DIVERSITY, DISTRIBUTION, AND IMPACTS OF INVASIVE ALIEN PLANT SPECIES IN LAKE CLUSTER AND ASSOCIATED LANDSCAPE IN POKHARA VALLEY, CENTRAL NEPAL

A THESIS SUBMITTED TO

CENTRAL DEPARTMENT OF BOTANY

INSTITUTE OF SCIENCE AND TECHNOLOGY

TRIBHUVAN UNIVERSITY

NEPAL

FOR THE AWARD OF

DOCTOR OF PHILOSOPHY

IN BOTANY

BY

HOM NATH PATHAK

SEPTEMBER 2022

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DEAN'S OFFICE
Kirtipur, Kathmandu, Nepal

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EXTERNAL EXAMINERS

The Title of Ph.D. Thesis: " Diversity, Distribution, and Impacts of Invasive Alien Plant Species in Lake Cluster and Associated Landscape in Pokhara Valley, Central Nepal "

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July 25, 2023

(Dr. Surendra Kumar Gautam)
Asst. Dean

DECLARATION

Thesis entitled "**Diversity, Distribution, and Impacts of Invasive Alien Plant Species in Lake Cluster and Associated Landscape in Pokhara Valley, Central Nepal**" is being submitted to the Central Department of Botany, Institute of Science and Technology (IOST), Tribhuvan University, Nepal for the award of the degree of Doctor of Philosophy (Ph.D.), is a research work carried out by myself under the supervision of Prof. Dr. Bharat Babu Shrestha, Central Department of Botany, Tribhuvan University and co-supervised by Dr. Dinesh Raj Bhuju, Academician, Nepal Academy of Science and Technology, Kathmandu.

This research is original and has not been submitted earlier in part or full in this or any other form to any university or institute, here or elsewhere, for the award of any degree.

Pathak

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Hom Nath Pathak

September 2022

RECOMMENDATION

This is to recommend that **Mr. Hom Nath Pathak** has carried out research entitled **"Diversity, Distribution, and Impacts of Invasive Alien Plant Species in Lake Cluster and Associated Landscape in Pokhara Valley, Central Nepal"** for the award of Doctor of Philosophy (Ph.D.) in **Botany** under our supervision. To our knowledge, this work has not been submitted for any other degree.

He has fulfilled all the requirements laid down by the Institute of Science and Technology (IOST), Tribhuvan University, Kirtipur for the submission of the thesis for the award of the Ph.D. degree.

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LETTER OF APPROVAL

Date: 2079-10-22

On the recommendation of Prof. Dr. Bharat Babu Shrestha, and Academician Dr. Dinesh Raj Bhuju, this Ph.D. thesis submitted by Hom Nath Pathak, entitled **"Diversity, Distribution, and Impacts of Invasive Alien Plant Species in Lake Cluster and Associated Landscape in Pokhara Valley, Central Nepal"** is forwarded by Central Department Research Committee (CDRC) to the Dean, Institute of Science and Technology, Tribhuvan University.

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Hom Nath Pathak

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ABSTRACT

Wetlands including lakes support high biodiversity providing essential ecosystem services, yet they are among the most vulnerable habitats worldwide. Several invasive alien plant species (IAPS) have invaded Nepal's wetlands. However, the available data are insufficient to inform policy and management decisions. This research was carried out in the Lake Cluster of Pokhara Valley (LCPV), a Ramsar site in central Nepal, with the objectives to 1) analyze the diversity of naturalized plant species in the LCPV, 2) identify IAPS and their spatial distribution in Pokhara valley, 3) assess the level of eutrophication in the LCPV, 4) identify the pathways of introduction and dispersal of the IAPS, and 5) assess the impacts of IAPS on ecosystem services in the study area.

Altogether 89 plots (20×5 m^2) were sampled to record flowering plants and their cover along the shoreline of the nine wetlands that constitute the LCPV. The species were identified, classified based on their life forms (Raunkiaer's life forms), and categorized into native and naturalized species. The variation of naturalized species richness with native species richness was analyzed by a generalized linear model. The relations of environmental variables with species composition were analyzed by ordination. A survey of roadside vegetation (201 5m × 5m plots) was carried out to record the diversity and distribution of the IAPS in Pokhara valley. To assess the eutrophication status, altogether 89 water samples were collected from all nine lakes, and estimated nitrate nitrogen and total phosphorus. To analyze the impacts of nutrient contents on species richness and cover of native and naturalized species, multiple regression was used. To trace the sources and dispersal pathways of the IAPS, residents (n=56, age >37 yrs) living around the wetlands with a high level of plant invasions (Begnas, Phewa, and Rupa) were interviewed. To assess the impacts of IAPS on ecosystem services, household surveys (n=273), focus group discussions (n=19) and key informants' interviews (n=23) were conducted among the beneficiaries of the LCPV such as the farmers, boaters, hoteliers, and fishermen.

The study recorded a total of 258 species of flowering plants (73 families and 191 genera). The most species-rich family was Asteraceae (27 spp), followed by Poaceae (26 spp), Fabaceae (19 spp), and Cyperaceae (19 spp). Therophytes (29%) and Hemicryptophytes (27%) were the most common among the life forms. The richness of naturalized species increased with increasing native richness whereas the nutrients had no significant effect on the species richness of naturalized plants. The study found a total of 22 IAPS in Pokhara valley. Four of the recorded IAPS, viz. *Chromolaena odorata*, *Lantana camara*, *Mikania micrantha*, and *Pontederia crassipes* were among the 100 of the world's worst invasive species. The most frequently encountered species were *Bidens pilosa* (63%), *Ageratum houstonianum* (61%), and *L. camara* (61%).

In water samples of the LCPV, the phosphorus level was 0.29-1.25 mg/L and the nitrate nitrogen 0.04-0.17 mg/L. Based on these two nutrients, the wetlands of the LCPV were classified as eutrophic. According to the residents, most of the aquatic IAPS found in the LCPV were brought from the southern Tarai region of Nepal and northern India between the 1970s and 1990s. Among the IAPS, *P. crassipes* and *Pistia stratiotes* were brought for their ornamental values and *Ipomoea carnea* subsp. *fistulosa* was introduced for fencing purposes. It appears that *Alternanthera philoxeroides* was introduced accidentally to Phewa lake recently (observed for the first time in 2019). Local respondents had been familiar with *Leersia hexandra* for a long period (>50 years) and were not aware of the time and mode of its introduction, suggesting that this species could have the longest history of introduction to the LCPV. The study enlisted 18 ecosystem services obtained from the LCPV. The most cited services were water for irrigation, fish farming, livestock fodder, traditional mat materials (*Machaerina rubiginosa*), habitat protection, and natural beauty. The total economic benefit generated by the provisioning services of the LCPV in 2019 was estimated to be International $ 0.10 million per household per year. Before the proliferation of the IAPS (1989), the estimated economic value was almost triple (International $ 0.29 million per household per year). The decline in economic value was the most pronounced in fish production (International $ 151.1 thousand) and supply of lotus (International $ 24.1 thousand).

The study revealed that the Ramsar enlisted wetlands of the Pokhara valley and the surrounding landscape have been invaded by several IAPS including some of the globally worst invasive species with significant negative impacts on wetland ecosystem services. As a recommendation, this study highlights science-based policy management for preventing the further spread of IAPS in the LCPV. It is suggested to prevention of the IAPS spread to non-invaded wetlands through public awareness and regular monitoring, and their control in the invaded wetlands through participatory approaches. Nonetheless, a well-managed IAPS in wetlands such as the LCPV not only supports the livelihood of the local people but also helps to meet national and global targets to conserve wetland biodiversity and habitats from further degradation.

Keywords: Biological invasion, Dispersal pathways, Ecosystem services, Floristic diversity, Native-naturalized relationship, Spatial distribution, Wetland eutrophication

LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	:	Analysis of Variance
APG	:	Angiosperm Phylogeny Group
CCA	:	Canonical Correspondence Analysis
CDB	:	Central Department of Botany
DCA	:	Detrended Correspondence Analysis
DHM	:	Department of Hydrology and Meteorology
EDS	:	Ecosystem Dis-services
EICAT	:	Environmental Impact Classification of Alien Taxa
ES	:	Ecosystem Services
FGD	:	Focus Group Discussion
GLM	:	Generalized Linear Model
GPS	:	Geographical Positioning System
IAPS	:	Invasive Alien Plant Species
INT. $	:	International Dollar
IUCN	:	International Union for Conservation of Nature
KATH	:	National Herbarium and Plant Laboratories
KII	:	Key Informant Interview
LCPV	:	Lake Cluster of Pokhara Valley
MEA	:	Millennium Ecosystem Assessment
MoFE	:	Ministry of Forests and Environment
MoFSC	:	Ministry of Forests and Soil Conservation
MRT	:	Minimum Residence Time
NPR	:	Nepalese Rupees
PAs	:	Protected Areas
PPP	:	Purchasing Power Parity
TU	:	Tribhuvan University
TUCH	:	Tribhuvan University Central Herbarium
US$	:	United States Dollar
WWF	:	World Wildlife Fund

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CHAPTER 1

1. INTRODUCTION

1.1 Background

Biodiversity and ecosystems have their own intrinsic values, and also contribute to societies providing benefits to people (IPBES, 2019) but are recently impacted negatively by biological invasions and other drivers of environmental degradation (Vila & Hulme, 2017). Biological Invasion is a significant component of human-induced global environmental change (Shackleton *et al.,* 2019). Plant and animal species have been moved from one place to another for hundreds of years. Not only the materials associated with trade and culture were exchanged and transported along with trades and travel but also plant and animal species, intentionally or accidentally, and sometimes without any special goal. Unfortunately, the redistribution of the world's species by humans is proving to be both environmentally and economically destructive, and the consequences are the rising number of alien and invasive species (Vitousek, 1996; Meyerson & Mooney, 2007; Seebens *et al.,* 2017; Yang *et al.,* 2021). Globally, biological invasion has created an alteration of the temporal and spatial pattern of disturbance which may be the most profound on ecosystem structure and function (Mack & D'Antonio, 1998; Ehrenfeld, 2010). It has increased the ecological and evolutionary pathways of natural ecosystems and impacted biodiversity (Aloo, 2013; Essl *et al.,* 2020) and ecosystem services (IPBES, 2019) affecting ecosystem functioning and causing disasters (Xie *et al.,* 2003). The consequences of biological invasion are directly related to global climate change and biodiversity loss (Lodge, 1993; Williamson & Griffiths, 1996; Wilson *et al.,* 2009). International trade is the main driver of global biological invasion (Hulme, 2021). For damages such as crop losses, habitat degradation, loss of ecosystem services, and management such as removal, restoration, and mitigation, an estimate of the cost of invasive species globally was found to be US$162.7 billion for the year 2017 (Diagne *et al.,* 2021).

In various parts of the world, plant species have their place of origin called native range. Species from native ranges cross geographical boundaries such as oceans, mountains, and deserts and arrive in a new area as a result of various means of introduction, such as global trade and travel (Banks *et al.,* 2015). They are called non-native, exotic, or alien plant species. Non-native plants become established as a result of human intervention, either directly or indirectly (Wilson *et al.,* 2009). The majority of alien species do not create self-replacing populations in the wild, but those that can are called naturalized (Sax & Brown, 2000). The invasive alien species are the naturalized plants that produce offspring in very large numbers, at distances from the parent plants, and thus have the potential to spread over a large area (Pysek *et al.,* 2004). Non-native cultivated plants that escape to the wild but are unable to establish self-replacing populations without human help are known as casual.

The IAPS have invaded several wetlands including Ramsar sites in Nepal (Tiwari *et al.,* 2005; Bhatt & Shrestha, 2021) and elsewhere in the world (Lazaro-Lobo & Ervin, 2021). Wetlands including lakes are among the world's most productive life support systems, and they are vital to humankind because they provide fresh water, food, and construction materials, as well as biodiversity, support flood management, groundwater recharge, and climate change mitigation (Halls, 1997). The introduction of alien species in lakes has been found to cause the loss of biodiversity and degradation of ecosystem services (Rodriguez, 2005). In the lakes and water bodies, the invasions also bring eutrophication that leads to species loss due to oxygen deficiency and insufficient light penetration (Chamier *et al.,* 2012). Wetlands account for 40.6% of worldwide ecosystem services value (Ramsar Convention on Wetlands, 2018). IAPS can have a significant impact on the services because they develop quickly and eventually cover the entire water surface. They restrict light penetration below the water surface, which has an impact on aquatic plants and animals, and they deplete oxygen (Mailu, 2001; Tellez *et al.,* 2008). IAPS have an impact on species diversity, water supply, drainage systems, hydropower inputs, river water flow, nutrient cycling, restricts people's access to water, increases disease vectors, sustains mosquito larvae, biological activity, and biochemical oxygen demand, and has the potential to obliterate native aquatic biota (Howard & Matindi, 2017). Many ecosystem services, such as water supply, flooding, habitat provision, power generation, and recreation, are affected by the number and distribution of IAPS in freshwater. The IAPS affect water through their physiology, morphology, behavior, and interactions with other species (Catford, 2014).

There are several hypotheses proposed to understand the mechanisms of biological invasions (Jeschke *et al.,* 2012). These hypotheses have highlighted the roles of different biotic and environmental factors that may affect the diversity of naturalized and invasive plant species. Two of these factors are the diversity of native species in an ecosystem (Biotic resistance hypothesis, Collins *et al.*, 2007) and fluctuations of nutrients and other resources including eutrophication (Fluctuating resources hypothesis, Davis *et al.*, 2000). Test of these two hypotheses using empirical data generated from wetlands can provide useful insights for the management of IAPS in the wetlands.

Periodic spatial distribution mapping is helpful to know the recent invaders and implement appropriate control measures. The standard program of mapping distributions, predicting future ranges, modeling species spread, assessing impacts, developing management guidelines, and screening the species are the steps of invasion studies with some limitations (Hulme, 2003). Spatial distribution mapping of invasive alien species using geographic information systems (GIS) is in common practice (Chuvieko & Salas, 1996; Dark, 2004; Martellucci *et al.*, 2020; Sayari *et al.*, 2021).

Plant invasions in wetlands are driven by a range of environmental factors and anthropogenic disturbances. Among them, eutrophication is a major factor, particularly in inland freshwater wetlands. Freshwater eutrophication enhances invasion success due to an increase in plant growth and in propagule pressure (Mormul *et al.*, 2020). For example, nitrogen addition (eutrophication) in San Francisco Bay increased the density and biomass of the invader and decreased the density of the native (Tyler *et al.*, 2007). Nitrogen-enriched eutrophication has a significant contribution to the successful invasion of *Spartina alterniflora* in China (Zhao *et al.*, 2015).

Species are introduced outside of their native range both intentionally as well as accidentally (Hulme *et al.*, 2008). While trade and travel are major causes of species introduction globally (Hulme, 2021), at a local level (e.g. landscape) anthropogenic disturbances (e.g. deforestation), infrastructure development (e.g. road construction), natural processes (e.g. flooding), and other biotic agents (e.g. birds) also play important roles in propagule dispersal and establishment. For example, waterbirds are found to act as important dispersal vectors for freshwater invasive species (Reynolds *et al.*, 2015). The world’s worst aquatic invasive alien species are introduced as ornamental species (Krishnakumar *et al.*, 2009). In China, 50% of invasive alien plants were intentionally introduced as pasture, animal feed, textile plants, medicinal plants, vegetables, ornamental plants, or lawn plants, but 25% of invasive alien plants were intentionally introduced as crops, ornamental plants, or biological control agents (Xu *et al.,* 2006).

Nature and its contributions to people, which together symbolize biodiversity and ecosystem functions and services, are declining worldwide (IPBES, 2019). The IAPS are known to have a variety of impacts on ecosystem services (Vila & Hulme, 2017). The ecosystem services are the benefits that the ecosystem provides to humanity (MEA, 2005; Steinman *et al.,* 2017). Ecosystem services connect ecological and economic factors with human well-being and life support systems, conservation and development, and private and public policy (Costanza *et al.,* 1997; Akinsete e*t al.,* 2019). Ecosystem services are generally classified as (1) provisioning, (2) cultural, (3) regulating, and (4) supporting services (MEA, 2005). Invasive species can limit the availability of ecosystem services. Habitat invasion by alien species has become a global issue with serious consequences for ecological, economic, and social systems (Dutta, 2018; Kuldip *et al.,* 2010). IAPS have been shown to lower local plant population and variety, enhance ecosystem productivity, and change the pace of nutrient cycling, all of which have a negative impact on ecosystem services and human well-being (Charles & Dukes, 2008; Keller *et al.,* 2011).

Nepal harbors 183 species of naturalized plants out of which at least 28 species are invasive including 6 aquatic ones (Shrestha & Shrestha, 2021, Shrestha *et al.,* 2021; Adhikari *et al.,* 2022). The number of naturalized plant species is the highest in central Nepal followed by eastern and western Nepal (Bhattarai *et al.,* 2014). They are gradually spreading towards western Nepal and the hilly region. Present anthropogenic climate change may amplify the plant invasion in areas which is currently less suitable for IAPS (Shrestha & Shrestha, 2019). The IAPS in Nepal has caused a range of impacts including losses of agriculture production, increased labor cost, suppression of native species, and health-related problems for humans and livestock (Shrestha, 2016). They are also degrading the habitats thereby impacting the ecosystem structure and function (Havel *et al.,* 2015). Several wetlands including Ramsar sites have been invaded by a number of IAPS (Tiwari *et al.,* 2005; Bhatt & Shrestha, 2021), threatening the biodiversity they support and the ecosystem services they deliver. In this context, the present study aimed to find the diversity, distribution, and impacts of IAPS in the lake cluster, and the associated landscape in Pokhara valley, Nepal.

1.2 Rationale

Wetlands are important ecosystems that provide valuable ecosystem services, yet wetlands are degrading fast due to various anthropogenic activities (Charles & Dukes, 2008). Wetlands are particularly prone to biological invasions. Wetland invasive species account for 24% (8 of 33) of the world's most invasive plants (Zedler & Kercher, 2004). The IAPS develop mono-dominant stands altering habitat structure, reducing biodiversity, altering nutrient cycling and productivity (often boosting it), and altering food webs (Zedler & Kercher, 2010). The problems of IAPS in wetlands are increasing in recent times. Sporadic efforts to manage them had remained less effective in Nepal. Long-term and systematic management planning requires detailed information on the diversity, distribution, and dispersal of naturalized and invasive plants in wetlands.

In Nepal, the impacts of biological invasions on ecosystem services provided by wetlands have not been studied. Several attempts have been made around the world to explore the effects of invasive alien species on ecosystem processes (Charles & Dukes, 2008). Ecosystem services provided by some of the wetlands of the Lake Cluster of Pokhara Valley (LCPV) have been evaluated. For example, Paudyal, *et al.* (2018) studied land-use change and ecosystem services delivery from the Phewa watershed. Similarly, Thapa *et al.* (2020) investigated the ecosystem services provided by the Begnas watershed. However, studies covering all nine wetlands of the LCPV were lacking. Furthermore, the impacts of rising plant invasions in these wetlands have never been accounted while investigating ecosystem services. Globally worst species like *Pontederia crassipes* have invaded major lakes of the LCPV including Phewa, Begnas, and Rupa (MoFE, 2018b) but their impacts on ecosystems and livelihood was largely unknown.

Pokhara is a famous mountain valley of beautiful lakes in Nepal. In 2016, the cluster of nine lakes in Pokhara valley has been declared a Ramsar site (Shrestha *et al.*, 2020). Local people depend on the ecosystem services provided by this wetland. Direct and indirect impacts of anthropogenic activities have degraded most of these wetlands. A recent rise in the abundance of the IAPS is an emerging management challenge. Understanding the diversity of invasive alien plants, their spatial distribution patterns, drivers affecting plant invasion including water nutrient content and dispersal pathways, and impacts of invasive plants on ecosystem services of the lakes can inform policy and management decisions for conservation and sustainable utilization of wetland resources.

1.3 Hypotheses

This research tested the following two hypotheses:

I. The diversity of naturalized plant species declines with the increasing diversity of native plant species.

II. Diversity and abundance of IAPS are positively correlated to the nutrient content of lake water.

1.4 Objectives

The general objective of the study was to analyze the diversity, distribution, and impacts of IAPS in the Lake Cluster of Pokhara Valley (LCPV), central Nepal. The specific objectives of the study were:

1. To analyze the diversity of naturalized plant species in the LCPV.
2. To identify the IAPS and their spatial distribution in Pokhara valley.
3. To assess the level of eutrophication in the waters of the LCPV.
4. To identify the pathways of introduction and dispersal of the wetland IAPS in the study area.
5. To evaluate the impacts of IAPS on ecosystem services provided by the LCPV.

1.5 Limitations

The following are the limitations of the present study:

a. For the floristic diversity study, plants were collected within the area of 15 m from the lakeshore (wetlands).

b. Among various ecosystem services, only provisioning services accounted for economic benefit estimation because provisioning services could be obtained from the household survey of the beneficiaries but the other services like regulating services, supporting services, and cultural services were obtained by value transfer method that could not be realistic.

c. Only flowering plants were included in the study.

d. Vegetation sampling was limited to the shoreline and did not cover the interior of the lake.

e. Determination of introduction and dispersal pathway was limited to aquatic IAPS only.

CHAPTER 2

2. LITERATURE REVIEW

2.1 Biological invasions

Biological invasion is a significant component of human-induced environmental change in the world (Canadell & Mooney, 2002; Westphal *et al.,* 2008; Wilson *et al.,* 2016; Shackleton *et al.,* 2019). The principal environmental implications of the biological invasion include species extinction, habitat loss, biodiversity loss, ecological succession disruption, and difficulty supplying ecosystem services to people (Charles & Dukes, 2008).

Most of the invasive plants can actively flourish and spread outside of their native distribution. This plant can be particularly invasive when it is introduced into an ecosystem where it may receive support from the new soil, plant, animals, and microbes and there are no organisms that are its predators (Mack *et al.,* 2000). The invasive alien plant species (IAPS) grow fast, spreads quickly, and cause serious damage to the native species and habitats in the world (Howard & Matindi, 2017). Invasion of habitats by invasive plants and animals is a global problem, with detrimental impacts on ecological, economic, and social systems (Dutta, 2018; Kuldip *et al.,* 2010). One-sixth of the global land surface is highly vulnerable to invasion including developing countries and biodiversity hotspots (Early *et al*., 2016). Risks of invasions are increasing globally due to expanding transportation networks, technological advancements, landscape transformation, climate change, and geopolitical events such as warfare, and movements (Ricciardi *et al.,* 2017). For example, areas occupied by the IAPS increased by 50% in South Africa between 2000 and 2016 (Henderson & Wilson, 2017). International trade and transport in the modern era of globalization have played important role in the spread of IAPS rapidly in the world (Hulme, 2009; Chapman, 2017). In tourist visit sites, the abundance and diversity of alien species are substantially greater than in control sites (Anderson *et al.,* 2015). Similarly, urban areas serve as hotspots for the establishment of IAPS (Gaertner *et al.,* 2017). Novel ecosystems created by new combinations of the native and alien species, have been developed by humans worldwide (Buckley & Catford, 2016). Invasive species are creating a significant threat to agriculture globally both in developed and developing economies (Paini *et al.,* 2016). They are also the major drivers of the extinction of native species (Bellard *et al.,* 2016).

2.2 Biological invasion in wetlands

Biological invasion, land-use change in watersheds, eutrophication, and pollution are the major threats to the wetlands (Early *et al.,* 2016). Invasion in wetlands are affected by native biodiversity, nutrients, disturbances, and availability and dispersal of propagules (Theoharides & Dukes, 2007). Despite the fact that wetlands make up only 6% of the earth's surface, wetland species account for 24% (8 of 33) of the world's most invasive plants (Zedler & Kercher, 2004). Wetlands are landscape drains that collect garbage, sediments, water, and nutrients, all of which promote invasions by creating a favorable environment for the establishment and spread of invasive alien species (Zedler & Kercher, 2004). The potential for wetlands to be invaded by invasive species is the combined influences of landscape sinks, including imports of effectively growing hydrophytes, although no single hypothesis or attribute of plants can explain all invasions of wetlands (Zedler & Kercher, 2004; Cronk & Fennessy, 2016). Invasive species in wetlands modify the natural environment and negatively affects ecosystem process and services (Martin & Valentine, 2011). Many wetland invaders also change habitat structure, biodiversity, nutrient cycling, and production, as well as food webs (Davis & Froend, 1999).

Freshwater ecosystems are particularly sensitive to the introduction of alien species for two reasons: there are multiple routes through which alien species might enter freshwater systems and freshwater systems are frequently impacted by various types of human activities (Rodriguez-Merino *et al.,* 2018). Freshwater wetlands of South Asia have been already invaded by a number of IAPS. For example, 71 wetland IAPS have invaded wetlands of Kashmir Himalaya, India (Shah & Reshi, 2014). Similarly, wetlands of Nepal are primarily invaded by six IAPS; they are *Pontederia crassipes, Pistia stratiotes, Leersia hexandra, Ipomoea carnea* subsp. *fistulosa, Alternanthera philoxeroides* and *Myriophyllum aquaticum* (Shrestha, 2016).

2.3 Diversity of naturalized plant species

According to the biotic resistance hypothesis, species-rich communities should be more resistant to invasive species establishment than species-poor populations (Collins *et al.,* 2007). Negative relations between native and naturalized species richness had been reported by Chen *et al.* (2010). The richness of naturalized and invasive plant species was found to decline with an increase in native species richness in a study at inner Tarai valley in central Nepal (Paudel *et al.*, 2022).

In contrast to the wide belief that alien plants competitively exclude native plant species, a positive correlation was reported between native and invasive species richness in 58 Ontario inland wetlands (Houlahan & Findlay, 2004). While this concept predicts that naturalized species in areas with more native species will be less diverse, macro-ecological analyses have found that the relationship between naturalized and native species richness is positive, not negative (Bartomeus *et al.*, 2012). It was similar to the Sax (2002) finding, in which naturalized plant richness patterns follow native plant richness patterns in Mediterranean scrub populations. Another study found that the richness of invasive and native species was strongly and positively associated (Ackerman *et al*., 2017). These findings corroborate previous research that found a favorable relationship between the number of native and introduced species (Espinosa-Garca *et al*., 2004). Native plants have no strong association with functional qualities and the environment, whereas naturalized plants do, and thus they do not compete and are independent (Milanovic *et al*., 2020). The biological invasion uncertainty refers to the coexistence of various lines of support implying both a negative and a positive link between native biodiversity and the diversity of invasive species (Fridley *et al*., 2007). Hence, the native richness cannot always affect the success of naturalized species (Heckman *et al.*, 2017).

The aquatic alien plant species richness is negatively correlated with the relative coverage and biomass of native plants but positively correlated with the total nitrogen (TN), total phosphorus (TP), and chemical oxygen demand (COD) in the water (Yu *et al.*, 2018). This underpins the idea of biotic resistance as well as the nutrient impact on native plants and their diversity.

The diversity and abundance of naturalized plants at disturbed sites were substantially higher than at undisturbed sites (Jauni *et al.*, 2015). In particular, the disturbance has a positive effect on naturalized plant species. For example, there was a stronger role of anthropogenic activities in shaping diversity patterns of naturalized plants across Pacific regions (Wohlwend *et al*., 2021).

2.4 Wetlands eutrophication

Eutrophication is characterized by excessive plant and algal development due to the increased availability of one or more growth components required for photosynthesis (Schindler, 2006). The overall nitrogen and total phosphorus ratio are used to determine whether a lake is oligotrophic or eutrophic. Significant levels of nitrogen and phosphorus are claimed to be present in the lake, making it eutrophic (Downing & McCauley, 1992). Based on the nitrogen and phosphorus content in water, lakes are classified into ultraoligotrophic, oligotrophic, mesotrophic, eutrophic, and hypertrophic (Table. 5, Material and Methods section). Excess fertilizer uses in farmlands, and detergents that contribute nitrogen and phosphorus to lakes, and other bodies of water are all eutrophication issues. The formation of dense blooms of toxic, foul-smelling phytoplankton, which impair water clarity and harm water quality, is the most visible result of anthropogenic eutrophication (Chislock, 2013). Algal blooms in littoral zones limit light penetration, stunt growth, and kill plants by blocking light and catching prey. Eutrophication affects the amount of light and nutrients available in a given ecosystem. As a result, the species' makeup changes, and only the most adaptable species survive, while new competing species emerge and out-compete the original population (King, 2013). These out-competitors could be invasive alien plants. Microbial breakdown reduces dissolved oxygen greatly when these dense algal blooms die, resulting in a hypoxic or anoxic 'dead zone (Chislock, 2013). Alien invaders, on the other hand, benefit more from increased food availability than native species (Dukes, 2000).

Changes in nutrient levels in water bodies are another well-known feature of biological invasion by fluctuating resources concept (Davis *et al.,* 2000). If the ecological impacts of invasive species are to be understood and eventually predicted, revealing the linkages between all factors of global change, and their effects on ecosystem processes (Scherer-Lorenzen *et al.,* 2007) in terms of biological invasion, alien invaders normally profit more from increased nutrition availability than indigenous species (Ehrenfeld, 2003; Scherer-Lorenzen *et al.,* 2016). The availability of light and certain nutrients in an ecosystem varies as a result of eutrophication. Thus, the species composition changes, and only the more tolerant species survive, while new competitive species invade and out-compete the original residents.

According to the nitrate nitrogen and/or total phosphorus content in most of the Nepalese lakes in the recent past, Koshi Tappu Wildlife Reserve (based on nitrate nitrogen), Maipokhari (based on phosphate as part of TP), Gosaikunda (based on TP), Ghodaghodi lake (based on both nitrate and TP), were hypertrophic. Beeshazari Lake (based on TP), and Gokyo (based on TP) were eutrophic lakes. Begnas, Phewa, Rara, Tilitso, and Rupa were oligotrophic lakes (Table 1). Among them, four lakes were hypertrophic, two were eutrophic, five were oligotrophic and rest of the others were mixed type based on nitrate nitrogen and total phosphorus concentration in water.

Table 1: Trophic status in lakes in Nepal and neighboring countries. Information on nitrate nitrogen and total phosphorus level in various wetlands in Nepal including Ramsar sites and level of eutrophication was predicted using the standard threshold level

SN	Wetland (name and location)	Elevation	Nitrogen content*			Phosphorus content*			Reference
			Value and unit	Measured parameter	Method	Value and unit	Measured parameter	Method	
1	KTWR, Sunsari	75-100 m	5.21 ± 1.65 mg/L	Nitrate	APHA, 1998	0.18 ± 0.05 mg/L	Phosphate	APHA, 1998	Pandey *et al.*, 2020
2	Beeshazari and associated lakes lake, Chitwan	286 m	1324.9 ± 501.8 µg/L = 1.32 mg/L	TN	APHA, AWWA, and WPCF, "Standard Methods for Examination of Water and Waste Water,"	218.7 ± 135.7 µg/L = 0.22 mg/L	TP	APHA, AWWA, and WPCF, "Standard Methods for Examination of Water and Waste Water,"	Niraula 2012
3	Jagdishpur reservoir, Kapilbastu	197 m	5.51 ± 1.321 mg/L	TN	Trivedi & Goel, 1984	-	-	-	Chaudahary & Devkota, 2018
4	Mai pokhari, Ilam	2150 m	0.261 mg/L	Ammonia	Phanate method	<0.1 mg/L	Phosphate	Stannous chloride method	Joshi & Sharma 2017
5	Rara lake, Mugu	3000 m	0 ± 0.01 mg/L	Nitrate	Tripathi *et al.*, 2016	0 ± 0.01 mg/L	Phosphate	APHA, 1998	Gurung *et al.*, 2018
6	Ghodaghodi lake, Kailali	205 m	1.45 ± 0.90 mg/L	Nitrate	APHA,1998	0.9 ± 0.07 mg/L	TP	APHA, 1998	Bhatta *et al.*, 2019
7	Gosaikunda and associated lakes, Rasuwa	4,380 m	1.53 (± 0.774) mg/L	TN	Standard Methods for the Examination of Water and Wastewater (APHA, 1998)	0.12 (± 0.026) mg/L	TP	Standard Methods for the Examination of Water and Wastewater (APHA, AWWA & WEF, 1998)	Raut *et al.*, 2012
8	Gokyo and associated lakes, Solukhumbu	4,700-5000 m	1.05 ± 0.71 mg/L	TN	Colorimetric method (Trivedi & Goel,1984)	0.57 ± 0.71 mg/L	TP	Colorimetric method (Trivedi & Goel, 1984)	Ghimire *et al.*, 2013
9	Lake 1, Panch Pokhari, Sindhupalchowk	4,100 m	2.29 (± 0.448) mg/L	Nitrate	UV Spectrophotometric (Screening) method	0.09 (± 0.018) mg/L	Phosphate	Ammonium molybdate ascorbic acid reduction method	Raut, *et al.*, 2014

	Lake 2	4,100 m	2.53 (± 0.661) mg/L	Nitrate	,	0.18 (± 0.153) mg/L	Phosphate	,	,
	Lake 3	4,100 m	1.78 (± 0.212) mg/L	Nitrate	,	0.11 (± 0.014) mg/L	Phosphate	,	,
	Lake 4	4,100 m	2.32 (± 0.000) mg/L	Nitrate	,	0.09 (±0.014) mg/L	Phosphate	,	,
	Lake 5	4,100 m	2.32 (± 0.014) mg/L	Nitrate	,	0.07 (± 0.014) mg/L	Phosphate	,	,
10	Phewa lake, Kaski	742 m	0.15 mg/L	TN	Autoanalyzer (Technicon, AA II)	0.01 mg/L	TP	autoanalyzer (Technicon, AA II)	Nakanishi *et al.*, 1988
	Begnas lake, Kaski	650 m	0.30 mg/L	TN	,	0.01 mg/L	TP	,	,
	Rupa lake, Kaski	600 m	0.28 mg/L	TN	,	0.03 mg/L	TP	,	,
11	Pangong Tso lake, Ladakh, India I lake	4,225 m	281 ± 340 µg/L = 0.28 mg/L	Nitrate	Mackereth *et al.* (1978), CSIR Pretoria (1974), and APHA (1998)	420 ± 31 µg/L	Phosphate	Mackereth *et al.* (1978), CSIR Pretoria (1974), and APHA (1998)	Bhat *et al.*, 2011
	II lake	4,225 m	315 ± 42 µg/L = 0.31	,		465 ± 109 µg/L	,		
	III Lake, 225 m	4,225 m	302 ± 44 µg/L = 0.30	,		507 ± 66 µg/L	,		
12	Tilitso lake, Manang	4,919 m	0.115 mg/L	TN	Otsuki *et al.*, 1984 Autoanalyzer	0.04 mg/L	TP	Otsuki *et al.*, 1984 Autoanalyzer	Aizaki *et al.*, 1987

*TP: Total phosphorus, TN: Total nitrogen

2.5 Introduction and dispersal pathways of IAPS

Alien species may be introduced to a new region through three mechanisms: importation of a commodity, the arrival of a transport vector, and/or natural spread from a neighboring region where the species is itself alien (Hulme, *et al.,* 2008). There are six principal pathways of these three mechanisms: release, escape, contaminant, stowaway, corridor, and unaided. Approaches to describe and quantify pathway attributes and how they interact with species traits and regional characteristics are important for management practices in four broad fields of pathway research and management: pathway classification, application of pathway information, management response, and management impact (Essl *et al.,* 2015). Recreational boaters' migration between lakes appears to be the most important overland distribution channel for many aquatic creatures including IAPS (Bossenbroek *et al.*, 2001). Boater traffic to individual lakes, distances traveled to reach these lakes, Great Lakes utilization, and migration from the Great Lakes to inland waterways were identified as four indicators of pathway features (Leung *et al.,* 2006). The Salt cedar distribution in Buenos Aires city, Argentina was found to be linked to watercourses and human-caused disturbances. Besides, the roads were found to be important for propagule introduction into new settings (Natale *et al.*, 2012).

Those species that are accidentally introduced and become invasive are, nevertheless, as extensively distributed as those that are intentionally introduced. Those introduced as contaminants create havoc on a wider spectrum of semi-natural environments. In terms of invasion success, there are two types of introductions: planned species introductions using commodities and not planned species introductions (Pysek *et al.,* 2011). Human-mediated extra-range dispersal which is the cause of biological invasions is frequently the result of many introductions from multiple sources to multiple regions (Wilson *et al.*, 2009).

Knowledge related to the introduction and dispersal pathways of most of the naturalized as well as IAPS is anecdotal without empirical data (Shrestha & Shrestha, 2021). Only a very few previous studies have attempted to identify dispersal pathways of wetland IAPS in Nepal. For example, intentional introduction for fish feed was the main pathway of *Pontederia crassipes* dispersal in the wetlands of Kanchanpur district, Western Nepal but the pathway was unknown for the other three wetland IAPS (Bhatta & Shrestha, 2021).

2.6 Impacts of biological invasion on ecosystem services

By modifying nutrient and pollutant cycling, hydrology, habitat structure, and disturbance regimes, many invasive alien species influence ecosystem functioning and the supply of ecosystem services (Pysek *et al.,* 2020). Impacts are also creating threats in the world, causing losses in biodiversity, changes in ecosystems, and impacts on economic sources such as agriculture, forestry, fishery, power production, and international trade. The influence of invasive species on ecosystem services has garnered worldwide attention. The importance of global cost for avoiding and controlling biological invasion is highlighted by large expenses around at least US$ 1.3 trillion between 1970 and 2017 (Novoa *et al.,* 2021).

The integration of ecology and economics into decision-making about the impacts of invasive species on ecosystem services is critical for repairing and maintaining the life-support systems on which all creatures rely on for their life cycle (Pejchar & Mooney, 2009). Negative impacts from IAPS can be strong if caused by floating aquatic plants that reduce access to freshwater for domestic uses, reduce fish collection, and change water cycling and composition of water (Keller *et al.,* 2018).

Invasive species have a significant negative impact on aquatic community abundance, particularly macrophytes, zooplankton, and fish (Gallardo, 2016). Increased amounts of water turbidity, nitrogen, and organic matter have been found in invaded environments, all of which are linked to invaders' ability to change habitats and cause eutrophication (Gallardo *et al.,* 2016). A strong negative impact of IAPS had been reported in a meta-analysis on the abundance of aquatic communities, viz. macrophytes, zooplankton, and fishes, however, there was no evidence for a decrease in species diversity in invaded communities of aquatic ecosystems (Gallardo *et al.,* 2016). There remains a time gap between rapid abundance changes and local extinctions. Most city dwellers have a bad impression of IAPS (i.e., agreeing to produce ecosystem dis-services), but many of them understand their value in delivering ecosystem services. While the majority of citizens were not opposed to IAPS management, it was not seen as a high priority when compared to other environmental concerns (Potgieter *et al.,* 2019). To get rid of the impacts of the IAPS on wetlands, habitat management, mechanical controls and direct interventions, chemical control by using herbicides, and biological control by herbivory are the possible options for wetland IAPS management (Lazaro-lobo & Ervin, 2021).

2.7 Biological invasion in wetlands of Nepal

There are about 163 lakes in Tarai, and 79 in the hills and mountains of Nepal (Bhuju *et al.,* 2010). The country has 10 Ramsar sites in Nepal. Ramsar sites have been designated for major lakes in Nepal. Ramsar sites in Nepal include the Koshi Tappu wildlife reserve, Bishazaari and associated lakes, Ghodaghodi lake area, Jagadhispur reservoir, Gosaikunda and associated lakes, Gokyo and associated lakes, Phoksundo lake, Rara lake, Maipokhari lake, and Lake Cluster of Pokhara Valley (MoFE, 2018a; Shrestha *et al.,* 2020). The Lake Cluster of Pokhara Valley (LCPV) is the most recently (February 2, 2016) declared Ramsar site of Nepal (WWF-Nepal, 2016). The LCPV includes nine wetlands: Phewa, Kamalpokhari, Begnas, Rupa, Dipang, Khaste, Gunde, Maidi, and Niureni. Although government institutions and several international organizations such as WWF-Nepal and IUCN are working on the wetlands of Nepal, the study on the impact and management of the invasive plants is limited (Shrestha *et al.*, 2020).

Mikania micrantha spreading as climbers infested in the Tarai and Siwaliks, blocked sunlight eventually killing native plants. Their manifestations were observed in KTWR, Chitwan valley, and are spreading further in the westward direction in Nepal. For the conservation of lakes, an integrated lake basin management approach, Nepal has drafted plans of Lake Cluster of Pokhara Valley, Gaidahawa lake, and Rajarani lake and stated that Nepal further needs to quantify and add value to wetlands benefits and services. *Pontederia crassipes, Ipomoea carnea* subsp. *fistulosa, and M. micrantha* were creating problems in the Terai wetlands (MoFE 2018a).

At least six IAPS have invaded wetlands in Nepal (Shrestha & Shrestha, 2021). They are Water hyacinth (*Pontederia crassipes* Mart), Alligator weed (*Alternanthera philoxeroides* (Mart.) Griseb), Bush morning glory (*Ipomoea carnea* Jacq. Enum), Water lettuce (*Pistia stratiotes* L.), Parrot's feather (*Myriophyllum aquaticum* (Vell.) Verdc.) and Southern Cutgrass (*Leersia hexandra* Sw).

2.8 Research gaps

The diversity of native and naturalized plant species, the level of eutrophication in lakes, the dispersal pathways of IAPS, the impacts of IAPS on ecosystem services, and biological invasion in wetlands are among the topics covered in a brief review of the literature. The gaps found in the reviewed research are: 1) Although, substantial works have been carried out in the field of diversity of the naturalized and invasive species in Nepal (Paudel *et al.*, 2022, Bhatta *et al.*, 2020, Shrestha 2019, Shrestha 2016, Bhattarai *et al.*, 2014, Siwakoti *et al.*, 2016), little was known about the diversity and distribution of IAPS in the Ramsar sites including the LCPV; 2) Scientists from different parts of the world are trying to trace out the factors leading to invasion success at a place. They put forward different theories and hypotheses in this regard. There is no information about the factors governing plant invasions in the LCPV; 3) Various Ramsar sites, including LCPV, had their nitrogen and phosphorus levels estimated, but their association with plant invasions has not been explored; 4) The LCPV was suspected to have a diverse pool of aquatic IAPS but their detail account had been lacking; 5) Water Hyacinth has invaded Phewa, Rupa, and Begnas Lakes but there has been no previous study about its dispersal pathway to these lakes; 5) In spite of the works by Thapa *et al.* (2020), Paudyal *et al.* (2019), Sharma *et al.* (2015), Bhatta *et al.* (2014), Birch *et al.* (2014) on ecosystem services, there is lack of studies examining the impacts of IAPS on wetland ecosystem services in Nepal. The generation of empirical data to address above mentioned research gaps will help to make informed policy and management decisions for the conservation of the LCPV and other wetlands of Nepal that have been degraded due to plant invasions.

CHAPTER 3

3. MATERIALS AND METHODS

3.1 Study area

The study area comprises the Pokhara valley including Puranchaur and Gagangaunda villages in the north and south respectively. Pokhara valley floor is surrounded by Hemja towards the north, Panchase towards North West, Kahudada towards North-East, and Bharat/Nirmal-pokhari towards the south. Pokhara in Kaski district and Gandaki province, is one of the most attractive valleys in Nepal, located in the central midlands and in front of the snow-capped Annapurna Mountain range. The valley is located between 27.55° and 28.23° north latitude and 83.48° and 84.11° east longitude, within an elevation range between 580-850 m asl (Figure 1). The Pokhara Metropolitan City occupies an area of 464.24 sq km. Pokhara valley forms caves, sinkholes, and pinnacles here and there because of the porous underground.

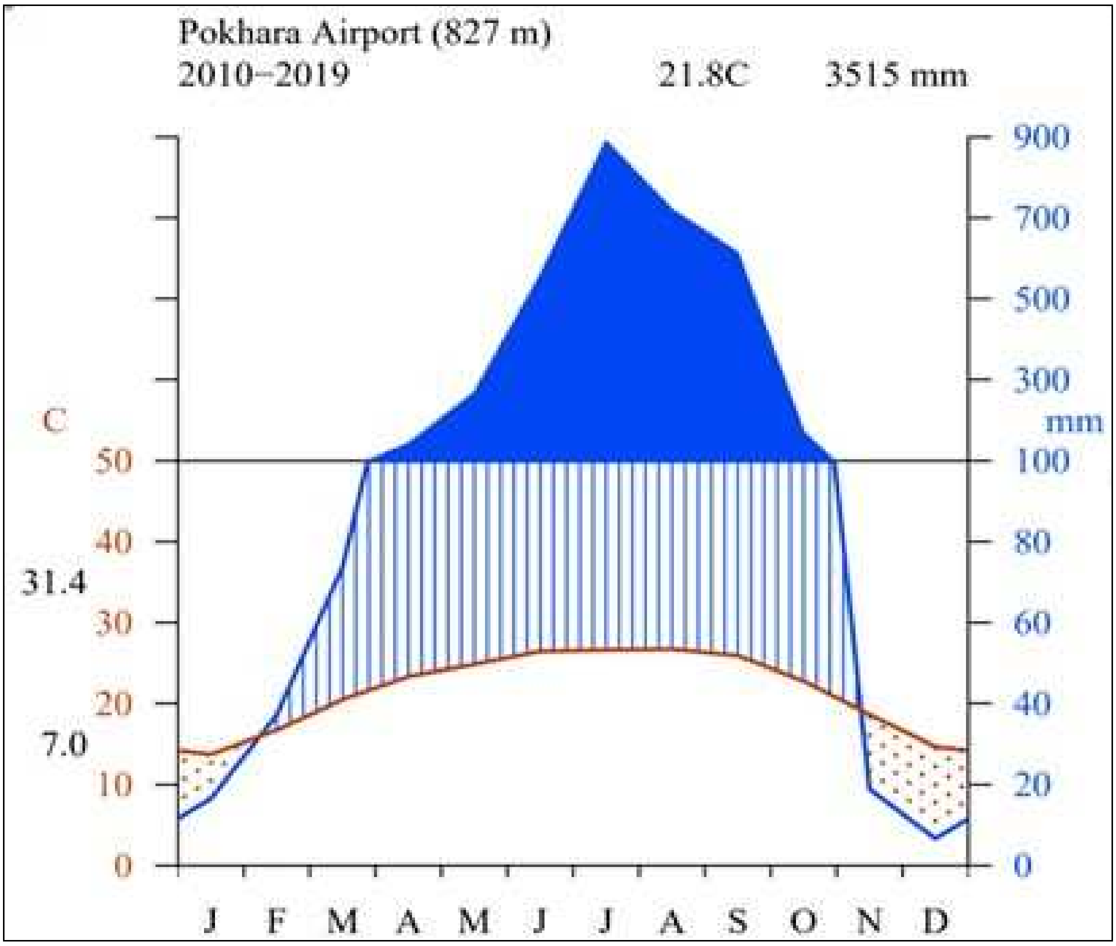


Figure 1: Ombrothermic diagram showing the climatic status in Pokhara valley (Data source: DHM, 2016)

The climate of the Pokhara valley floor is tropical, with summer monsoons. The minimum temperature in Pokhara airport area was 7°C (January) and maximum temperature was 31.4°C (July). The average temperature was 21.8°C in the valley's airport area. Similarly, the average annual precipitation in Pokhara airport was determined to be 3515 mm. The valley has wet seasons that last from mid-February to mid-November, with intense wet seasons lasting from March to October and peaking in June/July (Figure 1).

Pokhara valley has a cluster of nine lakes (LCPV) designated as a Ramsar site (Table 2). The freshwater wetlands (mountain springs) namely Sardikhola, Bhhurjungkhola, Khudikhola, Lastikhola, Chitrepanikhola, Yamdikhola, Khalikhola, Kahunkhola, Phusrekhola, Bijayakhola, Harpankhola are the feeding sources to these lake systems. Seti river is the main outlet of the valley to the south. *Shorea robusta* forest, and mixed *Schima-Castanopsis* forests are found in the Pokhara valley.

Table 2: General information on the Lake Cluster of Pokhara Valley, Nepal (Source: MoFE, 2018b)

Name of wetlands	Catchment area (km^2)	Max. depth (m)	Elevation (m asl)	Latitude (°)	Longitude (°)
Phewa	119.39	24	742	28.24	83.89
Rupa	26.02	4.5	600	28.17	84.13
Begnas	18.6	10	650	28.18	84.11
Khaste	2.69	2.0	723	28.20	84.15
Dipang	2.39	2.5	726	28.19	84.07
Maidi	1.6	2.0	850	28.18	84.08
Kamalpokhari	1.35	1.5	850	28.23	84.01
Gunde	0.61	0.5	766	28.19	84.04
Niureni	0.18	0.5	723	28.19	84.05

Pokhara is one of the most popular tourist destinations in Nepal. Almost one million tourists visit Pokhara valley annually (FFYP, 2019). It is estimated that some 40% of the foreign tourists visiting Nepal reach Pokhara. Pokhara is also the provincial capital of Gandaki province (Figure 2). It is about 200 km away from Kathmandu, the capital city of Nepal.

Land use types in the Pokhara valley include built-up areas, waterbody, forest cover, open fields, cultivated land, and sandy area (Table 3, Rimal, 2011). Land use percentage of the urban area/built-up area has increased; waterbody decreased; open area was in decreasing order; forest cover slightly declined but after 1991 it increased;

cultivated land declined; and, the sandy area slightly increased from 1997 to 2011. Land cover and land use change (2000-2018) reveals changes in water bodies by -0.23%, forest by 18.85%, cultivable land by -34.32%, grassland by 13.18%, barren land by -0.18%, and built-up area by 2.56% (Raut *et al.*, 2020). The land use and land cover map of Pokhara valley (Figure. 2 C) depicts that the study wetlands are surrounded by agricultural fields and forests. The density of the population of the Pokhara Metropolitan City is 1025 persons/km^2 (https://worldpopulationreview.com/ world-cities/pokhara-population, www.pokharamun.gov.np).

Table 3: Land use type of Pokhara Metropolis from 1977 to 2010 (Rimal, 2011)

Years	**1977**		**1990**		**1999**		**2010**	
Land-use type	km²	%	km²	%	km²	%	km²	%
Urban/built-up	3.50	6.33	11.11	20.08	18.62	33.66	28.44	51.42
Waterbody	7.73	13.97	6.85	12.38	7.10	12.84	7.02	12.69
Open field	6.46	11.68	4.44	8.03	3.53	6.38	4.26	7.70
Forest cover	0.84	1.52	0.75	1.36	0.87	1.57	1.22	2.21
Cultivated land	33.59	60.73	29.18	52.76	21.40	38.70	11.21	20.27
Sandy area	3.19	5.77	2.98	5.39	3.79	6.85	3.16	5.71
Total	55.31	100	55.31	100	55.31	100	55.31	100

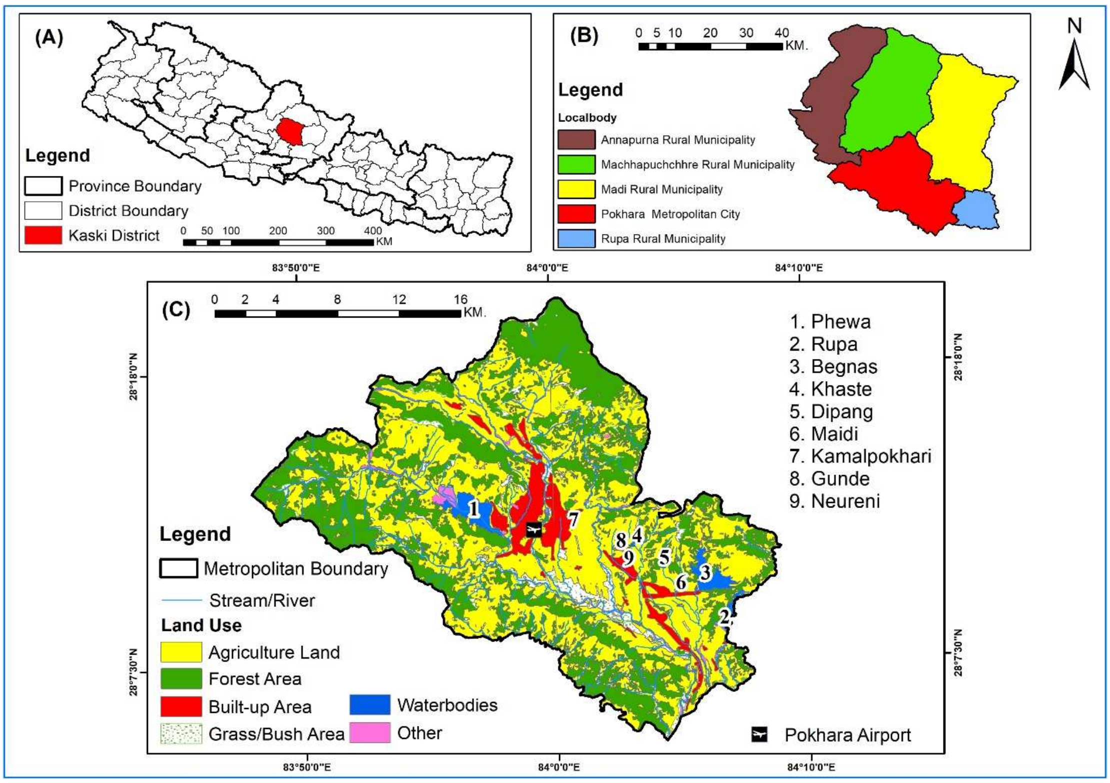


Figure 2: Map of Nepal (A), Kaski district (B) and lake cluster in Pokhara Metropolitan City (C).

3.2 Diversity of naturalized species

3.2.1 Reconnaissance survey

During the initial survey of Pokhara valley in August 2018, voucher specimens of IAPS were collected and their identification was confirmed by comparing with previous publications (Tiwari *et al.,* 2005; Shrestha, 2016). The specimens were obtained as part of a spatial distribution mapping survey. The voucher specimens were deposited at Tribhuvan University Central Herbarium (TUCH) in Kathmandu.

3.2.2 Vegetation and water sampling

3.2.2.1 Inventory of wetland flora

From June 2018 to December 2020, nine lakes of the LCPV were visited multiple times, representing monsoon (Jun-Aug) and post-monsoon (Sep-Nov) seasons. Flowering plant specimens were collected along lakeshores, within lakes, and around lakes (15 m from the lakeshore). Following Haynes (1984) the collection of free-floating and submerged species growing within 15 meters of the lakeshore was carried out. The specimens were pressed into the newspaper and dried by paper-change method. The prepared specimens were identified using regional floras [the Flora of Bhutan (Grierson & Long, 1983-2001), the Flora of China (Wu *et al.,* 1994-2008), and the Flora of Nepal (Watson *et al.,* 2011)]. The Tribhuvan University Central Herbarium (TUCH) and the National Herbarium and Plant Laboratories (KATH) were visited for further identification and verification of the species. Expert opinions were also considered for species identification.

The nomenclature of the families was based on APG-IV (Angiosperm Phylogeny Group, 2016; Chase, 2016), while that of the genera and species was based on the Catalogue of Life (Roskov *et al.,* 2020). Field observations and consulted floras were used to determine the species' habits. Raunkiaer's categorization was used to classify the life forms (Kent, 2012), and Plants of the World Online (POWO, 2021, www.plantsoftheworldonline.org) was used to determine the native ranges. Traditional uses of the plant species were compiled from the literature (e.g. Manandhar 2002; Sah *et al.,* 2002; Bishokarma *et al.,* 2005; Baral and Kurmi 2006; Acharya 2009; Joshi & Joshi 2009, Kunwar *et al.,* 2010, Conserva *et al.,* 2012: and Adhikari *et al.,* 2019).

3.2.2.2 Vegetation sampling

Vegetation sampling plots were established along the shorelines of water bodies. The vegetation was sampled using a rectangular plot (100 m^2; 20 m × 5 m) (Ellenberg & Mueller-Dombois, 1974; Harper & Macdonald, 2002). The plots were sampled along the shoreline in such a way that one-half of the plot was on land and another half on the water surface. The distance between subsequent plots was approximately 400 meters in large wetlands (such as Phewa, Begnas, Rupa, and Dipang) and it was approximately 200 meters in small wetlands (e.g., Kamalpokhari, Gunde, Maidi, Khaste, Niureni).

Table 4: Total number of plots studied in each wetland of LCPV

SN	Wetland	Number of plots
1	Phewa	23
2	Rupa	12
3	Begnas	21
4	Khaste	6
5	Dipang	7
6	Maidi	9
7	Kamalpokhari	2
8	Gunde	6
9	Niureni	3

Each plot was divided into five 20 m^2 (4 m × 5 m) sub-plots. In each sub-plot, plant species present were recorded and their cover was estimated visually (Kent, 2012). Cover of each species was categorized into one of six different classes: 0-5%, 5-25%, 25-50%, 50-75%, 75-95%, and 95-100% (Daubenmire, 1959). For this, the percentage of sub-plot area covered by the canopy of each plant species was visually estimated. During sampling, plant specimens were collected and herbarium prepared for future reference.

3.2.2.3 Plant identification and species categorization

Plant specimens were identified as described earlier in 3.2.2.1. With the use of online databases such as Plants of the World Online (www.plantsoftheworld.org) and e-flora (www.efloras.org), the identified species were classified as native and naturalized alien species established in the wild (Pysek *et al.*, 2004). Plant species in their place of origin are native plants whereas the alien plant species to their non-native range capable to self-replication in wild at least for ten years without human help are naturalized plants and the naturalized plants that produce reproductive offsprings in very large numbers away from their native range and capable to spread over a large area are called invasive plants (Pysek 2004). Using Invasive Alien Plants of Nepal (Adhikari *et al.,* 2022), naturalized species were further categorized into non-invasive and invasive species.

3.2.2.4 Data analysis

Species richness was defined as the number of species present in each plot (Magurran, 2004). For each plot, the species richness of the native and naturalized species was calculated separately. The species richness across the studied wetlands was compared by the Analysis of the Variance (one way ANOVA), followed by Tukey's range test. Statistical outputs of these analyses were presented as box-whisker plots. Variation of naturalized species richness with native species richness (hypothsis I of this study) was analyzed by the Generalized Linear Model (GLM) (McCullagh & Nelder, 2019).

Multiple linear regression analyses among the richness and coverage of native and naturalized species with Nitrogen and Phosphorus as nutrients were carried out (Olive, 2017). In this case, the richness and coverage of native and naturalized species were the dependent variables, and nutrients (N and P) were the independent variables. This analysis helped to test the second hypothesis of the present study. The GLM was based on the nutrient content of the lake in the form of N and P as dependent variables, as well as the plots' richness, and coverage as independent variables.

Ordination was done using the vegan package of R (Oksanen *et al.,* 2013) to determine the relationship between species composition and environmental variables (in this case, nitrate nitrogen and total phosphorus contents of water, and wetland identity). Ordinations like Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA) were performed. These analyses were done separately for the native and the naturalized plant species. For both categories of the species, the DCA first axis length was greater than 3.0 and the eigen value was greater than 0.5. Therefore, the CCA was used for further analyses (Leps & Smilauer, 2003). The interpretation of the position for each species and environmental variable in their space was based on the species and environmental scores acquired after the CCA. The values of these scores assisted us in determining the relationship between them and each of their axes.

3.2.3 Water sampling and laboratory analysis

From each of the vegetation sampling plots, one water sample was collected so that the vegetation and the nutrients in the water could be related. Altogether 89 water samples (1000 mL per plot; 200 mL/sub-plot) was collected in a clean bottle from the water surface. The collected water samples were promptly transported to the lab (Central Department of Environmental Sciences, Tribhuvan University, Kirtipur) at Kathmandu, where they were kept in refrigerator at 4-6ºC. They were used to determine the levels of nitrate nitrogen and total phosphorus in water samples following the method described by Trivedi and Goel (1984).

Nitrate nitrogen was obtained by Brucine method (Trivedi & Goel 1984). For this, water sample was taken with the addition of 2 mL of NaCl, 10 mL of H_2SO_4, and mixed with 0.5 mL of Brucine. The nitrate and brucine react to produce yellow color. Its intensity was measured at 410 nm. The test tubes with the mixture were kept in a boiling water bath for 20 minutes. The content was cooled and the reading was taken using a spectrophotometer (SSIUV2101). Then, nitrate nitrogen was determined from the standard curve prepared. About ten water samples with known concentrations were taken and their absorbance was determined using spectrophotometer. A line of fit was obtained in graph (by regression analysis) that provides the equation of a curve in the form of y=mx+c. From the value of the absorbance of the sample water obtained, the concentration of the nutrient was determined.

Total phosphorus was also estimated using the methods described by Trivedi and Goel (1984). For this, the water sample was digested by the H_2SO_4-HNO_3 method (25 mL was taken in Kjeldahl flask with addition further of 1mL H_2SO_4 and 5mL of HNO_3). The sample was heated until the solution become colorless after the complete removal of HNO_3. To the digest, 20 mL of distilled water and 1 mL of Phenolphthalein was added. The acid was neutralized by titrating it with 5N NaOH till the solution turns to pink. The pink color of Phenolphthalein disappeared after the addition of Ammonium Molybdate. The Phosphorus content was determined by preparing a standard curve for total Phosphorus and multiplying it with the dilution factor. All forms of Phosphorus were converted to inorganic forms (Orthophosphates) after the digestion process. The concentration of total phosphorus was determined using a spectrophotometer.

3.3 Distribution mapping

During a survey of IAPS in the Pokhara valley, a global positioning system (GPS Model Garmin etrex 10) was utilized to record the geographic coordinates of the areas where the IAPS were found. Because the roads are connected with trade and travel and mean of IAPS dispersal (Hulme *et al.*, 2008), road networks were used for distribution mapping. Regarding road length in Pokhara, black-topped, concrete, H&W road was 891.65 km. and earthen, gravel was 755.3 km with a total of 1646.95 km. (unpublished data obtained from Pokhara Metropolitan City official, received on 27 January 2022). The IAPS were studied at 201 sample plots (size: 5 m × 5 m) along roadside vegetation located at the interval of *ca*. 500 m. At each plot, the presence or absence of IAPS, the land use type, and geographic coordinates (latitude, longitude, and elevation) were recorded. Data were used to prepare distribution maps of individual IAPS in Pokhara valley using ArcGIS (Abd El-Ghani *et al.*, 2011).

3.4 Assessment of eutrophication in freshwater lakes

The concentration of nitrate nitrogen and total phosphorus in water samples collected from the lakes of the LCPV was obtained in milligrams per liter (see section 3.2.3). By comparing the concentrations of nitrate nitrogen and total phosphorus (Table 5) with the concentrations of the water sample obtained, the lakes were classified whether oligotrophic, eutrophic, or hypertrophic.

Table 5: Trophic statuses with nitrate nitrogen (NO_3-N) and total phosphorus (TP)

SN	Trophic status	NO_3-N (mg/L)*	Total phosphorus (mg/L)**
1	Ultraoligotrophic	—	<0.005
2	Oligotrophic	<0.3	0.01
3	Mesotrophic	0.3-0.5	0.01-0.035
4	Eutrophic	0.5-1.5	>0.035
5	Hypertrophic	>1.5	0.1

* MassWWP. Massachusetts Water Watch Partnership, USA, 2021

** Istvanovics, 2010

3.5 Introduction and dispersal pathways of IAPS

To know the possible sources and local dispersal pathways of IAPS, local inhabitants (n=56, age >37 yrs) of lake territories in Begnas (n=19), Phewa (n=20), and Rupa (n=17) were interviewed. The interview was conducted with inhabitants from these three lake territories because they were impacted highly by the major IAPS such as

Pontederia crassipes, Pistia stratiotes, and *Ipomoea carnea* subsp. *fistulosa*. For interviews, elderly boaters and fishermen and also some elderly inhabitants were selected from Pokhara valley. Open-ended questionnaires, as well as photographs of all aquatic IAPS from Nepal (*Pontederia crassipes, Pistia. stratiotes, Ipomoea carnea* subsp. *fistulosa*, *Leersia hexandra*, *Alternanthera philoxeroides,* and *Myriophyllum aquaticum*), were prepared. The determination of introduction and dispersal pathways was mainly focused on the aquatic IAPS. Interviews were taken and recorded with the permission of the respondents. The names of the respondents have been included in Appendix 1.

Alien species may have been introduced to a new region through three mechanisms: importation of a commodity, the arrival of a transport vector, and/or natural spread from the introduced range where the species is itself alien (Hulme *et al.*, 2008). There are six principal pathways of these three mechanisms: release, escape, contaminant, stowaway, corridor, and unaided. The dispersal pathways for the wetland IAPS in the study area are also identified, accordingly.

3.6 Impacts of IAPS on ecosystem services

3.6.1 Questionnaire survey and discussions

With the help of research papers (e.g., Costanza *et al.*, 1997; Sharma *et al.*, 2015; McInnes & Everard 2017; Steinman *et al.*, 2017), a list of potential ecosystem services of freshwater inland lakes was constructed (Appendix 2). The ecosystem services provided by the studied lakes were determined through focus group discussions (FGDs), key informant interviews (KIIs), and individual household surveys.

FGDs were held along the wetlands to gain a better grasp of the stakeholders' collective understanding of the ecosystem services supplied by the wetlands. Following Taylor *et al.* (2016), 19 focus groups with 5-10 people from a similar occupational background such as farmers, boaters, fishermen, and hoteliers were conducted. An open-ended questionnaire and a checklist of ecosystem services (Appendix 2) were employed to facilitate the discussions. Participants were urged to speak up about their experiences. The FGDs' discussions were recorded (with the participants' agreement) and photographs were taken. Among the total 152 participants, the majority (75.6%) were male (Appendix 3).

Table 6: Number of participants in the focus group discussions held in areas of the Lake Cluster of Pokhara Valley, Nepal

SN	Lake	Number of focus group discussions	Participants		
			Total	Male	Female
1	Phewa	4	47	42	5
2	Rupa	3	24	13	11
3	Begnas	4	31	19	12
4	Khaste/Niureni	3	12	9	3
5	Dipang	2	12	12	-
6	Maidi	1	7	4	3
7	Kamalpokhari	1	11	10	1
8	Gunde	1	8	6	2
	Total	19	152	115	37

Nineteen groups of people were interviewed, representing a variety of stakeholder groups i.e. Boaters, Hoteliers, Fishers, and Farmers (Table 6).

There were altogether twenty-three persons (Appendix 4) involved in Key Informants Interview (KII). Among them, were boaters (n=4), hoteliers (n=5), fishers (n=5), social worker (lake conservation committee, Maidi) (n=1), businessmen (n-1), farmers (n=5), retired government officials (n=1), and contractor (n=1).

The interviews with key informants were conducted in order to acquire particular information about the lakes' ecosystem services, as well as to cross-validate and/or confirm the data obtained through FGDs (Appendix 5).

Individual interviews and local market prices of the goods were used to quantify the economic value of the ecosystem services, particularly for provisioning services. To gather information on the IAPS' influence on the wetland ecosystem services offered by the lakes, household surveys (Appendix 6) were conducted among beneficiaries in the vicinity of the lake clusters. Members of the lake committees assisted in estimating the number of households in a 1 km area around the lake. For the survey, 10% of the houses were sampled using the snowball sampling method (Etikan, 2016). Interviews were conducted with the elderly members of the families. A total of 273 households were interviewed (Table 7), with farmers (162), boaters (47), hoteliers (35), and fishermen (29) (Appendix 7).

Table 7: Household survey in the vicinity of Lake Cluster of Pokhara Valley

SN	Lakes	Farmers	Boaters	Hoteliers	Fishermen
1	Phewa	21	35	19	11
2	Rupa	16	-	5	8
3	Begnas	17	12	10	5
4	Khaste- Niureni	29	-	1	3
5	Dipang	13	-	-	2
6	Maidi	23	-	-	-
7	Kamalpokhari	18	-	-	-
8	Gunde	25	-	-	-
	Total	162	47	35	29

3.6.2 Data analysis

An inventory of the IAPS found in the lakes was developed based on the field survey. Following the grading technique, the ecosystem services were prioritized (McInnes & Everard, 2017; Shrestha *et al.,* 2019). This assisted in determining the relative value of various ecosystem services. For the purpose of prioritizing ecosystem services, all individual comments obtained during the interviews were categorized under four categories: hotel, fisheries, boaters, and farmer's organizations. To prioritize the value of all 18 ecosystem services, they were given four values for the most important ecosystem service and one value for the least significant ecosystem service. The final score was calculated by adding all of the scores together. By dividing the score by the total score and multiplying by 100, the scoring percentage was computed.

The economic value of the main ecosystem services (Provisioning services) was estimated using direct and indirect market price methodologies (Sharma *et al.,* 2015). The average yearly value of directly utilized wetland products per household was determined for the provisioning services based on quantities harvested and prices, without considering what proportion was sold. The average annual value of resources harvested per household multiplied by the expected total number of dependent households was used to compute the total value of the wetland's provisioning services for all dependent households residing within 1 km of the lake territory (Sharma *et al.,* 2015). The following equation was used to determine the total economic value of the provisioning services (Viboonpun, 2000 as cited by Sharma *et al.,* 2015).

$$TVPi = \sum_{i=1}^{n} (\%hh_i \times HH \times NVi)$$

where,

i represents the different wetland provisioning services,

$\% hh_i$ is the percentage of total households sampled dependent on the *ith* provisioning service (i.e., dependency weight);

HH is the total number of households residing in the 1 km the territory of the study wetlands, and

NV_i is the average annual net benefit per user household.

CHAPTER 4

4. RESULTS

4.1 Diversity of native and naturalized plants

Altogether 155 plant species were recorded in 89 plots sampled across all nine wetlands of the Lake Cluster of Pokhara Valley. Among them, five species were cultivated, and one species (*Ceratophyllum* sp.) could be identified only to the genus level. These six species were excluded from further analyses. Of the remaining 149 species, 80% species were native and 20% were naturalized (Table 8, Appendix 8). Three of the families (Onagraceae, Oxalidaceae, and Verbenaceae) were represented only by the naturalized species. The largest number of native species (27%) were Phanerophytes but this life form was absent among the naturalized species. The largest number of naturalized species (40%) were therophytes.

Table 8: The number of native and naturalized species across taxonomic hierarchies and life-forms

Categories		Native	Naturalized	Total
Species		119	30	149
Genus		100	25	123
Family		53	14	56
Dicot species		89	25	114
Monocot species		30	5	35
Raunkiaer's life forms	Therophyte	23	12	35
	Phanerophyte	32	0	32
	Hemicryptophytes	31	7	38
	Cryptophytes	18	5	23
	Chamaephytes	15	6	21

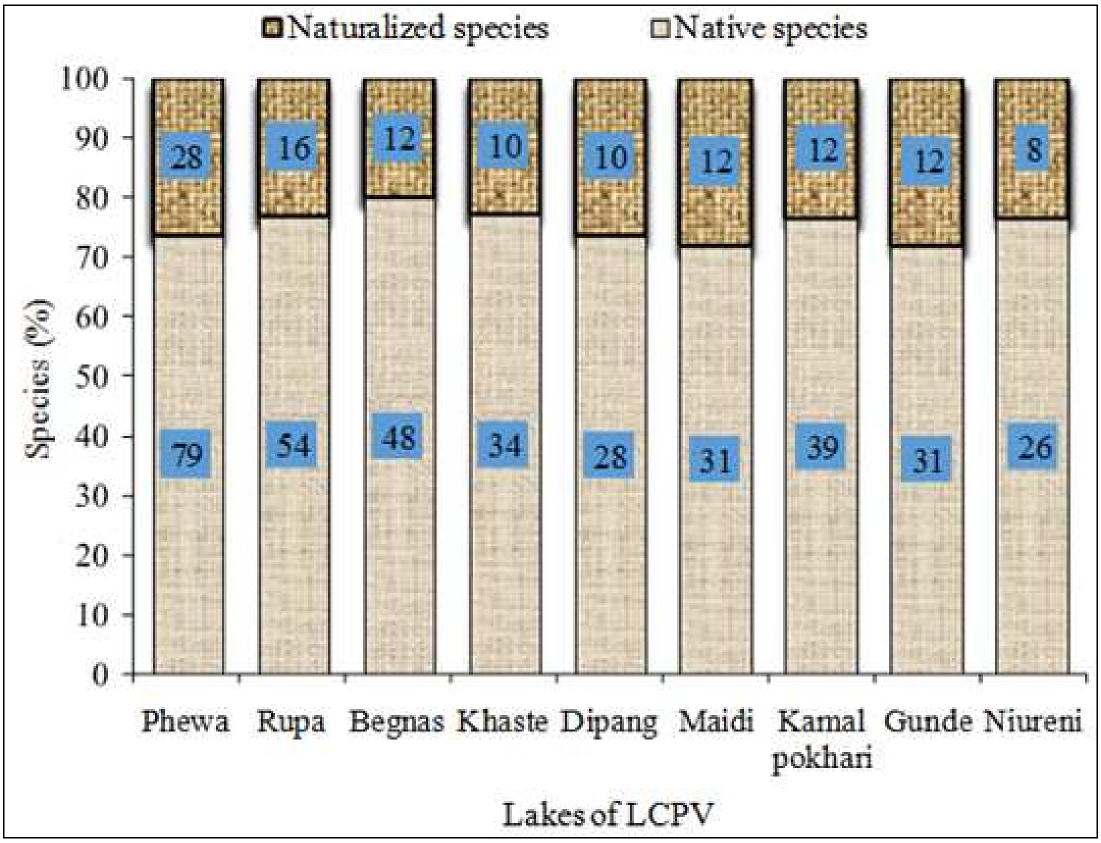
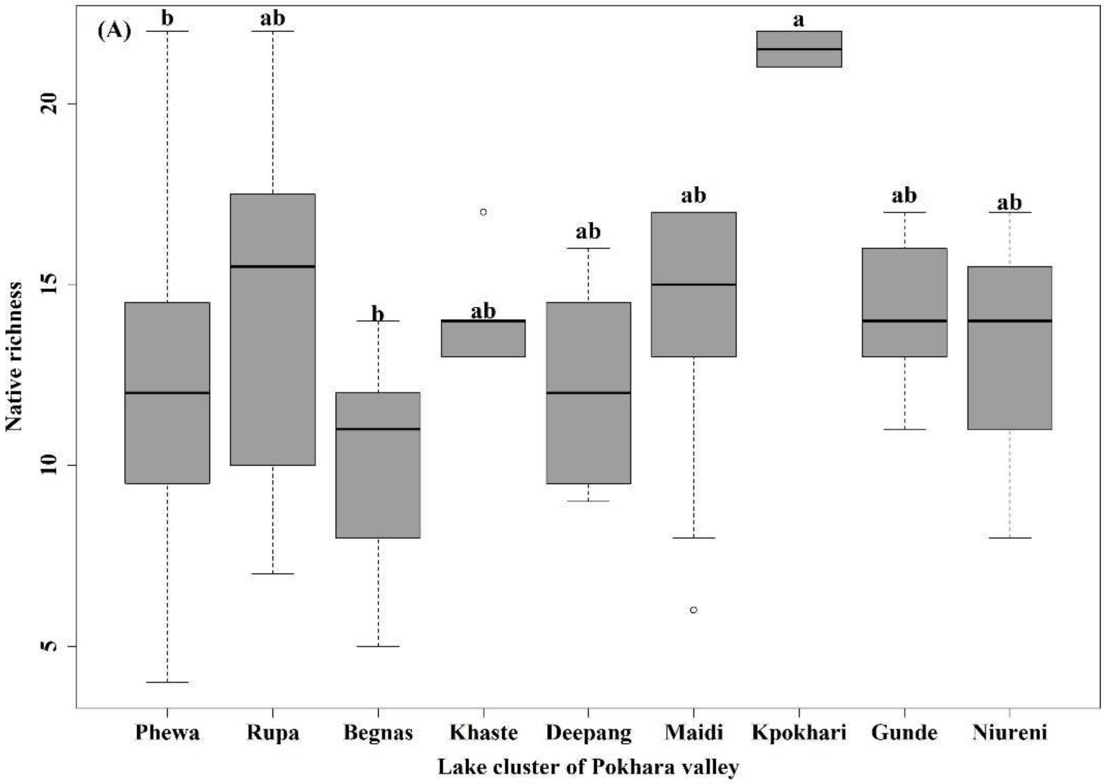


Figure 3: Number (within bar) and percentage (in y-axis) of native and naturalized species in the studied wetlands

The naturalized species accounted for 20-30% of the flowering plants in each of the individual wetlands. The percentage of naturalized species was the highest in Gunde and the lowest in Begnas lake (Figure 3). The species richness of the native and naturalized species varied significantly across the studied wetlands (Figure 4). The native species richness was the highest in Phewa and the lowest in Maidi and Gunde. Similarly, the richness of naturalized species was the highest in Phewa and the lowest in Khaste and Dipang.



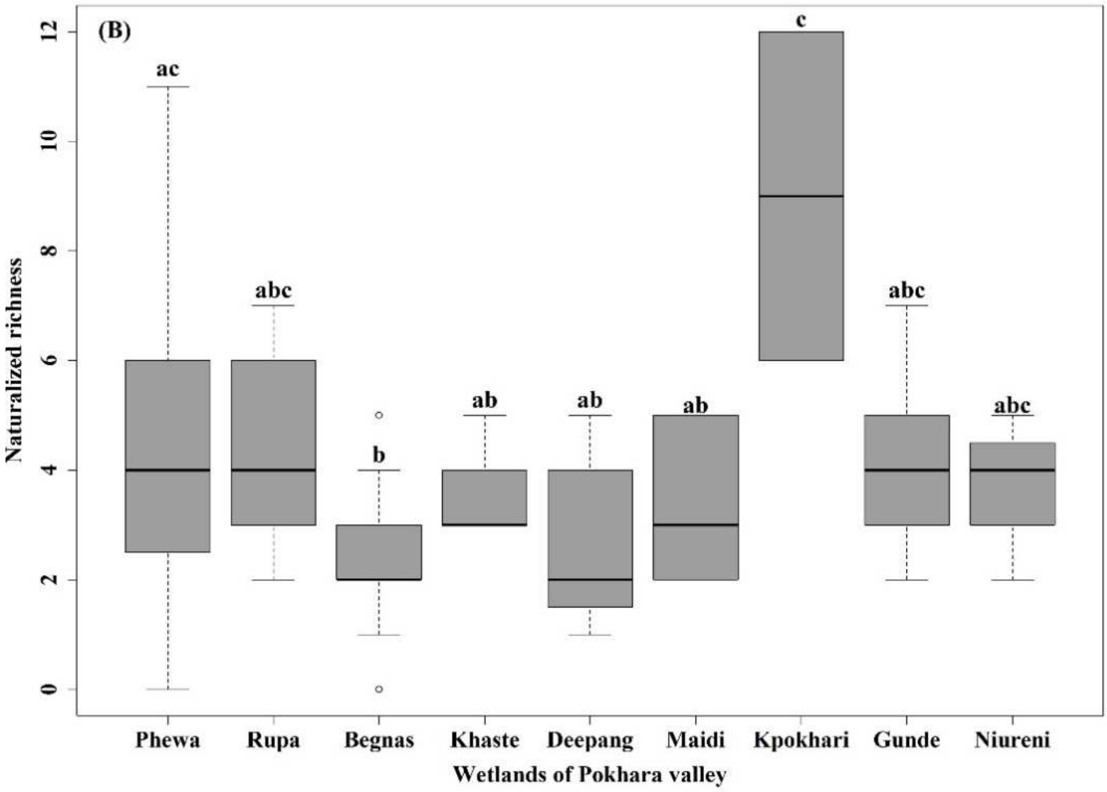


Figure 4: Box-whisker plot illustrating a variation of native and naturalized species richness (#species/100 m^2) across the studied wetlands. The wetlands with different alphabets above the box-whisker plots had significantly different mean species richness at $p<0.05$ (ANOVA followed by Tukey's range test)

4.1.1 Relation between native and naturalized species richness

Species richness of naturalized species had statistically significant positive linear relations with the richness of the native species (R^2 = 0.06, p=0.011) (Figure 5).

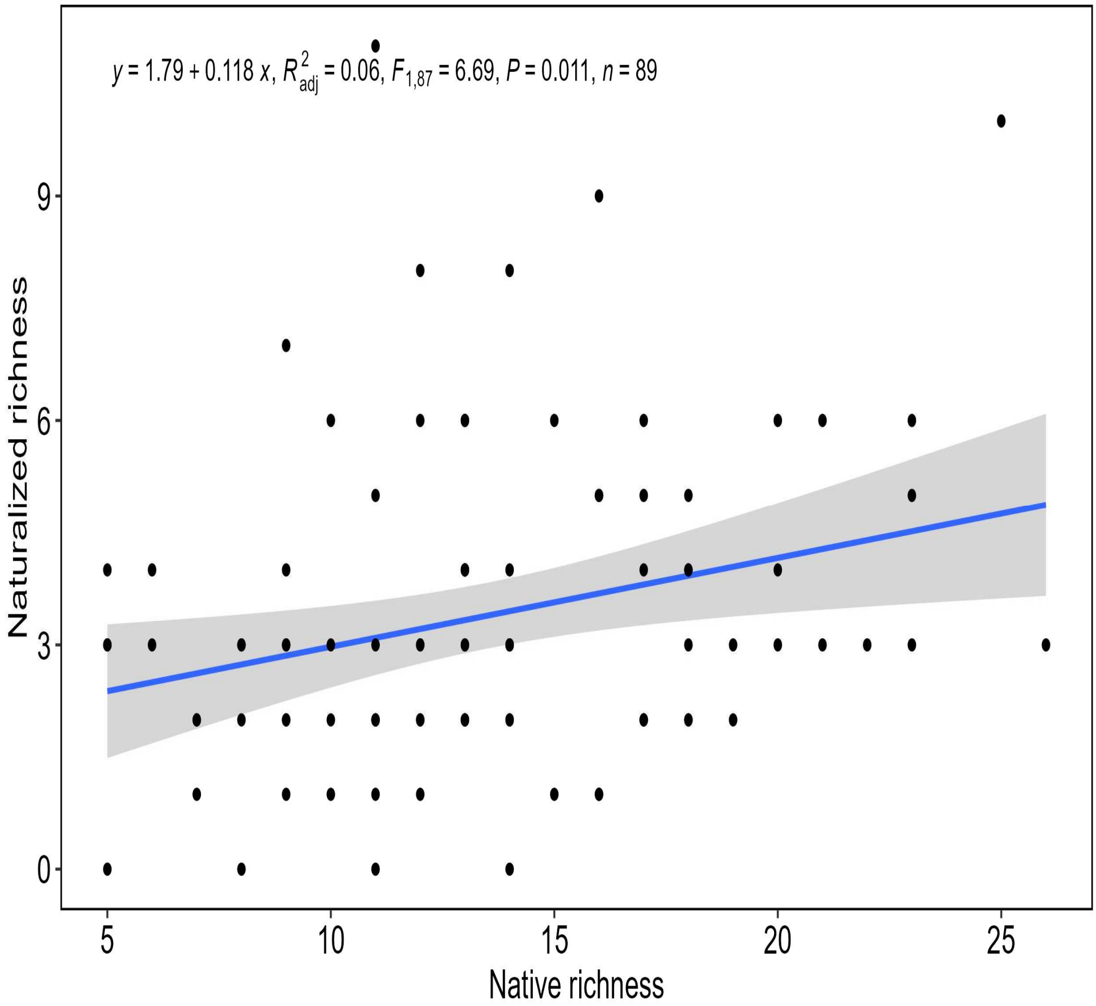


Figure 5: Variation of the species richness (#species/100 m^2) of naturalized species with the richness of native species. The fitted line was obtained from a generalized linear model

4.1.2 Nutrients and plant invasion

Regression of naturalized and native species richness with nutrient content showed that there was no significant relationship between them (Table 9). Similarly, when the regression was performed between nutrients and the coverage of the native and naturalized species (Table 9), the relation was again insignificant. The results showed that the nutrients have no definite relationship with the diversity and coverage of the native as well as the naturalized species in the study area.

Table 9: Results of multiple regression of species richness and cover of native and naturalized species with nitrate nitrogen and total phosphorus contents of water

Coefficients	**Estimate**	**Std error**	**t value**	**pr(>t)**
A. Native species richness with nutrients				
(Intercept)	13.3359	0.7660	17.411	2e-16***
N	-0.6273	5.1470	-0.122	0.903
P	-1.8506	1.5297	-1.210	0.230
B. Naturalized species richness with nutrients				
(Intercept)	1.35953	0.12198	11.145	>2e-16***
N	-0.60185	-0.93873	-0.841	0.523
P	0.04232	0.25141	-0.161	0.867
C. Coverage of native species with nutrients				
(Intercept)	26.39567	2.83401	9.314	1.13e-14***
N	-0.911412	19.04365	0.479	0.633
P	0.04286	5.65990	0.008	0.994
D. Coverage of naturalized species with nutrients				
(Intercept)	8.955	1.737	5.155	1.6e-06***
N	-0.7884	11.674	-0.675	0.501
P	2.250	3.470	0.648	0.518

4.1.3 Community composition and environmental variables

Present/absent (frequency), coverage, and richness of the plant species were the components of the vegetation composition and the nutrients in the form of nitrate nitrogen and total phosphorus along with the lakes were the environmental variables which were used to generate the CCA biplot (Appendix 9).

4.1.3.1 Native plant community

The native plant community composition of Phewa lake was distinctly different from rest of the other studied wetlands (Figure 6). Geographically closely located Begnas and Rupa lakes had similar species composition, and they were distinctly different from the remaining wetlands. The remaining wetlands were closer to each other in their native plant species composition. Species like *Ficus auriculata, Falconeria insignes, and Clocasia fallax* show affinity with Phewa lake and high nutrient (N). *Elephantopus scaber, Litsea monopetala, Pontederia hastata* had strong affinity with Rupa lake. Species like *Osbeckia stellata, Ficus benghalensis* had strong affinities with Begnas lake. *Koenigia campanulata, Trapa natans, Salomonia cantoniensis,* were among other species correlated with Dipang, Maidi, Gunde, Khaste, and

Kamalpokhari lakes (Figure 6). Nitrate nitrogen had strong affinity with the native plant species in Phewa lake whereas the total phosphorus had affinity with the native plant species from the Begnas lake.

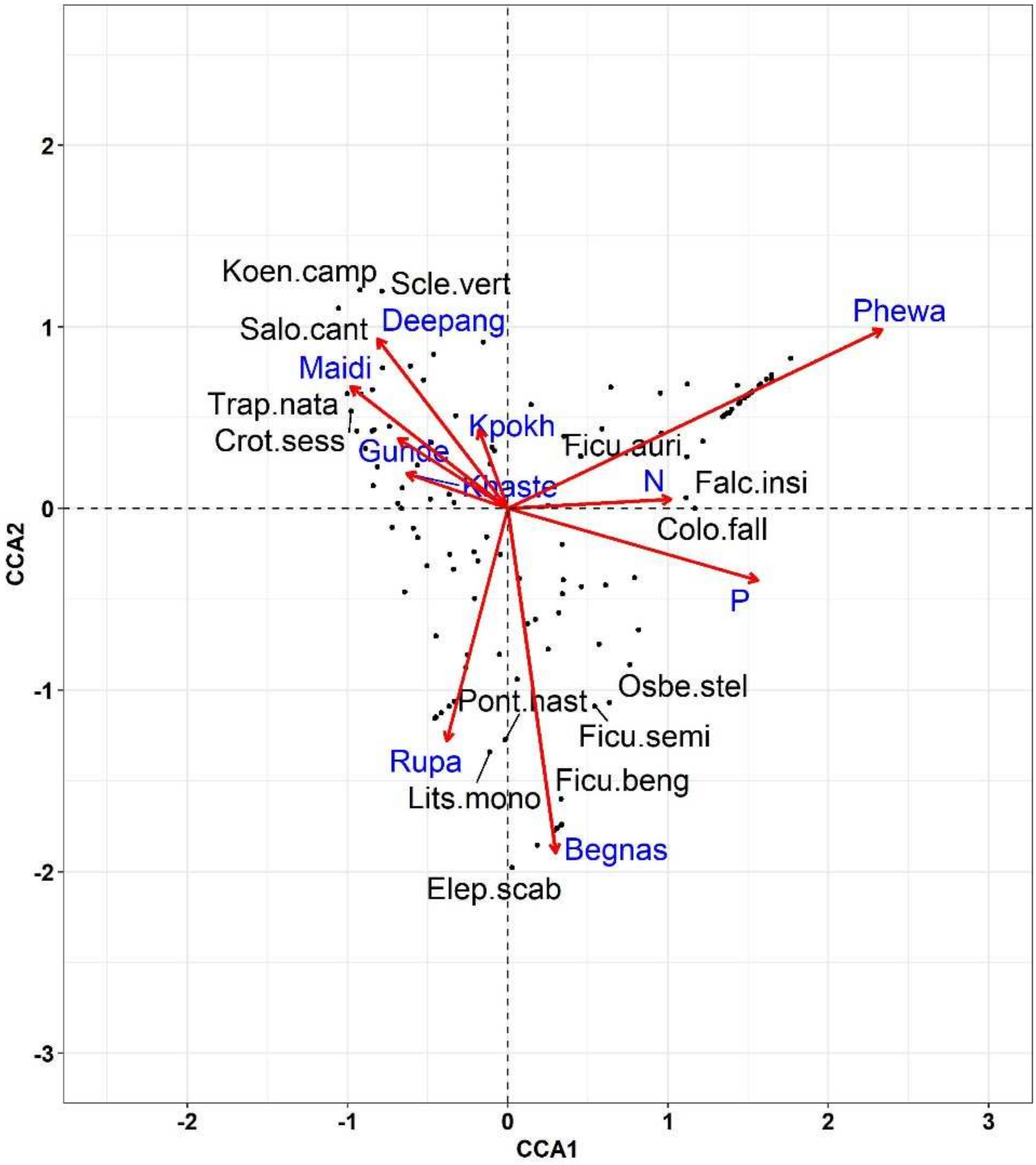


Figure 6: CCA biplot diagram showing the association of native plant species with study wetlands and environmental variables (nitrogen and phosphorus content in water). Species names were concatenated using the first four letters of generic and species names (Appendix 10).

4.1.3.2 Naturalized plant community

Among nine wetlands, Phewa lake was distinctly different from the rest of the other wetlands in naturalized species composition (Figure 7). Among the naturalized species, some notable IAPS such as *Pontederia crassipes*, *Ipomoea carnea* subsp.

fistulosa, *Lantana camara*, and *Ageratina adenophora* were more likely to be present in Phewa than in other wetlands. *Ageratum conyzoides*, an agricultural weed, was common in Rupa and Maidi while *Senna tora*, a weed of grazing lands, was common in Begnas area. Other IAPS such as *Ageratum houstonianum* and *Galinsoga quadriradiata* were associated with the plots having high nitrogen and phosphorus content in water (Figure 7). Most of the naturalized plant species had strong affinity with the total phosphorus and Phewa lake.

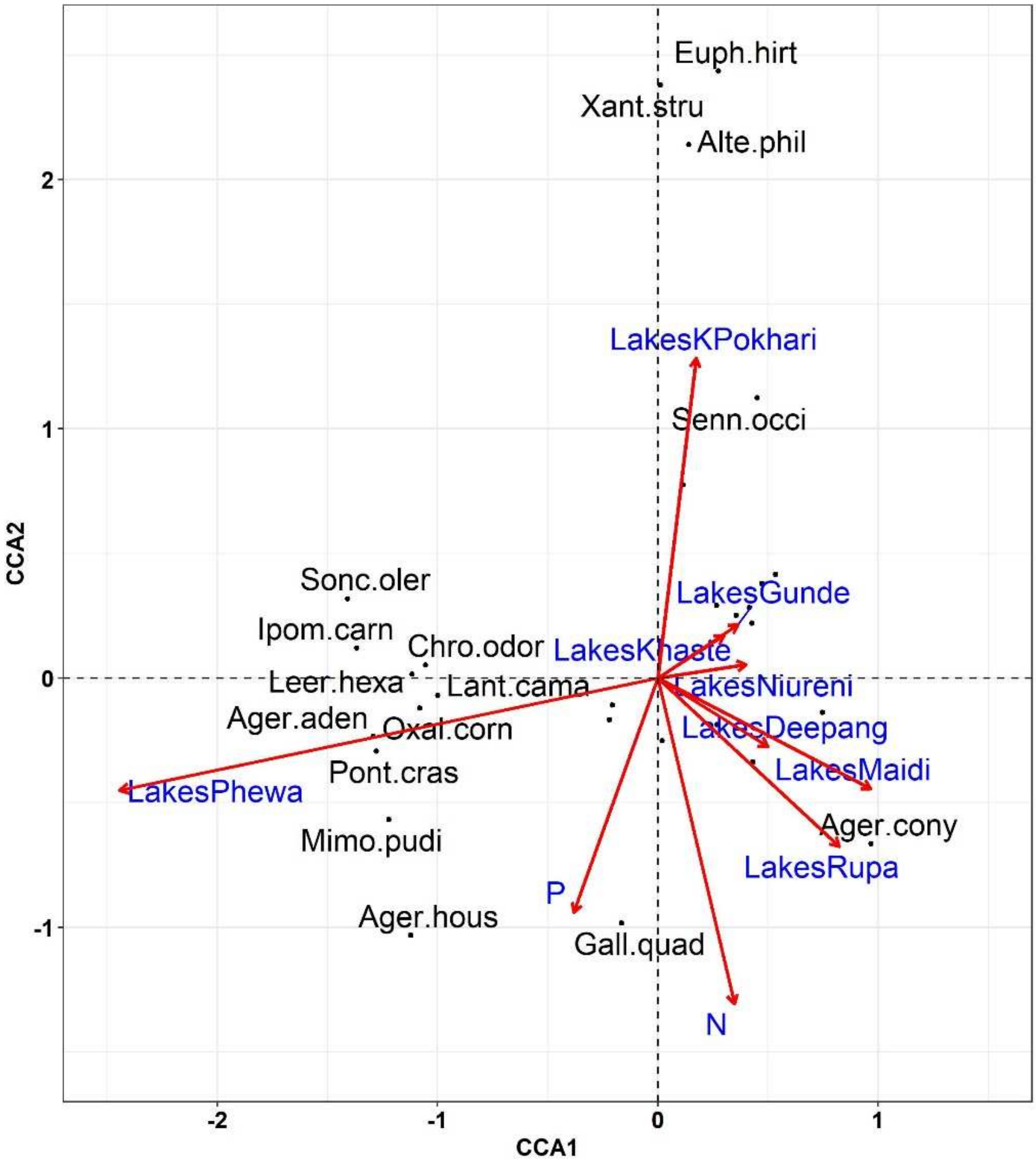


Figure 7: CCA biplot diagram showing the association of naturalized plant species with environmental variables (nitrate nitrogen and total phosphorus content in water). Species names were concatenated using the first four letters of generic and species name (Appendix 10).

4.1.4 Floristic diversity of LCPV

In the LCPV, there were 258 flowering plant species, belonging to 191 genera and 73 families (Appendix 8). There were 187 dicot species and 71 monocot species among them. There were two or more species in 37 of the 191 genera, while the rest were represented by a single species. The families with the most species were Asteraceae (27 species), Poaceae (26 species), Fabaceae (19 species), Cyperaceae (19 species), and Lamiaceae (12 species) (Table 10). Herbs, shrubs, and trees accounted for 182, 47, and 9 species, respectively. There were 81 annuals and 177 perennials in total.

Table 10: Number of species under different plant families recorded from the Lake Cluster of Pokhara Valley, Nepal

SN	Family	Number of species
1.	Asteraceae	27
2.	Poaceae	26
3.	Fabaceae	19
4.	Cyperaceae	19
5.	Lamiaceae	12
6.	Polygonaceae	10
7.	Rubiaceae, Acanthaceae	8
8.	Moraceae	7
9.	Malvaceae	6
10.	Orchidaceae	5
11.	Amaranthaceae, Commelinaceae, Rosaceae, Solanaceae, Urticaceae, Vitaceae, Euphorbiaceae,	4
12.	Hypericaceae, Phyllanthaceae, Primulaceae, Linderniaceae, Convolvulaceae, Dioscoreaceae, Boraginaceae	3
13.	Apocynaceae, Araceae, Caryophyllaceae, Balsaminaceae, Nymphyaceae, Oleaceae, Onagraceae, Oxalidaceae, Plantaginaceae, Pontederiaceae, Melastomataceae, Fagaceae, Lythraceae, Lauraceae	2
14.	Remaining 34 families	1

The IUCN red list category of the plant species was obtained. Out of the 258 species, 84 plant species were under the Least Concern category and the rest of the others (174 species) were not assessed to any threat category.

The majority of the species were native (212 species) while 46 species were alien species. Out of the 46 species, most of them were of American origin (Figure 8), 22 alien species were invasive (Table 11).

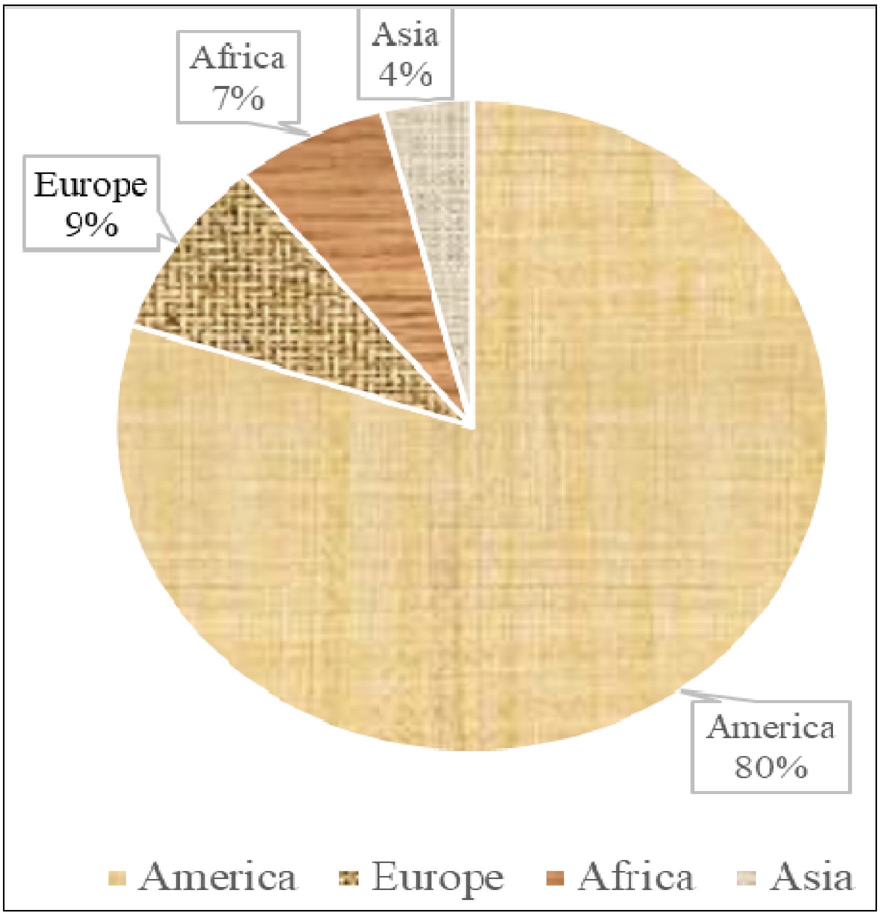


Figure 8: Percentage of alien species recorded from Pokhara valley, Nepal and their place of origin

Table 11: Floristic diversity of IAPS in LCPV and associated landscape of Pokhara valley

SN	Name of IAPS	Family	Local name	Common name	Native range	Major invaded habitats
1	*Ageratina adenophora* (L.) King & Robinson	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* (Spreng) King & Robinson	Asteraceae	Setobanmara	Siam weed; Chromolaena	Topical America, Jamaica, West Indies	Forest and Grassland

8	*Galinsoga quadriradiata* Rulz & Pavon	Asteraceae	Jhuse chitlange	Shagy soldier	South Mexico	Farmlands
9	*Ipomoea carnea* Jack subsp. *fistulosa* (Mart. ex Choisy) D.F. Austin*	Convolvulaceae	Besaram	Shrubby Morning glory	South America	Wetlands
10	*Lantana camara* L.	Verbenaceae	Kimekanda	Lantana	West Indies	Non irrigated, dry lands
11	*Leersia hexandra* Sw.*	Poaceae	Karaute ghans	Southern cut grass	Tropical and temperate Asia, Africa, Southern America, Australasia, and Northern America	Wetlands
12	*Mesosphaerum suaveolens* (L.) Kuntze	Lamiaceae	Bansilam	Pignut or Chan	Tropical regions of Mexico	Roadside
13	*Mikania micrantha* (L.) Wild	Asteraceae	Lahare Banmara	Miles a minute	Subtropical zones of North, Central, and South America	Grassland, Forest
14	*Mimosa pudica* L.	Fabaceae (Leguminosae)	Lajjawoti jhar	Sensitive plant, Sleeping grass	Topical America	Fallows and roadsides
15	*Oxalis latifolia* Kunth	Oxalidaceae	Chariamilo	Sorrel	Tropical & Subtropical America	Farmlands
16	*Pistia stratoites**	Araceae	Kumbhika	Water lettuce	Tropics and Subtropics	Wetlands
17	*Parthenium hysterophorus* L.	Asteraceae	Patijhar	Bitter weed, Carrot grass False ragweed, Fever few	Mexico, West Indies, Central, and South America	Road sides
18	*Pontederia crassipes* (Mart) Solms.*	Pontederiaceae	Jalkumbhi	Water hyacinth	South America	Aquatic habitat and Wetlands
19	*Senna occidentalis* (L.) Link	Fabaceae (Leguminosae)	Thulotapre	Coffesenna Coffee weed	Topical America	Shrubland
20	*Senna tora* (L.) Roxb.	Fabaceae (Leguminosae)	Sanotapre	Sickle senna	South America	Shrubland
21	*Spermacoce alata* Aubl.	Rubiaceae	Alupatejhar	Broad leaved false button weed	Tropical America	By farmlands
22	*Xanthium strumarium* L.	Asteraceae	Vedekuro	Rough cockle-Bur	America	Roadsides

*These are wetland IAPS reported from the LCPV

Therophytes and hemicryptophytes were the dominant lifeforms in the wetland flora of the study area (Figure 9). The herb species consisted of hemicryptophytes and cryptophytes. The chamaephytes were mostly shrub species, whilst the phanerophytes were trees and their accompanying epiphytes and climbers that grew in the wetlands' surrounding areas. *Trapa natans, Pontederia crassispes, Pistia stratiotes, Hydrilla verticillata, Leersia hexandra,* and *Ludwigia adscendens* were among the ten species of Hydrophytes (a component of Cryptophytes).

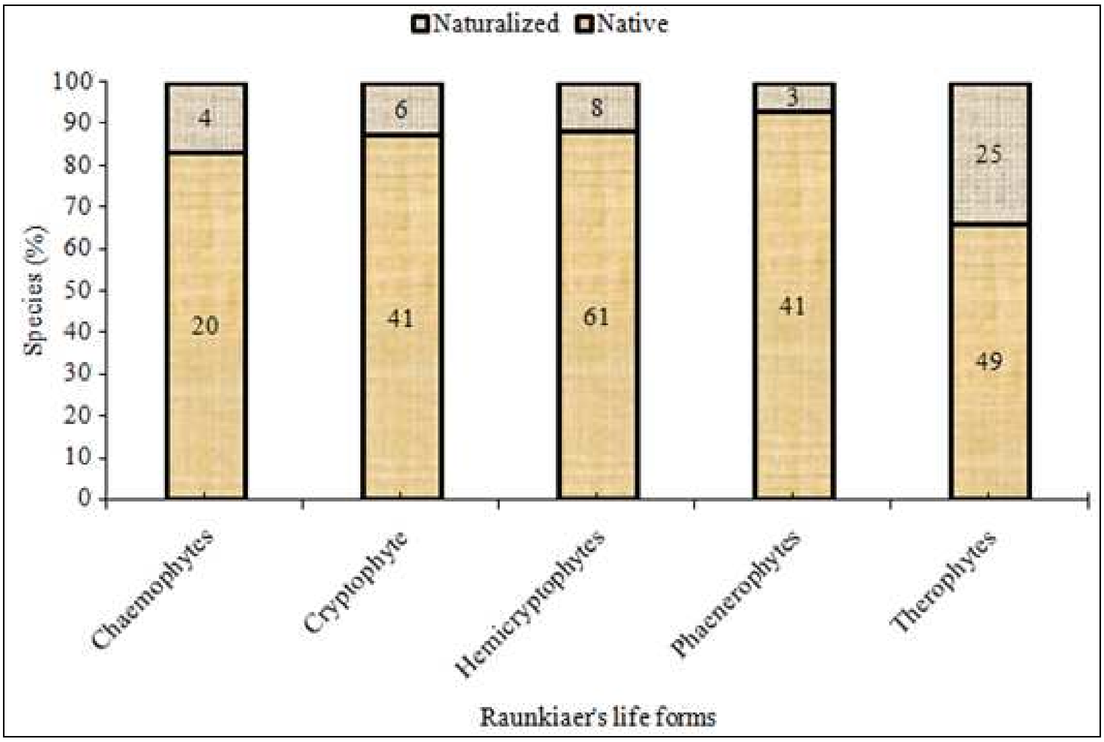


Figure 9: Percentage (y-axis) and number (within bar) of native and naturalized alien plant species categorized under different life forms. Values inside the bars represent the number of species

A review of the previous studies revealed that 71% (175 species) of the flowering plants documented in the LCPV have one or more use values (Table 12). The majority of them (60%) were used as medications, followed by forage and fodder (23%) and food (19%). This indicates that the vegetation of LCPV have potential to provide vital provisioning services to the people who live in the area around it.

Table 12: Uses of the plant species reported from the LCPV. Uses of the species have been compiled from the previous studies (See Appendix 8 for details)

SN	Use category	Number of species	Percentage of species
1	Medicinal uses	154	59.68
2	Fodder and forage	59	22.86
3	Food value	50	19.37
4	Fiber yielders	9	3.48
5	Rituals plants	4	1.55
6	Fuelwood	3	1.16
7	Fish poisons	2	0.77
8	Timber yielders	2	0.77
9	Ornamental plants	2	0.77
10	Tannin yielders	2	0.77
	Dye yielders	1	0.38
12	Use in construction	1	0.38
13	Green manure	1	0.38
14	Hedge plant	1	0.38
15	Soaping agent	1	0.38
16	Fermenting agent	1	0.38

4.2 Spatial distribution of IAPS

During the roadside survey, 20 IAPS were found in the Pokhara valley, accounting for 79 % of the 28 IAPS (Shrestha *et al.*, 2021; Adhikari *et al.*, 2022) found in Nepal (Figure 10). They were divided into 18 genera and 10 families. The Asteraceae family accounted for over half of the species (9 species). *Alternanthera philoxeroides, Pontederia crassipes, Ipomoea carnea* subsp. *fistulosa,* and *Leersia hexandra* were four of the 20 IAPS that were wetland species, whereas the remaining 16 were terrestrial IAPS. *Pontederia crassipes, Lantana camara, Mikania micrantha,* and *Chromolaena odorata* are among 100 of the world's worst invasive alien species (Lowe *et al.*, 2000).

4.2.1 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* subsp. *fistulosa, Spermacoce alata, Xanthium strumarium, Maesosphaerum suaveolens, Alternanthera philoxeroides, Mikania micrantha* had <5% frequency (Figure 10).

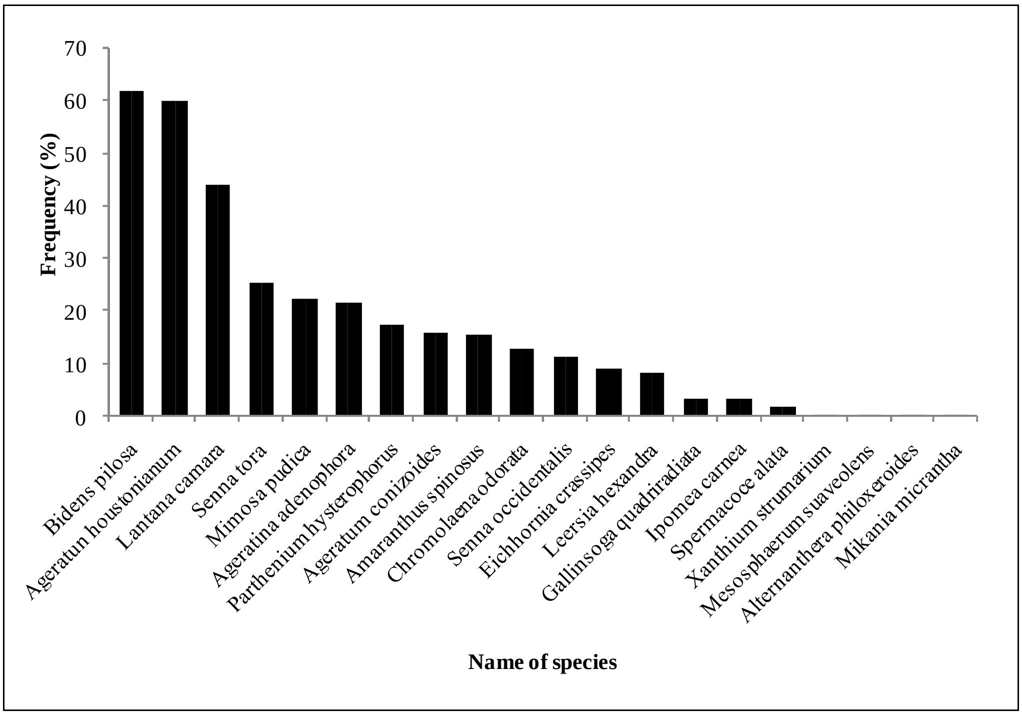


Figure 10: Frequency of different alien plant species in Pokhara valley, Nepal

4.2.2 Distribution of IAPS

Bidens pilosa was found to be the most widely dispersed invasive plant species in the Pokhara valley, according to maps of 20 distinct invasive plant species. *Ageratina adenophora* was found in almost every major location, though it was sparsely distributed. *Ageratum conyzoides* has been found in agricultural fields as well as urban settings. The *Ageratum houstonianum* was found all across the valley. *Amaranthus spinosus* was not found in the Lekhnath area, but it was found in the Lakhanchowk and Bhimsenchowk built-up areas. Lamachaur had a lot of *Bidens pilosa*. It was also common in Hemja, Bagar, Bhimsenchowk, Budhibazaar, Taalchowk, Birauta, and Pame as well. Pame and the International Airport Area have been reported as having *Chromolaena odorata* (Figure 11). Wetland IAPS *Pontederia crassipes* was found mostly in Phewa, Rupa, and Begnas lakes (Appendix 11). *Ipomoea carnea* subsp. *fistulosa*, a wetland IAP, was found largely along the water canal in the Lekhnath area. *Galinsoga quadriradiata* was found in farmlands of Lamachour area. A common poisonous plant, *Lantana camara*, was found all throughout the valley (Appendix 11). *Leersia hexandra* has been found in the lakes and canals. It produces a thick carpet over the lake water in Maidi Lake. *Mimosa pudica* was common in the Lekhnath area. The valley's built-up region was colonized by *Parthenium hysterophorus.* It was found in the Gagangaunda area of Lekhnath. In the Pokhara valley’s Lekhnath area, *Spermacoce alata* was common. It was also frequently found in Budhibazaar and Arghaun areas. *Xanthium strumarium* was found in the market area, but it was less frequent in Lekhnath. *Mesosphaerum suaveolens* and *Mikania micrantha* were found for the first time at Bacchedubuwa, near the Pokhara valley’s waste dumping site. Similarly, *Alternanthera philoxeroides* was found for the first time at the Khahare area of Phewa lake.

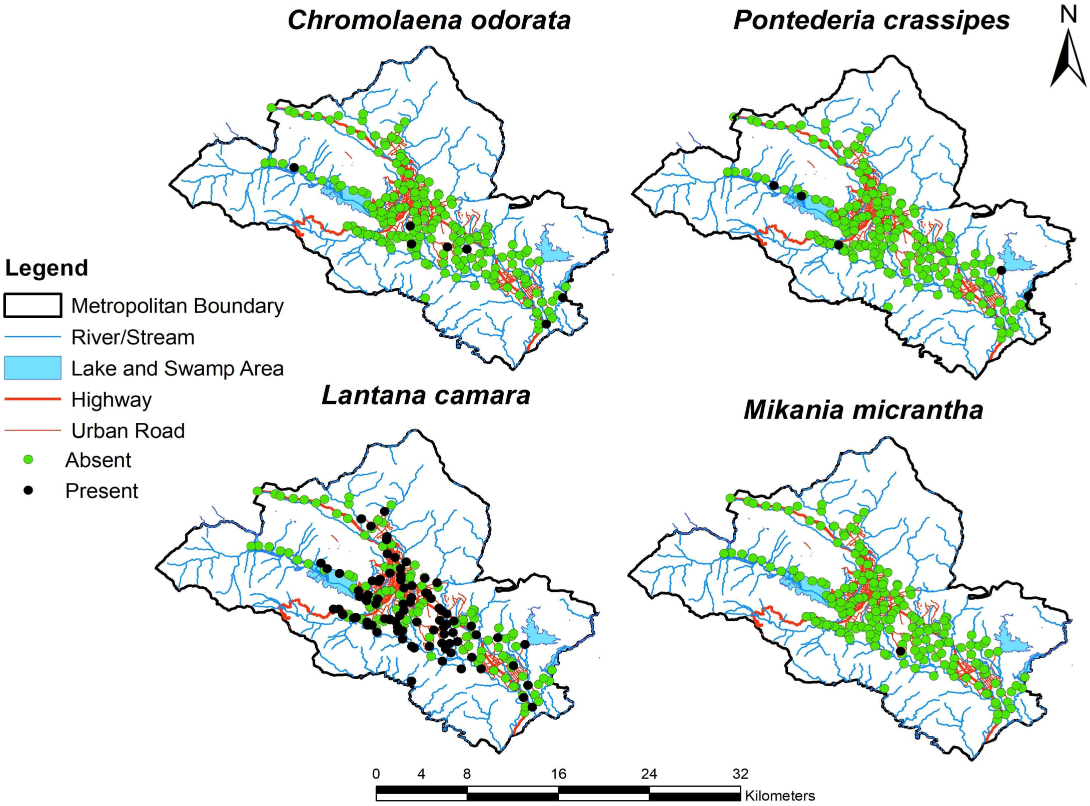


Figure 11: Distribution of four IAPS of global concern in Pokhara valley. (See Appendix 11 for the distribution of the remaining 16 species)

4.2.3 Species richness

The species diversity varied depending on the land use. The highest species diversity was found in shrubland, followed by fallow land and woodland (Figure 12). The species richness of grassland, non-irrigated farmland, and irrigated farmland were similar. Residential and commercial sectors had the lowest species diversity. There was considerable heterogeneity in the species richness of IAPS throughout space. In the Phewa lakeshore to Pame area, low species richness (1-3 species/plot) was noted (Figure 13). Plots with low species richness were observed spreaded around the commercial area in other regions. The plots with the highest species diversity were limited to the commercial areas of Lakhanchowk and Bhimsentole, as well as the surrounding territory.

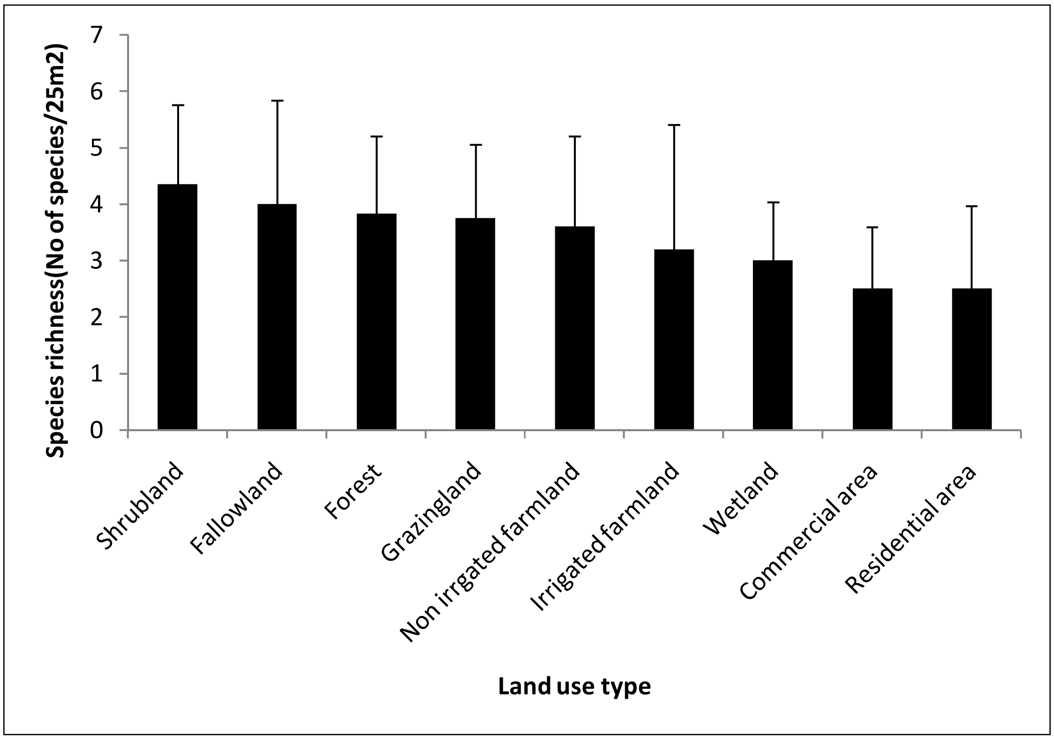


Figure 12: Variation of IAPS richness across land-use types in Pokhara Metropolis City, Nepal

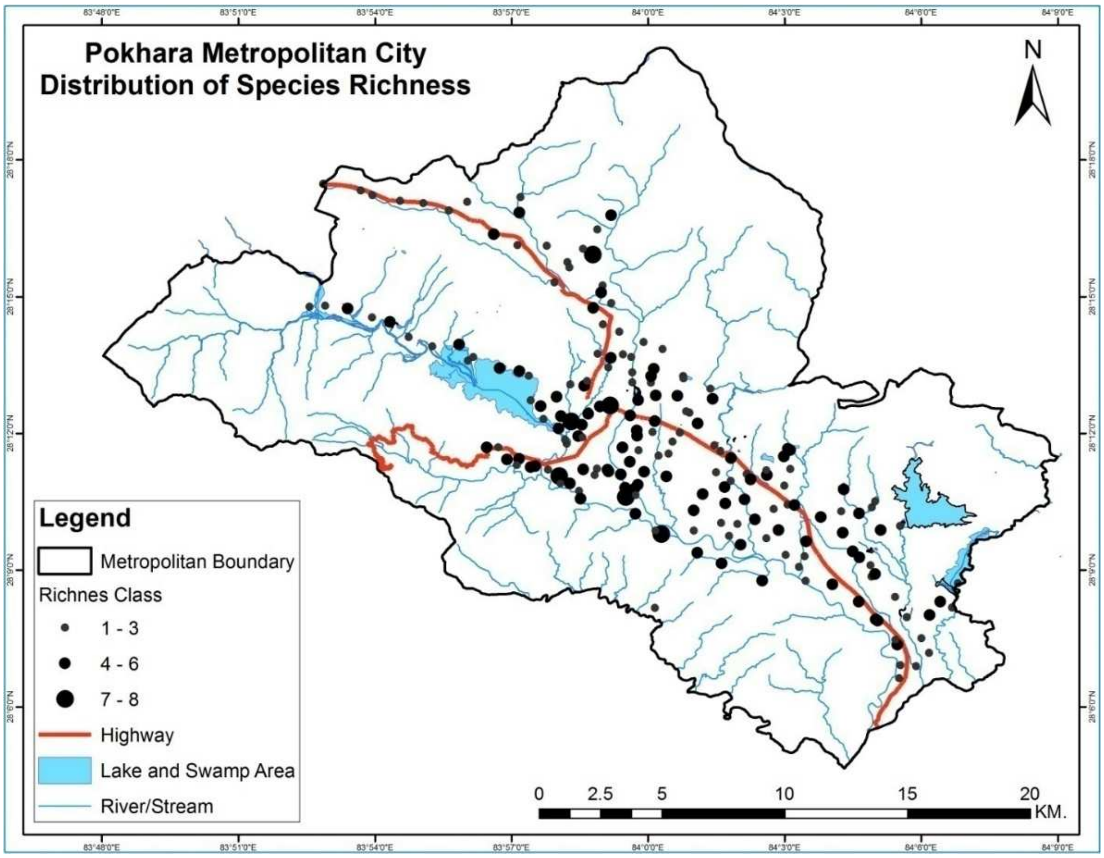


Figure 13: Spatial pattern of the species richness (species number/plot) of IAPS in the study area

4.3 Eutrophication in lakes

The highest value of nitrate nitrogen was found in water samples of Dipang and the lowest value was found in Phewa, Rupa, and Begnas. The total phosphorus content was found highest in Niureni and the lowest value was found in Khaste. Thus, nutrient analysis in LCPV revealed that the NO_3-N level ranged between 0.04-0.17 mg/L and the TP level ranged between 0.27-1.25 mg/L (Table 13). Since the nitrate nitrogen (N-NO_3) level in LCPV was <0.3 mg/L in the present study, the lakes are still oligotrophic (MassWWP 2021). Similarly, total phosphorus (TP) ranged >0.1 mg/L, suggesting that the wetlands are considered as hypertrophic (Istvanovics 2010).

Table 13: Mean value of nitrate nitrogen and total phosphorus with standard deviation

SN	Wetland	Sample size (20×5 m^2)	Nitrate nitrogen* (mg/L)	Total phosphorus** (mg/L)
1	Phewa	23	**0.04±0.002**	0.38±0.15
2	Rupa	12	**0.04±0.003**	0.47±0.48
3	Begnas	21	**0.04±0.002**	0.39±0.15
4	Khaste	6	0.05±0.00	**0.27±0.16**
5	Dipang	7	**0.17±0.03**	0.29±0.08
6	Maidi	9	0.07±0.06	0.30±0.20
7	Kamalpokhari	2	0.07±0.04	0.41±0.3
8	Gunde	6	0.07±0.07	0.36±0.43
9	Niureni	3	0.16±0.09	**1.25±0.98**

4.4 Introduction and dispersal pathway of IAPS

Pontederia crassipes was introduced in Phewa Lake in the 1980s decade. It was brought to Begnas Lake and Rupa Lake in the late 1990s. *Pistia stratiotes* was brought to Phewa during the early 1990s, in Begnas during the 1990s and 2000s, and in Rupa during the 1990s (Table 14). Similarly, *Ipomoea carnea* subsp. *fistulosa* was introduced in Phewa during the 1980s whereas at the end of the 1980s in Begnas. Likewise, it was brought to Rupa during the 1990s.

Table 14: Approximate time of the introduction of IAPS in LCPV

SN	IAPS	Lake	Time in Decade	Respondent (%)
1	*Pontederia crassipes*	Phewa	1980s	**80**
			1990s	20
		Begnas	1970s	11
			1980s	11
			1990s	**53**
			2000s	26
		Rupa	1980s	6
			1990s	**67**
			2000s	26
2	*Pistia stratiotes*	Phewa	1990s	**42**
			2000s	11
			2010s	16
		Begnas	1970s	11
			2080s	5
			2090s	**37**
			2000s	**37**
			2010s	5
			No response	11
		Rupa	1990s	**67**
			2000s	6
			No response	28
3	*Ipomoea carnea* subsp. *fistulosa*	Phewa	1980s	**35**
			1990s	20
			2000s	5
			No response	35
		Begnas	1980s	**21**
			1990s	16
			2000s	5
			No response	58
		Rupa	1970s	6
			1980s	11
			1990s	**44**
			2000s	22
			No response	17

According to local respondents, *Pontederia crassipes* was introduced to LCPV as an ornamental plant so that Lakes' beauty could be enhanced or as contaminant mixed with fingerlings (Figure 14). *Pistia stratiotes* also followed the same course as that by *Pontederia crassipes*. Both of them were brought to the LCPV from Tarai, India, or from abroad. *P. crassipes* was also introduced to Begnas and Rupa from Phewa. *Ipomoea carnea* subsp. *fistulosa* was introduced as a hedge or ornamental plant so that the water bodies could not flow the mud of the farmlands by it. It was introduced from Tarai and India.

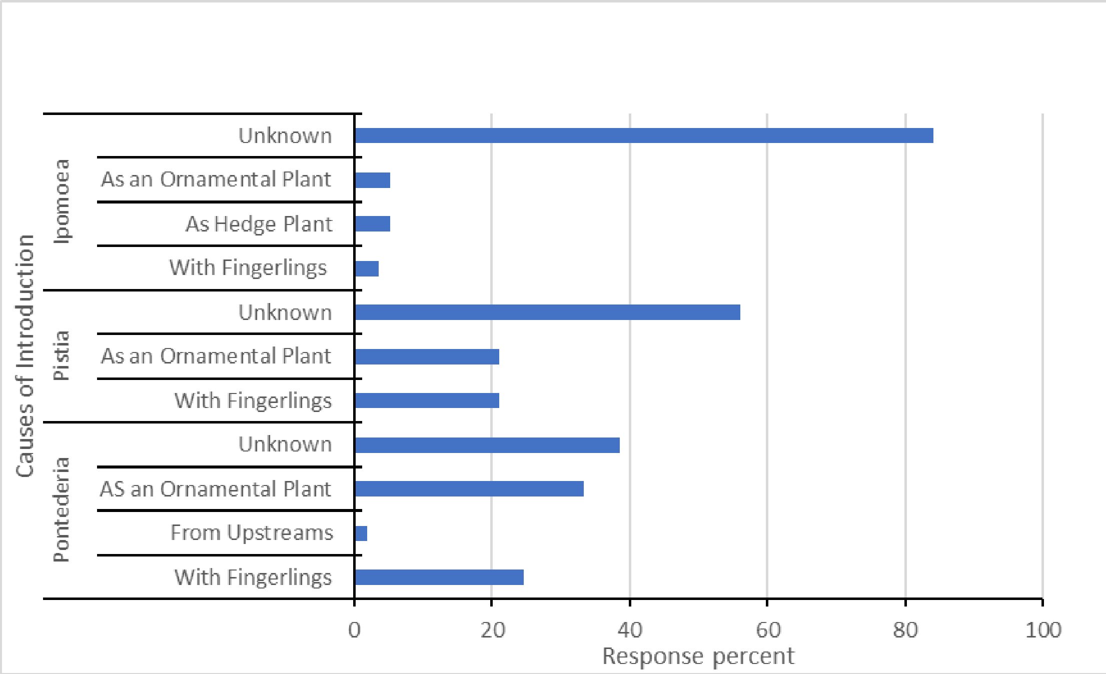


Figure 14: Causes of the introduction of IAPS in LCPV

Invasive plants in LCPV might have been introduced as an intentional introduction as ornamental plant but escaped to lakes. *Pontederia crassipes* and *Pistia stratiotes* were introduced in the form of a garden plant. They escaped from there to the lakes. However, *Ipomoea carnea* subsp. *fistulosa* was introduced for erosion control. It was introduced intentionally in the form of a commodity that was 'released' to the lakes. However, people could not inform the pathways for the introduction of *Alternanthera philoxeroides* but local respondents had been familiar with *Leersia hexandra* for a long period (>50 years) and were not aware of the time and mode of its introduction, suggesting that *Leersia hexandra* could have the longest history of introduction to the LCPV.

4.5 Impacts of IAPS on ecosystem services

4.5.1 Aquatic IAPS in LCPV

In the LCPV, five IAPS, namely: *Pontederia crassipes*, *Ipomoea carnea* subsp. *fistulosa*, *Leersia hexandra*, *Pistia stratiotes* and *Alternanthera philoxeroides* were recorded (Table 15). Detail records of the IAPS across nine lakes were tabulated in Table 11, where taxonomic details of these species are provided as additional information. Out of five listed IAPS, *Leersia hexandra* was recorded from all nine lakes, while *Alternanthera philoxeroides* was only recorded from Phewa lake.

Table 15: List of wetland IAPS present in each lake

SN	Name of the species	Phewa	Begnas	Rupa	Khaste	Maidi	Dipang	Kamal pokhari	Gunde	Niureni
1	*Pontederia crassipes*	√	√	√	×	×	×	×	×	×
2	*Pistia stratiotes*	√	√	√	×	×	×	√	×	×
3	*Ipomoea carnea* ssp. *Fistulosa*	√	√	√	×	×	√	×	√	×
4	*Alternanthera Philoxeroides*	√	×	×	×	×	×	×	×	×
5	*Leersia hexandra*	√	√	√	√	√	√	√	√	√

4.5.2 Ecosystem services provided by the lakes

The LCPV provided 18 ecosystem services, according to local informants. Provisioning, regulating, supporting, and cultural services were used to classify these ecosystem services (Table 16). Fisheries, wild edible fruits, medicinal plants, drinking water, the herb "Gund" for manufacturing a traditional mat, and fodder were among the provisioning services in the research area, according to the interviews.

Table 16: Local people’s response to the ecosystem services (CS: Cultural service, PS: Provisioning service, RS: Regulating service, SS: Supporting service) and response percentage for different ecosystem services in lakes of Pokhara valley

Services type	Ecosystem Services	Phewa	Begnas	Rupa	Khaste-Niureni	Maidi	Dipang	Kamal pokhari	Gunde	Average of each ES	Average of service type
CS	Natural beauty	98.8	100	88.7	78.8	100	20	5.6	92	73	
CS	Tourism & Religion	62.8	50	13.2	6.1	0	20	0	0	19	
CS	Boating	74.4	38.6	17	0	4.4	0	0	4	17.3	36.4
PS	Fodder	18.6	27.3	30.2	75.8	91.3	0	0	92	41.9	
PS	Medicines	23.3	13.6	60.4	75.8	65.2	0	11.1	60	38.7	
PS	Fishes	75.6	61.4	24.5	81.8	8.7	20	11.1	8	36.4	
PS	“Gund” for mat	2.3	0	0	75.8	82.6	0	0	92	31.6	
PS	Wild fruits	0	6.8	43.4	30.3	69.6	0	5.6	64	27.5	
PS	Duck feed	30.2	4.6	0	0	0	0	0	0	4.3	
PS	Edible plants	1.2	0	3.8	0	4.4	0	0	4	1.7	
PS	Water for drinking	4.7	6.8	0	0	0	0	0	0	1.4	22.9
RS	For fish farming	53.5	45.5	39.6	75.8	100	0	0	92	50.8	
RS	For irrigation	59.3	38.6	34	75.8	100	0	0	92	50	
RS	For cattle grazing	17.4	13.6	35.9	18.2	87	0	0	92	33	
RS	Bathing cattle	14	18.2	22.6	27.3	82.6	0	0	76	30.1	
RS	Flood control	46.5	38.6	13.2	69.7	13	0	0	12	24.1	37.6
SS	Habitats protection	95.4	95.5	88.7	81.8	100	20	11.1	92	73.1	
SS	Bio-diversity	94.2	97.7	88.7	81.8	95.7	20	11.1	92	72.6	72.8

4.5.3 Prioritizing ecosystem services

The current study identified 18 types of ecosystem services (Table 16). Habitats (73.1 %), natural beauty (73 %), and biodiversity (72.6 %) were the top three services mentioned by the majority of stakeholders. Farming support, irrigation, fodder, medicine, fishing, cow grazing, mat material, and cattle bath were among the services in the second group (>30 %). Tourism and boating were only ranked third (<30%); nevertheless, in Phewa and Begnas, which are larger, these services were listed in higher grades (>50%).

These lakes were also praised for their utility in fishing (more than 60%) and flood control (more than 38%). Fishing provided the greatest part of the services in Khaste-Niureni (81.82%). Supporting services were addressed in priority (72.85%) since they are offered the highest by our society. The means of delivering services that were given priority in the second category were regulating services (37.6%). The third category included cultural services (36.43%). Provisioning services were given a 22.93% weight because they are produced in huge quantities but are not in high demand.

Prioritization, on the other hand, varied by stakeholder group, including hoteliers, fishers, boaters, and farmers (Figure 15). Surprisingly, natural beauty was the highest value (>95%) of the lakes in all four categories. After natural beauty, hoteliers ranked fish, biodiversity conservation, and boating as the second, third, and fourth most important ecosystem services (ES). The fisheries group, on the other hand, ranked fishing as the second most important value, behind biodiversity, habitat, and boating. Farmers valued biodiversity as the lake's second most valuable service, after wildlife habitat, fisheries, and flood control.

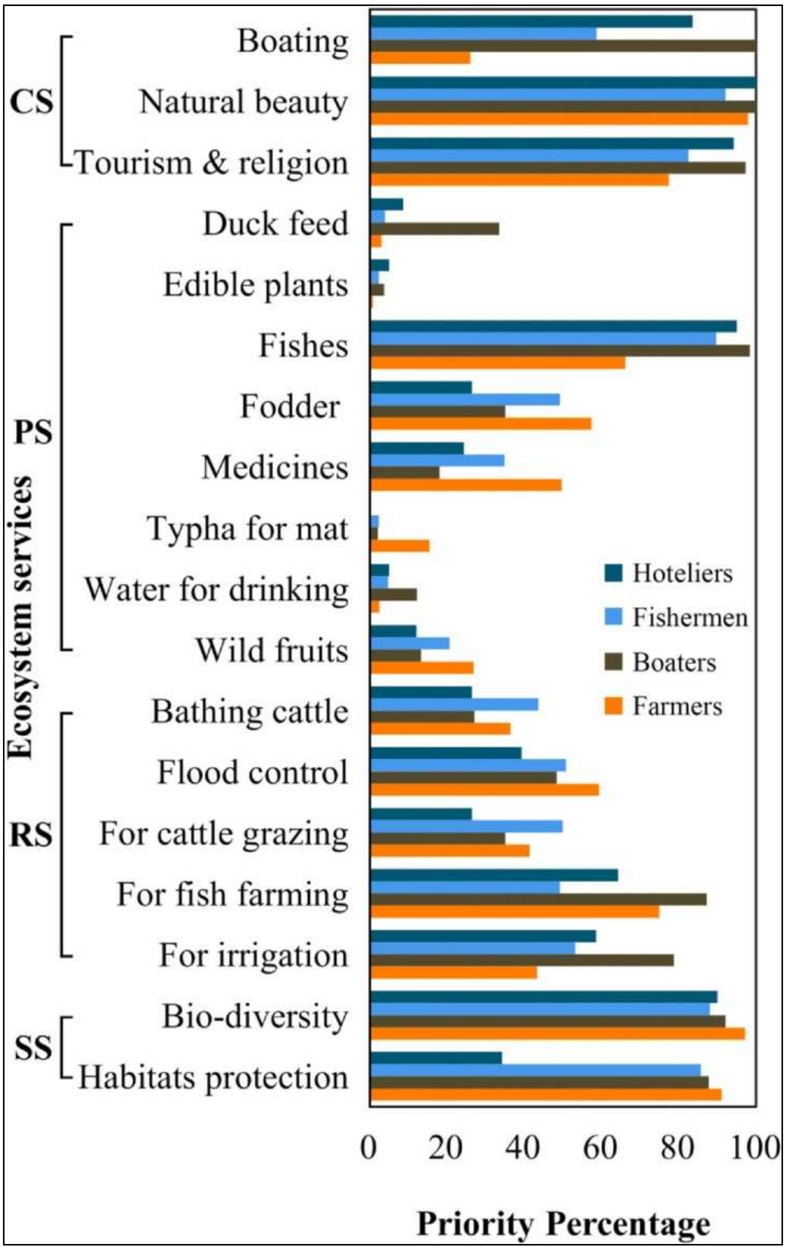


Figure 15: Prioritized ecosystem services in the periphery of lakes in Pokhara by different stakeholders Note: CS stands for cultural services, PS for Provisioning services, RS for Regulating services, and SS for Supporting services.

4.5.4 Valuation of provisioning services

The overall monetary value of provisioning services in the Pokhara valley lake cluster was estimated to be INT.$ 9.05 million. The worth of five key goods are included in this valuation: Lotus (food and medicinal), fish, fodder, "Gund" (locally known as Gund as mat material, *Machaerina rubiginosa* stem), and wild fruits. Lotus and fish were the most valuable of these products, at INT.$ 3.95 and 3.55 million respectively (Figure 16). According to respondents, lotus has a variety of medicinal and culinary purposes, including blooms, seeds, leaves, and rhizomes. Lotus fruits were marketed in the local market as a traditional remedy to treat jaundice, with Dipang, Kamalpokhari, Maidi, and Rupa lakes at the forefront. According to the informants, lotus flowers were also sold to individuals, especially during festivals.

Because fish is a popular item in restaurants and hotels, the economic value of fish harvesting was another major provisioning function provided by the LCPV. During the study, respondents indicated that a community known as "Jalari" was completely reliant on fisheries and that they had cooperatives in Phewa and Begnas.

Other marketable supply commodities accessible from the LCPV were fodder, leaf and stem of Gund (*Machaerina rubiginosa)* for the mat, and wild fruits. These items were primarily consumed by families, although they are also available for purchase at the local market. Lake clusters yielded fodder worth INT.$ 1.34 million, the biomass of *M. rubiginosa* worth INT.$ 0.22 million, and wild fruits worth less than INT.$ 0.01 million in 2019 (Figure 16).

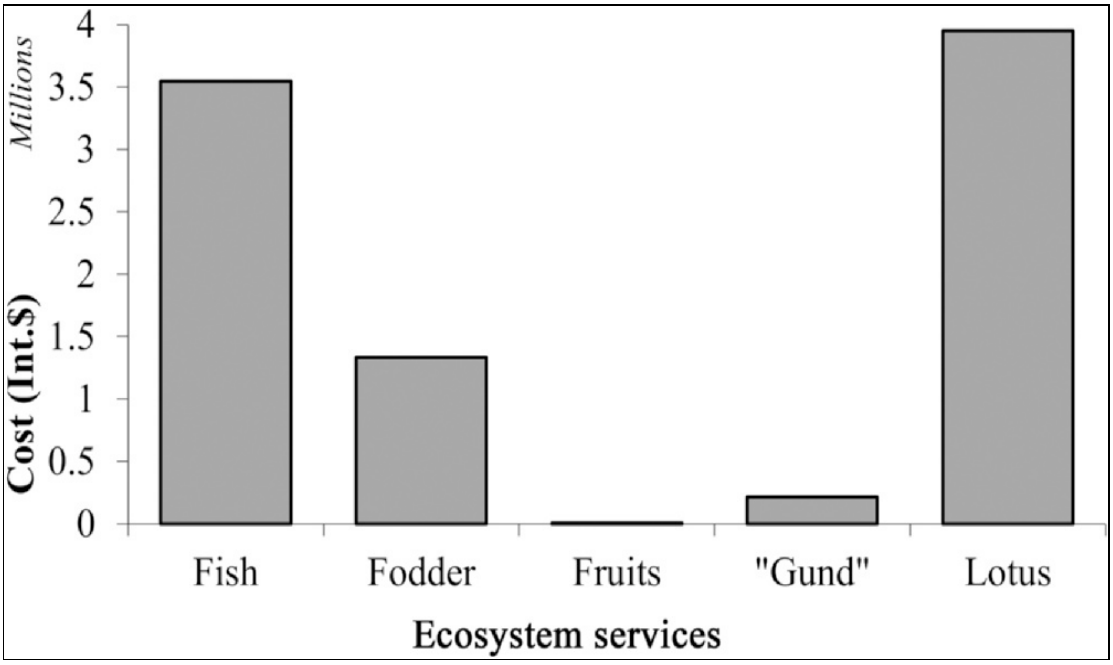


Figure 16: Economic values of provisioning services from lakes of Pokhara valley Nepal in 2019

Following the invasion of IAPS, items harvested from lake clusters were substantially reduced, according to respondents. In comparison to the time before the invasion, fish production, medicine, edible plants, and other items were diminished. According to the calculations, the economic value of provisioning services was INT.$ 0.28 million HH-1 year-1 before the invasion in 1989 (Figure 17), but it was INT.$ 0.10 million

HH-1 year-1 after the rampant invasion by IAPS. Among the five items studied, the drop was considerable for fish and lotus, but "gund" and fruits also saw a decrease compared to before the IAPS invasion.

According to the local people, the invasive species which generated peat in the lake and stimulated the growth of plants were used as fodder. The value of fodder in 2019 was higher than it was in 1989. Other ecosystem functions such as boats, whether for enjoyment or transportation, have been notoriously prevented by the IAPS. Furthermore, the lakes' natural beauty decreased, water quality declined, and biodiversity was harmed.

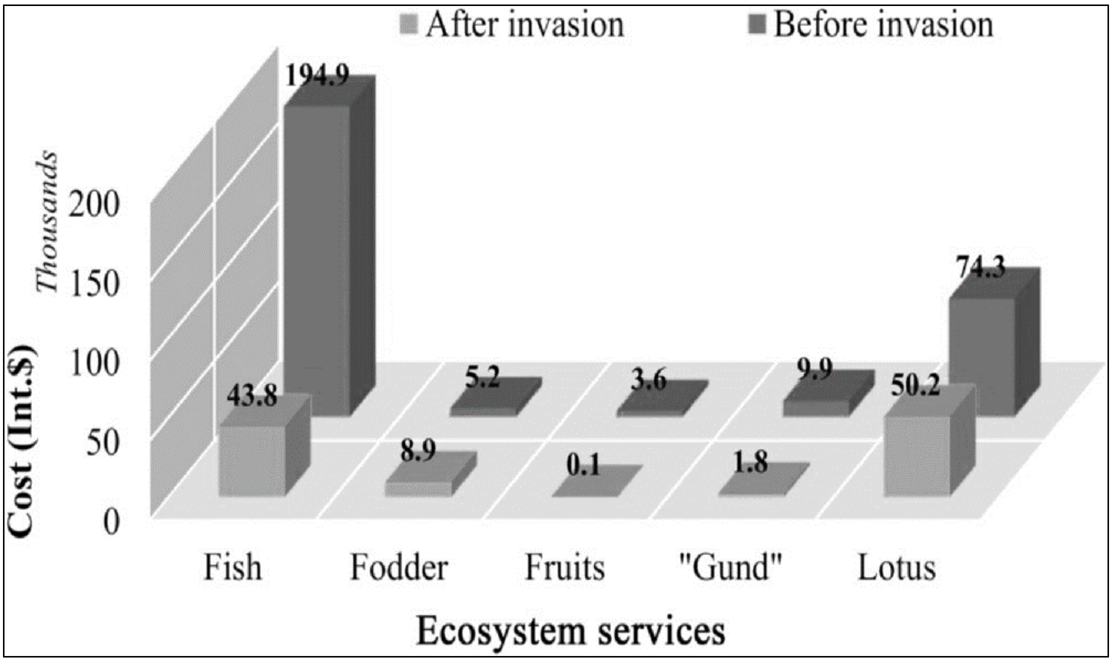


Figure 17: Comparison of economic values of provisioning services from lakes of Pokhara valley Nepal in 1989 and 2019

CHAPTER 5

5. DISCUSSION

5.1 Diversity of naturalized plants

In the present study, a checklist of 258 flowering plant species present in the LCPV was prepared based on vegetation sampling and survey. When compared with the list of 436 plant species mentioned in the LCPV management plan (MoFE, 2018b), the present study reported 155 additional species, suggesting that previous floristic investigations of the LCPV are far from complete. A number of wetland plant species have been reported from different parts of Nepal; for example 401 plant species in the Ghodaghodi lake area (Sah *et al.*, 2002), 115 species in wetlands of Rupandehi district (Sharma *et al.*, 2019), 108 plant species in Raja-Rani Tal of Morang (Sharma *et al.*, 2020), 117 plant species in the Rampurghol area of Chitwan (Dangol *et al.*, 2014). The most species-rich families in the LCPV's floristic composition were Asteraceae and Poaceae, which correspond to Nepal's overall floral make-up (Press *et al.*, 2000). Poaceae was also shown to be a prominent family in various parts of Nepal's wetlands (e.g., Chitwan by Dangol *et al.*, 2014). There was no government protection for any of the plant species found in the LCPV. However, some threatened animal species use the ecosystems that these plant species maintain (MoFE, 2018b).

According to the diversity-invasibility hypothesis (Collins *et al.*, 2007), native diversity controls the establishment and subsequent spread of naturalized plant diversity. It was found that the naturalized plant species richness was higher in areas with high native plant species richness in the LCPV. Our study revealed that there is a positive correlation between native and naturalized plant richness. In post-1 year-burn sites, the herbaceous community posed a positive correlation between the native and naturalized plant species (Sax, 2002). Here the fire plays the role of human disturbance that is responsible for resource fluctuation that invites the invasion process. In larger sample size studies (100 m^2), there appear positive correlations (Espinosa-García *et al*., 2004), and in smaller ones (1 m^2), there seem negative correlations between the native and naturalized plant species (Stohlgren *et al*., 1999). The direct biotic interactions (competitive exclusion) between native and exotic species caused the negative relation, whereas positive correlations likely reflect the more prominent influence of habitat heterogeneity on richness at larger spatial scales

(Chen *et al*., 2010). It is possibly the larger spatial scale in LCPV, there existed a positive correlation due to habitat heterogeneity. By reducing biotic resistance by native plants – the positive correlation facilitates the establishment and spread of both exotic and native plants that tolerate disturbed environments (Bartomeus *et al*., 2011).

Findings of an empirical study suggested that allelopathy of diverse communities (including native and naturalized plants) does not provide resistance but actually facilitates the germination of invaders (Yuan *et al.,* 2021). Native plants have no strong relationship with functional traits, and the environment but the naturalized plants do have and therefore, they do not compete with each other and are independent (Milanovic *et al.,* 2020). The uncertainty concerned with the biological invasion refers to the coexistence of separate lines of support suggesting both a negative and a positive link between native biodiversity and the diversity of invasive species (Fridley *et al.,* 2007).

However, many empirical studies have found a negative correlation between native and exotic plant richness. Nevertheless, it does not mean that there is no influence of the resources in invasion success. Non-native plant occurrence was negatively correlated to native plant richness across all study sites in communities and ecosystems in the USA, although the strength of biotic resistance varied across different ecological (Soil, moisture, and temperature, etc.), anthropogenic (flood, forest fire, etc.), and climatic contexts (Beaury *et al*., 2019). Species-rich native communities resist invasion because vacant niches are less common and the intensity of interspecific competition is more severe (Collins *et al*., 2007).

Moreover, the native richness cannot always affect the success of naturalized species (Heckman *et al.,* 2017). Although preserving native plant diversity reduces the risk of alien occurrence, more research is needed to better understand the broad-scale anthropogenic and environmental factors that contribute to ecosystem vulnerability to alien establishment and invasion (Beaury *et al.*, 2020).

Alien species invasion requires nutrient enrichment as a requirement (Lake & Leishman, 2004). However, the case is different in barren and phosphorus-limited areas where alien species cannot benefit from increased resources (Leishman & Thomson, 2005). Multiple linear regression between species richness of naturalized plants and nitrate nitrogen and total phosphorus in water showed no relation in the present study ($p>0.05$). However, nitrogen contributed significantly ($p<0.001$) to plant invasions in Temperate Floodplain and Swamp Forest in Slovakia (Hrivnak *et al.,* 2015). Additionally, the study in Slovakia revealed that phosphorus did not have significant impacts on plant invasions ($p=0.213$). The functional identity of native species within recipient communities, not the availability of resources, determines the impact of invasion (Gooden & French, 2015). Interestingly, some of the studies revealed that across terrestrial and wetland ecosystems, N and P enrichment had widespread and strong negative effects on plant species richness. N reduced plant species richness by 16% but not by P enrichment in experimental herbaceous communities (Soons *et al.,* 2016). The increase of many soil nutrients, not phosphorus alone is supporting the invasion of urban areas by alien plants (King & Buckney, 2002). During invasions, multiple drivers of alien success—increased natural enemy pressure on natives, increased soil nutrient supply, and low native species richness—may interact or act independently within a single system (Heckman *et al.,* 2017). However, there was an argument in support of the availability of nutrients and invasion success that concludes increased resource availability as a result of disturbance or eutrophication may favor alien species over native ones (Blumenthal, 2006). The aquatic naturalized plant species richness is negatively correlated with the native plants' relative coverage and biomass (Yu *et al*., 2018).

Multivariate analysis revealed that phosphorus and nitrogen content in water were associated with naturalized species in lake Phewa and Rupa. However, most of the naturalized species were not correlated with nutrients N and P indicating that they were independent of the nutrients (N and P).

In terms of the native plant community, Phewa and Begnas were closely related to nutrients N and P respectively. Some of the species such as *Pontederia hastata, Elephantopus scaber, Litsea monopetala* had strong affinity with the lake characteristics of Rupa lake and less affinity with nutrient conditions. Multiple interacting factors like N, P, and Si influence the abundance, and species composition of phytoplankton in Lake Champlain (Levine *et al.,* 1997). It states that certain native plants are under the influence of N and P enrichment.

The study of the native and naturalized plant diversity, their uses, and their correlation with environmental variables can be a suitable tool for science-based management of the lakes, and habitat mapping of important plants, birds, and animals of the LCPV.

5.2 Spatial distribution of IAPS

Based on data collected along with the road network, the current study inventoried IAPS and studied their distribution patterns in the Pokhara valley. Roads play a significant role in the dissemination of IAPS, which then expands to neighboring land-use types. *Bidens pilosa* had the highest frequency among 20 invasive plants in the study area, which could be attributable to its high seed production capacity and efficient seed distribution by human and animal vectors (Budumajji & Soloman Raju, 2018). Rapidly disseminating plants with rapid growth, excellent adaptability, and massive seed output are found all over the world (Yang *et al.,* 2019). Nearly one third of the IAPS recorded in the research area, in particular, *Mikania micrantha, Mesosphaerum suaveolens,* and *Alternanthera philoxeroides*, had a relatively low (5%) frequency, implying that they were still in the early stages of invasion. The early detection and rapid response (EDRR) technique can be used to effectively manage these species (Reaser *et al.,* 2020).

Mikania micrantha, one of the world's worst invasive weeds and difficult-to-manage species, is the most notable among them (Lowe *et al.,* 2000). This species is already common in the Tarai and Siwalik regions of eastern and central Nepal, and satellite populations are spreading to the hilly region of central Nepal (Shrestha *et al.,* 2018). Two such satellite communities were found in the Pokhara valley during the current investigation. Containment, if not elimination, of such populations of *M. micrantha, M. suaveolens,* and *A. philoxeroides* will prevent these species from spreading further and conserve the Pokhara valley's ecosystems and the surrounding landscape from their negative impacts. This is attainable if provincial and local government agencies involved in biodiversity and agriculture respond quickly and begin management activities.

Land use pattern is one of the decisive variables for plant invasions because it changes environmental conditions and the disturbance regime (Pauchard & Alaback, 2004). Anthropogenic disturbances such as grazing, fertilizer enrichment, and frequent soil and vegetation disturbances promote the invasion, damaging natural habitats. In such settings, the spread of IAPS alters the local plant population. Invasive alien plants, for example, outcompeted local species such as *Artemisia indica* and *Urtica dioica* predominantly on the edges of fallow areas, agricultural lands, and disturbed sites, according to Baral *et al.* (2017). The highest species richness was found in shrubland and agriculture fallow land, out of the nine land-use types studied. Open spaces such as shrublands with no tree canopy provide appropriate environments for IAPS to establish (Brothers & Spingarn 1992). Agriculture fallow lands that have been abandoned for a long time frequently have high nutrients and are thus vulnerable to invasion (McGrath *et al.,* 2001). The species richness of the IAPS was low in irrigated farmland, wetland, commercial area, and residential area. Low species richness in the commercial and residential sector of Pokhara valley could be attributable to a lack of space and severe disturbances that prohibited the growth of plant species including IAPS. However, in general, metropolitan regions are rich in IAPS compared to adjacent natural ecosystems (Chen, 2012).

Periodic surveys and mapping of invasive species of this kind may be important for the immediate prevention of possible new invaders and the eradication of the newly invaded satellite populations.

5.3 Introduction and dispersal pathway of IAPS

Pontederia crassipes was found problematic IAPS in Phewa, Rupa and Begnas lakes. Invasive aquatic plants introduced for the aquarium and ornamental pond industries have a high chance of escaping to the lakes (Azan, 2015). There is no invasion by *P. crassipes* in the other six lakes of LCPV: Dipang, Khaste, Gunde, Niureni, Maidi, and Kamalpokhari. It was introduced into Asia at the end of the nineteenth century via Japan and Indonesia (Tellez *et al.,* 2008). In Phewa lake, it might have been established as an 'escape' (*sensu* Hulme *et al.,* 2008) from the garden of hotels and/or private homes in the surrounding landscape. An alternative mode of introduction, as indicated by the local respondents, could also be as a 'contaminant' (*sensu* Hulme *et al.,* 2008) of fish lings imported to Pokhara. Probably, it might have originated in the southern part of Nepal (e.g. Chitwan, Bhairahawa), or India. In Rupa, it was introduced from Phewa lake by visitors. *P. crassipes* can threaten biodiversity, cause eutrophication, provide shelter to pests, block the waterways, impact agriculture and aquaculture, and recreational boating (Patel, 2012).

Pistia stratiotes was introduced from Chitwan, Bhairahawa, or India in fish lings as a contaminant in the form of propagules. It was introduced from Phewa to Begnas or Rupa almost five years after the introduction of the water hyacinth. *P. stratiotes* was reported to be prevalent long before the introduction of *P. crassipes* in many areas of the USA (Neuenschwander, 2009). *Pistia's* introduction to Nepal appears late due to a lack of suitable dispersal pathways. In southern Ontario and worldwide, both *Pontederia* and *Pistia* were commonly grown in the water garden and aquarium trade (Adebayo *et al.,* 2011).

Ipomoea carnea subsp. *fistulosa* was introduced in Phewa, Begnas, Rupa, Dipang, and Gunde during the 1980s. In Koshi Tappu wetland area, it is most problematic along with the *Pontederia crassipes* (Pandey *et al.,* 2020). It is used as a check dam to control the mud from following away by the slow-running water bodies. *Alternanthera philoxeroides* was introduced in Pokhara (Khahare, Phewa) recently during 2018/19. *A. philoxeroides* had been reported from Pokhara valley during the mapping of IAPS in central Nepal. It might have been introduced as forage for pigs or through contaminated goods of wetland products via India (Tiwari *et al.,* 2005).

People argue that *Leersia hexandra* was in Pokhara for many generations. It was found in all lakes of the LCPV. The data source is scarce about the cause of its introduction to LCPV. Sometimes, the time and mode of introduction remain obscure due to a lack of written historical documents. For example, it is still unknown how and why the *Pontederia crassipes* was introduced to Iran (Zarkami *et al.,* 2021).

Data shows that there are five aquatic invasive plant species that encroach on the lakes of LCPV. Their invasion history is different. The most problematic species is *Pontederia crassipes* which was found spreading in Phewa, Begnas, and Rupa Lakes. Its introduction to other lakes depends on the dispersal of its propagules to them in addition to the suitable nutrients and other conditions. Therefore, the management committee of the lake should focus on the dispersal pathway of the IAPS for its management.

5.4 Eutrophication in lake water

Since the nitrate nitrogen ($N\text{-}NO_3$) level in LCPV ranges between 0.04-0.17 mg/L (<0.3) in the present study, the lakes are still oligotrophic (MassWWP 2021). Similarly, total phosphorus (TP) ranged between 0.29-1.25 mg/L (>0.1 mg/L), suggesting that the wetlands can be considered hypertrophic (Istvanovics 2010). The level of eutrophication in the Phewa, Begnas, and Rupa lakes was determined by

Nakanishi *et al.* (1988). Total phosphorus availability at the time indicated that these lakes in Pokhara, Nepal were oligotrophic (Table 1).

Koshi Tappu Wildlife Reserve was significantly hypertrophic in terms of nitrate nitrogen levels (Pandey *et al.*, 2020) among three heterotrophic lakes of Nepal. The reservoir at Jagadishpur was found to be eutrophic (Chaudhary & Devkota, 2018). It is among the other two eutrophic lakes of the Ramsar site, Nepal. Gosaikunda lake was also reported as hypertrophic based on total phosphorus content (0.21 mg/L), despite it being located at a high altitude (Raut *et al.*, 2012). Nitrate nitrogen levels in Gokyo and Associate lakes range from 0.29 to 1.30 mg/L, indicating that this high-altitude lake is oligotrophic to eutrophic (Ghimire *et al.*, 2013). Gosaikunda and Gokyo lakes are high-altitude lakes that receive wastewater discharges from the surrounding human settlements (they are impacted by pilgrims). They seem eutrophic on the basis of total phosphorus.

Another mountain lake Rara had been reported as oligotrophic (Nitrate nitrogen 0.01 mg/L, Gurung *et al.*, 2018). Panchpokhari was hypertrophic (based on nitrate nitrogen concentration of 1.7-2.5 mg/L, Raut *et al.*, 2014). Tilitso lake in Manang is also a high-altitude lake in Nepal. It has a total phosphorus content of 0.04 mg/L. It also means that the lake was eutrophic (Aizaki *et al.*, 1987). In the Pangong Tso lakes in Ladakh, India, nitrate nitrogen levels range from 0.28 to 0.31 mg/L. As a result, they were called mesotrophic lakes (Bhat *et al.*, 2011). A limnological study says Beeshazar lake (also a Ramsar site in central Nepal) was hypertrophic according to the total phosphorus content in water samples collected (Niraula, 2012).

The total phosphorus level in Phewa, Begnas, and Rupa lakes increased substantially (0.01-0.03 mg/L, Nakanishi *et al.*, 1988 and 0.27-1.25 mg/L, in my present study in LCPV during 2019). The present study showed that the trend of the wetlands of LCPV was towards eutrophication caused by nutrient (nitrate nitrogen and total phosphorus) enrichments to the water of the lakes although further research are needed in other Ramsar sites to know the trends in all Ramsar lakes. The aquatic naturalized plant species richness can be positively correlated with the total nitrogen (TN) and total phosphorus (TP) of the water (Yu *et al.*, 2018). Further, increase in eutrophication in LCPV, may lead to an increase in macrophytes including IAPS that control light penetration, and cause biological oxygen demand to submerged and bottom dwellers of the lakes (Istvanovics, 2010). It is recommended that the management authorities build ways to prevent nutrient addition from the surrounding farmlands. It will not only prevent the succession process of the lakes by successive colonization of the macrophytes to land but also controls the area from the colonization of the invasive species that impact native plants and animals.

5.5 Impacts of IAPS

5.5.1 Aquatic IAPS in LCPV and their Impacts

Because invasive alien species are considered the world's second-greatest threat to biodiversity, their effects on biodiversity and ecosystem services have got a lot of attention (Simberloff *et al.*, 2013). In their review, Turbelin *et al.* (2017) identified 52 aquatic IAPS with ecological and socioeconomic consequences from around the world. Out of the six aquatic IAPS described by Shrestha *et al.* (2019), five IAPS were found invading the LCPV. Sharma *et al.* (2018) recorded six IAPS in Chitwan, Nepal's Beeshazari Lake, the most prevalent of which being *Pontederia crassipes* (79%). This species had been identified as the most frequent IAPS in 73 nations, creating havoc on the wetland ecology (Turbelin *et al.*, 2017). *Leersia hexandra* was found in all lakes in the LCPV, however, *P. crassipes* is more abundant in larger lakes such as Phewa, Begnas, and Rupa. The next most common species is *Ipomoea carnea* subsp. *fistulosa.* It can create floating mats on the water's surface and make irrigation difficult, as well as pose a threat to fisheries (Chaudhuri *et al.*, 1994). In four of the nine lakes, *Pistia stratiotes* and *Pontederia crassipes* had been found in large three lakes. Because it swiftly covers the water surface, *P. stratiotes* is known to have major detrimental effects on the utilization of water bodies (Akinbile & Yusoff, 2012). It can disrupt irrigation and drainage, obstruct boating and fishing, and provide an ideal environment for the spread of waterborne diseases (Mbati & Neuenschwander, 2005). Several locations in Nepal have already reported *P. crassipes* as a problematic IAPS (MoEF, 2018b).

Apart from being a healthy food supply, fish and fisheries are frequently associated with tourism because fish serves as both a food source and a game (Sousa *et al.*, 2013). Phewa Lake is the most popular tourist destination in the Pokhara valley for both domestic and foreign visitors. Begnas has become a popular tourist destination in recent years. The government encourages fish farming in both Phewa and Begnas. As a result, hoteliers and other groups may have placed a high priority on fishing in ecosystem services (>90%). Fish farming, on the other hand, is one of the leading sources of the introduction of alien species into lakes, particularly alien invasive fishes (MoFE, 2018b). Recently, LCPV stakeholders have recognized the threat posed by the introduction of alien fish species, which has resulted in the unintentional introduction of other invasive species, including IAPS.

5.5.2 Ecosystem services from LCPV

The present study identified 18 ecosystem services provided by the LCPV. Among them, 'natural beauty, and tourism' among the cultural services, 'fishery and fodder' among the provisioning services 'for irrigation' among regulating services, and 'biodiversity and habitat protection' among supporting services were under the priority list of the respondents of the study area.

Thapa *et al.* (2020) recorded 32 ecosystem services in the Begnas watershed while Paudyal *et al.* (2018) documented 23 ecosystem services in the Phewa watershed. They found fish, food, and medicinal plants to be provisioning services, which is similar to my findings. People have long recognized the intrinsic usefulness of lakes as a habitat for a diverse range of biota (Schallenberg *et al.*, 2013). Lakes are known to reduce floods by directing water away from the lake and reducing flooding in low-lying areas (Ramachandra *et al.*, 2012). Except for Dipang and Kamalpokhari, all of the participants in this study recognized such services that LCPV provided.

Wetland resources are not only significant to inhabitants since they provide habitats to plants and animals, but they also contribute to the local economy (Lamsal *et al.*, 2015). Thapa *et al.* (2020) emphasized the importance of wetland resources to the local economy in Begnas lake. With urbanization in the Pokhara valley, there are trade-offs made between nature and development by attempting to transfer the benefits obtained from the ecosystem to economic value (Rodríguez *et al.*, 2006). However, one of the major issues is the irregularities of value transfer (Schmidt *et al.*, 2016). Provisioning services and goods have a low level of uncertainty since they may be converted to market value at any given time. Therefore, only provisioning services were examined for inclusion in the economic valuation. Furthermore, prior research by Sharma *et al.* (2015) indicated that the economic advantages derived from delivering services alone account for around 85% of the Koshi Tappu Wildlife Reserve in Eastern Nepal. According to my calculations, the overall value of the provisioning ecosystem services of the Pokhara valley's lake cluster is around INT.$ 9.05 million. In Pokhara, "gund" (stems of *Machaerina rubiginosa*) is similarly important in the local economy, and local mat made from "gund" is extremely popular.

5.5.3 Impacts of IAPS on ecosystem services

A healthy wetland contributes to human well-being by providing a variety of commodities and services (Karki *et al.,* 2018). Unfortunately, the health of the wetland is declining, and local residents are trying to save it. IAPS are threatening aquatic habitats and biodiversity conservation all around the world (Vila *et al.,* 2011). IAPS limits wild fruit availability (Krivek *et al.,* 2020). IAPS alter the flow of water channels, displacing native fodder plants, lowering the natural attractiveness of lakes, and reducing their ecological value (Carlsson *et al.,* 2004). Invasive alien species (IAS) are posing a growing threat to Bangladesh's native flora, fauna, and ecosystems (Mukul *et al.,* 2020). Invasive species, such as mosquitoes and snails, increase disease vectors (Keller *et al.,* 2018). Invasions have also been reported to cause damage to electricity infrastructure and watercourses (Booy *et al.,* 2017). The economic value of supplying services before the invasion in 1989 and after the establishment of IAPS in LCPV differs by around INT.$ 0.19 million HH-1 year-1. When compared to 'before the invasion of IAPS' in 1989, the ecosystem service value of fish, lotus, and "gund" from lakes has decreased dramatically by 2019. The introduction of alien fish species into LCPV, as well as the invasion of IAPS, has resulted in a considerable reduction in the native fish population (MoFE, 2018b).

5.5.4 Economic costs due to IAPS

Economic losses as a result of IAPS' influence on supplying services are rarely reported. However, the region's ecosystem services have been found to have suffered total economic losses. According to Xu *et al.* (2006), The total economic losses caused by invasive alien species in China were US$ 14.45 billion during 2001 and 2003. Economic losses in Bangladesh's agricultural industry owing to IAS are widely documented, but it is stated that the losses are primarily attributable to IAPS management and eradication, such as *P. crassipes* (Mukul *et al.,* 2020). According to one account, in the early 2000s, the US spent $100 million per year to combat invasive aquatic plants (Lovell & Stone, 2005). From Beeshazari Lake in Chitwan, Nepal, an issue of high expense and minimal impact of mechanical or hand removal of IAPS (particularly *P. crassipes*) has been noted (Sharma *et al.*, 2018). As a result, biological control for scientific management of IAPS to maintain ecosystem values of LCPV appears to be a better alternative.

Therefore, the stakeholders of the LCPV are recommended to conserve the Simalkande (*Trapa natans*), Gund (*Machaerina rubiginosa*), and Lotus (*Nelumbo nucifera*) from being disappeared affecting the provisioning services provided by them to society. It is also recommended for further study on regulatory, and cultural services provided by the lakes in LCPV.

CHAPTER 6

6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

This study gives an insight into floral diversity in the Lake Cluster of Pokhara Valley (LCPV), their biogeography, as well as their uses. The presence of several invasive alien plant species in LCPV, some of them being globally worst, suggests that the wetland habitats of LCPV have been degrading. Management responses to plant invasions, together with other drives of degradation, will help to restore the habitats and ensure the continuous supply of ecosystem service. Most of the species were native, perennial, and Therophytes. The LCPV provides a habitat for several plant species with medicinal values. The presence of several IAPS, some of them being globally worst, suggests that the wetland habitats of LCPV have been degrading. Naturalized plant species richness increased with increasing native species richness in the present study area, which contracts with the prediction of the Biotic resistance hypothesis. Nitrogen and phosphorus content in wetland water could not explain the variation in the richness and abundance of naturalized plant species. It implies that management activities such as the prevention of IAPS introduction could be more important than the eutrophication level of wetland water in determining the level of plant invasions in wetlands.

The IAPS recorded in Pokhara valley varied significantly in their frequency of occurrence. Some species (e.g. *Ageratum houstonianum,* and *Lantana camara*) were widespread while others (e.g. *Mesosphaerum suaveolens, Alternanthera philoxeroides Mikania micrantha*) were in their early stage of invasions. Management responses aimed to contain these early invaders including the globally worst weed *M. micrantha* will prevent their spread and protect ecosystems from their harmful impacts. 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 the future. Periodic inventory and mapping of this kind are essential for the early detection of IAPS and rapid response for their management.

Most of the IAPS invading wetlands of the study area were introduced intentionally (for ornamental value; growing as a hedge plant). It implies that the introduction of the IAPS can be prevented if the concerned stakeholders including local communities are made aware of the environmental and socio-economic consequences of plant invasions in wetlands and other habitats. It also appears that some IAPS were introduced accidentally as contaminants of agriculture and aquaculture products when they were transported to Pokhara valley from different parts of the country. Internal quarantine and improved cleanliness of such products can prevent IAPS introduction to new areas.

The lakes in Pokhara valley play an important role in the livelihood of the inhabitants, as they provide various ecosystem services. Five IAPS were found to infest the lakes and cause various problems including a negative impact on ecosystem services. These IAPS are altering the ecosystem services provided by LCPV. The estimated economic valuation shows a huge loss after the invasion of IAPS. However, the rampant spread of IAPS has seriously threatened not only this intrinsic benefit but also a host of other ecosystem services such as habitat to wildlife habitat, flood control support, and recreational values. Although the significance of impacts was context-dependent, our study highlighted that IAPS have significant negative impacts on wetland ecosystem services.

Overall, the study highlights a growing threat of IAPS in inland freshwater wetlands including Ramsar sites located in the urban areas such as the LCPV. The study of the native and naturalized plant diversity, their uses, and their correlation with environmental variables can be a suitable tool for habitat mapping of the important plants, birds, animals of the LCPV, and helpful in IAPS management. This work will help stimulate research on wetlands in tourist destinations by highlighting the relationship between impacts at different levels of ecosystem services that could be valuable in making decisions for sustainable lake management. Management responses to plant invasions, together with other drives of degradation, will help to restore the habitats and ensure the continuous supply of ecosystem services. This will provide both economic as well as conservation benefits.

6.2 Recommendations

The present study makes the following recommendations for conservation and management of LCPV:

1. Study of the native and naturalized plant diversity, their uses, and their correlation with environmental variables can be a suitable tool for science-based management of the lakes, and habitat mapping of important plants, birds, and animals of the LCPV.

2. Periodic survey and mapping of invasive species is important for the immediate prevention of possible new invaders and the eradication of the newly invaded satellite populations. Thus, it is recommended for distribution mapping of this kind in invasion-prone areas for early detection and rapid response.

3. The trends of the Ramsar wetlands in Nepal are towards eutrophication caused by nutrient (Nitrogen and Phosphorus) enrichments. It will progress the succession process of the lakes by successive colonization of the macrophytes to water bodies. There must be some management interventions to prevent nutrient addition from the surrounding farmlands.

4. Data shows that there are five aquatic invasive plant species that encroach the lakes of LCPV. Their invasion history is different. The most problematic species is *Pontederia crassipes* which is found spreading in Phewa, Begnas, and Rupa Lakes. Its introduction to other lakes depends on the dispersal of its propagules to them in addition to the suitable nutrients and other conditions. Therefore, the management committee of the lake should focus on the dispersal pathways of the IAPS for its management.

5. Some species are disappearing such as Simalkande (*Trapa natans*), Gund (*Machaerina rubiginosa*), and Lotus (*Nelumbo nucifera*). It is recommended to conserve them since they provide provisioning services to the local inhabitants.

6. As in different parts of Nepal, the wetlands of LCPV are neglected although they provide various ecosystem services to the inhabitants. For the value addition of these wetlands, further studies on the cultural and regulatory services of the ecosystems are also recommended.

7. EDRR is the physical measure of the management of IAPS. There may be chemical measures but may not be environment friendly. The biological control measure using herbivores of the IAPS from their native range is the most effective one but it takes time. Though less effective, we have only the option to use self-motivated people and the machine (that the Pokhara Metropolis has) in LCPV till we develop the biological control measure.

CHAPTER 7

7. SUMMARY

Wetlands including lakes support high biodiversity and provide important ecosystem services. However, they are among the most neglected habitats by humans worldwide. Several IAPS have occupied wetlands of Nepal included in Ramsar site. However, the diversity and distribution of the IAPS and their impacts on ecosystem services had not been studied in the wetlands of the Pokhara valley. The present research was carried out in the Lake Cluster of Pokhara Valley (LCPV), the 10th Ramsar site of Nepal, and the associated landscape of Pokhara valley in central Nepal. The objectives of the study were to: analyze the diversity of naturalized plant species in the LCPV, identify IAPS and their spatial distribution in Pokhara valley including LCPV, assess the level of eutrophication in the water of the LCPV, identify the pathways of introduction and dispersal of the IAPS in the study area, and assess the impacts of IAPS on ecosystem services in the study area.

Altogether 89 plots (20×5 m^2) were sampled with five sub-plots of 4×5 m^2 to record the frequency and coverage of the flowering plants along the shoreline of all nine wetlands present in the LCPV. The species were identified following regional flora, comparing them with the specimens kept in KATH and TUCH, and following experts' opinion to species level, classified based on their life forms (Raunkiaer life forms, viz. Phanerophytes, Chaemophytes, Hemicryptophytes, Cryprtophytes, and Therophytes), and categorized into native and naturalized species. Invasive species were identified from among the naturalized plant species recorded from the LCPV. The relationship of naturalized plant species richness with native species richness was analyzed by a generalized linear model. Ordination was carried out to determine the relations of environmental variables on species composition. Furthermore, species present outside the plots ca. 15 m from the shoreline, were also recorded in all lake sites to prepare a final checklist of the species of the LCPV. Secondly, an inventory of the IAPS found along roadsides in the Pokhara Metropolitan city was prepared. Geographic coordinates, i.e., latitudes, and longitudes of the IAPS were recorded during the study sites. Geographic coordinates were used to prepare a distribution map of each IAPS using ArcGIS. Thirdly, water samples were collected from all of the vegetation sample plots (n = 89) and the content of nitrate nitrogen and total phosphorus were estimated by following (Trivedi & Goel, 1984). Multiple regression was used to analyze the impacts of nutrient contents on species richness and cover of native and naturalized species. To know the possible sources and local dispersal pathways of IAPS, local inhabitants (n=56, age >37 yrs) of lake territories of Phewa, Begnas, and Rupa lakes were interviewed. The aquatic IAPS were only included for the assessment of the dispersal pathways. Finally, to determine the number of ecosystem services provided by the LCPV household surveys (n = 273) were carried out, and for their confirmation, key informants' interviews (n = 23) were carried out in the vicinity of the LCPV. Also, 19 focus group discussions were organized. The respondents included farmers, boaters, hoteliers, fishermen, and senior citizens. The interviews were focused on the economic benefit provided by the provisioning services of the lakes and the impacts of IAPS on these services.

The research study recorded a total of 258 flowering plant species (73 families and 191 genera). The most species-rich family was Asteraceae (27 spp), followed by Poaceae (26 spp), Fabaceae (19 spp), and Cyperaceae (19 spp). Among the life forms, Therophytes (29%) were the most common, and others in decreasing order were Hemicryptophytes (27%), Cryptophytes (18%), Phanerophytes (17 %), and Chaemophytes (9%). Species richness of naturalized species increased with increasing native species richness thus possessing a positive correlation between them whereas the nutrients had no significant effect on species richness of naturalized plants.

The study found a total of 22 IAPS distributed in Pokhara valley, accounting for 79% of the total number of IAPS (28) reported from Nepal. Four of the recorded IAPS, viz. *Chromolaena odorata*, *Lantana camara*, *Mikania micrantha*, and *Pontederia crassipes* were among the 100 of the world's worst invasive species. The most commonly distributed species was *Bidens pilosa* (63%), followed by *Ageratum houstonianum* (61%), and *Lantana camara* (61%). *Alternanthera philoxeroides*, *Mesosphaerum suaveolens*, and *Mikania micrantha* had satellite populations at a few locations, therefore those species were at the initial stage of invasion in the valley and could be eradicated.

In the LCPV, the total phosphorus level in water was 0.29-1.25 mg/L and the nitrate nitrogen level was 0.04-0.17 mg/L. Thus, these wetlands are classified as hypertrophic according to the total phosphorus level and oligotrophic according to the nitrate nitrogen level.

According to the residents, most of the aquatic IAPS found in the LCPV were brought from the Tarai region located in the southern part of Nepal or northern India between the 1970s and 1990s. Among the IAPS, *P. crassipes* and *Pistia stratiotes* were brought for their ornamental values and *Ipomoea carnea* subsp. *fistulosa* was introduced for fencing purposes. It appears that *Alternanthera philoxeroides* was introduced accidentally to Phewa lake recently (observed for the first time in 2019). Local respondents had been familiar with *Leersia hexandra* for a long period (>50 years) and were not aware of the time and mode of its introduction, suggesting that *Leersia hexandra* could have the longest history of introduction to the LCPV.

A total of 18 ecosystem services were documented from the LCPV. The most cited services were water for irrigation, fish farming, fodder, materials for traditional mat preparation (*Machaerina rubiginosa,* a herbaceous plant of Cyperaceae), habitat protection, medicinal values, and natural beauty. Total economic benefits generated by the provisioning services of the LCPV, assessed in the year of data collection (2019), were estimated to be International $ 9.05 million, which was an International $ 0.10 million per household per year. Before the impact of IAPS, the estimated economic value was calculated to be International $ 0.29 million per household per year. The decline was significant for fish and lotus.

The study concludes that the Pokhara valley has profusely been occupied by a large number of invasive plant species. Some of them include globally worst and recently introduced species. This number is expected to increase in the future as a positive correlation between the native and naturalized plant species diversities was found. As observed in the ordination analysis, there was an indication of nutrients' influence on certain naturalized species bringing harm to the ecosystems, and degrading their services. The rampant spread of IAPS has seriously threatened not only the intrinsic benefit from the provisioning services but also regulatory and supporting services such as habitat to wildlife, flood control, and beauty of the frequently visited Lakes. To contain the IAPS and control their further distribution, early intervention through science-based management is required. For it, the IAPS should be prevented from introduction from the open border by strict quarantine. An early detected species can be eradicated by physical, chemical, and biological control methods for which this study provides basic information. Periodic inventory and mapping of the IAPS are recommended for early detection and rapid response for their management. The present study has highlighted the existing diversity and distribution of the IAPS in LCPV, and opened avenues of study in ecosystem restoration.

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APPENDICES

Appendix 1: List of respondents in dispersal pathways of IAPS in LCPV

SN	Name & age	Lake
1	Man Bdr Thapa, 56 yrs	Begnas
2	Raghunath Tiwari, 77 yrs	Begnas
3	Sujan Jalari, 35 yrs	Begnas
4	Meghanath Tiwari, 61 yrs	Begnas
5	Mrs Shiva Kandel, 60 yrs	Begnas
6	Maya Devi Bhattarai, 50 yrs	Begnas
7	Devi Kanel, 39 yrs	Begnas
8	Mrs Buddha Jalari, 55 yrs	Begnas
9	Prem Jalari, 57 yrs	Begnas
10	Chiza Nepali, 46 yrs	Begnas
11	Charimaya Jalari, 76 yrs	Begnas
12	Gyanu Jalari, 49 yrs	Begnas
13	Shanti Maya Jalari, 50 yrs	Begnas
14	Bini Maya Jalari, 65 yrs	Begnas
15	Bishwanath Khanal, 60 yrs	Begnas
16	Rajendra Jalari, 52 yrs	Begnas
17	Syanu Jalari, 55 yrs	Begnas
18	Buddhi Nepali, 45 yrs	Begnas
19	Mukti Subedi, 61 yrs	Begnas
20	Padma Raj Subedi, 57 yrs	Phewa
21	Moti Raj B aral, 50 yrs	Phewa
22	Hom Bdr Kunwar, 65yrs	Phewa
23	Akkal Bdr Sunar, 58 yrs	Phewa
24	Prem Bhattarai, 62 yrs	Phewa
25	Sundar BK, 55 yrs	Phewa
26	Ram Paneru, 59 yrs	Phewa
27	Ramji Paudel, 68 yrs	Phewa
28	Mangal Bdr Nepali, 60 yrs	Phewa
29	Kali Bdr Nepal, 62 yrs	Phewa
30	Chuda Mani Pahari, 70 yrs	Phewa
31	Gyan Bdr Jalari, 55 yrs	Phewa
32	Hom Bdr Lamichhane, 65 yrs	Phewa
33	Laxman Thapa, 65yrs	Phewa
34	Mitra Mani Timsina, 55 yrs	Phewa
35	Prakash Baral, 65 yrs	Phewa
36	Punya Poudel, 65 yrs	Phewa

37	Rana Bdr Thapa, 60 yrs	Phewa
38	Krishna Adhikari, 62 yrs	Phewa
39	Debendra bdr Lamchhane, 65 yrs	Phewa
40	Tulasi Pageni, 70 yrs	Rupa
41	Chandra Kanta Pageni, 75 yrs	Rupa
42	Basundhari Adhikari, 70 yrs	Rupa
43	Tulasiram Adhikari, 91 yrs	Rupa
44	Santa Bdr Gurung, 60 yrs	Rupa
45	Santos Babu Poudel, 37 yrs	Rupa
46	Shivahari Ojha, 40 yrs	Rupa
47	Sumitra Adhikari, 59 yrs	Rupa
48	Ram Prasad Adhikari, 68 yrs	Rupa
49	Som Maya Gurung, 46 Yrs	Rupa
50	Ram KC, 60 yrs	Rupa
51	Hommaya Gurung, 60 yrs	Rupa
52	Jaya mangal Adhikari, 61 yrs	Rupa
53	Tak Bdr Grg, 62 yrs	Rupa
54	Bishnu Hari Adhikasri, 55 yrs	Rupa
55	Man Bdr Ale, 70 yrs	Rupa
56	Pabitra Jalari, 40 yrs	Rupa

Appendix 2: Questionnaires_ FGD

Impacts of invasive alien plant species on ecosystem services of the Lake Cluster of Pokhara Valley, Nepal

- Supported by Hariyoban Program — WWF, Nepal

Date : ______________

SN Location: Pokhara metropolis .... Ward no........ Lake............

Group discussion

Introduction to respondent

Name Occupation Age Sex

Education Mobile no

1. What are the services provided by the lakes

____

____

2. Categorise the services according to uses.

SN	Ecosystem services	Very very useful	Very useful	useful	Less useful
1	Pisciculture				
2	Duck keeping				
3	Fodder to cattle				
4	Edible wild fruit				
5	Habitat				
6	Biodiversity				
7	Medicines				
8	Grazing land				
9	Carbon sequestration				
10	Tourism				
11	Irrigation				
12	Gund for matraess				
13	Drinking water				
14	Food security				
15	Bathing cattles				
16	Help to farming				
17	Flood control				
18	Natural beauty				
19					

3. What are the causes of the invasion of lakes?

____

____

4. When were the invasive species appeared in lakes?

Plants	
Pontederia crassipes	
Pistia stratiotes	
Leersia hexandra	
Ipomoea carnea subsp. *fistulosa*	
Myriophyllum aquaticum	

5. What are steps for management of invasive species?

____

____

6. Do you want to pay for the services provided by the lakes?

   a. Yes b. No

   If you want to pay, by which way?

   a. Labor b. cash

   c. Services d. suggestions

7. When were the invasive species appeared?

____

____

8. Were invasive species spread all around?

____

____

Researcher : Hom Nath Pathak

Level of study : Ph.D.

Appendix 3 : Names of the respondents of the questionnaire survey for FGD

SN	Name of FGD	Names of Respondents
1	Phewa_Hotel	
		Krishna Paudel
		Agraha Aryal
		Ramesh Ghimire
		Ganesh Khatiwada
		Prajwal Bharati
		Ramesh Aryal
		Binod Banjara
		Bhabiswor Ghimire
		Brihaspati Lamichhane
		Deep Bahadur Khadka
2	Phewa_Fishers	
		Gyan Bahadur Jalari
		Indra Bahadur Jalari
		Lok Nath Jalari
		Mishrilal Jalari
		Hema Jalari
		Parvati Jalari
3	Phewa_Farmers	
		Jhapat Bahadur Lamichhane
		Bibek Ghimire
		Ram Prasad Kafle
		Bal Krishna Adhikari
		Ganga Prasad Aryal
		Lesh Bahadur Gurung
		Durga Prasad Gurung
		Jaya Lal Khanal
		Tek Nath Subedi
		Ganga Bahadur Gurung
		Ek Prasad Baral
		Chitra Bahadur Gurung
4	Phewa_Boaters	
		Top Bahadur Bhujel
		Tara BK
		Sandeep Pariyar
		Yam Bahadur
		Buddhi Bahadur Pariyar
		Sabin
		purna Gurung
		Maya Bhujel
		Rudra Bhujel
		Saroj

		Bikash
		Dharma Raj Pariyar
		Tek Bahadur Bhujel
		Ram chandra Pariyar
		Ashish Paudel
		Sundar pariyar
		Resham Nepali
		Chhalu Pariyar
		Chandra BK
5	Khaste_Farmers	
		Chudamani Lamichhane
		Sakuntala BK
		Naba Raj Baral
		Surendra Kandel
		Khem Raj Baral
6	Khaste_Fishers	
		Raju Jalari
		Gyanu Jalari
		Shakuntala BK
		Chudamani Lamichhane
		Muktinath Adhikari
		Shakuntala BK
7	Khaste_Hotelier	
		Sarita Baral
		(Only one hotel)
8	Kamalpokhari_Farmers	
		Dil BK
		Nau Bahadur
		Jag Bahadur Rasaili
		Lekh Bahadur BK
		Lal Bahadur BK
		Purna Bahadur BK
		Goma BK
		Ganesh Karki
		Bharat Bahadur Karki
		Amrit Prasad BK
		Chudamani BK
9	Gunde_Farmers	
		Suryanath Bhandari
		Bhairab Bishwokarma
		Ganesh Baral
		Ananda Dhungana
		Khem Lal Adhikari
		Prakash Baral
		Parvati
		Gita

10	Maidi_Farmers	
		Bharat Raj Neupane
		Upendra Paudel
		Prem Bahadur Khadka
		Narayan Bahadur Chhetri
		Samjhana Khadka
		Sita Neupane
		Sushila Bhandari
11	Dipang_Farmers	
		Khem Bahadur Sunar
		Buddhi Bhurtel
		Muktiram Bastola
		Govinda Prasad Bastola
		Krishna Bahadur Lama
		Madhav Prasad Bastola
		Sukaraj Bastola
		Manoj Dhakal
		Kumar Bhujel
12	Dipang_Fishers	
		Shiva Mohan Adhikari
		Gyanu Jalari
		Raju Nepali
13	Begnas_Hoteliers	
		Roshan Khanal
		Nishan Thapa
		Binaysak Budhathoki
		Ram Thapa Magar
		Yogesh Thapa
		Manish KC
		Dipesh Sapkota
14	Begnas_Farmers	
		Rudra Bahadur Tamang
		Buddhi Bahadur Nepali
		Kumar Dura
		Sharmila Lama
		Basanti Paudel
		Sita Magar
		Radha Sapkota
		Nirmala Sapkota
		Khadka Bahadur Thapa
15	Begnas_Fishers	
		Rita Jalari
		Laxmi Jalari
		Parbati Jalari
		Som Maya Jalai

		Shanti Jalari
		Rina Jalari
		Syanu Jalari Gyanu Jalari
16	Begnas_Boaters	
		Chandra Kanta Bastola
		Surya Bahadur Thapa
		Bishwo Nath Kandel
		Ram Nepali
		Resham Sapkota
		Dhaneswor Kandel
		Shreemaya
		Goma KC
17	Rupa_Farmers	
		Gopilal Joshi
		Lal Bahadur Shrestha
		Sushila Shrestha
		Ganga Kumari Shrestha
		Dil Bahadur Shrestha
		Saraswati Shrestha
		Sukmaya Shrestha
		Laxmi Ghimire
		Kamala Shrestha
		Surya Kumari Shrestha
18	Rupa_Fishers	
		Krishna Bahadur Thapa
		Nava Raj Khadka
		Purna Bahadur Gurung
		Ram Chandra Lamichhane
		Sila Gurung
		Pabitra Jalari
19	Rupa_Hoteliers	
		Jagadish Tiwari
		Dharma Datta Subedi
		Buddhi Bahadur KC
		Krishna Hari Subedi
		Maya Tamang
		Anju Maya Gurung
		Ananda Sapkota
		Puja Gurung

Appendix 4 : Demographic information of the respondents of the questionnaire survey for KII

SN	Name	Address	Occupation	Edu	Age	Gender
1	Gyan Bdr Jalari	Pokh-18, Phewa	Fisher	Sec. level	51	M
2	Santosh Jalari	Pokh-18, Phewa	Fisher	Pri. level	32	M
3	Som Maya Jalari	Pokh-18, Phewa	Fisher	Informal	70	F
4	Bikal Tulachan	Pokh-6, Phewa	Hotelier	Graduate	42	M
5	Chiranjivi Pokhrel	Pokh-6, Phewa	Hotelier	Graduate	50	M
6	Dil Bdr BK	Pok-13, Kpokhari	Contractor	Sec. level	47	M
7	Jagdhis Tiwari	Rupa-10	Hotelier	Sec. level	35	M
8	Buddhi Bdr KC	Rupa-11	Hotelier	Literate	63	M
9	Upendra Paudel	Pok-30, Maidi	Jobholder	Graduate	51	M
10	Hari Psd Adhikari	Pok-26, Khas/Niu	Farmer	Graduate	62	M
11	Chudamani Lamichhane	Pok-26, Khas/Niu	Farmer	Sec. level	52	M
12	Bijaya Bhujel	Pok-30, Dipang	Farmer	Graduate	36	M
13	Shiva Mohan Adhikari	Pok-27, Dipang	Fisher	Graduate	49	M
14	Bharatraj Niupane	Pok-30,Maidi	Social worker	Graduate	50	M
15	Rishiram Bhandari	Pokh-26, Gunde	Businesman	Sec. level	52	M
16	Krishna Psd Timilsina	Pokh-31, Begnas	Hotelier	Sec. level	60	M
17	Rajendra Jalari	Pokh-31, Begnas	Fisher	Literate	50	M
18	Surya Bdr Thapa	Pokh-31, Begnas	Boater	Sec. level	52	M
19	Chandra Kanta Bastola	Pokh-31, Begnas	Farmer	Sec. level	36	M
20	Toya Nath Adhikari	Pokh-31, Begnas	Farmer	Pri. level	70	M
21	Dil Bdr Kunwar	Pokh-6, Phewa	Boater	Sec. level	74	M
22	Tara BK	Pokh-6, Phewa	Boater	Literate	42	M
23	Rudra Bhujel	Pokh-6, Phewa	Boater	Sec. level	26	M

Appendix 5: Questionnaire_KII

Questionnaires in our research make 32 pages in Nepali. I have translated one one sample of them for KII, FGD and HH survey

Impact of invasive alien plant species on ecosystem services of the Lake Cluster of Pokhara valley, Nepal

- Supported by Hariyoban Program — WWF, Nepal

Questionnaires

Pokhara Valley, Nepal

Date : ______________

SN Location: Pokhara metropolis .... Ward no.......... Lake.............

Key informant: Hotelier

Introduction to respondent

Name Occupation Age Sex

Education Mobile no

1. What are the services obtained from Lakes?

SN	Ecosystem services	Priorities	SN	Ecosystem services	Priorities
1	Pisciculture		12	Tourism	
2	Duck keeping		13	Irrigation	
3	Flood control		14	Gund for matress	
4	Wild fruit		15	Boating	
5	Habitat conservation		16	Drinking water	
7	Biodiversity conservation		17	Food security	
8	Medicines		18	Bathing cattle	
9	Grazing land		19	Help to farming	
10	Natural beauty		20		
11	Fodder to cattle		21		

2. It seems there are dangers to lakes. Which of the following seems most danger?

Dangers	Scoring
Invasive weeds	
Siltation	
Pollution	
Construction encroachment	
Agricultural encroachment	

3. Do you know the invasive plants in the photos?

Plants	Identity	Harm stratification
Eichhornia		
Pistia		
Leersia		
Ipomoea		
Myriophyllum		

4. What is the cause behind fast spread of the invasive plants?

a. Pollution   b. Fertilizers in farms   c. Tourism

d. Transport   e. Trade   f. Others

5. What are the impacts of invasive plants?

Impacts of invasive plants	Scoring
Shelter to mosquito	
Siltation	
Impact on native plants	
The obstacle to irrigation canals	
Others	

6. Are ecosystem services decrease after arrival of invasive species?

7. Which are the ecosystem services impacted by invasive species?

SN	Ecosystem services	Priorities	SN	Ecosystem services	Priorities
1	Pisciculture		12	Tourism	
2	Duck keeping		13	Irrigation	
3	Flood control		14	Gund for matress	
4	Wild fruit		15	Boating	
5	Habitat conservation		16	Drinking water	
7	Biodiversity conservation		17	Food secuirity	
8	Medicines		18	Bathing cattle	
9	Grazing land		19	Help to farming	
10	Natural beauty		20		
11	Fodder to cattles		21		

Researcher : Hom Nath Pathak

Level of study : Ph.D.

Appendix 6: Questionnaire _HH Survey

Impacts of invasive alien plant species on ecosystem services of the Lake Cluster of Pokhara Valley, Nepal

- Supported by Hariyoban Program — WWF, Nepal

Questionnaire

Date : ______________

SN Location: Pokhara metropolis .... Ward no.......... Lake.............

HH survey: Fishery group

Introduction to respondent

Name Occupation Age Sex

Education Mobile no

1. What are the services obtained from Lakes?

SN	Ecosystem services	Priorities	SN	Ecosystem services	Priorities
1	Pisciculture		11	Tourism	
2	Duck keeping		12	Irrigation	
3	Flood control		13	Gund for mattresss	
4	Wild fruit		14	Boating	
5	Habitat conservation		15	Drinking water	
6	Biodiversity conservation		16	Food secuirity	
7	Medicines		17	Bathing cattle	
8	Grazing land		18	Help to farming	
9	Natural beauty		19		
10	Fodder to cattle		20		

2. When did you involve in fishing?

____

____

3. What are the names of local fishes?

SN	Local fishes	SN	Local fishes	SN	Local fishes
1		4		7	
2		5		8	
3		6		9	

4. Are there invasive fishes like Trout and Tilapia? When and how did they arrive?

____

____

For how many days do you kill fishes in a month? ____

Are native fishes decrease due to arrival of invasive fishes? _____________________________________

Are invasive plant species like water hyacinth impacted on fish farming? How? ___________________

8. Are invasive species spreading all around? ____

Economic valuation

1. For how many days, do you involve in fishing?

   ____

2. What is the cost for a kg of fish you collect?

Fish	KG	Fish	KG	Fish	KG

3. What amount of fishes you harvest per day after and before invasion of the lake?

SN	**Before Invasion**	**After invasion**

4. How much kg fish is harvested from fish cage culture?

   ____

5. Is there decrease in fish collection after invasion of lake by invasive weeds?

SN	**Before Invasion**	**After invasion invasive weeds**

6. After the purchase of the machine to remove Water hyacinth, is there any change in harvesting cost of fish and amount of fish?

   ____

Researcher : Hom Nath Pathak

Level of study : Ph.D.

Appendix 7 : Demographic information of the respondents of the questionnaire for HH survey

SN	Name	Address	Occupation	Edu	Age	Gender
1	Krishna Bdr BK	Pokh-18, Phewa	Farmer	Literate	32	M
2	Srijana Nepali	Pokh-18, Phewa	Farmer	Sec. level	20	F
3	Durga Psd Poudel	Pokh-17, Phewa	Ex-teacher, farmer	Intermediate	77	M
4	Lesh Bdr Gurung	Pokh-17, Phewa	Ex-Army, farmer	Pri. level	66	M
5	Ganga Psd Aryal	Pokh-17, Phewa	Farmer	Informal	70	M
6	Bibek Ghimire	Pokh-17, Phewa	Business	Sec. Level	32	M
7	Sunita Khadka	Pokh-18, Phewa	Farmer	Pri. Level	27	F
8	Dinesh Nepali	Pokh-18, Phewa	Farmer	Sec. level	24	M
9	Ram Psd Kafle	Pokh-17, Phewa	Admin	Graduate	29	M
10	Chitra Bdr Gurung	Pokh-8, Phewa	Farmer	Literate	80	M
11	Ek Psd Baral	Pokh-17, Phewa	Farmer	Pri. level	70	M
12	Tek Nath Subedi	Pokh-17, Phewa	Farmer	Pri. level	62	M
13	Ganga Bdr Gurung	Pokh-17, Phewa	Ex Army, farmer	Literate	92	M
14	Jay Lal Khanal	Pokh-17, Phewa	Farmer	Literate	76	M
15	Balkrishna Adhikari	Pokh-17, Phewa	Farmer	Sec. level	40	M
16	Setu Thapa	Pokh-18, Phewa	Farmer	Informal	71	F
17	Binita Nepali	Pokh-18, Phewa	Farmer	Pri. level	27	F
18	Buddhi Bhujel	Pokh-18, Phewa	Farmer	Sec. level	53	M
19	Sabita Gurung	Pokh-18, Phewa	Farmer	Sec. level	25	F
20	Bharat Thapa	Pokh-18, Phewa	Farmer	Sec. level	48	M
21	Laxman Thapa	Pokh-18, Phewa	Farmer	Sec. level	44	M
22	Misire Jalari	Pokh-18, Phewa	Fisher	Informal	68	F
23	Parvati Jalari	Pokh-18, Phewa	Fisher	Literate	50	F
24	Ram Chandra Jalari	Pokh-18, Phewa	Fisher	Informal	60	M
25	Lok Maya Jalari	Pokh-18, Phewa	Fisher	Informal	48	F
26	Tek Bdr Jalari	Pokh-18, Phewa	Fisher	Pri. level	33	M
27	Indra Bdr Jalari	Pokh-18, Phewa	Fisher	Pri. level	33	M
28	Laxmi /jalari	Pokh-18, Phewa	Fisher	Pri. level	30	F
29	Setu Mayas Jalari	Pokh-18, Phewa	Fisher	Informal	40	F
30	Jyoti Jalari	Pokh-18, Phewa	Fisher	Informal	30	F
31	Sita Jalari	Pokh-18, Phewa	Fisher	Informal	50	F
32	Buddha Jalari	Pokh-18, Phewa	Fisher	Informal	40	F
33	Bipin Gurung	Pokh-6, Phewa	Boater	Sec. level	35	M
34	Deepak Nepali	Pokh-6, Phewa	Boater	Sec. level	25	M
35	Ajaya Gurung	Pokh-6, Phewa	Boater	Pri. level	26	M
36	Laxman Acharya	Pokh-6, Phewa	Boater	Sec. level	28	M

37	Avinas Pariyar	Pokh-6, Phewa	Boater	Sec. level	20	M
38	Bharat Thapa	Pokh-6, Phewa	Boater	Sec. level	39	M
39	Prakash Vaidya	Pokh-6, Phewa	Boater	Sec. level	40	M
40	Mina Pahari	Pokh-6, Phewa	Boater	Graduate	45	F
41	Ramu Priyar	Pokh-6, Phewa	Boater	Pri. level	52	M
42	Barti Psd Gurung	Pokh-6, Phewa	Boater	Sec. level	65	F
43	Ram Pariyar	Pokh-6, Phewa	Boater	Pri. level	43	M
44	Hari Bhakta Parajuli	Pokh-6, Phewa	Boater	Sec. level	36	M
45	Setu Autari	Pokh-6, Phewa	Boater	Pri. level	50	M
46	Suresh Tamang	Pokh-6, Phewa	Boater	Literate	37	M
47	Saroj Jalari	Pokh-6, Phewa	Boater	Sec.level	23	M
48	Aashis Pariyar	Pokh-6, Phewa	Boater	Sec. level	26	M
49	Sanjaya Subba	Pokh-6, Phewa	Boater	Sec. level	19	M
50	Rahul Gurung	Pokh-6, Phewa	Boater	Iliterate	24	M
51	Aashis Poudel	Pokh-6, Phewa	Boater	Pri. level	24	M
52	Prabin Gurung	Pokh-6, Phewa	Boater	Sec. level	25	M
53	Kunbha Singh Gurung	Pokh-6, Phewa	Boater	Pri. level	56	M
54	Dipesh Pariyar	Pokh-6, Phewa	Boater	Sec. level	24	M
55	Maya Bhujel	Pokh-6, Phewa	Boater	Informal	61	F
56	Sundar BK	Pokh-6, Phewa	Boater	Informal	51	M
57	Arjun Sunar	Pokh-6, Phewa	Boater	Pri. level	28	M
58	Binaya Shrestha	Pokh-6, Phewa	Boater	Sec. level	22	M
59	Purrna Gurung	Pokh-6, Phewa	Boater	Sec.Level	21	M
60	Mahabir Kunwar	Pokh-6, Phewa	Boater	Pri. level	20	M
61	Bikash Pariyar	Pokh-6, Phewa	Boater	Sec. level	25	M
62	Ujjwal Gurung	Pokh-6, Phewa	Boater	Sec. level	24	M
63	Baburam Puri	Pokh-6, Phewa	Boater	Pri level	42	M
64	Yam Bdr Pariyar	Pokh-6, Phewa	Boater	Literate	44	M
65	Dil Bdr Kunwar	Pokh-6, Phewa	Boater	Sec. level	64	M
66	Dhan Bdr	Pokh-6, Phewa	Boater	Illeterate	36	M
67	Bikal Thakali	Pokh-6, Phewa	Hotelier	Sec. level	40	M
68	Abhaya Basnet	Pokh-6, Phewa	Hotelier	Pri. level	24	M
69	Punam Gurung	Pokh-6, Phewa	Hotelier	Sec. level	24	F
70	Dal Bahadur Thapa Magar	Pokh-6, Phewa	Hotelier	Sec. level	40	M
71	Prabhu Gurung	Pokh-6, Phewa	Hotelier	Graduate	25	M
72	Sushil Bhujel	Pokh-6, Phewa	Hotelier	Graduate	35	M
73	Ram Lal Pandey	Pokh-6, Phewa	Hotelier	Sec. level	43	M
74	Ramesh Thapa	Pokh-6, Phewa	Hotelier	Sec. level	39	M

75	Sushma Gurung	Pokh-6, Phewa	Hotelier	Sec. level	26	F
76	Khim LaLAryal	Pokh-6, Phewa	Hotelier	Graduate	40	MHH
77	Naresh Pun	Pokh-6, Phewa	Hotelier	Sec. level	20	M
78	Shiva Lal Tiwari	Pokh-6, Phewa	Hotelier	Sec. level	28	M
79	Ramji Bhandari	Pokh-6, Phewa	Hotelier	Graduate	42	M
80	Mandira KC	Pokh-6, Phewa	Hotelier	Sec. level	21	F
81	Lila Budha	Pokh-6, Phewa	Hotelier	Sec. level	19	F
82	Yam Bdr Thapa	Pokh-6, Phewa	Hotelier	Sec. level	27	M
83	Bharat Parajuli	Pokh-6, Phewa	Hotelier	Post grad	45	M
84	Sushila Magar	Pokh-6, Phewa	Hotelier	Pri. level	45	F
85	Govinda Jalari	Pokh-31, Begnas	Farmer	Sec. Level	45	M
86	Pema Lama	Pokh-31, Begnas	Farmer	Informal	65	F
87	Muna Lama	Pokh-31, Begnas	Farmer	Pri. level	25	F
88	Anjali Nepali	Pokh-31, Begnas	Farmer	Literate	35	F
89	Kumar Dura	Pokh-31, Begnas	Farmer	Pri. level	58	M
90	Radha Sapkota	Pokh-31, Begnas	Farmer	Sec. level	31	F
91	Bed Nath Ojha	Pokh-31, Begnas	Farmer	Sec. level	55	M
92	Sharmila Lama	Pokh-31, Begnas	Farmer	Pri. level	28	F
93	Pema Lama	Pokh-31, Begnas	Farmer	Sec. level	20	F
94	Basanti Ojha	Pokh-31, Begnas	Farmer	Sec. level	45	F
95	Ganesh Bdr Gurung	Pokh-31, Begnas	Farmer	Sec. level	36	M
96	Dammar Bdr Magar	Pokh-31, Begnas	Farmer	Informal	62	M
97	Sita Sunar	Pokh-31, Begnas	Farmer	Literate	35	F
98	Suv Bdr Lama	Pokh-31, Begnas	Farmer	Informal	74	M
99	Khadka Bdr Thapa	Pokh-31, Begnas	Farmer	Literate	60	M
100	Gyanu Jalari	Pokh-31, Begnas	Fisher	Informal	45	M
101	Parvati Jalari	Pokh-31, Begnas	Fisher	Sec. level	35	F
102	Reena Jalari	Pokh-31, Begnas	Fisher	Sec. level	23	F
103	Syanu Jalari	Pokh-31, Begnas	Fisher	Literate	45	M
104	Chandra Nepali	Pokh-31, Begnas	Fisher	Informal	41	M
105	Sreemaya Nepali	Pokh-31, Begnas	Boater	Literate	26	F
106	Bhim Kandel	Pokh-31, Begnas	Boater	Sec. level	35	M
107	Ram Bdr Jalari	Pokh-31, Begnas	Boater	Sec. level	45	M
108	Rameshor Baral	Pokh-31, Begnas	Boater	Literate	56	M
109	Megh Nath Tiwari	Pokh-31, Begnas	Boater	Literate	60	M
110	Sahi Bdr Gurung	Pokh-28, Bgnas	Boater	Pri. level	65	M
111	Resham Sapkota	Pokh-31, Begnas	Boater	Pri. level	35	M
112	Shiv Prasad Pandey	Pokh-31, Begnas	Boater	Pri. level	52	M

113	Purna kala Himali	Pokh-31, Begnas	Boater	Sec. level	40	F
114	Brihaspati sapkota	Pokh-31, Begnas	Boater	Sec. level	51	M
115	Santoshi Kandel	Pokh-31, Begnas	Boater	Graduate	19	F
116	Lal Bahadur jalari	Pokh-31, Begnas	Boater	Informal	62	M
117	Ganga BK	Pokh-31, Begnas	Boater	Informal	30	F
118	Shanti Karki	Pokh-31, Begnas	Hotelier	Literate	35	F
119	Jamuna Karki	Pokh-31, Begnas	Hotelier	Sec. level	33	F
120	Durga Psd Adhikari	Pokh-31, Begnas	Hotelier	Graduate	45	M
121	Srijana Jalari	Pokh-31, Begnas	Hotelier	Sec. level	30	F
122	Bishnu Tulachan	Pokh-31, Begnas	Hotelier	Literate	45	F
123	Ramesh Pandey	Pokh-31, Begnas	Hotelier	Sec. level	26	M
124	Meeta Jalari	Pokh-31, Begnas	Hotelier	Sec. level	30	F
125	Sabitri Gautam	Pokh-31, Begnas	Hotelier	Literate	40	F
126	Krishna Kumar KC	Pokh-31, Begnas	Hotelier	Sec. level	40	M
127	Jhalak Bdr Thapa	Pokh-31, Begnas	Hotelier	Literate	55	M
128	Bhiairab Bishwokarma	Pokh-26, Gunde	Farmer	Literate	67	MII
129	Khem Lal Adhikari	Pokh-26, Gunde	Farmer, teacher	Graduate	72	M
130	Gyan Bdr Gurung	Pokh-26, Gunde	Farmer	Literate	72	M
131	Bam Bdr Gharti	Pokh-26, Gunde	Engineer	Graduate	67	M
132	Prakash Baral	Pokh-26, Gunde	Farmer	Sec. level	42	M
133	Kumar Sunar	Pokh-26, Gunde	Farmer	Sec. level	40	M
134	MiN Bdr Damai	Pokh-26, Gunde	Farmer, Tailor	Literate	51	M
135	Jhakku Maya Gurung	Pokh-26, Gunde	Farmer	Pri. level	38	F
136	Maya Baral	Pokh-26, Gunde	Farmer	Sec. level	43	F
137	Bam Dev Dhungana	Pokh-26, Gunde	Farmer	Graduate	64	M
138	Hari BK	Pokh-26, Gunde	Farmer	Graduate	24	M
139	Buddhi Bdr Budhathoki	Pokh-26, Gunde	Farmer	Informal	50	M
140	Hari Maya Gharti	Pokh-26, Gunde	Farmer	Sec. level	65	F
141	Ganga BK	Pokh-26, Gunde	Farmer	Literate	35	F
142	Surya Kumari Ranabhat	Pokh-26, Gunde	Farmer	Sec. level	40	F
143	Sudip Lamichhane	Pokh-26, Gunde	Farmer	Graduate	29	M
144	Indra Maya BK	Pokh-26, Gunde	Farmer	Literate	43	F
145	Sita Sunar	Pokh-26, Gunde	Farmer	Sec. level	29	F
146	Juna Rasaili	Pokh-26, Gunde	Farmer	Informal	50	F
147	Sharmila Magar	Pokh-26, Gunde	Farmer	Pri. level	30	F
148	Rajesh BK	Pokh-26, Gunde	Farmer	Graduate	21	M
149	Anand Dhungana	Pokh-26, Gunde	Farmer	Post grad	25	M
150	Ganesh Baral	Pokh-26, Gunde	Farmer	Sec. level	44	M

151	Tejuram BK	Pok-13,Kpokhari	Farmer	Pri. level	38	M
152	Kamal Bdr BK	Pok-13,Kpokhari	Farmer	Literate	55	M
153	Saraswoti Thapa	Pok-13, pokhari	Farmer	Informal	55	F
154	Vikash KC	Pok-13,Kpokhari	Farmer	Sec. level	50	M
155	Yam Maya Gurung	Pok-13,Kpokhari	Farmer	Literate	45	F
156	Aita Bdr Lama	PO-13, Kpokhari	Farmer	Sec. level	38	M
157	Gyanu Nepali	Pok-13,Kpokhari	Farmer	Literate	55	M
158	Nageda BK	Pok-13,Kpokhari	Painter	Literate	46	M
159	Jay Bdr Rasaili	Pok-13,Kpokhari	Thekedar	Informal	66	F
160	Lal Bdr BK	Pok-13,Kpokhari	Thekedar	Sec. level	45	M
161	Suraj BK	Pok-13,Kpokhari	Farmer	Sec. level	34	M
162	Kaman Sing Nepali	Pok-13,Kpokhari	Farmer	Sec. level	40	M
163	Chandra Bdr Lama	Pok-13,Kpokhari	Farmer	Pri. level	45	M
164	Sital Nepali	Pok-13,Kpokhari	Farmer	Sec. level	36	M
165	Surya Bdr BK	Pok-13 Kpokhari	Farmer	Informal	50	M
166	Bhim Ranabhat	Pok-13,Kpokhari	Farmer	Sec. level	44	M
167	Chudamani BK	Pok-13,Kpokhari	Farmer	Literate	50	M
168	Lekh Bdr	Pok-13,Kpokhari	Dakarmi	Pri. level	50	M
169	Namaraj Khadka	Rupa-6	Fisher	Post Grad	28	M
170	Pabitra Jalari	Rupa-6	Fisher	Informal	40	M
171	Sheela Gurung	Rupa-6	Fisher	Graduate	23	F
172	Jeevan Gurung	Rupa-6	Fisher	Illiterate	42	M
173	Surya Bdr Gurung	Rupa-6	Fisher	Pri. level	40	M
174	Manoj Nepali	Rupa-6	Banpale	Informal	57	M
175	Radhika Adhikari	Rupa-6	Farmer	Informal	70	F
176	Sita Sunar	Rupa-6	Farmer	Literate	40	F
177	Bhim Bdr Gurung	Rupa-6	Farmer	Informal	80	M
178	Ganga Maya Gurung	Rupa-6	Farmer	Informal	58	F
179	Susma Sunar	Rupa-6	Farmer	Pri. level	30	F
180	Rajendra Sunar	Rupa-6	Farmer	Pri. level	40	M
181	Sovita Neupane	Rupa-6	Farmer	Sec. level	39	F
182	Bishnu Maya Shrestha	Rupa-6	Farmer	Sec. level	45	F
183	Laxmi Subedi	Rupa-6	Farmer	Pri. level	30	F
184	Sunita Khadka	Rupa-6	Farmer	Sec. level	24	F
185	Tara Thapa	Rupa-6	Farmer	Pri. level	36	F
186	Jamuna KC	Rupa-6	Farmer	Literate	45	F
187	Anita Thapa	Rupa-6	Farmer	Sec. level	35	F
188	Santa Bdr Gurung	Rupa-7	Hotelier	Literate	60	M

189	Durga datta subedi	Rupa-8	Hotelier	Literate	77	M
190	Ananda Sapkota	Rupa-9	Hotelier	Post Grad	38	M
191	Krishna Hari subedi	Rupa-12	Hotelier	Literate	35	M
192	Saili ama (Maya Tamang)	Rupa-13	Hotelier	Literate	45	F
193	Ganga Maya Gurung	Rupa-14	Hotelier	Informal	45	F
194	Raju Nepali	Pok-26,Khas/Niu	Fisher	Pri. level	45	M
195	Gyan Bdr Jalari	Pok-26,Khas/Niu	Fisher	Literate	46	M
196	Sakuntala BK	Pok-26,Khas/Niu	Fisher	Pri. level	36	F
197	Sarita Baral	Pok-26,Khas/Niu	Hotelier	Sec. level	43	F
198	Indra Raj Ranabhat	Pok-26,Khas/Niu	Farmer	Sec. level	58	M
199	Kalpana Paudel	Pok-26,Khas/Niu	Farmer	Pri. level	39	F
200	Tara Nath Paudel	Pok-26,Khas/Niu	Farmer	Sec. level	45	M
201	Krishna Acharya	Pok-26,Khas/Niu	Fgarmer	Literate	35	F
202	Sabitri paudel	Pok-26,Khas/Niu	Farmer	Informal	39	F
203	Hem raj baral	Pok-26,Khas/Niu	Farmer	Graduate	50	M
204	Dil Maya Bhattrai	Pok-26,Khas/Niu	Farmer	Informal	55	F
205	Kalika Timilsina	Pok-26,Khas/Niu	Farmer	Graduate	45	F
206	Deepa Lamichhane	Pok-26,Khas/Niu	Farmer	Sec. level	30	F
207	Sujan Kumari Bhandari	Pok-26,Khas/Niu	Farmer	Post Grad	26	F
208	Puja Bhandari	Pok-26,Khas/Niu	Farmer	Sec. level	38	F
209	Narayani Asdhikari	Pok-26,Khas/Niu	Farmer	Pri. level	46	F
210	Bishnu Maya Adhikari	Pok-26,Khas/Niu	Farmer	Literate	32	F
211	Sita Adhikari	Pok-26,Khas/Niu	Farmer	Sec. level	26	F
212	Basanti BK	Pok-26,Khas/Niu	Farmer	Literate	40	F
213	Saraswoti Paudel	Pok-26,Khas/Niu	Farmer	Sec. level	40	F
214	Bharat Raj timilsina	Pok-26,Khas/Niu	Farmer	Sec. level	50	M
215	Rewatiraman Lamichhane	Pok-26,Khas/Niu	Farmer	Sec. level	65	M
216	Surya raj bastakoti	Pok-26,Khas/Niu	Farmer	Sec. level	40	M
217	Sree Prasad Adhikari	Pok-26,Khas/Niu	Farmer, offiucr	Graduate	50	M
218	Basudev Paudyal	Pok-26,Khas/Niu	Farmer	Sec. level	46	M
219	Kalika Acharya	Pok-26,Khas/Niu	Farmer, teacher	Post Grad	32	F
220	Nabarajv Dhungana	Pok-26,Khas/Niu	Farmer	Graduate	65	M
221	Laxmi bhakta Baral	Pok-26,Khas/Niu	Farmer	Literate	84	M
222	Bhanubhakta Lamichhane	Pok-26,Khas/Niu	Farmer	Sec. level	52	M
223	Nabaraj Baral	Pok-26,Khas/Niu	Teacher	Graduate	41	M
224	Surendra Kandel	Pok-26,Khas/Niu	Farmer	Sec, level	38	M
225	Khem Raj Baral	Pok-26,Khas/Niu	Farmer	Graduate	55	M
226	Muktinath Adhikari	Pok-26,Khas/Niu	Farmer	Sec. level	46	M

227	Basundhari Lamichhane	Pok-30, Maidi	Farmer	Literate	54	F
228	Laxmi Silwal	Pok-30, Maidi	Farmer	Pri. level	28	F
229	Sarita Nepali	Pok-30, Maidi	Farmer	Pri. level	30	F
230	Sarada subedi	Pok-30, Maidi	Farmer	Literate	55	F
231	Susma paudel	Pok-30, Maidi	Farmer	Sec. level	27	F
232	Bhim Kumari Bhandari	Pok-30, Maidi	Farmer	Informal	76	F
233	Dilliraman Tiwari	Pok-30, Maidi	Farmer	Sec. level	46	M
234	Dilliraman Tiwari II	Pok-30, Maidi	Farmer	Sec. level	48	M
235	Nabin Tiwari	Pok-30, Maidi	Farmer	Sec. level	34	M
236	Kamal BK	Pok-30, Maidi	Farmer	Literate	49	M
237	Sarita Tiwari Baral	Pok-30, Maidi	Farmer	Graduate	25	F
238	Sushila Bhandari	Pok-30, Maidi	Farmer	Sec. level	36	F
239	Prem Bahadur Khadka	Pok-30, Maidi	Farmer	Pri. level	58	M
240	Sara Pariyar	Pok-30, Maidi	Farmer	Literate	46	F
241	Laxmi BK	Pok-30, Maidi	Farmer	Pri. level	32	F
242	Tila Devi Adhikari	Pok-30, Maidi	Farmer	Informal	60	F
243	Krishna Kumari Nepali	Pok-30, Maidi	Farmer	Pri. level	38	F
244	Sita Niupane	Pok-30, Maidi	Farmer	Sec.evel	50	F
245	Samjhana Khadka	Pok-30, Maidi	Farmer	Sec. level	25	F
246	Govinda Silwal	Pok-30, Maidi	Farmer	Literate	68	M
247	Narayan Thapa	Pok-30, Maidi	Farmer	Literate	66	M
248	Khil nath Bhandari	Pok-30, Maidi	Farmer	Pri. level	67	M
249	Kamala Dhakal	Pok-30, Maidi	Farmer	Informal	65	F
250	Saraswoti GC	Pok-30, Dipang	Farmer	Sec. level	28	F
251	Maiya GC	Pok-30, Dipang	Farmer	Informal	60	F
252	Bimala Shrestha	Pok-30, Dipang	Farmer	Pri. level	35	F
253	Bishnu Bhujel	Pok-30, Dipang	Farmer	Literate	45	F
254	Rajendra Raj Bastola	Pok-30, Dipang	Farmer	Sec. level	64	M
255	Ramjee Adhikari	Pok-30, Dipang	Farmer	Informal	79	M
256	Asmita Tajhya	Pok-30, Dipang	Farmer	Sec. level	19	F
257	Buddhi Maya Lama	Pok-30, Dipang	Farmer	Informal	63	F
258	Hira Maya Chhetri	Pok-30, Dipang	Farmer	Informal	62	F
259	Shanta Kandel	Pok-30, Dipang	Farmer	Literate	57	F
260	Tara Nath Giri	Pok-30, Dipang	Farmer	Pri. level	52	M
261	Bishnu Maya giri	Pok-30, Dipang	Farmer	Informal	60	F
262	Pabitra Giri	Pok-30, Dipang	Farmer	Sec. level	36	F
263	Gyanu Jalari	Pok-27, Dipang	Fisher	Informal	46	M
264	Raju Nepali	Pok-27, Dipang	Fisher	Literate	46	M

Appendix 8. Checklist of plant species reported from the Lake Cluster of Pokhara Valley

SN	Family	Botanical name	IUCN categ	N/E	D/M	NRR	RC	H/S	A/P	Use value	Ref.	Coll. No
1	Cannaceae	*Canna indica* L		E	M	1	He	He	P			R96
2	Euphorbiaceae	*Euphorbia pulcherrima* Willd. ex Klotzsch**	LC	E	D	1	Ch	Sh	P	Me, Or	1	R104
3	Lauraceae	*Cinnamomum verum* J.S. Presl**		E	D	1	Ph	Tr	P			R125
4	Malvaceae	*Hibiscus rosa-sinensis* L**		E	D	1	Ph	Sh	P	Me Fo	1	K69
5	Myrtaceae	*Melaleuca citrina* (Curtis) Dum. Cours*		E	D	1	Ph	Tr	P	Fo	1	K67
	These species were not included in analysis											
1	Acanthaceae	*Achyranthes aspera* L**		N	D	1	Th	He	P	Me	1,12	G76
2	Acanthaceae	*Justicia adhatoda* L**	LC	N	D	1	Ch	He	P	Me	1	P109
3	Acanthaceae	*Justicia gendarussa* Burm. f.		N	D	4	He	Sh	P	Me	1	F 131
4	Acanthaceae	*Lepidagathis incurva* Buch.-Ham. ex D. Don		N	D	1	He	He	P	Fd	1, 2	M104
5	Acanthaceae	*Rostellularia procumbens* (L) Nees**		N	D	1	He	He	P	Me	1	B23
6	Acanthaceae	*Strobilanthes atropurpurea* Nees**		N	D	1	He	He	P	Me	1, 2	92
7	Acanthaceae	*Thunbergia fragrans* Roxb.		N	D	1	He	He	P			4
8	Acanthaceae	*Justicia simplex* D. Don		N	D	1	He	He	P	Me	1, 2	140
9	Acoraceae	*Acorus calamus* L.	LC	N	M	1	Cr	He	P	Me	1, 2, 3, 7, 9, 11, 14	R152
10	Amaranthaceae	*Alternanthera sessilis* (L.) R.Br. ex DC**	LC	N	D	1	He	He	P	Fd, Me, Fr	1, 2, 4, 7, 9, 12, 14, 15	70L8
11	Amaranthaceae	*Amaranthus spinosus* L**		E	D	1	He	He	A	Fd, Me, Fr	1, 4	R124
12	Amaranthaceae	*Dysphania ambrosioides* (L.) Mosyakin & Clemants		E	D	1	He	He	P	Fd, Me	1, 2	N267
13	Amaranthaceae	*Alternanthera philoxeroides* (Mart.) Griseb**		E	D	1	He	He	P			152
14	Amaryllidaceae	*Crinum amoenum* Ker Gawl. ex Roxb.		N	M	1	Cr	He	P	Me	1, 2	153
15	Apiaceae	*Centella asiatica* (L.) Urb**	LC	N	D	1	He	He	P	Me, Fd	1, 4, 5, 6, 7, 9, 12, 14	154
16	Apocynaceae	*Cryptolepis buchananii* Schult. ex Roem. & Schult.		N	D	1	Ph	Sh	P	Me, Fo, Fi	1, 2	G117
17	Apocynaceae	*Ichnocarpus frutescens* (L.) W.T.Aiton		N	D	1	Ph	Sh	P	Fd, Me, Fi	1, 2	M151
18	Araceae	*Colocasia fallax* Schott**	LC	N	M	1	Cr	He	P			R229
19	Araceae	*Pistia stratiotes* L.**	LC	E	M	5	Cr	He	P			P114
20	Asteraceae	*Acmella paniculata* (Wall. ex DC.) ** R.K. Jansen	LC	N	D	1	Th	He	A			115
21	Asteraceae	*Adenostemma lavenia* (L.) Kuntze		N	D	1	He	He	P	Me	1	15
22	Asteraceae	*Ageratina adenophora* (Spreng.) R.M. King & H. Rob**		E	D	1	Th	He	A	Me	2, 4, 5, 7, 11	R21

23	Asteraceae	*Ageratum conyzoides* L**		E	D	1	Th	He	A	Me, Fr	1, 2, 4, 6, 8, 12	65
24	Asteraceae	*Ageratum houstonianum* Mill**		E	D	1	Th	He	A	Me	2, 4	M10
25	Asteraceae	*Artemisia indica* Willd**		N	D	1	He	Sh	P	Me	1	P89
26	Asteraceae	*Bidens bipinnata* L.		E	D	4	Th	He	A	Fd, Me	1, 13	25
27	Asteraceae	*Bidens pilosa* L**		E	D	1	Th	He	A	Fd, Me, Fr	1, 2, 15	K123
28	Asteraceae	*Chromolaena odorata* (L.) R.M.King & H. Rob**		E	D	1	Th	Sh	A	Me	2	P225
29	Asteraceae	*Crassocephalum crepidioides* (Benth.) S. Moore		E	D	1	Th	He	A	Me	1, 2	P137
30	Asteraceae	*Cyanthillium cinereum* (L.) H. Rob		N	D	1	Th	He	A	Me	1	98
31	Asteraceae	*Duhaldea cappa* (Buch.-Ham. ex D. Don) Pruski & Anderb**		N	D	1	Ch	Sh	P	Me	1	M103
32	Asteraceae	*Eclipta prostrata* (L.) L.	LC	E	D	1	Th	He	A	Fd, Me, Fr	1, 2, 4, 6, 7, 12, 13, 15	P138
33	Asteraceae	*Elephantopus scaber* L**		N	D	1	He	He	P	Me, Fa	1, 2, 13, 15	26
34	Asteraceae	*Emilia sonchifolia* (L.) DC**		N	D	1	Th	He	A	Me, Fd, Fa	1, 15	107
35	Asteraceae	*Erigeron canadensis* L**		E	D	1	Th	He	A			159
36	Asteraceae	*Eschenbachia japonica* (Thunb.) J. Kost.		N	D	1	Th	He	A			164
37	Asteraceae	*Galinsoga quadriradiata* Ruiz & Pav**		E	D	1	Th	He	A	Fr, Me	1	79
38	Asteraceae	*Mikania micrantha* Kunth		E	D	1	He	He	P	Fr	15	D200
39	Asteraceae	*Parthenium hysterophorus* L.		E	D	1	Th	He	A			P 4
40	Asteraceae	*Pseudognaphalium affine* (D. Don) Anderb.		N	D	1	Th	He	A			417
41	Asteraceae	*Sonchus arvensis* L**		E	D	1	Th	He	A	Me, Fd	1, 2	81
42	Asteraceae	*Sonchus asper* (L.) Hill		N	D	1	Th	He	A	Fd, Me, Fr	1, 2	161
43	Asteraceae	*Sonchus oleraceus* L**		E	D	1	Th	He	A	Fd	1	P102
44	Asteraceae	*Synedrella nodiflora* (*L.*) *Gaertn.*		E	D	1	Th	He	A	Me	1, 2	P104
45	Asteraceae	*Tridax procumbens* L.		E	D	1	Th	He	A	Me	1, 2	278
46	Asteraceae	*Xanthium strumarium* L**		E	D	1	Th	He	A	Me	1, 9	R124
47	Balsaminaceae	*Impatiens insignis* DC		N	D	1	Th	He	A	Fr	1	162
48	Balsaminaceae	*Impatiens racemosa* DC**		N	D	1	Th	Sh	A	Fd	1	162
49	Bignoniaceae	*Oroxylum indicum* (L.) Benth. ex Kurz**		N	D	1	Ph	Tr	P	Me, Ri	1, 2, 3, 13	B 231
50	Boraginaceae	*Cynoglossum zeylanicum* (Vahl) Thunb. ex Lehm**		N	D	1	He	Sh	P			105
51	Boraginaceae	*Cynoglossum wallichii* G. Don		N	D	1	Th	He	A			27
52	Brassicaceae	*Nasturtium officinale* W.T. Aiton	LC	E	D	1	Th	He	P	Fd	1	163

53	Caryophyllaceae	*Drymaria cordata* (L.) Willd. ex Roem. & Schult.		E	D	1	Th	He	A	Fd, Me	1, 2	K153
54	Caryophyllaceae	*Stellaria media* (L.) Vill.		N	D	1	He	He	P	Fd, Me	1, 2	166
55	Ceratophyllaceae	*Ceratophyllum muricatum* Cham.		N	D	1	Cr	He	P			30
56	Commelinaceae	*Cyanotis vaga* (Lour.) Schult. & Schult.f.		N	M	1	Cr	He	P			N139
57	Commelinaceae	*Floscopa scandens* Lour**	LC	N	M	1	Cr	He	P	Me, Fr	1, 2, 4, 5, 14	23
58	Commelinaceae	*Murdannia nudiflora* (L.) Brenan**		N	M	1	Th	He	A	Fd, Me	1, 2, 9, 12	B145
59	Commelinaceae	*Commelina paludosa* Blume		N	M	1	Cr	He	P	Fd, Me	1, 2	103Kamal
60	Convolvulaceae	*Argyreia hookeri* C.B. Clarke**		N	D	1	Ch	Sh	P			B76
61	Convolvulaceae	*Ipomoea purpurea* (L.) Roth**		E	D	1	Th	He	A			168
62	Convolvulaceae	*Ipomoea carnea* subsp. *fistulosa* (Mart. ex Choisy) D.F.Austin**		E	D	1	Ch	He	P	He, Me	1, 2, 13, 14	101
63	Costaceae	*Hellenia speciosa* (J.Köenig) S.R.Dutta**	LC	N	M	1	He	He	P	Fd, Me	1, 2, 3	R128
64	Cucurbitaceae	*Solena heterophylla* Lour**		N	D	1	He	He	P	Fd, Me, Fo	1, 2	K100
65	Cyperaceae	*Carex cruciata* Wahlenb.		N	M	1	Cr	He	P			169
66	Cyperaceae	*Cyperus albescens* (Steud.) Larridon & Govaerts		N	M	1	Th	He	A			F151
67	Cyperaceae	*Cyperus brevifolius* (Rottb.) Hassk**	LC	N	M	1	Cr	He	P	Fr	9, 12	47
68	Cyperaceae	*Cyperus compressus* L.	LC	N	M	1	Th	He	A	Me, Fr	2, 12, 14	M205
69	Cyperaceae	*Cyperus corymbosus* Palla		N	M	1	Th	He	A			21
70	Cyperaceae	*Cyperus cyperoides* (L.) Kuntze	LC	N	M	1	Cr	He	P	Me	1, 2	P123
71	Cyperaceae	*Cyperus iria* L**	LC	N	M	1	Th	He	A	Fr, Me	2, 9, 12	M214
72	Cyperaceae	*Cyperus platystylis* R.Br.		N	M	1	Th	He	A			26
73	Cyperaceae	*Cyperus rotundus* L**	LC	N	M	1	Cr	He	P	Fr, Me	1, 12	P156
74	Cyperaceae	*Eleocharis congesta* D. Don	LC	N	M	1	Th	He	A			18
75	Cyperaceae	*Fimbristylis dichotoma* (L.) Vahl**	LC	N	M	1	Cr	He	A	Fo, Me	1, 2, 9, 12, 14, 15	K116
76	Cyperaceae	*Fimbristylis ovata* J. Kern**	LC	N	M	1	Cr	He	P	Fr	1	P116
77	Cyperaceae	*Fimbristylis schoenoides* (Retz.) Vahl**	LC	N	M	1	Cr	He	P			R65
78	Cyperaceae	*Schoenoplectiella juncoides* (Roxb.) Lye		N	M	1	Cr	He	P	Fi, Fo	1, 4	16phewa
79	Cyperaceae	*Schoenoplectiella lateriflora* (J.F.Gmel.) Lye		N	M	1	Th	He	A			K101
80	Cyperaceae	*Schoenoplectiella mucronata* (L.) J. Jung & H.K. Choi	LC	N	M	1	Cr	He	P	Fi, Fo	1, 4, 14	R198
81	Cyperaceae	*Scleria biflora* Roxb.	LC	N	M	1	Cr	He	P	Fo	1, 2	K102
82	Cyperaceae	*Scleria levis* Retz.		N	M	1	Cr	He	P			K109

83	Cyperaceae	*Actinoscirpus grossus* (L.f.) Goetgh. & D.A. Simpson	LC	N	M	1	Cr	He	P	Me, Fi	2	7
84	Dioscoreaceae	*Dioscorea pubera* Blume**		N	D	1	He	He	P			182
85	Dioscoreaceae	*Dioscorea bulbifera* L**		N	D	1	He	He	P	Fd, Me	1, 2	R103
86	Dioscoriaceae	*Dioscorea deltoidea* Wall. Ex Griseb**		N	M	1	He	Sh	P	Me, Fd	1	R201
87	Dipterocarpaceae	*Shorea robusta* Gaertn**	LC	N	D	1	Ph	Tr	P	Me, Ti, Tag	1, 2, 13	I91
88	Ebenaceae	*Diospyros malabarica* (Desr.) Kostel.**		N	D	1	Ph	Tr	P			P99
89	Eriocaulaceae	*Eriocaulon nepalense* Prescott ex Bong.	LC	N	M	1	Th	He	A	Me	1	P226
90	Euphorbiaceae	*Alchornea mollis* (Benth.) Müll. Arg.		N	D	1	Ch	Sh	P			M124
91	Euphorbiaceae	*Falconeria insignis* Royle**		N	D	1	Ph	Tr	P	Me, Fp	1, 2	B24
92	Euphorbiaceae	*Macaranga denticulata* (Blume) Müll. Arg.	LC	N	D	1	Ph	Tr	P	Me, Fo	1, 2	184
93	Euphorbiaceae	*Euphorbia hirta* L.**		N	D	1	He	He	A	Me	2	185
94	Fabaceae	*Aeschynomene indica* L**	LC	N	D	1	He	Sh	P	Me	2	G68
95	Fabaceae	*Bauhinia purpurea* L**	Lc	N	D	1	Ph	Tr	P	Fo, Cm, Fd, Fr, Me	1,2	R61
96	Fabaceae	*Chamaecrista leschenaultiana* (DC.) O. Deg.		N	D	1	He	He	P			41
97	Fabaceae	*Chamaecrista rotundifolia* (Pers.) Greene		E	D	1	He	He	P			46
98	Fabaceae	*Crotalaria alata* D. Don		N	D	1	He	Sh	P	Me	1	187
99	Fabaceae	*Crotalaria pallida* Aiton**		N	D	1	He	Sh	P			93
100	Fabaceae	*Crotalaria sessiliflora* L**		N	D	1	He	Sh	P	Me	1, 2	192
101	Fabaceae	*Desmodium concinnum* DC		N	D	4	He	He	P	Me	1, 2	P121
102	Fabaceae	*Desmodium heterocarpon* (L.) DC**		N	D	4	Th	He	A	Me	1, 2	56
103	Fabaceae	*Desmodium laxiflorum* DC		N	D	4	Th	He	A	Fo	1, 2	194
104	Fabaceae	*Desmodium multiflorum* DC		N	D	4	He	He	A	Me	1, 2	197
105	Fabaceae	*Dunbaria glandulosa* (Dalzell & A. Gibson) Prain		N	D	1	Th	He	A			201
106	Fabaceae	*Mimosa pudica* L**	LC	E	D	1	He	He	P	Me	1, 2, 8, 12, 15	19
107	Fabaceae	*Mimosa rubicaulis* Lam.		N	D	1	Ch	Sh	P	Me	1, 2	F150
108	Fabaceae	*Senna occidentalis* (L.) Link**		E	D	1	Th	Sh	A	Fd, Me	1, 2	P 2
109	Fabaceae	*Senna tora* (L.) Roxb**		E	D	1	Th	Sh	A	Fd, Me	1, 3, 8, 12	P213
110	Fabaceae	*Stylosanthes hamata* (L.) Taub.		E	D	1	Th	He	A			42
111	Fabaceae	*Sunhangia elegans* DC**		N	D	1	Ch	Sh	P	Fr, Me	1	K122
112	Fabaceae	*Indigofera atropurpurea* Buch.-Ham. Ex. Hornem.**		N	D	4	Ph	Sh	P			311
113	Fagaceae	*Quercus lanata* Sm**	LC	N	D	1	Ph	Tr	P	Fd, Me, Fo, Fw	1, 2	204

114	Fagaceae	*Castanopsis indica* (J. Roxb. ex Lindl.) A. DC**	LC	N	D	1	Ph	Tr	P	Me, Fd, Fw, Fo	1, 5	M201
115	Gesneriaceae	*Aeschynanthus parviflorus* (D. Don) Spreng.		E	D	1	Ph	He	P	Me	1, 2	123
116	Hydrocharitaceae	*Hydrilla verticillata* (L.f.) Royle**	LC	N	M	1	Cr	He	A	Me, Gm, Fr, Fd	1, 2, 4, 6	N140
117	Hypericaceae	*Hypericum japonicum* Thunb.		N	D	1	He	He	P	Me	1, 2	211
118	Hypericaceae	*Hypericum podocarpoides* N. Robson		N	D	1	Ch	Tr	P	Me	1	B23
119	Hypericaceae	*Hypericum uralum* Buch.-Ham. ex D. Don		N	D	1	Ch	He	P	Me, Fo	1, 2	89
120	Juglandaceae	Engelhardia spicata Lechen ex Blume.**	LC	N	D	1	Ph	Tr	P	Fo	1	R105
121	Juncaceae	*Juncus prismatocarpus* R. Br**	LC	N	M	1	Cr	He	P			G125
122	Lamiaceae	*Anisomeles indica* Kuntze		N	D	1	He	He	P	Me	1, 2	27
123	Lamiaceae	*Colebrookea oppositifolia* Sm**		N	D	1	Ch	Sh	P	Me	2, 9	62
124	Lamiaceae	*Melissa axillaris* (Benth.) Bakh. f.		N	D	1	He	He	P	Me	2	60
125	Lamiaceae	*Mentha arvensis* L**		N	D	1	He	He	P	Me	1	N115
126	Lamiaceae	*Mesosphaerum suaveolens* (L.) Kuntze**		E	D	1	Th	He	A	Me	2	235
127	Lamiaceae	*Ocimum gratissimum* L**		N	D	1	Th	He	A	Me	2	N177
128	Lamiaceae	*Ocimum tenuiflorum* L.		N	D	1	Th	He	A	Me, Ri	1, 2	K126
129	Lamiaceae	*Platostoma coloratum* (D. Don) A.J. Paton		N	D	1	He	He	P	Fd, Me	1, 2	87
130	Lamiaceae	*Plectranthus mollis* (Aiton) Spreng.		N	D	1	He	He	P	Me	1, 2	238
131	Lamiaceae	*Pogostemon auricularius* (L.) Hassk.**		N	D	1	He	He	P			105
132	Lamiaceae	*Scutellaria discolor* Colebr.		N	D	1	He	He	P	Me	1, 2	74
133	Lamiaceae	*Clerodendrum bracteatum* Wall. ex Walp.		N	D	1	Ch	Sh	P			R121
134	Lauraceae	*Dodecadenia grandiflora* Nees**		N	D	1	Ph	Tr	P	Fr	1	P108
135	Lauraceae	*Litsea monopetala* (Roxb.) Pers.**	LC	N	D	1	Ph	Tr	P	Fo, Me	1, 2	R211
136	Lentibulariaceae	*Utricularia australis* R. Br.	LC	N	D	1	Cr	He	P			251
137	Linaceae	*Reinwardtia indica* Dumort**		N	D	1	Ch	Sh	P	Me	1, 2	K136
138	Linderniaceae	*Lindernia hyssopioides* Haines**		N	D	1	Th	Sh	A			P125
139	Linderniaceae	*Torenia asiatica* L.		N	D	1	Th	He	A	Me	2	268
140	Linderniaceae	*Bonnaya ciliata* (Colsm.) Spreng**		N	D	1	Th	He	A	Me, Fd	2, 14	109
141	Lythraceae	*Woodfordia fruticosa* (L.) Kurz**	Lc	N	D	1	Ph	Sh	P	Me	2, 9	403
142	Lythraceae	*Cuphea procumbens* Ortega		E	D	1	He	He	P	Fo	1	9
143	Magnoliaceae	*Magnolia champaca* (L.) Baill. ex Pierre	LC	N	D	1	Ph	Tr	P	Me, Ti, Dy	1, 2	267

144	Malvaceae	*Abelmoschus manihot* (L) Medik**		N	D	1	Th	Sh	A	Me		G133
145	Malvaceae	*Sida acuta* Burm. f.		N	D	1	He	Sh	P	Me, Fi	1, 2	280
146	Malvaceae	*Sida cordifolia* L**		N	D	1	He	Sh	P	Me	1, 12, 15	R111
147	Malvaceae	*Sida rhombifolia* L.		N	D	1	He	He	P	Me, Fi	1, 2	281
148	Malvaceae	*Triumfetta rhomboidea* Jacq.		N	D	1	He	He	P	Me, Fd	1, 2	34
149	Malvaceae	*Urena lobata* L**	LC	N	D	1	He	Sh	P	Me, Fi, Ta, Fr	1, 2, 15	106
150	Melastomataceae	*Osbeckia nepalensis* Hook.		N	D	1	He	Sh	P	Me, Fd	1, 2	31
151	Melastomataceae	*Osbeckia stellata* Buch.-Ham. ex D. Don**		N	D	1	He	Sh	P	Me, Fd	1, 2	32
152	Meliaceae	*Toona hexandra* (Wall.) M. Roem.**	LC	N	D	1	Ph	Tr	P	Me, Ti	1, 2, 5	B23
153	Menispermiaceae	*Cissampelos pareira* L**		N	D	1	Ph	He	P	Me, Fi	1, 2, 7, 13	M207
154	Menyanthaceae	*Nymphoides indica* (L.) Kuntze	LC	N	M	1	Cr	He	A			22
155	Moraceae	*Ficus auriculata* Lour**	LC	N	D	1	Ph	Tr	P	Fr, Me, Fd	1	P201
156	Moraceae	*Ficus benghalensis* L**		N	D	1	Ph	Tr	P	Me, Fr, Fd	1	P108
157	Moraceae	*Ficus benjamina* L**	Lc	N	D	1	Ph	Tr	P	Me	1	P67
158	Moraceae	*Ficus religiosa* L**		N	D	1	Ph	Tr	P	Me, Fd	1,2; 1	P81
159	Moraceae	*Ficus sarmentosa* Buch.-Ham. ex Sm.**		N	D	1	Ph	Tr	P	Fd, Fo	1, 2	P140
160	Moraceae	*Ficus semicordata* Buch.-Ham. ex Sm**	Lc	N	D	1	Ph	Tr	P	Me, Fo, Fd	1,2;1;1	R70
161	Moraceae	*Ficus racemosa* L**	LC	N	D	1	Ph	Tr	P	Fd, Fw, Fo	1, 2	M205
162	Myricaceae	*Morella esculenta* (Buch.-Ham. ex D. Don) I.M. Turner**		N	D	1	Ph	Tr	P	Me, Fd	1, 2, 5, 13	B23
163	Myrtaceae	*Syzygium cumini* (L.) Skeels	Lc	N	D	1	Ph	Tr	P	Me, Ta, Dy	1, 2	284
164	Nelumbonaceae	*Nelumbo nucifera* Gaertn.**		N	M	1	Cr	He	P	Fd, Me, Ri	1, 2, 4, 6, 9	288
165	Nymphaeaceae	*Nymphaea nouchali* Burm. f.**	LC	N	D	1	Cr	He	P	Me	1	P119
166	Nymphaeaceae	*Nymphaea rubra* Roxb. ex Salisb.	Lc	N	M	1	Cr	He	A	Me	2	P122
167	Oleaceae	*Fraxinus floribunda* Wall**	Lc	N	D	1	Ph	Tr	P	Me	1, 2	291
168	Oleaceae	*Jasminum multiflorum* Andrews		N	D	1	Ch	He	P	Me, Or, Ri	1, 2	15
169	Onagraceae	*Ludwigia adscendens* (L.) H. Hara	Lc	N	D	1	Cr	He	A	Me	1, 2	297
170	Onagraceae	*Ludwigia hyssopifolia* (G. Don) Exell**	LC	E	D	1	Ch	He	P	Me	2	32
171	Orchidaceae	*Apostasia wallichii* R.Br.		N	M	1	He	He	P			M151
172	Orchidaceae	*Bulbophyllum affine* Wall. ex Lindl.		N	M	1	Ph	He	P			147 M
173	Orchidaceae	*Bulbophyllum careyanum* (Hook.) Spreng.		N	M	1	Ph	He	P			302

174	Orchidaceae	*Rhynchostylis retusa* (L.) Blume		N	M	1	Ph	He	P	Me	1, 2	303
175	Orchidaceae	*Zeuxine strateumatica* (L.) Schltr.	LC	N	M	1	Cr	He	P			211Maidi
176	Orobanchaceae	*Lindenbergia indica* Vatke	LC	N	D	1	He	He	p	Me	1, 2	25
177	Oxalidaceae	*Oxalis latifolia* Kunth**		E	D	1	Th	He	A			K134
178	Oxalidaceae	*Oxalis corniculata* L**		E	D	1	Th	He	A	Fd, Me	1, 2, 4, 6, 8, 12	303
179	Pentaphyllaceae	*Eurya cerasifolia* (D. Don) Kobuski**		N	D	1	Ph	Tr	P	Fd	1	R63
180	Phyllanthaceae	*Phyllanthus emblica* L.	LC	N	D	1	Ph	Tr	P	Me		B31
181	Phyllanthaceae	*Phyllanthus urinaria* L**		N	D	1	He	He	P	Me	2, 12	304
182	Phyllanthaceae	*Phyllanthus virgatus* G. Forst		N	D	1	He	Sh	P			312
183	Plantaginaceae	*Limnophila chinensis* (Osbeck) Merr.	LC	N	D	1	Th	He	A			61
184	Plantaginaceae	*Limnophila sessiliflora* (Vahl) Blume**	LC	N	D	1	Th	He	A			P124
185	Poaceae	*Brachiaria villosa* (Lam.) A. Camus**		N	M	1	Cr	He	P			P123
186	Poaceae	*Cenchrus purpureus* (Schumach.) Morrone**	LC	E	M	1	Cr	He	P			96
187	Poaceae	*Cymbopogon pendulus* (Nees ex Steud.) W. Watson**		N	M	1	Cr	He	P			314
188	Poaceae	*Digitaria ciliaris* (Retz.) Koeler**		N	M	1	Cr	He	P	Fo	1	325
189	Poaceae	*Drepanostachyum falcatum* (Nees) Keng. f.**		N	M	1	Ph	Sh	P	Fr	1	P106
190	Poaceae	*Eleusine indica* (L.) Gaertn.**	LC	N	M	1	Th	He	A	Me	2, 12	323
191	Poaceae	*Eragrostis atrovirens* (Desf.) Trin. ex Steud.	LC	N	M	1	Th	He	A			327
192	Poaceae	*Eragrostis tenella* (L.) P. Beauv. ex Roem. & Schult.		N	M	1	Th	He	A	Fr	1, 12	G120
193	Poaceae	*Eragrostis unioloides* (Retz.) Nees ex Steud.	LC	N	M	1	Th	He	A	Fr	1	G121
194	Poaceae	*Eragrostis viscosa* (Retz.) Trin**		N	M	1	Th	He	A	Fr	1	B104
195	Poaceae	*Imperata cylindrica* (L.) P. Beauv.**		E	M	1	Cr	He	P	Me	1, 2, 12	D 153
196	Poaceae	*Leersia hexandra* Sw**	LC	E	M	GRIIS	Cr	He	P	Me, Fr	1, 2, 4, 14	330
197	Poaceae	*Microstegium fasciculatum* (L.) Henrard		N	M	1	Th	He	A	Fo	1	8
198	Poaceae	*Oryza rufipogon* Griff.**	LC	N	M	1	Cr	He	A			26
199	Poaceae	*Panicum miliaceum* L**		N	M	1	Th	He	A	Fr	1	57
200	Poaceae	*Paspalum dilatatum* Poir.**		E	M	1	Cr	He	P	Fr	9	45
201	Poaceae	*Paspalum scrobiculatum* L.**	LC	N	M	1	Th	He	A	Fr, Me	1, 2, 9	P103
202	Poaceae	*Pogonatherum paniceum* (Lam.) Hack**	LC	N	M	1	He	He	P	Fr	1	P216
203	Poaceae	Saccharum spontaneum L**	LC	N	M	1	Ch	He	P	Fr, Me	1	N133

204	Poaceae	*Sacciolepis indica* (L.) Chase	LC	N	M	1	Th	He	A	Fr	1	97
205	Poaceae	*Setaria pumila* (Poir.) Roem. & Schult**		N	M	1	Cr	He	P	Fr	1, 12, 15	K 113
206	Poaceae	*Sporobolus fertilis* (Steud.) Clayton		N	M	1	Cr	He	P			23
207	Poaceae	*Themeda triandra* Forssk**		N	M	1	Cr	He	P			N220
208	Poaceae	*Thysanolaena latifolia* (Roxb. ex Hornem.) Honda**		N	M	1	He	Sh	P	Me, Fo, Fi	2; 1	D76
209	Poaceae	*Arthraxon hispidus* (Thunb.) Makino		N	M	1	Cr	He	P			48
210	Poceae	*Cynodon dactylon* (L.)Pers**		N	M	1	He	He	P	Me	1,2	P83
211	Polygalaceae	*Salomonia cantoniensis* Lour.**		N	D	1	Th	He	A	Me	1, 2	346
212	Polygonaceae	*Koenigia polystachya* (Wall. Ex Meisn) T.M. Schust & Rev.**		N	D	1	He	He	A			95
213	Polygonaceae	*Persicaria barbata* (L.) H. Hara	LC	N	D	1	Th	He	P	Fd, Me, Fp	1, 4, 6, 9	21
214	Polygonaceae	*Persicaria capitata* (Buch.-Ham. ex D. Don) H. Gross**		N	D	1	Cr	He	P	Me, Fo	1, 2	216
215	Polygonaceae	*Persicaria hydropiper* (L.) Spach**	LC	N	D	1	Th	He	A	Me, Fp	1, 2, 4, 9, 14, 15	57
216	Polygonaceae	*Persicaria lapathifolia* (L.) Delarbre	LC	N	D	1	Th	He	A			21
217	Polygonaceae	*Persicaria perfoliata* (L.) H. Gross**		N	D	1	Th	He	A	Fd, Me, Fr	1, 2	72
218	Polygonaceae	*Persicaria posumbu* (Buch.-Ham. ex D. Don) H. Gross		N	D	1	Th	He	A			M112
219	Polygonaceae	*Polygonum plebeium* R.Br.		N	D	1	Th	He	A	Fd, Me	1, 2	31
220	Polygonaceae	*Koenigia campanulata* (Hook. fil.) T.M. Schust. & Reveal**		N	D	1	He	He	P	Fd	1, 2	95
221	Polygonaceae	Persicaria pubescens (Blume) Hara**		N	D	1	Th	He	P			P231
222	Pontederiaceae	*Pontederia hastata* L.**		N	M	1	Cr	He	P	Fd, Me	1, 2, 14	122
223	Pontederiaceae	*Pontederia crassipes Mart.***		E	M	1	Cr	He	P	Fd, Gm	4, 9	31
224	Potamogetonaceae	*Potamogeton crispus* L.		N	M	1	Cr	He	P			355
225	Primulaceae	*Maesa chisia* D. Don**		N	D	1	Ch	Sh	P	Me, Fd, Fi	1	M83
226	Primulaceae	*Maesa macrophylla* Wall. ex Roxb.		N	D	1	Ph	Sh	P	Me	1, 2	R162
227	Primulaceae	*Myrsine seguinii* H. Lev*+*		N	D	1	Ph	Tr	P	Fd, Fr	1	R126
228	Ranunculaceae	*Ranunculus sceleratus* L.	LC	N	D		Cr	He	A	Fd, Me	1, 2, 4, 6, 9	28
229	Rosaceae	*Pyracantha crenulata* (D. Don) M. Roem**		N	D	1	Ch	Sh	P	Me; Fo	1,2;1	R64
230	Rosaceae	*Rubus ellipticus* Sm.**	LC	N	D	1	Ch	Sh	P	Fd, Me, Fo	1, 2	366
231	Rosaceae	*Rubus kumaonensis* Balakr.**		N	D	1	Ch	Sh	P			M119

232	Rosaceae	*Potentilla indica* (Andr.) Wolf		N	D	1	He	He	P	Fd, Me	1, 2	M120
233	Rubiaceae	*Dimetia scandens* (Roxb.) R.J. Wang**		N	D	1	He	He	P	Me, Fo	1, 2	B25
234	Rubiaceae	*Exallage auricularia* (L.) Bremek.		N	D	1	He	He	P			G231
235	Rubiaceae	*Knoxia sumatrensis* (Retz.) DC		N	D	1	He	He	P			367
236	Rubiaceae	*Mussaenda frondosa* L.**		N	D	1	Ch	Sh	P	Me	1	M84
237	Rubiaceae	*Oldenlandia corymbosa* L.	LC	N	D	1	Th	He	A			109
238	Rubiaceae	*Scleromitrion verticillatum* (L.) R.J. Wang**		N	D	1	He	He	P			206
239	Rubiaceae	*Spermacoce alata* Aubl.**		E	D	1	He	He	P	Me	10	40
240	Rubiaceae	*Galium aparine* L.**		N	D	1	Th	He	A	Me	1, 2	130
241	Simaroubaceae	Brucea javanica Merr.**	LC	N	D	1	Ph	Tr	P			B36
242	Smilacaceae	*Smilax aspera* L**		N	M	1	Ch	Sh	P	Me, Fd	1	G556
243	Solanaceae	*Solanum nigrum* L.**		N	D	1	He	He	P	Fd, Me	1, 2, 13	29
244	Solanaceae	*Solanum torvum* Sw.**		E	D	1	Ch	Sh	P	Fd, Me	1, 2	57
245	Solanaceae	*Solanum virginianum* L.**		N	D	1	He	Sh	P	Me	1	K81
246	Solanaceae	*Datura metel* L.		E	D	1	Ph	Sh	P	Me	1, 2	D227
247	Theaceae	*Schima wallichii* (DC.) Korth.**	LC	N	D	1	Ph	Tr	P	Me, Cn	1, 2, 5	M200
248	Trapaceae	*Trapa natans* L.**	LC	N	D	1	Cr	He	P	Me	2	385
249	Urticaceae	*Gonostegia hirta* (Blume ex Hassk.) Miq.**		N	D	1	He	He	P	Fd, Me, Sa	1, 2, 7	386
250	Urticaceae	*Pilea scripta* (Buch.-Ham. ex D. Don) Wedd.**		N	D	1	He	He	P			41
251	Urticaceae	*Pouzolzia zeylanica* (L.) Benn. & R.Br.**		N	D	1	He	He	P	Fd, Me	1, 2	105
252	Urticaceae	*Boehmeria virgata* (G.Forst.) Guill.**	LC	E	D	1	Ch	He	P	Me, Fi	1, 2	14
253	Verbenaceae	*Lantana camara* L.**		E	D	1	Ph	Sh	P	Fd, Me, He	1, 13	R120
254	Viktaceae	*Ampelocissus sikkimensis* (M.A. Lawson) Planch**		N	D	1	Ph	Sh	P	Fd	1,11	R211
255	Vitaceae	*Cissus javana* DC**		N	D	1	Ph	He	P	Me, Fr	1, 2	R127
256	Vitaceae	*Leea asiatica* (L.) Ridsdale**		N	D	1	Ch	He	P	Fr	4	R136
257	Vitaceae	*Vitis heyneana* Roem. & Schult**		N	D	1	Ph	Sh	P	Me, Fd	1	D33
258	Zingiberaceae	*Hedychium ellipticum* Buch. Ham. ex Sm.		N	M	1	He	He	P			397

**Plants enumerated in sampling plots and rest of others from study on floral diversity.

Abbreviations: N/E-Native alien; RC-Raunkiaeer's classification, i.e., Ph-Phanerophyte, Ch-Chamaephyte, Cr-Cryptophyte, He-Hemicryptophyte, Th-Therophyte; H/S/T-Herb, shrub or tree; A/P-Annual/Perennial. Native range reference (NRR): 1 (POWO, www.plantsoftheworldonline.org/), 2 (Weeds of Australia, www.weeds.org.au), 3 (www.eflora.org), 4 (GRIIS, www.griis.org); Red-list categories are *LC* (Least concerned); D/M-Dicots & Monocots; IUCN categ-IUCN threatened categories

Appendix 9: Transect-wise nutrients, coverage, and richness of native and naturalized species

SN	Plots	Wetland	Phosphorus	Nitrogen	Coverage of aliens	Richness of aliens	Coverage of natives	Richness of Natives
1	Transect 1	Phewa	0.26	0.04	16.5	3	8	5
2	Transect 2	Phewa	0.23	0.04	46.5	11	16.5	11
3	Transect 3	Phewa	0.40	0.04	46.5	8	62.5	12
4	Transect 4	Phewa	0.25	0.04	27	4	14.5	5
5	Transect 5	Phewa	0.49	0.04	6.5	3	10.5	8
6	Transect 6	Phewa	0.55	0.04	23.5	9	38.7	16
7	Transect 7	Phewa	0.27	0.04	21.5	8	19	14
8	Transect 8	Phewa	0.31	0.04	27	6	33.3	21
9	Transect 9	Phewa	0.31	0.04	6.5	4	9.2	6
10	Transect 10	Phewa	0.85	0.04	6.5	5	38.5	11
11	Transect 11	Phewa	0.46	0.04	4.5	7	26.4	9
12	Transect 12	Phewa	0.54	0.05	6.5	3	15.5	11
13	Transect 13	Phewa	0.21	0.05	6.5	4	27.5	13
14	Transect 14	Phewa	0.35	0.05	1	1	17.1	9
15	Transect 15	Phewa	0.50	0.04	3	2	14	11
16	Transect 16	Phewa	0.21	0.04	13.5	3	23	12
17	Transect 17	Phewa	0.41	0.04	10.5	3	27	13
18	Transect 18	Phewa	0.32	0.05	3.5	5	22	18
19	Transect 19	Phewa	0.40	0.04	3.5	3	16.5	21
20	Transect 20	Phewa	0.21	0.04	1.5	3	29	23
21	Transect 21	Phewa	0.39	0.04	0.5	1	58.5	15
22	Transect 22	Phewa	0.38	0.05	1	1	25	16
23	Transect 23	Phewa	0.44	0.04	0	0	61.7	8
24	Transect 1	Rupa	0.30	0.04	2.5	3	21.5	12
25	Transect 2	Rupa	0.45	0.04	5.5	3	16	8
26	Transect 3	Rupa	0.33	0.04	8	5	26.4	16
27	Transect 4	Rupa	0.39	0.04	4.5	2	75.6	17
28	ransect 5	Rupa	0.25	0.04	12	3	51.5	26
29	Transect 6	Rupa	0.33	0.04	8.5	3	59.5	19
30	Transect 7	Rupa	0.12	0.04	17	5	61.5	23

31	Transect 8	Rupa	0.20	0.05	19	6	15.5	10
32	Transect 9	Rupa	0.76	0.04	19.5	1	46.5	7
33	Transect 10	Rupa	0.35	0.04	15	6	39	20
34	Transect 11	Rupa	0.35	0.04	13	3	32.5	22
35	Transect 12	Rupa	0.34	0.04	2.5	3	16.5	18
36	Transect 1	Begnas	0.53	0.05	3.5	2	8	7
37	Transect 2	Begnas	0.44	0.05	4	3	9	6
38	Transerct 3	Begnas	0.32	0.04	4	2	12	11
39	Transect 4	Begnas	0.19	0.05	3	2	13	11
40	Transect 5	Begnas	0.48	0.04	8.5	3	18	14
41	Transect 6	Begnas	0.12	0.04	5	6	18.5	13
42	Transect 7	Begnas	0.73	0.04	7.5	4	21	14
43	Transect 8	Begnas	0.48	0.04	1.5	2	19	9
44	Transect 9	Begnas	0.32	0.04	10.5	2	19.5	13
45	Transect 10	Begnas	0.72	0.04	26.5	2	13	8
46	Transect 11	Begnas	0.41	0.05	2	2	12.5	7
47	Transect 12	Begnas	0.42	0.04	2.5	4	27.5	13
48	Transect 13	Begnas	0.22	0.04	3	1	16.95	11
49	Transect 14	Begnas	0.32	0.04	1.5	2	18	13
50	Transect 15	Begnas	0.42	0.04	2	2	22	12
51	Transect 16	Begnas	0.30	0.04	2	3	19.5	9
52	Transect 17	Begnas	0.50	0.05	9	2	15	10
53	Transect 18	Begnas	0.29	0.05	7	1	13.5	10
54	Transect 19	Begnas	0.34	0.04	0	0	10	5
55	Transect 20	Begnas	0.27	0.04	2	3	16	14
56	Transect 21	Begnas	0.40	0.04	1	1	14	12
57	Transect 1	Khaste	0.16	0.06	3.5	3	26	13
58	Transect 2	Khaste	0.15	0.04	2.5	1	33	16
59	Transect 3	Khaste	0.18	0.04	9.5	3	18	14
60	Transect 4	Khaste	0.34	0.04	1	2	44.5	14
61	Transect 5	Khaste	0.21	0.04	3.5	2	25.5	17
62	Transect 6	Khaste	0.56	0.05	6	4	30	20
63	Transect 1	Gunde	0.12	0.04	1	2	31	19

64	Transect 2	Gunde	0.29	0.04	3.5	4	38	17
65	Transect 3	Gunde	0.27	0.04	11.4	4	21.9	18
66	Transect 4	Gunde	0.15	0.04	3.2	2	14.5	12
67	Transect 5	Gunde	0.29	0.05	3.5	2	18.5	14
68	Transect 6	Gunde	0.15	0.04	11	6	17	12
69	Transect 1	K Pokhari	0.19	0.10	16.5	10	52.5	25
70	Transect 2	K Pokhari	0.62	0.04	7.5	6	58.5	23
71	Transect 1	Deepang	0.27	0.05	8.7	6	29.2	15
72	Transect 2	Deepang	0.41	0.04	0	0	42.5	14
73	Transect 3	Deepang	0.20	0.05	14.5	4	23.5	18
74	Transect 4	Deepang	0.22	0.04	6.5	4	9.5	9
75	Transect 5	Deepang	0.26	0.05	4	3	49	10
76	Transect 6	Deepang	0.37	0.05	1.5	2	54.5	13
77	Transect 7	Deepang	0.76	0.05	5	3	9.5	9
78	Transect 1	Niureni	0.31	0.04	0	0	20.9	11
79	Transect 2	Niureni	0.41	0.04	21.5	5	27.1	16
80	Transect 3	Niureni	0.16	0.05	6	5	20.5	17
81	Transect 1	Maidi	0.17	0.04	2.5	2	54	18
82	Transect 2	Maidi	0.44	0.04	1.5	2	67.5	17
83	Transect 3	Maidi	0.12	0.05	12.5	3	40.5	20
84	Transect 4	Maidi	0.78	0.05	14	3	9.5	5
85	Transect 5	Maidi	0.31	0.05	24.5	4	37.3	13
86	Transect 6	Maidi	0.27	0.05	12	2	29	18
87	Transect 7	Maidi	0.18	0.05	24	6	19	13
88	Transect 8	Maidi	0.21	0.04	18	6	26	17
89	Transect 9	Maidi	0.27	0.05	3	2	22.5	9

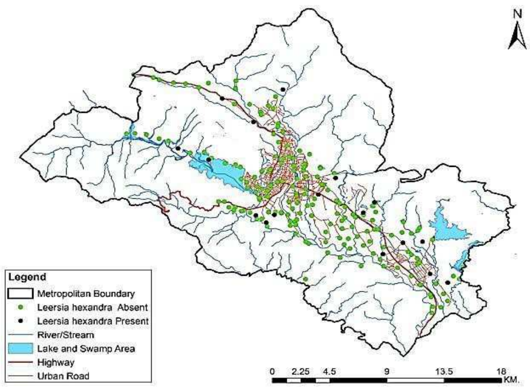
Appendix 10 : Native and naturalized plant species' CCA summary

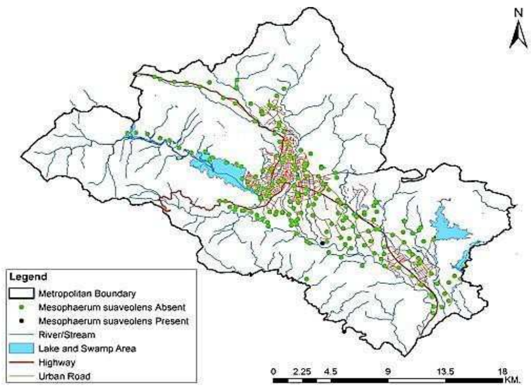
SN	CCA scores for native species			SN	CCA scores for naturalized species		
	Names	**CCA1**	**CCA2**		**Names**	**CCA1**	**CCA2**
1	Just.adha	**-0.66**	0.11	1	Alte.phil	0.14	**2.14**
2	Rost.proc	**0.46**	-0.43	2	Alte.sess	0.27	**0.29**
3	Achy.aspe	**-0.59**	-0.11	3	Amar.spin	**0.54**	0.42
4	Cent.asia	0.13	**-0.64**	4	Pist.stra	**-0.22**	-0.17
5	Colo.fall	**1.17**	0.00	5	Ager.aden	**-1.29**	-0.23
6	Acme.pani	-0.45	**-0.70**	6	Ager.cony	**0.97**	-0.66
7	Arte.indi	**1.51**	0.63	7	Ager.hous	**-1.12**	-1.03
8	Duha.capp	**1.45**	0.59	8	Bide.pilo	**0.27**	-0.19
9	Emil.sonc	0.57	**-0.75**	9	Chro.odor	**-1.05**	0.05
10	Elep.scab	0.03	**-1.98**	10	Erig.cana	**0.47**	0.38
11	Impa.race	**1.34**	0.50	11	Gall.quad	-0.16	**-0.98**
12	Orox.indi	-0.21	**-0.50**	12	Sonc.oler	**-1.41**	0.32
13	Cyno.zeyl	-0.33	**0.51**	13	Xant.stru	0.01	**2.38**
14	Flos.scan	**-0.34**	0.03	14	Ipom.purp	0.11	**0.77**
15	Murd.nudi	**-0.83**	0.43	15	Ipom.carn	**-1.37**	0.12
16	Argy.hook	-0.19	**-0.29**	16	Euph.hirt	0.28	**2.43**
17	Hell.spec	**0.82**	-0.67	17	Mimo.pudi	**-1.22**	-0.57
18	Sole.hete	**-0.68**	0.03	18	Senn.occi	0.45	**1.12**
19	Cype.brev	**0.95**	0.63	19	Senn.tora	**0.42**	0.28
20	Cype.iria	0.25	**-0.78**	20	Meso.suav	0.02	**-0.25**
21	Cype.rotu	**0.46**	0.29	21	Sida.cord	**0.36**	0.25
22	Fimb.dich	**1.57**	0.68	22	Ludw.hyss	0.96	**-2.10**
23	Fimb.ovat	**1.36**	0.52	23	Oxal.corn	**-1.08**	-0.12
24	Fimb.scho	-0.37	**-1.09**	24	Oxal.lati	**-0.21**	-0.11
25	Dios.bulb	0.76	**-0.86**	25	Cenc.purp	**0.43**	0.22
26	Dios.delt	**-0.81**	0.23	26	Leer.hexa	**-1.12**	0.02
27	Dios.pube	-0.34	-0.34	27	Pasp.dist	**0.43**	-0.34
28	Shor.robu	0.33	**-1.75**	28	Pont.cras	**-1.28**	-0.29
29	Dios.mala	**1.35**	0.51	29	Sper.alat	**0.75**	-0.14
30	Falc.insi	**1.11**	0.06	30	Lant.cama	**-1.00**	-0.07
31	Eury.sera	-0.15	**0.92**				
32	Aesc.indi	0.64	**0.67**				
33	Bauh.purp	-0.46	**0.85**				
34	Crot.pall	0.34	**-1.74**				
35	Crot.sess	**-0.98**	0.54				
36	Desm.hete	**-0.36**	0.08				
37	Indi.atro	**-0.56**	-0.16				
38	Sunh.eleg	**-0.84**	0.43				

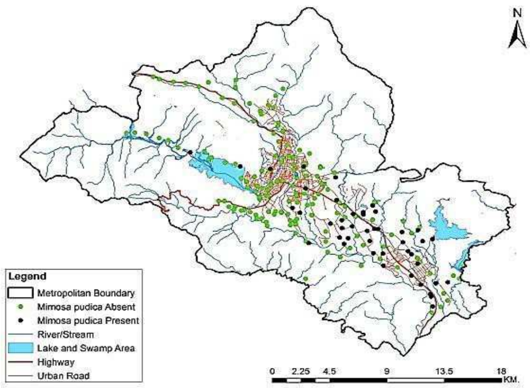
39	Cast.indi	**-0.89**	0.33
40	Quer.lana	**-0.56**	0.24
41	Hydr.vert	**0.79**	-0.38
42	Enge.spic	**-0.48**	0.05
43	Junc.pris	0.35	**-0.39**
44	Cole.oppo	0.07	**-0.39**
45	Ment.arve	**-0.85**	0.65
46	Ocim.grat	**-0.64**	-0.46
47	Pogo.auri	0.35	**0.40**
48	Dode.gran	**1.62**	0.71
49	Lits.mono	-0.11	**-1.34**
50	Rein.indi	**-0.78**	0.77
51	Bonn.cili	-0.53	**0.71**
52	Lind.hyss	**1.52**	0.64
53	Trap.nata	**-1.00**	0.63
54	Wood.frut	0.31	**-1.76**
55	Abel.mani	-0.45	**-1.15**
56	Uren.loba	**-0.83**	0.12
57	Osbe.stel	0.63	**-1.07**
58	Toon.hexa	**-0.48**	0.36
59	Ciss.pare	**-0.66**	0.00
60	Ficu.auri	**1.12**	0.29
61	Ficu.beng	0.34	**-1.60**
62	Ficu.benj	**1.40**	0.55
63	Ficu.race	0.06	**-0.94**
64	Ficu.reli	**0.59**	0.44
65	Ficu.sarm	**1.48**	0.61
66	Ficu.semi	0.54	**-1.09**
67	More_.escu	0.32	**-0.57**
68	Myrs.segu	**-0.94**	0.43
69	Nelu.nuci	**0.45**	0.29
70	Nymp.nouc	**1.50**	0.62
71	Frax.flor	0.18	**-1.86**
72	Phyl.urin	-0.08	**0.32**
73	Limn.sess	**1.58**	0.68
74	Brac.vill	**1.44**	0.58
75	Cymb.pend	-0.15	**0.92**
76	Cyno.dact	**1.43**	0.68
77	Digi.cili	**1.77**	0.83
78	Drep.falc	**1.53**	0.64
79	Eleu.indi	**1.65**	0.71

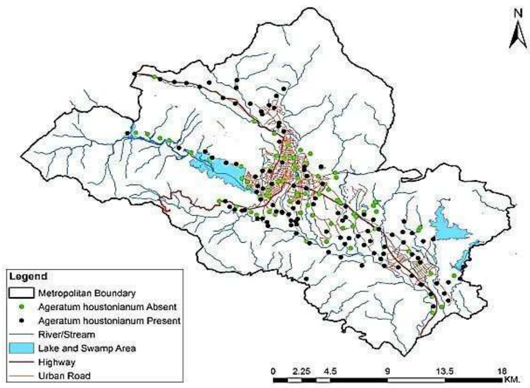
80	Erag.vico	0.29	**-1.78**
81	Impe.cyli	**-0.91**	0.63
82	Oryz.rufi	-0.41	**-1.12**
83	Pani.mili	**-0.50**	-0.32
84	Pasp.scro	**1.65**	0.74
85	Pogo.pani	**1.12**	0.68
86	Sacc.spon	-0.11	**0.25**
87	Seta.pumi	-0.46	**-1.16**
88	Them.tria	**1.22**	0.37
89	Thys.lati	**-0.74**	0.45
90	Salo.cant	-1.06	**1.10**
91	Koen.camp	-0.92	**1.20**
92	Koen.poly	0.15	**0.57**
93	Pers.capi	**1.44**	0.58
94	Pers.hydr	**1.38**	0.53
95	Pers.perf	**1.50**	0.62
96	Pers.pube	**0.25**	0.02
97	Pont.hast	-0.02	**-1.27**
98	Maes.chis	0.17	**-0.61**
99	Pyra.cren	**0.96**	0.41
100	Rubu.elli	**0.34**	-0.20
101	Rubu.kuma	**1.37**	0.52
102	Dime.scan	0.31	**-1.76**
103	Gall.apar	-0.26	**-0.87**
104	Muss.macr	-0.13	**-0.16**
105	Scle.vert	-0.78	**1.20**
106	Stro.atro	-0.61	**0.78**
107	Bruc.java	-0.05	**-0.25**
108	Smil.aspe	-0.05	**-0.80**
109	Sola.nigr	**1.51**	0.64
110	Sola.virg	**-0.36**	-0.25
111	Schi.wall	0.34	**-0.47**
112	Boeh.plat	**1.45**	0.58
113	Gono.hirt	-0.33	**-1.06**
114	Pile.scri	**0.04**	0.00
115	Pouz.zeyl	-0.10	**0.34**
116	Ampe.sikk	-0.21	**-0.24**
117	Ciss.disc	-0.25	**-0.80**
118	Leea.asia	**-0.72**	-0.10
119	Viti.heyn	**0.61**	-0.42

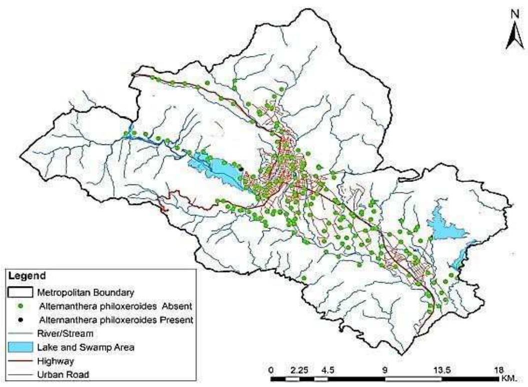
Appendix 11 : Spatial distribution maps of IAPS fromPokhara Valley, Nepal

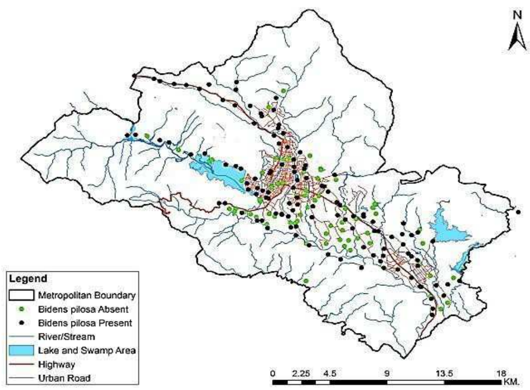


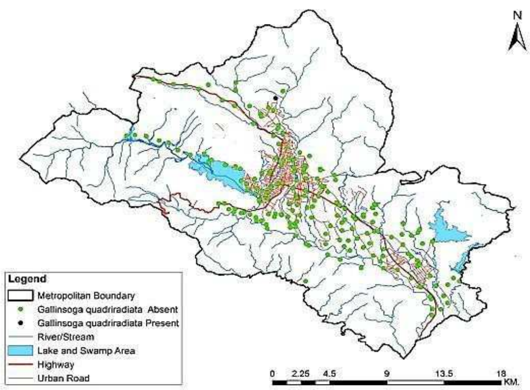


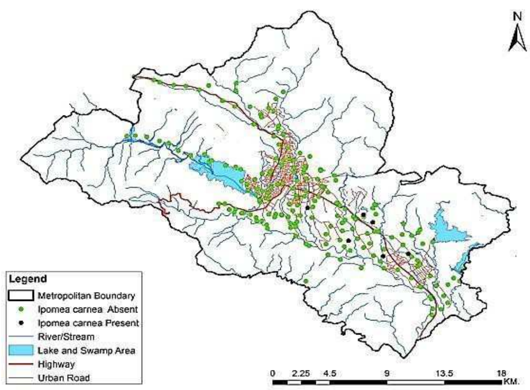


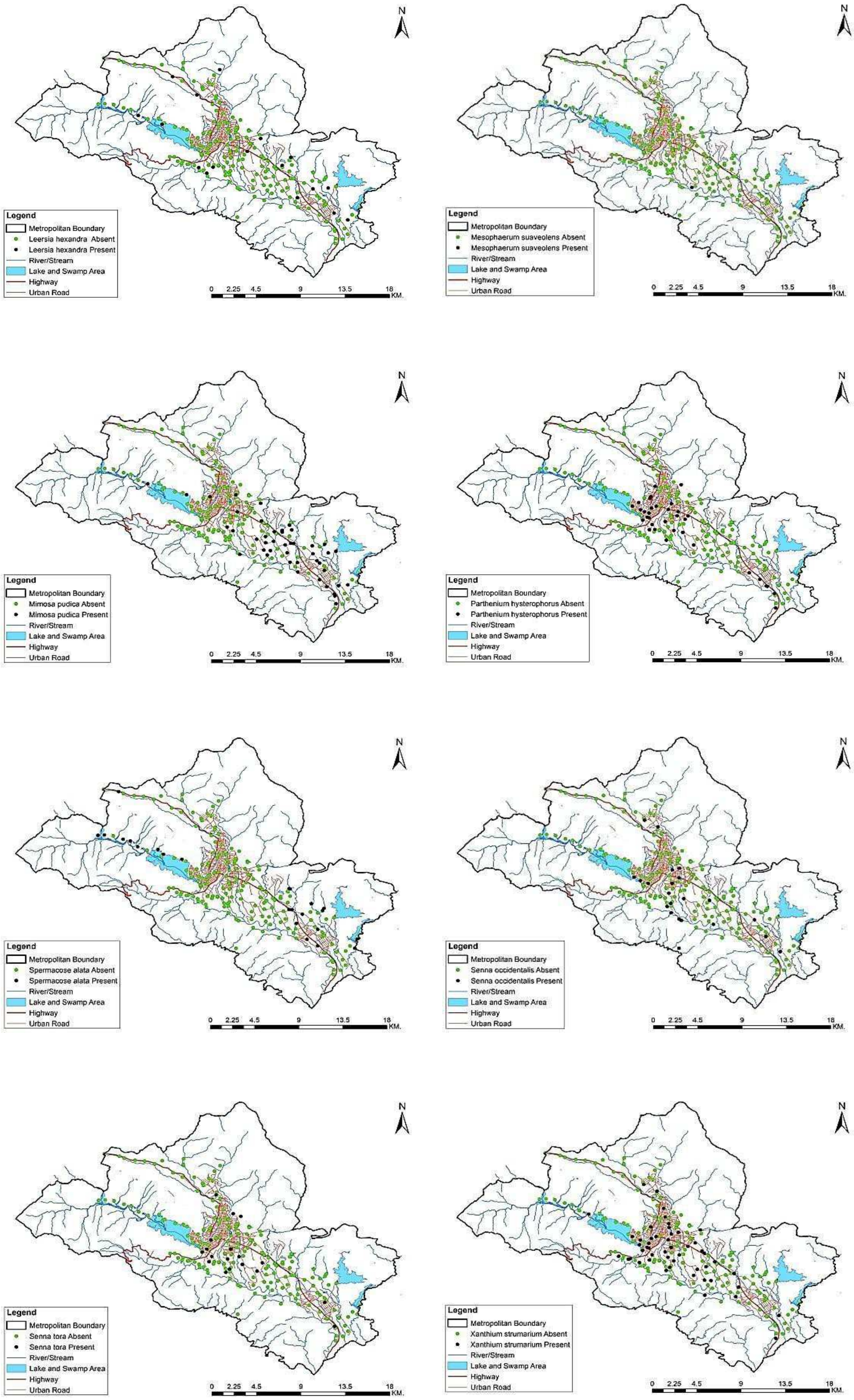











N
Legend
Metropolitan Boundary
Leersia hexandra Absent
Leersia hexandra Present
River/Stream
Lake and Swamp Area
Highway
Urban Road
0 2.25 4.5 9 13.5 18 KM.
N
Legend
Metropolitan Boundary
Mesophaerum suaveolens Absent
Mesophaerum suaveolens Present
River/Stream
Lake and Swamp Area
Highway
Urban Road
0 2.25 4.5 9 13.5 18 KM.
N
Legend
Metropolitan Boundary
Mimosa pudica Absent
Mimosa pudica Present
River/Stream
Lake and Swamp Area
Highway
Urban Road
0 2.25 4.5 9 13.5 18 KM.
N
Legend
Metropolitan Boundary
Parthenium hysterophorus Absent
Parthenium hysterophorus Present
River/Stream
Lake and Swamp Area
Highway
Urban Road
0 2.25 4.5 9 13.5 18 KM.
N
Legend
Metropolitan Boundary
Spermacose alata Absent
Spermacose alata Present
River/Stream
Lake and Swamp Area
Highway
Urban Road
0 2.25 4.5 9 13.5 18 KM.
N
Legend
Metropolitan Boundary
Senna occidentalis Absent
Senna occidentalis Present
River/Stream
Lake and Swamp Area
Highway
Urban Road
0 2.25 4.5 9 13.5 18 KM.
N
Legend
Metropolitan Boundary
Senna tora Absent
Senna tora Present
River/Stream
Lake and Swamp Area
Highway
Urban Road
0 2.25 4.5 9 13.5 18 KM.
N
Legend
Metropolitan Boundary
Xanthium strumarium Absent
Xanthium strumarium Present
River/Stream
Lake and Swamp Area
Highway
Urban Road
0 2.25 4.5 9 13.5 18 KM.

Appendix 12: List of publications

a. Pathak, H. N., Shrestha, B. B., Bhuju, D. R., & Subedi, D. S. (2021). Spatial distribution of invasive alien plants in Pokhara valley, Nepal. *Pak. J. Bot*, 53(3): 1015-1024. DOI: http://dx.doi.org/10.30848/PJB2021-3(2).

b. Pathak, H. N., Bhuju, D. R., Shrestha, B. B., & Ranjitkar, S. (2021). Impacts of invasive alien plants on ecosystem services of Ramsar lake cluster in middle mountain Nepal. *Global Ecology and Conservation*, 27, e01597. DOI: https://doi.org/10.1016/j.gecco.2021.e01597

c. Pathak, H. N., Shrestha, B. B., Bhuju, D. R., & Bhandari, P. (2020). Floristic Diversity in the Lake Cluster of Pokhara Valley, Central Nepal. *Journal of Natural History Museum*, 31(1):1-32. DOI: https://doi.org/10.3126/jnhm.v31i1.39371

Appendix 13: List of articles under preparation.

- Pathak, H.N., Bhuju, D.R. & Shrestha, B.B. *Invasion History of a few Problematic Invasive Alien Plants from Pokhara Valley*.

- Pathak, H.N., Baniya, C.B., Bhuju, D.R. & Shrestha, B.B. *Diversity of Naturalized Plant Species in Lake Cluster of Pokhara Valley, Central Nepal*.

Appendix 14: Conference participation (oral presentation)

1. Pathak, H.N., Bhuju, D.R. & Shrestha, B.B. (2020). Impacts of invasive alien plant species on ecosystem services in the Tenth Ramsar Site (Lake Cluster of Pokhara Valley), Nepal. National Conference on Integrating Biological Resources for Prosperity held at Biratnagar, February 6-7, 2020.

2. Pathak, H.N., Bhuju, D.R. & Shrestha, B.B. (2019). Spatial distribution of invasive alien plant species in lake cluster of Pokhara valley, central Nepal. Fourth International Conference on ‘Mountain in the Changing World’ (MochWo) held at Kathmandu, October 18-19, 2019.

3. Pathak, H.N., Shrestha, B.B., Bhuju, D.R. & Bhandari, P. (2021). Floristic diversity in Lake Cluster of Pokhara valley. Himalayan Knowledge Conclave, Seventh Graduate Conference on Environment and Sustainable Development held at Kathmandu, May 24-25, 2021.

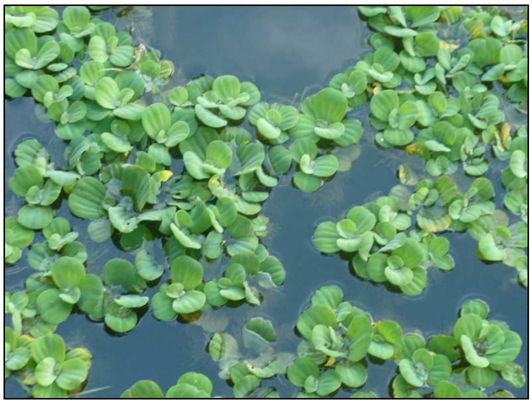
4. Pathak, H.N., Shrestha, B.B., Bhuju, D.R. & Baniya, C.B. (2022). Diversity of naturalized plant species in Lake Cluster of Pokhara Valley, Nepal. International Conference on Biodiversity and Bio-prospecting held at Kathmandu, June 22-24th, 2022.

PHOTO PLATES

FGD with Begnas Farmers

HH Survey with Rupa farmer

Mikania micrantha at Bachhe dubuwa



Pistia invasion in Kamalpokhari

Vegetation Survey by Rupa lakeshore

Water hycinth in Phewa during 2020

Taking readings from spectrophotometer

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Impacts of invasive alien plants on ecosystem services of Ramsar lake cluster in middle mountain Nepal

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Southern cut grass

A B S T R A C T

Biological invasions have significant impacts on ecosystems, the services provided by ecosystems, and associated economies. In wetlands, invasion by alien plants can impact the ecosystem services that are fundamental to human well-being. We conducted a stakeholder analysis in Ramsar sites in the Pokhara Valley to understand ecosystem services, the economic valuation of provisioning services, invasive alien plants, and their impacts. We collected information from locals living near the Ramsar site using focus group discussions, key informant interviews, and household (HH) surveys. We identified five invasive alien plants in the Ramsar sites in Pokhara Valley. A total of 18 ecosystem services were recorded from discussions with residents living near the Ramsar sites. Our study found that the economic benefits generated from the provisioning service, calculated based on the market price in the year of data collection, were worth a total of International$ 9.05 million. The value of provisioning services was International$ 0.1 million HH^{-1} $year^{-1}$. Our estimate showed that the value of provisioning services before the occurrence of invasive alien plants in 1989 was International$ 0.19 million HH^{-1} $year^{-1}$ higher than in 2019. Those who benefit from the Lake clusters mentioned that the invasive alien plants led to a decrease in economically important plants such as medicine and fruits and decreased fish production. Other impacts have included: reduced natural beauty, loss of biodiversity, and obstruction of recreational boating, which has discouraged tourism in recent years, among other impacts. Our results show that the rampant spread of invasive alien plants has a severe impact on ecosystem services. The impact on the associated economic value is alarming. There is an urgent need for proper management of wetlands. The findings from our results can help make decision-makers aware of the need to act in order to restore and maintain the services provided by the wetlands.

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1. Introduction

In the Anthropocene era, global change is accelerating with increasing human activities that alter biodiversity and ecosystem functioning. Invasion of ecosystems by alien species is an essential drivers of ecosystem functioning and affects biodiversity (Charles and Dukes, 2008; Keller et al., 2011; Linders et al., 2019). Globalization of trade and travel has facilitated the spread of invasive alien plants (IAPs) across continents. Habitat invasion has become a global phenomenon with severe impacts on ecological, economic, and social systems (Dogra et al., 2010; Dutta, 2018). IAPs reduce local plant population and diversity, alter ecosystem productivity and nutrient cycling. Hence, they affect ecosystem services and human well-being (Charles and Dukes, 2008, Keller et al., 2011; Rai and Singh, 2020).

Human well-being has been placed as a core element in Millennium Ecosystem Assessment (MEA, 2005). Therefore, considering human well-being has become necessary in policy development at Ecosystem Services (Akinsete et al., 2019). Ecosystem services are the benefits to humans provided by the ecosystem (MEA, 2005; Steinman et al., 2017). Ecosystem services bridge ecological and economic aspects with human well-being and life support systems (Costanza et al., 1997; Akinsete et al., 2019), conservation and development, and private and public policy (Braat and dr Groot, 2012). The economic valuation of ecosystem services, typically described as (1) provisioning, (2) cultural, (3) regulating, and (4) supporting (MEA, 2005), includes several components. These several components are categorized within a total economic value framework and then assigned a monetary value (Costanza et al., 1997). The monetary values can be obtained from market prices or non-market valuations (Grainger and Stoeckl, 2019). Many studies have included the ecological and financial impacts of invasive alien species. However, less attention has been paid to the impacts of IAPs on human livelihoods (Keller et al., 2018). Predictably, the impacts of IAPs can be considerable because they can reduce the supply of ecosystem services that are important to humans (Aloo et al., 2013; Keller et al., 2018). This loss of ecosystem services is likely to cause the most severe impacts on human well-being in cases where local economics are closely linked to the harvest of biological resources, and/or where subsistence agriculture is practiced.

IAPs pose a particularly-severe threat to wetlands, an essential ecosystem that accounts for 40.6% of global ecosystem services (Ramsar Convention on Wetlands, 2018), growing rapidly and soon covering the entire water surface. They reduce light penetration below the water surface, affecting aquatic plants and animals, and consume oxygen (Mailu, 2001; Téllez et al., 2008). IAPs alter wetland habitat, species number, and quality, and alter nutrient cycling. The quantity and distribution of IAPs in freshwater are fundamental to many ecosystem services. Such species affect water through their physiology, morphology, behavior, and interactions with other species (Catford, 2017). IAPs affect water supply, drainage systems, inflows for hydropower, river water flow, reduced water access for people, increased disease vector, support mosquito larvae, increased microbial activities, and biochemical oxygen demand (Howard and Matindi, 2012). They can dominate native aquatic biota.

In Nepal, wetlands cover about 5% of the landmass with tremendous water storage capacity and support large numbers of migratory birds such as waterfowl (MoFE, 2018a). Wetlands in ten locations in Nepal are designated as Ramsar sites, which are of international importance. Of these, the Lake Cluster of Pokhara Valley (LCPV), comprising nine lakes, is the largest and is important both ecologically and to the local community. The LCPV hosts a range of biological species including several globally threatened (also 60 species listed in CITES I and II) birds, mammals, reptiles, fish, and flora (MoFE, 2018b). In addition, LCPV provides benefits to the local community through various resources and support for tourism (Thapa et al., 2020). However, wetlands in urban areas such as Pokhara with very high tourist traffic are subject to various anthropogenic disturbances. Many tourism-related activities can promote alien plant species. Although several studies on this lake cluster focused on limnology and lake characteristics (Bhuju et al., 2012) and although a recent review by Xu et al. (2020) reported five scientific publications on wetland ecosystem services from Nepal, very few studies address vulnerability due to invasive alien species and economic valuation of ecosystem services in a lake or lake cluster in Pokhara Valley (e.g., IUCN, 2004; MoFE, 2018b; Thapa et al., 2020). One of these studies by MoFE (2018b), categorized LCPV based on several factors that include invasive alien species (both animals and plants). One of these species, *Eichhornia crassipes,* is listed as a highly invasive and problematic alien plants in the LCPV (MoFE, 2018b). *E. crassipes* have threatened the natural beauty, ecosystem, and ecotourism business in Nepal (Mandal et al., 2017). Another inquiry into the damage caused by invasive alien species was undertaken by Thapa et al. (2020), who conducted a study on the overall ecosystem services of the Begnas watershed. However, researchers and policymakers rarely directly address the link between invasions and ecosystem services. Several attempts have been made worldwide to study the

Table 1
General information of the lake cluster in Pokhara Valley, Nepal.
Source: MoFE, 2018b.

SN	Lakes	Location (Ward)	Area (Sq. Km)	Max. Depth (m)	Elevation (masl)
1	Phewa	6	4.33	24	742
2	Begnas	31	3.13	10	650
3	Rupa	33	1.11	4.5	600
4	Khaste	26	0.13	2.0	723
5	Maidi	28	0.01	2.0	850
6	Dipang	27	0.14	2.5	726
7	Kamalpokhari	13	0.02	1.5	850
8	Gunde	26	0.08	0.5	766
9	Neureni	26	0.03	0.5	723

impacts of invasive alien species on ecosystem processes. However, there lack a linkages between these mechanisms and ecosystem services (Charles and Dukes, 2008), which is also true in the context of Nepal. This is the significant gap in data that we seek to remedy in this study—on invasive alien aquatic plants and their impacts on Ramsar sites' ecosystem services.

More specifically, a global survey of wetland ecosystem services conducted by Xu et al. (2020) concluded that there is a large gap in research on provisioning services. Existing research mainly focused on supporting and regulating services, but studies on provisioning and cultural services are lacking (Xu et al., 2020). There is a need to conduct a detailed study on ecosystem services value, especially provisioning services. They are directly linked to the residents' livelihoods around the wetlands and tourism, so it may be important to understand how IAPs could change the value of these services. To this end, a study was conducted to determine the status of ecosystem services and quantify their economic value, focusing on the provisioning and impact of IAPs on these services. The results are expected to support evidence-based policymaking and decisions for sustainable management of Ramsar sites, including conservation of native biodiversity and revitalization of livelihoods for residents.

2. Materials and methods

2.1. Study area

Located in central Nepal (27°55'−28°23' N; 83°48'−84°11' E), the Pokhara Valley has a sub-tropical climate with dry periods extending from mid-November to mid-February. Humid periods begin from mid-February to mid-November. March to October is uncomfortably humid, with peaks in June/July (Supplementary material Fig. S1). The mean annual temperature is 24 °C, with a maximum temperature of 36 °C in June/July and a minimum of 5 °C in January/February. Over 25 yr (1985–2010), the average rainfall was 473 mm in the pre-monsoon season, 3336 mm in the monsoon season, 171 mm in the post-monsoon season, and 82 mm in winter (DoM, 2016). The valley attracts millions of visitors annually, mainly because of the majestic views of the Annapurna Mountain Range and LCPV (Table 1). The LCPV includes Phewa, Begnas, Rupa, Dipang, Maidi, Khaste, Neureni, Gunde and Kamalpokhari lakes (Fig. 1). Among these, the major lakes with high tourism activities are Phewa, Begnas, Rupa, and Dipang. Pokhara metropolis encompasses 464.24 square kilometers, with a total population of 4,02,995 (CBS, 2011). Among these lakes, only Phewa Lake had a densely populated eastern shore. Otherwise, these lakes surrounding areas consist mostly of farmlands (48%), forest lands, and bushes (MoFE, 2018b). Most farmers live near the lakes in LCPV. While hoteliers, boaters, and fishermen are mostly living around larger lakes or tourist sites.

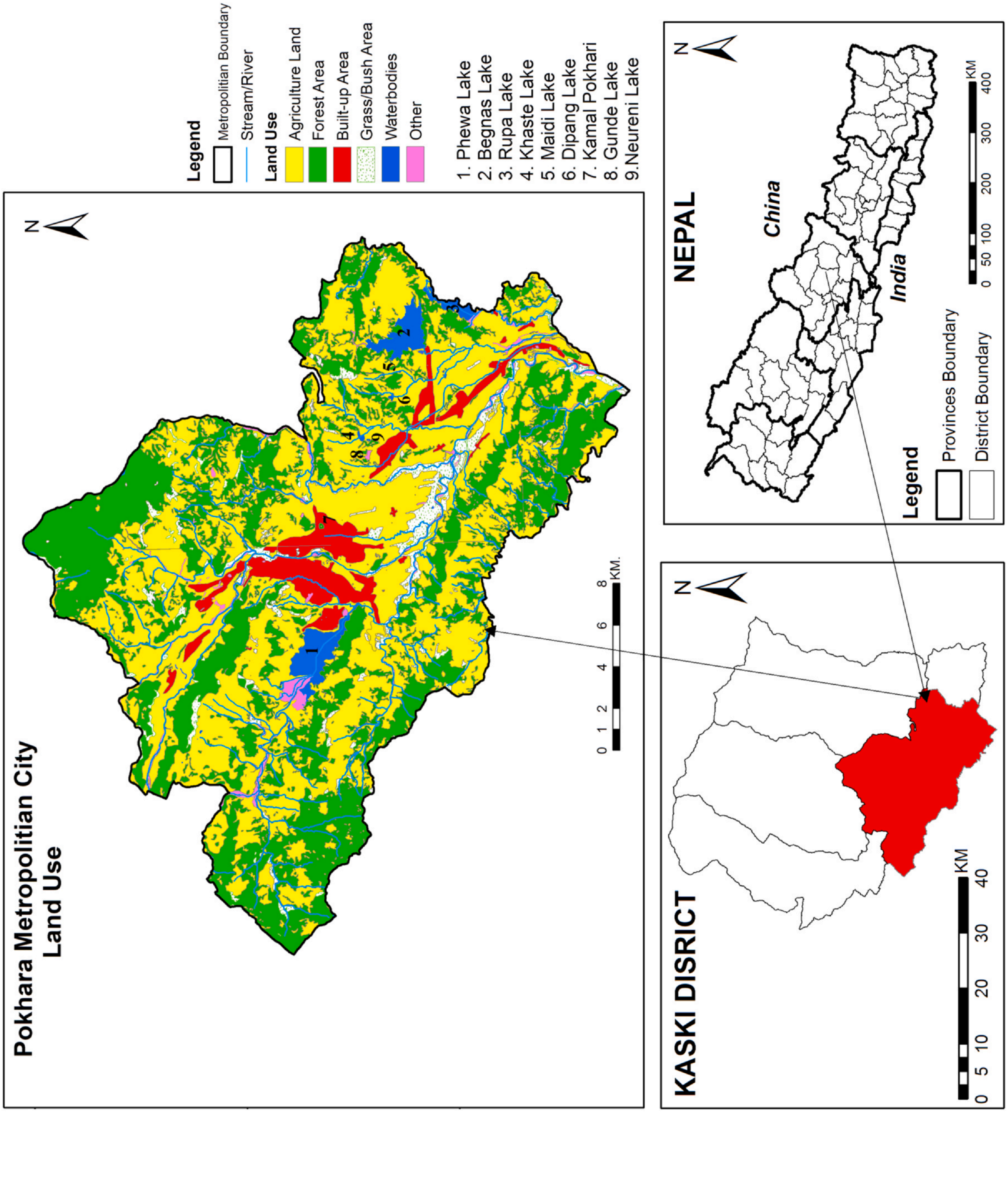

Fig. 1. Lake cluster of Pokhara valley in Kaski District, Gandaki Province (4), Nepal.

Table 2
Number of participants in the Focus Group Discussions held in Lake Cluster of Pokhara Valley, Nepal.

SN	Lake	FGDs	Participants		
			Total	Male	Female
1	Phewa	4	47	42	5
2	Begnas	4	31	19	12
3	Rupa	3	24	13	11
4	Khaste/Neureni	3	12	9	3
5	Maidi	1	7	4	3
6	Dipang	2	12	12	–
7	Kamalpokhari	1	11	10	1
8	Gunde	1	8	6	2
	Total	29	152	115	37

Table 3
Household survey in the vicinity of Lake Cluster in Pokhara Valley.

SN	Lakes	Farmers	Boaters	Hoteliers	Fishermen
1	Phewa	21	35	19	11
2	Begnas	17	12	10	5
3	Rupa	16	–	5	8
4	Khaste- Neureni	29		1	3
5	Maidi	23	–	–	–
6	Dipang	13	–	–	2
7	Kamalpokhari	18	–	–	–
8	Gunde	25	–	–	–
	Total	162	47	35	29

2.2. IAPs enumeration

We conducted a field survey to enumerate species in LCPV and compile an inventory of 230 native and naturalized plant species. The voucher specimens were used to identify the enumerated species and deposited in the Tribhuvan University Central Herbarium (TUCH) of the Central Department of Botany, Tribhuvan University, Kathmandu. Our main concern was to understand and enumerate IAPs in LCPV. Hence, we included only IAPs identified based on the findings of Shrestha (2016). We used photographs of enumerated IAPs from the lake areas during the group discussion and household survey in the study area.

2.3. Wetland ecosystem services and impacts of IAPs on ecosystem services

We compiled and listed the potential ecosystem services of freshwater inland lakes based on the available literature (e.g., Costanza et al., 1997; Sharma et al., 2015; McInnes and Everard, 2017; Steinman et al., 2017). We collected data on all types of ecosystem services provided by the lakes during focus group discussions (FGDs) and Key Informant's interviews (KIIs). To obtain a collective stakeholder understanding of the lakes' ecosystem services, we conducted FGDs at the lakeshores (Table 2). Separate FGDs were conducted for four types of stakeholders: farmers, hoteliers, boaters, and fishermen. Smaller lakes like Gunde, Khaste, and Neureni had only one or two types of stakeholders, and the number of FGDs were also reduced. We had 29 FGDs comprising 7–14 participants in each with a homogeneous background (Taylor et al., 2016), such as farmers, boatmen, fishermen, and hoteliers. An open-ended questionnaire was used for discussion, along with a checklist of ecosystem services and photos of the listed IAPs. Participants were encouraged to express their opinions. FGDs discussions were recorded, and photos were also taken for later reference.

We conducted interviews with 23 individuals as key-informant representing various stakeholder groups, including hotel associations, boaters' associations, government officials, teachers, local conservation leaders, women's groups, and elderly farmers. The purpose of the interviews with these key informants was to obtain specific information about lake ecosystem services and to validate and/or confirm data obtained from the FGDs.

We conducted household surveys among primary beneficiaries (Table 3) of lake clusters to collect information on the impact of IAPs on wetland ecosystem services provided by lakes. The number of households within a 1-km area around the lake area was estimated using Lake Committee members. Of these, 10% of the households were selected for the survey using the snowball method. A total of 273 households were surveyed, which included four different beneficiaries (Table 3), namely farmers (162), boaters (47), hoteliers (35), and fishermen (29). The distribution of the four beneficiaries is not homogeneous on all lakes. The smaller lakes are mainly inhabited by farmers, while boaters and hoteliers are more common around the larger lakes. The discussion, the key informant interview, and the household survey focused on answering the following questions: (1) What services are obtained from the lakes? (2) Are they aware of the IAPs in the lakes? (3) When did the IAPs appear in the lakes? (4) What is the cause of the rapid spread of the IAPs? (5) What are the impacts of IAPs? (6) Do ecosystem services decrease after the

Table 4
List of invasive alien plants present in each lake.

SN	Name of the species	Phewa	Begnas	Rupa	Khaste	Maidi	Dipang	Kamal Pokhari	Gunde	Neureni
1	*Eichhornia crassipes*	√	√	√	×	×	√	×	×	×
2	*Pistia stratiotes*	√	√	√	×	×	×	√	×	×
3	*Ipomoea carnea* ssp. *Fistulosa*	√	√	√	×	×	√	×	√	×
4	*Alternanthera philoxeroides*	√	×	×	×	×	×	×	×	×
5	*Leersia hexandra*	√	√	√	√	√	√	√	√	√

invasion with alien plants? (7) What ecosystem services are affected by IAPs? (8) What are the current market prices for lake-derived goods?

2.4. Data analysis

Based on the field survey, we compiled an inventory of IAPs present in the lakes. We prioritized the ecosystem services identified during the FGDs using the scoring method formulated by Shrestha et al. (2019). To prioritize ecosystem services, each of the listed ecosystem services was scored on a linear scale, e.g., 0–4. A score of 0 represented lack of service, 1 represented the least important service. A score of 4 represented the most important service in each category of services and goods. The scores obtained for all ecosystem services were added together. The maximum scores of 4 were determined for each of the listed services and summed. The percentage priority was calculated using the following relationship

$$Priority\ Percentage = \frac{Total\ score\ obtained\ for\ a\ service}{Total\ maximum\ score\ for\ all\ services} \times 100$$

The prioritization of ecosystem services was useful in determining the relative importance of different types of ecosystem services. Direct and indirect market price methods were used to estimate the economic value of ecosystem services (Sharma et al., 2015). The market price method was used to quantify the direct utility values (fish, food and commodities) using market prices. Since the provisioning services meet the people's basic needs and help uplift the beneficiaries' socio-economic status, we calculated the economic value of the provisioning services. Moreover, local people are directly affected by the provisioning services. They can therefore provide reliable information to quantify the listed services. The average annual value of wetland products directly used per household was estimated based on average harvest volumes and prices, without considering what proportion was sold. The total value of wetland provisioning services for all dependent households living within 1 km of the lake area was calculated as the average annual value of harvested resources per household multiplied by the estimated total number of dependent households (Sharma et al., 2015). We used the following equation to determine the total economic value of the provisioning services.

Table 5
Local people's response on the ecosystem services and respond percentage for different ecosystem services in lakes of Pokhara Valley.

Services type	Ecosystem services	Phewa	Begnas	Rupa	Khaste-Neureni	Maidi	Dipang	Kamal Pokhari	Gunde	Average of each ES	Average of service type
CS	Natural beauty	98.8	100	88.7	78.8	100	20	5.6	92	73	
CS	Tourism & religion	62.8	50	13.2	6.1	0	20	0	0	19	
CS	Boating	74.4	38.6	17	0	4.4	0	0	4	17.3	36.4
PS	Fodder	18.6	27.3	30.2	75.8	91.3	0	0	92	41.9	
PS	Medicines	23.3	13.6	60.4	75.8	65.2	0	11.1	60	38.7	
PS	Fishes	75.6	61.4	24.5	81.8	8.7	20	11.1	8	36.4	
PS	"Gund" for mat	2.3	0	0	75.8	82.6	0	0	92	31.6	
PS	Wild fruits	0	6.8	43.4	30.3	69.6	0	5.6	64	27.5	
PS	Duck feed	30.2	4.6	0	0	0	0	0	0	4.3	
PS	Edible plants	1.2	0	3.8	0	4.4	0	0	4	1.7	
PS	Water for drinking	4.7	6.8	0	0	0	0	0	0	1.4	22.9
RS	For fish farming	53.5	45.5	39.6	75.8	100	0	0	92	50.8	
RS	For irrigation	59.3	38.6	34	75.8	100	0	0	92	50	
RS	For cattle grazing	17.4	13.6	35.9	18.2	87	0	0	92	33	
RS	Bathing cattle	14	18.2	22.6	27.3	82.6	0	0	76	30.1	
RS	Flood control	46.5	38.6	13.2	69.7	13	0	0	12	24.1	37.6
SS	Habitats protection	95.4	95.5	88.7	81.8	100	20	11.1	92	73.1	
SS	Bio-diversity	94.2	97.7	88.7	81.8	95.7	20	11.1	92	72.6	72.8

CS – Cultural services; PS – Provisioning services; RS – Regulating services; SS – Supporting services.

$$\mathrm{TVP}_i = \sum_{i=1}^{n} (\%hh_i \times HH \times NV_i)$$

where i represents the different wetland provisioning services, $\% \, hh_i$ is the percentage of total households dependent on the ith provisioning service (i.e., dependency weight); HH is the total number of households residing in the 1 Km territory of Lake; and NV_i is the average annual net benefit per user household (Viboonpun, 2000 as cited by Sharma et al., 2015).

To compare pre-invasion values of ecosystem services and goods with IAPs, we looked at a total economic value per household per year in the year of the survey and one year before the invasion in 1989. We listed the cost of goods from lakes before the invasion in 1989 using literature (e.g., FAO, 1999; Gurung et al., 2005), news archives, information from local co-operatives, and responses from key informants. Prices for the same goods were almost ten times lower in 1989 than in 2019. All values were adjusted to 2019 values using Nepal's GDP deflators and then converted to international dollars (INT.$) relative to 2019 using purchasing power parity (PPP) conversion factors. The GDP deflators and PPP conversion factors were based on the 'World Development Indicators' (https://datacatalog.worldbank.org/dataset/world-development-indicators). The PPP for Nepal is 34 LCU (local currency unit) per INT.$ in 2019. PPPs are the currency conversion rates that attempt to equalize different currencies' purchasing power by eliminating differences in price levels between countries (OECD, 2021). It uses INT.$, which is also known as the Geary-Khamis dollar and is a hypothetical currency unit used to standardize monetary values across countries by adjusting it to the same purchasing power that the US$ had in the United States at a given point in time (de Groot et al., 2012; Ackland et al., 2013). Therefore, to make the estimate of the economic value of provisioning service at present comparable to that before the invasion of alien species, the data collected were converted to a standard set of units in INT.$.

3. Results

3.1. IAPs in LCPV

In the LCPV, we recorded five IAPs, namely: *Echhornia crassipes* (Water hyacinth, Fam. Pontederiaceae), *Ipomoea carnea* ssp *fistulosa* (Morning glory, Fa. Convolvulaceae), *Leersia hexandra* (Southern cutgrass, Fam. Poaceae), *Pistia stratiotes* (Water lettuce, Fam. Araceae) and *Alternanthera philoxeroides* (Alligator weed, Fam. Amaranthaceae). Detailed records of IAPs across nine lakes have been tabulated in Table 4. Taxonomic details of these species are provided as supplementary information (S2). Of the five IAPs listed, L. *hexandra* was recorded from all nine lakes. *A. philoxeroides* was recorded only from Phewa Lake.

3.2. Ecosystem services provided by the lakes

Local informants identified a total of 18 ecosystem services provided by LCPV. We categorized these ecosystem services into provisioning, regulating, supporting, and cultural (Table 5). Based on interviews, provisioning services in the study area included fisheries, edible wild fruits, medicinal plants, water for domestic use, duck rearing, branching rush (*Juncus* spp., known locally as "gund") for making a traditional mat, and forage.

3.3. Prioritizing ecosystem services

Out of 18 types of ecosystem services (Table 5), the top three services mentioned by the majority of stakeholders were: habitats (73%), natural beauty (73%), and biodiversity (72%). In the second category (> 30%) the services supported agriculture, irrigation, fodder, medicine, fisheries, livestock grazing, matting, and livestock bathing. Tourism and boating ranked only third (< 30%); however, these services were mentioned to a higher extent (> 50%) in Phewa and Begnas, which are larger. These lakes were also valued for fishing (> 60%) and flood control (> 38%). The highest percentages of services were provided by fishing in Khaste-Neureni (81.82%). Supportive services were given priority responses (72.85%). Regulatory services (37.6%) were the priority services provided in the second category. Cultural services were in the third category (36.43%). Provisioning services were ranked as important at 22.93% because they are produced in large quantities and are less in demand.

However, prioritization differed among stakeholder groups including hoteliers, fishermen, boaters, and farmers (Fig. 2). Interestingly, all of these four groups had natural beauty as the top value (> 95%) of the lakes. In the perception of hoteliers, after natural beauty, fish (for consumption), biodiversity conservation, and boating were the second, third, and fourth priorities. On the other hand, the fishermen group prioritized fishing as the second most important value, followed by biodiversity, habitat, and boating. Farmers had biodiversity as the second most valuable lake service, followed by wildlife habitat, fishing, and flood control. The results revealed that we should not underestimate the importance of natural beauty to people in this region.

3.4. Valuation of provisioning services

Our estimate gave INT.$ 9.05 million year^{-1} in 2019 as the total monetary value of provisioning services of the lake cluster of Pokhara valley. This estimate includes the values of five main products, lotus (food and medicine), fish, fodder, "gund" and wild fruits. Among these products, lotus and fish had the highest value, which was INT.$ 3.95 and 3.55 million year^{-1} respectively (Fig. 3). The respondents indicated that the lotus has several uses, such as flowers, seeds, leaves, and rhizomes for medicine and food. Lotus fruits were sold as traditional medicine for jaundice treatment in the local market, with Dipang, Kamal Pokhari,

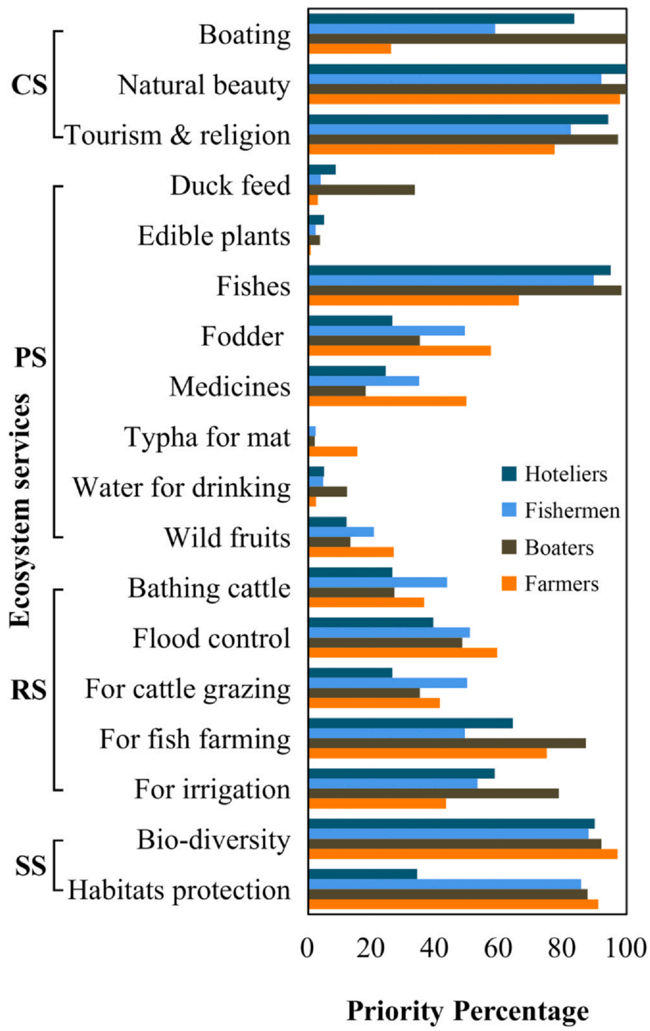

Fig. 2. Prioritized ecosystem services in the periphery of lakes in Pokhara by different stakeholders.

Maidi, and Rupa lakes topping the list. According to informants, lotus flowers were also sold in the market, especially during festivals. The economic value of fish harvesting was another important provisioning service of the lakes in Pokhara valley as fish is a popular item in restaurants and hotels. During the interview, the informants mentioned that a community called Jalari is completely dependent on fishing. They have cooperatives in Phewa and Begnas.

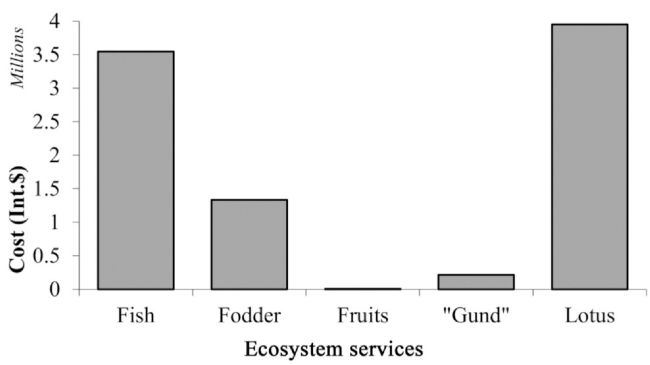

Fig. 3. Economic values of provisioning services from the lakes of Pokhara Valley Nepal in 2019.

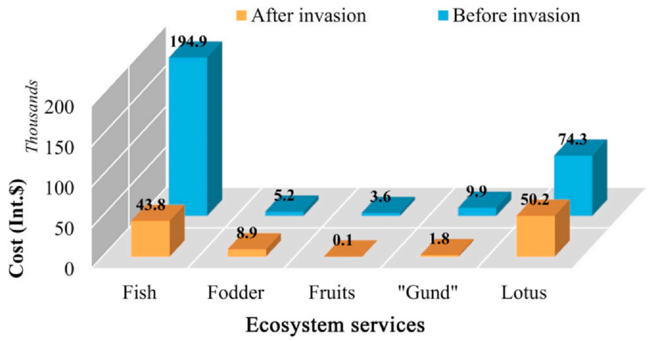

Fig. 4. Comparison of economic values of provisioning services of lakes clusters of Pokhara Valley Nepal in 1989 and 2019.

Fodder, "gund" and wild fruits were other supplies provided by LCPV and had a market value. These commodities were mainly consumed in households, but they are also sold in the local market. In 2019, fodder valued at INT.$ 1.34 million year^{-1}, "gund" valued at INT.$ 0.22 million year^{-1} and wild fruits valued at less than INT.$ 0.01 million year^{-1} were estimated to come from the lake clusters. The wild fruits are mainly the water chestnut (*Trapa bispinosa* Roxb.), known locally as "simalkande" and used as a refreshment, coolant, and delicacy. The collection of products from the lake is seasonal, except for fish collected all year round. Local farmers living near Gunde, Dipang, Maidi, and Rupa collect fodder from May to October to feed their livestock.

According to the respondents, the commodities harvested from the lake clusters were drastically reduced after the invasion of IAPs. Fish production, medicine, edible plants, and other commodities were reduced compared to those before the invasion. Our estimate showed that before the invasion by IAPs in 1989, the economic value of provisioning services was INT.$ 0.28 million HH^{-1} year^{-1} (Fig. 4). However, the economic value received by people after rampant invasion by IAPs was INT.$ 0.1 million HH^{-1} year^{-1}. Among the five commodities considered in this study, the decline was significant for fish and lotus with "gund" and fruits also reduced compared to the pre-invasion value by IAPs. The value of fodder in 2019 was higher compared to that in 1989. According to the respondents, invasive plants formed peat in the lake that favors the growth of plants used as forage. In addition to provisioning services, IAPs have notoriously impacted other ecosystem services, such as boating, whether for recreation or transportation. They have also degraded the natural beauty of the lakes, lowered water quality, and impaired biodiversity.

4. Discussion

The impacts of invasive alien species on biodiversity and ecosystem services have attracted global attention as they are considered the second most significant threat to biodiversity worldwide (Simberloff et al., 2013). A global meta-analysis showed that IAPs significantly reduced the fitness and growth of native plant species by 41.7% and 22.1%, respectively (Vilà et al., 2011). They found that IAPs also significantly reduced the fitness of animal species by 16.5%. Turbelin et al. (2017) reported 52 aquatic IAPs worldwide in their review, showing ecological and socioeconomic impacts. Our results revealed that five IAPs were present in the LCPV out of the six aquatic IAPs reported by Shrestha (2016) in Nepal. Sharma et al. (2016) recorded six IAPs in Beeshazari Lake of Chitwan, Nepal, among which *E. crassipes* is the most common (79%). *E. crassipes* is reported as the most common IAPs from 73 countries that severely affect the wetland ecosystem (Turbelin et al. 2017). However, in LCPV, L. *hexandra* is more frequent than *E. crassipes*, recorded in all lakes although *E. crassipes* is found only in larger lakes. According to the CABI (2020) online database (https://www.cabi.org/isc), L. *hexandra* harbors several pests of economic importance that cause severe rice yield loss problems. To our knowledge, no such problem has been reported in Nepal. However, precautions should be taken to avoid yield losses in rice.

I. carnea ssp. *fistulosa* is the next common species that can cause a serious rice cultivation problem and displace native vegetation (Tiwari et al., 2005). It can form dense stand in wetlands, causing blockages and difficulties in irrigation and also causing fisheries problems (Chaudhuri et al., 1994). *P. stratiotes* and *E. crassipes* are reported as having invaded four out of nine lakes. *P. stratiotes* are known to have serious negative impacts on water bodies' use as it quickly covers the water surface. It can cause problems with irrigation and drainage, interfere with boating and fishing, and create a suitable condition for waterborne diseases (Mbati and Neuenschwander, 2005). *E. crassipes* have already been reported as problematic IAP from several sites in Nepal (e.g., Mandal et al., 2017; MoFE, 2018b). This species can cause all the above problems of other IAPs. It can increase water losses by very high evapotranspiration, 32–51% above average (Rao, 1988). Our enumeration shows the presence of *A. philoxeroides* only in Phewa Lake. The presence of these IAPs causes varying degrees of problems in LCPV, which include severe degradation of ecosystem services.

Our study identified 18 ecosystem services in the LCPV. Most of the services listed are similar to those of MoFE (2018b). Elsewhere, in Jagdishpur (southwest Nepal), Baral et al. (2016) documented 24 services and goods from an artificial wetland and Ramsar site. There are very few publications on Nepal's wetland ecosystem services, though they are worth reviewing and discussing here. Because most of those publication are from the Pokhara Valley. Thapa et al. (2020) documented 32 services from the Begnas watershed, and Paudyal et al. (2018) documented 23 services from the Phewa watershed. These earlier researches documented fish, food, medicinal plants, birds, and tourism with direct use value. Our findings establish similar uses from the lakes. Lakes provide habitat for a variety range of biota, and people have long recognized this intrinsic value (Schallenberg et al., 2013). Lakes regulate flooding by controlling water from the lake area and preventing lowland flooding (Ramachandra et al., 2012). In the present study, all except Dipang and Kamalpokhari provided such services.

Werner et al. (2014) put fisheries first in their study on the benthic marine ecosystem. Besides being a nutritious food source, fish and fisheries are often associated with tourism, as fish can both be featured on the menu and provide sport for tourists (Sousa et al., 2013). The lure of fishing is one reason that in the Pokhara Valley, Phewa Lake is the most popular destination for domestic as well as international tourists. In recent years, Begnas has also become such a tourist attraction. In both Phewa and Begnas, fish farming is encouraged by the government. Therefore, hoteliers, and other groups might have prioritized fishing in ecosystem services (> 90%). On the other hand, fish farming is one of the causes of alien species in the lakes, especially alien invasive fishes (MoFE, 2018b). Recently, stakeholders in LCPV recognize the threat from the introduction of alien species of fish, which are also responsible for the accidental introduction of other invasive species, including IAPs.

Our survey found that wetland resources are important to residents and contribute to the local economy. Thapa et al. (2020) also mentions the importance of wetland resources to the local economy around the Begnas wetland. The ecosystem services' economic value is significantly higher than that of Jagadishpur Lake (Baral et al., 2016) and Ghodaghodi Lake (Lamsal et al., 2015), both in western Nepal. Given recent development and rapid urbanization, explaining the benefits we receive from the ecosystem to economic value is important to better understand the trade-offs we make between nature and development. However, since value transfer uncertainty poses a significant obstacle to quantifying the market value of the ecosystem as a whole, we have considered only provisioning services for transfer into the economic valuation (Schmidt et al., 2016). Moreover, previous studies, such as Sharma et al. (2015) have found that the economic benefits generated from provisioning services alone account for about 85% of Koshi Tappu Wildlife Reserve in Eastern Nepal. Our estimate shows that the total valuation of the provisioning ecosystem services of the lake cluster of Pokhara valley is about INT.$ 9.05million. Thapa et al. (2020) estimated US$ 3.91 million from all services provided by Begnas Watershed and provisioning services contributing a significant amount. Previously, IUCN (2003) had calculated a total value of US$ 9 million for ecosystem services provided by Koshi Tappu Wildlife Reserve. Using a combination of market-based and value transfer methods, Sharma et al. (2015) calculated the economic value of the equivalent of US$ 16 million per year for the selective ecosystem services provided by Koshi Tappu Wildlife Reserve. The services included flood plain agriculture, fodder, fisheries, fuelwood, fruits, and construction materials. Our survey also found that edible plants, medicines, fodder, and fish are important resources. "Gund" is equally important in the local economy in Pokhara as local mat prepared from "gund" is top-rated.

A healthy wetland provides a range of goods and services that contribute to human well-being (Karki et al., 2018). Unfortunately, the health of wetlands is deteriorating, and local people are desperately trying to protect them. Around the globe, IAPs pose a threat to aquatic habitats and biodiversity conservation (Vilà et al., 2011). IAPs reduce the availability of wild fruits (Krivek et al., 2020). IAPs disrupt water channels, displace native fodder plants, reduce the natural beauty of lakes, and significantly damage lakes' ecological value (Carlsson et al., 2004). van Wilgen and Gorgens (2004) reported outbreaks of waterborne disease due to invasive species in lakes. Invasive alien species are increasingly threatening the native flora, fauna, and ecosystems in Bangladesh (Mukul et al., 2020). They increase disease vectors, such as mosquitoes, snails (Keller et al., 2018). Invasions have also been found to damage infrastructures created for energy flow and watercourses (Booy et al., 2017). The damage done by IAPs is reflected in the net difference of about INT.$ 0.19 million HH^{-1} $year^{-1}$ of the economic value of provisioning services before the invasion in 1989 and after introducing IAPs in LCPV. Our results show a remarkable decline in the ecosystem service value of fish, lotus, and "gund" from lakes by 2019 compared to that before the invasion of IAPs in 1989. The invasion of IAPs and alien fish species introduced in LCPV significantly reduces the native fish population (MoFE, 2018b). Economic losses due to the impact of IAPs on provisioning services have rarely been reported. However, overall economic losses in ecosystem services from the region have been reported. Xu et al. (2006) reported that China lost about US$ 14.45 billion due to invasive alien species in 2006. Economic losses due to IAS in the agricultural sector in Bangladesh are well documented. However, it is claimed that the losses are mainly due to the management and eradication of IAPs such as *E. crassipes* (Mukul et al., 2020). According to one report, the U.S. spent US$ 100 million annually in the early 2000 s to control aquatic IAPs (Lovell and Stone, 2005). The problem of high cost and low impact of mechanical or manual removal of IAPs (especially *E. crassipes*) has been reported in Nepal from Beeshazari Lake in Chitwan (Sharma et al., 2018). Therefore, preventing introduction of noxious IAPs such as *E. crassipes* to those lakes where it is currently absent is the most cost effective strategy to maintain ecosystem values of LCPV. In already infested lakes, community participation and seeking biological control for scientific management of IAPs to maintain ecosystem values of wetland such as LCPV seems to be an option.

5. Conclusion

The lakes in the Pokhara Valley play an important role in the inhabitants' livelihood, as they sustain various ecosystem services. Five notorious IAPs were found to infest the water bodies and cause various problems, including a negative impact on ecosystem services. Among the IAPs, L. *hexandra* was found in all nine lakes, while *E. crassipes* and *P. stratiotes*, and *I. carnea* are aggressively advancing. These IAPs are altering the ecosystem services provided by LCPV. The estimated economic valuation shows a huge loss after the invasion of IAPs. However, the rampant spread of IAPs has seriously threatened not only this intrinsic benefit but also a host of other environmental services such as habitat to wildlife habitat, flood control support and carbon sequestration, and the attractiveness of the lakes f for research, recreation, and religious purposes. Although the significance of impacts was context-dependent, our study highlighted that invasive alien plants significantly impact wetland ecosystem services. Mechanical efforts to manage these IAPs are not as effective and need to include further research on potential biological control. We hope our work will help stimulate research on wetlands in tourist destinations by highlighting the relationship between biological invasion and their impacts at different levels of ecological services. Additionally, the findings could be valuable in making decisions for sustainable lake management.

CRediT authorship contribution statement

Hom Nath Pathak: Data curation, Formal analysis, Writing - original draft. **Dinesh Raj Bhuju:** Conceptualization, Writing - review & editing. **Bharat Babu Shrestha:** Conceptualization. **Sailesh Ranjitkar:** Analysis, Writing - review & editing.

Declaration of Competing Interest

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

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Authors' contributions

DRB, **BBS**: Conceptualization. **HNP** conducted field research, Data curation, Formal analysis, Writing - original draft. **SR**, **DRB:** Writing - review & editing. All authors read and approved the final manuscript.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2021.e01597.

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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.

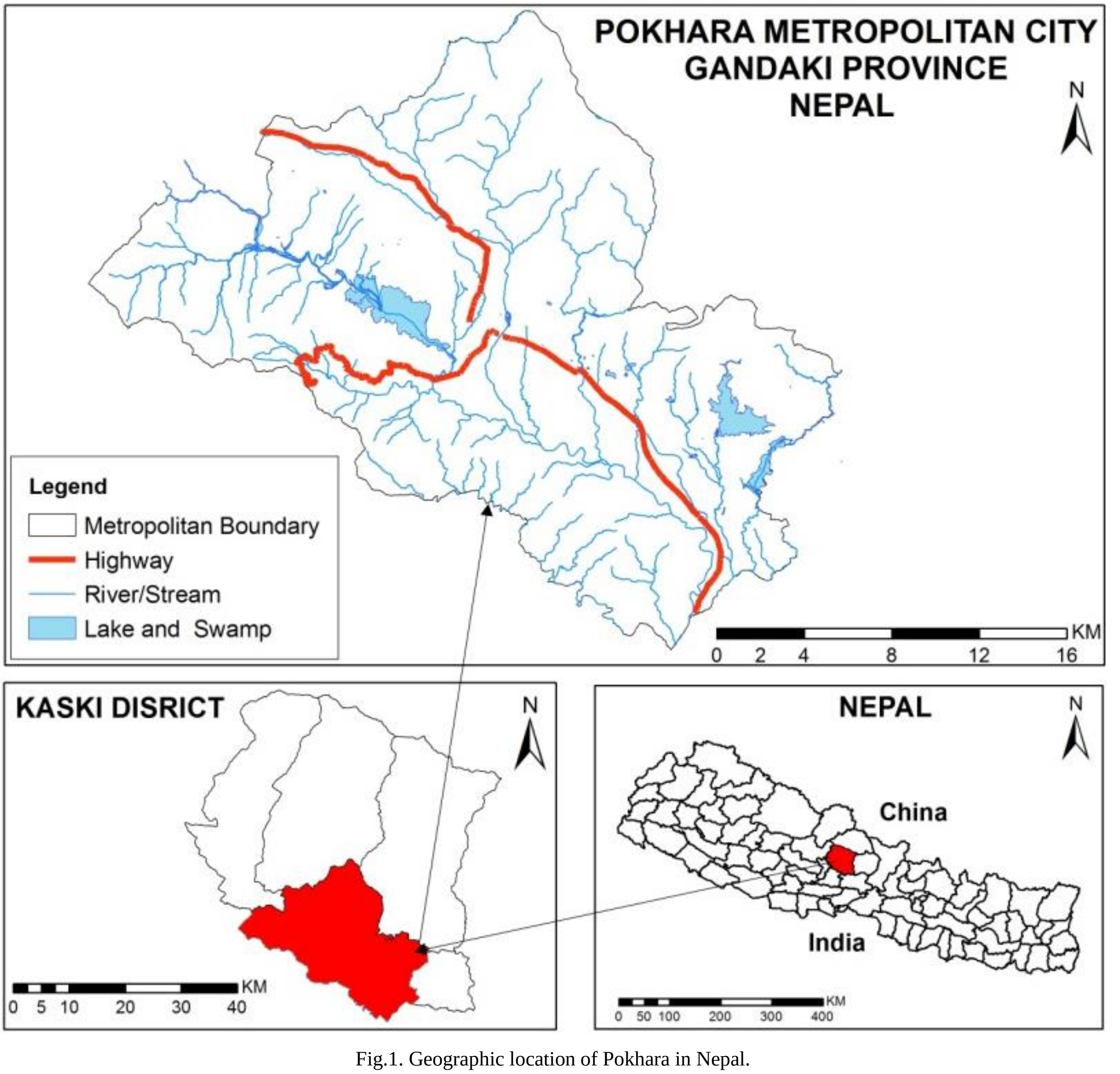


Fig.1. Geographic location of Pokhara in Nepal.

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.

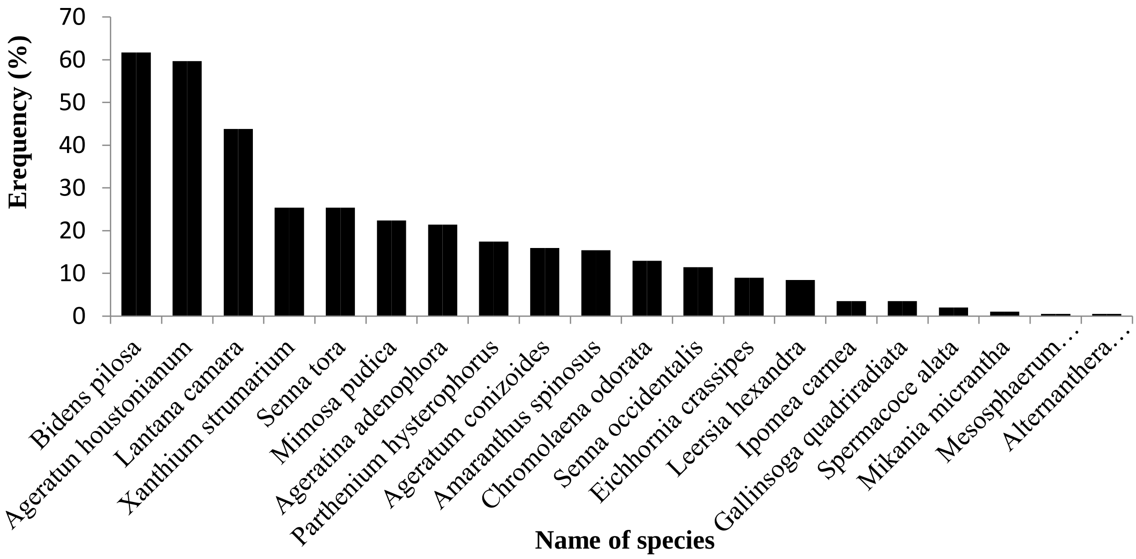


Fig. 2. Frequency of different invasive alien plant species in the study area.

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

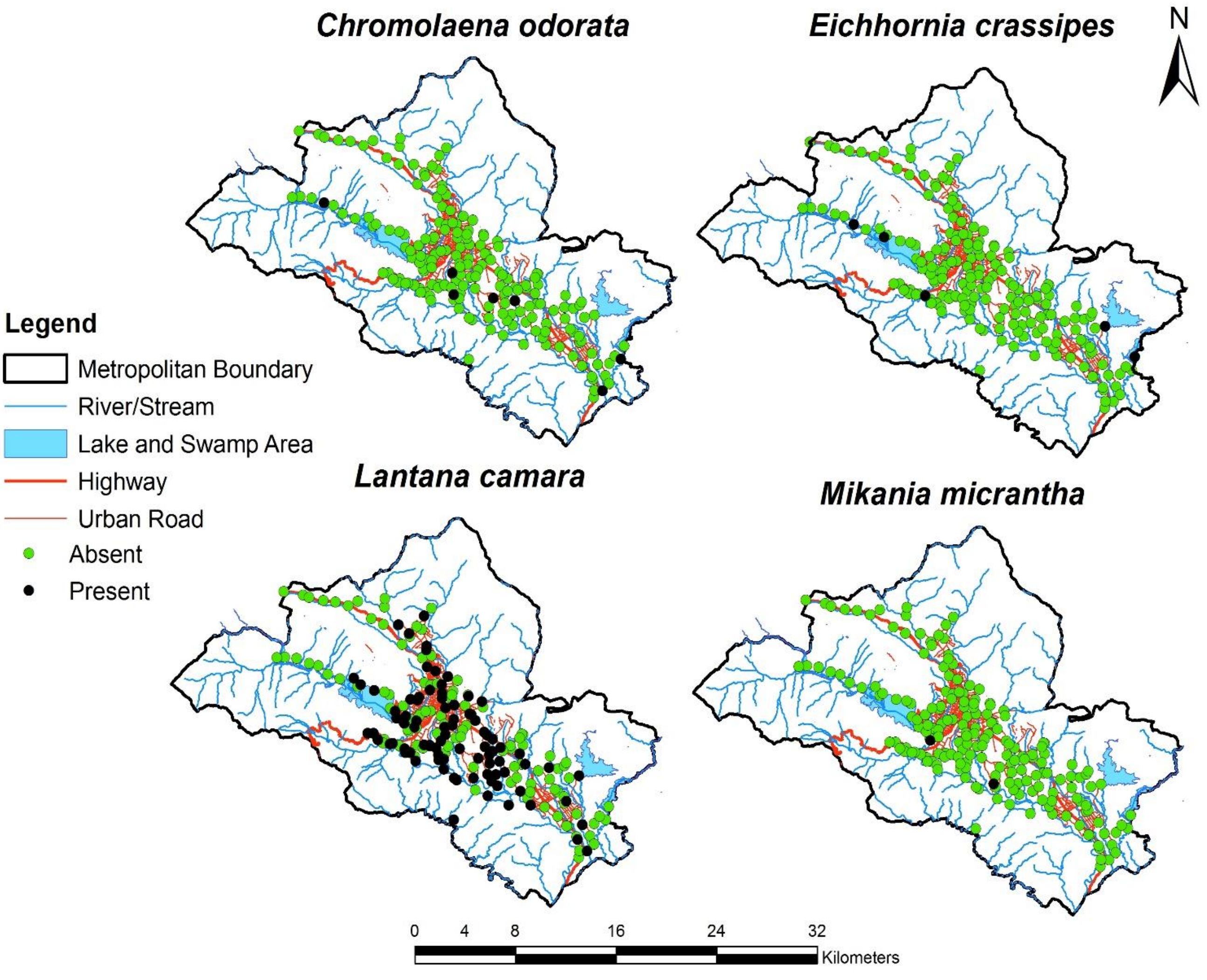


Fig. 3. Distribution of four IAPs in Pokhara valley which are globally important. Distribution of remaining 16 species has been presented in Appendix 1.

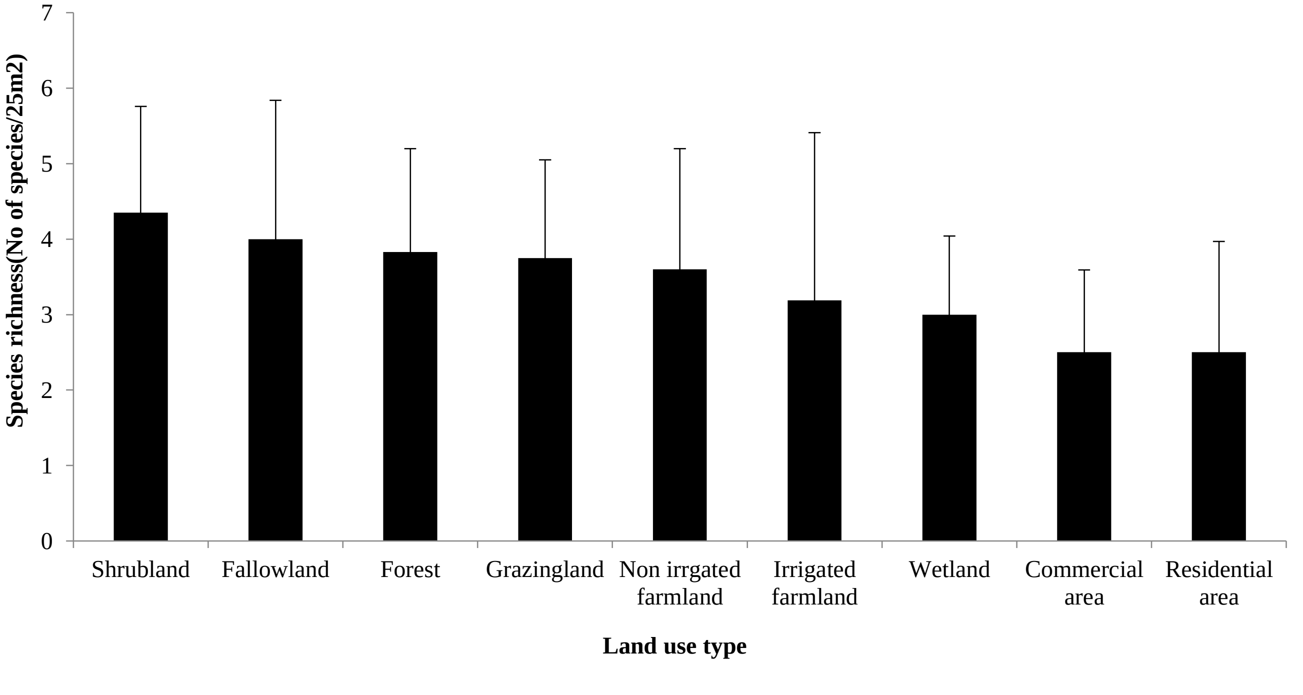
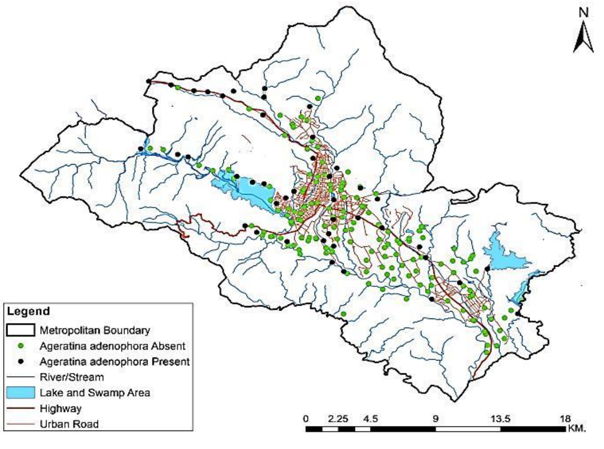
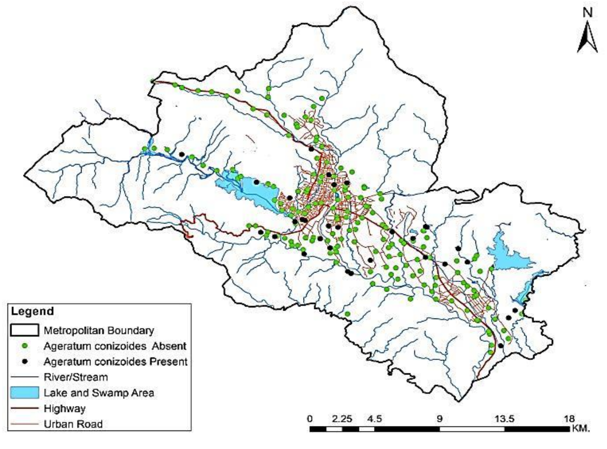
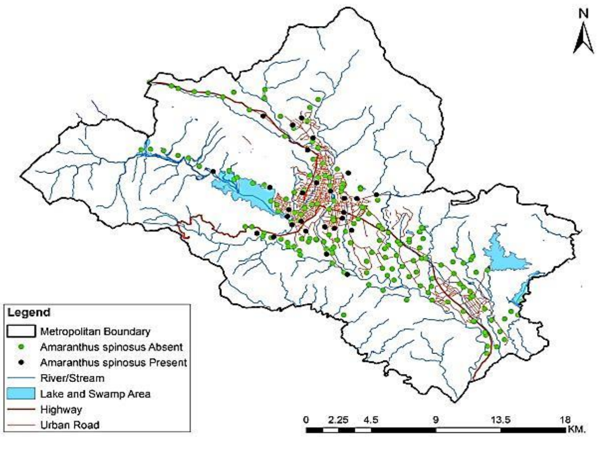
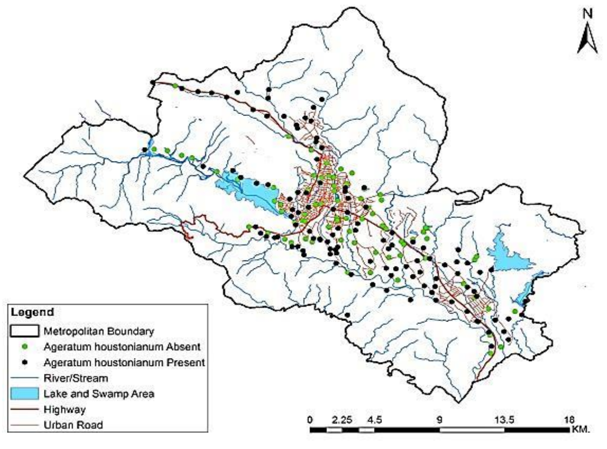


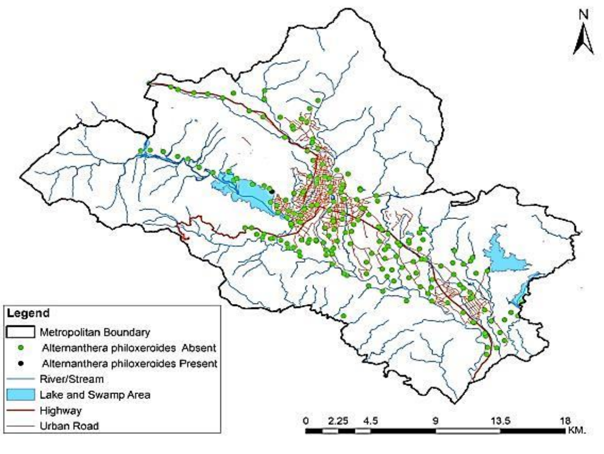
Fig. 4. Variation of IAPs richness across land use types.

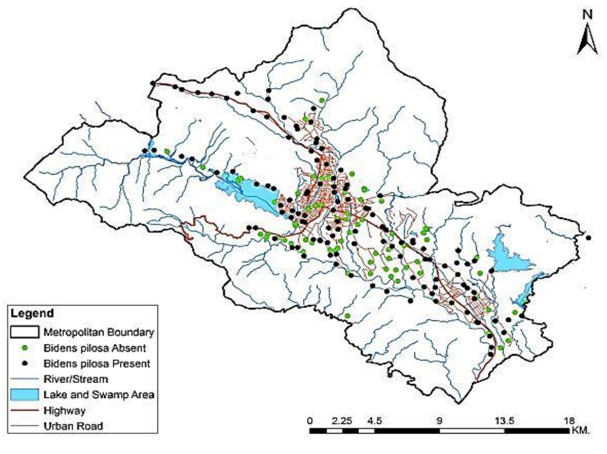

N
Legend
Metropolitan Boundary
Ageratina adenophora Absent
Ageratina adenophora Present
River/Stream
Lake and Swamp Area
Highway
Urban Road
0 2.25 4.5 9 13.5 18
KM.

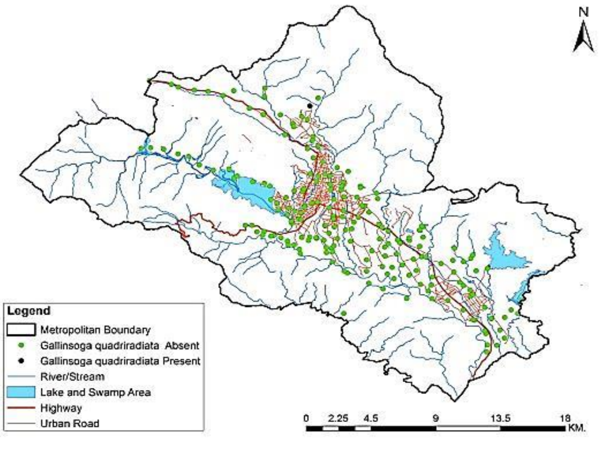

N
Legend
Metropolitan Boundary
Ageratum conizoides Absent
Ageratum conizoides Present
River/Stream
Lake and Swamp Area
Highway
Urban Road
0 2.25 4.5 9 13.5 18
KM.

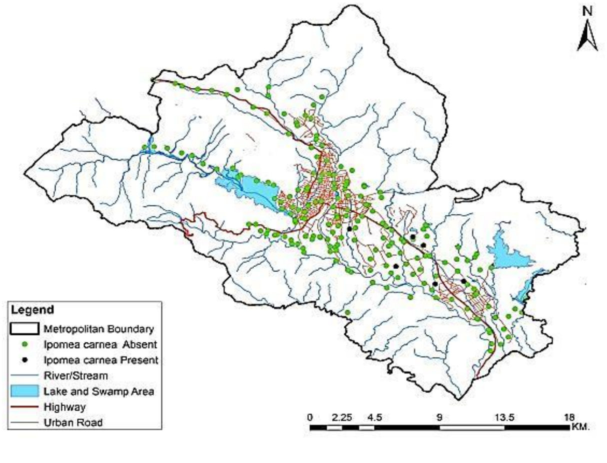

N
Legend
Metropolitan Boundary
Amaranthus spinosus Absent
Amaranthus spinosus Present
River/Stream
Lake and Swamp Area
Highway
Urban Road
0 2.25 4.5 9 13.5 18
KM.

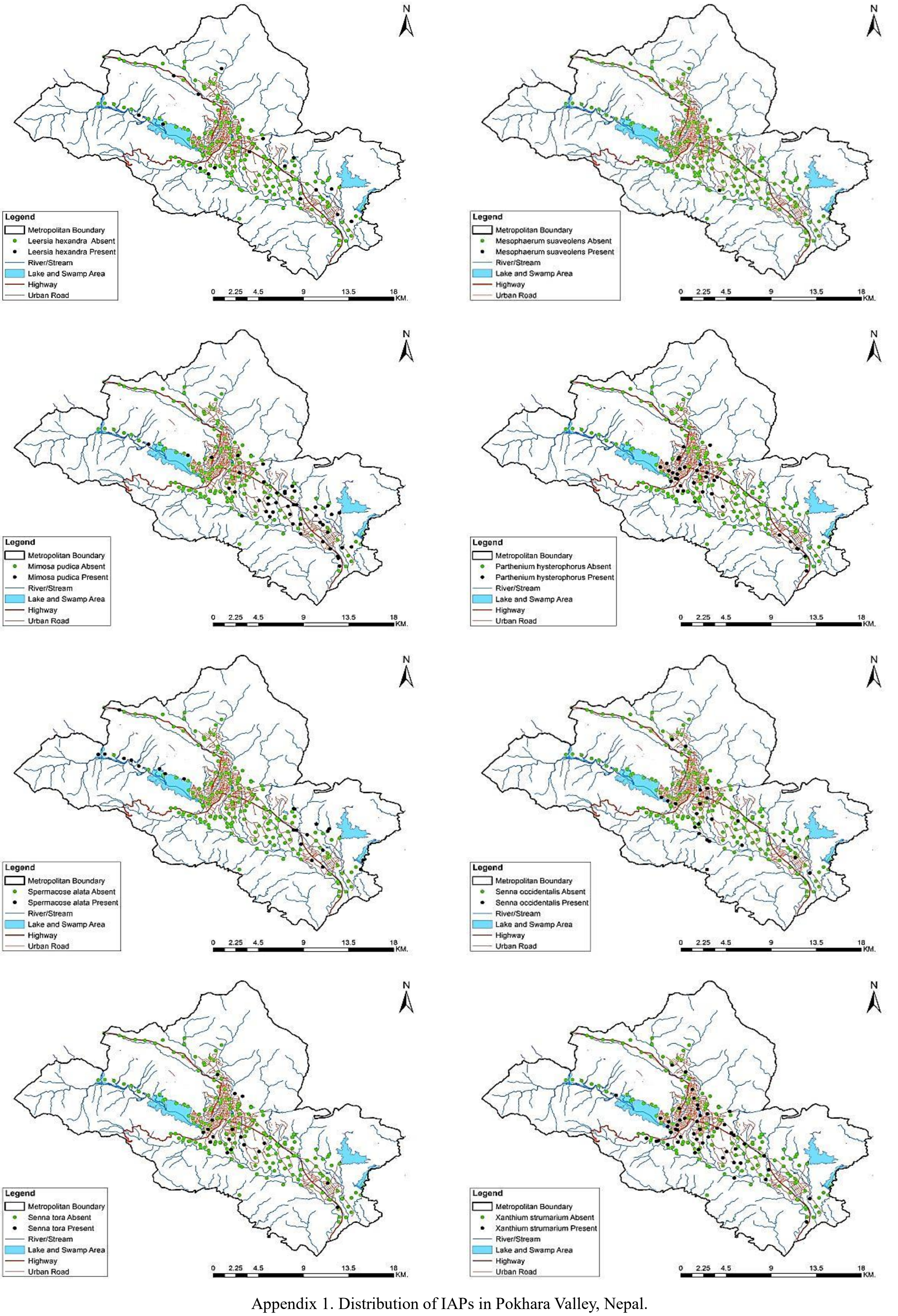

N
Legend
Metropolitan Boundary
Ageratum houstonianum Absent
Ageratum houstonianum Present
River/Stream
Lake and Swamp Area
Highway
Urban Road
0 2.25 4.5 9 13.5 18
KM.


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.

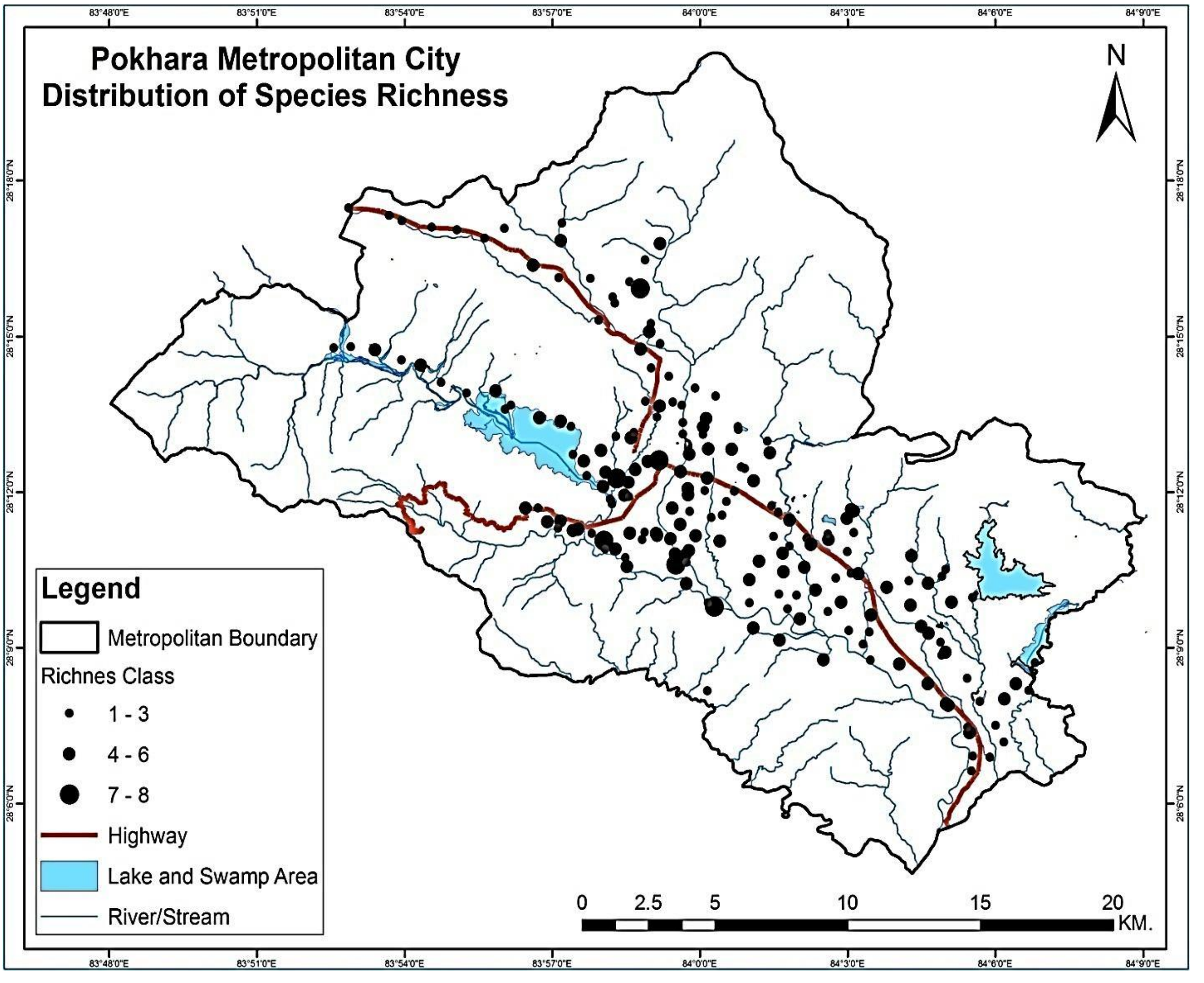


Fig. 5. Spatial pattern of the species richness (species number/25m^2 plot) of IAPs in the study area.

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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Floristic Diversity in the Lake Cluster of Pokhara Valley, Central Nepal

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ABSTRACT

Wetlands support exceptionally high biodiversity and provide valuable ecosystem services, yet they are among the most threatened habitats due to anthropogenic activities. Conservation and management planning of wetlands requires, among others, a comprehensive floristic account. In this study, we prepared a checklist of the flowering plants found in the wetlands of the Lake Cluster of Pokhara Valley (LCPV), a Ramsar site of Nepal, located in a rapidly urbanizing capital city of Gandaki Province in Central Nepal. Voucher specimens were collected from the study sites through multiple visits during the monsoon (June-August) and autumn (September-November) seasons. Species were categorized based on their life forms (Raunkiaer's classification) and native distribution range (native, naturalized, invasive). Ethno-botanical uses of the plant species were compiled from the published literature. We identified 230 plant species belonging to 70 families and 177 genera. Asteraceae (25 species), Poaceae (22 species), Fabaceae (18 species), Cyperaceae (16 species), and Lamiaceae (11 species) were species-rich families. Therophytes (30%) were the dominant life form followed by Hemicryptophytes (27%). Among 230 species, 183 species were native and 47 species naturalized; among the naturalized species, 21 species were invasive. Most of the plant species (61%) have medicinal values while others have food (24%) and fodder values (13%).

Keywords: invasive alien species, Ramsar site, Raunkiaer's life form, wetland flora

INTRODUCTION

Wetlands are areas of marsh, fen, peatland, or sea, whether natural or artificial, permanent or temporary, with fresh, brackish, or saltwater that is stagnant or flowing, including areas of marine water not exceeding six meters in depth at low tide (Ramsar Convention Secretariat, 2013). Wetlands are also called nature's supermarkets as they provide diverse goods and services to mankind and kidney of nature as they purify and filter water (Mandal & Mukherjee, 2012). For example, 21ethnic communities out of 101 in Nepal depend on wetland resources for their subsistence (Lamsal *et al.,* 2014). Wetlands are among the most productive life support systems in the world which are also immensely important for mankind as they provide humanity the freshwater supply, food and construction materials, and biodiversity, flood control, groundwater recharge, and climate change mitigation(Halls, 1997, https://www.ramsar.org). Wetlands that are the habitat of threatened species and provide valuable ecosystem services are designated as a Ramsar site under the Ramsar Convention on Wetlands (https://www.ramsar.org/). There are over 2400 Ramsar sites in the world including 10 sites in Nepal. The total area covered by all Ramsar sites in the world exceeds 2.5 million square kilometers (https://www.ramsar.org/about/wetlands-of-international-importance-ramsar-sites). Ramsar sites in Nepal occupy 605.61 square kilometers (MoFE, 2018a).

Wetlands support exceptionally high biodiversity and provide habitats to both water and land organisms (Denny, 1994). Floral diversity constitute a major resource in wetlands. A prerequisite to understanding the ecosystem type and biodiversity pattern of the region is a knowledge of the floral diversity of any region (Singh *et al.,* 2017). Such floristic data will be useful for tracking changes in the pattern of vegetation in the future. In Nepal, the analysis of wetland flora is limited. A specific gap exists for the floristic studies in LCPV. Ethno-botanical studies of plants and plant products are essential for proper management of plant resources, in addition to the flora research (Cunningham, 2001).

Lake Cluster of Pokhara Valley (LCPV) is the most recently declared Ramsar site of Nepal (MoFE, 2018b). The LCPV includes nine lakes located in Pokhara Metropolitan, a rapidly urbanizing city of touristic attraction in Central Nepal. This study was carried out to prepare a checklist of the flowering plants found in the LCPV and analyzes their taxonomic diversity, life forms, biogeographic status, and ethnobotanical uses. The results of this study are useful for the management and conservation planning of the LCPV.

Study area

The study was carried out in the Lake Cluster of Pokhara Valley (LCPV) which includes nine lakes located within Pokhara Metropolitan City, central Nepal (fig. 1). The Valley is located between 27˚55'-28˚23' N latitude and 83˚48'-84˚11' E longitude, with an area of 133.41 sq. km in Pokhara Metropolitan City (Shrestha & Kshetri, 2008). Pokhara is one of the most popular tourist destinations in Nepal, and a provincial capital of Gandaki Province. Of the nine lakes (table. 1), Phewa, Begnas, Rupa, and Deepang are visited by tourists frequently for natural beauty, fishing, and boating. The lakes and other water bodies are important sources of drinking water, fishery, irrigation, and hydropower (MoFE, 2018b). Besides they provide recreational, religious, spiritual, and inspirational values to local people and tourists.

Table 1. General information on the Lake Cluster of Pokhara Valley (MoFE, 2018b).

SN	Attributes	Phewa	Begnas	Rupa	Dipang	Maidi	Kamal pokhari	Gunde	Neureni	Khaste
1	Ward number	6	31	33	27	28	13	26	26	26
2	Area occupied by water (Km^2)	4.33	3.13	1.11	0.14	0.007	0.013	0.08	0.027	0.13
3	Catchment area (Km^2)	119.39	18.6	26.02	2.39	1.6	1.35	0.61	0.18	2.69
4	Lowest elevation (m asl)	763	647	580	687	672	822	741	742	739

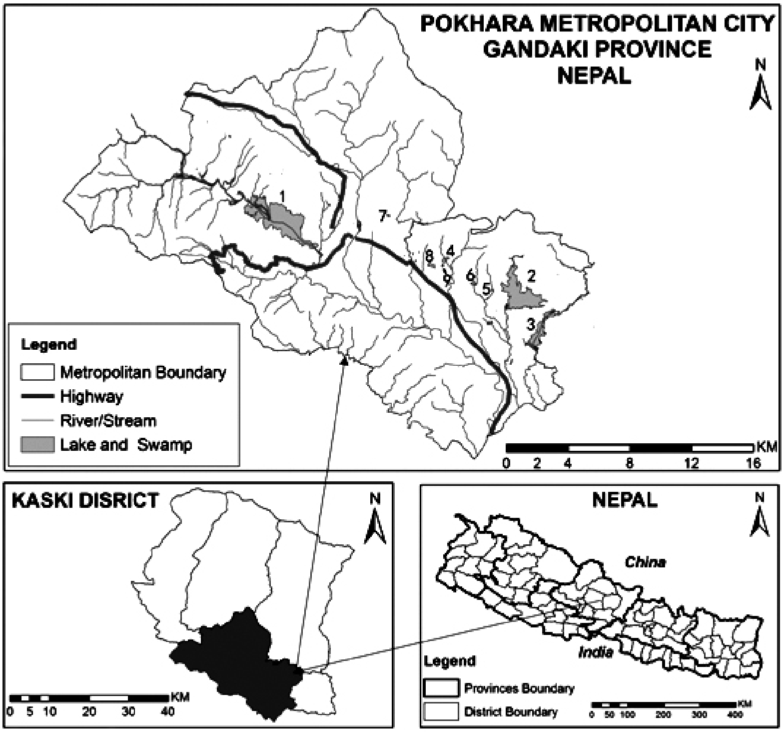

Fig.1. Lake Cluster of Pokhara Valley, Kaski District, Gandaki Province, Nepal. (Numerical values in Pokhara Metropolitan City map represent different lakes: 1. Phewa, 2. Begnas, 3. Rupa, 4. Khaste, 5. Maidi, 6. Deepang, 7. Kamalpokhari, 8. Gunde, 9. Niureni).

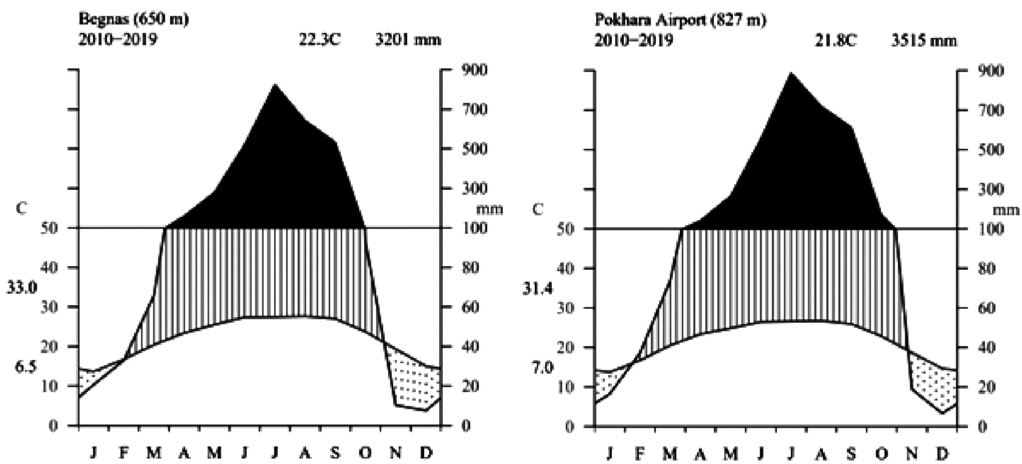

Fig.2. Ombrothermic diagram of the climatic data between2010 to 2019 at Begnas and Pokhara airport.

Pokhara Valley lies in a subtropical region dominated by *Schima-Castanopsis* vegetation, while small patches of the riverine forest dominated by *Acacia catechu, Alnus nepalensis, Pandanus furcatus* are also found in the gorges of Seti and other associated rivers. The minimum temperature was recorded at 6.5ºC at the Begnas weather station and 7ºC at the Pokhara airport. Similarly, the maximum temperature recorded at Begnas was 33ºC and 31.4 ºC at the airport. The mean annual temperatures were 22.3ºC and 21.8ºC, respectively at Begnas andthe airport. Similarly, average annual precipitation was 3201 mm and 3515 mm at Begnas and Pokhara airport respectively (fig. 2). Dry periods are from mid-November to mid-February and the wet periods from mid-February to mid-November. The extreme wet periods extend between March to October and peak in June/July.

METERIALS AND METHODS

Specimen collection and identification

Lakes of LCPV were visited for six times from June 2018 to December 2020, representing two different seasons: monsoon (June-August) and autumn (September-November) because they are the peak flowering seasons of the wetland flora. Voucher specimens of flowering plant species were collected along the shore, inside the lakes, and around the lakes. The free-floating and submerged species growing within the territory of the lakeshore were collected following Haynes (1974). The collected specimens were pressed and dried using newspaper and herbarium pressure. The prepared specimens were identified consulting regional and national floras (Grierson & Long, 1983-2001; Wu *et al.,* 1994-2008; Watson *et al*., 2011). During the identification process, the collected samples were also cross-checked with the specimens available at the National Herbarium and Plant Laboratories (KATH) and Tribhuvan University Central Herbarium (TUCH). For some doubtful species, expert views were also considered. The nomenclature of the families followed APG-IV (Angiosperm Phylogeny Group, version IV) (Chase *et al*., 2016), while the nomenclature of the genera and species followed Roskov *et al.* (2020). Identified specimens were deposited in TUCH and KATH.

Species categorization and ethnobotanical use

Habits of the species (herb, shrub or tree;annual or perennial) were determined based on field observations of the flora (Grierson & Long, 1983-2001, Wu *et al*., 1994-2008, Watson *et al*., 2011). The life forms of the identified species were classified following

Raunkiaer's classification as Phanerophytes (Perennating buds from aerial parts more than 2m from the soil surface), Chamaephytes (Perennating buds on aerial parts less than 2m from the soil surface), Hemicryptophytes (Buds at ground level), Cryptophytes (Buds below ground or water), and Therophytes (Plants that survive unfavourable conditions as seeds) (Kent, 2012). The native ranges were extracted from Wu *et al*. (1994-2008) and Plants of the World Online (2020) (http://www.plantsoftheworldonline.org/); for some species with uncertain native range, experts' advice was also solicited. Continents (e.g. Europe, Americas) of the native distribution range of the naturalized alien species were identified. Some of the naturalized alien species were categorized as 'invasive' following the list of invasive alien plants of Nepal by Shrestha (2019). International Union for Conservation of Nature (IUCN) threatened categories were identified for each species (www.iucnredlist.org). The collected plant species were compared with the list of species reported by the Ministry of Forests and environment (MoFE, 2018b) from the LCPV. Ethnobotanical uses of the collected plant species in Nepal were obtained from the following references: Manandhar (2002), Sah *et al* .(2002), Bishokarma *et al.* (2005), Baral & Kurmi (2006), Acharya (2009), Joshi & Joshi (2009), Kunwar *et al.* (2010), Niroula & Singh (2011), Lamsal *et al.* (2014), Kunwar *et al.* (2015), Adhikari *et al.* (2019), Budha-Magar *et al.* (2020), Bhatt & Kunwar, (2020), and Sharma *et al.* (2020). Uses of the plant species were grouped into the following categories: medicines, food, forage, fodder, fiber yielders, rituals plants, fish poisons, timber yielders, fuel-woods, ornamentals, dye yielders, construction materials, green manures, hedge plants, tannin yielders, soaping agents and fermenting agents. Use percent was calculated by dividing the number of times the plant used (e.g. as medicine) by total plant species enumerated (e.g. 216) multiplied by hundred. Due to multiple uses of single plant species, a sum of the percentage values of the different use categories was more than 100%.

RESULTS AND DISCUSSION

Altogether 230 flowering plant species were collected belonging to 177 genera and 70 families from the LCPV (Appendix I). Among them, 168 species were dicots and 62 species monocots. Out of 177 genera, 34 genera had two or more than two species while the rest of others was represented by a single species. Asteraceae (25 species), Poaceae (22 species), Fabaceae (18 species), Cyperaceae (16 species) and Lamiaceae (11 species) were the species-rich families (table 2). Analysis of the floristic composition of the LCPV revealed Asteraceae and Poaceaeae as the dominant families, which agree with the general floral composition of Nepal (Press *et al.,* 2000). Poaceae was also reported as a dominant family in the wetlands of other parts of Nepal (e.g. Chitwan by Dangol *et al*., 2014). In Nepal, the analysis of wetland flora is limited. Sah *et al.* (2002) reported altogether 401 plant species belonging to 264 genera under 84 families from the Ghodaghodi lake area. Altogether 115 species belonging to 45 families were recorded from the wetland flora of Rupandehi district (Sharma *et al.,* 2019). A total of 108 plant species were recorded from the wetland and periphery of Raja-Rani Tal, Morang (Sharma *et al.,* 2020). Dangol *et al.* (2014) documented 117 plant species belonging to 39 families and 92 generain the area of Rampurghol, Chitwan. Compared to the list of 436 plant species reported in the management plan of the LCPV (MoFE, 2018b), this research revealed the presence of 155 additional plant species suggesting that previous floristic studies of the LCPV are far from complete.Regarding habits, 167 species were herbs, 38 shrubs and 25 trees. Out of the total, 76 were annuals and 154 perennials.

Table 2. Number of species recorded from the Lake Cluster of Pokhara Valley that belong to different families.

S.N.	Family	Number of species
1.	Asteraceae	25
2.	Poaceae	22
3.	Fabaceae	18
4.	Cyperaceae	16
5.	Lamiaceae	11
6.	Polygonaceae, Rubiaceae	8
7.	Malvaceae	6
8.	Acanthaceae, Euphorbiaceae, Moraceae, Orchidaceae	5
9.	Amaranthaceae, Commelinaceae, Rosaceae, Solanaceae, Urticaceae	4
10.	Hypericaceae, Phyllanthaceae,	3
11.	Apocynaceae, Araceae, Boraginaceae, Caryophyllaceae, Convolvulaceae, Dioscoreaceae, Fagaceae, Lauraceae, Linderniaceae, Lythraceae, Melastomataceae, Myrtaceae, Oleaceae, Onagraceae, Oxalidaceae, Plantaginaceae, Pontederiaceae, Primulaceae, Vitaceae	2
12	Remaining 32 families	1

The IUCN red list category of the plant species were attempted to find. Out of the 230 species, 67 plant species were under the Least Concern category and the rest of the others(163 species) were not assessed to any threat category. None of the plants were government protected. However, the ecosystems maintained by these plant species are the habitat of several threatened animal species (MoFE, 2018b).

The majority of the species were native (183 species) while 47 species were naturalized alien species. Out of them, 21 naturalized species were invasive (table 3). Though the flora of LCPV was dominated by the native species, the presence of naturalized species contributing to one-fifth of the total flora recorded during the present study could not be underestimated. Furthermore, globally worst invasive species such as *Eicchornia crassipes, Chromolaena odorata, Lantana camara* and *Mikania micrantha* (Lowe *et al.,* 2000) had already invaded LCPV. The majority of the naturalized species (81%) and all of the invasive alien species were native of the Americas (fig. 3, table 3). The dominance of the American native plant species in the naturalized flora has been also reported at the national level (Bhattarai *et al.,* 2012).

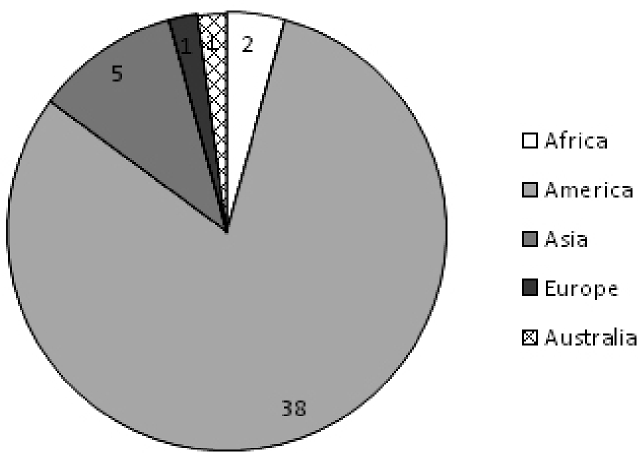

Fig. 3. Number of naturalized species with their place of origin.

TABLE 3. Floristic diversity of invasive alien plant species in Lake Cluster of Pokhara Valley.RC- Raunkiaers life form classification: He-hemicryptophyte, Ch-Chemaephytes, Th-Therophyte, Cr-Cryptophyte, Ph-Phanerophyte; Uses: Me-Medicine, Fr-forage, Fd-fodder, Gm-green manure.

SN	Latin name	Family	Native range	Collection sites	RC	Herb (H)/ Shrub S)	Annual (A)/ Perennialn (P)	Uses	References for uses
1	*Ageratina adenophora* (Spreng.) R.M.King & H.Rob.	Asteraceae	Mexico	Rupa	Ch	H	P	Me	Acharya (2009), Adhikari *et al*. (2019), Budhamagar *et al*. (2020)
2	*Ageratum conyzoides* L.	Asteraceae	Mexico	Kamal pokhari	Th	H	A	Me, Fr	Lamsal *et al*. (2014), Kunwar *et al*. (2010), Bhatt *et al*. (2020)
3	*Ageratum houstonianum* Mill.	Asteraceae	Mexico to Central America	Maidi	Th	H	A	Me	Baral *et al*. (2006), Joshi *et al*. (2009)
4	*Alternanthera philoxeroides* (Mart.) Griseb.	Amaranthaceae	Trinidad to N. Argentina	Phewa	He	H	P		
5	*Amaranthus spinosus* L.	Amaranthaceae	Mexico to Tropical America	Rupa	Th	H	A	Fd, Me, Fr	Manandhar (2002), Joshi *et al*. (2009)
6	*Bidens pilosa* L.	Asteraceae	Tropical & Subtropical America	Khaste	Th	H	A	Fd, Me, Fr	Manandhar (2002), Baral *et al*. (2006), Sharma *et al*. (2020)

7	*Chromolaena odorata* (L.) R.M.King & H.Rob.	Asteraceae	Tropical & Subtropical America	Phewa	Ch	S	P	Me	Baral *et al.* (2006)
8	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	S. Tropical America	Phewa	Cr	H	P	Fd, Gm	Joshi *et al.* (2009), Sah *et al.* (2002)
9	*Galinsoga quadriradiata* Ruiz & Pav.	Asteraceae	Mexico to S. Tropical America	Khaste	Th	H	A	Fd	Manandhar (2002),
10	*Ipomoea carnea* subsp. *fistulosa* (Mart. ex Choisy) D.F.Austin	Convolvulaceae	Mexico to S. Tropical America	Phewa	Ch	S	P	He, Me	Manandhar (2002), Baral *et al.* (2006), Kunwar *et al.* (2015)
11	*Lantana camara* L.	Verbenaceae	Mexico to Tropical America	Rupa	Ch	S	P	Fd, Me, He	Manandhar (2002), Kunwar *et al.* (2015)
12	*Mesosphaerum suaveolens* (L.) Kuntze	Lamiaceae	Mexico to Tropical America	Rupa	Th	H	A	Me	Baral *et al.* (2006)
13	*Mikania micrantha* Kunth	Asteraceae	Tropical & Subtropical America	Phewa	He	H	P	Fr	Sharma *et al.* (2020)
14	*Mimosa pudica* L.	Fabaceae	Tropical America	Phewa	He	H	P	Me	Manandhar (2002), Baral *et al.* (2006), Kunwar *et al.* (2010)

15	*Oxalis latifolia* Kunth	Oxalidaceae	Tropical & Subtropical America	Kamal pokhari	Cr	H	P		
16	*Parthenium hysterophorus* L.	Asteraceae	Tropical & Subtropical America	Phewa	Th	H	A		
17	*Pistia stratiotes* L.	Araceae	South America	Phewa	Cr	H	P		
18	*Senna occidentalis* (L.) Link	Fabaceae	Tropical & Subtropical America	Phewa	Th	H	A	Fd, Me	Manandhar (2002), Baral *et al.* (2006)
19	*Senna tora* (L.) Roxb.	Fabaceae	Central America	Phewa	Th	H	A	Fd, Me	Manandhar (2002), Bishwakarma (2005), Baral *et al.* (2006)
20	*Spermacoce alata* Aubl.	Rubiaceae	Colombia to N. South America and W. Brazil	Phewa	He	H	P	Me	
21	*Xanthium strumarium* L.	Asteraceae	N. America, Peru to Brazil and S. South America	Rupa	Th	H	A	Me	Manandhar (2002), Sah *et al.*(2002)

The life form of dominant plant species is one of the basic physiognomic attributes (Beard, 1978), which show the plant-environment interaction, and it helps to understand the micro and macroclimate under which plant species flourish (Khan *et al.,* 2018). The vegetation in our study area ranged from phanerophytes to therophytes with the dominance of therophytes and hemicryptophytes (fig. 4). The hemicryptophytes and cryptophytes constituted the species of the herb. The chamaephytes observed were mainly woody shrub species while the phanerophytes constituted the trees and the associated epiphytes and climbers, growing in the adjoining areas of wetlands. Hydrophytes (a component of Cryptophytes) constituted 10 species; common among them were *Trapa natans, Eichhormia crassispes, Pistia stratiotes, Hydrilla verticillata, Leersia hexandra* and *Ludwigia adscendens*. Such dominancy of hydrophytes was also reported from a study in wetlands of Central Nepal (Burlakoti & Karmacharya, 2004).

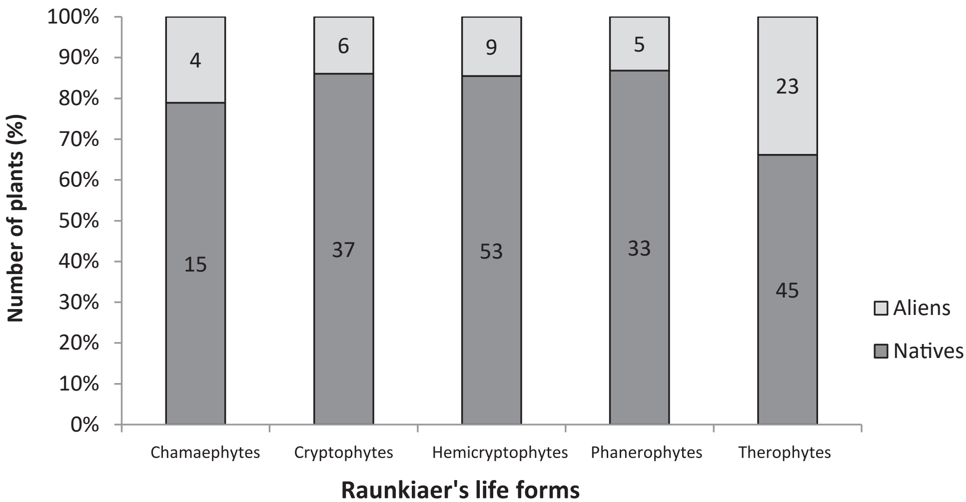

Fig. 4. Percentage of native and naturalized aline plant species in each life form. Values inside the bars represents the number of species.

A review of the previous studies revealed that about 71% (166 species) of the flowering plants recorded in the LCPV have one or moreuse values (table 4). Most of them (59%) were used as medicines, followed by food (25%) and forage and fodder (13%). This suggests that the LCPV provides important provisioning services to the people living in the landscape surrounding the LCPV. A similar type of research was reported by Sah *et al.* (2002) in the Ghodaghodi lake area and Dangol (2014) in Rampur Ghol, Chitwan.

Table 4. Uses of the plant species reported from the LCPV. Uses of the species have been compiled from the previous studies (See Appendix I and II for details).

S.N.	Use category	Number of species	Percentage of species
1.	Medicinal uses	141	61.30
2.	Food value	57	24.78
3.	Fodder and forage	31	13.47
5.	Fiber yielders	8	3.47
6.	Rituals plants	4	1.73
7.	Fish poisons	4	1.73
8.	Timber yielders	3	1.30
9.	Fuelwood	2	0.86
10.	Ornamental plants	2	0.86
11.	Dye yielders	2	0.86
12.	Use in construction	2	0.86
13.	Green manure	1	0.43
14.	Hedge plant	1	0.43
15.	Tannin yielders	1	0.43
16.	Soaping agent	1	0.43
17.	Fermenting agent	1	0.43

This study gives an insight into floral diversityin the LCPV, their biogeography, as well as their uses. Most of the species were native, perennial, and Therophytes. The LCPV provides habitat for several plant species with medicinal values. The presence of several invasive alien plant species, some of them being globally worst, suggests that the wetland habitats of LCPV have been degrading. Management responses to plant invasions, together with other drives of degradation, will help to restore the habitats and ensure the continuous supply of ecosystem services. This will provide both economic as well as conservation benefits.

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APPENDIX 1. Checklist of plant species reported from the Lake Cluster of Pokhara Valley.

SN	Family	Latin name	*IUCN categ*	N/E	D/M	NRR	RC	H/S	A/P	Use value	References for uses	Wetland	Coll. Num.
1	Acanthaceae	*Justicia gendarussa* Burm. f.		N	D	1	He	Sh	P	Me		Phewa	F 131
2	Acanthaceae	*Justicia simplex* D.Don		N	D	1	He	He	P	Me	1, 2	Niureni	140
3	Acanthaceae	*Lepidagathis incurva* Buch.-Ham. ex D.Don		N	D	1	He	He	P	Fd	1, 2	Maidi	M104
4	Acanthaceae	*Strobilanthes atropurpurea* Nees		N	D	1	He	He	P	Me	1, 2	Dipang	92
5	Acanthaceae	*Thunbergia fragrans* Roxb.		N	D	1	He	He	P			Phewa	4
6	Acoraceae	*Acorus calamus* L.	*LC*	N	M	1	Cr	He	P	Me	1, 2, 3, 7, 9, 11, 14	Rupa	R152
7	Amaranthaceae	*Alternanthera philoxeroides* (Mart.) Griseb.		E	D	1	He	He	P			Phewa	152
8	Amaranthaceae	*Alternanthera sessilis* (L.) R.Br. ex DC.	*LC*	E	D	1	He	He	P	Fd, Me, Fr	1, 2, 4, 7, 9, 12, 14, 15	Phewa	70
9	Amaranthaceae	*Amaranthus spinosus* L.		E	D	1	Th	He	A	Fd, Me, Fr	1, 4	Rupa	R124
10	Amaranthaceae	*Dysphania ambrosioides* (L.) Mosyakin & Clemants		E	D	1	He	He	P	Fd, Me	1, 2	Niureni	N 267
11	Amaryllidaceae	*Crinum amoenum* Ker Gawl. ex Roxb.		N	M	1	Cr	He	P	Me	1, 2	Phewa	153
12	Apiaceae	*Centella asiatica* (L.) Urb.	*LC*	N	D	1	He	He	P	Me, Fd	1, 4, 5, 6, 7, 9, 12, 14	Phewa	154
13	Apocynaceae	*Cryptolepis buchananii* Schult. ex Roem. & Schult.		N	D	1	Ph	Sh	P	Me, Fo, Fi	1, 2	Gunde	G117
14	Apocynaceae	*Ichnocarpus frutescens* (L.) W.T.Aiton		N	D	1	Ph	Sh	P	Fd, Me, Fi	1, 2	Maidi	M151
15	Araceae	*Colocasia fallax* Schott	*LC*	N	M	1	Cr	He	P			Rupa	R229

16	Araceae	*Pistia stratiotes* L.	*LC*	E	M	2	Cr	He	P			Phewa	P114
17	Asteraceae	*Acmella paniculata* (Wall. ex DC.) R.K.Jansen	*LC*	N	D	1	Th	He	A			Kamal pokhari	115
18	Asteraceae	*Adenostemma lavenia* (L.) Kuntze		N	D	1	He	He	P			Phewa	15
19	Asteraceae	*Ageratina adenophora* (Spreng.) R.M.King & H.Rob.		E	D	1	Ch	He	P	Me	2, 4, 5, 7, 11	Rupa	R21
20	Asteraceae	*Ageratum conyzoides* L.		E	D	1	Th	He	A	Me, Fr	1, 2, 4, 6, 8, 12	Kamal pokhari	65
21	Asteraceae	*Ageratum houstonianum* Mill.		E	D	1	Th	He	A	Me	2, 4	Maidi	M10
22	Asteraceae	*Bidens bipinnata* L.		N	D		Th	He	A	Fd, Me	1, 13	Phewa	25
23	Asteraceae	*Bidens pilosa* L.		E	D	1	Th	He	A	Fd, Me, Fr	1, 2, 15	Khaste	K123
24	Asteraceae	*Chromolaena odorata* (L.) R.M.King & H.Rob.		E	D	1	Ch	Sh	P	Me	2	Phewa	P225
25	Asteraceae	*Crassocephalum crepidioides* (Benth.) S.Moore		E	D	1	Th	He	A	Me	1, 2	Phewa	P137
26	Asteraceae	*Cyanthillium cinereum* (L.) H.Rob		N	D	1	Th	He	A	Me		Khaste	98
27	Asteraceae	*Duhaldea cappa* (Buch.-Ham. ex D.Don) Pruski & Anderb.		N	D	1	Ch	Sh	P	Me	1	Maidi	M103
28	Asteraceae	*Eclipta prostrata* (L.) L.	*LC*	E	D	1	Th	He	A	Fd, Me, Fr	1, 2, 4, 6, 7, 12, 13, 15	Phewa	P138
29	Asteraceae	*Elephantopus scaber* L.		N	D	1	He	He	P	Me, Fa	1, 2, 13, 15	Khaste	26
30	Asteraceae	*Emilia sonchifolia* (L.) DC.		N	D	1	Th	He	A	Me, Fd, Fa	1, 15	Gunde	107
31	Asteraceae	*Erigeron canadensis* L.		E	D	1	Th	He	A			Phewa	159
32	Asteraceae	*Eschenbachia japonica* (Thunb.) J.Kost.		N	D	1	Th	He	A			Niureni	164
33	Asteraceae	*Mikania micrantha* Kunth		E	D	1	He	He	P	Fr	15	Phewa	P200

34	Asteraceae	*Parthenium hysterophorus* L.		E	D	1	Th	He	A			Phewa	P 4
35	Asteraceae	*Pseudognaphalium affine* (D.Don) Anderb.		N	D	1	Th	He	A			Dipang	417
36	Asteraceae	*Sonchus arvensis* L.		E	D	1	Th	He	A	Me, Fd	1, 2	Gunde	81
37	Asteraceae	*Sonchus asper* (L.) Hill		N	D	1	Th	He	A	Fd, Me, Fr	1, 2	Phewa	161
38	Asteraceae	*Sonchus oleraceus* L.		E	D	1	Th	He	A	Fd	1	Phewa	P102
39	Asteraceae	*Synedrella nodiflora* (L.) Gaertn.		E	D	1	Th	He	A	Me	1, 2	Phewa	P104
40	Asteraceae	*Tridax procumbens* L.		E	D	1	Th	He	A	Me	1, 2	Gunde	278
41	Asteraceae	*Xanthium strumarium* L.		E	D	1	Th	He	A	Me	1, 9	Rupa	R124
42	Balsaminaceae	*Impatiens insignis* DC.		N	D	1	Th	He	A	Fr	1	Phewa	162
43	Bignoniaceae	*Oroxylum indicum* (L.) Kurz		N	D	1	Ph	Tr	P	Me, Ri	1, 2, 3, 13	Begnas	B 231
44	Boraginaceae	*Cynoglossum zeylanicum* (Vahl) Thunb. ex Lehm.		N	D	1	He	Sh	P			Gunde	105
45	Boraginaceae	*Cynoglossum wallichii* G. Don		N	D	1	Th	He	A			Khaste	27
46	Brassicaceae	*Nasturtium officinale*W.T.Aiton	*LC*	E	D	1	Cr	He	P	Fd	1	Kamal pokhari	163
47	Caryophyllaceae	*Drymaria cordata* (L.) Willd. ex Roem. & Schult.		E	D	1	Th	He	A	Fd, Me	1, 2	Rupa	K153
48	Caryophyllaceae	*Stellaria media* (L.) Vill.		N	D	1	He	He	P	Fd, Me	1, 2	Kamal pokhari	166
49	Ceratophyllaceae	*Ceratophyllum muricatum* Cham.		N	D	1	Cr	He	P			Phewa	30
50	Commelinaceae	*Commelina paludosa* Blume		N	M	1	Cr	He	P	Fd, Me	1, 2	Kamal pokhari	103 Kamal
51	Commelinaceae	*Cyanotis vaga* (Lour.) Schult. & Schult.f.		N	M	1	Cr	He	P			Niureni	N139
52	Commelinaceae	*Floscopa scandens* Lour.	*LC*	N	M	1	Cr	He	P	Me, Fr	1, 2, 4, 5, 14	Gunde	23

53	Commelinaceae	*Murdannia nudiflora* (L.) Brenan		N	M	1	Th	He	A	Fd, Me	1, 2, 9, 12	Begnas	B145
54	Convolvulaceae	*Ipomoea carnea* subsp. *fistulosa* (Mart. ex Choisy) D.F.Austin		E	D	1	Ch	He	P	He, Me	1, 2, 13, 14	Phewa	101
55	Convolvulaceae	*Ipomoea purpurea* (L.) Roth		E	D	1	Th	He	A			Niureni	168
56	Costaceae	*Hellenia speciosa* (J.Köenig) S.R.Dutta	*LC*	N	M	1	He	He	P	Fd, Me	1, 2, 3	Rupa	R128
57	Cucurbitaceae	*Solena heterophylla* Lour.		N	D	1	He	He	P	Fd, Me, Fo	1, 2	Khaste	K100
58	Cyperaceae	*Actinoscirpus grossus* (L.f.) Goetgh. & D.A.Simpson	*LC*	N	M	1	Cr	He	P	Me, Fi	2	Rupa	7
59	Cyperaceae	*Carex cruciata* Wahlenb.		N	M	1	Cr	He	P			Phewa	169
60	Cyperaceae	*Cyperus albescens* (Steud.) Larridon & Govaerts		N	M	1	Th	He	A			Phewa	F151
61	Cyperaceae	*Cyperus brevifolius* (Rottb.) Hassk.	*LC*	N	M	1	Cr	He	P	Fr	9, 12	Phewa	47
62	Cyperaceae	*Cyperus compressus* L.	*LC*	N	M	1	Th	He	A	Me, Fr	2, 12, 14	Maidi	M205
63	Cyperaceae	*Cyperus corymbosus* Palla		N	M	1	Th	He	A			Phewa	21
64	Cyperaceae	*Cyperus cyperoides* (L.)Kuntze	*LC*	N	M	1	Cr	He	P	Me	1, 2	Phewa	P123
65	Cyperaceae	*Cyperus iria* L.	*LC*	N	M	1	Th	He	A	Fr, Me	2, 9, 12	Maidi	M214
66	Cyperaceae	*Cyperus platystylis* R.Br.		N	M	1	Th	He	A			Kamal pokhari	26
67	Cyperaceae	*Eleocharis congesta* D.Don	*LC*	N	M	1	Th	He	A			Khaste	18
68	Cyperaceae	*Fimbristylis dichotoma* (L.) Vahl	*LC*	N	M	1	Cr	He	P	Fo, Me	1, 2, 9, 12, 14, 15	Khaste	K116
69	Cyperaceae	*Schoenoplectiella juncoides* (Roxb.) Lye		N	M	1	Cr	He	P	Fi, Fo	1, 4	Phewa	16 phewa
70	Cyperaceae	*Schoenoplectiella lateriflora* (J.F.Gmel.) Lye		N	M	1	Th	He	A			Khaste	K101

71	Cyperaceae	*Schoenoplectiella mucronata* (L.) J.Jung & H.K.Choi	*LC*	N	M	1	Cr	He	P	Fi, Fo	1, 4, 14	Rupa	R198
72	Cyperaceae	*Scleria biflora* Roxb.	*LC*	N	M	1	Cr	He	P	Fo	1, 2	Khaste	K102
73	Cyperaceae	*Scleria levis* Retz.		N	M	1	Cr	He	P			Khaste	K109
74	Dioscoreaceae	*Dioscorea bulbifera* L		N	D	1	He	He	P	Fd, Me	1, 2	Rupa	R103
75	Dioscoreaceae	*Dioscorea pubera* Blume		N	D	1	He	He	P			Niureni	182
76	Dipterocarpaceae	*Shorea robusta* Gaertn.	*LC*	N	D	1	Ph	Tr	P	Me, Ti, Tag	1, 2, 13	Maidi	I91
77	Eriocaulaceae	*Eriocaulon nepalense* Prescott ex Bong.	*LC*	N	M	1	Th	He	A	Me	1	Phewa	P226
78	Euphorbiaceae	*Alchornea mollis* (Benth.) Müll.Arg.		N	D	1	Ch	Sh	P			Maidi	M124
79	Euphorbiaceae	*Euphorbia hirta* L.		N	D	1	Th	He	A	Me	2	Phewa	185
80	Euphorbiaceae	*Euphorbia pulcherrima* Willd. ex Klotzsch	*LC*	N	D	1	Ch	Sh	P	Me, Or	1	Rupa	R104
81	Euphorbiaceae	*Falconeria insignis* Royle		N	D	1	Ph	Tr	P	Me, Fp	1, 2	Begnas	B24
82	Euphorbiaceae	*Macaranga denticulata* (Blume) Müll.Arg.	*LC*	N	D	1	Ph	Tr	P	Me, Fo	1, 2	Phewa	184
83	Fabaceae	*Aeschynomene indica* L.	*LC*	N	D	1	He	Sh	P	Me	2	Gunde	G68
84	Fabaceae	*Bauhinia purpurea* L	*Lc*	N	D	1	Ph	Tr	P	Fo, Cm, Fd, Fr, Me	1,2	Rupa	R61
85	Fabaceae	*Chamaecrista leschenaultiana* (DC.) O.Deg.		N	D	1	He	He	P			Phewa	41
86	Fabaceae	*Chamaecrista rotundifolia* (Pers.) Greene		E	D	1	He	He	P			Phewa	46
87	Fabaceae	*Crotalaria alata* D.Ddon		N	D	1	He	Sh	P	Me	1	Khaste	187
88	Fabaceae	*Crotalaria pallida* Aiton		N	D	1	He	Sh	P			Dipang	93

89	Fabaceae	*Crotalaria sessiliflora* L.		N	D	1	He	Sh	P	Me	1, 2	Gunde	192
90	Fabaceae	*Desmodium concinnum* DC.		N	D	1	He	He	P	Me	1, 2	Phewa	P121
91	Fabaceae	*Desmodium heterocarpon* (L.) DC.		N	D	1	Th	He	A	Me	1, 2	Phewa	56
92	Fabaceae	*Desmodium laxiflorum* DC.		N	D	1	Th	He	A	Fo	1, 2	Phewa	194
93	Fabaceae	*Desmodium multiflorum* DC		N	D	1	Ch	He	P	Me	1, 2	Gunde	197
94	Fabaceae	*Dunbaria glandulosa* (Dalzell & A.Gibson) Prain		N	D	1	Th	He	A			Maidi	201
95	Fabaceae	*Indigofera atropurpurea* Hornem.		N	D	3	Ph	Sh	P			Rupa	311
96	Fabaceae	*Mimosa pudica* L.	*LC*	E	D	1	He	He	P	Me	1, 2, 8, 12, 15	Phewa	19
97	Fabaceae	*Mimosa rubicaulis* Lam.		N	D	1	Ch	Sh	P	Me	1, 2	Phewa	F150
98	Fabaceae	*Senna occidentalis* (L.) Link		E	D	1	Th	Sh	A	Fd, Me	1, 2	Phewa	P 2
99	Fabaceae	*Senna tora* (L.) Roxb.		E	D	1	Th	Sh	A	Fd, Me	1, 3, 8, 12	Phewa	P213
100	Fabaceae	*Stylosanthes hamata* (L.) Taub.		E	D	1	Th	He	A			Phewa	42
101	Fagaceae	*Castanopsis indica* (J.Roxb. ex Lindl.) A.DC.	*LC*	N	D	1	Ph	Tr	P	Me, Fd, Fw, Fo	1, 5	Maidi	M201
102	Fagaceae	*Quercus lanata* Sm.	*LC*	N	D	1	Ph	Tr	P	Fd, Me, Fo, Fw	1, 2	Rupa	204
103	Gesneriaceae	*Aeschynanthus parviflorus* (D.Don) Spreng.		E	D	1	Ph	He	P	Me	1, 2	Niureni	123
104	Hydrocharitaceae	*Hydrilla verticillata* (L.f.) Royle	*LC*	N	M	1	Cr	He	P	Me, Gm, Fr, Fd	1, 2, 4, 6	Niureni	N140
105	Hypericaceae	*Hypericum japonicum* Thunb.		N	D	1	He	He	P	Me	1, 2	Khaste	211

106	Hypericaceae	*Hypericum podocarpoides* N.Robson		N	D	1	Ch	Tr	P	Me	1	Begnas	B23
107	Hypericaceae	*Hypericum uralum* Buch.-Ham. ex D. Don		N	D	1	Ch	He	P	Me, Fo	1, 2	Maidi	89
108	Juncaceae	*Juncus prismatocarpus* R.Br.	*LC*	N	M	1	Cr	He	P			Gunde	G125
109	Lamiaceae	*Clerodendrum bracteatum* Wall. ex Walp.		N	D	1	Ch	Sh	P			Rupa	R121
110	Lamiaceae	*Anisomeles indica* Kuntze		N	D	1	He	He	P	Me	1, 2	Phewa	27
111	Lamiaceae	*Colebrookea oppositifolia* Sm.		N	D	1	Ph	Sh	P	Me	2, 9	Kamal pokhari	62
112	Lamiaceae	*Melissa axillaris* (Benth.) Bakh.f.		N	D	1	He	He	P	Me	2	Phewa	60
113	Lamiaceae	*Mesosphaerum suaveolens* (L.) Kuntze		E	D	1	Th	He	A	Me	2	Rupa	235
114	Lamiaceae	*Ocimum gratissimum* L.		N	D	1	Th	He	A	Me	2	Niureni	N177
115	Lamiaceae	*Ocimum tenuiflorum* L.		N	D	1	Th	He	A	Me, Ri	1, 2	Kamal pokhari	K126
116	Lamiaceae	*Platostoma coloratum* (D.Don) A.J.Paton		N	D	1	He	He	P	Fd, Me	1, 2	Maidi	87
117	Lamiaceae	*Plectranthus mollis* (Aiton) Spreng.		N	D	1	He	He	P	Me	1, 2	Gunde	238
118	Lamiaceae	*Pogostemon auricularius* (L.) Hassk.		N	D	1	He	He	P			Gunde	105
119	Lamiaceae	*Scutellaria discolor* Colebr.		N	D	1	He	He	P	Me	1, 2	Gunde	74
120	Lauraceae	*Cinnamomum verum* J.S.Presl		N	D	1	Ph	Tr	P			Rupa	R125
121	Lauraceae	*Litsea monopetala* (Roxb.) Pers.	*LC*	N	D	1	Ph	Tr	P	Fo, Me	1, 2	Rupa	R211
122	Lentibulariaceae	*Utricularia australis* R.Br.	*LC*	N	D	1	Cr	He	P			Maidi	251
123	Linaceae	*Reinwardtia indica* Dumort.		N	D	1	Ch	Sh	P	Me	1, 2	Kamal pokhari	K136
124	Linderniaceae	*Torenia asiatica* L.		N	D	1	Th	He	A	Me	2	Kamal pokhari	268

125	Linderniaceae	*Bonnaya ciliata* (Colsm.) Spreng.		N	D	1	Th	He	A	Me, Fd	2, 14	Khaste	109
126	Lythraceae	*Cuphea procumbens* Ortega		E	D	1	He	He	P	Fo	1	Phewa	9
127	Lythraceae	*Woodfordia fruticosa* (L.) Kurz	*LC*	N	D	1	Ph	Sh	P	Me	2, 9	Begnas	403
128	Magnoliaceae	*Magnolia champaca* (L.) Baill. ex Pierre	*LC*	N	D	1	Ph	Tr	P	Me, Ti, Dy	1, 2	Maidi	267
129	Malvaceae	*Abelmoschus manihot* (L) Medik		N	D	1	Th	Sh	A	Me		Gunde	G133
130	Malvaceae	*Hibiscus rosa-sinensis* L		E	D	1	Ph	Sh	P	Me Fo	1	Khaste	K69
131	Malvaceae	*Sida acuta* Burm.f.		N	D	1	He	Sh	P	Me, Fi	1, 2	Kamal pokhari	280
132	Malvaceae	*Sida rhombifolia* L.		N	D	1	He	He	P	Me, Fi	1, 2	Kamal pokhari	281
133	Malvaceae	*Triumfetta rhomboidea* Jacq.		N	D	1	He	He	P	Me, Fd	1, 2	Niureni	34
134	Malvaceae	*Urena lobata* L.	*LC*	N	D	1	He	Sh	P	Me, Fi, Ta, Fr	1, 2, 15	Khaste	106
135	Melastomataceae	*Osbeckia nepalensis* Hook.		N	D	1	He	Sh	P	Me, Fd	1, 2	Phewa	31
136	Melastomataceae	*Osbeckia stellata* Buch.-Ham. ex D.Don		N	D	1	He	Sh	P	Me, Fd	1, 2	Phewa	32
137	Meliaceae	*Toona ciliata* M.Roem.	*LC*	N	D	1	Ph	Tr	P	Me, Ti	1, 2, 5	Begnas	B23
138	Menispermiaceae	*Cissampelos pareira* L.		N	D	1	Ph	He	P	Me, Fi	1, 2, 7, 13	Maidi	M207
139	Menyanthaceae	*Nymphoides indica* (L.) Kuntze	*LC*	N	M	1	Cr	He	P			Phewa	22
140	Moraceae	*Ficus benjamina* L	*Lc*	N	D	1	Ph	Tr	P	Me	1	Phewa	P67
141	Moraceae	*Ficus racemosa* L.	*LC*	N	D	1	Ph	Tr	P	Fd, Fw, Fo	1, 2	Maidi	M205
142	Moraceae	*Ficus religiosa* L		N	D	1	Ph	Tr	P	Me, Fd	1,2; 1	Phewa	P81
143	Moraceae	*Ficus sarmentosa* Buch.-Ham. ex Sm.		N	D	1	Ph	Tr	P	Fd, Fo	1, 2	Phewa	P140

144	Moraceae	*Ficus semicordata* Buch.-Ham. ex Sm.	*Lc*	N	D	1	Ph	Tr	P	Me, Fo, Fd	1,2;1;1	Rupa	R70
145	Myricaceae	*Morella esculenta* (Buch.-Ham. ex D.Don) I.M.Turner		N	D	1	Ph	Tr	P	Me, Fd	1, 2, 5, 13	Begnas	B23
146	Myrtaceae	*Melaleuca citrina* (Curtis) Dum. Cours.		E	D	1	Ph	Tr	P	Fo	1	Khaste	K67
147	Myrtaceae	*Syzygium cumini* (L.) Skeels	*LC*	N	D	1	Ph	Tr	P	Me, Ta, Dy	1, 2	Rupa	284
148	Nelumbonaceae	*Nelumbo nucifera* Gaertn.		N	M	1	Cr	He	P	Fd, Me, Ri	1, 2, 4, 6, 9	Kamal pokhari	288
149	Nymphaeaceae	*Nymphaea rubra* Roxb. ex Salisb.	*LC*	N	M	1	Cr	He	P	Me	2	Phewa	P122
150	Oleaceae	*Fraxinus floribunda* Wall.	*LC*	N	D	1	Ph	Tr	P	Me	1, 2	Rupa	291
151	Oleaceae	*Jasminum multiflorum* Andrews		N	D	1	Ch	He	P	Me, Or, Ri	1, 2	Deepang	15
152	Onagraceae	*Ludwigia adscendens* (L.) H.Hara	*LC*	N	D	1	He	He	P	Me	1, 2	Maidi	297
153	Onagraceae	*Ludwigia hyssopifolia* (G.Don) Exell	*LC*	E	D	1	Ch	He	P	Me	2	Kamal pokhari	32
154	Orchidaceae	*Apostasia wallichii* R.Br.		N	M	1	He	He	P			Dipang	D151
155	Orchidaceae	*Bulbophyllum affine* Wall. ex Lindl.		N	M	1	Ph	He	P			Maidi	147 M
156	Orchidaceae	*Bulbophyllum careyanum*(Hook.) Spreng.		N	M	1	Ph	He	P			Maidi	302
157	Orchidaceae	*Rhynchostylis retusa* (L.) Blume		N	M	1	Ph	He	P	Me	1, 2	Maidi	303
158	Orchidaceae	*Zeuxine strateumatica* (L.) Schltr.	*LC*	N	M	1	Cr	He	P			Maidi	211 Maidi
159	Orobanchaceae	*Lindenbergia indica* Vatke	*LC*	N	D	1	He	He	p	Me	1, 2	Phewa	25
160	Oxalidaceae	*Oxalis corniculata* L.		E	D	1	Th	He	A	Fd, Me	1, 2, 4, 6, 8, 12	Phewa	303

161	Oxalidaceae	*Oxalis latifolia* Kunth		E	D	1	Th	He	A			Kamal pokhari	K134
162	Pentaphyllaceae	*Eurya cerasifolia* (D.Don) Kobuski		N	D	1	Ph	Tr	P	Fd	1	Rupa lake	R63
163	Phyllanthaceae	*Phyllanthus emblica* L	*LC*	N	D	1	Ph	Tr	P	Me		Begnas	B31
164	Phyllanthaceae	*Phyllanthus urinaria* L.		N	D	1	He	He	P	Me	2, 12	phewa	304
165	Phyllanthaceae	*Phyllanthus virgatus* G.Forst		N	D	1	He	Sh	P			Rupa	312
166	Plantaginaceae	*Limnophila chinensis* (Osbeck) Merr.	*LC*	N	D	1	Th	He	A			Kamal pokhari	61
167	Plantaginaceae	*Limnophila sessiliflora* Blume	*LC*	N	D	1	Th	He	A			Phewa	P124
168	Poaceae	*Arthraxon hispidus* (Thunb.) Makino		N	M	1	Cr	He	P			Phewa	48
169	Poaceae	*Brachiaria villosa* (Lam.) A.Camus		N	M	1	Cr	He	P			Phewa	P123
170	Poaceae	*Cenchrus purpureus* (Schumach.) Morrone	*LC*	E	M	1	Cr	He	P			Khaste	96
171	Poaceae	*Cymbopogon pendulus* (Nees ex Steud.) W.Watson		N	M	1	Cr	He	P			Rupa	314
172	Poceae	*Cynodon dactylon* (L.) Pers.		N	M	1	He	He	P	Me	1,2	Phewa	P83
173	Poaceae	*Digitaria ciliaris* (Retz.) Koeler		N	M	1	Cr	He	P	Fo	1	Phewa	325
174	Poaceae	*Eleusine indica* (L.) Gaertn.	*LC*	N	M	1	Th	He	A	Me	2, 12	Kamal pokhari	323
175	Poaceae	*Eragrostis atrovirens* (Desf.) Trin. ex Steud.	*LC*	N	M	1	Th	He	A			Gunde	327
176	Poaceae	*Eragrostis tenella* (L.) P.Beauv. ex Roem. & Schult.		N	M	1	Th	He	A	Fr	1, 12	Gunde	G120
177	Poaceae	*Eragrostis unioloides* (Retz.) Nees ex Steud.	*LC*	N	M	1	Th	He	A	Fr	1	Gunde	G121
178	Poaceae	*Imperata cylindrica* (L.) P.Beauv.		N	M	1	Cr	He	P	Me	1, 2, 12	Dipang	D 153
179	Poaceae	*Leersia hexandra* Sw.	*LC*	E	M	4	Cr	He	P	Me, Fr	1, 2, 4, 14	phewa	330

180	Poaceae	*Microstegium fasciculatum* (L.) Henrard		N	M	1	Th	He	A	Fo	1	Phewa	8
181	Poaceae	*Oryza rufipogon* Griff.	*LC*	N	M	1	Cr	He	P			Phewa	26
182	Poaceae	*Panicum miliaceum* L.		N	M	1	Th	He	A	Fr	1	Phewa	57
183	Poaceae	*Paspalum dilatatum* Poir.		E	M	1	Cr	He	P	Fr	9	Phewa	45
184	Poaceae	*Paspalum scrobiculatum* L.	*LC*	N	M	1	Th	He	A	Fr, Me	1, 2, 9	Phewa	P103
185	Poaceae	*Sacciolepis indica* (L.) Chase	*LC*	N	M	1	Th	He	A	Fr	1	Khaste	97
186	Poaceae	*Setaria pumila* (Poir.) Roem. & Schult.		N	M	1	Cr	He	P	Fr	1, 12, 15	Khaste	K 113
187	Poaceae	*Sporobolus fertilis* (Steud.) Clayton		N	M	1	Cr	He	P			Phewa	23
188	Poaceae	*Themeda triandra* Forssk.		N	M	1	Cr	He	P			Niureni	N220
189	Poaceae	*Thysanolaena latifolia* (Roxb. ex Hornem.) Honda		N	M	1	He	Sh	P	Me, Fo, Fi	2; 1	Dipang	D76
190	Polygalaceae	*Salomonia cantoniensis* Lour.		N	D	1	Th	He	A	Me	1, 2	Khaste	346
191	Polygonaceae	*Persicaria barbata* (L.) H.Hara	*LC*	N	D	1	He	He	P	Fd, Me, Fp	1, 4, 6, 9	Phewa	21
192	Polygonaceae	*Persicaria capitata* (Buch.-Ham. ex D.Don) H.Gross		N	D	1	Cr	He	P	Me, Fo	1, 2	Rupa	216
193	Polygonaceae	*Persicaria hydropiper* (L.) Spach	*LC*	N	D	1	Th	He	A	Me, Fp	1, 2, 4, 9, 14, 15	Phewa	57
194	Polygonaceae	*Persicaria lapathifolia* (L.) Delarbre	*LC*	N	D	1	Th	He	A			Phewa	21
195	Polygonaceae	*Persicaria perfoliata* (L.) H.Gross		N	D	1	Th	He	A	Fd, Me, Fr	1, 2	Kamal pokhari	72
196	Polygonaceae	*Persicaria posumbu* (Buch.-Ham. ex D.Don) H.Gross		N	D	1	Th	He	A			Maidi	M112
197	Polygonaceae	*Polygonum plebejum* R.Br.		N	D	4	Th	He	A	Fd, Me	1, 2	Kamal pokhari	31

198	Polygonaceae	*Koenigia campanulata* (Hook.fil.) T.M. Schust. & Reveal		N	D	1	He	He	P	Fd	1, 2	Niureni	95
199	Pontederiaceae	*Eichhornia crassipes* (Mart.) Solms		E	M	1	Cr	He	P	Fd, Gm	4, 9	Phewa	31
200	Pontederiaceae	*Pontederia hastata* L.		N	M	1	Cr	He	P	Fd, Me	1, 2, 14	Gunde	122
201	Potamogetonaceae	*Potamogetoncrispus* L		N	M	1	Cr	He	P			Kamal pokhari	355
202	Primulaceae	*Maesa macrophylla* Wall. ex Roxb.		N	D	1	Ph	Sh	P	Me	1, 2	Rupa	R162
203	Primulaceae	*Maesa chisia* D Don		N	D	1	Ch	Sh	P	Me, Fd, Fi	1	Maidi	M83
204	Ranunculaceae	*Ranunculus sceleratus* L.	*LC*	N	D		Th	Th	A	Fd, Me	1, 2, 4, 6, 9	Kamal pokhari	28
205	Rosaceae	*Rubus ellipticus* Sm.	*LC*	N	D	1	Ch	Sh	P	Fd, Me, Fo	1, 2	Phewa	366
206	Rosaceae	*Rubus kumaonensis* Balakr.		N	D	1	Ch	Sh	P			Maidi	M119
207	Rosaceae	*Potentilla indica* (Andr.) Wolf		N	D	1	He	He	P	Fd, Me	1, 2	Maidi	M120
208	Rosaceae	*Pyracantha crenulata* (D.Don) M.Roem.		N	D	1	Ch	Sh	P	Md; Fo	1,2	Rupa	R64
209	Rubiaceae	*Dimetia scandens* (Roxb.) R.J.Wang		N	D	1	He	He	P	Me, Fo	1, 2	Begnas	B25
210	Rubiaceae	*Exallage auricularia* (L.) Bremek.		N	D	1	He	He	P			Gunde	G231
211	Rubiaceae	*Galium aparine* L.		N	D	1	Th	He	A	Me	1, 2	Phewa	130
212	Rubiaceae	*Knoxia sumatrensis* (Retz.) DC.		N	D	1	He	He	P			Phewa	367
213	Rubiaceae	*Mussaenda frondosa* L.		N	D	1	Ch	Sh	P	Me	1	Maidi	M84
214	Rubiaceae	*Oldenlandia corymbosa* L.	*LC*	N	D	1	Th	He	A			Rupa	R167
215	Rubiaceae	*Scleromitrion verticillatum* (L.) R.J.Wang		N	D	1	He	He	P			Khaste	206
216	Rubiaceae	*Spermacoce alata* Aubl.		E	D	1	He	He	P	Me	10	Phewa	40

217	Solanaceae	*Datura metel* L.		E	D	1	Ph	Sh	P	Me	1, 2	Dipang	D227
218	Solanaceae	*Solanum nigrum* L.		N	D	1	He	He	P	Fd, Me	1, 2, 13	Phewa	29
219	Solanaceae	*Solanum torvum* Sw.		E	D	1	Ch	Sh	P	Fd, Me	1, 2	Phewa	57
220	Solanaceae	*Solanum virginianum* L.		N	D	1	He	Sh	P	Me	1	Kamalpokhari	K81
221	Theaceae	*Schima wallichii* (DC.) Korth.	*LC*	N	D	1	Ph	Tr	P	Me, Cn	1, 2, 5	Maidi	M200
222	Trapaceae	*Trapa natans* L.	*LC*	N	D	1	Cr	He	P	Me	2	Maidi	385
223	Urticaceae	*Boehmeria virgata* (G.Forst.) Guill.	*LC*	E	D	1	Ch	He	P	Me, Fi	1, 2	Phewa	14
224	Urticaceae	*Gonostegia hirta* (Blume ex Hassk.) Miq.		N	D	1	He	He	P	Fd, Me, Sa	1, 2, 7	Maidi	386
225	Urticaceae	*Pilea scripta* (Buch.-Ham. ex D.Don) Wedd.		N	D	1	He	He	P			Gunde	41
226	Urticaceae	*Pouzolzia zeylanica* (L.) Benn. & R.Br.		N	D	1	He	He	P	Fd, Me	1, 2	Kamal pokhari	105
227	Verbenaceae	*Lantana camara* L.		E	D	1	Ph	Sh	P	Fd, Me, He	1, 13	Rupa	R120
228	Vitaceae	*Cissus javana* DC.		N	D	1	Ph	He	P	Me, Fr	1, 2	Rupa	R127
229	Vitaceae	*Leea asiatica* (L.) Ridsdale		N	D	1	Ch	He	P	Fr		Rupa	R136
230	Zingiberaceae	*Hedychium ellipticum* Buch.-Ham. ex Sm.		N	M	1	He	He	P			Rupa	397

Abbreviations: N/E-Native exotic; RC-Raunkiear's classification, *i.e.* Ph-Phanerophyte, Ch-Chamaephyte, Cr-Cryptophyte, He-Hemicryptophyte, Th-Therophyte; H/S/T-Herb, shrub or tree; A/P-Annual/Perennial. Native range referece (NRR): 1 (POWO, www.plantsoftheworldonline.org/), 2 (Weeds of Australia, www.weeds.org.au), 3(www.eflora.org), 4(GRIIS, www.griis.org); Redlist categories are *LC* (Least concerned); D/M-Dicots & Monocots; IUCN categ-IUCN threatened categoriers.

Appendix II

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