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SPATIAL DISTRIBUTION OF INVASIVE ALIEN PLANTS IN POKHARA VALLEY, NEPAL

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Abstract

Urban areas often provide suitable microhabitats for the establishment of invasive alien plants (IAPs), which subsequently disseminate their propagules for further spread in surrounding landscape. Periodic survey of IAPs in urban areas not only brings opportunities for early detection and eradication of the invaders but also generate science-based information for the management of established IAPs. In this study, we inventoried IAPs and documented their spatial distribution in Pokhara valley, a popular tourist destination in Nepal. Using a checklist of 26 IAPs that have been reported from Nepal, we examined roadside vegetation in 201 plots (size: 5 m × 5 m) located at the interval of ca. 500 m in the valley. In each plot, the IAPs present were recorded along with geographic coordinates and land use type. Field data were used to calculate species richness, frequency, and prepare distribution maps of the IAPs. In Pokhara valley we recorded 20 IAPs, i.e. 77% of the total number of IAPs reported from Nepal. Four of the recorded IAPs: *Chromolaena odorata, Eichhornia crassipes, Lantana camara* and *Mikania micrantha* were among the 100 of the world's worst invasive species. *Bidens pilosa* had the highest frequency (63%), followed by *Ageratum houstonianum* (61%) and *Lantana camara* (44%). Small population of *Alternanthera philoxeroides*, and *Mesosphaerum suaveolens* were spotted at a single locations and *Mikania micrantha* at two locations, suggesting that they were at the early stage of invasion in the valley. Richness of IAPs was the highest in shrub land, followed by agriculture fallow land, and forest. Our data revealed that the Pokhara valley has already been invaded by a large number of IAPs, with possibility of arrival of new IAPs in near future. Periodic inventory and mapping of the IAPs would be helpful in identifying new IAPs and making management decisions timely.

Key words: Biological invasions, Land use pattern, Roadside survey, Satellite population, Species richness, Urban areas.

Introduction

Biological invasions have been attributed to species extinction, degradation of habitat, loss of biodiversity, alteration in ecological processes, and reduced ecosystem services to mankind (Charles & Dukes, 2007). Species introductions outside of their native range have been continuously increasing worldwide (Seebens *et al*., 2017). Some introduced plant species became naturalized, reproducing at high rate, and spreading rapidly (Richardson *et al*., 2000). A subset of the naturalized plants is invasive that colonize rapidly and cause significant harm to the natural environment, economy, and human health. Globalization of trade, travel and recent climate change have facilitated the spread of alien species across continents in the earth (Hulme, 2009), and Nepal is not an exception (Bhuju, *et al*. 2013, Shrestha *et al*., 2018).

At the landscape-level, species distribution is often the outcome of ecological processes like availability of suitable micro-habitat, composition in the neighborhood (i.e. landscape context), land-use changes, and dispersal (With, 2002). Understanding land use and land cover changes is useful for early detection and management of invasive plant species (Wang *et al*, 2016). Urban areas function as hot spots for biological invasions for which urban managers are not paying proper attention (Gaertner *et al*., 2017). Pokhara valley, the gateway to Annapurna range is one of such urban areas in Nepal, which is the largest city next to Kathmandu valley that attracts many tourists. The Valley has nine lakes which have been included in Ramsar site in 2016 (DDC Kaski, 2017).

Although IAPs were found in the Valley (Poudel, 2015), there has been no attempts to document their spatial distribution. Therefore, the present study was undertaken with following objectives: 1) to inventory the invasive alien plant species in Pokhara valley, and 2) to map their spatial distribution in relations to land use types. The results of this study have direct implications for the informed management decision to control plant invasions in the Pokhara valley.

Materials and Methods

Study area: The study area includes Pokhara valley including Puranchaur village in north and Gagangaunda village in south. The valley is located in central Nepal between 27˚55'-28˚23' north latitude and 83˚48'-84˚11' east longitude (Fig. 1). The study site accounts for an area of 133.41 sq. km in Pokhara Metropolitan city (Shrestha & Kshetri, 2008). Pokhara is one of the most visited tourist destinations in Nepal. It is estimated that some 40% of the tourists visiting Nepal reach Pokhara (Parajuli & Paudel, 2014). Pokhara is also the provincial capital of Gandaki province.

The Pokhara valley has sub-tropical climate with summer monsoon. The mean annual temperature is 24˚C, with maximum temperature 36˚C in June/July and minimum 5˚C in January/February. There was average rainfall of 473 mm in pre-monsoon season, 3336 mm in the monsoon season, 171 mm in post monsoon season and 82 mm in the winter over the period of 25 years (1985-2010) (DoM, 2016).

The valley has a cluster of nine lakes designated as a Ramsar site. They include Phewa, Begnas, Rupa, Deepang, Maidi, Khaste, Niureni, Gunde and Kamalpokhari. The fresh water wetlands namely Sardikhola, Bhhurjungkhola, Khudikhola, Lastikhola, Chitrepanikhola, Yamdikhola, Khalikhola, Kahunkhola, Phusrekhola, Bijayakhola, Harpankhola are the feeding sources to these lake system. Seti river is the main outlet of the valley to the south.

Inventory of IAPs in Pokhara valley: We collected herbarium specimens of the IAPs from Pokhara valley and tallied with IAPs that were reported from Nepal (Tiwari *et al*., 2005, Shrestha 2016). The specimens were collected during field survey for spatial distribution mapping. Identification of the IAPs were confirmed with the help of literatures mentioned above. The voucher specimens were deposited at Tribhuvan University Central Herbarium (TUCH), Kathmandu.

Distribution mapping: We used global positioning system (GPS Model Garmin etrex 10) to record geographic coordinates of the locations where the IAPs were found during the survey in Pokhara valley. Along the road networks, the IAPs were examined at 201 sample plots (size: 5 m × 5 m) located at the interval of *ca*. 500m. At each plot, the presence of IAPs, the land use type, and geographic coordinates (latitude, longitude) were recorded. Data were used to prepare distribution maps of individual IAPs in Pokhara valley using ArcGIS (Abd El-Ghani *et al*., 2011).

Frequency and species richness: Frequency of all species was obtained following Kent & Coker (1992). Species richness was considered as the number of IAPs enumerated in each plot. Mean value of species richness with standard deviation was calculated. Mean species richness was calculated separately for the plots located in different land use types. Sample plots were categorized into three groups based on the species richness: 1-3 species, 3-6 species and 6-8 species/25m^2 plot. Plots of different categories were depicted in the map of Pokhara valley.

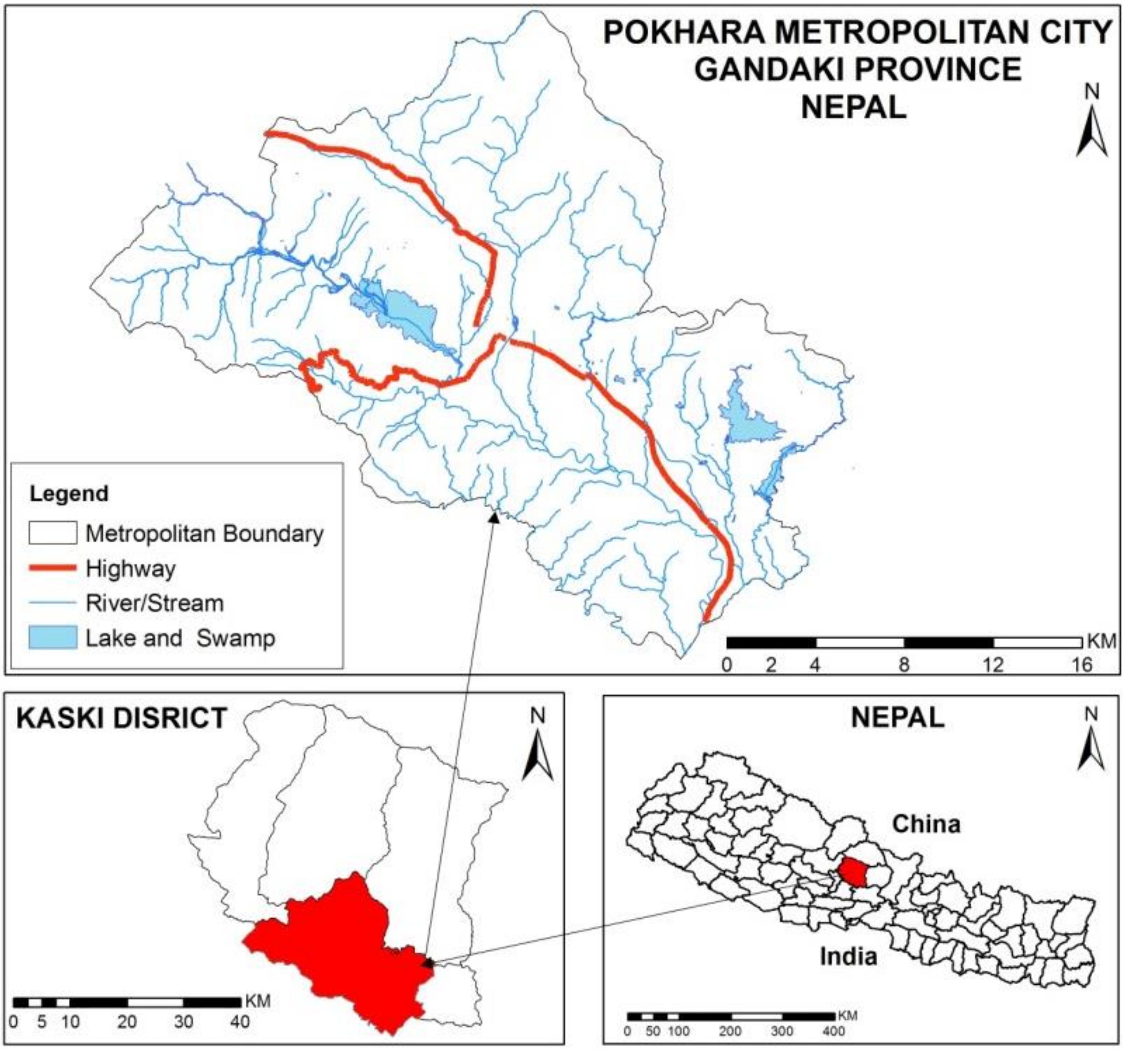


Fig.1. Geographic location of Pokhara in Nepal.

Results

Invasive alien plant species in Pokhara valley: Twenty invasive alien plant species (IAPs), representing 77% of 26 IAPs present in Nepal, were reported from Pokhara valley during the roadside survey (Table 1). They belong to 18 genera and 10 families. Nearly half of the species (9 species) belonged to family Asteraceae. Four of the 20 IAPs *i.e. Alternanthera philoxeroides*, *Eichhornia crassipes*, *Ipomoea carnea* subsp *fistulosa* and *Leersia hexandra* were wetland species whereas the remaining 16 species were terrestrial IAPs. Out of 20 IAPs, *E. crassipes*, *Lantana camara*, *Mikania micrantha* and *Chromolaena odorata* are in the IUCN's list of 100 of the world's worst invasive alien species (Lowe *et al*., 2000).

Frequency of the IAPs: Among the IAPs recorded in Pokhara valley, *Bidens pilosa* had the highest frequency (>63%), followed by *Ageratum houstonianum* (61%) and *Lantana camara* (44%). Other species like *Galinsoga quadriradiata, Ipomoea carnea, Spermacoce alata, Mesosphaerum suaveolens, Alternanthera philoxeroides* and *Mikania micrantha* had <5% frequency (Fig. 2).

Distribution of IAPs: Maps of 20 IAPs in Pokhara valley revealed that *Bidens pilosa* was widely distributed throughout the valley (Appendix 1). *Ageratina adenophora* was sparsely distributed but present in almost every major location. *Ageratum conyzoides* was reported from agricultural fields and it was also found from built-up areas. *Ageratum houstonianum* was found throughout the valley. *Amaranthus spinosus* was absent in Lekhnath area but present in built-up area of Lakhanchowk and Bhimsenchowk. *Bidens pilosa* was common in Lamachaur, Hemja, Bagar, Bhimsenchowk, Budhibazaar, Taalchowk, Birauta and Pame. *Chromolaena odorata* was reported from Pame and international airport area. *Eichhornia crassipe*s, a wetland IAPs, was recorded mainly from Phewa and Begnas lakes (Fig. 3). Another wetland IAPs, *Ipomoea carnea* subsp *fistulosa* was recorded mostly along water canal in Lekhnath area. *Galinsoga quadriradiata* was in farmlands of Lamachour area. *Lantana camara*, a common noxious shrub, was found widespread in the valley (Fig. 3). *Leersia hexandra* was reported from lakes and canals of the city. In Maidi lake, it forms thick carpet over the lake water. *Mimosa pudica* was frequently found in Lekhnath area. *Parthenium hysterophorus* colonized built-up area of the valley. In Lekhnath area, it was recorded from Gagangaunda. *Spermacoce alata* was common in Budhibazaar and Arghaun. *Xanthium strumarium* was found around bazaar area but rare in Lekhnath. *Mesosphaerum suaveolens* was spotted at Bacchedubuwa near the garbage dumping site of the Pokhara valley and *Mikania micrantha* at Bachhedubuwa and Damsite area near Raniban. Similarly, *Alternanthera philoxeroides* was found at Khahare area of the Phewa lake.

Species richness: Species richness varied across land use types. Shrubland had the highest species richness, followed by the fallow land and forest (Fig. 4). Grassland, non-irrigated farmland and irrigated farmland had similar species richness. The lowest species richness was recorded in residential and commercial areas.

There was also spatial variation in species richness of IAPs. Low species richness (1-3 species/25m^2 plot) was observed in Phewa lakeside to Pame area (Fig. 5). In other areas, plots with low species richness were found scattered along bazaar area. The plots with high species richness were confined to the bazaar area of Lakhanchowk and Bhimsentole and the territory.

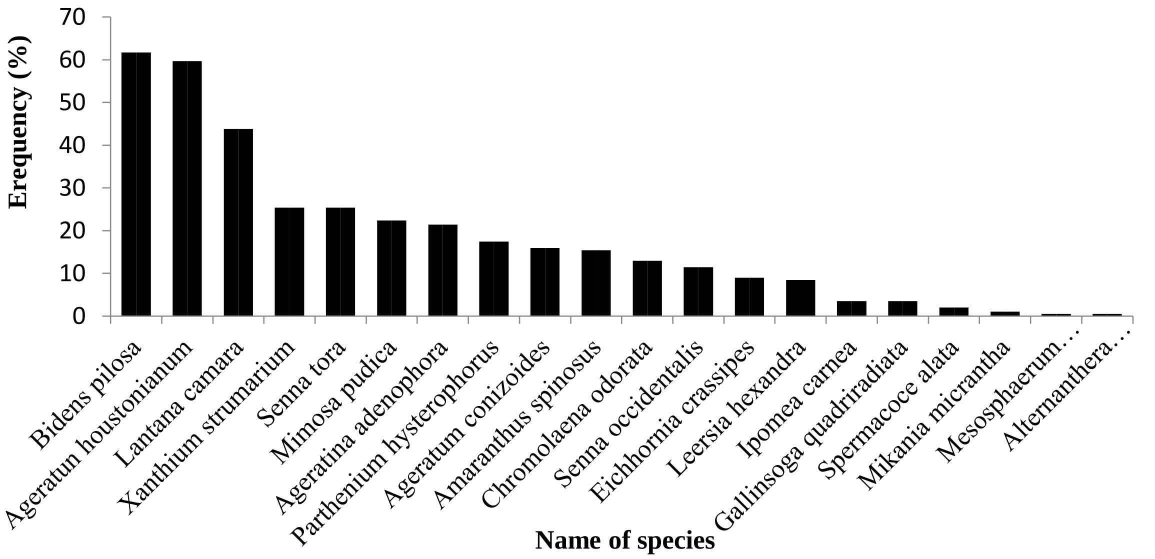


Fig. 2. Frequency of different invasive alien plant species in the study area.

Table1. Invasive alien plant species recorded in Pokhara valley.

S. No.	Name of IAPs	Family	Local name	Common name	Native range	Major invaded habitats
1.	*Ageratina adenophora* (Spreng.) R. King & H. Rob.	Asteraceae	Kalobanmara	Crofton weed	Center America(Mexico)	Road and streamside
2.	*Ageratum conyzoides* L.	Asteraceae	Setogandhe	Billy goat weed, Chick weed	South America	Farmland
3.	*Ageratum houstonianum* Mill.	Asteraceae	Nilogandhe	Floss Flower	Mexico	Almost all habitats
4.	*Amaranthus spinosus* L.	Amaranthaceae	Lude	Spiny pigweed	Topical America	Roadside
5.	*Alternanthera philoxeroides* (Mart) Griseb.	Amaranthaceae	Alternanthera	Aligator weed	South America	Wetland
6.	*Bidens pilosa* L.	Asteraceae	Kalokuro	Beggar's Stick	Topical America	Road side
7.	*Chromolaena odorata* (L.) R. King & H. Rob.	Asteraceae	Setobanmara	Siam weed; Chromolaena	Topical America, Jamaica, West Indies	Setobanmara
8.	*Eichhornia crassipes* Solms.	Pontederiaceae	Jalkumbhi	Water hyacinth	South America	Aquatic habitat and Wetlands
9.	*Galinsoga quadriradiata* Ruiz & Pav.	Asteraceae	Jhusechitlange	Shagy soldier	South Mexico	Crop fields
10.	*Ipomoea carnea* Jack ssp. *fistulosa* (Mart. ex Choisy) D.F. Austin	Convolvulaceae	Besarum	Shrubby morning glory	South America	Wetlands
11.	*Lantana camara* L.	Verbenaceae	Kimekanda	Lantana	West Indies	Non irrigated, dry lands
12.	*Leersia hexandra* Sw.	Poaceae	Karauteghans	Southern cut grass	Tropical and temperate Asia, Africa, Southern America, Australasia, and Northern America	Wetlands
13.	*Mesosphaerum suaveolens* Kuntze	Lamiaceae	Bansilam	Pignut or Chan	Tropical regions of Mexico	Roadside
14.	*Mikania micrantha* Kunth	Asteraceae	Lahare Banmara	Miles a minute	Subtropical zones of North, Central and South America	Grassland, Forest
15.	*Mimosa pudica* L.	Fabaceae	Lajjawoti jhar	Sensitive plant, Sleeping grass	Topical America	Fallows and roadsides
16.	*Parthenium hysterophorus* L.	Asteraceae	Patijhar	Bitter weed, Carrot grass False ragweed, Fever few	Mexico, West Indies, Central and South America	Road sides
17.	*Senna occidentalis* (L.) Link	Fabaceae	Thulotapre	Coffesenna Coffee weed	Topical America	Shrubland
18.	*Senna tora* (L.) Roxb.	Fabaceae	Sanotapre	Sickle senna	South America	Shrubland
19.	*Spermacoce alata* Aubl.	Rubiaceae	Alupatejhar	Broad leaved false button weed	Tropical America	By farmlands
20.	*Xanthium strumarium* L.	Asteraceae	Vedekuro	Rough cockle-Bur	America	Roadsides

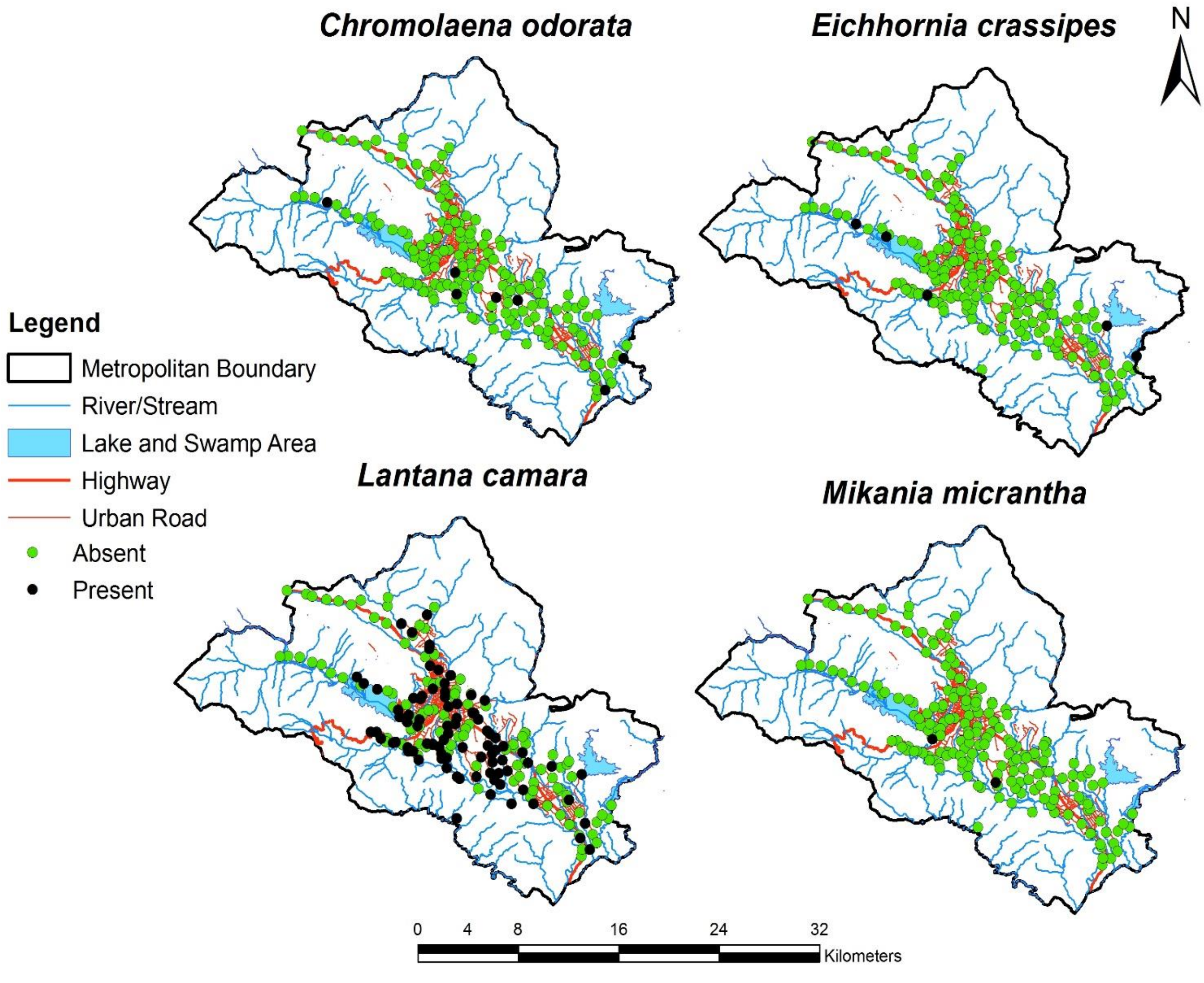


Fig. 3. Distribution of four IAPs in Pokhara valley which are globally important. Distribution of remaining 16 species has been presented in Appendix 1.

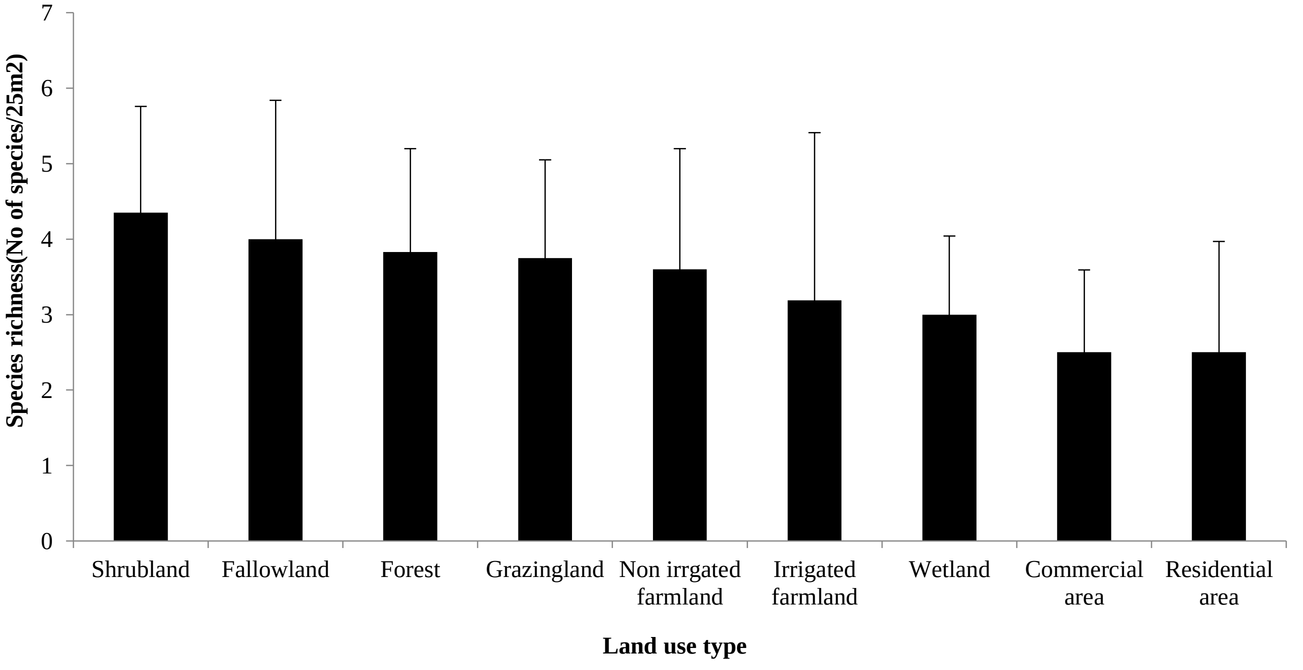
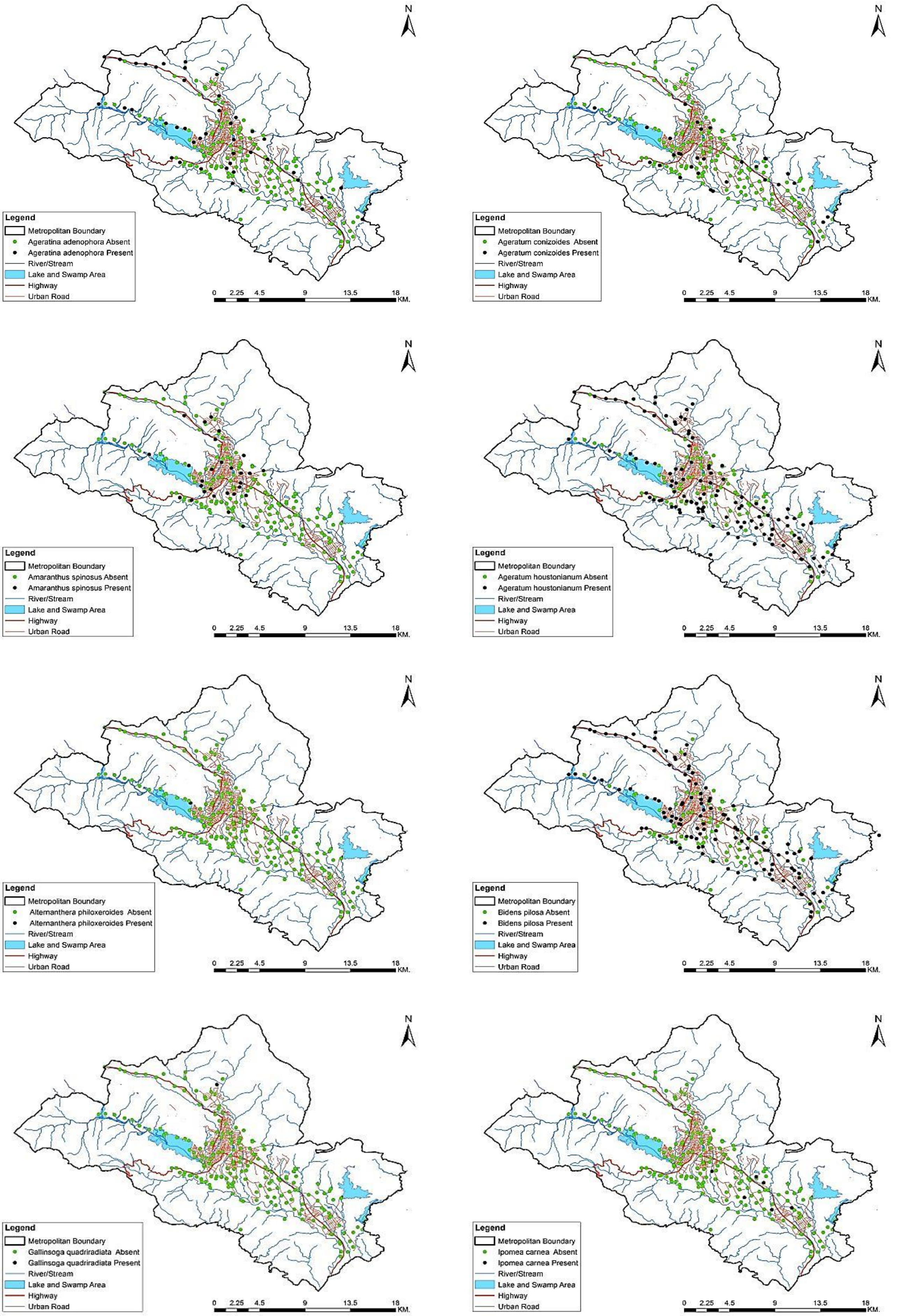
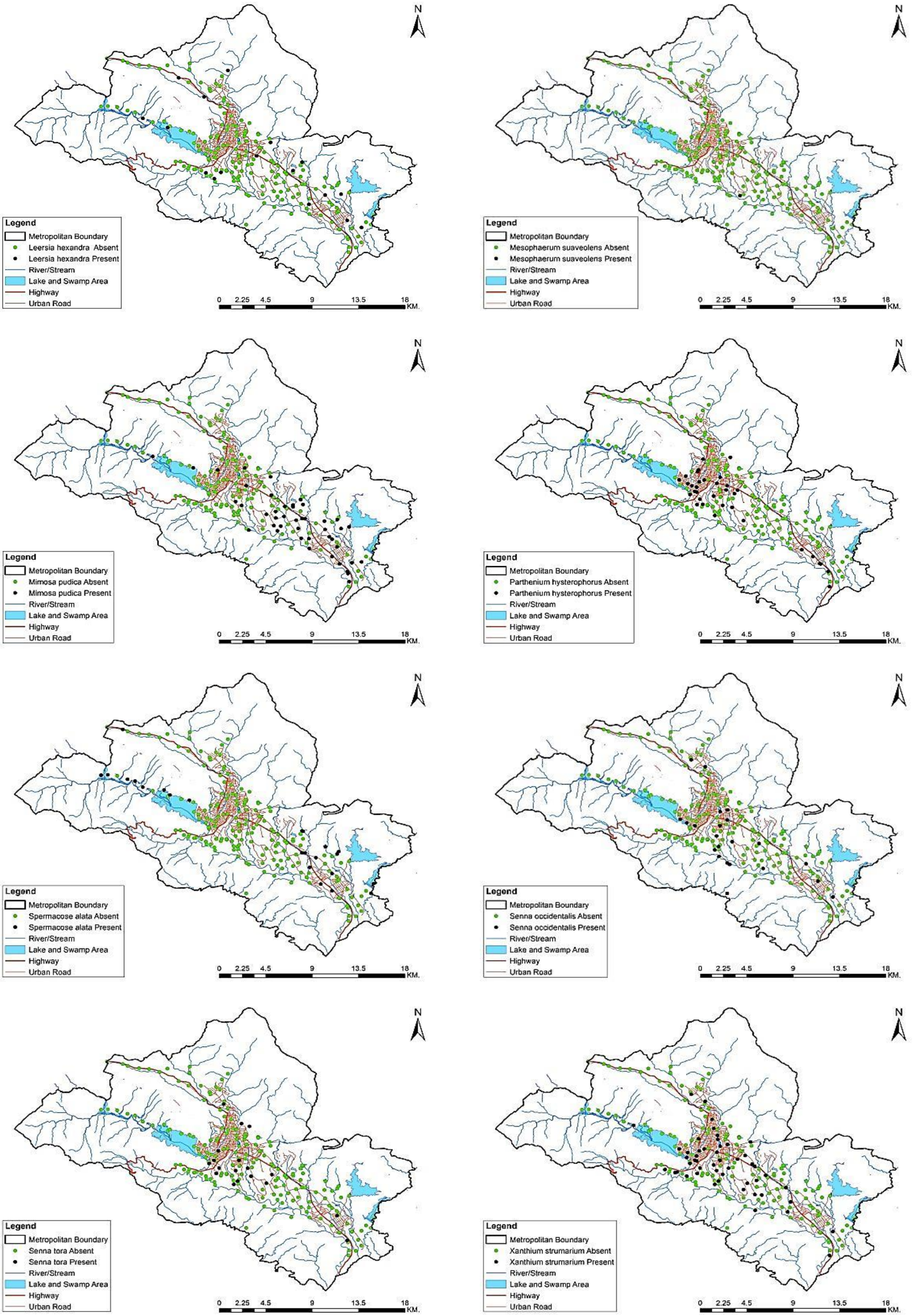


Fig. 4. Variation of IAPs richness across land use types.


N
Legend
Metropolitan Boundary
Ageratina adenophora Absent
Ageratina adenophora Present
River/Stream
Lake and Swamp Area
Highway
Urban Road
0 2.25 4.5 9 13.5 18 KM.
N
Legend
Metropolitan Boundary
Ageratum conizoides Absent
Ageratum conizoides Present
River/Stream
Lake and Swamp Area
Highway
Urban Road
0 2.25 4.5 9 13.5 18 KM.
N
Legend
Metropolitan Boundary
Amaranthus spinosus Absent
Amaranthus spinosus Present
River/Stream
Lake and Swamp Area
Highway
Urban Road
0 2.25 4.5 9 13.5 18 KM.
N
Legend
Metropolitan Boundary
Ageratum houstonianum Absent
Ageratum houstonianum Present
River/Stream
Lake and Swamp Area
Highway
Urban Road
0 2.25 4.5 9 13.5 18 KM.
N
Legend
Metropolitan Boundary
Alternanthera philoxeroides Absent
Alternanthera philoxeroides Present
River/Stream
Lake and Swamp Area
Highway
Urban Road
0 2.25 4.5 9 13.5 18 KM.
N
Legend
Metropolitan Boundary
Bidens pilosa Absent
Bidens pilosa Present
River/Stream
Lake and Swamp Area
Highway
Urban Road
0 2.25 4.5 9 13.5 18 KM.
N
Legend
Metropolitan Boundary
Gallinsoga quadriradiata Absent
Gallinsoga quadriradiata Present
River/Stream
Lake and Swamp Area
Highway
Urban Road
0 2.25 4.5 9 13.5 18 KM.
N
Legend
Metropolitan Boundary
Ipomea carnea Absent
Ipomea carnea Present
River/Stream
Lake and Swamp Area
Highway
Urban Road
0 2.25 4.5 9 13.5 18 KM.



Appendix 1. Distribution of IAPs in Pokhara Valley, Nepal.

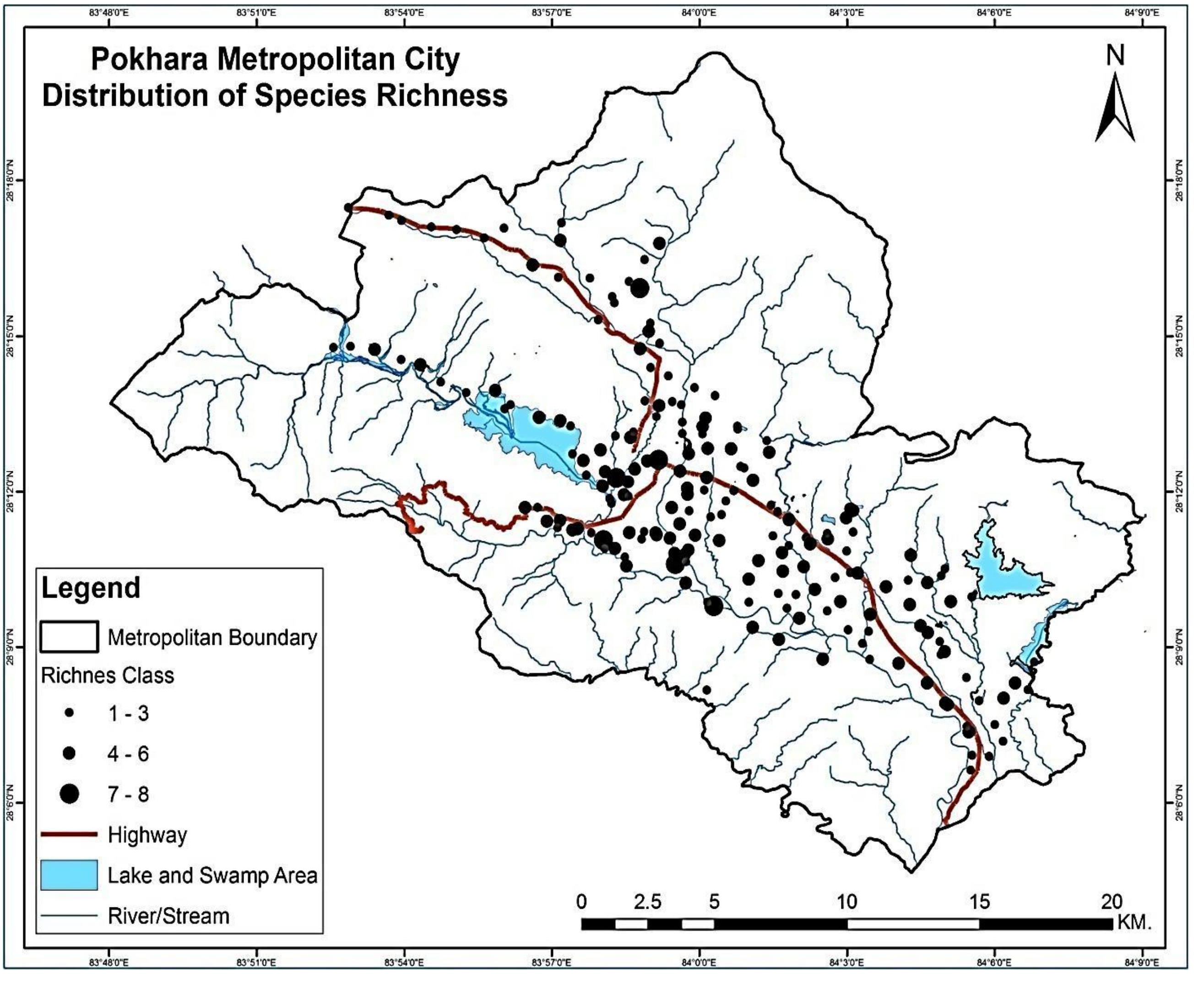


Fig. 5. Spatial pattern of the species richness (species number/25m^2 plot) of IAPs in the study area.

Discussion

The present study inventoried IAPs and analyzed their distribution patterns in Pokhara valley, Nepal based on the data collected along road network. Roads serve as an important corridor for the dispersal of IAPs, with subsequent spread into the adjoining landuse types. Among 20 invasive plants in the study sites, the highest frequency of *Bidens pilosa* could be attributed to its high seed production capacity and efficient seed dispersal by human and animal vectors (Budumajji & Soloman Raju, 2018). Plants with rapid growth, high adaptability and large seed production disseminate throughout the world rapidly (Yang *et al*., 2019). It was present in all types of microhabitats in the study area (personal observation of first author). Nearly 1/3rd of the IAPs reported in the study area have very low (<5%) frequency, suggesting that they were at the early stage of invasion in the year of data collection. In particular, *Mikania micrantha*, *Mesosphaerum suaveolens*, and *Alternanthera philoxeroides* have not been reported from Pokhara valley in earlier mapping of IAPs in central Nepal (Poudel, 2015). These kinds of species can be managed effectively through early detection and rapid reponse (EDRR) approach (Reaser *et al.*, 2020). The most noteworthy species among them is *Mikania micrantha* which is one of the world's worst invasive weed and difficult-to-manage species (Lowe *et al*., 2000). This species is already widespread in Tarai and Siwalik regions of eastern and central Nepal, and expanding to hilly region in central Nepal through the establishment of satellite populations (Shrestha *et al*., 2018). Small populations that we spotted in the Pokhara valley during the present study were two such satellite populations. Containment, if not eradication, of such populations of *M. micrantha*, *M. suaveolens* and *A. philoxeroides* will prevent further expansion of these species and protect ecosystems of the Pokhara valley and the surrounding landscape from their negative impacts. This would be possible if provincial and local government institutions working on biodiversity and agriculture respond and initiate management activities as early as possible.

Land use pattern is one of the determining factors for plant invasions because it alters environmental conditions and modifies the disturbance regime (Pauchard & Alaback, 2004). The invasion is fueled by anthropogenic disturbances such as grazing, nutrient enrichment, frequent disturbances to soil and vegetation, thereby degrading natural habitats. Growth of IAPs in such habitats, modify native plant community. For example, Baral *et al*., (2017) reported that native species such as *Artemisia indica* and *Urtica dioica* were outcompeted mostly in the fringes of fallow lands, agricultural lands and in the disturbed sites by the invasive alien plants. Among the nine landuse types that we analyzed, shrub land and fallow land had the highest species richness. Agriculture fallow lands soon after abandonment often have high nutrients and therefore susceptible to invasion (McGrath *et al*., 2001). Species richness in grazing land, forest and non-irrigated farmlands were lower than in fallow land. Grazing land had open area for sufficient light and nutrients because the topsoil of grazing land generally has high nutrient content (Gao-Lin, 2017). Irrigated farm land, wetland, commercial area and residential area possessed low species richness of the IAPs. Low species richness in commercial and residential area in Pokhara valley could be due to less availability of space and severe disturbances that might have prevented growth of plant species including IAPs. But, in general metropolitan areas are rich in IAPs (Chen, 2012). Shrublands of the present study area generally had monoculture stands of species like *Lantana camara*. Such open areas without tree canopy often provide suitable habitats for the establishment of IAPs (Brothers & Spingarn, 1992).

Conclusion

We recorded a total of 20 IAPs in the Pokhara valley. Among them, *Bidens pilosa*, *Ageratum houstonianum* and *Lantana camara* were the frequently occurring species whereas other species such as *Mesosphaerum suaveolens*, and *Alternanthera philoxeroides* were spotted at a single locations and *Mikania micrantha* at two locations. Management responses aimed to contain these early invaders including globally worst weed *M. micrantha* will prevent their spread and protect ecosystems from their harmful impacts. Four species found in the study area were among the world's worst invasive species. Shrubland, fallowland and forest had high richness of IAPs whereas the wetland, commercial area and residential area had low species richness. Our data revealed that the Pokhara valley had been already invaded by a large number of IAPs and their number and abundance might increase in future. Periodic inventory and mapping of this kind is essential for early detection of IAPs and rapid response for their management.

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