Final Report

on

# Distribution and Impacts of Major Invasive Alien Plant Species in Gandaki Province

*Photo: Nischal Sedhain*

Provincial Government

Ministry of Forest, Environment and Soil Conservation

**Forest Research and Training Centre**

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# Acronyms and abbreviations

| | |
|---|---|
| ASL | : Above sea level |
| AUC | : Area under the reciver operating characterstatics curve |
| CF | : Community forest |
| CFUG | : Community forest users' group |
| FGD | : Focused group discusion |
| IAPS | : Invasive alien plant species |
| MIROC | : Model for interdisciplinary research on climate |
| SDM | : Speceis distribution model |
| SSP | : Shared socio-economic pathways |
| TSS | : True skill stasticts |
| VIF | : Variation inflation factor |
| USGS | : United States Geological Survey |

# Executive summary

Biological invasion is one the major environmental problems at all levels of spatial, geographic and political (jurisdictional) scales with range of impacts on biodiversity, agriculture production, livelihood, health and economy. The problem of biological invasions is ever increasing with rising and diversified global trade and travel. Other components of global environmental changes such as land use and land cover change, climate change, and pollution have further augmented the invasion process. In recent decades, Nepal is also witnessing a rising number of invasive alien plant species (IAPS), expansion of IAPS in to new areas, and increasing negative impacts on biodiversity, ecosystem services, wildlife habitat, agriculture production and human health. These changes and impacts have been also anticipated and observed in Gandaki Province.

Located in central Nepal, the Province is rich in floral and faunal diversity, including many endemic and threatened species.A few previous studies have shown that the IAPS already have a range of impacts on biodiversity and livelihoods, and a large proportion of the region within Gandaki Province is suitable for noxious invasive weeds. However, these data are not adequate to inform decisions for the management of IAPS in the Province. In specific, there is lack of district level data on diversity, distribution and impacts of IAPS in Gandaki Province which are essential to formulate management strategies at district to province levels. In this context, the present study was accomplished with following objectives:

- To document diversity of IAPS in the Gandaki Province and prioritize six major IAPS.
- To analyze current and future potential distribution of the selected six IAPS.
- To document environmental and socio-economic impacts of the IAPS.
- To identify the methods of community practices of IAPS management.
- To suggest preventive and control measures for major IAPS.

Primary data were collected through Focused groupd discussions (FGD) among users of the Community forests (N = 18) and distribution mapping of IAPS in selected grids (25 $km^2$, N = 56). Following information were collected during the FGDs: level of awareness on plant invasions, occurrence of IAPS in habitats managed by local communities, list of five most problematic IAPS, and management and utilization of IAPS by local communities. During the distribution mapping, 268 plots (25 $m^2$) were sampled in 56 grids to record the occurrence of IAPS, their cover, impacts, habitat type, and geographic coordinates of the plots. Six priority species were identified by scoring method that combined community perceptions, species status in national and global context, and experts' opinions. Distribution maps of all IAPS were prepared by combining primary data collected during the present study with secondaray data available from previous studies and publicly available database. Climatically suitable areas of six priority species were

predicted under current and future climate scenario (Shared Socioeconomic Pathway, SSP 2-4.5 for 2050) using occurrence data and bioclimatic variables (obtained from WorldClim) in MaxEnt modelling platform. Management options were identified based on the results of present study and review of literature including various management strategies.

Twenty five IAPS were known to have invaded various habitats in Gandaki Province that account formore than 80% of the IAPS reported in Nepal. Five of the six globally noxious IAPS present in Nepal (*Chromolaena odorata, Lantana camara, Leucanena leucocephala, Mikania micrantha* and *Pontederia crassipes*)were also invading various ecosystems of Gandaki Province. The number of species in each district ranged from 3 (Mustang) to 23 (Kaski) and the districts having the high number of the IAPS (>15 species) included Kaski, Nawalpur, Tanahun and Gorkha. Species like *Ageratina adenophora,Bidens pilosa* and *Galinsoga quadriradiata* were found in all districts whereas species like *Argemone mexicana* was found in a single district (Nawalpur).*Ageratum houstonianum* was the most frequently recorded IAPS in plots followed by *Bidens pilosa, Ageratina adenophora, Chromolaena odorata* and *Parthenium hysterophorus*.The six prioritized species identified for Gandaki Province included *Ageratum houstonianum, Ageratina adenophora, Chromolaena odorata, Mikania micrantha, Parthenium hysterophorus* and *Lantana camara*. Among them, *Ageratina adenophora, Ageratum houstonianum, Chromolaena odorata* and *Parthenium hysterophorus* were currently widespread whereas other two species *Lantana camara* and *Mikania micrantha* had limited distribution. Climatically suitable areas of these IAPS under current climate was predicted to range from 7% (*Mikania micrantha*) to 36% (*Ageratina adenophora*) of the total area of Gandaki Province. In the future (2050), climatically suitable areas of all species were predicted to increase and it varied from 3% for *Chromolaena odorata* to 65% for *Mikania micrantha*. Consultation with local communities and direct observations revealed that the IAPS had increased weed problems in farmlands, suppressed other useful species and reduced tree regeneration. Some of the IAPS were utilized by local communities as composting materials, livestock feed, herbal medicine and vegetable. Common methods of IAPS management practiced by local communities included uprooting and buring, utilization of biomass for composting, burying and herbicide uses. Most of the Community forests included in this study had not included IAPS management components in Operational plans of the forests they are managing. The participants of the FGDs informed that they had not received any information and educational materials from the government and other institutions on the IAPS problems.

Various management options have been identified depending on the species in question, invasion stage, dispersal pathways, and invaded habitats as summarized below:

- Prevevntion of species (*Sphagneticola trilobata, Mimosa diplotricha, Myriophyllum aquaticum, Tithonia diversifolia* and *Erigeron karvinskianus*) that are currently absent in Gankaki province but have already invaded other regions in Nepal
- Eradication of satellite populations of *Mikania micrantha, Lantana camara* and *Parthenium hysterophorus* in their invasion fronts to prevent their further spread.
- Eradication of *Pontederia crassipes* and *Pistia stratiotes*from wetlands including Ramsar sites
- Ban on cultivation of *Pontederia crassipes, Pistia stratiotes*and *Lantana camara* in ornamental gardens; deprioritization of *Leucaena leucocephala* in plantation and agroforestry activities.
- Mass rearing of a biological control agent (*Zygogramma bicolorata*) against *Parthenium hysterophorus* and release in to the invaded sites.
- Selective removal of target IAPS with minimum damage to other species during silvicultural practices in community managed forests.

The problem of plant invasion is likely to increase the further in future due to, among others, the high probability of introduction of additional IAPS, expansion of currently established IAPS to new locations and increase in climatically suitable areas as a result of climate change. Furthermore, there is a lack of government strategy and institution at the national and province level to guide and coordinate IAPS management activities at various goverment levels. Participation of local communites is indispensable for effective management of IAPS but their participation can be anticipated only when communities are informed and educated adequately, effectively and timely. There are data gaps but the current knowledge is adequate for the national and province level governments to initiate prevention and control programs targeting priority species identified in this research. There are opportunities for prevention, eradication and containment of some IAPS in Gandaki Province but such opportunities will be lost over the time if no action is taken on time. Timely implementation of management options identified in this research not only deliver benefits to local communities but also helps to meet several national (e.g. National Biodiversity Strategy and Action Plan) and global goals/targets (e.g. Sustainable Development Goals, targets of Post-2020 Global Biodiversity Framework of the Convention on Biological Diversity) related to biodiversity conservation and sustainable development.

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# 1. Introduction

## 1.1 Background

Biological invasions is one of the five major impacts that human has on earth's environment (IPBES 2019). International trade and travel are the major drivers of biological invasions at global scale while other factors such as land use and land cover change, climate change, pollution also promote invasions at regional and local levels (Hulme 2021). The number of alien species has been increasing continuously without any sign of saturation suggesting that the it will continue to increase in future too unless stringent measures are implemented to prevent and control them (Seebens *et al*. 2017). Similarly, more than 13,000 species of plants are reported to have established outside of their native range and their number is relatively high in regions with high economy such as North America, Europe, East Asia (particularly Japan) and Oceania (particularly Australia and New Zea Land) (van Kleunen *et al*. 2015). The International Union for Conservation of Nature (IUCN) has prepared a list of 100 of the globally worst invasive alien species (IAS) which includes 37 land and aquatic plants (Lowe *et al*. 2000, Luque *et al*. 2014). Among these 37 plant species, at least 21 species are invasive in Asia with 17 species in South Asia (Shrestha *et al*. 2022).

The IAS have been attributed for the loss of biodiversity, change in ecosystem process and services, degradation of the natural habitats, reduction in agriculture productions, among others.For example, the IAS are second most common threats associated with the species that have gone extinct since 1500 AD (Bellard *et al*. 2016). Economic cost of prevention, control and impacts of IAS is massive and increasing every next year/decade (Diagne *et al.* 2021). Similarly, forest sector is being affected severely due to threat of IAS worldwide (FAO, 2020), leading to loss of biodiversity and change in ecosystem functions (Linders *et al*. 2019). These impacts of the invasive alien species are pervasive from local, regional to global levels. Considering the extent of the impacts that IAS have on diverse sectors including biodiversity, the Aichi Biodiversity Target 9 of the Convention on Biological Diversity (CBD) call upon for the identification of the priority IAS, their prevention through management of their introduction pathways, and reduction of their impacts through control measures (https://www.cbd.int/sp/targets/). Prevention and control of the IAS is also an important target (Target 15.8: "introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species")of the United Nation Sustainable Development Goal

15 (https://sdgs.un.org/goals/goal15). Post 2020 Global Biodiversity Framework [Draft] of the CBD has included invasive species management in Target 6: "Eliminate or reduce the impacts caused by invasive alien species on native biodiversity, by managing pathways for the introduction of alien species, preventing the introduction and establishment of all priority invasive species, reducing the rate of introduction of other known or potential invasive species by at least 50 per cent and eradicating or controlling invasive alien species" (CBD 2022). Currently, the Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Service (IPBES) is also commissioning a thematic assessment of invasive alien species and their control with a aim to inform policy decision by the governments around the world (https://ipbes.net/invasive-alien-species-assessment). Similarly, various global (e.g. McNeely *et al*. 2001) and regional (e.g. European Strategy, Genovesi and Shine 2004). Countries have either separate strategies for the IAS management (e.g. United States of America, Canada) or they have included IAS management activities in national biodiversity strategy and action plan (e.g. Nepal, India).

Biological invasions is also one of the major environmental issues in Nepal and the invasive alien plant species (IAPS) are known to have a range of impacts on biodiversity, wildlife habitat, agriculture production, and people's livelihoods (Shrestha and Shrestha 2021, Shrestha 2019). Nepal Biodiversity Strategy and Action Plan (NBSAP) (MFSC 2014) and other policy instruments of Nepal have also identified IAPS as one of the major threats to biodiversity (Siwakoti and Shrestha 2015).Nation-wide survey of priority invasive alien plant species (IAPS), publication of atlas of IAPS for easy identification, enhancement of national quarantine capacity to detect alien species in borders, implementation of community awareness programs, and initiation of biological control programs have been include in the NBSAP of Nepal as strategies to prevent and control of IAS. In Nepal, more than 180 alien plant species are naturalized and 30 of them are considered as invasive (Shrestha and Shrestha 2021, Shrestha *et al*. 2021, Shrestha *et al*., in press).Many IAPS including *Lantana camara, Chromolaena odorata, Parthenium hysterophorus* are widespread in Nepal while a few species like *Mimosa diplotricha, Sphagneticola trilobata* are confined in a small areas. Species distribution modellings have revealed that climatically suitable areas of most of these IAPS will increase in future due to climate change (Shrestha et al., 2018; Shrestha and Shrestha, 2019). These and other studies suggests that the diversity and impacts of IAPS will continuously increase unless some stringent measures are not in place to prevent their further spread and reduce their abundance through various control methods.

The IAPS has been also considered as one of the major threats to biodiversity conservation in Gandaki Province, together with other threats such as habitat degradation, land use changes and climate change.Located in central Nepal,the Gandaki Provinceis rich in floral and faunal diversity. The Province also represents a region of confluence between Eastern and Western Himalayan floristic regions. Theunique geographic position and a wide elevational and climatic gradients of the Province supports a wide range of flora and fauna, including many endemic and threatened species. A few previous studies have shown that a large proportion of the region within Gandaki Province is suitable for noxious invasive weeds such as *Ageratina adenophora* (Poudel *et al*. 2020) and *Parthenium hysterophorus* (Maharjan *et al*. 2019). The IAPS are also known to have a range of impacts on agriculture production, forage supply, forest regeneration, among others, in this region (Shrestha *et al*. 2019a). Besides this, a significant negative impacts of the IAPS on wetlands of the international significant (Ramsar site) have been also reported in Gandaki Province (Pathak *et al*. 2021a). However, these data are not adequate to inform decisions for the management of IAPS in the Province. In specific, there is lack of district level data on diversity, distribution and impacts of IAPS in Gandaki Province which are essential to formulate management strategies at district to province levels. The present study has been planned to address this data gap.

## 1.2 Objectives

The general objective of this study is to analyze diversity, distribution and impacts of invasive alien plantspecies (IAPS) in the Gandaki Province. The specific objectives of the study are:

i. To document diversity of IAPS inthe Gandaki Province and prioritize sixmajor IAPS based on their extent of occurrence and realized/potential impacts.

ii. To analyze current and future potential distribution patterns of the selected six IAPS in Gandaki Province.

iii. To document environmental and socio-economic impacts of the IAPS

iv. To identify the methods of management, control and eradication of IAPS practiced by local communities and concerned stakeholders

v. To suggest preventive and control measures for major IAPS.

# 2. Materials and methods

## 2.1 Study area

Gandaki Province is situated in central Nepal and encompasses 11 districts: Nawalpur, Tanahun, Gorkha, Lamjung, Kaski, Syanjya, Parbat, Baglung, Myagdi, Mustang and Manang (Fig. 1). There are 85 local government bodies including Pokhara metropolitan city, 26 municipalities, and 58 rural municipalities. Physiographically, the Province can be divided from south to north into four regions: Siwalik, Middle Mountains, High Mountains and High Himalaya. The total area of the Province is 21,976.34 km$^2$, i.e. 14.93% of the total area of Nepal. The elevation ranges from 93 m asl near Narayani-Gandak barrage (Nawalpur) in the south to >8000 m asl in the north (Mt. Dhaulagiri, Mt. Manasalu, Mt. Annapurna I).

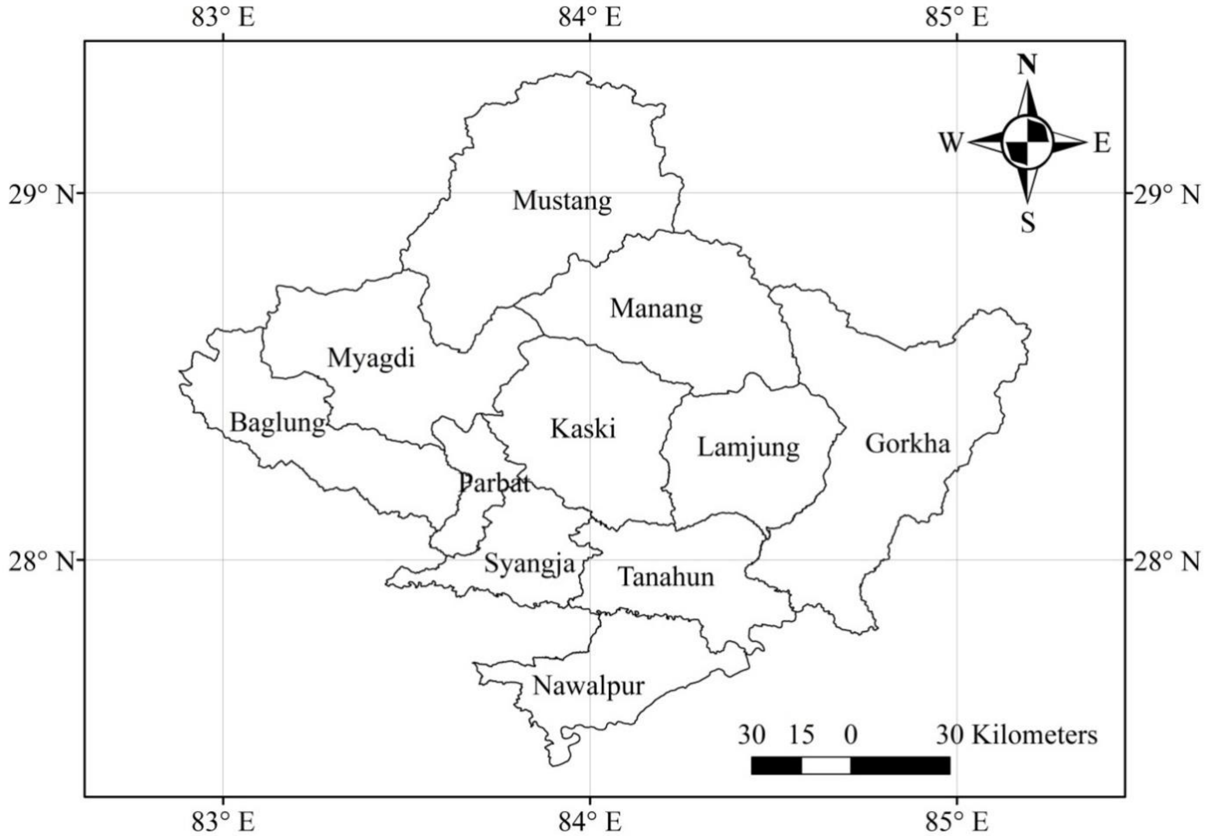



**Figure 1: District map of Gandaki Province**

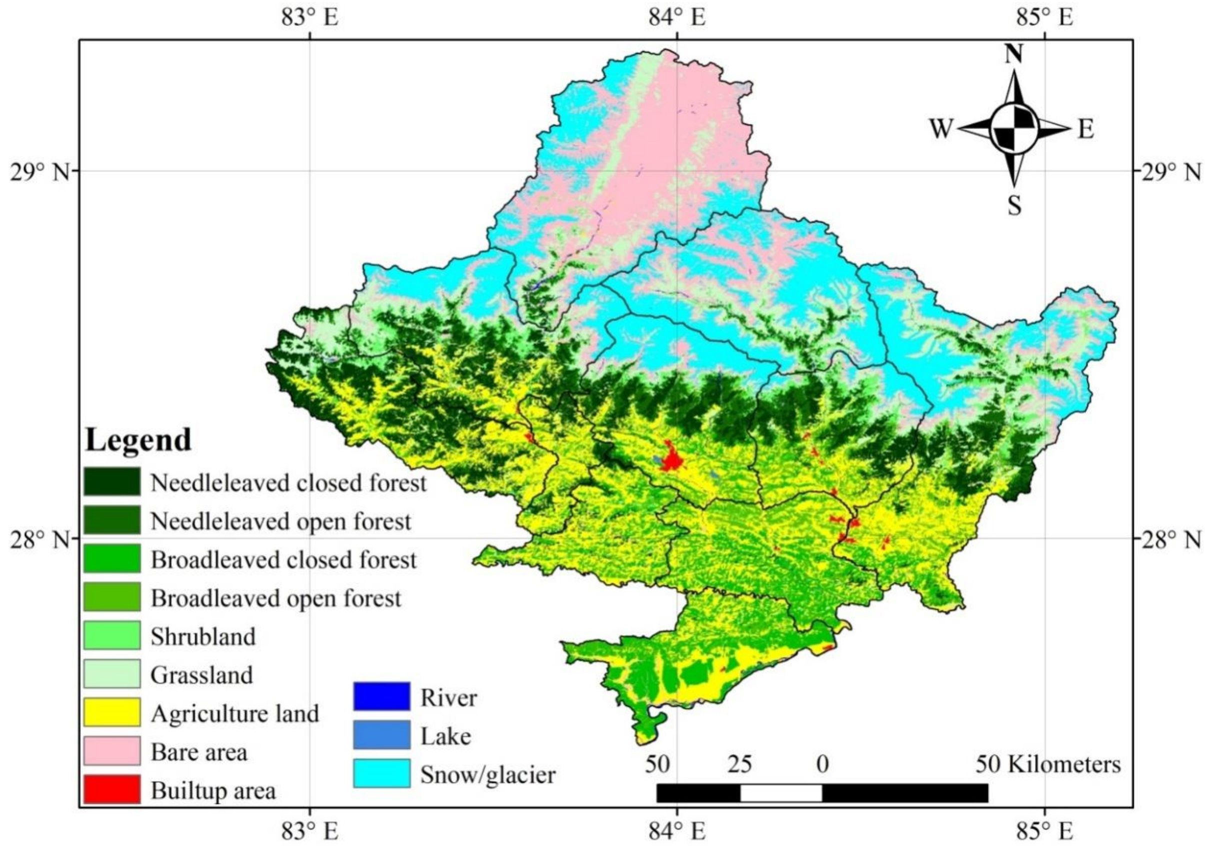



**Figure 2: Land use land cover map of Gankaki Province**
(Map source: Uddin *et al*. 2015)

The land uses on the southern half of the province mainly constitute forests and agriculture lands while bare areas and snow/glacier are the dominant land use types on northern part (Fig. 2). The vegetation ranges from subtropical seasonal dry forests (e.g. broadleaved forests such as*Shorea robusta* forests, *Dalbergia sissoo* forest) at low elevation to alpine pasture in high mountain region. Most of the region of Gandaki Province receive full influence of monsoon with some regions receiving >5000 mm annual precipitation (Lumle region of Kaski district). However, two northern districts Manang and Mustang districts lies on the rain-shadow area (north of Annapurna-Dhaulagiri mountain range); most part of these two districts are semi-arid with some regions receiving <500 mm annual precipitation. There are one national park (Chitwan national park, mainly buffer zone area), one hunting reserve (Dhorpatan, partly), two conservation areas (Manasalu and Annapurna), one Ramsar site (Lake Cluster of Pokhara valley), and one protected forest (Panchase Protected forest). Budhigandaki, Marshangdi, Madi, Seti, Kaligandakri are major rivers that drain Gandaki Province. Annapurna Conservation Area is the largest protected areas in Nepal and the number of tourist visiting this region is the highest among the protected areas in Nepal.

## 2.2 Data collection

Both secondary and primary data were used in this study. The secondary data were compiled from previous studies and biodiversity database. Primary data were collected through stakeholder consultations and field sampling.

### 2.2.1 Secondary data compilation

Occurrence data (geographic coordinates) of individual IAPS were compiled from previous studies (e.g. Maharjan *et al*. 2019, Shrestha and Shrestha 2019, Poudel *et al*. 2020, Pathak *et al*. 2021b), publicly available biodiversity database such as Global Biodiversity Information Facility (https://www.gbif.org/), and research report (e.g. FRTC 2021).

### 2.2.2 **Stakeholder consultation and group discussion**

Discussions with the concerned stakeholder such as Division Forest Offices and selected Community Forest Users Groups (CFUGs)were conducted to get preliminary information about IAPS problems in different districts.Altogether 18 Focused group discussions (FGDs)were organized among selected CFUGs in nine districts (Fig. 3, Table 1). By consulting Division Forest Offices, the CFUGs were selected based on: 1) diversity and impacts of IAPS in their forests, 2) occurrence of globally and nationally noxious IAPS, and 3) management interventions initiated by the CFUGs. In two districts (Manang and Mustang), the FGD was not conducted because a preliminary assessment revealed that there was no problem of the IAPS in these two districts. During the FGDs, we followed the methods used by Shrestha *et al*. (2019a) to document 1) awareness of communities to IAPS problems, 2) occurrence of IAPS in their locality and the habitats that the IAPS have invaded, 3) impacts of IAPS on ecosystems and livelihoods, 4) species prioritized by CFUGs for management, and 5) community practices for the management of IAPS. A semi-structured questionnaire was used to record information during the FGDs (Appendix 1).

**Figure 3: Focused group discussions conducted during the study**

**Table 1: Summary of the Focused Group Discussions organized during the study**

Details of the participants can be found in Appendix 2.

| SN | District | Locality | Name of CFUG | Number of participants (Male + Female) |
|---|---|---|---|---|
| FGD 1 | Gorkha | Ajirkot-4, Baluwa | Simjung | 5 (2+3) |
| FGD 2 | Gorkha | Palungtar-1, Satdobato | Khoplang | 6 (6+0) |
| FGD 3 | Parbat | Kusma – 11, Chapa | Sirbari | 6 (1+5) |
| FGD 4 | Parbat | Kusma – 3, Deurali (Durlung) | Jhakri Salla | 5 (4+1) |
| FGD 5 | Syanja | Kaligandaki – 1, Lehug | Private forest | 9 (2+7) |
| FGD 6 | Syanja | Putalibazaar – 12, Pelkachaur | Manakamana | |
| FGD 7 | Kaski | Pokhara Metropolitan – 23, Harpan | Bhirpani | 11 (7+4) |
| FGD 8 | Kaski | Pokhara Metropolitan – 21, Shivadhunga | Baunnelek | 6 (3+3) |
| FGD 9 | Kaski | Madi – 4, Sanke Pakha | Sanike Thaleka | 8 (8+0) |
| FGD 10 | Lamjung | Madhya Nepal – 3, Suryapal | Suryapal | 5 (4+1) |
| FGD 11 | Myagdi | Malika - 7 | Banchare | 5 (3+1) |
| FGD 12 | Baglung | Kathe Khola – 5, Thandande | Thandande | 5 (4+1) |
| FGD 13 | Baglung | Dhorpatan – 1, Khapri Bang | Turture Khani | 5 (4+1) |
| FGD 14 | Tanahun | Anbu Khaireni – 4, Aklang | Aklang | 7 (6+1) |
| FGD 15 | Tanahun | Anbu Khaireni – 3, Panighatta | Paharepaani | 5 (2+3) |
| FGD 16 | Nawalparasi | Hupsekot – 1, Beluwa Tol | Trikone | 8 (6+2) |
| FGD 17 | Nawalparasi | Kawaswoti – 15, Baghkhore | Gundrahidhakaha Buffer Zone | 5 (5+0) |
| FGD 18 | Nawalparasi | Kawaswoti – 10, Magarkot | Krishnasaar Buffer Zone | 5 (4+1) |

### 2.2.3 Distribution mapping

For distribution mapping, the Province was divided in to 5 km × 5 km (25 $km^2$) grids. Previous studies in Nepal including Gandaki Province have revealed that the known IAPS are absent at elevation >3000 m asl (Shrestha and Shrestha 2019). Therefore, the regions at elevation <3000 m asl in the district was divided in to 25 $km^2$ grids. From 475 such grids, 120 grids (>25%) were selected randomly (Fig.4).Of the selected ones, 56 grids were surveyed during the study and the remaining grids could not be included in the study due to inaccessibility of these grids through road and available time. In each grid, survey of IAPS was done along road network at an interval of 1km distance by sampling 25 $m^2$ (5 m × 5 m) plot. Altogether 268 plots were sampled covering all 11 districts of the Province (Appendix 3). In addition different habitats such as forests, shrubland, grassland, wetlands and agriculture lands were also visited to record the occurrence of the species. At each survey location (plot), we recorded: 1) IAPS and their cover, 2) geographic coordinates, 3) land use, 4) human disturbance, and 5) any visible impact of IAPS on native species. The data sheet that was used in this mapping has been included in Appendix 4.

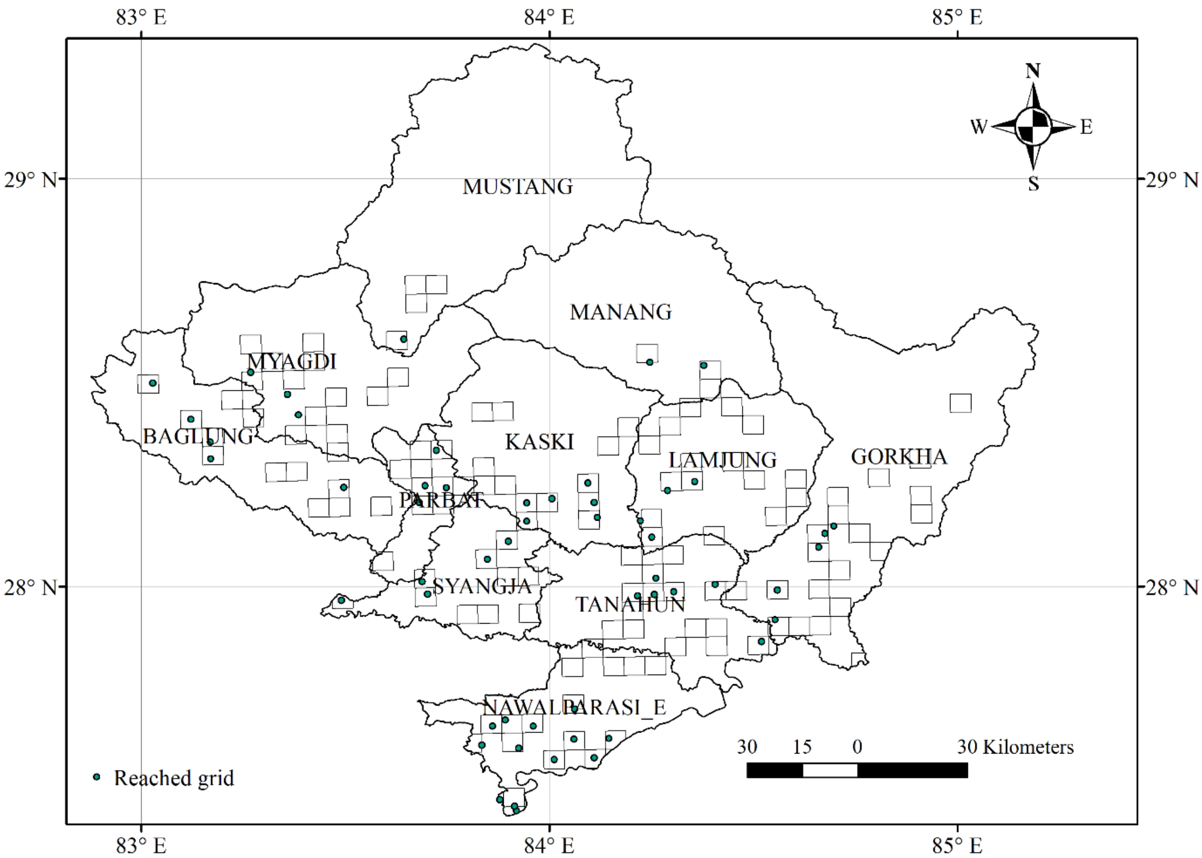



**Figure 4: Division of areas below 3,000 m asl in Gandaki Province in to 25 $km^2$ grids**

## 2.3 Prioritization of six species

Based on the community perceptions of the impacts of IAPS, their spatial distribution in Gandaki Province, and previous national (Adhikari *et al*. 2022) and global assessments (Lowe *et al*. 2000), six most problematic IAPS were identified as priority species for distribution modeling. Opinion of experts were solicited during the selection of six priority species. The prioritization mainly followed the scoring method used by Shrestha *et al*. (2019a). During the FGDs, participants were asked to list five most problematic species in decreasing order considering their impacts and management needs (position 1: the highest priority; position 5: lowest priority) (see Appendix 1 for the questionnaire). Then, the species ranked first was given a score of 5, second 4, third 3, fourth 2 and fifth 1. The score values were standardized and the score percentage of each species was calculated following Shrestha *et al*. (2019a). Then, the community score was given 80% weightage. Additional 10% weightage was given to species categorization at national level (Adhikari *et al*. 2022). The IAPS of Nepal were also grouped in to five different categories (Minimal concern, Minor, Moderate, Major and Massive) by Adhikari *et al*. (2022) which followed IUCN Environmental Impact Categorization of Alien Taxa (IUCN 2020). Species categorized as Massive was given score 10, Major 8, Moderate 6, Minor 4 and Minimal concern 2. The remaining 10% weightage was given to the global assessment: score 10 if included in the 100 of the world's worst invasive alien species (Lowe et al. 2000) and 0 if not. From this scoring exercise, the IAPS were ranked in a decreasing order of the score percentage and following were the five top ranked species: *Ageratum houstonianum, Ageratina adenophora, Chromolaena odorata*, *Bidens pilosa* and *Mikania micrantha*(See Result section for details). Though *Bidens pilosa* was ranked fourth, the species was not selected for modelling because it is palatable to animals (livestock and wildlife) and thus deprioritized based on expert opinions. Instead, *Parthenium hysterophorus* was selected considering its widespread occurrence in Nepal including Gankari province (Shrestha *et al*. 2019b, Poudel *et al*. 2020) and ecological and socio-economic impacts at national (Shrestha *et al*. 2015) and global levels (Mao *et al*. 2021). Similarly, another species *Lantana camara* was also added in the priority list considering its widespread occurrence in Nepal (Adhikari *et al*. 2022, Shrestha and Shrestha 2019), being one of the 100 of the world's worst invasive alien species (Lowe *et al*. 2000), and ecological and socioeconomic impacts (Negi *et al*. 2019, Mungi *et al*. 2020). In this way, the final list of the priority species for further modelling was: *Ageratum houstonianum, Ageratina adenophora, Chromolaena odorata, Mikania micrantha, Parthenium hysterophorus* and *Lantana camara*.

## 2.4Distribution modelling

Species distribution modelling (SDM) utilizes bioclimatic conditions, generally referred to as environmental variables, of the locations where the species are present to predict regions with similar bioclimatic conditions. It is generally assumed that the species in question can establish in these predicted regions when their propagules are dispersed. Therefore, prediction of potentially suitable areas requires species occurrence location (geographic coordinates) and the environmental variables of these locations. This study predicted suitable areas of six priority species in the Gandaki Province.

### 2.4.1. Species occurrence data

Species occurrence data obtained from field work of the present study (for detail, refer Section 2.2.3) was combined with the secondary data (for details, refer Section 2.2.1) to prepare an updated occurrence database of the IAPS.

### 2.4.2. Environmental variables

The environmental variables were downloaded from freely available sources (Table 1) and pre-processed in ArcGIS (ESRI, 2017) to make appropriate format (ASCII) and same spatial resolution (1 km). Some variables with vector features (i.e. point and line) were also converted into raster format having the same resolution (1 km). The environmental variables were divided into two categories as follows.

#### *2.4.2.1 Bio-climatic variables*

The bio-climatic variables are biologically meaningful variables for characterising species distribution at continent-scale(Blach-Overgaard *et al*. 2015) as well as at regional scale (Kandel *et al*. 2015). Bio-climatic variables were downloaded from the WorldClim database (http://worldclim.org/). The WorldClim database (version 2) is a set of global climate layers that derived from over 4000 weather stations between 1950 and 2000, including annual time series with annual means, seasonality, and extreme or limiting temperature and precipitation data (Hijmans *et al*. 2005). In this study, 19 bio-climatic layers with a spatial resolution of 1 km were used (Table 2). Furthermore same variables of Shared Socio-economic Pathways (SSP) 2-4.5 for Model for Interdisciplinary Research on Climate (MIROC6) were obtained from WorlClim (http://worldclim.org/)to project the future suitable habitat. For the projection of future climate scenarios, the SSPs have been adopted by the sixth assessment report of the Inter-governmental Panel for Climate Change (IPCC 2021).

#### *2.4.2.2 Topographic variables*

Topographical variables were used for the habitat modelling of the species since the beginning of the century (Osborne *et al*. 2001). Digital Elevation Model (DEM) of 1 km resolution was downloaded from the website of United States Geographical

Survey(https://earthexplorer.usgs.gov/), and slope and aspect were calculated from the DEM using ArcGIS software (ESRI, 2017)(Table 2).

**Table 2: Environmental variables considered during modeling**

| Data Sources | Categories | Variables | Abbreviation | Units |
|---|---|---|---|---|
| WorldClim | Bio-climatic | Annual mean temperature | bio1 | ◦ C |
| | | Mean diurnal range (mean of monthly (max temp – min temp)) | bio2 | ◦ C |
| | | Isothermality (BIO2/BIO7) | bio3 | Dimensionless |
| | | Temperature seasonality (standard deviation) | bio4 | ◦ C |
| | | Max temperature of warmest month | bio5 | ◦ C |
| | | Min temperature of coldest month | bio6 | ◦ C |
| | | Temperature annual range (BIO5-BIO6) | bio7 | ◦ C |
| | | Mean temperature of wettest quarter | bio8 | ◦ C |
| | | Mean temperature of driest quarter | bio9 | ◦ C |
| | | Mean temperature of warmest quarter | bio10 | ◦ C |
| | | Mean temperature of coldest quarter | bio11 | ◦ C |
| | | Annual precipitation | bio12 | mm |
| | | Precipitation of wettest month | bio13 | mm |
| | | Precipitation of driest month | bio14 | mm |
| | | Precipitation seasonality (coefficient of variation) | bio15 | Dimensionless |
| | | Precipitation of wettest quarter | bio16 | mm |
| | | Precipitation of driest quarter | bio17 | mm |
| | | Precipitation of warmest quarter | bio18 | mm |
| | | Precipitation of coldest quarter | bio19 | mm |
| USGS GTOPO30 | Topographic | Elevation | elevation | m |
| | | Aspect | aspect | Degree |
| | | Slope | slope | Degree |

### 2.4.3. Distribution modeling of species

Maximum Entropy (MaxEnt) software was used to predict the current and future suitable habitat of invasive species by using the species occurrence points and environmental variables (Elith *et al*. 2006, Phillips *et al*. 2006). This tool is established as a widely used tool for predicting the distribution and habitat suitability of the species in Nepal (Aryal *et al*. 2016, Bista *et al*. 2018, KC *et al*. 2019, Panthi *et al*. 2019, Shrestha and Bawa 2014, Thapa *et al*. 2018). Only one point was randomly selected in one grid to lessen the spatial auto-correlation. Variation Inflation Factors (VIFs) of predictor variables were calculated with the help of R software (R Core Team, 2018) to avoid multicollinearity in the model.

#### *2.4.3.1 Variable selection and climate change scenario*

The study used all the variables in the model as they had VIF<10. After removing the highly correlated variables, only less correlated variables were used for the modelling (Table 3-8). A total of 70 % of the species occurrence points were allocated for the training dataset, and 30 % was used as a testing /validation dataset for all models. This study used 1,000 maximum iterations and 5,000 background points for the modeling.

Climate change may have impact on the extent of suitable areas for the invasive alien species (Hulme 2017). This study has projected the climatically suitable areas of six invasive alien plant species for 2050. Future variables of Shared Socio-economic Pathways (SSP) 2.4-5 for Model for Interdisciplinary Research on Climate (MIROC6) were used to project the future suitable habitat of these prioritized species.

**Table 3: Variables used to model the suitable habitat of *Ageratina adenophora***

| S.N. | Variables | Abbreviation | Units |
|---|---|---|---|
| 1 | Isothermality (BIO2/BIO7) | bio3 | Dimensionless |
| 2 | Temperature seasonality (standard deviation) | bio4 | ◦ C |
| 3 | Temperature annual range (BIO5-BIO6) | bio7 | ◦ C |
| 4 | Precipitation of driest month | bio14 | mm |
| 5 | Precipitation seasonality (coefficient of variation) | bio15 | Dimensionless |
| 6 | Precipitation of warmest quarter | bio18 | mm |
| 7 | Precipitation of coldest quarter | bio19 | mm |
| 8 | Elevation | elevation | m |
| 9 | Aspect | aspect | Degree |
| 10 | Slope | slope | Degree |

**Table 4: Variables used to model the suitable habitat of *Ageratina adenophora***

| S.N. | Variables | Abbreviation | Units |
|---|---|---|---|
| 1 | Isothermality (BIO2/BIO7) | bio3 | Dimensionless |
| 2 | Temperature seasonality (standard deviation) | bio4 | ◦ C |
| 3 | Temperature annual range (BIO5-BIO6) | bio7 | ◦ C |
| 4 | Annual precipitation | bio12 | mm |
| 5 | Precipitation of driest month | bio14 | mm |
| 6 | Precipitation seasonality (coefficient of variation) | bio15 | Dimensionless |
| 7 | Precipitation of driest quarter | bio17 | mm |
| 8 | Precipitation of warmest quarter | bio18 | mm |
| 9 | Elevation | elevation | m |
| 10 | Aspect | aspect | Degree |
| 11 | Slope | slope | Degree |

**Table 5: Variables used to model the suitable habitat of *Chromolaena odorata***

| S.N. | Variables | Abbreviation | Units |
|---|---|---|---|
| 1 | Isothermality (BIO2/BIO7) | bio3 | Dimensionless |
| 2 | Temperature seasonality (standard deviation) | bio4 | ◦ C |
| 3 | Temperature annual range (BIO5-BIO6) | bio7 | ◦ C |
| 4 | Precipitation of wettest month | bio13 | mm |
| 5 | Precipitation of driest month | bio14 | mm |
| 6 | Precipitation of driest quarter | bio17 | mm |
| 7 | Precipitation of warmest quarter | bio18 | mm |
| 8 | Elevation | elevation | m |
| 9 | Aspect | aspect | Degree |
| 10 | Slope | slope | Degree |

**Table 6: Variables used to model the suitable habitat of *Lantana camara***

| S.N. | Variables | Abbreviation | Units |
|---|---|---|---|
| 1 | Isothermality (BIO2/BIO7) | bio3 | Dimensionless |
| 2 | Temperature seasonality (standard deviation) | bio4 | ◦ C |
| 3 | Temperature annual range (BIO5-BIO6) | bio7 | ◦ C |
| 4 | Precipitation of driest month | bio14 | mm |
| 5 | Precipitation seasonality (coefficient of variation) | bio15 | Dimensionless |
| 6 | Precipitation of warmest quarter | bio18 | mm |
| 7 | Precipitation of coldest quarter | bio19 | mm |
| 8 | Aspect | aspect | Degree |
| 9 | Slope | slope | Degree |

**Table 7: Variables used to model the suitable habitat of *Mikania micrantha***

| S.N. | Variables | Abbreviation | Units |
|---|---|---|---|
| 1 | Isothermality (BIO2/BIO7) | bio3 | Dimensionless |
| 2 | Temperature seasonality (standard deviation) | bio4 | ◦ C |
| 3 | Temperature annual range (BIO5-BIO6) | bio7 | ◦ C |
| 4 | Precipitation of wettest month | bio13 | mm |
| 5 | Precipitation of driest month | bio14 | mm |
| 6 | Precipitation of warmest quarter | bio18 | mm |
| 7 | Precipitation of coldest quarter | bio19 | mm |
| 8 | Aspect | aspect | Degree |
| 9 | Slope | slope | Degree |

**Table 8: Variables used to model the suitable habitat of *Parthenium hysterophorus***

| S.N. | Variables | Abbreviation | Units |
|---|---|---|---|
| 1 | Isothermality (BIO2/BIO7) | bio3 | Dimensionless |
| 2 | Temperature seasonality (standard deviation) | bio4 | ◦ C |
| 3 | Temperature annual range (BIO5-BIO6) | bio7 | ◦ C |
| 4 | Annual precipitation | bio12 | mm |
| 5 | Precipitation of driest quarter | bio17 | mm |
| 6 | Precipitation of warmest quarter | bio18 | mm |
| 7 | Elevation | elevation | m |
| 8 | Aspect | aspect | Degree |
| 9 | Slope | slope | Degree |

#### 2.4.3.2 Accuracy assessment of the modeling

Assessment of the accuracy was essential to validate the models and to understand the performance of the models. The models were evaluated by two methods. One method was threshold independent, and another was threshold dependent. In the threshold independent method, the area under the receiver-operator curve (AUC) of models was reported (Phillips *et al*. 2006, Wiley *et al*. 2003). The higher the AUC, the higher the model performance was. The AUC<0.7 denoted poor model performance, 0.7–0.9 denoted moderately useful model performance, and >0.9 denoted excellent model performance (Pearce and Ferrier 2000).Although AUC is a classical and widely used model evaluation parameter, it is criticized by some researchers (Lobo *et al*. 2008). Therefore, threshold dependent accuracy assessment: True Skill Statistic (TSS) was alsoperformed for the model evaluation (Merow *et al*. 2013).TSS was calculated for all model outputs (0-9 replications), and the final TSS was averaged for all 10 replications (Jiang *et al*. 2014; Panthi *et al*. 2019). Thresholds to maximize the sum of sensitivity and specificity are recommended threshold (Liu *et al*., 2013) so it was used to calculate the TSS.

### 2.5Preparation of distribution and suitability maps

After the modeling,mapsshowing climatically suitable areas of the prioritized sixIAPS were prepared by using ArcGIS(ESRI, 2017). The output of the MaxEnt was processed to prepare the map showing climatically suitable areas of the IAPS. Thresholds to maximize the sum of sensitivity and specificity are recommended threshold (Liu *et al*. 2013).Therefore, it was used to convert the habitat suitability map (raw output of MaxEnt) and to calculate the TSS.

In addition to the climatic suitability maps of the prioritized species, distribution maps of all the IAPS recorded in Gandaki Province were also prepared using primary and secondary data.

### 2.6Identification of Impacts and Management Options

Data related to the environmental and socio-economic impacts of IAPS were collected during the FGDs and other stakeholder meetings as mentioned above. Additional data were also collected during field survey for distribution mapping. The data collected during the present study were combined with the findings of the previous studies to present a comprehensive account of the impacts of IAPS in Gandaki Province. A similar approach was used to identify suitable options for the management of IAPS. National, regional and global strategies for the management of IAPS were also reviewed during this process (e.g. McNeely *et al*. 2001, Wittenberg and Cock 2001, US Department of the Interior 2016).

## 3.Results

### *3.1 Diversity of invasive alien plant species*

Twenty-five invasive alien plant species (IAPS) were recorded in the Gandaki Province (Table 9, Fig. 5). All but one species are native of Americas; the remaining species (*Spergula arvensis*) is native of Europe. Five species (*Chromolaena odorata*, *Lantana camara, Leucaena leucocephala*, *Mikania micrantha,* and *Pontederia crassipes*) found in the Province were among the 100 of the world’s worst invasive alien species (Lowe *et al*. 2000). The number of species in each district ranged from 3 (Mustang) to 23 (Kaski) (Table 10, Fig. 6). Districts having high number of the IAPS (>15 species) included Kaski, Nawalpur, Tanahun and Gorkha. Species like *Ageratina adenophora,Bidens pilosa*and *Galinsoga* *quadriradiata*were found in all districts whereas species like *Argemone mexicana* was found in a single district (Nawalpur).

**Table 9: List of invasive alien plant species recorded in Gandaki Province**

| SN | Name of IAPS | Common name | Nepali name | Family | Native range |
|---|---|---|---|---|---|
| 1 | *Ageratina adenophora*(Spreng.) R.M.King & H.Rob. | Crofton weed | Kalo banmara | Asteraceae | Mexico |
| 2 | *Ageratum conyzoides*L. | Billygoat | Seto Gandhe | Asteraceae | Central and South America |
| 3 | *Ageratum houstonianum*Mill. | Blue-billygoat | Nilo Ghandhe | Asteraceae | Mexico and Central America |
| 4 | *Alternanthera philoxeroides*(Mart.) Griseb. | Alligator weed | Jal jambhu/Pat pate | Amaranthaceae | South America |
| 5 | *Amaranthus spinosus*L. | Spiny pigweed | Kande lunge | Amaranthaceae | Tropical America |
| 6 | *Argemone mexicana*L. | Mexican poppy | Thakal | Papaveraceae | Tropical America |
| 7 | *Bidens pilosa*L. | Hairy Beggar-tick | Kalo Kuro | Asteraceae | Tropical America |
| 8 | *Chromolaena odorata*(Spreng.) R.M.King & H.Rob | Siam weed | Seto banmara | Asteraceae | Mexico, Central and South America |
| 9 | *Galinsoga quadriradiata*Ruiz & Pav. | Shaggy Soldier | Jhuse chitlange | Asteraceae | Mexico |
| 10 | *Ipomoea carnea* subsp. *fistulosa* (Mart. ex Choisy) D.F. Austin | Bush morning glory | Besharam | Convolvulaceae | Mexico, Central and South America |
| 11 | *Lantana camara* L. | Lantana | Kirne kanda | Verbanaceae | Central and South America |
| 12 | *Leersia hexandra* Swartz. | Southern cut grass | Karaute ghans | Poaceae | Tropical America |
| 13 | *Leucaena leucocephala* (Lam.) de Wit | Subabul | Ipil ipil | Fabaceae | Mexico and Central America |
| 14 | *Mesosphaerum suaveolens*(L.) Kuntze | Bush mint | Ban silam | Lamiaceae | Tropical America |
| 15 | *Mikania micrantha*Kunth | Mile-a-minute | Lahare banmara | Asteraceae | Central and South America |
| 16 | *Mimosa pudica* L. | Sensitive plant | Lajjawati | Fabaceae | Mexico to South America |
| 17 | *Oxalis latifolia*Kunth. | Purple wood sorel | Thulo chari amilo | Oxalidaceae | Central and South America |
| 18 | *Parthenium hysterophorus*L. | Parthenium | Pati jhar | Asteraceae | Southern USA to South America |
| 19 | *Pistia stratiotes* L. | Water lettuce | Kumbhika | Araceae | Central and South America |
| 20 | *Pontederia crassipes* (Mart.) Solms. | Water hyacinth | Jal kumbhi | Pontederiaceae | South America |
| 21 | *Senna occidentalis* (L.) Link. | Coffee senna | Thulo tapre | Fabaceae | Tropical America |
| 22 | *Senna tora* (L.) Roxb. | Sickle pod senna | Sano tapre | Fabaceae | Tropical America |
| 23 | *Spergula arvensis* L. | Corn spurry | Thangne jhar | Caryophyllaceae | Europe |
| 24 | *Spermacoce alata* Aubl. | Broadleaf button weed | Alu pate jhar | Rubiaceae | West Indies and Tropical America |
| 25 | *Xanthium strumarium* L. | Rough cockle-Bur | Bhede kuro | Asteraceae | South America |


**Figure 5: Invasive alien plant species reported in Gandaki Province**
(Photo: BB Shrestha)

**Table 10: Occurrence of the IAPS in districts of Gandaki Province**

| SN | Name of IAPS | Baglung | Gorkha | Kaski | Lamjung | Manang | Mustang | Myagdi | Nawalpur | Parbat | Syangja | Tanahun |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | *Ageratina adenophora* | * | * | * | * | * | * | * | * | * | * | * |
| 2 | *Ageratum conyzoides* | * | * | * | * | | | * | * | * | * | * |
| 3 | *Ageratum houstonianum* | * | * | * | * | | | * | * | * | * | * |
| 4 | *Alternanthera philoxeroides* | | | * | * | | | | | | | |
| 5 | *Amaranthus spinosus* | * | * | * | * | | | * | * | * | * | * |
| 6 | *Argemone mexicana* | | | | | | | | * | | | |
| 7 | *Bidens pilosa* | * | * | * | * | * | * | * | * | * | * | * |
| 8 | *Chromolaena odorata* | * | * | * | * | | | | * | * | * | * |
| 9 | *Galinsoga quadriradiata* | * | * | * | * | * | * | * | * | * | * | * |
| 10 | *Ipomoea carnea* | | * | * | * | | | * | * | | | * |
| 11 | *Lantana camara* | * | * | * | | | | * | * | * | * | * |
| 12 | *Leersia hexandra* | | | * | | | | | * | | | |
| 13 | *Leucaena leucocephala* | | * | * | * | | | | * | | * | * |
| 14 | *Mesosphaerum suaveolens* | * | * | * | | | | | * | | | * |
| 15 | *Mikania micrantha* | | * | * | * | | | | * | | | * |
| 16 | *Mimosa pudica* | * | * | * | * | | | | * | * | * | * |
| 17 | *Oxalis latifolia* | * | | * | | * | * | | * | | * | * |
| 18 | *Parthenium hysterophorus* | * | * | * | * | | | * | * | * | * | * |
| 19 | *Pistia stratiotes* | | | * | | | | | * | | | |
| 20 | *Pontederia crassipes* | | | * | | | | | * | | | |
| 21 | *Senna occidentalis* | * | * | * | * | | | * | * | * | * | * |
| 22 | *Senna tora* | * | * | * | | | | * | * | * | * | * |
| 23 | *Spergula arvensis* | * | | | | | | | | * | | |
| 24 | *Spermacoce alata* | | | * | * | | | | * | | | * |
| 25 | *Xanthium strumarium* | * | * | * | * | | | * | * | * | | * |

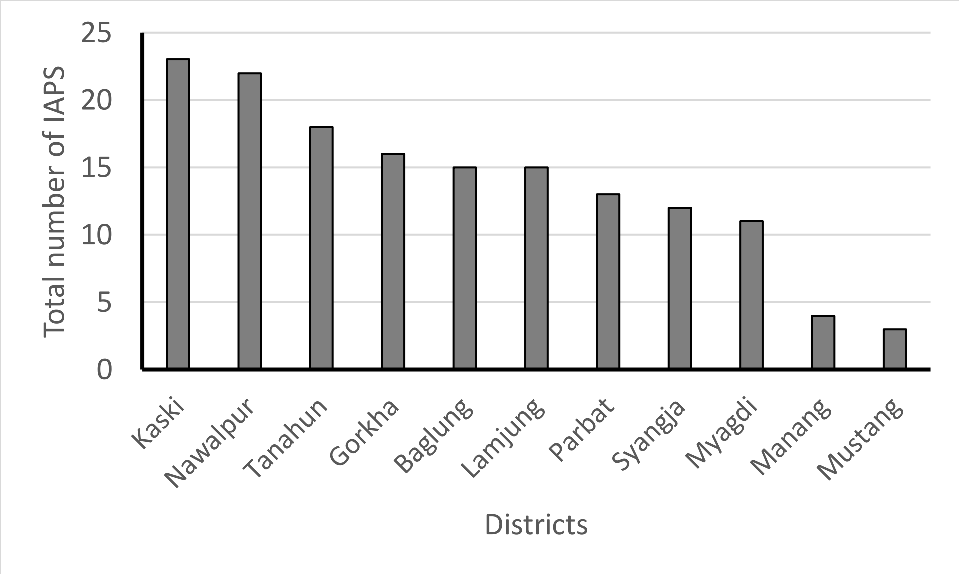



**Figure 6: Number of invasive alien species reported in each district of the Gandaki Province**

In the sample plots, 17 species were recorded (Fig. 7). Among them, *Ageratum houstonianum* was the most frequently recorded followed by *Bidens pilosa*, *Ageratina adenophora*, *Chromolaena odorata* and *Parthenium hysterophorus*; these species had frequency >10%. Species like *Amaranthus spinosus* and *Oxalis latifolia* were recorded only very less frequently. Mean species richness of IAPS varied from 1.43 (Baglung) to 2.56 species/25 $m^2$ (Nawalpur) (Table 11). Similarly, mean cover of the IAPS in the plots varied from 10 to 56%; the IAPS were absent in the plots of Manang and Mustang districts. The districts having relatively high IAPS cover (>50%) were Nawalpur, Syanga and Tanahun. Among the species, *Ageratum houstonianum* and *Ageratina adenophora* had the highest mean cover in the sample plots.

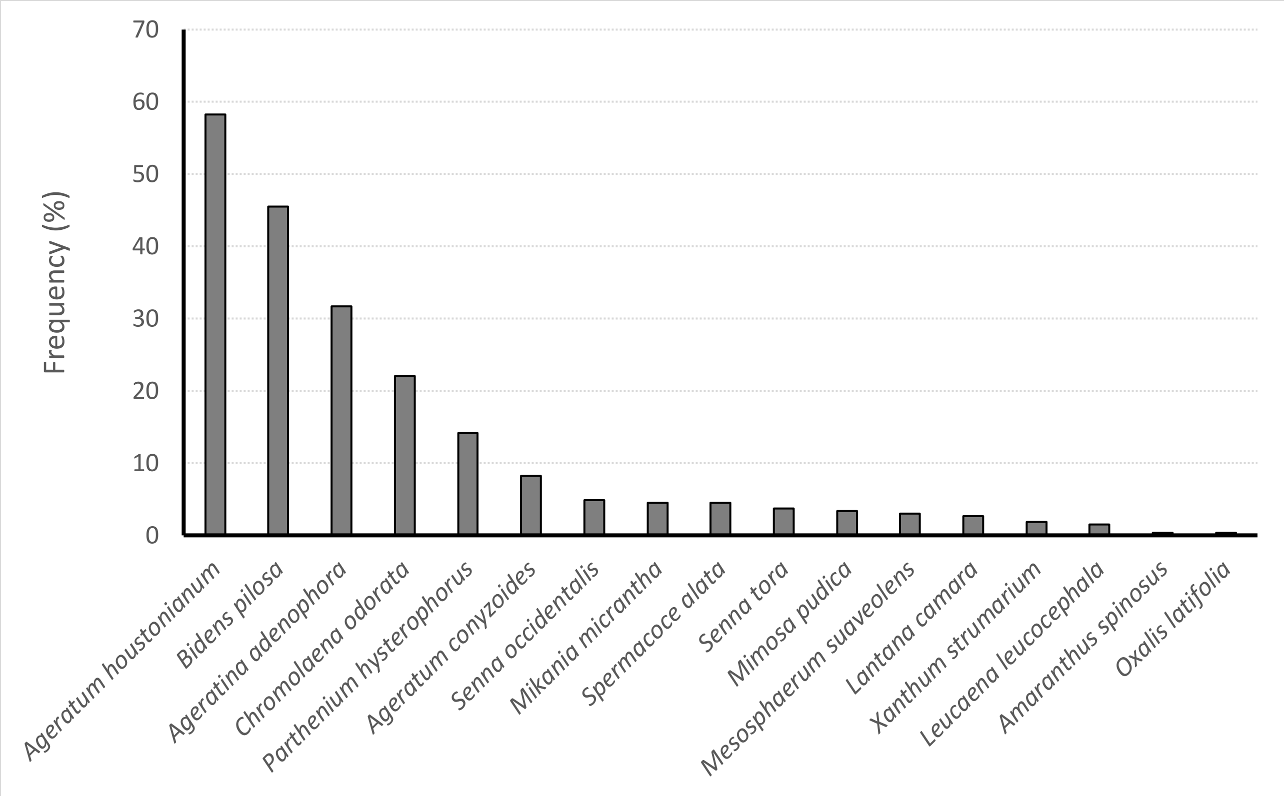



**Figure 7: Frequency of occurrence of the IAPS in sample plots**

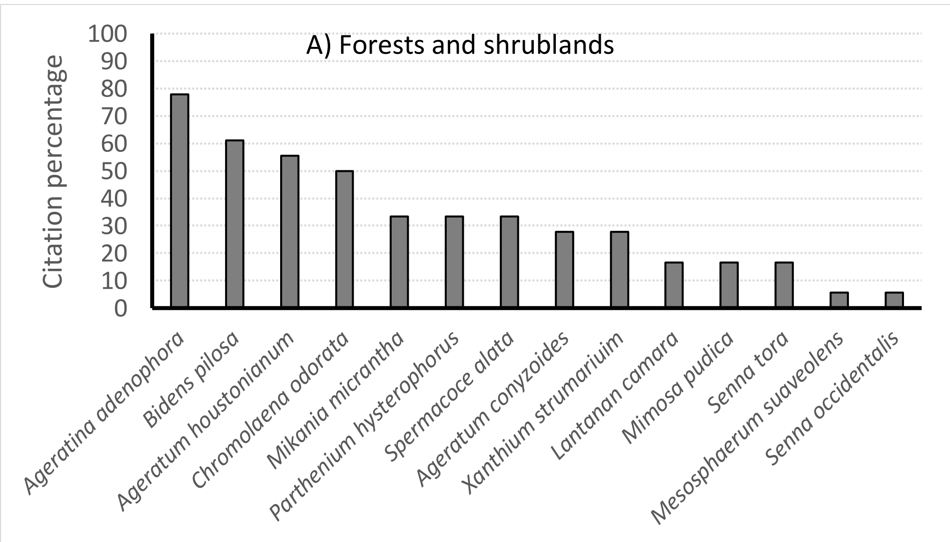
[N = 268]

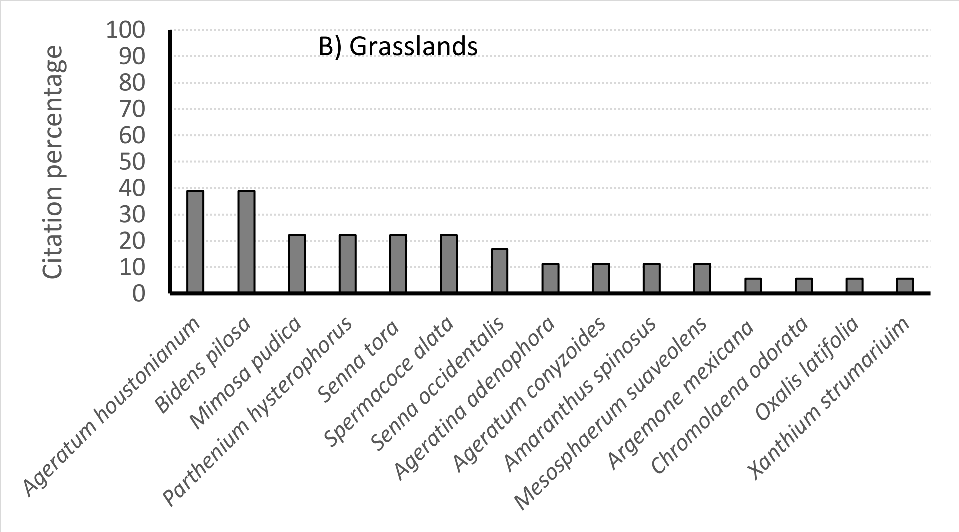
**Table 11: Species richness and cover of IAPS in plots sampled in different districts**

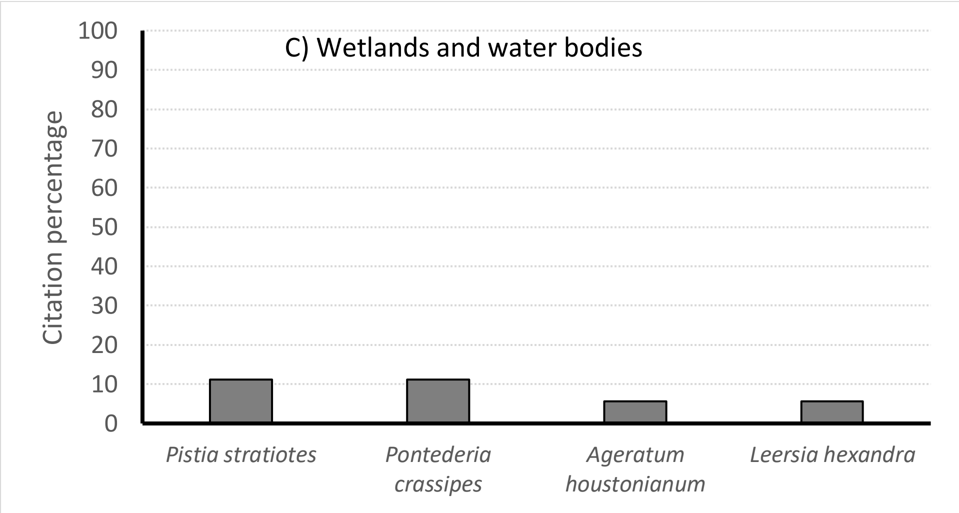
| SN | Districts | No. Plots | IAPS richness | IAPS cover (%) | Common species (Cover percentage) |
|---|---|---|---|---|---|
| 1 | Baglung | 23 | 1.43 ± 0.90 | 10 ± 9 | *Ageratina adenophora* (5%), *Bidens pilosa* (2%), *Ageratum houstonianum* (1%) |
| 2 | Gorkha | 24 | 2.08 ± 1.06 | 25 ± 16 | *Ageratina adenophora* (7%), *Ageratum houstonianum* (7%), *Partheniumhysterophorus* (6%) |
| 3 | Kaski | 37 | 2.03 ± 1.09 | 21 ± 18 | *Ageratinaadenophora* (7%), *Ageratum houstonianum* (6%), *Bidens pilosa* (4%) |
| 4 | Lamjung | 18 | 1.94 ± 0.94 | 35 ± 18 | *Ageratum houstonianum* (23%), |

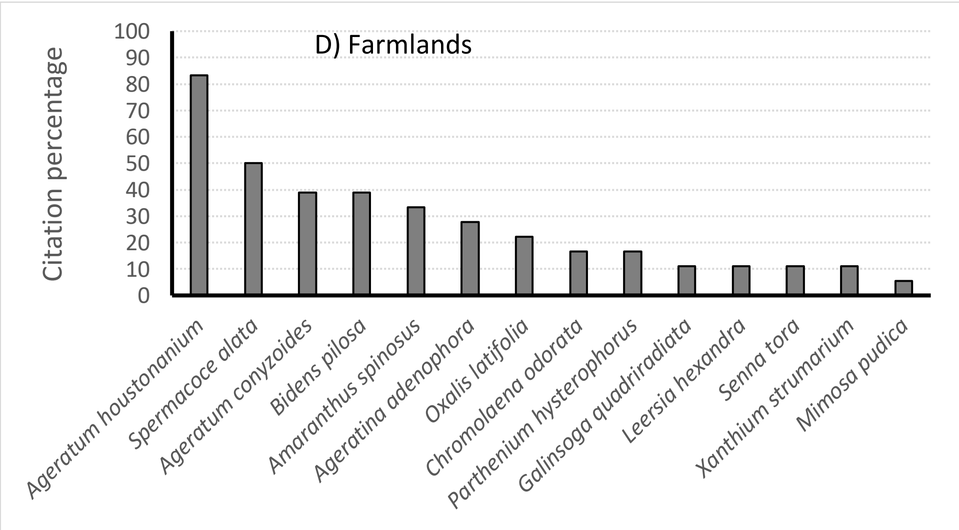
| | | | | | |
|---|---|---|---|---|---|
| | | | | | *Ageratinaadenophora* (5%), *Parthenium hysterophorus* (3%) |
| 5 | Manang | 8 | - | - | - |
| 6 | Mustang | 2 | - | - | - |
| 7 | Myagdi | 12 | 2.42 ± 0.67 | 19 ± 7 | *Ageratina adenophora* (8%), *Ageratum houstonianum* (3%), *Bidens pilosa* (3%) |
| 8 | Nawalpur | 71 | 2.56 ± 1.76 | 52 ± 37 | *Ageratum houstonianum* (31%), *Chromolaena odorata* (6%), *Mesosphaerum suaveolens* (4%) |
| 9 | Parbat | 18 | 2.00 ± 1.03 | 33 ± 25 | *Ageratum houstonianum* (19%), *Ageratina adenophora* (9%), *Bidens pilosa* (2%) |
| 10 | Syangja | 25 | 2.48 ± 0.65 | 56 ± 26 | *Ageratum houstonianum* (18%), *Ageratina adenophora* (16%), *Chromolaena odorata* (8%) |
| 11 | Tanahun | 30 | 2.00 ± 1.31 | 56 ± 39 | *Ageratum houstonianum* (24%), *Lantana camara* (9%), *Chromolaena odorata* (8%) |

The participants of the FGDs reported various IAPS invading different habitats. They reported 14 IAPS invading forest and shrublands, 15 in grasslands, 4 in wetlands and water bodies, 14 in farm lands and 12 in residential areas (Fig. 8). The most frequently cited species were *Ageratina adenophora*, *Bidens pilosa* and *Ageratum houstonianum* in forest and shrublands; *Ageratum houstonianum*, *Bidens pilosa* and *Mimosa pudica* in grasslands; *Pistia stratiotes* and *Pontederia crassipes* in wetlands and water bodies; *Ageratum houstonianum, Spermacoce alata* and *Ageratum conyzoides* in farmlands; *Ageratum houstonianum*, *Bidens pilosa* and *Oxalis latifolia* in residential areas.




B) Grasslands
Citation percentage
100
90
80
70
60
50
40
30
20
10
0
Ageratum houstonianum
Bidens pilosa
Mimosa pudica
Parthenium hysterophorus
Senna tora
Spermacoce alata
Senna occidentalis
Ageratina adenophora
Ageratum conyzoides
Amaranthus spinosus
Mesosphaerum suaveolens
Argemone mexicana
Chromolaena odorata
Oxalis latifolia
Xanthium strumariuim


C) Wetlands and water bodies
Citation percentage
100
90
80
70
60
50
40
30
20
10
0
Pistia stratiotes
Pontederia crassipes
Ageratum houstonianum
Leersia hexandra


D) Farmlands
Citation percentage
100
90
80
70
60
50
40
30
20
10
0
Ageratum houstonanium
Spermacoce alata
Ageratum conyzoides
Bidens pilosa
Amaranthus spinosus
Ageratina adenophora
Oxalis latifolia
Chromolaena odorata
Parthenium hysterophorus
Galinsoga quadriradiata
Leersia hexandra
Senna tora
Xanthium strumarium
Mimosa pudica

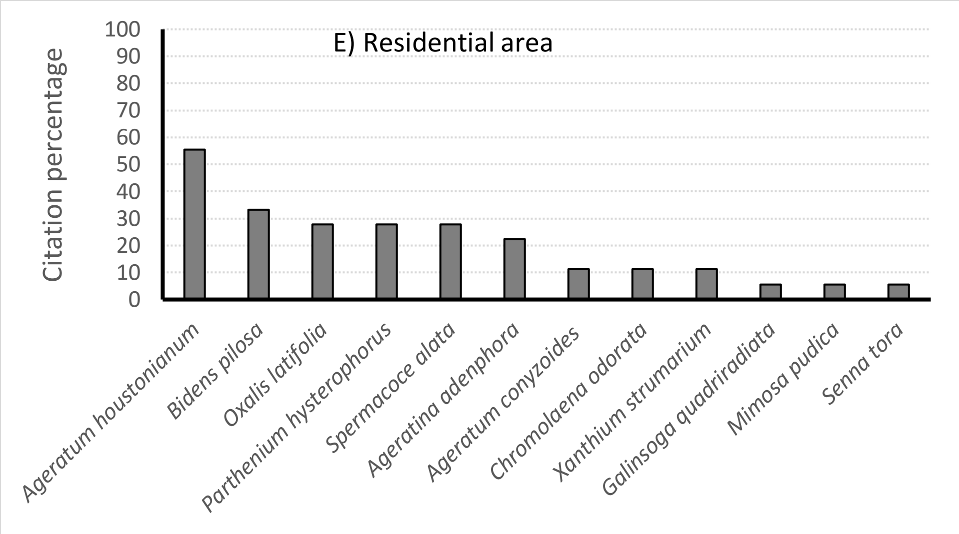



**Figure 8: Citation percentage of the IAPS invading different habitats during the FGDs**

## *3.2 Distribution of prioritized and other species*

### 3.2.1 Prioritized species

Score percentage of the IAPS prioritized for management based on the perception local communities, national list of priority species and invasiveness at global level. *Ageratum houstonianum, Ageratina adenophora, Chromolaena odorata, Bidens pilosa* and *Mikania micrantha* were the five top-ranked species in the prioritization exercise (Fig. 9). However, as mentioned in the method section (Section 2.3), *Bidens pilosa* was deprioritized and it was replaced by *Parthenium hysterophorus*. Additionally, *Lantana camara* was added to the priority list considering its' widespread occurrence and impacts at national and global levels (see Section 2.3 for details). Therefore, the final list of prioritized species for Gandaki Province based on their realized and potential impacts included following six species: *Ageratum houstonianum*, *Ageratina adenophora*, *Chromolaena odorata, Mikania micrantha, Parthenium hysterophorus* and *Lantana camara*.

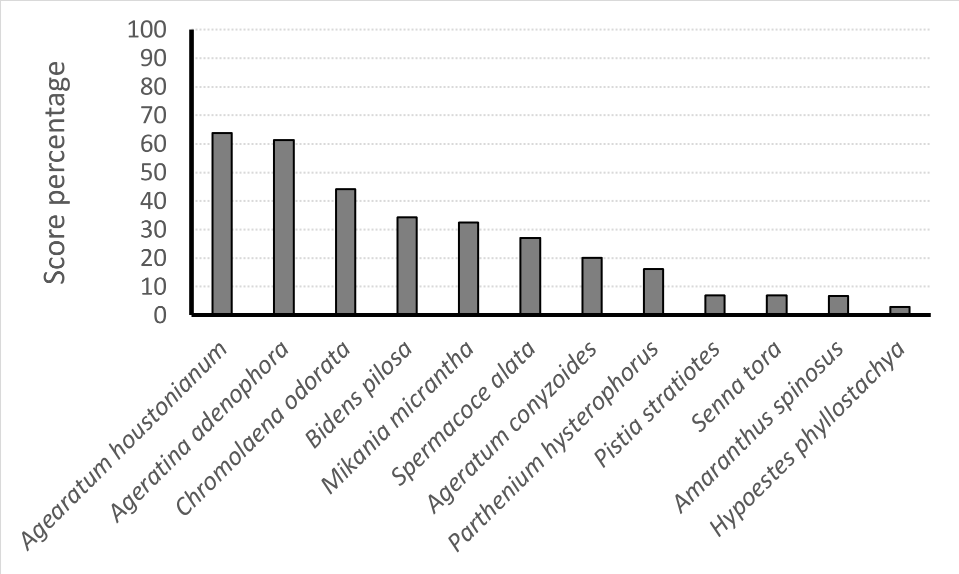
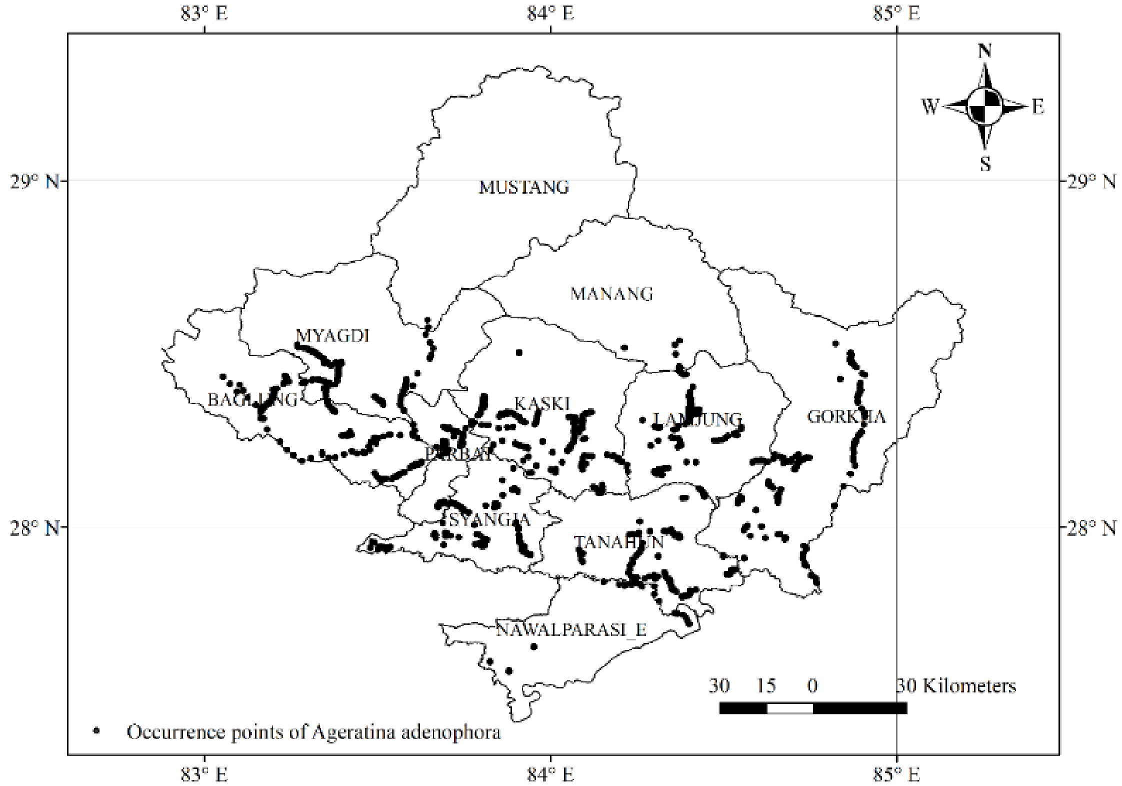


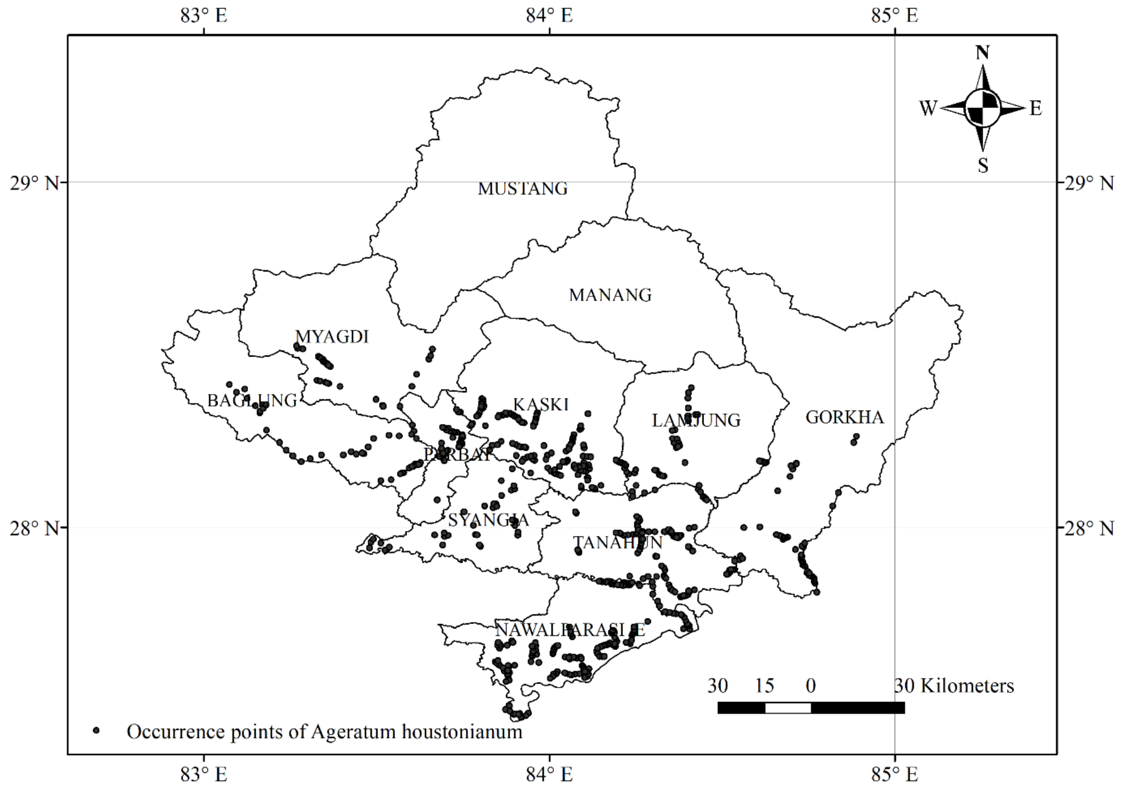

**Figure 9: Score percentage of the IAPS prioritized for management**

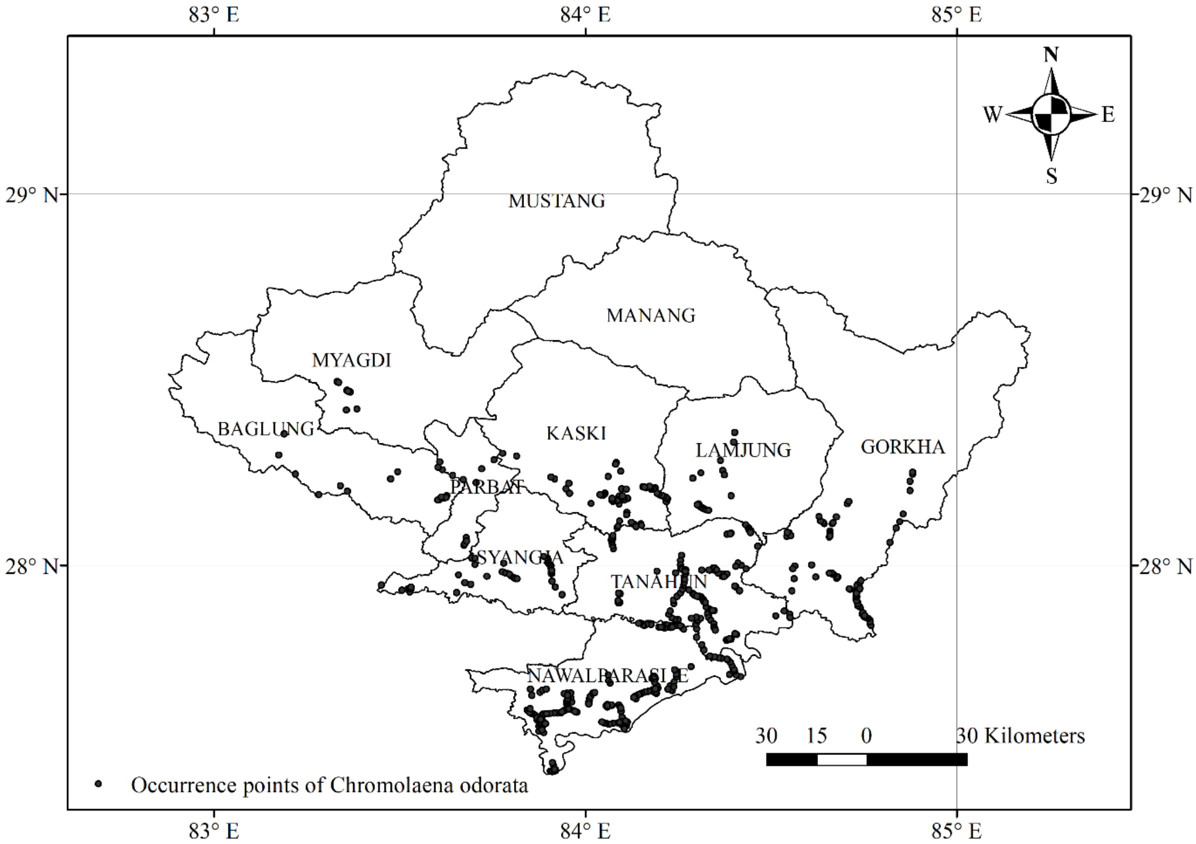
## 3.2.2 Distribution and habitat suitability of prioritized species

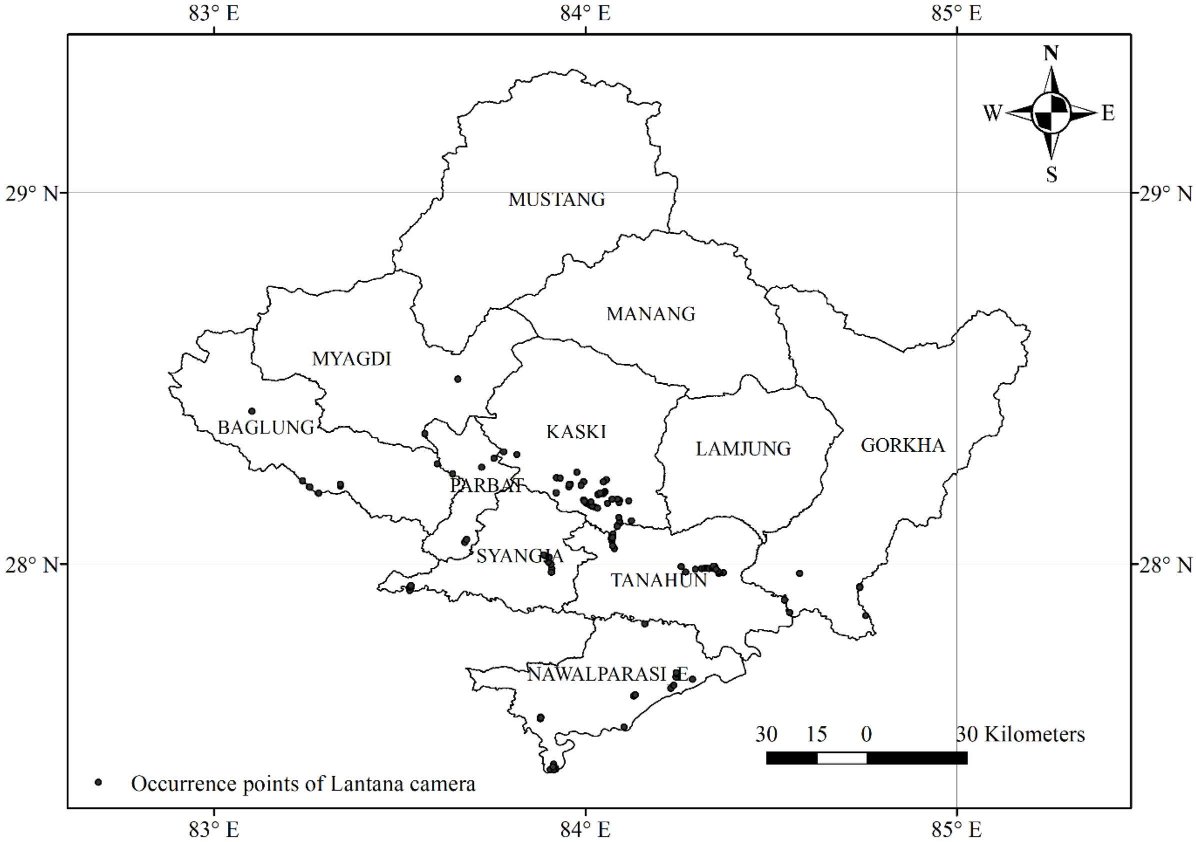
### *3.2.2.1 Current distribution*

Current distribution of the prioritized IAPS revealed that species like *Ageratina adenophora, Ageratum houstonianum*, *Chromolaena odorata* and *Parthenium hysterophorus* were widespread whereas other two species *Lantana camara* and *Mikania micrantha* limited distribution. *Ageratina adenophora* was found in all districts whereas all other species were absent in Manang and Mustang districts. While *A. adenophora* was quite common in hilly districts, it was recorded only at a few locations in Nawalpur district. Additionally, *Lantana camara* was not recorded in Lamjung and *Mikania micrantha* in Baglung, Myagdi, Parbat and Syangja districts. Among six species, *M. micrantha* had invaded a relatively limited areas with some isolated satellite pupulations (i.e. small population established far from large population) in Kaski, Tanahun, Lamjung and Gorkha. Such satellite populations of *Lantanacamara* were also found in Baglung and Mygdi, and of *Parthenium hysterophorus* in Baglung, Myagdi and Lamjung. Primary data collected during the current study were combined with secondary data to prepare distribution maps (Fig. 10).


83° E
84° E
85° E
29° N
28° N
N
W
E
S
MUSTANG
MANANG
MYAGDI
BAGLUNG
KASKI
LAMJUNG
GORKHA
PARBAT
SYANGJA
TANAHUN
NAWALPARASI_E
30 15 0 30 Kilometers
Occurrence points of Ageratina adenophora


83° E
84° E
85° E
29° N
28° N
N
W
E
S
MUSTANG
MANANG
MYAGDI
BAGLUNG
KASKI
LAMJUNG
GORKHA
PARBAT
SYANGJA
TANAHUN
NAWALPARASI_E
30 15 0 30 Kilometers
Occurrence points of Ageratum houstonianum


83° E
84° E
85° E
29° N
28° N
N
W
E
S
MUSTANG
MANANG
MYAGDI
BAGLUNG
KASKI
LAMJUNG
GORKHA
PARBAT
SYANGJA
TANAHUN
NAWALPARASI_E
30 15 0 30 Kilometers
Occurrence points of Chromolaena odorata


83° E
84° E
85° E
29° N
28° N
N
W
E
S
MUSTANG
MANANG
MYAGDI
BAGLUNG
KASKI
LAMJUNG
GORKHA
PARBAT
SYANGJA
TANAHUN
NAWALPARASI_E
30 15 0 30 Kilometers
Occurrence points of Lantana camera

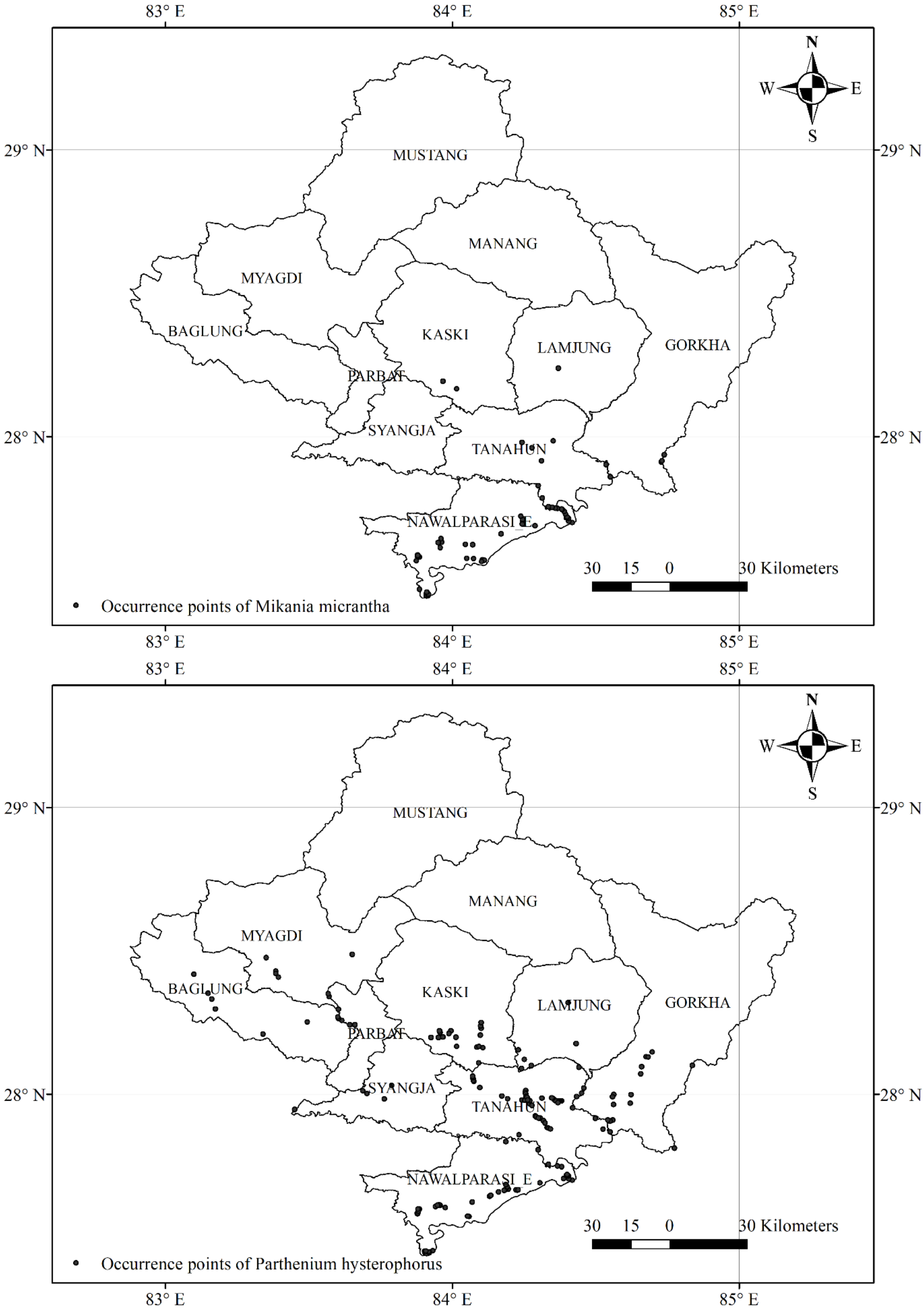



**Figure 10: Occurrence of six prioritized species in Gandaki Province**

### *3.2.2.2 Predicted suitable areas*

Assessment of the accuracy was essential to validate the models and to understand the performance of the models. The models were evaluated by two methods. One method was threshold independent, and another was threshold dependent. In the threshold independent method, the area under the receiver-operator curve (AUC) of models was reported (Phillips *et al*. 2006, Wiley *et al*. 2003). The higher the AUC, the higher the model performance was. The AUC<0.7 denoted poor model performance, 0.7–0.9 denoted moderately useful model performance, and >0.9 denoted excellent model performance (Pearce and Ferrier, 2000).Although AUC is a classical and widely used model evaluation parameter, it is criticized by some researchers (Lobo *et al*. 2008). Therefore, threshold dependent accuracy assessment: True Skill Statistic (TSS) was alsoperformed for the model evaluation (Merow *et al*. 2013).TSS was calculated for all model outputs (0-9 replications), and the final TSS was averaged for all 10 replications (Jiang *et al*. 2014, Panthi *et al*. 2019). Thresholds to maximize the sum of sensitivity and specificity are recommended threshold (Liu *et al*. 2013);therefore it was used to calculate the TSS.

**Table 12: Thresholds and accuracies of different replications during the modelling of habitat suitability of the prioritized species**

a. *Ageratina adenophora*

| SN | Accuracy/Run | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Mean | Std |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Threashold | 0.320 | 0.410 | 0.370 | 0.250 | 0.310 | 0.280 | 0.300 | 0.300 | 0.310 | 0.370 | 0.322 | 0.048 |
| 2 | TSS | 0.565 | 0.609 | 0.593 | 0.547 | 0.575 | 0.576 | 0.570 | 0.565 | 0.583 | 0.552 | 0.573 | 0.018 |
| 3 | AUC | 0.821 | 0.840 | 0.816 | 0.803 | 0.824 | 0.827 | 0.814 | 0.816 | 0.825 | 0.821 | 0.821 | 0.010 |

b) *Ageratum houstonianum*

| SN | Accuracy/Run | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Mean | Std |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Threashold | 0.310 | 0.310 | 0.370 | 0.270 | 0.270 | 0.160 | 0.300 | 0.360 | 0.270 | 0.180 | 0.280 | 0.068 |
| 2 | TSS | 0.614 | 0.649 | 0.613 | 0.620 | 0.599 | 0.591 | 0.615 | 0.664 | 0.629 | 0.587 | 0.618 | 0.024 |
| 3 | AUC | 0.862 | 0.865 | 0.861 | 0.861 | 0.848 | 0.837 | 0.857 | 0.879 | 0.863 | 0.842 | 0.858 | 0.012 |

c) *Chromolaena odorata*

| SN | Accuracy/Run | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Mean | Std |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Threashold | 0.130 | 0.180 | 0.270 | 0.150 | 0.290 | 0.210 | 0.180 | 0.260 | 0.130 | 0.290 | 0.209 | 0.064 |
| 2 | TSS | 0.676 | 0.698 | 0.703 | 0.687 | 0.704 | 0.678 | 0.685 | 0.690 | 0.659 | 0.679 | 0.686 | 0.014 |
| 3 | AUC | 0.885 | 0.893 | 0.891 | 0.879 | 0.887 | 0.888 | 0.880 | 0.878 | 0.875 | 0.888 | 0.884 | 0.006 |

d) *Lantana camara*

| SN | Accuracy/Run | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Mean | Std |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Threashold | 0.120 | 0.090 | 0.390 | 0.150 | 0.180 | 0.100 | 0.080 | 0.240 | 0.260 | 0.190 | 0.180 | 0.096 |
| 2 | TSS | 0.720 | 0.745 | 0.740 | 0.790 | 0.790 | 0.721 | 0.719 | 0.790 | 0.798 | 0.700 | 0.752 | 0.037 |
| 3 | AUC | 0.923 | 0.917 | 0.928 | 0.916 | 0.928 | 0.918 | 0.920 | 0.933 | 0.930 | 0.920 | 0.923 | 0.006 |

e) *Mikeania micarantha*

| SN | Accuracy/Run | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Mean | Std |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Threashold | 0.010 | 0.170 | 0.460 | 0.180 | 0.060 | 0.450 | 0.220 | 0.240 | 0.160 | 0.010 | 0.196 | 0.159 |
| 2 | TSS | 0.756 | 0.795 | 0.834 | 0.908 | 0.841 | 0.960 | 0.742 | 0.862 | 0.856 | 0.738 | 0.829 | 0.073 |
| 3 | AUC | 0.939 | 0.938 | 0.941 | 0.965 | 0.963 | 0.978 | 0.923 | 0.968 | 0.960 | 0.945 | 0.952 | 0.017 |

f) *Parthenium hysterophorus*

| SN | Accuracy/Run | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Mean | Std |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Threashold | 0.170 | 0.190 | 0.310 | 0.100 | 0.190 | 0.190 | 0.100 | 0.080 | 0.260 | 0.240 | 0.183 | 0.075 |
| 2 | TSS | 0.707 | 0.688 | 0.659 | 0.655 | 0.673 | 0.672 | 0.681 | 0.643 | 0.788 | 0.732 | 0.690 | 0.043 |
| 3 | AUC | 0.893 | 0.915 | 0.896 | 0.897 | 0.892 | 0.904 | 0.893 | 0.890 | 0.928 | 0.914 | 0.902 | 0.013 |

Climatically suitable areas of the prioritized six IAPS under current climate was predicted to range from 7% (*Mikania micrantha*) to 36% (*Ageratina adenophora*) of the total area of Gandaki Province. The predicted suitable area was >20% of the Province for four (*Ageratina adenophora*, *Ageratum houstonianum, Chromolaena odorata* and *Parthenium hysterophorus*) of the six IAPS. Climatically suitable areas of all species were predicted to increase in future (2050) and it varied from 3% for *Chromolaena odorata* to 65% for *Mikania micrantha*. Consequently, climatically suitable area predicted for 2050 ranged from 12% (*Mikania micrantha*) to 38% (*Ageratina adenophora*).

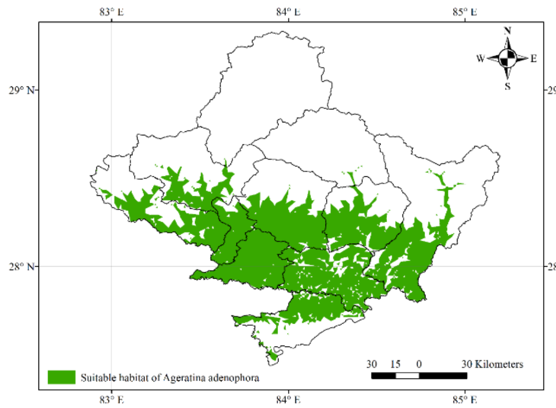
**Table 13: Predicted suitable areas of six prioritized species under current and future climate scenarios**

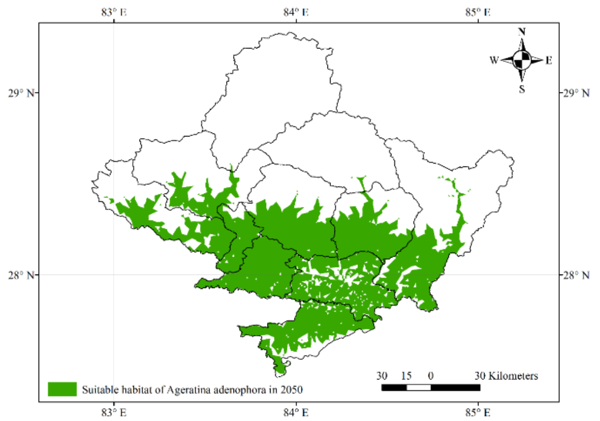
| SN | Species | Suitable area (km$^2$) | | |
|---|---|---|---|---|
| | | **Current** | **Future (2050)** | **Change (%)** |
| 1 | *Ageratina adenophora* | 7,876 (36%) | 8,279 (38%) | + 5 |
| 2 | *Ageratum houstonianum* | 6,765 (31%) | 7,806 (36%) | + 15 |
| 3 | *Chromolaena odorata* | 6,234 (28%) | 6,403 (29%) | + 3 |
| 4 | *Lantana camara* | 3,662 (17%) | 4,115 (19%) | + 12 |
| 5 | *Mikania micrantha* | 1,647 (7%) | 2,721 (12%) | + 65 |
| 6 | *Parthenium hysterophorus* | 5,680 (26%) | 6,275 (29%) | + 10 |

For *Ageratina adenophora*, most parts of Tanahun, Syangja and Parbat districts were predicted to be suitable under current as well as future climate scenario. Significant parts of Nawalpur, Gorkha, Lamjung, Kaski, Baglung and Myagdi were also predicted to be suitable. Only a very small areas in Manang and Mustang districts were predicted to be suitable for Ageratina adenophora. For *Ageratum houstonianum*, most parts of Tanahun, Nawalpur, Syangja and Parbat were predicted to be suitable. Currently, climatically suitable areas of *A. houstonianum* in Baglung and Myagdi were relatively low but such areas were predicted to increase significantly in these two disticts in future. The modelling also revealed that the climatically suitable areas of this species in Kaski district may decline in future. For *Chromolaena odorata*, the currently suitable areas in Nawalpur may be lost in future but it was predicted to increase in Parbat, Baglung and Myagdi districts. For *Lantana camara*, a significant portion of Nawalpur, Tanahun, Syangja and Kaski districts were predicted to be currently suitable. The suitable area of *L. camara* was predicted to increase significantly in Lamjung district in future. Currently, a significant portion of Nawalpur district was climatically suitable for *Mikania micrantha* whereas small patches of suitable areas were also predicted in other districts such as Gorkha, Tanahun, Kaski, Synagja, Parbat and Myagdi. In the future, these small patches of suitable areas may increase and expand in other districts like Lamjung and Baglung. For *Parthenium hysterophorus*, the predicted suitable areas were mainly distributed in Nawalpur, Tanahun, Syangja and Gorkha. In future, the suitable areas of *P. hysterophorus* were predicted to expand mainly in Gorkha, Lamjung, Baglung and Myagdi whereas a declined in suitable areas were predicted in Kaski district.

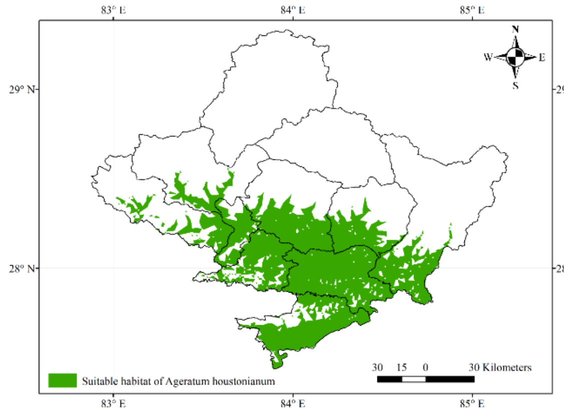
Overall, southern part of the Gandaki Province, particularly Nawalpur and Tanahun districts, were climatically suitable under both current and future climate whereas the northern part of the province was unsuitable for most of the species included in this study. In the future, a notable expansion of suitable area was predicted in Gorkha, Lamjung, Baglung and Myagdi districts, particularly in the northern parts.

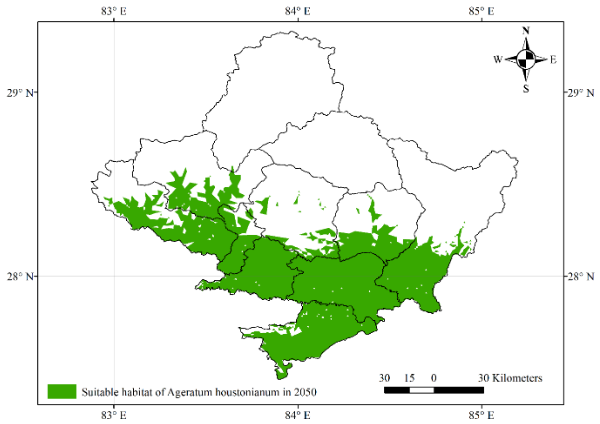
*Ageratina adenophora*



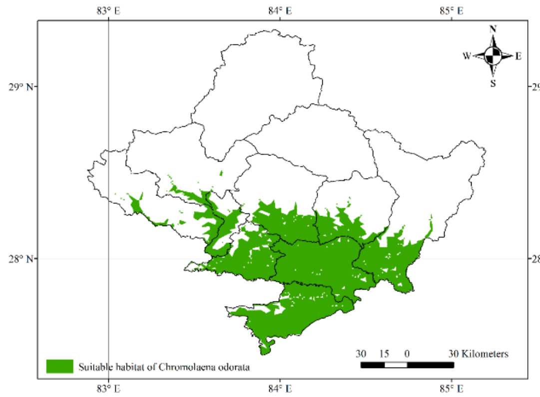



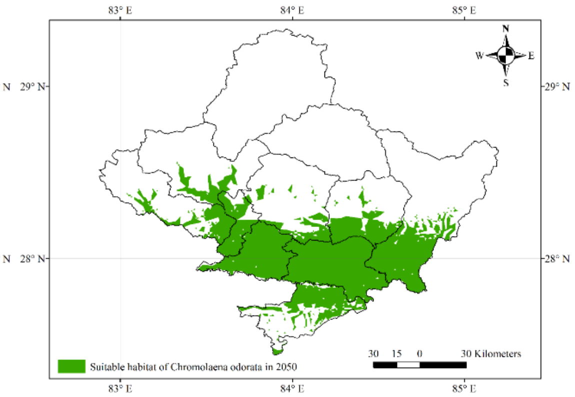

*Ageratum houstonianum*



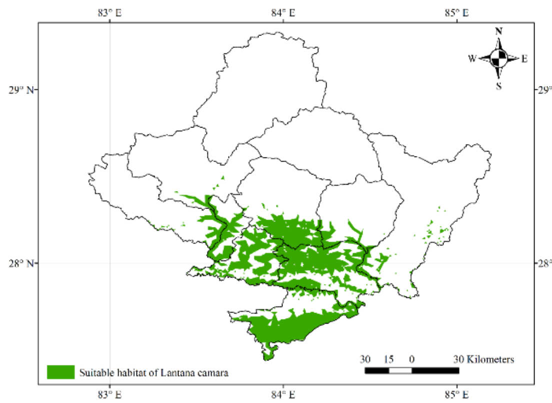



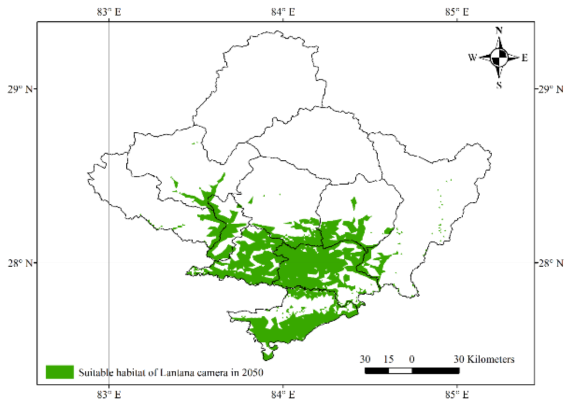

*Chromolaena odorata*



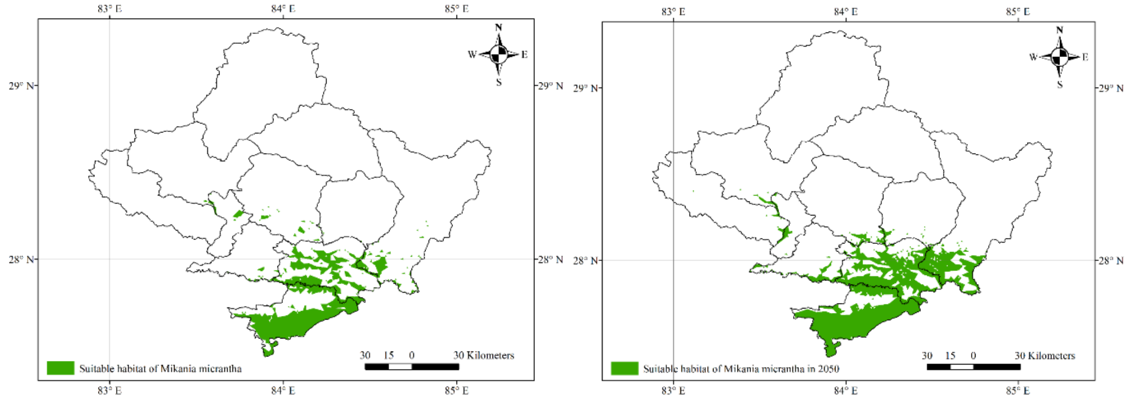




*Lantana camara*




*Mikania micrantha*




*Parthenium hysterophorus*

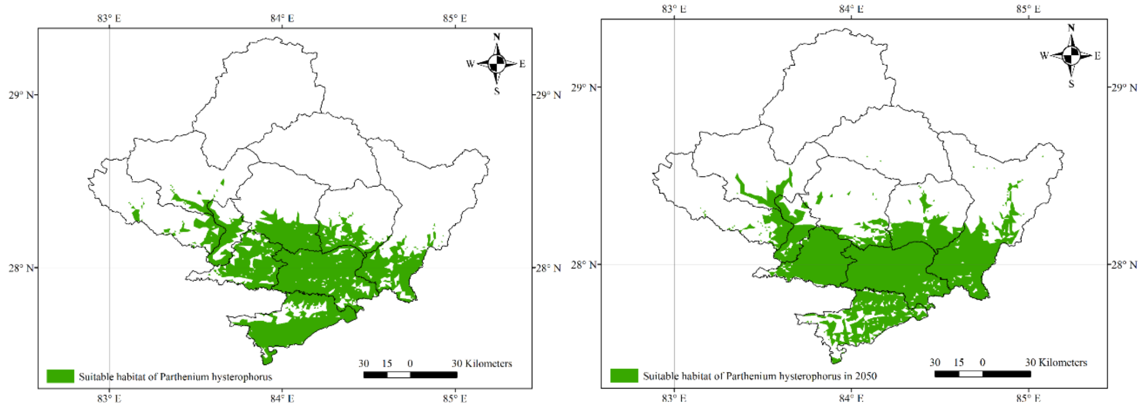
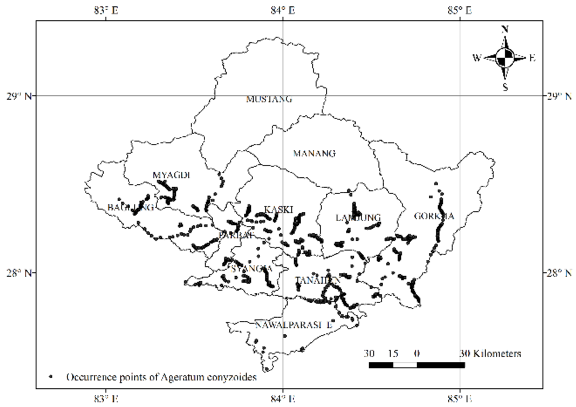


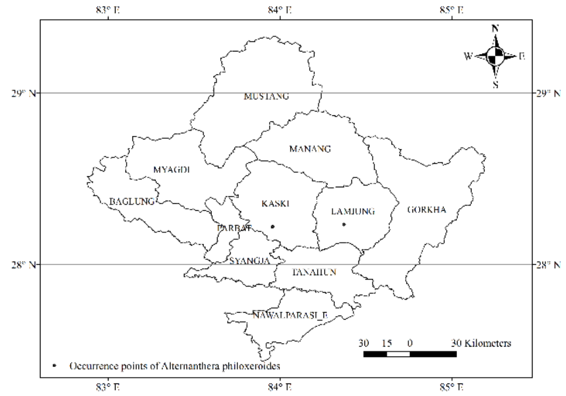

**Figure 11: Climatically suitable areas of six prioritized species under current (right) and future (SSP 245 for 2050) climate scenarios. Suitable areas were predicted by MaxEnt modeling.**

### 3.2.3 Distribution of other species

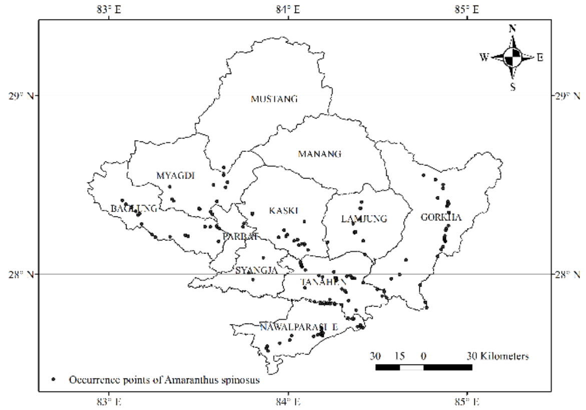
The distribution of 19 IAPS other than above mentioned six prioritized species has been presented in Fig. 12. Primary data collected during the present study were combined with the secondary data from the previous studies and publicly available database to prepare distribution maps. Species varied widely in their extent of invasions. Species like *Ageratum conyzoides*, *Amaratnhus spinosus*, *Bidens pilosa*, *Mimosa pudica*, *Senna occidentalis*, *S. tora*, *Spermacoce alata* and *Xanthium strumarium* were widespread while other species such as *Alternanthera philoxeroides*, *Argemone mexicana*, *Oxalis latifolia*, *Pistia stratiotes*, *Pontederia crassipes* and *Spergula arvensis* had limited distributions.



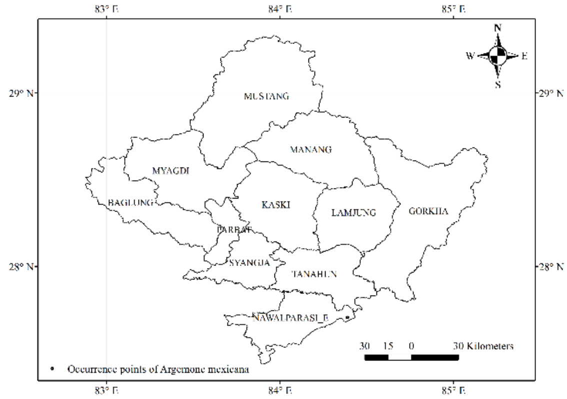

*Ageratum conyzoides*



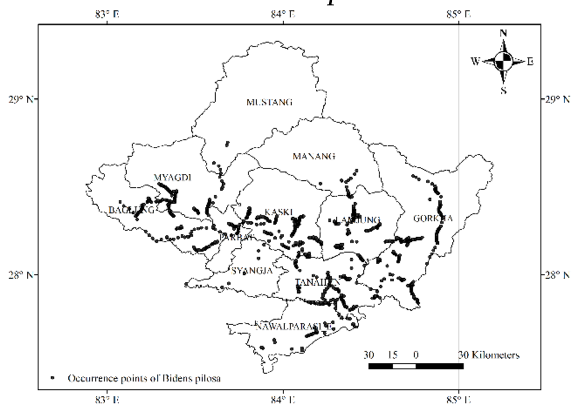

*Alternanthera philoxeroides*



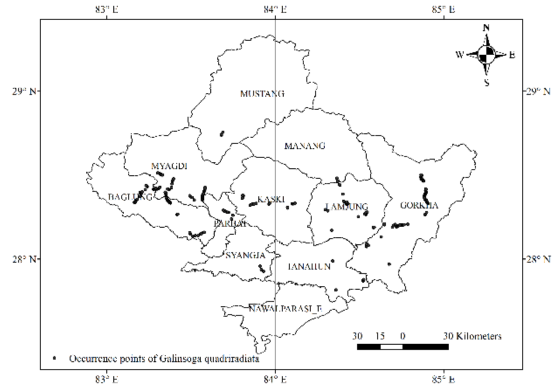

*Amaratnhus spinosus*



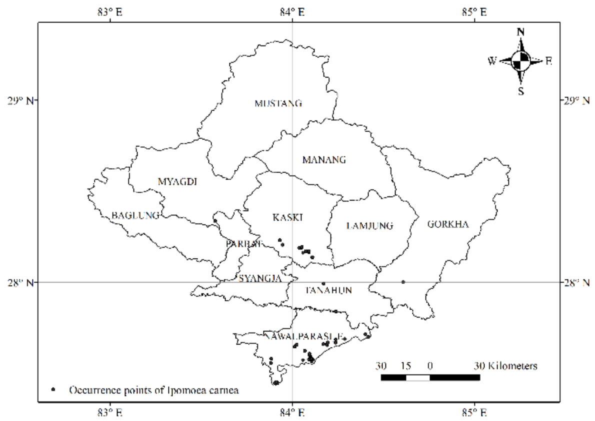

*Argemone mexicana*



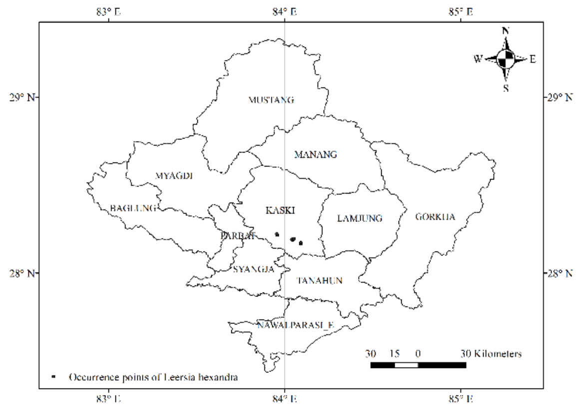

*Bidens pilosa*



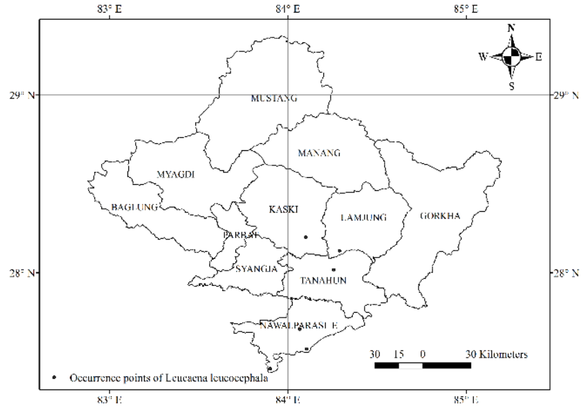

*Galinsoga quadriradiata*



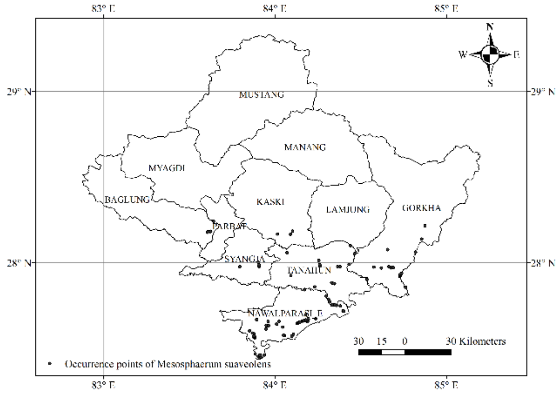

*Ipomoea carnea* ssp *fistulosa*



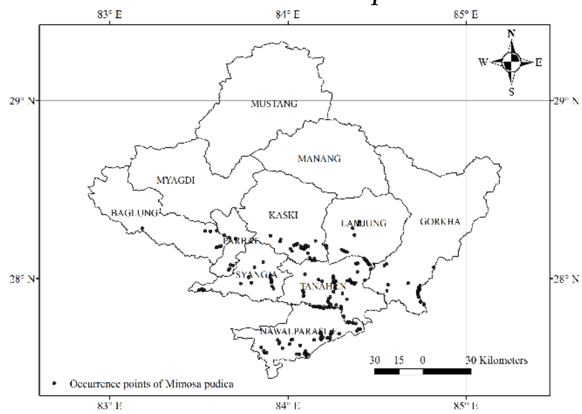

*Leersia hexandra*



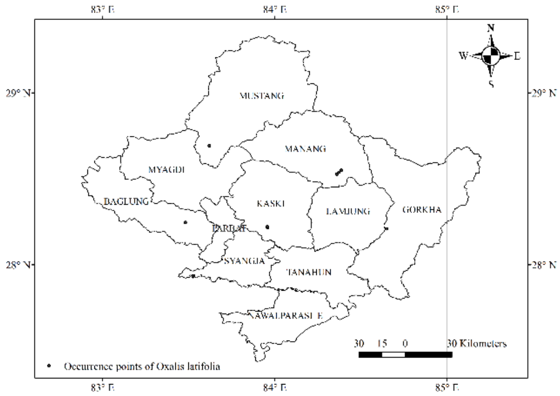

*Leucaena leucocephala*



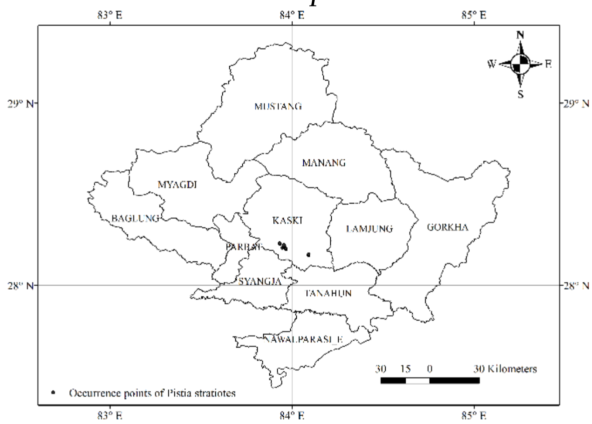

*Mesosphaerum suaveolens*



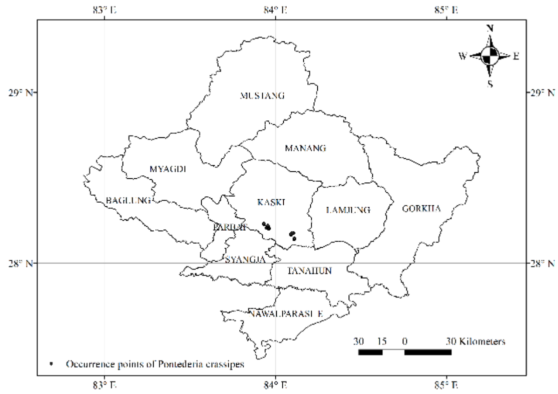

*Mimosa pudica*



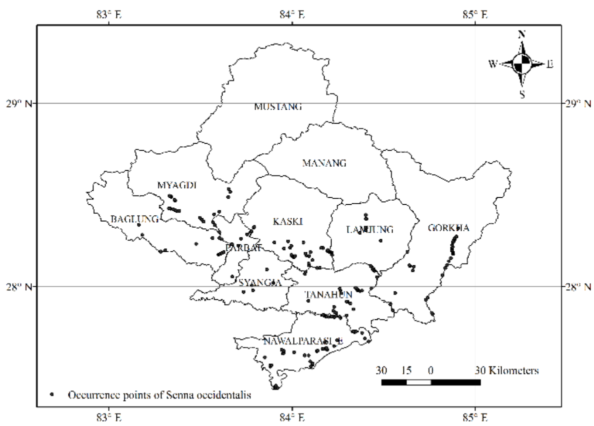

*Oxalis latifolia*



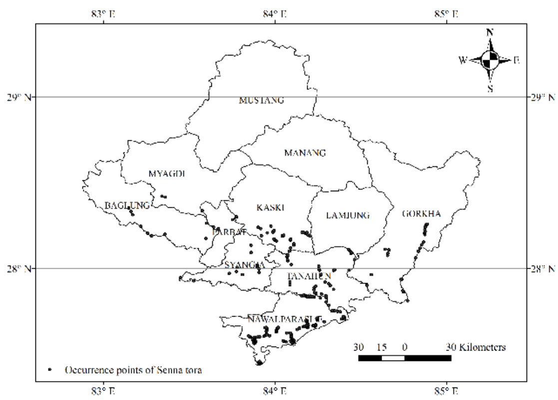

*Pistia stratiotes*



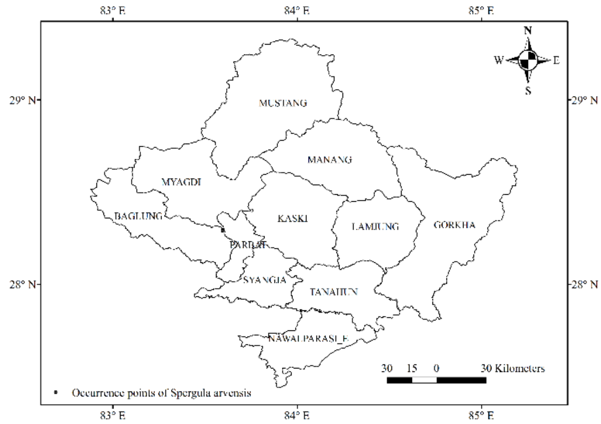

*Pontederia crassipes*



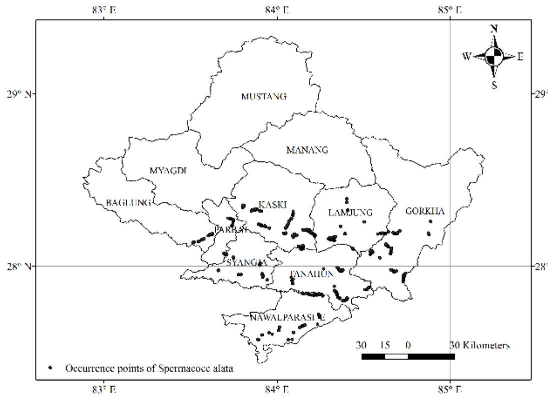

*Senna occidentalis*



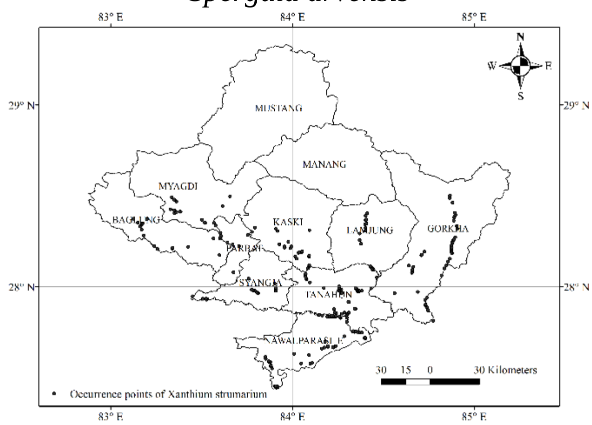

*Senna tora*




*Spergula arvensis*




*Spermacoce alata*




*Xanthium strumarium*

**Figure 12: Occurrence of additional 19 species in Gandaki Province**

## *3.3 Environmental and socio-economic impacts*

Impacts of the IAPS were recorded during distribution mapping as well as during the FGDs. During the distribution mappingeight IAPS were recorded as agriculture weeds; seven IAPS species were observed displacing forage species; and, four species reducing tree regeneration (Table 14).*Ageratina adenophora* was observed as a colonizer of landslide area thereby preventing soil erosion. Range of impacts were also reported by participants during the FGDs (Table 15). High level of invasion of *Ageratum houstonianum* was particularly reported in agriculture lands (Fig. 13). In addition to agriculture weeds and displacement of other species, two IAPS (*Chromolaena odorata* and *Mikania micrantha*) were also reported as degrading natural habitats. In addition, participants of the FGD organized at Anbu Khaireni of Tanahun district reported that the problems of *Pistia stratiotes* as weed in paddy field had been increasing in recent years. Similarly, decline of some IAPS such as *Senna tora* due to expansion of other weeds (e.g. *Lantana camara*, *Chromolaena odorata*) had been also reported at a few places (Kawaswoti of Nawalparasi district).

**Table 14: Environmental impacts of the IAPS observed during their distribution mapping**

| SN | Environmental impacts | IAPS causing the impacts |
|---|---|---|
| 1 | Agriculture weed | *Ageratina adenophora, Ageratum conyzoides, A. houstonianum, Bidens pilosa, Chromolaena odorata, Lantana camara, Parthenium hysterophorus, Spermacoce alata,* |
| 2 | Displacement of forage plants | *Ageratina adenophora, Ageratum conyzoides, A. houstonianum, Chromolaena odorata, Mikania micrantha, Mesosphaerum suaveolens* |
| 3 | Reduction of tree regeneration | *Ageratina adenophora, Chromolaena odorata, Lantana camara, Mikania micrantha* |
| 4 | Colonization at landslide area | *Ageratina adenophora* |

**Table 15: Environmental and socioeconomic impacts of the IAPS reported during the FGDs**

| SN | Environmental impacts | IAPS causing the impacts |
|---|---|---|
| 1 | Agriculture weed | *Ageratum conyzoides, Ageratum houstonianum, Parthenium hysterophorus* |
| 2 | Displacement of forage and other plants | *Ageratina adenophora, Chromolaena odorata, Mikania micrantha, Pistia stratiotes* |
| 3 | Habitat degradation | *Chromolaena odorata, Mikania micrantha* |

**Figure 13: Agroecosystem invaded by *Ageratum houstonianum* in Nawalpur**
(Photo: Adarsha Subedi)

## *3.4 Methods of managementpracticed by local communities*

Local communities had put some efforts to manage IAPS in their localities. Most frequently used method of controlling IAPS was uprooting/mowing and burning; at least nine species were targeted in this method of management (Table 16). Other measures practices at a few locations included cultural methods and use of herbicides. As an effort to control the IAPS, biomass of two species (*Ageratina adenophora* and *Chromolaena odorata*) were also used for composting. Despite these efforts put by local communities to manage IAPS, the effectiveness of these measures were very low. In addition to the community practices, a biological control agent (stem galling insect *Procecidochares utilis*) of *Ageratina adenophora* was observed active at some locations of Kaski, Baglung and Tanahun districts.

**Table 16: Management practices adopted by the communities**

| Management practices | Species (# FGD) | Effectiveness/Remarks |
|---|---|---|
| Uprooting/Mowing/Burning | *Ageratum houstonanum* (12)<br>*Bidens pilosa* (6)<br>*Ageratina adenophora* (5),<br>*Ageratum conyzoides* (4)<br>*Chromolaena odorata* (3)<br>*Mikania micrantha* (2)<br>*Parthenium hysterophorus* (2)<br>*Amaranthus spinosus* (1)<br>*Senna tora* (1) | In most cases, the effectiveness was very low but abundance of *Parthenium hysterophorus* reduced to half in a small area |
| Biomass utilization for composting | *Ageratina adenophora* (1)<br>*Chromolaena odorata* (1) | Not effective |
| Cultural method (Burying within soil) | *Pistia stratiotes* (1) | Slightly effective |
| Herbicide use | *Ageratum houstonianum* (1) | Slightly effective |

*Note*: Values inside parentheses is the number of FGD reporting the particular method of management for the given species.

## *3.5 Utilizations*

Some IAPS were put in to use by local communities. Five IAPS were used for composting/ mulching, and among them *Chromolaena odorata* was the most frequently cited species followed by *Ageratina adenophora* (Table 17). Similarly, the IAPS had been also used as medicinal plants (four species), fodder plant (four species) and vegetable (*Amaranthus spinosus*).

**Table 17: Utilization of IAPS by local communities**

| Utilization | Species (# FGD) | Remarks |
|---|---|---|
| Composting and mulching | *Chromolaena odorata* (5)<br>*Ageratina adenophora* (2)<br>*Ageratum houstonianum* (1)<br>*Bidens pilosa* (1)<br>*Senna tora* (1) | |
| Medicinal | *Ageratina adenophora* (1)<br>*Amaranthus spinosus* (2)<br>*Mimosa pudica* (1)<br>*Senna tora* (1) | Antiseptic uses<br>Urinary problems<br>Jaundice<br>Seeds for cough |
| Fodder | *Ageratum conyzoides* (2)<br>*Ageratina adenophora* (1)<br>*Mimosa pudica* (1)<br>*Spermacoce alata* (1) | |
| Vegetable | *Amaranthus spinosus* (2) | |

*Note*: Values inside parentheses is the number of FGD reporting the particular method of management for the given species.

## *3.6 IAPS in the Operational Plan of Community Forests*

Among the studied 18 community managed forests, management of the IAPS had not been included in the Operational plans of the Community forests except in one Community forest of Nawalpur (Krishnasaar Buffer Zone Community forest of Kawaswoti, Nawalpur). In this Community forest, removal of the IAPS was prioritized over the other plant species. Although, some silviculture activities such as clearing ground vegetation, weeding had been included in the operational plans of the most community managed forests, these activities were not focused to the IAPS. Instead, all ground vegetation including seedlings of native tree species had been removed during these silviculture practices.

## *3.7 Community education and awarness*

As described in the preceeding sections (3.3, 3.4 and 3.5), local communities had experienced range of impacts, implemented various control measures, and put some IAPS in to uses. However, results of the present study revealed that communities had not been educated/informed about nature of IAPS and their management measure. Participants of the sixteen FGDs reported that they had never received any information or training on the issues related to IAPS problems. Participants of one of the remaining two FGDs (Kushma, Parbat) informed that a training was organized a few years back to make compost from the biomass of IAPS and other plants. Participants of the remaining FGD (Pokhara, Kaski) reported that they were informed about IAPS problems and management options during a training workshop organized by Forest Sub-Division Office with support from Hariyo Ban program implemented by WWF Nepal.

In spite of the lack of formal education and programs related to the IAPS, local communities had knowledge of first observation of any particular IAPS in their locality. Altogether, the parcipants of the FGDs reported year of first observation of ten species (Table 18). The results showed that some IAPS had invaded some places only recently. For example, *Ageratum houstonianum* was first observed at Madi of Kaski district recently in 2018.

**Table 18: First observation of the IAPS as reported by the participants during the FGDs**

| SN | Name of the IAPS | Year of first observations [Place] | |
|---|---|---|---|
| | | Oldest | Most recent |
| 1 | *Ageratina adenophora* | 1980 [Lamjung, Madhya Nepal; FGD 10] | 2010 [Synanja, Putalibazaar; FGD 6] |
| 2 | *Ageratum conyzoides* | 1990 [Kaski, Pokhara; FGD 8] | 2005 [Nawalparasi, Hupsikot; FGD 16] |
| 3 | *Ageratum houstonianum* | 1990 [Kaski, Pokhara; FGD 8] | 2018 [Kaski, Madi; FGD 9] |
| 4 | *Amaranthus spinosus* | - | 2010 [Tanahun, Anbukhaireni; FGD 14] |
| 5 | *Bidens pilosa* | 1950 [Tanahun, Anbukhaireni; FGD 14] | 2005 [Baglung, Kathe Khola; FGD 12] |
| 6 | *Chromolaena odorata* | 2000 [Nawalpur, Kawaswoti; FGD 18] | 2010 [Nawalpur, Kawaswoti; FGD 17] |
| 7 | *Mikania micrantha* | 2010 [Kaski, Pokhara; FGD 7] | - |
| 8 | *Parthenium hysterophorus* | 2005 [Lamjung, Madhya Nepal; FGD 10] | - |
| 9 | *Spermacoce alata* | 2005 [Syanja, Putalibazaar; FGD 6 and Kaski, Madi; 9] | 2010 [Parbat, Kushma; FGD 4; Kaski, Pokhara; FGD 8] |
| 10 | *Xanthium strumarium* | 1995 [Parbat, Kushma; FGD 4] | - |

# 4. Discussions

The present research has presented diversity and distribution of invasive alien plant species (IAPS) in Gandaki Provice by combining primary data collected during this study with secondary data compiled from the previous studies. This research has also identified six priority IAPS based on their extent of invasions, environmental and socio-economic impacts, and potential for future expansions. How local communities are responding and managing IAPS has also been documented. Finally, various management options have been identified considering invasion stage of the IAPS and invaded habitats. This is first of this kind of study conducted at the province level in Nepal. Implementation of the management options suggested in this report may prevent introduction of new IAPS, contain species with limited extent of invasions and reduce abundance of widespread species, thereby protecting habitat, biodiversity and livelihood from negative impacts of the IAPS.

## *4.1 Diversity*

More than 80% of the IAPS reported in Nepal are found in Gandaki Province. In Nepal, at least 30 species of alien plants are reported to be invasive (Shrestha *et al*. 2021, Adhikari *et al*. 2022, Shrestha *et al.* in press). Among them, *Erigeron karvinskianus, Mimosa diplotricha, Myriophyllum aquaticum, Sphagneticola trilobata* and *Tithonia diversifolia* have not been reported in Gankaki Province. *Mimosa diplotricha* has been reported only from eastern Nepal (Sharma *et al*. 2020); *Sphagneticola triloboata* in Kavrepalanchwok district (Shrestha *et al*. 2021); *Myriophyllum aquaticum* in Kathmandu valley (Adhikari *et al*. 2022); and *Tithonia diversifilia* in eastern Nepal (Shrestha *et al*., in press). *Erigeron karvinskianus* has been reported from eastern and western Nepal but not from central Nepal (Adhikari *et al*. 2022). Among 100 of the world's worst invasive alien species (Lowe *et al.* 2000), six plant species are present in Nepal (Shrestha and Shrestha 2021, Shrestha *et al.* 2001). Out of the six species, the only species not so far reported in Gandaki Province is *Sphagneticola trilobata* which has been reported only from Kavreplanachwok district of Bagmati Province in central Nepal (Shrestha *et al*. 2021).

The results, as discussed above, suggest that the threats of IAPS is already high in Gandaki Province. However, diversity of the IAPS and threats of invasions are not equal among districts of Gandaki Province. Diversity and extent of invasions were found to be high in southern part of the Province including Nawalpur, Tanahun, Syangja and Parbat Districts, and southern parts of Gorkha, Lamjung and Kaski Districts. These regions with subtropical and warm temperate climate are expected to be suitable because most of the invasive and naturalized plant species of Nepal are native of tropical Americas (Bhattarai *et al*. 2014, Shrestha and Shrestha 2021). The invasion was relatively low in northern parts of the Province including the entire Manang and Mustang Districts. With cool temperate, subalpine, alpine to nival climate, these northern regions are climatically unsuitable for most of the currently known IAPS of Nepal (Shrestha and Shrestha 2019, Maharjan *et al*. 2019, Poudel *et al*. 2020). However, a few IAPS such as *Ageratina adenophora, Bidens pilosa* and *Galinsoga quadriradiata* were found to invade upper temperate regions of disticts like Gorkha, Manang and Mustang. Therefore, northern parts of the Province are not completely immune to plant invasions though the diversity and extent of invasions are currently low.

## 4.2 Priority species, their distribution and suitable areas

Six high priority species identified during this study for Gandaki Province include: *Ageratina adenophora*, *Ageratum houstonianum*, *Chromolaena odorata*, *Lantana camara*, *Mikania micrantha* and *Parthenium hysterophorus*. Among them, *Ageratina adenophora* was also ranked first among the highly problematic IAPS of Nepal (Tiwari *et al*. 2005). In Asia, highly suitable areas for this speices have been predicted primarily in the Himalaya, South-east Asia and East Asia (Changjun *et al*. 2021). *Ageratum houstonianum* has been also reported as the most problematic invasive weeds in agro-ecosystems in Chitwan Annapurna Landscape (Shrestha *et al*. 2019), which mostly lies in Gandaki Province, and in the hilly region of far-west Nepal (Bist and Shrestha 2022).*Chromolaena odorata*, *Lantana camara* and *Mikania micrantha* are globally noxious weed (Lowe *et al*. 2000) and categorized as the IAPS having 'massive' ecological impacts in Nepal (Adhikari *et al*. 2022). The remaining species*Parthenium hysterophorus* is also rapidly expanding globally and nationally with multitude of ecological and socioeconomic impacts (Shrestha *et al*. 2015, Shrestha *et al*. 2019b,Mao *et al*. 2021).Therefore, the species prioritized in this study are also problematic in Nepal and elsewhere in the world.

The occurrence of these six species in the Province and their suitable areas under current and future climate vary significantly among species. Widespread occurrence of *Ageratina adenophora*, *Ageratum houstonianum*, *Chromolana odorata* and *Parthenuim hysterophorus* in Gandaki provice can be attributed to efficient dispersal mechanisms (species producing small and light seeds that can be dispersed by wind, water and vehiclie) and climatic suitability. Previous studies in Chitwan Annapurna Landscape also revealed that a large section of this region are climatically suitable for *Ageratina adenophora* (Poudel *et al*. 2020) and *Parthenium hysterophorus* (Maharjan *et al*. 2019). Relatively low occurrence of *Lantana camara* and *Mikania micrantha* in the Gandaki Province might be due to a relatively short history of invasion of these species in the area. *Mikania micrantha* was reported in Kaski only recently (Pathak *et al*. 2021b) and only a small patch of this species was recorded in Lamjung district during this study (Fig.14), suggesting that the species is still expanding to new locations. Generally, the species with relatively short invasion history invades only a fraction of potentially suitable areas (Wilson *et al.* 2007). Species that are in the continuous process of invading in to new areas often have isolated satellite populations in their invasion fronts (Radocevich *et al*. 2007, Shrestha *et al*. 2019b). Such species provide opportunities for their containment by eradicating satellite populations (Wittenberg and Cook 2001).

**Figure 14: A patch of Mikania micrantha recorded at bus park of Besisahar in Lamjung district**
(Photo: BB Shrestha)

MaxEnt modelling revealed that climatically suitable areas of all six priority species will expand, with the greatest expansion predicted from *Mikania micrantha*. Such expansions of climatically suitable areas have been predicted for various invasive alien species at global (Bellard *et al*. 2013), regional (Thapa *et al*. 2018), national (Shrestha and Shrestha 2019) and subnational levels (Maharjan *et al*. 2019, Poudel *et al*. 2020).Notable expansion may occur in mountain region to the north, particularly in Gorkha, Lamjung, Baglung and Myagdi Districts. Future expansion of the IAPS in mountain region provides additional challenges for their management because the IAPS management in mountain region is more challenging than in lowland due to low accessibility and difficulties in locating invaded habitats (McDougall*et al* 2011, Joshi *et al*. 2022). Therefore prevention of further expansion of the IAPS in mountain landscape is more demanding than in lowland plain areas.

## 4.3 Impacts and utilizations

Invasive alien species may have both negative and positive impacts but the negative impacts often outweight the positive impacts (e.g. Ngorima and Shackleton 2019, Shrestha *et al*. 2019a). Results of the present study also showed that the negative impacts of the IAPS ranged from increasing weed problems, displacement of native species to suppression of tree regeneration whereas the positive impacts included soil erosion control at landslide area and diversified biological resources as the IAPS had been used for composting, feeding livestock and traditional healthcare. As the sample size (number of focused group discussions = 18) was relatively small, some of the impacts might have been missed in the present study. These and additional negative (e.g. livestock poisoning) and positive (e.g. flood control) impacts of the IAPS have been also reported from the Chitwan Annapurna Landscape (Shrestha *et al*. 2019a). Both negative and positive impacts of the IAPS are seldom realized or observed at their early stage of invasions. By the time when species are widespread and impacts are substantial, their control is quite difficult. Under such situation, local communities may accept the invasive species as new 'resource' if they can be put in to some kind of uses. At the local level such practice may help to diversify the livelihood options of marginal communities who depends on forest resources (Rai *et al*. 2012). It is often argued that utilization of the IAPS may help to their control but such benefits are seldom significant because of the small volume of the biomass being utilized. Benefits towards the control of IAPS are low even when the IAPS biomass is used for commercial production of charcoal, bio-briquette, furniture and other items.

The impacts of the IAPS can be far beyond what has been reported in this study. A wide range of impacts on ecosystem services of the Lake Cluster of Pokhara Valley – an important Ramsar site in Gandaki Province due to IAPS have been reported recently which is an important Ramsar site and tourist attraction of Gandaki Province (Pathak *et al.* 2021a). Furthermore, the current study focused forest ecosystems whereas the IAPS are known to affect almost all kinds of ecosystems including wetlands. Quantification of the impacts is also very essential to understand full range of the impacts. Therefore, the extent of impacts reported in this study, particularly the negative ones, are likely an underestimate of the actual impacts of the IAPS in the region.

## *4.4 Community practices of management*

Communities responded to the increasing problems of IAPS in way how common agriculture weeds are managed; this included uprooting, burning, burying and herbicide uses. Some IAPS were put in to use but such utilization could not have measurable impacts towards control of the IAPS. These are the common management practices adopted by local communities where external supports are not available (Shrestha 2019, Shrestha *et al*. 2019a). These practices can be effective in controlling IAPS in small areas (e.g. small scale farmlands) but mostly ineffective at ecosystem and landscape levels. Furthermore, community practices of management have not been targeted for any specific IAPS but they have been practiced as a regular weed control activities in their lands. Importantly, communities were mostly unaware of the origin and nature of what researchers and technocrats call 'invasive alien species'. It is not surprising because communities have never been informed and educated systematically and adequately about the IAPS, their potential impacts and management options. A large sections of national forests in Nepal are being managed by local communities as Community Forests (CFs) with many success stories (Oldekop*et al*. 2019) but Operational Plans of these CFs have not included IAPS management activities. It is to be noted that the Operational Plans are prepared with the help of technical personnel and many CFs are heavily invaded by the IAPS. Participations of local communities are indispensable for the management of IAPS (Boudjelas 2009) but the current management activities practiced by the local communities of Gandaki Province seems inadequate for effective management of the IAPS. However, active community participation with targeted activities can be anticipated only when they are informed and educated effectively, adequately and timely. Although some efforts have been made to communicate IAPS problems with communities by government (e.g. publication of photographic poster of

IAPS found in Gandaki Province by Forest Research and Training Center of Gandaki Province) and other institutions (e.g. field guide published by Nepal Academy of Science and Technology – Adhikari *et al*. 2022), they seem to be inadequate. Publication of educational material *per se* does not ensure that they reach to the targeted communities. Therefore, institutionalization of more effective means of communication is essential to inform local communities adequately and timely on various aspects of IAPS problems and their managements.

## 4.5 Management options

Management of invasive alien species is highly contextual and specific measures depend on stage of invasion, invaded habitats and dispersal pathways (McNeely *et al*. 2001, Wittenberg and Cock 2001, McGeoch*et al*. 2016, US Department of the Interior 2016). Based on the results of the present study and review of literatures including management strategies, following following management options have been identified. Importantly, success of all these management options depends on the level of awareness and participation of diverse stakeholders including local communities.

### 4.5.1 Prevention

Prevention is the first line of defence against invasive alien species. At least five plant species which are invasive elsewhere in Nepal have not been reported in Gandaki Province; they are: *Sphagneticola trilobata, Mimosa diplotricha, Myriophyllum aquaticum, Tithonia diversifolia* and *Erigeron karvinskianus* (Fig. 15).Among them first two species are well known for their detrimental impacts. *Sphagneticola trilobata* has been enlisted in 100 of the world's worst invasive alien species (Lowe *et al*. 2000) which is widespread in several Asian countries and Pacific islands with wide range of environmental impacts (CABI: https://www.cabi.org/isc/datasheet/56714). *Mimosa diplotricha* has also invaded several countries in Asia, Africa and Oceania with several serious negative impacts on agriculture, biodiversity conservation and livelihoods (Uyi 2020). Prevention of these five speies with particular focus to *Sphagneticola trilobata* and *Mimosa diplotricha*will protect the region from their negative impacts. For prevention, it is essential to make all stakeholders (e.g. forestry and agriculture officials, local communities, ornamental plant traders, gardeners) aware of these species. Publication of pest alert (a leaflet) with description of these species can be one way of raising awareness among stakeholders.


**Figure 15: Species that can prevented from invation to Gandaki Province**

### 4.5.2 Early detection and rapid response

Early detection and rapid response (EDRR) is the next effective way of IAPS management if prevention fails. The EDRR includes detection of species before they are widespread, rapid assessment to map invaded areas and habitats, and eradication of species or population by implementing all possible measures (US Department of the Intetior 2016). Species like *Alternanthera philoxeroides*, *Argemone mexicana*, and*Pistia stratiotes* have been detected only at a few locations. Eradication of these population through EDRR will eliminate the species from Gandaki Province. Similarly, eradication of satellite populations of *Mikania micrantha*, *Lantana camara* and *Parthenium hysterophorus* in their invasion fronts will prevent further expansion of this species and protect remaining areas which are climatically suitable to these species. Traditional methods such as uprooting and burning of the targeted species may lead to eradication of such satellite population if implemented regularly for few years until the species completely disappear. Participation of local communities is essential for such EDRR and this can be achieved by making them aware of the problems.

### 4.5.3 Control

#### *4.5.3.1 Physical and mechanical control*

Physical and mechanical control measures are the most commonly employed methods of IAPS control. As discussed in a previous Section (4.4), these methods have been also implemented by local communities but with little success. Community efforts can be improved through education and technical supports. Considering the probability of success and scale of problems, two wetlands species *Pontederia crassipes* and *Pistia stratiotes* can be prioritized for control (if not eradication) by physical and mechanical methods. *Pontederia* *crassipes* has been targeted in a few wetlands of Pokhara valley (Phewa and Begnas) but the current efforts are neither adequate (i.e. not removing all individuals) nor scientifically informed (i.e. dumping biomass on the bank of the wetlands). In isolated habitat such as small lakes and wetlands, eradication *Pontederia crassipes* and *Pistia stratiotes* would be possible if removal is continued until the the last one is removed from the habitat. Follow-up surveillance is require in subsequent years because species may regenerate from dormant propagules. Biomass produced from the removal can be used for composting and the process should be long enough to decompose all vegetative parts to prevent unintended dispersal of the species to new locations.

#### 4.5.3.2 Cultural methods

*Pontederia crassipes, Pistia stratiotes, Lantana camara* and *Leucaena leucocephala* be targeted for cultural methods of control. These three species are still grown as ornamental plants in gardens managed by private households, hotels and offices. Ban on cultivation and transport of these species will prevent further spread in new locations.

The remaining species *Leucaena leucocephala* is a 'conflict' species. In one hand it is one of the globally worstinvasive species invading several countries in Asia, Africa and Oceania (Lowe *et al*. 2000, Luo *et al*. 2020, CABI: https://www.cabi.org/isc/datasheet/31634) with impacts ranging from reduction of native tree regeneration (Hata *et al*. 2007) to reduced native biodiversity and altered ecological processes (Yoshida and Oka 2004). On the other hand, the species was introduced as 'miracle' tree in agroforestry system to increase fodder supply to the livestock (Jackson 1994). In addition to the agroecosystem, the species has been also planted in natural/semi-natural habitats and along roadside. Since natural regeneration from seeds of this plant has been observed at several locations in Nepal, the species is in naturalization process with high potential to spread in to natural habitats. As a precaution, following measuers are recommended to prevent undesirable impacts in future:

- Ban on plantation of *Leucaena leucocephala* in natural/seminatural habitats and roadside; remove them where it was planted in the past
- Discourage nurseries to raise seedlings of this species
- Discourage farmers and local communities to plant new seedlings
- Prevent fruiting in already planted trees by frequent lopping [lang owner would do this]

#### *4.5.3.3 Biological control*

In biological control, natural enemies selected carefully (e.g. no-choice experiments requiring 3-5 years of experimentations) from the native range of the targeted IAPS are released in the introduced range of the species (Day and Witt 2019). The biological control program of IAPS has not been initiated in Nepal, however, a few biological control agents have arrived naturally from the neighbouring countries where they were released in the past (Shrestha 2019). The most notable and effective among them is a leaf feeding beetle against *Parthenium hysterophorus* (Shrestha *et al*. 2019b). Though the beetle populations are already established at many locations in some districts of Gandaki Province, effectiveness is relatively low due to small population size of beetle. Laboratory rearing of this beetle in mass and release in to areas invaded by *Parthenium hysterophorus* will reduce the abundance of weed and allow natural regeneration of native species. This may require collaboration with Nepal Agriculture Research Council (NARC, Khumaltar, Lalitpur) which has facilities and experiences for mass-rearing of insects.

### 4.5.4 Ecosystem based approaches

Careful management of ecosystems can reduce the probability of the establishment of new IAPS while reducing the abundance of previously established IAPS (Hobbs and Humphries 1994, Schuster *et al*. 2018). A large section of national forest has been managed by local communities where silviculture activities are regularly implemented. During these silvicultural activities, selective removal of target IAPS with minimum damage to other species will suppress IAPS and promote other species. Gound vegetation is often cleared during silviculture activities which can be counter-productive in terms of IAPS management because such activities provide conducive environment for establishment of and recolonization by IAPS. Increase in tree canopy can also suppress growth of IAPS in forest (Khaniya and Shrestha 2020, Sharma *et al*. 2022) which is an untold success story of many Community forests of Nepal.

For effective management of IAPS in community managed forests, it is essential to include IAPS management components in the Operational Plans of the Community forests. More importantly, communication of IAPS related information with community members timely and in effective way will ensure their participation in the management of IAPS in forests and beyond.

## 5. Conclusions

The problem of plant invasions is already high in Gandaki Province with occurrence of more than 80% of the invasive alien plant species (IAPS) reported in Nepal. Five of the six globally noxious IAPS present in Nepal are also invading various ecosystems of Gandaki Province. The problem of plant invasion is likely to increase further in future due to, among others, high probability of introduction of additional IAPS, expansion of currently established IAPS to new locations and increase in climatically suitable areas as a result of climate change. Local communities have put some efforts to manage IAPS in their own at the local level but they are mostly ineffective due to lack of required knowledge and technical supports. Furthermore, there is a lack of formal and dedicated government strategy and institution at the national and province level to guide and coordinate IAPS management activities at various goverment levels. Participation of local communites including agrarian and forest dependent households is indispensable for effective management of IAPS but their participation can be anticipated only when communities are informed and educated adequately, effectively and timely.

Management options are available, as elaborated in a previous section (4.5), depending on the species in question, invasion stage, dispersal pathways and invaded habitats with several success stories in different parts of the world. There are data gaps but the current knowledge is adequate for the national and province level governments to initiate prevention and control programs targeting priority species identified by this study. There are opportunities for prevention, eradication and containment of some IAPS in Gandaki Province but such opportunities will be lost over the time if not action taken on time. Timely implementation of management options identified in this research reports not only delivers benefits to local communities but also helps to meet several national (e.g. National Biodiversity Strategy and Action Plan) and global goals/targets (e.g. Sustainable Development Goals, targets of Post-2020 Global Biodiversity Framework of the Convention on Biological Diversity) related to biodiversity conservation and sustainable development.

# 6. Way forwards

To address the emerging problems of plant invasions in Gandaki Province, various management options have been identified and elaborated in a previous section (4.5). They are summarized below:

- Prevevntion of species (*Sphagneticola trilobata, Mimosa diplotricha, Myriophyllum aquaticum, Tithonia diversifolia* and *Erigeron karvinskianus*) that are currently absent in Gankaki province but have already invaded other regions in Nepal
- Eradication of satellite populations of *Mikania micrantha, Lantana camara* and *Parthenium hysterophorus* in their invasion fronts to prevent their further spread.
- Eradication of *Pontederia crassipes* and *Pistia stratiotes*from wetlands including Ramsar sites
- Ban on cultivation of *Pontederia crassipes, Pistia stratiotes*and *Lantana camara* in ornamental gardens; deprioritization of *Leucaena leucocephala* in plantation and agroforestry activities.
- Mass rearing of a biological control agent (*Zygogramma bicolorata*) against *Parthenium hysterophorus* and release in to the invaded sites.

- Selective removal of target IAPS with minimum damage to other species during silvicultural practices in community managed forests.

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# Appendix

## Appendix 1. Checklist of the questionnaire for the Focus Group Discussions

### Distribution and Impacts of Five Major Invasive Alien Plant Species in Gandaki Province

**(Supported by *FRTC, Gandaki*; Commissioned by *SMART Pvt Ltd.*)**

**Checklist of the questions for Focus Group Discussion**

SN: ………..… Date (Y/M/D): 2078/………/……..... District: ………………………………
Rural/Municipality: …………………… Ward no:……… Locality:……………………….
Name of CFUG:………………………………………… Year of hand over (BS): ………
Area (ha): …………. Number of households: ………………Forest type: ……………………
Dominant tree species:……………………………………………………………………
………………………………………………………………………………………………
Other noteworthy species: ……………………………………………………………………

1. **What are the problematic invasive alien plant speciesin different ecosystems?**

| Land use | Problematic invasive alien plant species (IAPS) |
|---|---|
| Forest | |
| Shrubland | |
| Grassland | |
| Farmlands | |
| Wetlands and water bodies | |
| Residential areas | |

2. **What are the most problematic five invasive alien plant species? *[1: most problematic, 5: least problematic]***

| SN | Name of IAPS | Invaded Ecosystems | Major impacts on ecosystems and livelihood |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |

*3.* **When the IAPS were first observed? In which ecosystems were they sighted first?**

| SN | Name of IAPS | When was first sighted (Years before) | First sighted in (Name of ecosystems/Habitat) | Possible dispersal modes |
|---|---|---|---|---|
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |

*4.* **What are the current methods of management of IAPS?**

| SN | Name of IAPS | Details of the methods used | Effectiveness of the management |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| | | | |

**5. Was any of the IAPS put into use? [e.g. c*omposting, fencing, ornamental*]**

| SN | Name of IAPS | Details of the uses |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |
| 6 | | |

*6. Have you ever been informed by any person or institutions (government/non-government) about the problem of IAPS? If yes, when? By which institution? What did they inform?*

*7. Is there any activity included in the Operational Plan of the Community forests to manage IAPS? If yes, what are they?*

*8.* Any other relevant information?

*9. Details of the FGD participants*

| SN | Name | Gender | Age | Education | Position in CFUG |
|---|---|---|---|---|---|
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| 5 | | | | | |
| 6 | | | | | |
| 7 | | | | | |
| 8 | | | | | |

| Name of researcher (s): |
|---|

## *Appendix 2. List of participants of the Focused Group Discussions (FGD)*

| SN | Name | Gender (M: male/F: Female) | Position in CFUG |
|---|---|---|---|
| *FGD 1: Gorkha; Ajirkot-4, Baluwa [Simjung CFUG]* | | | |
| 1 | Khomaya Gurung | F | General member |
| 2 | Ratnaman Gurung | M | General member |
| 3 | Manoj Kunwar | M | General member |
| 4 | Dhankumari Kunwar | F | General member |
| 5 | Rina Tamang | F | General member |
| *FGD 2: Gorkha; Palungtar-1, Satdobato [Khoplang CFUG]* | | | |
| 1 | Ishwor Adikari | M | President |
| 2 | Rajan Shrestha | M | Executive member |
| 3 | Govinda Shrestha | M | Executive member |
| 4 | Krishna Bdr. Kumal | M | Executive member |
| 5 | Basuraj Bista | M | Executive member |
| 6 | Mangal Bdr. Kumal | M | Executive member |
| *FGD 3: Parbat; Kusma – 11, Chapa [Sirbari CFUG]* | | | |
| 1 | Durga Rana | F | General member |
| 2 | Shambhu Sharma | M | General member |
| 3 | Geeta Thapa | F | General member |
| 4 | Kalawati Rana | F | General member |
| 5 | Durga Sharma | F | General member |
| 6 | Tika Rana | F | General member |
| *FGD 4: Parbat; Kusma – 3, Deurali (Durlung) [Jhakri Salla CFUG]* | | | |
| 1 | Sher Bdr. Chettri | M | Past President |
| 2 | Bhagawati Chettri | F | General member |
| 3 | Man Chettri | M | General member |
| 4 | Ganesh Bdr. Chettri | M | General member |
| 5 | Sher Bdr. Chettri | M | General member |
| *FGD 5: Syanja; Kaligandaki – 1, Lehug [Private forest]* | | | |
| 1 | Minaloa Lamichhane | F | General member |
| 2 | Joni Gaha Magar | F | General member |
| 3 | Bishal Gaha Magar | M | General member |
| 4 | Dilu Gaha Magar | F | General member |
| 5 | Karishma Gaha Magar | F | General member |
| 6 | Tek Bdr. Gaha Magar | M | General member |
| 7 | Rana Manu Gaha Magar | F | General member |
| 8 | Topali Gaha Magar | F | General member |
| 9 | Ati Reshmi Gaha Magar | F | General member |
| *FGD 6: Syanja; Putalibazaar – 12, Pelkachaur [Manakamana CFUG]* | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

| | | | |
|---|---|---|---|
| *FGD 7: Kaski; Pokhara Metropolitan – 23, Harpan [Bhirpani CFUG]* | | | |
| 1 | Haribhakta Poudel | M | President |
| 2 | Baburam Poudel | M | Vice Chair Person |
| 3 | Sagar Poudel | M | General member |
| 4 | Khanlal Poudel | M | General member |
| 5 | Apsara Poudel | F | General member |
| 6 | Sita Poudel | F | General member |
| 7 | Apsara Kumari Poudel | F | General member |
| 8 | Gyan Bdr. Chettri | M | General member |
| 9 | Tarka Prasad Poudel | M | General member |
| 10 | Durga Prasad Poudel | M | General member |
| 11 | Kalpana Poudel | F | Executive member |
| *FGD 8: Kaski; Pokhara Metropolitan – 21, Shivadhunga [Baunnelek CFUG]* | | | |
| 1 | Hasta Bdr. Kusta | M | General member |
| 2 | Sita Kunwar | F | General member |
| 3 | Pratima Kunwar | F | Executive member |
| 4 | Devi Kunwar | F | Executive member |
| 5 | Dallu Bhujel | M | General member |
| 6 | Kaaji Kunwar | M | General member |
| *FGD 9: Kaski; Madi – 4, Sanke Pakha [Sanike Thaleka CFUG]* | | | |
| 1 | Krishna Bdr. B.K | M | General member |
| 2 | Teknath Sapkota | M | General member |
| 3 | Bhupal Pariyar | M | General member |
| 4 | Baburam Sapkota | M | General member |
| 5 | Ananda Sapkota | M | General member |
| 6 | Sukra Pariyar | M | General member |
| 7 | Man Bdr. Shahi | M | General member |
| 8 | Saroj Thapa | M | General member |
| *FGD 10: Lamjung; Madhya Nepal – 3, Suryapal [Suryapal CFUG]* | | | |
| 1 | Shiva Sharma | M | General member |
| 2 | Saroj Pahari | M | General member |
| 3 | Puspa Dawadi | F | General member |
| 4 | Indra Dawadi | M | General member |
| 5 | Krishna Poudel | M | General member |
| *FGD 11: Myagdi Malika – 7 Darbang [Banchare CFUG]* | | | |
| 1 | Harka Bahadur Tamang | M | General member |
| 2 | Daiaba Karki | F | General member |
| 3 | Hit Bahadur Magar | M | General member |
| 4 | Sun Maya Tamang | F | General member |
| 5 | Chitra Bahadur Magar | M | General member |
| *FGD 12: Baglung; Kathe Khola – 5, Thandande [Thandande CFUG]* | | | |
| 1 | Rajesh Paudel | M | General member |
| 2 | Kaashi Paudel | M | General member |
| 3 | Bhola Prasad Sharma | M | General member |
| 4 | Tarake Bahadur Chhetri | M | General member |
| 5 | Hari Maya | F | General member |

| | | | |
|---|---|---|---|
| *FGD 13: Baglung, Dhorpatan – 1, Khapri Bang [Turture Khani CFUG]* | | | |
| 1 | Rajesh Paudel | M | General member |
| 2 | Kaashi Paudel | M | General member |
| 3 | Bhola Prasad Sharma | M | General member |
| 4 | Tarake Bahadur Chhetri | M | General member |
| 5 | Hari Maya | F | General member |
| *FGD 14: Tanahun; Anbu Khaireni – 4, Aklang [Aklang CFUG]* | | | |
| 1 | Top Bahadur Magar | M | General member |
| 2 | Ramesh Chuman | M | Treasurer |
| 3 | Keshav Kandel | M | General member |
| 4 | Jarpan Adhikari | M | General member |
| 5 | Prakash Gurung | M | General member |
| 6 | Buddhi B. Kandel | M | General member |
| 7 | Kamala Shrestha | F | Secretary |
| *FGD 15: Tanahun; Anbu Khaireni – 3, Panighatta [Paharepaani CFUG]* | | | |
| 1 | Khim Bahadur Thapa Magar | M | Executive member |
| 2 | Harimaya Thapa Magar | F | Executive member |
| 3 | Krishnamaya Thapa Magar | F | Executive member |
| 4 | Suraj Thapa Magar | M | Executive member |
| 5 | Sanju Thapa Magar | F | Executive member |
| *FGD 16: Nawalparasi, Hupsekot – 1, Beluwa Tol [Trikone CFUG]* | | | |
| 1 | Hal Bahadur Soti | M | President |
| 2 | Man Bahadur Lama | M | Executive member |
| 3 | Dal Bahadur Thapa | M | Vice President |
| 4 | Ram Bahadur Gurung | M | Executive member |
| 5 | Nanda Kumari Mahato | F | Secretary |
| 6 | Khim Bahadur Pun | M | General member |
| 7 | Suman Pun | M | General member |
| 8 | Dhan Maya Malla | F | Executive member |
| *FGD 17: Nawalparasi; Kawaswoti – 15, Baghkhore [Gundrahidhakaha Buffer Zone CFUG]* | | | |
| 1 | Dambar Bahadur Mahato | M | Executive member |
| 2 | Nar Bahadur Mahato | M | President |
| 3 | Krishna Bahadur Mahato | M | General member |
| 4 | Nabin Mahato | M | General member |
| 5 | Prem Narayan Mahato | M | Executive member |
| *FGD 18: Nawalparasi; Kawaswoti – 10, Magarkot [Krishnasaar Buffer Zone CFUG]* | | | |
| 1 | Rishikesh Bhattarai | M | Past President |
| 2 | Krishna Prasad Poudel | M | General member |
| 3 | Lok Raj Bhattarai | M | Secretary |
| 4 | Basundhara Bhurtel | F | General member |
| 5 | Madhav Aryal | M | General member |

## *Appendix 3. Location of grids and sample plots*

| SN | Grid No | Plot No | District | Rural/ Municipality | Ward No | Locality | Latitude | Longitude | Elevation |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 12 | 1 | Gorkha | Ajirkot | 4 | Simjung | 28.1479 | 84.6974 | 716m |
| 2 | 12 | 2 | Gorkha | Ajirkot | 4 | Baluwa | 28.1693 | 84.7043 | 808m |
| 3 | 12 | 3 | Gorkha | Ajirkot | | Barpak Fedi | 28.1866 | 84.7157 | 889m |
| 4 | 12 | 4 | Gorkha | Ajirkot | 4 | Simjung | 28.1788 | 84.6993 | 1333m |
| 5 | 12 | 5 | Gorkha | Ajirkot | | | 28.1752 | 84.7110 | 870m |
| | | | | | | | | | |
| 6 | 88 | 1 | Gorkha | Palungtar | 1 | Satdobato | 28.0039 | 84.5696 | 434m |
| 7 | 88 | 2 | Gorkha | Palungtar | 1 | Satdobato | 27.9987 | 84.5634 | 482m |
| 8 | 88 | 3 | Gorkha | Palungtar | 1 | khoplang,Sat dobato | 27.9996 | 84.5629 | 424m |
| 9 | 88 | 4 | Gorkha | Palungtar | 1 | Satdobato roadway | 27.9918 | 84.5579 | 483m |
| 10 | 88 | 5 | Gorkha | Palungtar | 1 | | | | |
| | | | | | | | | | |
| 11 | 73 | 1 | Parbat | Kushma | | Ratmata | 28.2571 | 83.7446 | 1130m |
| 12 | 73 | 2 | Parbat | Kushma | 11 | Chapa | | | |
| 13 | 73 | 3 | Parbat | Kushma | | Thati | 28.2402 | 83.7414 | 1514m |
| 14 | 73 | 4 | Parbat | Kushma | 11 | Bhalukhola | 28.2444 | 83.7394 | 1358m |
| 15 | 73 | 5 | Parbat | Kushma | | Thulipokhari | 28.2429 | 83.7471 | 1558m |
| | | | | | | | | | |
| 16 | 124 | 1 | Parbat | Kushma | 3 | Durlung | 28.2445 | 83.6875 | 1521m |
| 17 | 124 | 2 | Parbat | Kushma | 3 | Durlung | 28.2289 | 83.6881 | 1183m |
| 18 | 124 | 3 | Parbat | Kushma | 3 | Durlung | 28.2483 | 83.6889 | 1602m |
| 19 | 124 | 4 | Parbat | Kushma | 3 | Durlung | 28.2473 | 83.6957 | 1455m |
| 20 | 124 | 5 | Parbat | Kushma | | upper part of Chuwa | 28.2405 | 83.6979 | 1176m |
| | | | | | | | | | |
| 21 | 115 | 1 | Syangja | Kaligandaki | 1 | Lehog | 27.9582 | 83.4838 | 1181m |
| 22 | 115 | 4 | Syangja | Kaligandaki | 1 | Chandi Bhanjyang | 27.9416 | 83.4783 | 1184m |
| 23 | 115 | 2 | Syangja | Kaligandaki | | Almadevi | 27.9555 | 83.5119 | 1319m |
| 24 | 115 | 3 | Syangja | Kaligandaki | 1 | Chapdada | 27.9566 | 83.4912 | 1214m |
| 25 | 115 | 5 | Syangja | Kaligandaki | 1 | Beldhara | 27.9663 | 83.4898 | 701m |
| | | | | | | | | | |
| 26 | 137 | 1 | Syangja | Putalibazzar | 1 | Pelkachaur | 28.0685 | 83.8462 | 1371m |
| 27 | 137 | 2 | Syangja | Putalibazzar | 1 | Pelkachaur | 28.0579 | 83.8364 | 1459m |
| 28 | 137 | 3 | Syangja | Putalibazzar | | | 28.0686 | 83.8387 | 1360m |
| 29 | 137 | 4 | Syangja | Putalibazzar | | | 28.0613 | 83.8482 | 1704m |
| 30 | 137 | 5 | Syangja | Putalibazzar | | Lumdi | 28.0667 | 83.8478 | 1390m |
| | | | | | | | | | |
| 31 | 113 | 1 | Parbat | Kushma | | Simliphant | 28.2149 | 83.6878 | 783m |
| 32 | 113 | 2 | Parbat | Kushma | | Chaupari | 28.2123 | 83.6952 | 889m |
| 33 | 113 | 3 | Parbat | Kushma | | Patheswori Mandir | 28.2061 | 83.6812 | 847m |

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| 34 | 113 | 4 | Parbat | Kushma | | Khariya bridge | 28.2156 | 83.6922 | 852m |
| 35 | 113 | 5 | Parbat | Kushma | | Lange ban | 28.1936 | 83.6952 | 993m |
| | | | | | | | | | |
| 36 | 122 | 1 | Kaski | Pokhara Metropolitician | 23 | Ghatichina | 28.2398 | 83.8497 | 982m |
| 37 | 122 | 2 | Kaski | Pokhara Metropolitician | 23 | Harpankot Village | 28.2493 | 83.8607 | 1229m |
| 38 | 122 | 3 | Kaski | Pokhara Metropolitician | 23 | Harpankot Village | 28.8436 | 83.8414 | 1063m |
| 39 | 122 | 4 | Kaski | Pokhara Metropolitician | 23 | Kubindanda Village | 28.2379 | 83.8343 | 1355m |
| 40 | 122 | 5 | Kaski | Pokhara Metropolitician | 23 | Lower Sidhane | 28.2258 | 83.8273 | 1575m |
| | | | | | | | | | |
| 41 | 111 | 1 | Kaski | Pokhara Metropolitician | 17 | Shiv dhunga | 28.1567 | 83.9377 | 1165m |
| 42 | 111 | 2 | Kaski | Pokhara Metropolitician | 17 | Nachnechuar | 28.2493 | 83.8607 | 1229m |
| 43 | 111 | 3 | Kaski | Pokhara Metropolitician | 21 | Thakuri Gau | 28.1603 | 83.9445 | 1289m |
| 44 | 111 | 4 | Kaski | Pokhara Metropolitician | 17 | Pumdi | 28.1769 | 83.9584 | 907m |
| 45 | 111 | 5 | Kaski | Pokhara Metropolitician | 17 | Kristi | 28.1582 | 83.9460 | 1224m |
| | | | | | | | | | |
| 46 | 18 | 2 | Baglung | Dhorpatan | | | 28.4956 | 83.0467 | 2879m |
| 47 | 18 | 3 | Baglung | Dhorpatan | | | 28.4992 | 83.0274 | 2868m |
| 48 | 18 | 4 | Baglung | Dhorpatan | | | 28.5065 | 83.0161 | 2862m |
| | | | | | | | | | |
| 49 | 36 | 1 | Baglung | Dhorpatan | | | 28.2971 | 83.1739 | 1016m |
| 50 | 36 | 2 | Baglung | Dhorpatan | | | 28.3059 | 83.1754 | 1065m |
| 51 | 36 | 3 | Baglung | Dhorpatan | | Burtibang-shera | 28.3136 | 83.1703 | 1156m |
| 52 | 36 | 4 | Baglung | Dhorpatan | 2 | Shera | 28.3140 | 83.1624 | 1056m |
| 53 | 36 | 5 | Baglung | Dhorpatan | | Kuthapla | 28.3261 | 83.1553 | 1214m |
| | | | | | | | | | |
| 54 | 126 | 2 | Myagdi | Dhaulagiri | 7 | Takam | 28.4674 | 83.3664 | 1635m |
| 55 | 126 | 3 | Myagdi | Dhaulagiri | 7 | Takam | 28.4719 | 83.3575 | 1664m |
| 56 | 126 | 4 | Myagdi | Dhaulagiri | 7 | Takam High School | 28.4716 | 83.3580 | 1660m |
| 57 | 126 | 5 | Myagdi | Dhaulagiri | 7 | Devisthan/ Takam | 28.4772 | 83.3510 | 1705m |
| 58 | 126 | 1 | Myagdi | Dhaulagiri | 7 | Takam | 28.4741 | 83.3469 | 1897m |
| | | | | | | | | | |
| 59 | 114 | 1 | Myagdi | Malika | 7 | | 28.4296 | 83.3841 | 1167m |
| 60 | 114 | 2 | Myagdi | Malika | 7 | Darbang | 28.4132 | 83.3874 | 1141m |
| 61 | 114 | 3 | Myagdi | Malika | 7 | Darbang-Muna | 28.4212 | 83.3848 | 1246m |
| 62 | 114 | 4 | Myagdi | Malika | 7 | Si Redi | 28.4085 | 83.3938 | 1359m |
| | | | | | | | | | |
| 63 | | 1 | Myagdi | Dhaulagiri | 4 | Muna-Takam | 28.5181 | 83.2850 | 2188m |
| 64 | | 2 | Myagdi | Dhaulagiri | 3 | Muna- | 28.5199 | 83.2710 | 2376m |

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| | | | | | | Mareni | | | |
| 65 | | 3 | Myagdi | Dhaulagiri | | Lulang | 28.5257 | 83.2678 | 2358m |
| | | | | | | | | | |
| 66 | 15 | 1 | Baglung | Kanthekhola | 5 | Thandanda | 28.2487 | 83.4880 | |
| 67 | 15 | 2 | Baglung | | 5 | Pokhara Bajar | 28.2582 | 83.4912 | 1775m |
| 68 | 15 | 3 | Baglung | Kanthekhola | 6 | Bihunkot | 28.2570 | 83.5020 | 1784m |
| 69 | 15 | 4 | Baglung | Kanthekhola | 5 | Bihunkot | 28.2434 | 83.4961 | 1563m |
| 70 | 15 | 5 | Baglung | Kanthekhola | 5 | Suldanda | 28.2522 | 83.4941 | 1665m |
| | | | | | | | | | |
| 71 | 131 | 1 | Baglung | Dhorpatan | 1 | Burtibang | 28.3376 | 83.1612 | 1137m |
| 72 | 131 | 2 | Baglung | Dhorpatan | 1 | Hundraphedi( Mandirthan) | 28.3467 | 83.1652 | 1481m |
| 73 | 131 | 3 | Baglung | Dhorpatan | | Purkot-Hundraphedi | 28.3549 | 83.1693 | |
| 74 | 131 | 4 | Baglung | Dhorpatan | 1 | Hundraphedi | 28.3546 | 83.1791 | 1219m |
| 75 | 131 | 5 | Baglung | Dhorpatan | 1 | Dhaibang | 28.3546 | 83.1887 | 1511m |
| | | | | | | | | | |
| 76 | 40 | 1 | Kaski | Madi | 4 | Sapkota Gau, Tarkang | 28.2306 | 84.0999 | 939m |
| 77 | 40 | 2 | Kaski | Madi | 4 | Tarkang | 28.2389 | 84.0981 | 1020m |
| 78 | 40 | 3 | Kaski | Madi | 3 | Thumako Danda | 28.2545 | 84.0946 | 1325m |
| 79 | 40 | 4 | Kaski | Madi | 4 | Thumako Danda | 28.2504 | 84.1004 | 1423m |
| 80 | 40 | 5 | Kaski | Madi | 3 | Madi Gaupalika Office | 28.2559 | 84.1006 | 1460m |
| | | | | | | | | | |
| 81 | 39 | 1 | Tanahun | Vyas | 11 | Amreni | 27.9878 | 84.2872 | 347m |
| 82 | 39 | 2 | Tanahun | Vyas | 11 | Ghasikuwa | 27.9860 | 84.2966 | 352m |
| 83 | 39 | 3 | Tanahun | Vyas | 11 | Ghasikuwa | 27.9874 | 84.3051 | 342m |
| 84 | 39 | 4 | Tanahun | Vyas | 11 | Ghasikuwa | 27.9874 | 84.3128 | 348m |
| 85 | 39 | 5 | Tanahun | Vyas | 11 | Ghasikuwa | 27.9889 | 84.3218 | 485m |
| | | | | | | | | | |
| 86 | 49 | 1 | Tanahun | Vyas | 10 | Dumsibazar | 28.0100 | 84.2543 | 349m |
| 87 | 49 | 2 | Tanahun | Vyas | 10 | Dumsibazar | 28.0163 | 84.2576 | 340m |
| 88 | 49 | 3 | Tanahun | Vyas | 10 | Khahare | 28.0203 | 84.2613 | 342m |
| 89 | 49 | 4 | Tanahun | Vyas | 10 | Kasleti | 28.0273 | 84.2581 | 332m |
| 90 | 49 | 5 | Tanahun | Vyas | 10 | Kalesti | 28.0316 | 84.2532 | 369m |
| | | | | | | | | | |
| 91 | 26 | 1 | Tanahun | Aabukhaireni | | Chhimkeshw ori | 27.8716 | 84.5201 | 1076m |
| 92 | 26 | 2 | Tanahun | Aabukhaireni | N/A | Chhimkeshw ori | 27.8698 | 84.5212 | 1111m |
| 93 | 26 | 3 | Tanahun | Aabukhaireni | | Chhimkeshw ori | 27.8651 | 84.5198 | 1247m |
| 94 | 26 | 4 | Tanahun | Aabukhaireni | | Chhimkeshw ori | 27.8634 | 84.5146 | 1376m |
| 95 | 26 | 5 | Tanahun | Aabukhaireni | | Chhimkeshw ori | 27.8650 | 84.5084 | 1380m |
| | | | | | | | | | |

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|---|---|---|---|---|---|---|---|---|---|
| 96 | 85 | 1 | Tanahun | Bhanu | 5 | Bhansar | 28.0006 | 84.4190 | 445m |
| 97 | 85 | 2 | Tanahun | Bhanu | 5 | Bhansar | 28.0068 | 84.4115 | 480m |
| 98 | 85 | 3 | Tanahun | Bhanu | 5 | Bhanu | 28.0056 | 84.4057 | 471m |
| 99 | 85 | 4 | Tanahun | Bhanu | 5 | Bhansar | 27.9974 | 84.4048 | 483m |
| 100 | 85 | 5 | Tanahun | Bhanu | 5 | Bhansar | 27.9944 | 84.4052 | 489m |
| | | | | | | | | | |
| 101 | 33 | 1 | Tanahun | Vyas | 5 | Sirdi | 27.9807 | 84.2431 | 415m |
| 102 | 33 | 2 | Tanahun | Vyas | 5 | Sirdi | 27.9809 | 84.2509 | 400m |
| 103 | 33 | 3 | Tanahun | Vyas | 5 | Sirdi | 27.9810 | 84.2570 | 330m |
| 104 | 33 | 4 | Tanahun | Vyas | 5 | Sirdi | 27.9844 | 84.2544 | 324m |
| 105 | 33 | 5 | Tanahun | Vyas | 5 | Chapaghat | 27.9791 | 84.2647 | 318m |
| | | | | | | | | | |
| 106 | 3 | 1 | Tanahun | Myagde | 1 | Gunadi | 27.9798 | 84.2362 | 466m |
| 107 | 3 | 2 | Tanahun | Myagde | 1 | Gunadi | 27.9786 | 84.2270 | 500m |
| 108 | 3 | 3 | Tanahun | Myagde | 1 | Gunadi | 27.9778 | 84.2153 | 510m |
| 109 | 3 | 4 | Tanahun | Myagde | 1 | Gunadi | 27.9815 | 84.2080 | 510m |
| 110 | 3 | 5 | Tanahun | Myagde | 1 | Gunadi | 27.9837 | 84.2028 | 478m |
| | | | | | | | | | |
| 111 | 91 | 1 | Nawalpur | Kawasoti | 15 | Shergunj | 27.5906 | 84.1138 | 140m |
| 112 | 91 | 2 | Nawalpur | Kawasoti | 15 | Shergunj | 27.5848 | 84.1070 | 154m |
| 113 | 91 | 3 | Nawalpur | Kawasoti | 15 | Shergunj | 27.5796 | 84.1092 | 144m |
| 114 | 91 | 4 | Nawalpur | Kawasoti | 15 | Shergunj | 27.5716 | 84.1051 | 138m |
| 115 | 91 | 5 | Nawalpur | Kawasoti | 15 | Shergunj | 27.5687 | 84.1098 | 147m |
| | | | | | | | | | |
| 116 | 138 | 1 | Nawalpur | Kawasoti | 13 | Forest | 27.6413 | 84.1367 | 183m |
| 117 | 138 | 2 | Nawalpur | Kawasoti | 13 | Kusneli | 27.6339 | 84.1404 | 160m |
| 118 | 138 | 3 | Nawalpur | Kawasoti | 13 | Kusneli | 27.6268 | 84.1455 | 156m |
| 119 | 138 | 4 | Nawalpur | Kawasoti | 13 | Laukhali | 27.6271 | 84.1526 | 164m |
| 120 | 138 | 5 | Nawalpur | Kawasoti | 13 | | 27.6267 | 84.1587 | 157m |
| | | | | | | | | | |
| 121 | 72 | 1 | Nawalpur | Susta RM | 2 | Saatpati | 27.4755 | 83.8644 | 122m |
| 122 | 72 | 2 | Nawalpur | Susta RM | 2 | Saatpati | 27.4732 | 83.8732 | 122m |
| 123 | 72 | 3 | Nawalpur | Susta RM | 2 | Saatpati | 27.4772 | 83.8784 | 148m |
| 124 | 72 | 4 | Nawalpur | Susta RM | 2 | Saatpati | 27.4838 | 83.8838 | 165m |
| 125 | 72 | 5 | Nawalpur | Susta RM | 1 | Saatpati | 27.4686 | 83.8855 | 118m |
| | | | | | | | | | |
| 126 | 83 | 1 | Nawalpur | Triveni RM | 3 | Sunahi | 27.6595 | 83.8770 | 190m |
| 127 | 83 | 2 | Nawalpur | Triveni RM | 3 | Sunahi | 27.6652 | 83.8846 | 216m |
| 128 | 83 | 3 | Nawalpur | Triveni RM | 3 | Upper sunahi | 27.6725 | 83.8916 | 223m |
| 129 | 83 | 4 | Nawalpur | Triveni RM | 3 | Sunahi | 27.6680 | 83.8936 | 212m |
| 130 | 83 | 5 | Nawalpur | Triveni RM | 3 | Forest | 27.6683 | 83.9089 | 258m |
| | | | | | | | | | |
| 131 | 47 | 1 | Nawalpur | Madhyabindu Municipality | 5 | Daunbari | 27.5826 | 84.0224 | 138m |
| 132 | 47 | 2 | Nawalpur | Madhyabindu Municipality | 6 | Hardiya | 27.5758 | 84.0203 | 136m |
| 133 | 47 | 3 | Nawalpur | Madhyabindu Municipality | 6 | Ghadara | 27.5755 | 84.0115 | 136m |

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| 134 | 47 | 4 | Nawalpur | Madhyabindu Municipality | 6 | Bhandara | 27.5685 | 84.0094 | 131m |
| 135 | 47 | 5 | Nawalpur | Madhyabindu Municipality | 6 | Bhandara | 27.5630 | 84.0025 | 130m |
| | | | | | | | | | |
| 136 | 56 | 1 | Nawalpur | Triveni Municipality | 1 | Forest | 27.6014 | 83.8991 | 193m |
| 137 | 56 | 2 | Nawalpur | Triveni Municipality | 1 | Forest | 27.6020 | 83.9098 | 192m |
| 138 | 56 | 3 | Nawalpur | Triveni Municipality | 1 | Forest | 27.6038 | 83.9241 | 199m |
| 139 | 56 | 4 | Nawalpur | Triveni Municipality | 1 | Forest | 27.6050 | 83.9348 | 190m |
| 140 | 56 | 5 | Nawalpur | Madhyabindu Municipality | 10 | Madhyabindu | 27.6125 | 83.9464 | 182m |
| | | | | | | | | | |
| 141 | 1 | 1 | Nawalpur | Kawasoti Municipality | N/A | Danda | 27.6219 | 84.0800 | 175m |
| 142 | 1 | 2 | Nawalpur | Kawasoti Municipality | N/A | Danda | 27.6244 | 84.0707 | 201m |
| 143 | 1 | 3 | Nawalpur | Madhyabindu Municipality | N/A | Madhyabindu | 27.6258 | 84.0598 | 209m |
| 144 | 1 | 4 | Nawalpur | Madhyabindu Municipality | N/A | Madhyabindu | 27.6196 | 84.0586 | 199m |
| 145 | 1 | 5 | Nawalpur | Madhyabindu Municipality | N/A | Madhyabindu | 27.6247 | 84.0460 | 181m |
| | | | | | | | | | |
| 146 | 66 | 1 | Nawalpur | Madhyabindu Municipality | 11 | Khayar Sal | 27.6337 | 83.9637 | 184m |
| 147 | 66 | 2 | Nawalpur | Madhyabindu Municipality | 11 | Khayar Sal | 27.6453 | 83.9608 | 212m |
| 148 | 66 | 3 | Nawalpur | Madhyabindu Municipality | 11 | Khayar Sal | 27.6574 | 83.9605 | 205m |
| 149 | 66 | 4 | Nawalpur | Madhyabindu Municipality | 11 | Khayar Sal | 27.6664 | 83.9599 | 207m |
| 150 | 66 | 5 | Nawalpur | Madhyabindu Municipality | 11 | Khayar Sal | 27.6744 | 83.9600 | 238m |
| | | | | | | | | | |
| 151 | 91 | 1 | Nawalpur | Kawasoti Municipality | 15 | Kathauna | 27.5906 | 84.1138 | 150m |
| 152 | 91 | 2 | Nawalpur | Kawasoti Municipality | 15 | Sherganja | 27.5848 | 84.1070 | 155m |
| 153 | 91 | 3 | Nawalpur | Kawasoti Municipality | 15 | Sherganja | 27.5796 | 84.1092 | 148m |
| 154 | 91 | 4 | Nawalpur | Kawasoti Municipality | 15 | Godar | 27.5716 | 84.1051 | 151m |
| 155 | 91 | 5 | Nawalpur | Kawasoti Municipality | 15 | | 27.5687 | 84.1098 | 142m |
| | | | | | | | | | |
| 156 | 107 | 1 | Nawalpur | Triveni RM | | Forest | 27.6512 | 83.8549 | 191m |
| 157 | 107 | 2 | Nawalpur | Triveni RM | 3 | Sardi | 27.6597 | 83.8492 | 182m |
| 158 | 107 | 3 | Nawalpur | Triveni RM | 3 | Sardi(Katibas ghari) | 27.6574 | 83.8601 | 179m |
| 159 | 107 | 4 | Nawalpur | Triveni RM | 3 | Sardi | 27.6623 | 83.8572 | 187m |
| 160 | 107 | 5 | Nawalpur | Triveni RM | 3 | Sardi | 27.6673 | 83.8512 | 190m |
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| 161 | 80 | 1 | Nawalpur | Hupsikot RM | 4 | Hupsikot | 27.6834 | 84.0664 | 258m |
| 162 | 80 | 2 | Nawalpur | Hupsikot RM | 4 | Hupsikot | 27.6900 | 84.0621 | 161m |
| 163 | 80 | 3 | Nawalpur | Hupsikot RM | 4 | Jhyalbas | 27.6994 | 84.0619 | 303m |
| 164 | 80 | 4 | Nawalpur | Hupsikot RM | 4 | Kalodhunga | 27.7058 | 84.0612 | 303m |
| 165 | 80 | 5 | Nawalpur | Hupsikot RM | 4 | Kalodhunga | 27.7124 | 84.0578 | 323m |
| | | | | | | | | | |
| 166 | 44 | 1 | Nawalpur | Triveni RM | 6 | Keulani | 27.4620 | 83.9382 | 127m |
| 167 | 44 | 2 | Nawalpur | Triveni RM | 6 | Keulani | 27.4547 | 83.9322 | 121m |
| 168 | 44 | 3 | Nawalpur | Triveni RM | 6 | Keulani | 27.4502 | 83.9196 | 123m |
| 169 | 44 | 4 | Nawalpur | Triveni RM | 7 | Siprugadhi | 27.4520 | 83.9090 | |
| 170 | 44 | 5 | Nawalpur | Triveni RM | | | 27.4585 | 83.8969 | |
| | | | | | | | | | |
| 171 | 109 | 1 | Nawalpur | Triveni RM | 7 | Buddhanagar( Sipurgadhi) | 27.4605 | 83.9018 | 113m |
| 172 | 109 | 2 | Nawalpur | Triveni RM | 7 | | 27.4646 | 83.0982 | 117m |
| 173 | 109 | 3 | Nawalpur | Binaya Triveni RM | 6 | Kuwa Tole | 27.4613 | 83.9142 | 120m |
| 174 | 109 | 4 | Nawalpur | Triveni RM | 6 | Forest | 27.4700 | 83.9107 | 143m |
| 175 | 109 | 5 | Nawalpur | Triveni RM | 3 | Tandi | 27.6673 | 83.8512 | 198m |
| | | | | | | | | | |
| 176 | 32 | 1 | Nawalpur | Triveni RM | | | 27.6012 | 83.8552 | 160m |
| 177 | 32 | 2 | Nawalpur | Triveni RM | | | 27.6066 | 83.8487 | 174m |
| 178 | 32 | 3 | Nawalpur | Triveni RM | 2 | Dandajor | 27.6111 | 83.8432 | 186m |
| 179 | 32 | 4 | Nawalpur | Triveni RM | 2 | Ghaderi Tandi | 27.6115 | 83.8341 | 230m |
| 180 | 32 | 5 | Nawalpur | Triveni RM | 2 | Forest | 27.6117 | 83.8245 | 232m |
| 181 | 32 | 6 | Nawalpur | Triveni RM | 2 | Forest | 27.6152 | 83.8164 | 276m |
| | | | | | | | | | |
| 182 | 48 | 1 | Syangja | Putalibazar | | Badh Khola | 28.1077 | 83.8894 | 986 |
| 183 | 48 | 2 | Syangja | Putalibazar | | Badh Khola | 28.1136 | 83.8949 | 1151 |
| 184 | 48 | 3 | Syangja | Putalibazar | | Dandathar | 28.1115 | 83.8993 | 1094 |
| 185 | 48 | 4 | Syangja | Putalibazar | | Raniswara | 28.1212 | 83.8971 | 1364 |
| 186 | 48 | 5 | Syangja | Putalibazar | | Chaur | 28.1044 | 83.9050 | 968 |
| | | | | | | | | | |
| 187 | 90 | 5 | Syangja | Bhirkot | | Deurali Bhanjang | 28.0192 | 83.6944 | 1107 |
| 188 | 90 | 4 | Syangja | Bhirkot | | Dumre bhanjyang | 28.0020 | 83.7026 | 927 |
| 189 | 90 | 3 | Syangja | Bhirkot | | Chaapa | 28.0122 | 83.6875 | 1471 |
| 190 | 90 | 2 | Syangja | Bhirkot | | Hulkang | 28.0210 | 83.6931 | 1081 |
| 191 | 90 | 1 | Syangja | Bhirkot | | Kapasey | 28.0198 | 83.7025 | 1256 |
| | | | | | | | | | |
| 192 | 130 | 1 | Syangja | | | | 27.9740 | 83.6965 | 917 |
| 193 | 130 | 2 | Syangja | | | Khanidanda | 27.9773 | 83.7067 | 811 |
| 194 | 130 | 3 | Syangja | | | Dubindanda( Majhgare) | 27.9818 | 83.7009 | 902 |
| 195 | 130 | 4 | Syangja | | | Dadhakharka | 27.9841 | 83.6953 | 842 |
| 196 | 130 | 5 | Syangja | | | Udiyachaur | 27.9754 | 83.7105 | 781 |
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| 197 | 119 | 1 | Gorkha | Sahid Lakhan | | Bontar | 27.9038 | 84.5459 | 308 |
| 198 | 119 | 2 | Gorkha | Sahid Lakhan | 3 | Keurani | 27.9076 | 84.5498 | 337 |
| 199 | 119 | 3 | Gorkha | Sahid Lakhan | | | 27.9182 | 84.5534 | 782 |
| 200 | 119 | 4 | Gorkha | Sahid Lakhan | | Aarubot | 27.9106 | 84.5591 | 716 |
| | | | | | | | | | |
| 201 | 103 | 1 | Gorkha | Siranchowk | | Srinathkot | 28.0848 | 84.6588 | 579 |
| 202 | 103 | 2 | Gorkha | Siranchowk | | Bhalu Swarna | 28.0719 | 84.6574 | 558 |
| 203 | 103 | 3 | Gorkha | Siranchowk | | Alahul | 28.0966 | 84.6598 | 574 |
| 204 | 103 | 4 | Gorkha | Siranchowk | | | 28.0888 | 84.6534 | 541 |
| 205 | 103 | 5 | Gorkha | Siranchowk | | Shreenathkot | 28.1036 | 84.6615 | 617 |
| | | | | | | | | | |
| 206 | 42 | 1 | Gorkha | Ajirkot | | Chanaute | 28.1129 | 84.6648 | 628 |
| 207 | 42 | 2 | Gorkha | Ajirkot | | Chanaute | 28.1155 | 84.6669 | 655 |
| 208 | 42 | 3 | Gorkha | Ajirkot | | Ramche | 28.1309 | 84.6753 | 888 |
| 209 | 42 | 4 | Gorkha | Ajirkot | | Jiwadanda | 28.1305 | 84.6832 | 675 |
| 210 | 42 | 5 | Gorkha | Ajirkot | | Mucche Chowk | 28.1278 | 84.6623 | 1306 |
| | | | | | | | | | |
| 211 | 95 | 1 | Lamjung | Beshisahar | | Ram danda | 28.2399 | 84.3741 | 759 |
| 212 | 95 | 2 | Lamjung | Beshisahar | | Chandisthan | 28.2456 | 84.3609 | 1105 |
| 213 | 95 | 3 | Lamjung | Beshisahar | | Chandisthan | 28.2576 | 84.3566 | 1020 |
| 214 | 95 | 4 | Lamjung | Beshisahar | | Chandisthan | 28.2590 | 84.3492 | 940 |
| 215 | 95 | 5 | Lamjung | Beshisahar | | Chandisthan | 28.2605 | 84.3456 | 892 |
| | | | | | | | | | |
| 216 | 86 | 1 | Lamjung | Khwolashattar | | Ghaleshing | 28.2493 | 84.3115 | 1671 |
| 217 | 86 | 2 | Lamjung | Khwolashattar | | Maling | 28.2355 | 84.2893 | 1413 |
| 218 | 86 | 3 | Lamjung | Khwolashattar | | Ghalel Gaun | 28.2753 | 84.3117 | 2086 |
| | | | | | | | | | |
| 219 | 59 | 1 | Lamjung | Madhya Nepal | | Bhaguwa Bazar | 28.1088 | 84.3059 | 503 |
| 220 | 59 | 2 | Lamjung | Madhya Nepal | | Soti Pasal | 28.1006 | 84.2749 | 496 |
| 221 | 59 | 3 | Lamjung | Madhya Nepal | | Sami bhanjyang | 28.1217 | 84.2509 | 845 |
| 222 | 59 | 4 | Lamjung | Madhya Nepal | | Deurali | 28.1040 | 84.2403 | 644 |
| 223 | 59 | 5 | Lamjung | Madhya Nepal | | Duipiple | 28.0900 | 84.2409 | 460 |
| | | | | | | | | | |
| 224 | 27 | 1 | Lamjung | Madhya Nepal | | Karputar | 28.1581 | 84.2468 | 539 |
| 225 | 27 | 2 | Lamjung | Madhya Nepal | | Karputar | 28.1549 | 84.2296 | 483 |
| 226 | 27 | 3 | Lamjung | Madhya Nepal | | Bhorletar | 28.1607 | 84.2235 | 486 |
| 227 | 27 | 4 | Lamjung | Madhya Nepal | | Karputar | 28.1668 | 84.2498 | 485 |
| 228 | 27 | 5 | Lamjung | Madhya Nepal | | Sauli Bazar | 28.1777 | 84.2645 | 583 |
| | | | | | | | | | |
| 229 | 61 | 1 | Manang | Chame | | Chame | 28.5509 | 84.2405 | 2710 |
| 230 | 61 | 2 | Manang | Chame | | Chame | 28.5501 | 84.2456 | 2695 |
| 231 | 61 | 3 | Manang | Chame | | Koto Qupar | 28.5518 | 84.2607 | 2639 |
| | | | | | | | | | |
| 232 | 101 | 1 | Manang | Naso | | Tilche | 28.5724 | 84.4078 | 2508 |
| 233 | 101 | 2 | Manang | Naso | | Tilche | 28.5724 | 84.4078 | 2239 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 234 | 101 | 3 | Manang | Naso | | Tilche | 28.5425 | 84.3781 | 2248 |
| 235 | 101 | 4 | Manang | Naso | | Tilche | 28.5314 | 84.3669 | 2234 |
| 236 | 101 | 5 | Manang | Naso | | Tilche | 28.5324 | 84.3684 | 2232 |
| | | | | | | | | | |
| 237 | 127 | 1 | Kaski | Annapurna | | Sudame | 28.3348 | 83.7422 | 1311 |
| 238 | 127 | 2 | Kaski | Annapurna | | Hile | 28.3439 | 83.7420 | 1529 |
| 239 | 127 | 3 | Parbat | Modi | | Midu | 28.3341 | 83.7232 | 1746 |
| 240 | 127 | 4 | Parbat | Modi | | Chandi Chan | 28.3359 | 83.7356 | 1457 |
| 241 | 127 | 5 | Parbat | Modi | | Jhilli bharyang | 28.3417 | 83.7314 | 1711 |
| | | | | | | | | | |
| 242 | 133 | 1 | Kaski | Pokhara | | Vanu Chautirako Bhir | 28.1878 | 84.0914 | 750 |
| 243 | 133 | 2 | Kaski | Pokhara | | Syangkhudi | 28.1991 | 84.0943 | 829 |
| 244 | 133 | 3 | Kaski | Pokhara | | Bhurtel Gaun | 28.2073 | 84.0978 | 1015 |
| 245 | 133 | 4 | Kaski | Pokhara | | Lamichane Gau | 28.2062 | 84.1099 | 1045 |
| 246 | 133 | 5 | Kaski | Pokhara | | Majthana | 28.2046 | 84.1198 | 1138 |
| | | | | | | | | | |
| 247 | 74 | 1 | Kaski | Pokhara | | Buddhachow k | 28.2065 | 83.9941 | 844 |
| 248 | 74 | 2 | Kaski | Pokhara | | Ramghat | 28.2099 | 83.9941 | 846 |
| 249 | 74 | 3 | Kaski | Pokhara | | Matepani Ghumba | 28.2159 | 84.0060 | 863 |
| 250 | 74 | 4 | Kaski | Pokhara | | Nayagaun | 28.1978 | 83.9904 | 827 |
| 251 | 74 | 5 | Kaski | Pokhara | | Ban Campus | 28.1887 | 83.9911 | 808 |
| | | | | | | | | | |
| 252 | 24 | 1 | Mustang | Thasang | | Lete | 28.6003 | 83.6435 | 2015 |
| 253 | 24 | 2 | Mustang | Thasang | | Lete | 28.6074 | 83.6431 | 2115 |
| | | | | | | | | | |
| 254 | 46 | 1 | Kaski | Pokhara | | Khudi | 28.1526 | 84.0831 | 680 |
| 255 | 46 | 2 | Kaski | Pokhara | | Sundari danda | 28.1621 | 84.1072 | 811 |
| 256 | 46 | 3 | Kaski | Pokhara | | Majhikuna | 28.1697 | 84.1169 | 706 |
| 257 | 46 | 4 | Kaski | Pokhara | | Paachabhaya | 28.1637 | 84.0971 | 711 |
| 258 | 46 | 5 | Kaski | Pokhara | | Nagarchowk | 28.1605 | 84.0857 | 683 |
| | | | | | | | | | |
| 259 | 19 | 1 | Kaski | Pokhara | | Chorepatan | 28.1947 | 83.9565 | 786 |
| 260 | 19 | 2 | Kaski | Pokhara | | Way to Chinese Ghumba | 28.1981 | 83.9511 | 1022 |
| 261 | 19 | 3 | Kaski | Pokhara | | Shambala(Stu pa) | 28.2059 | 83.9441 | 873 |
| 262 | 19 | 4 | Kaski | Pokhara | | Pumdikot, Raniban Retreat | 28.2038 | 83.9355 | 1140 |
| 263 | 19 | 5 | Kaski | Pokhara | | Pumdikot | 28.1984 | 83.9259 | 1288 |
| | | | | | | | | | |
| 264 | 125 | 1 | Baglung | Dhorpatan | | | 28.4185 | 83.0984 | 1810 |
| 265 | 125 | 2 | Baglung | Dhorpatan | | | 28.4116 | 83.1011 | 1749 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 266 | 125 | 3 | Baglung | Dhorpatan | | Fedi | 28.4099 | 83.1215 | |
| 267 | 125 | 4 | Baglung | Dhorpatan | | | 28.4011 | 83.1179 | 1173 |
| 268 | 125 | 5 | Baglung | Dhorpatan | | | 28.3943 | 83.1114 | 1546 |

## Appendix 4. Data sheet for mapping invasive plants

**Distribution and Impacts of Five Major Invasive Alien Plant Species in Gandaki Province**

**(Supported by FRTC, Gandaki; Commissioned by SMART Pvt Ltd.)**

**Field Data Sheet**

SN:……… Grid no.:…………… Plot no. …………….. Locality:………………………….…
District:……..…………*Rural*/Municipality: ………………… *Ward no:…………………*
Way *point:* ………Lat.*(DD)* ………………, Long.*(DD)* …………… *Elev. (m): …………*
Aspect:………...…, Slope: ………………..……,
Pathway of search walk: 1) road, 2) major trail, 3) minor trail, 5) Others:……………
**Disturbance:** 1) Tree felling, 2) Grazing and trampling, 3) Fire, 4) Flood, 5) Landslide, 6) Excavation, 7) Construction activities, 8) Others: ………………………………

**Enumeration of invasive alien plant species *(IAPS)*** *(within ca. 5m x 5m plot)*

| SN | Name of IAPS | Cover class# | SN | Name of IAPS | Cover class# |
|---|---|---|---|---|---|
| 1 | | | 6 | | |
| 2 | | | 7 | | |
| 3 | | | 8 | | |
| 4 | | | 9 | | |
| 5 | | | 10 | | |

#Daubenmire Cover class – 1) 0-5%, 2) 5-25%, 3) 25-50%, 4) 50-75%, 5) 75-95%, 6) 95-100%

***IAPS found within ±20 m distance from the plot:***
*1)……………………………, 2) ……………………………, 3) …………………………………..*
*4)……………………………, 5) ……………………………….., 6) ………………………………….*

**Biological control agent of IAPS**:
1) *Stem galling in* Ageratina, *2) Beetle in* Parthenium, *3) Winter rust in* Parthenium

***Observed ecological/environmental impacts****[e.g. agriculture weed, prevent tree regeneration, displacement of forage species]*

| **SN** | **Observed impacts** | **Causative species** |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |

**Land use:**
A) Forest: Closed (canopy>40%), Open (canopy<40%); Forest type: …………………,
Dom. trees: 1) ……………………..… 2) ……………….............., 3) …………………
B) Shrubland: Dominant species: 1) ……………………….., 2) ……………………….…,
3) ………………………………..…………
C) Grassland: Dominant species: 1) ……………..……, 2) ……………………..………..
3) ……………………………..………..
D) Farmland: Irrigated/non-irrigated; Crops: 1) ……………………………
2) ………………………………..……… 3) ……………………………………………
E) Wetland: 1) pond (<8 ha), 2) lake (>8 ha), 3) river/spring side;
Dominant species: 1) ………………… 2) ……………….…, 3) ………………………

Additional information, if any:……………………………………………………………………
………………………………………………………………………………………………

………………………………………………………………………………………………

………………………………………………………………………………………………

………………………………………………………………………………………………

……………

**Name of enumerator *(s)***:…………………………………..
Date: ………………………… Photo no.:
……………………………………………………