholders, 2004 Nov 25, Kathmandu, Nepal. Himalayan Nature, IUCN, Kathmandu and CAB International, Waliingford.

Poudel BS & Thapa HB. 2012. An assessment of existing studies in invasive alien plants species of Nepal. *Banko Janakari* **22**:28-36.

Pyšek P & Richardson DM. 2007. Traits associated with invasiveness in alien plants: where do we stand? In: *Ecological Studies* Nentwig W. (Ed.), Springer-Verlag Berlin, Heidelberg, Germany.

Raghubanshi AS, Rai LC, Gaur JP & Singh JS. 2005. Invasive alien species and biodiversity in India. *Current Science* **88**: 539-540.

Rai RK & Rai R. 2013. Assessing the temporal variation in the perceived effects of invasive plant species on rural livelihoods: a case of *Mikania micrantha* invasion in Nepal. *Conservation Science* **1**: 13-18.

Rai RK, Scarborough H, Subedi N & Lamichhane B. 2012. Invasive plants – do they devastate or diversify rural livelihoods? rural farmer's perception of three invasive plants in Nepal. *Journal for Nature Conservation* **20**: 170-176.

Reddy CS. 2008. Catalogue of invasive alien flora of India. *Life Science Journal* **5**: 84-89.

Rejmanek M. 2000. Invasive plants: approaches and predictions. *Australian Ecology* **25**: 497-506.

Rejmanek M and Richardson DM. 1996. What attributes make some plant species more invasive*? Ecology* **77**: 1655–1661.

Rejmanek M. 2011. Invasiveness. In: *Encyclopedia of Biological Invasion* (Eds.) Simberloff D & Rejmanek M. University of California Press, Berkeley, California. Pp: 379-385.

Reshi ZA & Khuroo AA. 2012. Alien plant invasion in India: current status and management challenges. *Proceedings of National Academy of Sciences, India, Section B: Biological Sciences* **82**: 305-312.

Richardson DM, Allsopp N, D'Antonio CM, Milton SJ & Rejmánek M. 2000. Plant invasions - the role of mutualisms. *Biological Reviews* **75**: 65-93.

Richardson DM, Pyšek P, Rejmanek M, Barbour G, Panetta FD & West CJ. 2000. Naturalization and invasion of alien plants: concepts and definitions. *Diversity and Distributions* **6**: 93-107.

Richardson DM & Pyšek P. 2006. Plant invasions: merging the concepts of species invasiveness and community invisibility. *Progress in Physical Geography* **30**: 409-431.

Sakai AK, Allendorf FW & Holt JS. 2001. The population biology of invasive species. *Annual Review in Ecology and Systematics* **32**: 305-332.

Sankaran T .1973. Biological control of weeds in India. A review of introductions and current investigations of natural enemies. In: *Proceedings of the Second International Symposium on Biological Control of Weeds*, (Ed.) Dunn PH, Slough, UK: Commonwealth Agricultural Bureaux.

Sapkota L .2007. Ecology and management issues of *Mikania micrantha* in Chitwan National Park, Nepal. *Banko Janakari*. **17**: 27-39.

Schiffman PM .1997.Animal-mediated dispersal and disturbance: driving forces behind alien plant naturalization. In: *Assessment and Management of Plant Invasions* (Eds.) Luken JO & Thieret JW, Springer, New York. Pp 87-94.

Sharma GP, Singh JS & Raghuvanshi AS. 2005. Plant invasions: emerging trends and future implications. *Current Science* **88**: 726-734.

Sharma KC & Chhetri GKK. 1977. Reports on studies on the biological control of *Eupatorium adenophorum*. *Nepalese Journal of Agriculture* **12**: 135-157.

Shea K & Chesson P. 2002. Community ecology theory as a framework for biological invasions. *Trends in Ecology and Evolution* **17**: 170-176.

Shreshtha BB, Shabbir A & Adkins SW. 2015. *Parthenium hysterophorus* in Nepal: a review of its weed status and possibilities for management. *Weed Research* **55**: 132-144.

Shrestha BB. 2012. Parthenium weed in Chitwan National Park, Nepal. *International Parthenium News* **5**: 6-7.

Shrestha BB, Poudel A, KC J, Karki D, Gautam RD & Jha PK. 2010. Fortuitous biological control of *Parthenium hysterophorus* by *Zygogramma bicolorata* in Nepal. *Journal of Natural History Museum* **25**: 333-338.

Shrestha K, Wilson E & Gay H. 2008. Ecological and environmental study of *Eupatorium adenophorum* Sprengel (*Banmara*) with reference to its gall formation in Gorkha-Langtang route Nepal. *Journal of Natural History Museum* **23**: 108-124.

Sinden J, Jones R, Hester S, Odom D, Kalisch C, James R & Cacho O. 2004. *The Economic Impact of Weeds in Australia*. Technical Series No.8, CRC for Australian Weed Management, Adelaide, Australia.

Simberloff D. 2011. How common are invasion-induced ecosystem impacts? *Biological Invasions* **13**:1255-1268.

Singh AG & Sharma A. 2014. Documentation of invasive alien plant species of Rupandehi district, Western Nepal. *International Journal of Applied Sciences and Biotechnology* **2**: 168-175.

Singh JS, Singh SP & Gupta SR. 2008. *Ecology, Environment and Resource Conservation*, Anamaya Publishers, New Delhi.

Siwakoti M. 2007. Mikania weed: a challenge for conservationists. *Our Nature* **5**:70-74.

Sorensen AE. 1986. Seed dispersal by adhesion. *Annual Review of Ecological Systematics* **17**: 443-463.

Sullivan J, Williams P, Timmins S & Smale M. 2009. Distribution and spread of environmental weeds along New Zealand roadsides. *New Zealand Journal of Ecology* **33**: 190-204.

Theoharides KA & Dukes JS. 2007. Plant invasion across space and time: factors affecting non-indigenous species success during four stages of invasion. *New Phytologist* **176**: 256-273.

Thompson K, Hodgson JG, Grime P & Burke MJW. 2001. Plant traits and temporal scale: evidence from a 5-year invasion experiment using native species. *Journal of Ecology* 89: 1054-1060.

Timsina B, Shrestha BB, Rokaya MB & Munzbergova. 2011. Impact of *Parthenium hysterophorus* L. invasion on plant species composition and soil properties of grassland communities in Nepal. *Flora* **206**: 233-240.

Tiwari S, Adhikari B, Siwakoti M & Subedi K. 2005. *An Inventory and Assessment of Invasive Alien Plant Species of Nepal.* IUCN-The World Conservation Union, Nepal.

Vitousek P, Antonio C, Loope L, Rejmanek M & R. Westbrooks R. 1997. Introduced species: a significant component of human-caused global change. *New Zealand Journal of Ecology* **21**: 1-16.

Vitousek P, D'Antonic C, Loope L & Westbrooks R. 1996. Biological invasions as global environmental change. *American Scientist* **84**: 468.

Von der Lippe M & Kowarik I. 2007. Long-distance dispersal of plants by vehicles as a driver of plant invasions. *Conservation Biology* **21**: 986-996.

Wabuyele E, Lsuweti A, Bisikwa J, Kyenune G, Clark K, Lotter WD, McConnachie AJ & Wondi M. 2014. A roadside survey of the invasive weed *Parthenium hysterophorus* (Asteraceae) in East Africa. *Journal of East African Natural History* **103**: 49-57.

Weber E & Li B. 2008. Plant invasions in China: What is to be expected in the wake of economic development? *Bioscience* **58**: 437-444.

Weber E, Sun SG & Li B. 2008. Invasive alien plants in China: diversity and ecological insights. *Biological Invasions* **10**: 1411-1429.

Williamson M. & Fitter A. 1996.The varying success of invaders. *Ecology* **77**: 1661-1666.

Wu RR & Xu XJ. 1992. Control of *Chromolaena odorata* (L.) R.M. King & H. Robinson by planting signal grass (*Brachiaria Decumbens* Starf) in Southern Yunnan, China. *Pratacultural Science* **9**: 18-20 (in Chinese with an English abstract).

Wu SH, Sun HT, Teng YC, Rejmanek M, Chaw SM, Yang TYA & Hsieh CF. 2010. Patterns of plant invasion in China: taxonomic, biogeographic, climatic approaches and anthropogenic effects. *Biological Invasions* **12**: 2179-2206.

Xu H, Qiang S, Genovesi P, Ding H, Wu J, Meng L, Han Z, Miao J, Hu B, Guo J, Sun H, Huang C, Lei J, Le Z, Zhang X, He S, Wu Y, Zhang Z, Chen L, Jarosik V & Pysek P. 2012. An inventory of invasive alien species in China. *Neo Biota.* **15**: 1-26.

Yan X, Zhenyu L, Gregg WP & Dianmo L. 2001. Invasive species in China- an overview. *Biodiversity and Conservation* **10**: 1317-1341.

Zhang WJ & Chen B. 2011. Environment patterns and influential factors of biological invasions: a worldwide survey. *Proceedings of the International Academy of Ecology and Environmental Sciences* **1**: 1-14.

Zhao GJ & Ma YP**.** 1989. The investigation research on the distribution and harmfulness of *Eupatorium adenophorum* Spreng. in Yunnan province. *Journal of Weed Science.* **3**: 37-40 (in Chinese with an English abstract).

Zobel DB, Jha PK, Behan MJ & Yadav UKR. 1987. *A Practical Manual for Ecology.* Ratna Book Distributors, Bagbazzar, Kathmandu, Nepal.

Appendix 1: Field data sheet used during our survey of IAPS along road network in Central Nepal (2013).

Diversity of invasive alien plant species along road networks

SN: ……… Date: ………….. Way point: ………….. Aspect: …………….

Lat: ………… Long: …………. Elevation: ………… Slope: ………………

District: ………. VDC/ Municipality: …………………… Locality: ………………....

Land use: ………………………………………… Road: ……………………………….

Invasive alien plant species (ca. 10m× 10m)

SN	**Name**	**Phenophase**	**SN**	**Name**	**Phenophase**
1			6		
2			7		
3			8		
4			9		
5			10		

Biocontrol agents, if any: ……………………………………………………………………

Most dominant 3 species (in terms of coverage): ………………………Photo no: ………….

Other IAPS in surroundings: ……………………………………………………………..

Appendix 2: District wise distribution of individual IAPS obtained from our survey.

IAS / Districts	*Chromolaena odorata*	*Ageratina adenophora*	*Lantana camara*	*Eichhornia crassipes*	*Ipomoea carnea* ssp. *fistulosa*	*Mikania micrantha*	*Alternanthera philoxeroides*	*Parthenium hysterophorus*	*Ageratum conyzoides*	*Amaranrhus spinosus*	*Argemone mexicana*	*Cassia tora*	*Hyptis suaveolens*	*Bidens pilosa*	*Cassia occidentalis*	*Mimosa pudica*	*Oxalis latifolia*	*Xanthium strumarium*
Baglung	°	°	°					•	°	°		°		°	°	°	°	•
Parbat	°	°	°					•	°	°		°	•	°		•		•
Myagdi		•	°					•	•	°		•		°		•		
Kapilbastu	•		°	°	°			°	°	°	°	°	°	•	°	°	°	°
Arghakhanchi	•	°	°		•			•	°	°		°		°	°	°	°	°
Gulmi		°	°					•	°	°	°	°	•	°	°	°	°	•
Rupandehi	°		°	°	°	°	•	°	°	°	°	°	°	•	°	°	°	°
Palpa	°	°	°		°			°	°	°		°	•	°	°	°	°	°
Nawalparasi	°	°	°	°	°	°		°	°	°	°	°	°	•	°	°	°	°
Syangja	•	°	°		•			•	•	°		•	•	°	°	°	°	•
Kaski	•	°	°	•	•			•	°	•		•	•	•	•	•		•
Tanahun	•	°	°		•			•	°	°		°	•	°	°	°	°	•
Lamjung	•	•			•			•	°	°		•	•	°	°	°		°
Gorkha	•	°	°		•			•	°	°		•	•	°	•	°		•
Chitwan	°	°	°	°	°	°	°	°	°	°	°	°	°	•	°	°	°	°
Makwanpur	°	°	°	°		•	°	°	°	°	°	°	°	°	°	°	°	°
Parsa	°		°	°	°	°	°	°	°	°	°	°	°	•	°	°	°	°
Bara	°		°	°	°	°	°	°	°	°	°	°	°	•	°	°	°	°
Rautahat	°		°	°	°	°	°	°	°	°	°	°	°		°	°	°	°
Dhading	°	°	°			•		•	°	°		°	°	°	°	°		•
Nuwakot	°	•	•					°	°	°		°	°	•	°	°		°
Rasuwa		°						•	°					•	°	°		°
Kathmandu		•	°	°	•		°	°	°	°	°	•	•	°	°	°	°	•
Lalitpur		•	°	°			°	°	°	°		•	•	°	°	°	°	•

Bhaktapur	●	○	○	○	●		○	○	○	○		●	●	○	○	○	○	●
Kavre	○	○	○		●		●	●	○	○	●	●	●	○	○	○		●
Sindhupalchowk	●	○	●		●		●	○	○	○		●		●	●			●
Sarlahi	○		○	○	○	○	○	○	○	○	○	○	○		○	○	○	○
Mahottari	○		○	○	○	○	○	○	○	○	○	○	○	●	○	○	○	○
Dhanusa	○		○	○	○	○	○	○	○	○	○	○	○		○	○	○	○
Sindhuli	○	○	○		●			●	○	○	●	○	●	○	○	○	○	●
Ramechhap	○	○	○					●	●	○	●	●	●	○	○	○		●
Dolakha	●	●	●					●	●	○		●	●		●	●	●	●
Siraha	●		●		●			●		●		●	●					●

○ = IUCN Reported Districts ● = Present Reported Districts

Appendix 3: Elevational range of individual IAPS.

SN	Name of IAPS	Elevational Range (m)
1	*Chromolaena odorata*	105- 1713
2	*Ageratum conyzoides*	180- 1990
3	*Argemone mexicana*	65- 700
4	*Cassia tora*	75- 1127
5	*Bidens pilosa*	130- 2320
6	*Cassia occidentalis*	75- 1130
7	*Mimosa pudica*	80- 1495
8	*Amaranthus spinosus*	70- 1750
9	*Xanthium strumarium*	70- 1810
10	*Ageratina adenophora*	395- 2570
11	*Ipomoea carnea* ssp. *fistulosa*	70- 1340
12	*Lantana camara*	105- 1715
13	*Mikania micrantha*	70- 335
14	*Hyptis suaveolens*	105-1065
15	*Oxalis latifolia*	1100- 1990
16	*Parthenium hysterophorus*	70- 1545
17	*Alternanthera philoxeroides*	65- 1505
18	*Eichhornia crassipes*	65- 675

Appendix 4: Minimum residence time of particular IAPS with their first reported date in Nepal.

SN	Name of IAPS	First Reported date in Nepal	Minimum Residence Time (Yr)
1	*Chromolaena odorata*	1825	189
2	*Ageratum conyzoides*	1910	104
3	*Argemone mexicana*	1910	104
4	*Cassia tora*	1910	104
5	*Bidens pilosa*	1910	104
6	*Cassia occidentalis*	1910	104
7	*Mimosa pudica*	1910	104
8	*Amaranthus spinosus*	1955	59
9	*Xanthium strumarium*	1955	59
10	*Ageratina adenophora*	1958	56
11	*Ipomoea carnea* ssp. *fistulosa*	1966	48
12	*Lantana camara*	1966	48
13	*Mikania micrantha*	1966	48
14	*Hyptis suaveolens*	1966	48
15	*Oxalis latifolia*	1966	48
16	*Parthenium hysterophorus*	1982	32
17	*Alternanthera philoxeroides*	1994	20
18	*Eichhornia crassipes*	1996	18

PHOTOPLATES

IAPS considered in the present study


Ageratina adenophora


Ageratum conyzoides


Alternanthera philoxeroides


Amaranthus spinosus


Argemone mexicana


Bidens pilosa

Cassia occidentalis

Cassia tora

Chromolaena odorata

Eichhornia crassipes

Hyptis suaveolens

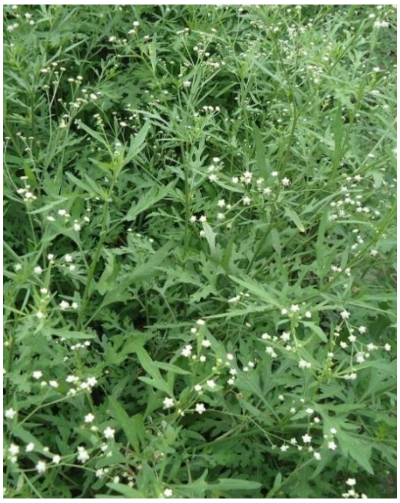
Ipomoea carnea ssp. fistulosa

Lantana camara

Mikania micrantha

Mimosa pudica

Oxalis latifolia



Parthenium hysterophorus

Xanthium strumarium