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REVIEW

Impact, management, and use of invasive alien plant species in Nepal's protected area: a systematic review

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Background: Invasive alien plant species (IAP) significantly threaten Nepal's protected areas and local communities. Understanding their distribution, impact, management, and utilization is essential for developing effective management strategies and sustainable utilization practices. The systematic literature review of publications from 2010 to 2023. The search was conducted through the database Nepal Journal online database (NepJOL) and Google Scholar, yielding an initial pool of 4,304 publication. After applying inclusion and exclusion criteria; we meticulously reviewed 43 articles for data extraction.
Results: Seventeen IAP are found in protected area, Nepal with the highest prevalence observed in Koshi Tappu Wildlife Reserve, followed by Chitwan and Sukhlaphanta National Park. The most problematic species in terrestrial ecosystems are *Mikania micrantha*, *Lantana camara*, and *Chromolaena odorata*. The grassland ecosystems of wildlife habitats, primarily in the Terai and Siwalik regions, are the most invaded. Various management approaches are employed to mitigate the spread and impact of IAP, including mechanical methods such as uprooting, burning, and cutting. However, these methods are costly, and context-specific interventions are needed. The study also explores the potential use of IAP for economic, ecological, or cultural purposes, such as medicinal properties, energy production potential, and economic viability. Local communities utilize these plants for animal bedding, mulching, green manure, briquette, and charcoal production.
Conclusions: Applying silvicultural practices alongside mechanical management is recommended to maintain a healthy terrestrial ecosystem and utilize the removed biomass for valuable products, thereby reducing removal costs and increasing income sources, potentially benefitting both local communities and wildlife in protected areas.

Keywords: invasive alien plant species, native species, protected area, wildlife habitat

Introduction

Nepal boasts remarkable botanical richness, evident in its extensive and diverse plant life. The country has 188 ecosystems across various physiographic zones (Bhattacharjee et al. 2017; Paudel et al. 2012). Anthropogenic activities have significantly impacted the global environment, including climate change, habitat loss and fragmentation, unsustainable harvesting of natural resources, pollution, and the introduction of invasive alien plant species (IAP) (Shiferaw et al. 2018). Biological invasion, a well-established ecological concept, is one of the five primary effects of human activity on the global ecosystem (IPBES 2019). Introducing non-native plants, animals, and other organisms to new environments can transform them into invasive species capable of rapid reproduction and widespread distribution, significantly altering the ecological dynamics of diverse ecosystems (Simberloff et al. 2013). Invasive alien plant species are distributed as a problematic species at worldwide. They are particularly dangerous as they can displace native species, disturb ecosystem functioning, and cause harm to both biodiversity and human populations (Bhatta et al. 2021; Convention on Biological Diversity [CBD] 1992; Potgieter et al. 2019; Roy et al. 2019; Shackleton et al. 2018). Therefore, this kind of invasion is risky for the earth's biodiversity (Binggeli 1996).

The mechanisms that contribute to spread IAP seed are dispersal by water, air, animal and human action of trade and transportation in different landscape (Catford et al. 2016; Kleyheeg et al. 2017; Li et al. 2012; Wenny et al. 2011).

The tourism and recreation, population pressure on natural resources, introduced IAP for medicinal or ornamental purposes, infrastructure development, deforestation, agricultural expansion are also the causes of spreading (Adhikari et al. 2019; Muscolo et al. 2014). Moreover, IAP enters through the activities of road and air link for international tourism, travel, and trade at globally and the way is used Indian boarder (Gupta et al. 2021) and spread throughout the country at locally. For example, IAP such as *Lantana camara* was reported early in 19th century for using as ornamental purpose but now the situation is different, it is invaded throughout the country. It impact has been seen in the form of competition with native species, transformation of ecological system, depletion of biodiversity in natural habitat, reduction of crop yield, and increase livestock mortality in agriculture land (Adhikari et al. 2019). Furthermore, climate change effects such as landslide, flood, soil erosion, forest fire, are also expected to establish and spread IAP with its creative action of favorable environment in terrestrial ecosystem (Adhikari et al. 2019; Brooks et al. 2004; Hobbs and Huenneke 1992; Lake and Leishman 2004).

Protected areas of Nepal is also not free from the spreading of IAP so it has already under threat to impose the particular habitat, although the area is not successfully explored actual record of biodiversity (Rico-Sánchez et al. 2020). Protected areas are established to safeguard representative regions of ecological processes, biodiversity, and natural landscapes while also playing a crucial role in promoting economic expansion (Margules and Pressy 2000). While the borders of parks are intended to prevent the introduction of exotic species into the core areas, transportation, infrastructure, and human habitation in proximity to protected areas, become conduits for the spread of IAP (Foxcroft et al. 2011). In case of Nepal, settlements of people are found around the protected park of buffer zone and they are involved to protect the park with buffering settlement concept. The people are dependent on forest of park to support their livelihood for using timber, firewood, food, leaf litter, fodder, medicinal plant and so on. When IAP enters the forest ecosystem in protected areas, it affects native plants and its regeneration in the form of competition for light, space, and water as well as climb tree and other structure and block the sunlight, reduce species diversity, richness, growth, and finally displacement (Ministry of Forests and Soil Conservation 2014; Shrestha 2016). Invasive alien plant species contribute negatively on plant regeneration on its soil properties such as content of organic matter, nutrient to run the ecosystem (Chaudhary et al. 2020). Furthermore, it decreases soil microbial biomass and activity which lead to change in soil carbon and nutrient cycling (Vitousek et al. 1987). When severe effects arise then it contributes to collapse the ecosystem and impact seen on the forest habitat and socio-economic life of the people (Shrestha et al. 2023). Therefore, IAP has play the negative role towards the socio-economic aspects such as habitat degradation, low agricultural productivity, loss biodiversity, low availability of food for wildlife and livestock (Shrestha et al. 2018). Out of twenty-seven species found in Nepal (Bhatt et al. 2021), among them four IAP *Mikania micrantha*, *Chromolaena odorata*, *L. camara*, and *Eichornia crassipes* found world worst list (Lowe et al. 2000). *Mikania micrantha* as well as *L. camara* are the most problematic IAP found in Chitwan and Bardiya National Park respectively. About twenty-three species are noted from in and around the protected areas and among twenty-three species most prevalent species are *L. camara*, *Ageratina adenophora*, *C. odorata*, and *Ageratum conyzoides* (Bhatta et al. 2021; Shrestha et al. 2019a). Therefore, protected areas have highlighted the problem of IAP and its control and management policy and activities are included in their management plan to manage the ecosystem properly. Laws, policies, and regulations can help to stop the spread of IAP by 1) governing the introduction, propagation, distribution, and management of IAP, 2) implementing inspections and regulations on plant and product materials, 3) formulating phytosanitary standards and procedures, and 4) implementing effective quarantine measures to safeguard against the entry and introduction of IAP. In addition, guidelines for assessing, detecting, and controlling IAP are also important. Plant Quarantine and Pesticide Management Centre (PQPMC) and International Plant Protection Convention (IPPC) are responsible for the activities at Nepal and global level respectively. The control measures are also the key process to manage and eradicate spreading IAP by the help of physical, chemical, biological and cultural control methods and practices (Bolch et al. 2020). Convention on Biological Diversity is active for recommending different approaches to control the IAP for prevention, early detection and rapid response and similarly, control and eradication, restoration and rehabilitation at global level (CBD 2014). Working organization such as the International Union for Conservation of Nature (IUCN). In case of Nepal, Ministry of Forests and Environment and Department of Plant Resources are responsible at national level and Community Forest User Group (CFUG), Buffer Zone Community Forest User Group (BZCFUG) at local level. National Biodiversity Strategy and Action Plan (NBSAP) are playing the important role to solve the IAP problem by supporting to make a guideline for rules, regulation and policy at national level and implement through the National Parks and Wildlife Conservation Act 2073, Forest Act 1993 and policy. These significant actions are focused on conservation of biodiversity, and protection of ecosystems which are needed for the future generations. The strategy of IAP 2019 of Nepal is involved to control and manage the IAP through the guideline and basically focused on risk assessment, early detection and rapid response, monitoring, and evaluation of IAP in protected ar-

eas (Shrestha 2016).

Addressing these challenges requires a thorough assessment the impact of IAP on forest ecosystems, specifically in terms of tree stand, regeneration, and wildlife habitat within the protected areas, which is a crucial resource for the well-being of animals and humans. While both plants and animals are affected by IAP, the harm caused by invasive plants is more pronounced in natural environments, including animals' habitats and local livelihoods, as plants have a higher potential for unintentional introduction, rapid spread, and the capacity to alter the local flora compared to animals significantly in the protected areas. Additionally, plant invasion poses a more numerous and significant threat to global diversity than animal invasion (Bhandari 2019). The present study aims to find answers such as (a) What types of IAP are present in protected areas? (b) How are these species distributed in various ecosystems? (c) Does the presence of IAP impact terrestrial ecosystems? (d) What local-level activities are being implemented to manage IAP? (e) How do local communities utilize the biomass of IAP for various purposes? To fulfilled above research questions and analyze the impact of IAP and struggle for existence within the terrestrial ecosystem. The occurrence of IAP has been recognized in any habitat then threat occurs and imbalance the normal biodiversity in protected areas. Therefore, it is crucial to find appropriate technology and management strategies to control and manage IAP, as well as to utilize their biomass for producing useful local products. This study helps to make a management strategy for policymakers, decision–makers, foresters, environmentalists, conservationists, academics, local communities, and business entrepreneurs and other interested people in this field. Its findings can contribute to achievement of the goal of sustainable forest management.

Materials and Methods

Study area

Protected areas of Nepal are specifically used as a study area. In Nepal, there are twenty protected area, among them twelve National Parks, six Conservation Areas, one Wildlife Reserve, and one Hunting Reserve, as well as thirteen Buffer Zones ranging from the lowlands of Terai to the high highlands.

Article searching criteria

This study follows the methodology of preferred reporting items are systematic reviews and meta-analysis (PRISMA) framework. In this framework four criteria such as identification, screening, eligibility, and inclusion to be fulfilled selecting the article. The study focused on the research and review articles from 2010–2023 related to IAP in Nepal and elsewhere. Published literature was selected based on predetermined criteria for assessing the IAP in the context of their distribution, impact, management, and utilization practice within the terrestrial habitat. The search for publications was performed using databases such as Google Scholar and Nepal Journal online database (NepJOL) and Google search from January 1, 2022, to October 15, 2023, using predetermined keywords and fulfilled the criteria. The keywords used for identification and screening the articles are 'invasive alien plant species', 'protected area of Nepal', 'distribution', 'impact on a tree stand, regeneration, and wildlife habitat', 'management', and 'use'. The main articles were selected to achieve the goal of a systematic literature review that includes only terrestrial ecosystems, focusing on protected areas of Nepal. Duplicate and irrelevant articles were removed. Four thousand three hundred four articles were found under identification process, and 158 articles were selected under the screening process, and final 43 articles were used for systematic reviews after removing irrelevant and duplicate articles.

Results and Discussion

Invasive alien plant species distribution in protected areas

Among twenty protected areas, thirteen (Seven National Parks, five Conservation Areas, and one Wildlife Reserve) have reported invasion by IAP and seven (five National Parks, One Conservation Area, and one Hunting Reserve), are void of IAP invasion. As noted by Shrestha et al. (2019a) and Bhatt et al. (2021), the invaded areas exhibit degradation across different ecosystems. Koshi Tappu Wildlife Reserve has the highest number of invasions, reporting among seventeen IAP, followed closely by Chitwan National Park and Shukla Phanta National Park, with sixteen IAP. In contrast, Khaptad National Park records the least number of IAP, standing only two in its habitat. Despite being the largest conservation area, Annapurna Conservation Area reports only eight IAP. Similarly, Shey Phoskundo National Park, the second-largest area, stands out as an exception, being free from IAP invasion. The number of IAP are recorded depends on geographical location and climatic circumstances in protected areas (Shrestha et al. 2019a). Most IAP have been reported from the Terai and Siwalik regions (Chaudhary et al. 2020). Out of twelve National Parks, Seven National Parks have reported IAP. Among them, *L. camara*, *M. micrantha*, and *C. odorata* have been found as the most problematic species in protected area and five National Parks did not have any IAP recorded. Similarly, among six Conservation Areas, except Manaslu Conservation Area, all others have reported IAP. The only one Wildlife Reserve had the highest number of IAP, while the Hunting Reserve had no IAP. It was found that the IAP were prevalent in low and mid-land areas, while IAP were

not present in the highland areas of Nepal (Shrestha 2019a). The number of IAP has been increasing continuously and invading new areas of Nepal with multiple socio-ecological impacts (Shrestha et al. 2019a, 2019b) which can be seen in following Table 1.

Invasive alien plant species threats in the protected areas

Thirteen protected areas in Nepal are affected by various IAP in forest, grassland, and agricultural landscapes. In that order, the highest incidence of invasion occurs in grasslands, followed by forests, and agricultural areas. Among identified invasive species, *L. camara*, *M. micrantha*, and *C. odorata* are prominent in terrestrial ecosystems which are shown in Table 1.

Impact of the invasive alien plant species on terrestrial ecosystems

Many IAP affect components such as tree stands, regeneration, and wildlife habitat of the protected area in forest, grassland, and agro-ecosystems. Protected areas support the conservation of natural habitats for the protection of wildlife and the well-being of humans who depends on forest. However, IAP pose a significant threat to the ecosystems and its components. Global invasion is the second main factor leading to the loss of biodiversity, after habitat degradation (Glowka et al. 1994; Shrestha 2016). To stop more damage to the environment, it is vital to manage these protected areas in a way that balances the requirements of humans and animals.

The presence of soil microbes in the soil can cause fungi to occur more frequently and gradually adapt to the allelochemical effects of IAP, reducing their allopathic effects. This can lead to the regrowth of *Shorea robusta* and

Table 1 Distribution and threatened invasive alien plant species found in terrestrial ecosystem of protected area

Protected area	Area (km^2)		Number of IAP in protected area	Most threatened IAP in protected area	Impact ecosystems		
	Core area	Buffer zone area			Forest	Grass land	Agriculture land
Banke National Park	550	343	13	*Lantana camara*	O	O	
Bardiya National Park	968	327	12	*L. camara*	O	O	
Chitwan National Park	953	729	16	*Mikania micrantha*	O	O	
Khaptad National Park	225	216	2	*L. camara, A. conyzoides*		O	
Langtang National Park	1,710	420	NA				
Makalu Barun National Park	1,500	830	NA				
Parsa National Park	627	285	14	*Chromolaena odorata, L. camara*		O	
Rara National Park	106	198	NA				
Sagarmatha National Park	1,148	275	NA				
Shey Phoksundo National Park	3,555	1,349	NA				
Shivapuri Nagargun National Park	159	119	12	*L. camara, A. adenophora, P. hysterophorus, B. pilosa*		O	
Shukla Phanta National Park	305	244	16	*L. camara*		O	
Annapurna Conservation Area	7,629		8	*A. adenophora, C. odorata, A. houstonianum*	O	O	
Api nampa Conservation Area	1,903		10	*A. adenophora, A. conyzoides, L. camara, P. hysterophorus*	O		O
Gaurishankar Conservation Area	17		7	*L. camara*	O		
Krishnasaar Conservation Area	2,035		4	*P. hysterophorus, S. tora, I. carnea, L. camara*		O	
Kanchanjunga Conservation Area	1,663		3	*A. adenophora, A. conyzoides, B. pilosa*	O		
Manaslu Conservation Area	2,179		NA				
Koshi Tapu Wildlife Reserve	349		17	*M. micrantha, C. odorata*		O	
Dhorpatan Hunting Reserve	1,325		NA				
Total					7	10	1

IAP: invasive alien plant species; NA: not available.

the loss of native species, such as *Pinus* and *Alnus* forests, as well as the degradation of forest habitat (Shah et al. 2020; Shrestha 2019a; Singh and Ghimire 2022).

Ageratina adenophora effects on species richness, composition and diminishing food availability for the wild animal as well as livestock therefore fodder collection time is increased. This ecosystem is important for the specifically wild animal which is degrading day by day (Shrestha et al. 2019a). Upward shifting of IAP due to climate change process which may be adversely impact on wildlife habitat of endangered animal species such as *Moschus chysogaste* and *Ailurus fulgens* in Langtang National Park (Lamsal et al. 2017; Poudel et al. 2020).

Ageratum conyzoides are found in forest, grasslands and agricultural ecosystem (Singh and Ghimire 2022). The IAP contributed to degrade agricultural and quantity and quality of crop (Baral et al. 2022; Shrestha et al. 2019a). Moreover, *A. conyzoides* harmful to animal due to poisoning, and biodiversity loss in forest (Singh and Ghimire 2022). Allelopathic effects lower agricultural output and biodiversity because they cannot suppress the famous *A. conyzoides* species, which produces low quality of seeds and germinating capacity cause lower the agricultural output due to alleopathic effects (Pertin et al. 2018).

Ageratum houstonianum distribute on grasslands and agro-ecosystems and forest with under high tension line (Panedy et al. 2021; Sapkota et al. 2023). The IAP and its toxic capacity the animal and livestock are in threat (Bhatta et al. 2022; Pertin et al. 2018; Sapkota et al. 2023; Shrestha et al. 2019a). The wild animal is in vulnerable condition in the forest ecosystem (Chaudhary et al. 2020; Lu et al. 2014).

Argemone mexicana are found in agricultural and forest land therefore its harmful effect can be seen on plant and animal habitat in the form of increasing crop loss, decrease production, risk to biodiversity (Shah et al. 2020). As shown by (Namkeleja et al. 2014), the growth of wild plant species is noticeably obstructed in wildlife-protected regions.

Biden pilosa is found in agro-ecosystems and grasslands (Shrestha 2016); Singh and Ghimire (2022), confirm its spreading inside agricultural fields. Due to the occurrence of allopathic content, this species, which has a high richness and dispersal capacity, adversely impacts the growth and of native species in the Siwalik region (Joshi 2019). Specifically, in the *Terminalia-Shorea-Trewia* mixed population in Nepal's far west, there is a higher than average occurrence of these IAP (Sapkota et al. 2023).

Chromolaena odorata stands out as one of the most challenging IAP in Nepal, listed among the hundred problematic species globally; this resilient species is pervasive, spanning various ecosystems such as forests, shrub land, grasslands, and agro-ecosystems. Notably, it exhibits high richness in areas disturbed by human activities, including roadsides, park headquarters, range posts, and settlements, as evidenced by the studies conducted by (Bhatta et al. 2020; Chaudhary et al. 2020). The impact of *C. odorata* extends to the determent of native species richness, composition, and regeneration, particularly affecting species like *S. robusta* in the tropical forests of Nepal, according to research by Thapa in 2016. Furthermore, its adverse effects are evident in the declining populations of ungulates, such as deer and wild pigs, in various National Parks. These invasive species alter grassland quality, replacing native plant species in Chitwan National Park (Adhikari et al. 2022; Gorchov et al. 2021). Similarly, the prime habitat of the one-horned rhinoceros in Bardiya National Park in the southwest region of Nepal faces a significant vision by *C. odorata*, as highlighted in the study by Bhatta et al. (2020).

Lantana camara stands out as one of the most troublesome species identified in protected areas of Nepal, particularly impacting Bardiya National Park in the Western Terai region. Renowned for providing habitat to iconic wildlife species such as the Asian elephant (*Elephis maximus*), the one-horned rhinoceros (*Rhinoceros unicornis*), the Bengal tiger (*Panthera tigris*), Leopard (*Panthera pardus*), and various deer species (Prins et al. 2022), Birdiya National Park faces severe invasions by *L. camara*. Invasive alien plant species have been documented within this habitat, with *L. camara*, *C. odorata*, and *A. houstonicneum* being the most heavily invaded within the park. These IAP significantly contribute to diminishing the richness and diversity of native plant species (Bhatta et al. 2020, 2021). Similarly, Suklaphanta National Park, with sixteen recorded IAP, experiences degradation due to alterations in grass species, negatively impacting grassland ecosystems (Bhatta et al. 2021; Bhattarai 2012). This alteration affects the vital habitat of *P. tigris*, *R. unicornis*, and *Servus duvauceli*. Banke National Park is also invaded by thirteen IAP, including *L. camara*, acting as a primary contributor to the degradation of wildlife habitats for species like *P. tigris*, *Elephas maximus*, and four-horned antelope in grassland ecosystem (Napit 2015). *Lantana camara* is identified as one of the most destructive IAP in Parsa National Park, among fourteen others, causing a decline in tree species and adversely impacting tree regeneration in settlement areas (Chaudhary et al. 2020). Grass species play a crucial role in maintaining ecosystem balance and are vital for the survival of herbivorous animals in Shivapuri Nagarjun National Park. Invasive alien plant species, notably *L. camara*, pose a threat to preferred grass species like *Saccharum spontaneum* and *Cynodon dactylon*, leading to increasing degradation of grasslands and posing a threat to biodiversity, agriculture, and livestock in agro-ecosystems (Bhatta et al. 2021; Shah et al. 2020). In Krishnasaar Conservation Area, *L. camara* is identified as a threat to palatable grass species vital for the Blackbuck (Krishnasaar) habitat, causing degradation in the grassland ecosystem (Bhatta et al. 2021; Gyawali et al. 2020). In addition that, degrading prime habitats for the endangered Red panda (*Ailurus ful-*

gns) and native species are documented (Bhatta et al. 2021). Similarly, Khaptad National Park records the presence of *L. camara*, which can potentially degrade the medicinal herb habitat, emphasizing this invasive species' far-reaching impact on diverse ecosystems.

Mikania macrantha also stands out as one of the most problematic invasive species globally, numbering among hundreds. It poses a significant threat in Nepal, particularly in Chitwan National Park, where it heavily invades wildlife habitat. Sixteen IAP are identified within this habitat, with *M. macrantha* being one of the important IAP (Bhatt et al. 2021). Chitwan National Park, Nepal's first established park and a designated World Heritage and Ramsar Site, is crucial for sheltering endangered species such as *R. unicornis*, *P. tigris*, and the *Gharial crocodile*, making it a prominent tourist destination (Ministry of Culture Tourism and Civil Aviation Planning and Evaluation Division 2013). Research by Murphy et al. (2013) indicated that *M. macrantha* negatively impacts on habitat of the endangered one-horned rhinoceros in Chitwan National Park, affecting 44% of their habitat by suppressing grass growth and tree regeneration. In the terrestrial ecosystem of Chitwan National Park, *M. macrantha* is identified as the most severe weed that extends to the northern part of the core and buffer zone area weed as IAP (Poudel et al. 2019). *Mikania macrantha* is invasive and affects vegetation structure and carbon sequestration in ecosystems (Ulak et al. 2016), creating an unfavorable environment for the growth of native species. The aggressive colonization of this weed inhibits the regeneration and growth of local species in the altered microhabitats, significantly impacting forest regeneration and carbon stock (Gaudel et al. 2016a, 2016b; Ulak et al. 2016). In the Terai and Siwalik region, the prime habitat of rhinoceros and ungulates, *M. macranths* are highly detrimental (Bhatt et al. 2021; Murphy et al. 2013). Beyond Chitwan National Park, *M. macrantha* effects can be found in Shuklaphanta National Park. Here, it is a serious threat to grass species and may soon have an influence on habitat of deer. Grass species have a critical role in preserving the equilibrium of the ecosystem, especially in the food chain that supports herbivorous animals like the deer. The possible harm to the environment is further highlighted by the high risk of IAP species affecting highly desired grass species as *S. spontaneum* and *C. dactylon* (Bhatt et al. 2021).

Amaranthus spinosus has the potential to disturb native plants and degrade forest habitats (Shrestha 2016). *Erigeron karvinskianus* has been shown to affect native species and soil qualities. It is found in a variety of environments, such as forests, shrublands, grasslands, and agro-ecosystems (Bhatta et al. 2021; Shrestha 2016). *Xanthium strumarium* is an impact on native species, vegetation structure, and composition, although detailed information is limited (Shah et al. 2020).

Galinsoga quadriradiata is observed only few impacts on the agro-habitat (Shrestha 2016). *Mimosa pudica*, *Senna occidentalis*, *Oxalis latifolia*, and *X. strumarium* are least impactful IAP found in forests, directly influencing nearby vegetation (Neupane and Acharya 2019; Singh and Ghimire 2022). Summarize form of the IAP impact as shown in following Table 2.

Management practices of Invasive alien plant species

The management of IAP is becoming increasingly challenging due to the inadequacy of prior global initiatives aimed at controlling the extent of invasion and the growing influence of globalization on trade transportation. Nepal is particularly susceptible to future IAP invasion due to a lack of scientific information and public awareness, which hampers the formulation of effective control and management policies. The invasion of IAP is predominantly observed in natural ecosystems across various altitudes, from lowlands to highlands in Nepal. This invasive phenomenon presents a significant challenge in developed nations and developing countries such as Nepal, where limited expertise and resources compound the issue. Nepal's protected areas primarily situated in the Terai, Siwalik, and Middle Mountain regions confront invasions by one or more IAP, with some identified among the world's most detrimental (Bhatt et al. 2021). Effective management is crucial for preserving the health and sustainability of terrestrial ecosystems within these protected areas. Three primary management strategies have been identified: prevention, eradication, and control (Radosevich et al. 2009). Prevention, involving strict quarantine and monitoring, is hindered by globalization and human mobility. Eradication, while theoretically effective, is rendered impossible due to the presence of IAP in limited areas. Consequently, the focus shifts to control as the primary strategy, although its efficacy is uncertain given the extensive spread of IAP.

Biological control agents play a crucial role, with Nepal currently hosting only two such agents, *Zygogramma bicolorata* Pallister and *Puccinia abrupta* var. partheniicola for *Parthenium hysterophorus* (Maharjan et al. 2021; Shrestha et al. 2015b) and *Procecidochares utilis* Stone and *Passalora ageratinae* Crous and AR wood for *A. adenophora* (Winston et al. 2014).

Interestingly, these agents entered Nepal naturally from neighboring countries instead of being officially introduced after quarantine screening (Shah et al. 2020). However, field observation reveals marginal effectiveness, emphasizing the need for a comprehensive approach. A specific study in Nepal underscores the potential of *Z. bicolorata* Pallister as an effective biocontrol agent against *P. hysterophorus*. It controls the further spread of *P. hysterophorus* in terai, siwalik and hilly region of Nepal (Shrestha et al. 2019b). The research recommends mass rearing and releasing these beetles as a viable management tool; despite

Table 2 Impact of invasive alien plant species on terrestrial ecosystem

No.	IAP in protected areas	Impact found on native tree/regeneration/wildlife habitat	Sources
1	*Ageratina adenophora*	Suitable habitat forest's edge and on abandoned agricultural land. Altered species richness. Allopathic effect on regeneration. Loss of native species. Affect an endangered animal due to degrade of wildlife habitat.	Binadi et al. 2023; Bhatt et al. 2021; Li et al. 2015; Poudel et al. 2020; Shah et al. 2020; Shrestha et al. 2019a; Singh and Ghimire 2022
2	*Ageratum conyzoides*	Found on grassland, forest and agro-ecosystem. Biodiversity loss. Livestock poisoning. Diminished agricultural production. Reduced forage supply. Negatively affect regeneration in forests and grasslands.	Baral et al. 2022; Lamsal et al. 2019; Pertin et al. 2018; Shrestha et al. 2019a; Singh and Ghimire 2022
3	*Ageratum houstonianum*	Suitable habitats are grassland, forest and agro-ecosystems. Toxic effect to livestock. Allopathic impact on crops. Risk to native species. Biodiversity loss.	Bhatta et al. 2022; Chaudhary et al. 2020; Panedy et al. 2021; Pertin et al. 2018; Sapkota et al. 2023
4	*Amaranthus spinosus*	Impact on native plant species. Degradation of the forest habitat.	Shrestha 2016
5	*Argemone mexicana*	Primarily found on agro-ecosystems. Crop loss and escalating production cost. Affect the germination and growth of native plant. Biodiversity loss.	Namkeleja et al. 2014; Shah et al. 2020
6	*Bidens pilosa*	Suitable habitat grassland, agro-ecosystem. Adversely effects on growth and germination of native species. Impact on mixed species community.	Joshi 2019; Sapkota et al. 2023; Shrestha 2016
7	*Chromolaena odorata*	Found on forest, shrubland, grassland and agro-ecosystem. Impact native species richness, composition, regeneration. Decline population of ungulates. Altered grassland quality.	Adhikari et al. 2022; Bhatta et al. 2020; Chaudhary et al. 2020; Thapa et al. 2016
8	*Erigeron karvinskianus*	Found on forest, shrub land and grassland and agro-ecosystem. Impact on the native species.	Bhatta et al. 2021; Shrestha 2016
9	*Galinsoga quadriradiata*	Suitable habitat is agro-ecosystem. Impact on agro-habitat.	Bhatt et al. 2021; Singh and Ghimire 2022
10	*Lantana camara*	Altered the plant community structure. Diminishing the species richness, diversity of the native species. Impact on regeneration and native plants. Habitat degradation for flora and fauna. Diminished on availability of food for wildlife and birds.	Bhatt et al. 2021; Chaudhary et al. 2020; Gyawali et al. 2020; Napit 2015
11	*Mikania micrantha*	Modification of native plant structure and composition of species. Effect on carbon sequestration. Impact on regeneration, protected wildlife and native biodiversity. Changes in wildlife habitat reduce tourism revenue. Impact on soil properties.	Baral and Adhikari 2017; Chaudhary et al. 2020; Gaudel et al. 2016a, 2016b; Khadka 2017; Murphy et al. 2013; Poudel et al. 2020
12	*Mimosa pudica*	Impact on native species and regeneration.	Rai and Singh 2020
13	*Oxalis latifolia*	Impact on native species, structure composition, and regeneration due to alterations in the soil's properties.	Bhandari 2019
14	*Senna occidentalis*	Impact on timber growth of native species due to the allopathic effect.	Singh and Ghimire 2022
15	*Xanthium strumarium*	Adversely affects native species, structure, and composition.	Neupane and Acharya 2019

IAP: invasive alien plant species.

this insight, practical implementation is lacking in Nepal (Gupta et al. 2021). Similarly, chemical control, another potential strategy, is hindered by financial constraints. Its feasibility is limited to high-value species in small areas, making it impractical for widespread IAP management where invasion is extensive. A comprehensive control approach, combining biological control agents, displacement by competitive plant species, and cultural, physical, and chemical measures, is essential for effective IAP management (Adkins and Shabbir 2014). Many protected areas in Nepal have already succumbed to IAP invasions, making prevention and eradication unattainable. The only viable option remains to control these invasions and curb their proliferation. In case of Nepal, the mechanical technique

has proven effective, with few accidental introductions of biological control agents reported (Shrestha 2019a). Mechanical methods, such as uprooting, manual cutting, controlled burning, removal, and plowing have been adopted (Singh and Ghimire 2022). However, manual cleaning poses challenges in grassland habitats. Therefore, biannual burning benefits herbivores for fodder, while successive fires can impede invasion. Nevertheless, uncontrolled burning and indiscriminate chopping negatively impact species composition, small species' survival, and small mammals' habitat. It is imperative to exercise caution and implement controlled burning and meticulous management practices to ensure effective grassland conservation (Adhikari et al. 2019). For instance, Chitwan National Park and its buffer zone (2018–2022) identified *M. macarantha* and *C. odorata* as the most problematic species, employing cutting and controlled burning as control methods (Chitwan National Park 2018). Only control burning is an effective management such as manual techniques in grassland ecosystems, reduces the growth of *M. macarantha* and promotes the growth of grass species (Aryal et al. 2018). The Buffer Zone Area Management Plan (2018–2022) of Parsa National Park introduced techniques such as manual removal, uprooting, and burning in both grassland and forest ecosystems (Parsa National Park 2018). Similarly, burning and uprooting were used as control methods at Bardiya National Park and its buffer zone management plan (2016–2020). Moreover, Shivapuri Nagarjun National Park, Buffer Zone, and its management plan (2017–2021) initiated control measures such as uprooting, drying, and burning. The western region and its Buffer Zone (2018–2022) faced major IAP problems, addressing them through periodic uprooting, cutting, and burning in the terrestrial ecosystem, while employing manual removal techniques in the wetland ecosystem (Koshi Tappu Wildlife Reserve 2018). The Koshi Tappu Wildlife Reserve identified IAP as a significant threat to grassland degradation and recommendations like burning, hand uprooting, and ploughing for suppression (Koshi Tappu Wildlife Reserve 2018). Similarly, bush clearance and slash-and-burn agriculture in rangelands are traditional adaptation measures to control the IAP in Langtang National Park (Barsila 2022). Central Nepal is witnessing increased invasion by *A. houstonianum,* posing a threat due to its toxic effect on livestock (Shreshta et al. 2019b). Consequently, controlling newly introduced IAP before they escalate into invasions is a crucial preventive strategy. Some protected areas, lack control management plans for IAP due to the absence of invasion reports. Relying solely on one method has proven insufficient; hence, continually adopting newer environmental techniques is imperative. Notably, research on using tools, silvicultural operations, and species-focused treatments for IAP control in protected areas is scarce. Moreover, the absence of continuous monitoring, follow-up, and budget allocation for appropriate activities hinders effective control mechanisms (Chitwan National Park 2018). The management techniques of IAP practice in Nepal are shown in Figure 1.

Use of invasive alien plant species

While IAP pose a significant threat to the valuable wildlife landscape, both within and around the protected areas, there is potential to transform these invasive plants into positive resources at the local level. The biomass obtained by removing IAP can be employed in various practical applications, including medicine, green manure, animal bedding, charcoal, fertilizer, and handicrafts, among other products (Bhatta et al. 2021; Karki et al. 2022; Shah et al. 2020). Additionally, it offers a range of forest services and goods, including animal feed, fuel wood, soil conservation, the restoration of damaged areas, and cultural values; nevertheless, these advantages are outweighed by their negative effects. This dual application not only aids in controlling the spread of IAP but also mitigates their invasive

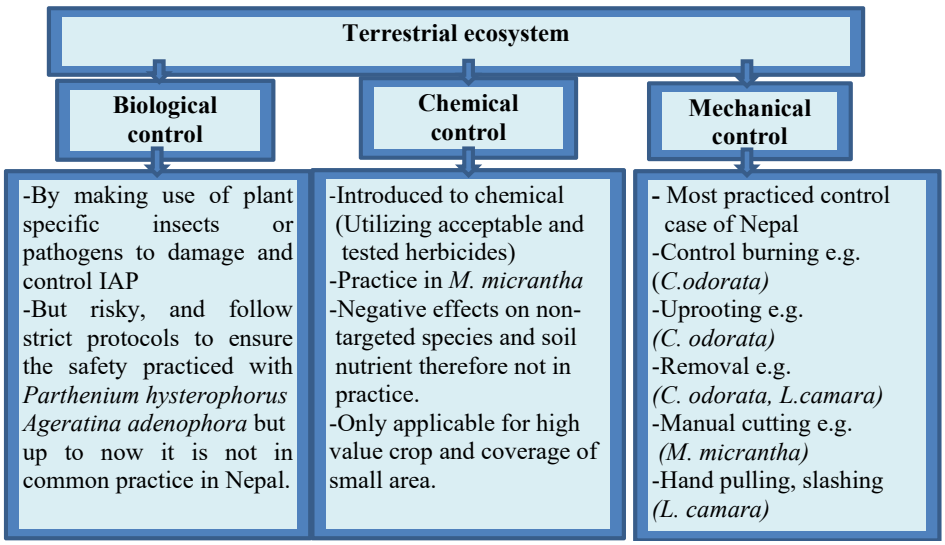

Fig. 1 Management techniques adopted to remove invasive alien plant species (IAP) in Nepal.

impact, concurrently offering valuable resources for local communities.

Ageratina adenophora is valued for its medicinal properties, particularly in wound healing and expediting blood clotting (Singh and Ghimire 2022). In Nepal, local communities utilize *A. adenophora* for cattle bedding, fodder, erosion control, hedge fencing, food (edible vegetables), composting, charcoal, green manure, and briquette production (Baral and Adhikari 2017; Baral et al. 2017; Poudel et al. 2020; Shrestha et al. 2019a, 2019b). Moreover, beyond its local applications, it serves as a source of raw materials for developing diverse antibiotics with a broad spectrum of activity, owing to the high amounts of alkaloids, saponin, tannin, and flavonoids present in the plants' phytochemical screening, which makes it valuable for pharmaceutical companies (Singh and Ghimire 2022). Globally, *A. adenophora* is recognized for its medicinal properties in treating tuberculosis and malaria (Shrestha et al. 2018; Singh et al. 2015).

The multifaceted uses of *A. conyzoides* are used as a medicinal application for treatment of cancer, burn wounds, fever, skin disease as well as agricultural functioning as an insecticide, herbicide, and contributing to the production of manure and fodder (Baral et al. 2022), essential oil and herbal medicine from its aerial parts (Satyal et al. 2018), charcoal (Bhatta et al. 2021). Its global significance extends to traditional medicine practices, where it treats burns and wounds and exhibits antimicrobial properties beneficial for conditions like arthrosis, headaches, pneumonia, and stomach ailments (Kamboj and Saluja 2008).

Ageratum houstonianum holds significance in traditional medicine practices, particularly in Nepal. Its global application extends to its medicinal use, specifically for alleviating swelling and soreness in the throat. This therapeutic use is documented in studies by Lu et al. (2014) and Chaudhary et al. (2020).

Chromolaena odorata is utilized as animal bedding, briquette, and organic manure production. The fresh juice extracted from this plant is used to control bleeding. Additionally, the mature stems are valuable resources for firewood and fencing. While it serves as fodder for goats, caution is advised against its consumption by other animals due to its toxic nature (Shilpa et al. 2020). Moreover, *C. odorata* plays a role in biogas production. On a global scale, this plant is recognized for its medicinal properties, encompassing anticancer, anti-inflammatory, wound-healing, antifungal, and anti-diabetic activities. These versatile applications and medicinal properties have been substantiated by research studies, notably by Jha et al. (2016).

Lantana camara is also utilized as a source of firewood and for crafting, briquettes, and charcoal (Bhatta et al. 2021). This plant is commonly grown as a hedge; its bark and leaves hold medicinal value. The young stems find use in tooth brushing, while the older ones are employed as firewood. As a fodder, it is very poisonous to cattle (IUCN 2018). Similarly, on a global scale, this plant finds applications in diverse industries. It is employed in producing medicine, cosmetics, and insect repellents. Additionally, it is utilized in bioenergy production and for crafting tensile sticks used in furniture, basket making, and various cottage industries. Its significance extends to butterfly gardening and honey farming (Negi et al. 2019).

Mikania micrantha is used as a fodder, green manure, and fertilizer due to its richness in phytochemicals. In eastern Nepal, compost derived from *M. micrantha* serves as livestock fodder (Shrestha 2019a). However, using IAP as fodder is problematic due to their rapid spread and adverse effects on landscapes, reducing milk yield and causing animal abdominal disorders (Baral and Adhikari 2017; Baral et al. 2022). It is also employed and planted for soil erosion control. Globally, this plant is harnessed for various purposes, acting as green herbicides, insecticides, biocides, and fungicides. Its applications extend to the paper and rubber industries, as highlighted in studies by (Mishra 2015; Shrestha 2016; Shrestha et al. 2018).

Parthenium hysterophorus is employed in Nepal for animal bedding and composting, biochar, green manure, pulp, and paper (Kishor et al. 2010; Shah et al. 2020) also, it is utilized as a medication (Kumar and Pandey 2013).

Eupatorium adenophorum is use to make a biochar, which also has therapeutic uses (Bhatta et al. 2021). Being a hemostatic, it efficiently halts bleeding from wounds and cuts. It may also be converted into organic fertilizer and used as a medication (Bhatta et al. 2021; Liu et al. 2022; Subba and Kandel 2012). It is utilized worldwide as a source for textile colors (Bhandari and Rani 2024) and produced charcoal (Bhatta et al. 2021).

Eupatorium odoratum is used for making charcoal (Bhatta et al. 2021) and textile dyes (Bhandari and Rani 2024). The IAP have both positive and negative impacts on ecosystems and livelihoods. For example, IAP supply various forest products and services, such as fuel wood, animal's bedding, soil conservation, and cultural values. However, the negative impact on ecosystems outweighs the benefits necessitating their management. The IAP adversely impact different ecosystems, requiring their removal. Park management, in collaboration with local communities in buffer zones to control and utilize IAP can transform biomass into valuable products. The potential utilization of IAP in Nepal and from a global perspective is summarized in Table 3.

Conclusions

Of twenty-seven IAP in Nepal, twenty-three IAP are found in protected areas. Most IAP are in lowland areas such as the Terai and Siwalik zones. Invasive alien plant

Table 3 Use of invasive alien plant species

No.	Invasive species	Potential uses		References
		Nepal	World	
1	*Ageratina adenophora*	Medicinal, vegetable, food, fodder, composting, cattle bedding, erosion control, hedge fencing, charcoal production, green manure, briquette.	Medicine for tuberculosis and malaria.	Baral et al. 2017; Poudel et al. 2020; Shrestha et al. 2018; Shrestha et al. 2019a; Singh et al. 2015
2	*Ageratum conyzoides*	Charcoal, extracting essential oil from the aerial parts, traditional herbal, agriculture application such as insecticides, herbicides, manure, fodder, etc.	Traditional medicine for treating of burns and wounds headaches, pneumonia, stomach.	Baral et al. 2022; Bhatta et al. 2021; Kamboj and Saluja 2008; Satyal et al. 2018
3	*Ageratum houstonianum*	Traditional medicine and therapy.	Medicine, hunting, and fishing, reduce swelling, and soreness in the throat.	Chaudhary et al. 2020; Lu et al. 2014; Singh and Ghimire 2022
4	*Chromolaena odorata*	Animal bedding, organic manure, fresh juice to control bleeding, mature stem used to firewood and fencing, fodder for goats, Biogas but poisonous to other domestic animals.	Used as a medicine with anticancer, anti-inflammatory, wound healing, antifungal, and anti-diabetic activities.	Shilpa et al. 2020; Shrestha et al. 2018
5	*Lantana camara*	Firewood, briquette, charcoal, hedge, medicine, tooth brushing, fodder.	Medicine, cosmetics, insect repellents, bioenergy, tensile sticks for furniture, basket making, cottage industry, butterfly gardening, and honey farming.	Bhatta et al. 2021; Negi et al. 2019; Shah et al. 2020
6	*Mikania micrantha*	Fodder, green manure, and fertilizer, erosion control.	*M. micrantha*: green herbicides, insecticides, biocides, and fungicides used in the paper and rubber industries.	Baral and Adhikari 2017; Baral et al. 2022; Mishra 2015; Shrestha 2016; Shrestha et al. 2018; Shrestha et al. 2019a
7	*Parthenium hysterophorus*	Animal bedding, composting.	Biochar, compost, green manure, pulp, and paper.	Kishor et al. 2010; Kumar and Pandey 2013; Shah et al. 2020
8	*Eupatorium adenophorum*	Biochar, charcoal medicinal applications as a control bleeding.	Medicinal use, organic fertilizer.	Bhatta et al. 2021; Liu et al. 2022; Subba and Kandel 2012
9	*Eupatorium odoratum*	Making charcoal.	Textile dyes.	Bhandari and Rani 2024; Bhatta et al. 2021

species are shifting from lowlands to highlands due to natural causes and anthropogenic causes such as seed dispersal by wind or animals, flood, wildfire, climate change, land use change, urbanization, and tourism. Invasive alien plant species are seen as having an impact on forests and other ecosystems. It adversely affects native plant regeneration while altering ecosystem function, species composition, and wildlife habitat, affecting the socioeconomic life of the people. If the invasion is continued to spread, they may further contribute to the decline of biodiversity. Persistent invasions by IAP can have negative impacts on ecosystems which can increased economic costs. Removing the IAP from forests, grasslands, and agricultural land is necessary to save native species, regeneration, and biodiversity from the precious wildlife habitat. However, due to some economic benefits of the IAP, it can be used to produce valuable products such as biochar, bio briquette, traditional medicine. Therefore, scientific knowledge and appropriate management plan for IAP are necessary. Management actions such as habitat management, native plant restoration, quarantine measures, regulation and monitoring, early detection and rapid response and activities to increase public awareness and education are important with the co-ordination and collaboration among stakeholders.

For future research, it is needed to evaluate the impact on IAP in different forest types and landscapes. Invasive alien plant species impact are seen in different ecosystem and which impact mechanisms such as competition, physical, structural effects might vary among ecosystems and habitats. In additions, the effectiveness of management measures related to IAP removal tools, techniques, and protocols are necessary. Beneficial use of IAP biomass at a local level are needed to be indentified. This systematic review suggested that that the science and practice of forest management must be more closely integrated to address this difficulty.

Abbreviations

NepJOL: Nepal Journal online database
IAP: Invasive alien plant species
CBD: Convention on Biological Diversity
PQPMC: Plant Quarantine and Pesticide Management Centre
IPPC: International Plant Protection Convention
IUCN: International Union for Conservation of Nature
CFUG: Community Forest User Group
BZCFUG: Buffer Zone Community Forest User Group
NBSAP: National Biodiversity Strategy and Action Plan

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Authors' contributions

SD, NY, SS conceptualized and designed methodology. SD analysed data and performed investigation. SD, NY, SS validated the data and results. SD wrote original draft. SD, NY, SS reviewed and edited the manuscript. NY, SS supervised this project. SD, NY, SS provided funding. All the authors have read and agreed to published version of the manuscript.

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Availability of data and materials

All data reviewed in this study are available from the corresponding author on request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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