INVASIVE ALIEN PLANT SPECIES IN WETLANDS OF KANCHANPUR DISTRICT, FAR WESTERN NEPAL

A Dissertation Submitted for the Partial Fulfillment of the Requirement for the Master's Degree in Science in Botany, Institute of Science and Technology, Tribhuvan University, Kathmandu, Nepal

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Batch: 2073/76

T.U. Reg. No. 5-2-61-62-2012

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August, 2020

ACKNOWLEDGEMENTS

First of all, I would like to express my sincere gratitude to my Supervisor Associate Prof. Dr. Bharat Babu Shrestha, for his encouragement, valuable comments, suggestions, guidance and continuous support throughout this research period which helped me to complete this work. I am also thankful to Head of Department, Prof. Dr. Ram Kailash Prasad Yadav for his academic and administrative support.

I am grateful to Ministry of Tourism, Industry, Forests and Environment, Far Western State, Dhangadi, Kailali, and President Chure- Terai Madesh Conservation Programme Khumultar, Lalitpur, Nepal for providing me financial support to conduct this research. I am thankful to Idea Wild for providing instrumental support for this work. Similarly, I am also thankful to Department of National Parks and Wildlife Conservation (DNPWC) and Suklaphanta National Park for giving me permission to carryout research work in Kalikich Tal of Suklaphanta National Park.

I am also grateful to Mr. Anil Kumar Chaudhary for helping me to make Geographic Information System (GIS) maps. I am also thankful to Dr. Chitra Bahadur Baniya for helping me in R analysis. I can't remain without thanking Mr. Khem Raj Pant, Technical Officer (Genetics and Plant breeding) at National Wheat Research Program, Bhairahawa, for his immense support during field work and for providing me technical support, valuable suggestions and guidance.

I am heartly thankful to my friend Yagya Raj Joshi for his help during field work. My thanks also goes to my friends Ashmita Dhami, Kanchan Upadhaya, Kaushlya Joshi, Manita KC, Manisha Basnet, Sunita Sharma and Tika Regmi for their help during field work, lab work and data analysis. I am also thankful to my seniors Mahesh Raj Bist, Bhawani Nyaupane, Suneeta Bhatta and Ganesh Joshi. Similarly, I am thankful to all seniors, juniors, colleagues and administrative staffs of Central Department of Botany and Central department of Environmental Science (T.U) for their direct and indirect support, co-operation for this work.

At last but not least, I express my gratitude to my parents Mr. Pramanand Bhatt and Mrs. Roopa Bhatt for their help during field work and their encouragement, care, love and never ending faith to me which gave me strength to complete this work. I am also thankful to my sister Arju Bhatt and brother Bipin Bhatt for their support throughout this work.

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ABBREVIATIONS AND ACRONYMS

asl	Above sea level
CBD	Convention on Biological Diversity
CCA	Canonical Correspondence Analysis
DCA	Detrended Correspondence Analysis
DHM	Department of Hydrology and Meteorology
DNPWC	Department of National Park and Wildlife Conservation
QGIS	Quantum Geography Information System
GPS	Global Positioning System
GoN	Government of Nepal
IAPS	Invasive Alien Plant Species
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature and Natural Resources
Max. / Min.	Maximum/ Minimum
MoFE	Ministry of Forests and Environment
s.d.	Standard Deviation
ssp	Subspecies
TUCH	Tribhuvan University Central Herbarium

ABSTRACT

Wetlands have a significant role in conservation of biodiversity and genetic resources but this important habitat has been degrading worldwide due to biological invasions and other anthropogenic activities. Successful management of wetland invasive plants requires a comprehensive information, including spatial distribution of invasive species, understanding the drivers of invasions, determining risk of invasion at currently unoccupied sites, and prioritizing control and management efforts. However, comprehensive study on the plant invasions in most of the wetland is still awaiting in Nepal. This study aimed to 1) identify invasive alien plant species (IAPS) invading wetlands of Kanchanpur district; 2) undertake spatial distribution mapping of IAPS in these wetlands; 3) prioritize major dispersal pathways of wetland IAPS for management; and 4) identify major drivers responsible for IAPS invasions in wetlands. This study was carried out in different 19 wetlands of Kanchanpur districts. Cover of IAPS were estimated visually; potential dispersal pathways of *Eichhornia crassipes* were identified by Focus Group Discussion with subsequent prioritization by scoring method; nitrogen and phosphorus content were measured in water samples; and major drivers of wetland invasions were identified by multivariate analyses. Of the six wetland IAPS found in Nepal, four were recorded in the wetlands of Kanchnapur district. Spatial distribution map of these four wetland IAPS was prepared by using geographical coordinates. The most frequently occurring and problematic IAPS were *Ipomoea carnea* ssp *fistulosa* with frequency 63% and *Eichhornia crassipes* with frequency 42%. Though the frequency of *Eichhornia crassipes* was less than that of *Ipomoea carnea* ssp *fistulosa*, *E. crassipes* was found to be dominant in terms of coverage. Intentional introduction of *E. crassipes* for feeding fishes was found to be major pathway of dispersal, followed by the intentional introduction for ornamental value, and by flooding. It has been found that 26% of the wetlands of Kanchanpur district were highly invaded (i.e., Cover of IAPS > 50%) by these IAPS, 42% were moderately invaded (Cover < 50%), and 31% were free of invasion. We found that variables such as the distance to road and settlements, nutrient content, elevation, and other disturbances such as grazing facilitate the plant invasions in wetlands. It has been found that lowland wetlands near road and settlements are at the highest risk of invasion from these species. Regular monitoring and proper management strategies can reduce and prevent their spread to the non-invaded wetlands.

Keywords: Wetland invasion, Dispersal pathways, Tarai, Wetland management

CHAPTER I: INTRODUCTION

1.1 Background

Alien species refers to a collection of plants and animals that have been moved or imported intentionally or unintentionally by humans from their natural habitat in new habitats (Sousa et al. 2011; Hornoy et al., 2011). Invasive species are considered second only to habitat loss as the greatest threat to biological diversity (CBD, 1992). Increasing trade and tourism associated with globalization and the expansion of the human population have facilitated the intentional and unintentional movements of species outside their natural boundaries (Levine and D'Antonio 2003, Hulme 2009). Many alien species have been introduced into new regions and of them, a small proportion have become invasive (Jeschke and Strayer 2014). Inland wetlands are especially vulnerable to plant invasions as they acts as landscape sinks where plant propagules and pollutants, including nutrient from upstream can accumulate (Zelder and Kercher 2004). Invasive plants can negatively affect wetland ecosystems by outcompeting native vegetation, reducing species diversity, decreasing wildlife habitat, reducing water quality, and altering nutrient cycling (Zelder and Kercher 2005).

Impacts of invasive species on native biota, communities and ecosystems have been widely acknowledged since the late 1950s (Elton, 1958; Lodge, 1993; Simberloff, 1996) and are now considered a growing threats of biodiversity (IPBES, 2018). Invasion by IAPS are a major drivers of global environmental change. IAPS have the potential to reduce biodiversity, affect entire ecosystems (Sala et al. 2000; Lodge, 2001) and impose high economic damage (Pimetel et al. 2000). Aquatic and terrestrial invasive species can disrupt the function of ecosystems, replace native species, and destroy human-oriented constructions such as fisheries (Simberloff et al. 2005). Invasive wetland plants reduce both the plant and animal diversity (Werner & Zelder, 2002). IAPS have persistent effects on habitat structure, biodiversity and food web functioning and also affect the productivity, nutrient cycling and microorganisms (Zelder & Kercher, 2004). IAPS that differ from native species in biomass and productivity can alter nutrient dynamics (Ravit et al. 2003).

Understanding how invasive species spread is of particular concern in the current era of globalization and rapid environmental change (Kelly et al. 2014). Human impact on global nutrient cycling can benefit invasive species (Dukes & Mooney, 1999; Galloway et al. 2008) and many native plant communities are susceptible to invasion by undesirable species under elevated nutrients (e.g. Nitrate & Phosphate) (Hunneke et al. 1990; Galatowitsch & Rosen 2004). Blooming industrial development has accelerated eutrophication in inlands waterways and also holds consequences for biological invaders. Nutrient in urban and industrial wastewater as well as in fertilizer, are increasingly being deposited into freshwater systems (Liu and Diamond 2005); which enhances invasions by introduced aquatic plants. The growth and reproduction of aquatic plants, such as *Eichhornia crassipes* (water hyacinth), have been repeatedly correlated with high concentration of nitrogen and phosphorous in eutrophic freshwater systems (Xie et al. 2004, Zaho et al. 2006). A fundamental challenge to invasion ecology is to determine what factors cause an exotic species to spread rapidly after the initial introduction (Kettenring et al. 2011). Understanding the ecological mechanisms governing plant invasions, such as nutrient enrichment can be used to improve invasive plant management.

Successful management of wetland invasive plants requires a comprehensive information, including mapping the current distribution of invasive species, understanding the drivers of invasions, determining risk of invasion at currently unoccupied sites, and prioritizing control and management efforts. Increase of transport due to trade and travel, new globalized patterns of consumption, and the transformation of native ecosystems have emerged as main drivers of biological invasions at global level (Seebans et al. 2013). In addition to these global drivers, drivers of plant invasion in wetlands may also include the land use practices in the surrounding landscape, connectivity with other wetlands, utilization of wetland resources by local communities, and human efforts to introduce invasive plants. Identifying drivers is necessary to understand the processes behind biological invasions, management of invasive species, and also to generate policy initiatives that address threats to biodiversity (Bradly and Marvin 2011). Developing a scientific basis for monitoring and managing invasive species and implementing measures to manage pathways to prevent introductions is one of the Convention on Biological Diversity Aichi Target 9 for 2020 (https://www.cbd.int/sp/targets). Because of the increased vulnerability of wetlands to invasion there is a need for innovative tools for IAPS monitoring and management. Detailed distribution data across large extents are important for successful invasive species management (Bradly and Marvin 2011). Identifying environmental factors that may increase the likelihood of invasion, and predicting areas vulnerable to invasion, is another important aspect of invasive species management in wetlands (Gallien et al. 2010, Jakubowski et al. 2010, Bradley and Marvin 2011).

Introduction of alien species is one of the major problems for the degradation of Nepal's wetlands. Many native species in wetland sites of Nepal have been threatened by Invasive alien plant species (IAPS) (Tiwari et al. 2005). Invasions by alien species like *Eichhornia crassipes* have been identified as one of the major threats to biodiversity and ecosystem health of tropical and subtropical wetlands in Nepal (MFSC 2014). Accurate maps of distribution and abundance of IAPS are very important for risk assessment. Distribution mapping of IAPS in wetlands help in early detection and control of invasive plant species in wetlands.

1.2 Justification of Study

Wetlands are the most productive ecosystem on the earth and provides wide array of goods and services to the local communities as well as global communities (Doods et al. 2008). In spite of all these services provided by wetlands these are under various threats, and introduction of new IAPS and spread of existing alien species is considered as one of the major threat (IUCN, 2004). The importance of wetlands and their threats has been recognized in Nepal and different legislations have been formulated in Nepal's Wetland Policy 2013. But the policies itself cannot manage wetlands without its appropriate implementation (K.C et al. 2013). Thus there is greater need of review and strong implementation of the existing policies. Most of the wetlands of Nepal, particularly of tropical and subtropical regions, are witnessing a rapid invasion by aquatic invasive species with noticeable negative effects on biodiversity and livelihood of indigenous communities (MFSC 2014). Several IAPS have been reported in Nepal. Water hyacinth (*Eichhornia crassipes*), present in Nepal for many years, is widespread and is assumed to alter aquatic ecosystems to some extent (IUCN, 2004). Invasions by alien species like *Eichhornia crassipes* have been identified as one of the major threats to biodiversity and ecosystem health of tropical and subtropical wetlands in Nepal (MFSC 2014). IAPS such as *Ipomoea carnea* ssp. *fistulosa* is also becoming abundant in area near wetlands, thereby affecting habitats of water birds and other wetland dependent fauna as well. Therefore, management of wetland invasive plants has been given high priority in National Biodiversity Strategy and Action Plan 2014-2020 (MFSC 2014) as well as in National Ramsar Strategy and Action Plan 2018-2024 (MFE 2018). In the meantime, inadequate knowledge on the invasion processes, dispersal pathways, and other drivers of invasions are also identified as challenges for invasive species management in Nepal (MFSC 2014). Management of wetland invasive alien plants (IAPS) will requires a comprehensive information, including spatial distribution of invasive species, understanding the drivers of invasions, determining risk of invasion at currently unoccupied sites, and prioritizing control and management efforts. However, comprehensive study on the plant invasions in most of the wetland is still awaiting in Nepal. Therefore, it is urgent to undertake comprehensive study to determine the state of invasion in wetlands focusing on identify the major drivers of invasion in wetlands to initiate science-based management interventions through informed policy decision.

Invaded wetlands may serves as sources of propagules for non-invaded wetlands. Thus, such wetlands should be monitored timely to prevent introduction and spread of IAPS to non-invaded wetlands. This type of research will be also useful for the local level policy making bodies and wetlands managers. Results of this study will be useful for conservation and management of wetlands in Kanchanpur district and other similar regions in Nepal and the South Asia.

1.3 Objectives

The objectives of this study were:

- To enumerate the IAPS in different wetlands of Kanchanpur district, Far western Nepal.
- To map spatial distribution of wetland IAPS of Kanchanpur district, Far Western Nepal.
- To identify dispersal pathways of the IAPS in the study area
- To identify major drivers of plant invasions in wetlands

CHAPTER 2: LITERATURE REVIEW

2.1 Freshwater Wetlands

Freshwater invasions are of special concern, as freshwater ecosystems are among the most diverse and endangered ecosystems in the world (Dudgeon, et al. 2006), harboring more than a quarter of all freshwater flora and fauna threatened or recently extinct (UNEP, 2011). Although freshwater biodiversity provides wide variety of valuable economic goods and irreplaceable ecosystem services for humanity, it is increasingly threatened by overexploitation, pollution, water flow changes, habitat degradation and invasion by alien species (Dudgeon et al. 2006). Of these threats, the spread of invasive species appears the most severe (Zedler & Kercher, 2004; Olden et al. 2006) and causes considerable damage with cascading effects on structural organization and functional integrity of freshwater ecosystems.

Nepal's wetlands are the Himalayan water palace, unique, biological hotspots and supermarket of biodiversity (Pokharel & Nakamura 2010). Wetlands cover roughly five percent of Nepal's land area (DOAD, 1992). Nepal has approximately 6,000 rivers and rivulets, including permanent and seasonal rivers, streams and creeks (WECS, 2002). IUCN has identified 163 wetlands in 19 Terai districts covering 724,257 hectares in these districts (Bhandari, 1998a). An inventory carried out by ICIMOD (International Centre for Integrated Mountain Development) and UNEP (United Nations Environment Programme) listed 2,323 glacial lakes (75.70 km2) above 3,500 m in Nepal. These include 182 lakes of 8 hectares or more, and 2,141 with areas less than 8 hectares (ICIMOD, 2002). As in the rest of the world, wetlands in Nepal have significant human use values. The wetlands of Nepal also provide important habitats of biodiversity including several globally threatened and migratory species. However, these are under various threats, and biological invasions is one of the major threats (MFSC 2014).

2.2 Biological Invasions

Human-mediated dispersal of species into new regions is known as biological invasion. Biological invasions is homogenizing the world's biota (Winter et al. 2010). Invasive alien species are a subset of naturalized alien species which often spread widely from the point of introduction (Richardson et al. 2000; Blackburn et al. 2011) and cause negative impacts on the environment (Blackburn et al. 2014). According to CBD (2000) “an alien species whose introduction and/or spread threatens biological diversity”, are called as invasive alien species. Alien species that have established self-sustaining populations without direct human intervention are naturalized plants (Richardson et al. 2000, Pysek et al. 2004, Blackburn et al. 2011, Essl et al. 2018).

Invasive alien species (IAS) pose a significant threat to biodiversity. Invasive alien species alter ecosystem processes (Raizada et al. 2008), decrease native species abundance and richness via competition, predation, hybridization and indirect effects (Gaertner et al. 2009), change community structure (Hejda et al. 2009) and alter genetic diversity (Hulme et al. 2009). Increases in the number and spread of alien species appear to be strongly associated with substantial increases in the extent and volume of trade and transport, particularly over the last 25 years (Hulme, 2009).

Globally there are 13,168 naturalized plant species which is equivalent to 3.9% of the extant global flora (Kleunen, et al. 2015). According to Shrestha et al. 2018a, 179 exotic species of flowering plants (one gymnosperm sp. (*Pinus patula*) and 178 spp. of angiosperm) have been naturalized in Nepal. First assessment of Invasive Species in Nepal was done by IUCN from 2002-2003 and reported 21 IAPS (Tiwari et al. 2005). But recently, 26 species (23 dicotyledonous; 3 monocotyledonous) were recorded as invasive in Nepal (Shrestha, 2019). They belong to 14 families with the highest number of species in Asteraceae (10 spp.); followed by Fabaceae (3spp.) and Amaranthaceae (2spp.); the rest of families have one species each. Lowe et al. (2009) reported 100 of the world’s worst alien invasive species among them 4 IAPS are also reported from Nepal. They are *Eicchornia crassipes, Lantana camara, Mikania micrantha,* and *Chromolena odorata* (Shrestha 2016). Despite a significant increase in the number of national and international IAPS policy and plans (Butchart et al. 2010), spread of IAPS and mitigation of their effects have become major challenges for conservation.

2.3 Plant Invasions in Wetlands

Wetland invasion is a global issue and considered as a major component of global environmental change. Nutrient loading from agricultural runoff, solid wastes, industrial effluents, etc. facilitates the wetland invasion (Tyler et al. 2007). Biological invasions, as a major component of global change, have caused significant ecological and economic impacts on aquatic ecosystems, together with the impacts of other factors, such as global warming, eutrophication, and flooding (Hastwell et al. 2008). Significant wetlands of Nepal are covered by IAPS. Shrestha (2016) recorded six aquatic IAPS from various wetlands of Nepal; they are *Eicchornia crassipes, Alternanthera philoxeroides, Ipomoea carnea* ssp*. fistulosa, Pistia stratitoes, Myriophyllum aquaticum* and *Leersia hexandra*. *Eicchornia crassipes* belongs to 100 of the world worst invasive alien species (Lowe et al. 2009). It is the most problematic species that has invaded most wetlands of the Terai and mid-hills. This species occurs in all over Nepal extended from Kanchanpur to Jhapa districts in Terai as well as Kathmandu and Pokhara valleys in mid-hills (Tiwari et al. 2005).

Invasive alien plants are a significant environmental problem in wetland ecosystems (Richardson et al. 1997). IAPS increases biomass and evapotranspiration and thereby decrease both surface water runoff and groundwater recharge (Gorgens and Van Wilgen, 2004). Plant invasions significantly reduce biodiversity (Richardson and Van Wilgen, 2004). Several alien aquatic plant species are important invaders of rivers and water bodies in Nepal. These plants include *Eichhornia crassipes* (water hyacinth), *Pistia stratiotes* (water lettuce), *Alternanthera philoxeroides* (Alligator weed) *Myriophyllum aquaticum* (parrot's feather) and *Leersia hexandra* (Cut grass). *Myriophyllum aquaticum* has been reported only from the Kathmandu Valley (Tiwari et al. 2005), while other wetland species have become relatively widespread, forming dense mats in nutrient-rich aquatic ecosystems, either as floating weeds or rooted to shallow sediments or river banks (e.g., parrots feather). In Ramsar sites of Terai, Siwalik and Middle Mountains, the major IAPS are *Eichhonia crassipes*, *Ipomoea carnea* ssp. *fistulosa*, *Pistia stratiotes*, and *Lessersia hexandra* (Siwakoti and Karki, 2009; Shrestha et al. 2016). Invasions of aquatic weeds are associated with a range of impacts on water quality. Dense mats of these weeds can impede water flow, which increases the rate of siltation in water bodies, and inhibit the diffusion of air into water, resulting in lower concentrations of dissolved oxygen (Raid and Munshi, 1979; Tellez et al. 2008). Lower oxygen concentrations, combined with the increased amounts of organic detritus that collect beneath these floating mats, can increase sediment accumulation rates and accelerate eutrophication processes. Increased eutrophication can be lethal to fish, cause algal blooms and render the water toxic and uninhabitable for native animal and plant species (Pieterse, 1989).

2.4 Dispersal Pathways for Wetland Invasions

Pathways describe the processes that result in the introduction of alien species from one location to another. Alien species may arrive and enter a new region through three broad mechanisms: importation of a commodity, arrival of a transport vector, and/or natural spread from a neighboring region where the species is itself alien (Hulme et al. 2008). These three mechanisms result in six principal pathways: release, escape, contaminant, stowaway, corridor and unaided. Alien species transported as commodities may be introduced as a deliberate release or as an escape from captivity. Many species are not intentionally transported but arrive as a contaminant of a commodity, for example pathogens and pests. Stowaways are directly associated with human transport but arrive independently of a specific commodity, for example organisms transported in ballast water, cargo and airfreight. The corridor pathway highlights the role transport infrastructures play in the introduction of alien species. The unaided pathway describes situations where natural spread results in alien species arriving into a new region from a donor region where it is also alien (Hulme et al. 2008).

The Convention on Biological Diversity and its Strategic Plan for Biodiversity 2011–2020, supported by most of the world's countries, provide an overarching framework for all parties engaged in biodiversity management and policy development to save biodiversity and to enhance its benefits for people (https://www.cbd.int/sp/targets). One of the Strategic Plan's 20 Aichi Targets for achieving this aim concerns invasive alien species. Aichi biodiversity target focuses on the control or eradication of invasive alien species and the management of their introduction pathways. Specifically, meeting this target globally will require identification and prioritization of IAPS and Pathways, control or eradication of IAPS and measures to manage pathways to prevent their introduction and establishment (https://www.cbd.inat/sp/trgets/).

Invasions of alien species begin with the human-assisted movement of living individuals or propagules across biogeographic barriers (Blackburn et al. 2011). The accelerating worldwide movement of people and goods is driving the increasing rate at which biological invasions are occurring (e.g., Essl et al. 2011, Seebens et al. 2013). As a result, the contributions of specific pathways (i.e., any means that allows the entry or spread of an alien species into a region; FAO 2007) to introduction and subsequent invasion. Information on pathways is fundamental to alien-species risk assessments, management, monitoring, and surveillance (e.g., Clout and Williams 2009, Simberloff and Rejmanek 2011). For example, prevention strategies that consider pathways together with protocols focused on individual taxa are essential for reducing the arrival of new and damaging species in a particular region (e.g., Keller et al. 2009). To aid these efforts, a standardized pathway terminology and classification has been proposed (Hulme et al. 2008), and additional work has contributed to a better understanding of socioeconomic and other factors that affect the dissemination of propagules to and within new regions (Wilson et al. 2009).

An invasion pathway includes both the vector that carries an organism and the route along which it travels (Carlton and Ruiz 2005). Most basically, pathways can be distinguished either by whether they are deliberate (intentional) or accidental (unintentional) or in terms of the introduction mechanism: (a) the importation of a commodity, (b) the arrival of a transport vector, or (c) the natural spread from a region where the species is itself alien. These mechanisms can be divided into five pathways of introduction (release, escape, contaminant, stowaway, and corridor), and an additional category (unaided) to describe the natural spread of a species after its initial introduction into another territory (Hulme et al. 2008). These six categories defined by Hulme et al. 2008 have been further modified and developed into a hierarchical pathway classification, which was adopted by the Convention on Biological Diversity (CBD 2014). Thus for the management of biological invasions, identification and prioritization of dispersal pathways is indispensable, which is also mentioned in Convention on Biological Diversity, its current strategic plan, and specifically Aichi Target 9.

2.5 Drivers of Biological Invasions in Wetlands

The term driving forces refers to the changes in the social, economic or institutional domains that trigger the introduction, release, spread and establishment of invasive species. Alien species are, by definition, taxa that are introduced outside of their natural range either intentionally or unintentionally by human agency (IUCN 2000). Globalization and economic growth are widely recognized as important drivers of biological invasions (Essl et al. 2010). Human activities are the most important large scale determinants of biological invasions (Sharma et al. 2010). Introduction and spread of IAPS strongly depends on socioeconomic activities (Pysek et al. 2010; Essl et al. 2011) especially transport and tourism that are directly associated with the pathways of introduction e.g., ornamental trade & tourism (Hulme 2009) or the intensity of anthropogenic disturbance (Hulme 2009, Pysek et al. 2010, Spear et al. 2013, Dalmazzone and Giaccaria 2014). The effects of land- use factors are also known as important drivers of IAPS (Chytry et al. 2012, Mattingly and Orrock 2013).Human agency facilitates plant invasions by a broad array of pathways leading to species introduction to new regions and to subsequent invasion processes (Hodkinson & Thompson 1997; Kowarik 2003). Understanding the mechanisms of range expansion is a crucial prerequisite for both prevention and management of invasions (Pysek & Hulme 2005). The different studies demonstrated that increase of transport due to trade and travel, new globalized patterns of consumption and the transformation of hosting ecosystems emerge as main drivers of biological invasions.

IPCC (2007) identifies climate change as one of the factors for the emergence of invasive plant species. Increase in atmospheric temperature and carbon dioxide concentrations are likely to increase invasion of plant species because of their adaptability and ability to disturb a broad range of biogeographic conditions and environments (Mooney and Hobbs, 2000). Climatic similarity with the native region is considered an essential requirement for successful invasions (Thuiller et al. 2005, Ficetola et al. 2007, Gallien et al. 2010, Gallardo et al. 2015), but other abiotic factors can also play an important role. For instance, the propagule pressure is one of the key drivers of successful introduction of IAPS (Hulme 2009). Socioeconomic driving forces of biological invasions operate at different levels Le Maitre et al. (2004). Nearest distance to seaports, release of ballast water due to increasing global trade and transport play major role for all the aquatic (marine) current invasions worldwide (Gallardo and Aldridge 2013, Seebens et al. 2013). Moreover, nearest distance to airport and human population density (proxy of propagule pressure) were important predictors for terrestrial invasions (Bellerd et al. 2016. Biotic interactions or local climatic conditions are also possible drivers of invasions (Araujo and Luoto 2007, Kharouba et al. 2013, Wisz et al. 2013).

According to Catford et al. (2011), modification of the disturbance regime may facilitate invasion either indirectly by reducing the abundance of, and competition from, native species or directly by providing hydrological conditions to which IAPS are well adapted. Because fast economic development has been demonstrated to accelerate biological invasions (Lin et al. 2007), like other developing countries Nepal is also at high risk of invasions. Biological invasions, as well as their driving forces, operate at several scales and levels. Increase of some trends such as trade and tourism at the regional as well as global scale and the recurrent local patterns such as urbanization, fragmentation of ecosystems, etc. in different countries contribute to make biological invasions a global environmental problem. Thus, responses will depend on the level at which the action is required, helping the design of policy and management options.

2.6 Management of Invasive Plants in Wetlands

Invasive species can be enormously costly to manage, so resources must be committed to where they are likely to be most cost-effective (Krug et al. 2009). Major challenges arise from the large number of species involved, from distinguishing those that are invasive from those that are not, and the expense of acquiring and assessing the information needed to support decision making (Hulme 2009). Problems and opportunities must therefore be ranked or prioritized, according to the severity of actual and potential impacts on biodiversity and ecosystems (Carrasco et al. 2010; Kumschick et al. 2012**).** Prioritization to support cost-effective allocation of resources is part of decision-making at nearly every stage of the invasion process. For example, pathways may be prioritized for the purpose of preventing the introduction of harmful alien species (pre-invasion or pre-border). Once an invasive alien species (IAS) has arrived and is established (post-invasion or post-border), the focus moves to preventing its spread and to the protection of high priority sites. When a species with demonstrated impact threatens to spread, prioritization is focused on the feasibility of its eradication or containment. Preventing the introduction and further spread of IAPS seems to be the easiest way to reduce current and future negative impacts and management costs associated with IAPS (Maki and Galatowitsch, 2004).

2.7 Research Gap

The main gap is in unavailability of data regarding IAPS in freshwater ecosystems in Nepal. Their diversity, potential dispersal pathways, major drivers as well as their impacts are poorly understood and management practices are limited to mechanical removal only. There are a number of threats to lowland wetlands in Nepal. Most of the wetlands of Kanchanpur district are under degrading condition (DoF, 2017). Converting the wetlands into agricultural field especially paddy fields and grazing land was observed in some wetlands. Habitat destruction and degradation, introduction and spread of IAPS, loss of ecosystem integrity and depletion of species abundance and diversity are major threats of these wetlands. Thus for the long term and systematic management planning detailed information on diversity, distribution, potential dispersal pathways and drivers of introduction IAPS in wetlands are required. The importance of wetlands and their threats has been recognized in Nepal. Recognizing the importance of wetlands, different legislations have been formulated to restore the degraded condition of wetlands and to promote the wise use (IUCN, 2004). But the policies itself cannot manage the wetlands without its appropriate implementation. Generation of additional data on diversity, distribution and dispersal of IAPS will help to effectively promote policy into management practices.

CHAPTER 3: MATERIALS AND METHODS

3.1 Study Area

Study area map was prepared from geographic co-ordinates recorded in GPS from field survey and by compiling administrative boundary of Nepal from Land Resource Mapping Project (LRMP, 1986) and Land use map from ICIMOD, 2010.

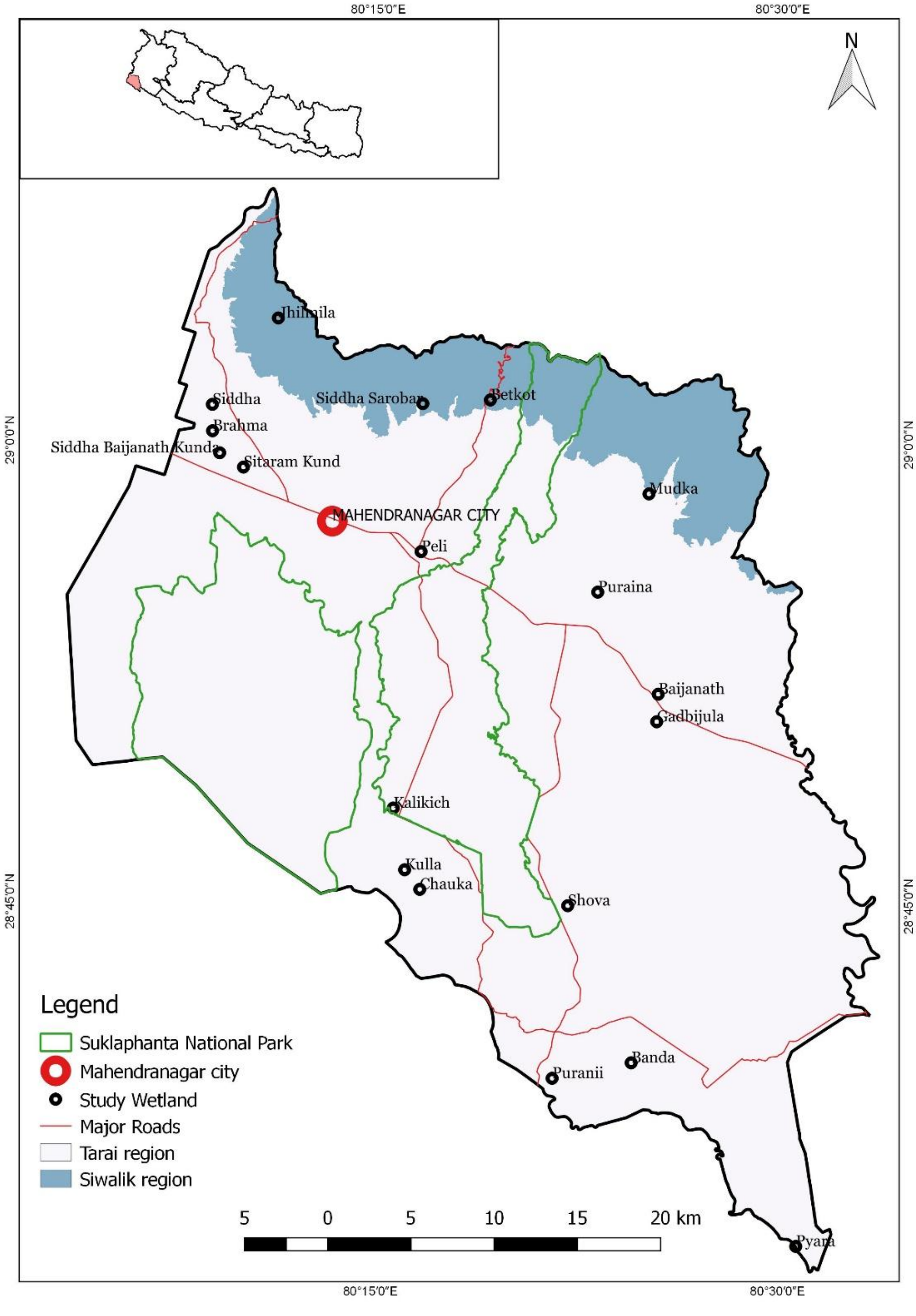

Figure 1. Map showing studied wetlands of Kanchanpur district

3.1.1 Geographical Location

The study was conducted in wetlands of Kanchanpur district of Far- western Nepal, Sudurpaschim Province, which has the total area of 1610 square Kilometer (1, 61,741 hectare). Topographically, the district is divided into three regions: Churia hills, Bhabar range and Terai Plain. The elevation ranges from 160m to 1528m above sea level (http://ddckanchanpur.gov.np/ne-brief-introduction). This research was carried out in both invaded and non- invaded wetlands of Kanchanpur district.

3.1.2 Climate

The climate of Kanchanpur district is dry tropical type with rainy summer and dry winter season. The climatic data of Mahendranagar station of the past 10 years from 2008 to 2018 shows that the mean monthly maximum temperature was 37.24°C in July and the mean monthly minimum temperature was 7.88°C in January (Figure 2). The mean annual precipitation was 2079 mm with the highest monthly precipitation in July at 659.3 mm and lowest in November at 5.2 mm. Climatic data of Mahendranagar station of Kanchanpur district for 10 years is given in **Appendix 1**.

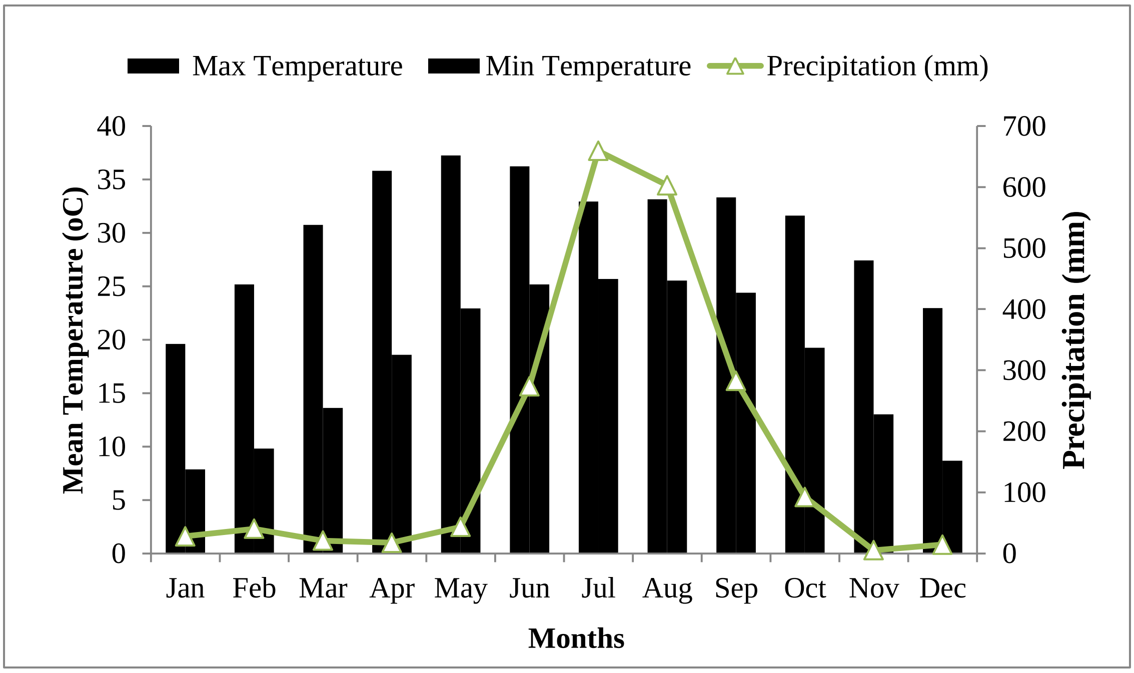

Figure 2. Ten years (2008-2018) average monthly temperature and precipitation data recorded at Mahendranagar Station of Kanchanpur district (Source: Department of Hydrology and Meteorology, Government of Nepal; data obtained on November, 2019)

3.1.3 Vegetation

Vegetation of Kanchanpur district is dominated by different forest types such as riverine deciduous forest, mixed deciduous forest and Sal and grassland. Most of the forest area of Kanchanpur district is covered with commercially and naturally important trees such as *Shorea robusta* (Sal), *Acacia catcheu* (Khayer), *Dalbergia sissoo* (Shishau) etc (Pant & Yadav, 2014). A number of other trees are associated with Sal such as *Terminalia chebula*, *T. bellirica*, *Adina cardifolia*, *Bombax cebia*, *Pterocarpous marsupium*, etc. Tropical deciduous riverine forest composed mainly of the *Acacia catechu* and *Dalbergia sisssoo*. Grassland of Suklaphanta is dominated by *Imperata cylindrica* supporting over a third of the world's remaining swamp deer population, with over 1000 animals (Henshaw 1994), together with Nepal's largest populations of Bengal florican (Poudyal et al. 2008) and hispid hare (Bell 1986).

3.1.4 Wetlands in Kanchanpur

Wetlands of Kanchanpur district are rich in biodiversity with diverse species of birds, mammals, herpeto fauna and fishes. There are a number of lakes with high religio-cultural values. Jhilmila Tal is one of remarkable wetland in Kanchanpur district with >25,000 annual visitors (DoF, 2017). Kalikich Tal in Kanchanpur district share boundaries with Suklaphanta Wildlife Reserve. DoF (2017) recorded 28 wetlands in Kanchanpur district. In our study we found total 31 wetlands and out of 31, 19 wetlands were selected for further study, because remaining 12 wetlands were excluded because these wetlands are found to be degraded due to different anthropogenic activities like land use change, drying due to drainage for crop production, conversion of wetlands into agricultural land (Nani Tal was found to be converted into agricultural land) and fish ponds (Pipermandi and Ajayan Kunda were dried by local people to make fish pond) was also observed in some wetlands. Similarily, wetland drying due to natural drought has also been observed in some wetlands (Newland lake, Jharna Tal, Naranga lake small, Naranga lake big, Ajinger lake, Gangla Tal and Kakri Tal). Naranga lake small, Naranga lake big, Ajinger lake, Gangla Tal and Kakri Tal were now converted into grazing land.

3.2 Field Data Collection

The study was conducted in two seasons; Pre-monsoon and monsoon. In first field visit i.e., pre-monsoon season preliminary survey was carried on all 31 wetlands of Kanchanpur district from May- 26 to June 8. Among these 31 wetlands only 19 wetlands were selected for detailed study. During field visit it has been found that some of the wetlands were lost and converted into other land types such as agricultural field, grazing land, fish pond, etc. Thus wetlands having high level of disturbance were excluded from study. Second detailed field survey was carried out from September 4 to September 14, 2019.

3.2.1 Inventory of Invasive Plants in Wetlands

For the documentation of IAPS from different wetlands a checklist of 26 IAPS with 6 wetland species reported from Nepal by Shrestha (2016) was used. For visual estimation of IAPS cover, wetlands smaller than 0.25 ha area was considered as single sampling unit. The larger wetlands (>0.25 ha) were divided into 50 m × 50 m grid in map by using GIS and each grid was considered as sampling unit. The coverage of every IAPS was recorded according to Daubenmire cover class method (Daubenmire 1959). Water sample was also collected from each grid for chloride, nitrate and phosphate analysis. Specimens of each IAPS was collected to prepare herbarium for the confirmation of identification and to deposit at Tribhuvan University Central Herbarium (TUCH) for future reference. Geographical locations (latitude, longitude, and elevation) of collection sites were recorded by using Global Positioning System (GPS).The herbarium specimens were identified to species level with the help of relevant literatures (e.g. Rajbhandari et al. (2016), Tiwari *et.al*. (2005)) and by comparing with specimens deposited at TUCH.

3.2.2 Water Sampling and Analysis

Nitrate and phosphate are the major nutrients which increases the likelihood of plant invasion in the wetlands and ultimately responsible for eutrophication of wetlands .Thus,from each wetland, single composite water sample was collected to determine nitrogen and phosphorus content by Phenol Disulphonic method and ammonium molybdate method (Trivedy and Goel, 1984). In smaller wetlands (<0.25 ha), three sub samples (500 ml) was collected at equidistant from the shoreline and 1L composite sample was collected from the mixture of three sub samples. The number of sub samples were higher in larger wetlands (>0.25 ha) depending on the size of the individual wetland. Collected water samples were analyzed in laboratory of the Central Department of Environmental Science, Tribhuwan University, Kirtipur, Kathmandu. The methods for chemical analysis of water samples are as follows.

pH: pH is negative logarithm of the hydrogen ion concentration. The pH scale of value extents from 0 (Very acidic) to 14 (Very alkaline) with the neutral value (pH=7). It was measured by using pH meter with electrode according to Trivedy and Goel (1986). For the determination of pH of water sample electrode was rinsed in deionized water and carefully wiped with tissue paper. pH meter was then calibrated in buffer solution of pH 4.0, 7.0, and 9. After that pH meter or electrode was placed into the water sample and pH value was recorded.

Chloride: Chloride generally present in natural water and wastewater. Chlorides may get into surface water from several source including rock containing chlorides, agricultural runoff, industrial effluents and domestic wastewater (Maharjan, 2014).It was measured based on Argentometric titration method (Trivedy and Goel, 1984). For the sample preparation, 50 ml filtered sample was taken in a conical flask and 3 drops of potassium dichromate was added on sample. Then, sample was titrated with silver nitrate (0.02N) solution until the color changed into reddish brown. The calculation formula is Cl (mg/L) =

$$\frac{\text{Volume of } AgNO_3 \text{ consumed} \times \text{normality of } AgNO_3 \times 35.5 \times 1000}{\text{Volume of sample taken}}$$

Nitrate: The Phenol disulphonic acid method (Trivedy and Goel, 1984) was used to estimate nitrate- nitrogen content in water sample. Water sample (50 ml) was taken in porcelain basin. Equivalent quantity of silver solution was added to remove chlorides. The solution was evaporated to dryness. The residue was cooled and 2 ml phenol disulphonic acid was added and was diluted to 50 ml then 6 ml of liquid ammonia was added to develop yellow color. Absorbance was measured using SSIUV2101 spectrophotometer at 410 nm wavelength. Each sample was analyzed three times and then average absorbance was calculated and concentration was calculated by calibration curve of standard solution. Nitrate stock and standard solution was prepared by dissolving 0.722g of KNO_3 in distilled water and made up to 1000ml in a volumetric flask. Then Calibration curve was prepared by diluting the stock solution with distilled water. The absorbance of standard solution was taken and graph was plotted between absorbance and concentration (Appendix VII). Finally nitrate concentration of water sample was calculated by equation $y = 0.076x + 0.046$, where y = absorbance of water sample and x is nitrate concentration.

Phosphate: Phosphate of a water sample was determined by ammonium molybdate method (Trivedy and Goel, 1984). Ammonium molybdate reacts with phosphate to form molybdophosphoric acid which is reduced to blue color complex by adding stannous chloride. Ammonium molybdate (2 ml) and 5 drops of stannous solution was added to 50 ml of water sample and absorbance was taken at 690 nm wavelength using SSIUV2101 spectrophotometer. Each sample was analyzed three times and then average absorbance was calculated and concentration was calculated by calibration curve of standard solution. The standard solution was prepared by dissolving 4.388gm of dried anhydrous potassium hydrogen phosphate (K_2HPO_4) in distilled water and volume was made 1litre in volumetric flask. Then Calibration curve was prepared by diluting the stock phosphate solution with distilled water (Appendix VI). Finally phosphate concentration of water sample was calculated by equation, $y = 0.8195x + 0.1092$ where y = absorbance of water sample and x is phosphate concentration.

3.2.3 Focus Group Discussion

This study documents the local knowledge and understanding about IAPS, and compiles community perceptions about the utilization values of wetlands, threats of wetlands, impacts of identified IAPS and year and purpose of their introduction of some problematic wetland IAPS, uses and benefits of IAPS and the management efforts carried out by local communities, Rural municipal and municipality for wetland management and prioritize them based on scoring method.

Focus group discussion (FGD) was carried out in a group of 6-8 people for understanding past and current status of wetland IAPS, utilization value of wetlands, threats of wetlands and impacts of IAPS. Of the 19 wetlands we conducted 17 FGDs, 1 for each wetland. In two wetlands namely; Sitaram Kunda and Sidhha Baijanath

Kund FGDs were not carried out, because these wetlands are situated far from the settlement due to which it was not possible to organize FGD. The FGDs were conducted in Nepali language; participants were first informed about the invasive species and their potential impacts on the environment and livelihoods. Colored photographs of 26 IAPS found in Nepal was distributed to participants to recognize IAPS to them. The major issues discussed during FGD were; (i) Overall knowledge about IAPS and the number and names of IAPS found in wetlands and surrounding landscapes. (ii) Utilization values of wetlands (iii) threats of wetlands (iv) Impacts of identified IAPS (v) Uses and benefits of IAPS found in study area and (v) The management efforts carried out by local communities, Rural municipal and Municipality for wetlands.

FGDs were also conducted for understanding the introduction and potential dispersal pathway. From FGDs only information on dispersal pathways of *Eichhornia crassipes* were obtained. People does not have exact information about the first arrival and introduction of other documented wetland IAPS. Thus potential dispersal pathway of only *Eichhornia crassipes* in study area were identified. The information obtained from FGD were analyzed by scoring method used by Shrestha et al. (2019). FGDs gave the information on potential dispersal pathways of *Eichhornia crassipes*. These pathways were ranked based on the people's perception. Based on respondent's ranking pathways were prioritized to find out possible pathways responsible for introduction and dispersal of *Eichhornia crassipes*. The main focus of survey was on how first time wetland IAPS arrived there? If they were introduced there intentionally, for what purpose were they introduced? And if they were introduced accidently from which agent or path they might have arrived there? Can the invaded lakes be source of propagules for further invasion to new lakes? These questionnaires help to identify introduction and dispersal pathway which will be important for pathway management.

3.3 Data Analysis

3.3.1 Spatial Mapping

The spatial distribution map of 4 wetland species recorded from wetlands of Kanchanpur district were prepared by using geographic co-ordinates recorded in GPS from field survey and by compiling Administrative boundary of Nepal and Physiographic Zones from LRMP (1986) with the help of QGIS software (www.osgeo.org/projects/qgis). In the maps presence of IAPS in wetlands along with their cover percentage were shown. Six cover classes of Daubenmire (1959) were grouped into four cover classes (0, upto 25%, 25-50%, 50% above) in order to simplify the data.

3.3.2 Frequency and Cover

Frequency and coverage of all IAPS were calculated. The frequency of each IAPS was calculated according to Zobel et al. (1987) by using following formula.

$$\text{Frequency (\%)} = \frac{\text{Number of wetlands in which species occurred}}{\text{Total no. of wetlands}} \times 100$$

Cover of each IAPS in wetlands was estimated by visual estimation method, considering each grid as 100% and by placing each species in the suitable cover class. We have considered cover values 1/2/3/4/5/6 for Daubenmire cover class 0-5%, 5-25%, 25-50%, 50-75%, 75-95%, 95-100% respectively and then mid-values for each cover class was taken and finally mean value was obtained.

$$\text{Cover of IAPS (\%)} = \frac{\text{Average mid-value of cover class of particular species}}{\text{Total no. of wetland}} \times 100$$

3.3.3 Prioritization of Dispersal Pathways

The information obtained from FGD were analyzed by scoring method used by Shrestha et al. (2019). Different possible pathways were ranked first, second, third and fourth in each FGD were given scores of 4, 3, 2, and 1 respectively. Thus for the each pathway, the total score was obtained by the summation of the scores obtained from FGDs and they were used to derive a percentage score to prevent data skewness. The pathway with the highest score percentage was considered as the major pathway responsible for introduction and dispersal of *Eichhornia crassipes* in study area. The total maximum possible score of each pathway was calculated by using following formula:

Total possible maximum score of each pathway = Total no. of wetlands in which *Eichhornia* present ×Highest Score (i.e., 4)

For example, Total maximum possible score for introduction of *Eichhornia* = 8×4

=32

Score percentage of introduction of *Eichhornia crassipes* as feed for fish

$$= \frac{\text{sum of score of introduction of } \textit{Eichhornia crassipes} \text{ as feed for fish}}{\text{Total maximum score}} \times 100$$

$$= 5/32 \times 100$$

$$=15.625\%$$

Using above method, Score of the remaining pathways were also calculated.

3.3.4 Uses of and threats to wetlands

Most of the data on uses and threats of wetlands, obtained from FGD were descriptive and some of them were analyzed by scoring and prioritization method used by Shrestha et al. (2019). FGDs among local people gave general scenarios of number of IAPS presence and their first arrival time in the study area. According to perception of participants of FGD, every socio-economic parameter i.e., Utilization value of wetlands, Wetland threats, Impact of IAPS taken were ranked as first, second, third, fourth, fifth, sixth and seventh in each FGD were given scores of seven, six, five, four, three, two, and one respectively and they were used to derive a percentage score to prevent data skewness. Scores of each Socio-economic parameter were summed up separately to obtain a total score of each parameter. Based on the total number of FGDs a maximum possible score for each parameter was calculated which was used to derive score percentage of each parameter. The total maximum possible score of each parameter was calculated by using following formula: Total possible maximum score of each parameter = Total number of wetlands × Highest score (i.e. 7).

For example,

Total maximum possible score for Inappropriate wetland management = 19×7 = 133

Total maximum possible score for each parameter is equal i.e., 133

Score % of each parameter was calculated as follows;

Score % for inappropriate wetland management

$$= \frac{\text{Sum of Score of inappropriate wetland management}}{\text{Total maximum possible score}} \times 100$$

$$=109/133 \times 100$$

$$=81.95$$

3.3.5 Impacts of IAPS on Wetland

Impacts of IAPS on wetland were identified by FGD. Impacts of IAPS like high economic cost to remove, effect to native flora and fauna, biodiversity loss, difficultly in fishing, impact on recreational values and loss of appetite in some animals were discussed during FGD and were prioritized by scoring method used by Shrestha et al., (2019).

3.3.6 Identification of Major Drivers

Multivariate analysis were performed to understand the relationship between distribution and coverage of aquatic IAPS and environmental variables and were presented by using CANOCO for windows 4.5. Coverage of wetland IAPS was taken as species data and environmental variables (i.e., Distance from road, distance from settlement, grazing, elevation, pH, nitrate, phosphate concentration) were taken as environmental data. Distance from road and distance from settlement were measured by using QGIS Software. Grazing was recorded during field survey based on intensity of grazing i.e., >80% grazed was recorded as high, 20-80% grazed was recorded as moderate and < 20% grazed was considered as low. Relative importance of the environmental variables and their impact on abundance of aquatic invasive alien species was derived from the Monte Carlo Permutation test Firstly, unconstrained gradient analysis, Detrended Correspondence Analysis (DCA), was done for aquatic invasive alien plant species, which revealed gradient length 2.7. Therefore, Canonical Correspondence Analysis (CCA) was done by using CANOCO version 4.5. All graphs were drawn by using CANODRAW 4.5.

CHAPTER 4: RESULTS

4.1 Inventory of Wetland Invasive Plants in Wetlands

Of the 6 wetland IAPS recorded from different wetlands of Nepal by Shrestha (2016), only 4 aquatic species i.e., *Eichhornia crassipes, Ipomoea carnea* ssp. *fistulosa, Pistia stratiotes* and *Alternanthera philoxeroides* were recorded from different wetlands of Kanchanpur district **(Table 1)**. Besides these wetland IAPS, other shoreline IAPS in wetlands were also documented **(Table 2)**.

Table 1. Wetland IAPS recorded from different wetlands of Kanchanpur district

S.N.	Name of species	Common Name	Local Name	Family	Native distribution	First report in Nepal*
1.	*Eichhornia crassipes* (Mart.) solms	Water hyacinth	Jalkumbhi	Pontederiaceae	S. America	1966
2	*Ipomoea carnea* ssp. *fistulosa* (Mart. Ex Choisy) D.F. Austin	Bush morning glory	Besaram	Convolvulaceae	Mexixo, C & S America	1966
3	*Alternanthera philoxeroides* (Mart.) Verdc.	Parrot's feather	Jalajambhu	Amaranthaceae	S America	1994
4	*Pistia stratiotes* L.	Water lettuce	Kumbhika	Araceae	S America	1952

*Source: Shrestha (2019)

Table 2. List of terrestrial IAPS recorded from different wetlands of Kanchanpur, district

S.N.	***Name of species***	**Common Name**	**Local Name**	**Family**	**Native distribution***	**First report in Nepal***
1.	*Ageratina adenophora* L.	Crotfton weed	Kalo banmara	Asteraceae	Mexico	1952
2.	*Ageratum houstonianum* Mill.	Blue Billygoat weed	Nilo gandhe	Asteraceae	Mexico & C America	
3.	*Ageratum conyzoides* L.	Billygoat	Gandhe	Asteraceae	C & S America	1910
4.	*Lantana camara* L.	Lantana	Kirne kanda	Verbenaceae	C & S America	1848
5.	*Xanthium strumarium* L.	Rough cockle- Bur	Bhede kuro	Asteracea	America	1952
6.	*Oxalis latifolia* Kunth.	Purple wood sorel	Chari amilo	Oxalidaceae	Mexico to S America	1954

*Shrestha (2019)

4.2 Distribution and Cover of IAPS

Spatial distribution map of 4 wetland species *Eicchornia crassipes*, *Ipomoea carnea* ssp. *fistulosa*, *Pistia stratiotes* and *Alternanthera philoxeroides* was prepared from geographic co-ordinates recorded during field survey and with the help of QGIS software **(Figure 3)**. Most of the wetlands of Kanchanpur district, especially wetlands situated in terai region of Kanchanpur district are invaded by IAPS. It has been observed that wetlands such as Baijanath Tal, Chauka Tal, Kalikich Tal, Kulla Tal and Pyara Tal situated very near to road and settlement have highest cover and IAPS richness. Thus it can be concluded that Richness of IAPS was high in wetlands situated near settlement and roadside.

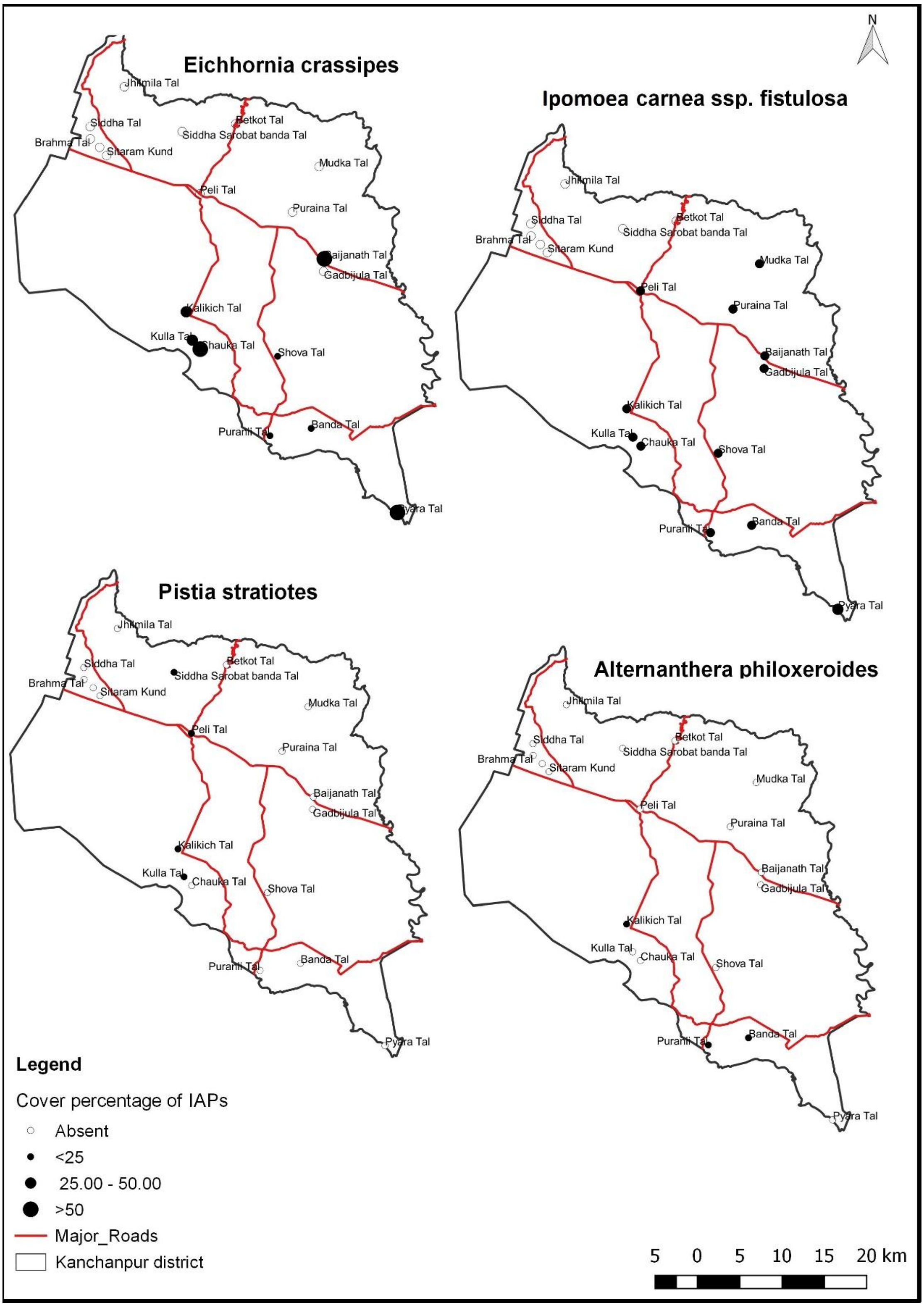

Figure 3. Spatial distribution of wetland IAPS of Kanchanpur district

Among 4 wetland IAPS recorded from different wetlands of Kanchanpur district, *Eichhornia crassipes* have highest cover i.e. 85% in Chauka Tal, 56.25% in Baijanath Tal, 50.2% in Pyara Tal, 32.5% in Kulla Tal and 32.2 % in Kalikich Tal, followed by *Ipomoea carnea* ssp. *fistulosa*, *Pistia stratiotes* and *Alternanthera philoxeroides* have least cover among all documented wetland IAPS in study area **(Appendix V)**.

4.3 Frequency of Wetland Invasive Alien Plant Species

The frequency of *Ipomoea carnea* ssp. *fistulosa* was found to be highest i.e., 63% followed by *Eichhornia crassipes* (42%), *Pistia stratiotes* (31%) and *Alternanthera philoxeroides* (16%). The most frequently occurring and problematic IAPS were *Eichhornia crassipes* and *Ipomoea carnea* subsp. *fistulosa.*

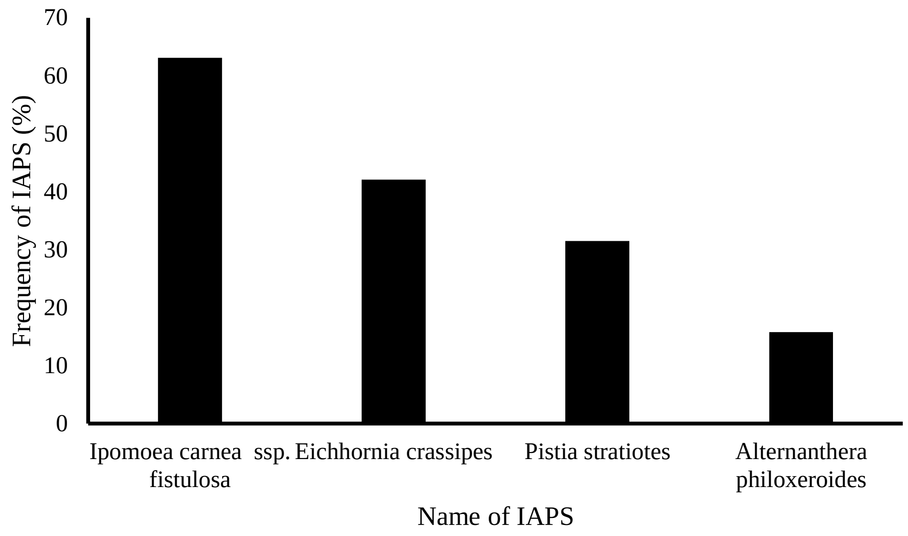

Figure 4. Frequency of IAPS in Wetlands of Kanchanpur district

4.4 Chemical properties of water

Different chemical properties of water samples were analyzed which are shown in table below.

Table 3. Variation of the selected chemical properties of water in the studied wetlants

S.N.	Name of Wetland	Number of subsample	pH	Chloride (mg/l)	Nitrate (mg/l)	Phosphate (mg/l)
1.	Baijanath Tal	3	6.8	21.3	260.7	0.82
2.	Gadbijula Tal	4	6.75	42.6	75	0.93
3.	Mudka Tal	3	6.87	35.5	2.5	0.21
4.	Puraina Tal	4	6.62	14.2	85	0.79
5.	Peli Tal	5	6.6	21.3	95.5	0.91
6.	Kalikich Tal	9	6.67	21.3	85.8	0.82
7.	Kulla Tal	6	6.88	14.2	269.6	0.77
8.	Chauka Tal	5	6.66	35.5	203.9	0.37
9.	Shova Tal	6	6.32	28.4	2.2	0.29
10.	Puranii Tal	8	6.11	35.5	46.6	0.14
11.	Banda Tal	8	6.92	21.3	21.4	0.21
12.	Pyara Tal	11	6.89	14.2	245.7	0.97
13.	Siddha sarobar banda Tal	4	6.35	14.2	269.7	0.15
14.	Bharma Tal	2	6.41	28.4	0.3	0.21
15.	Bedkot Tal	5	6.41	14.2	13.2	0.02
16.	Jhilmila Tal	4	6.21	21.3	26.9	0.09
17.	Siddha Tal	2	6.68	14.2	0.18	0.20
18.	Siddha baijanath Kunda	3	6.9	21.3	0.12	0.26
19.	Sitaram Kunda	2	6.98	14.2	0.09	0.32

4.5 Community perceptions

4.5.1 Dispersal Pathways

According to FGD, different pathways for *Eicchornia Crassipes* invasion including the introduced year for the wetlands were collected (Appendix XI). In majority of cases *Eichhornia crassipes was* introduced intentionally as a feed for fishes which was for 5 different wetlands i.e. Kulla Tal, Chauka Tal, Shova Tal, Banda Tal and Pyara Tal out of total 8 wetlands invaded by *Eichhornia crassipes*. Thus it was considered as most important pathway for dispersal of *Eichhornia crassipes* in different wetlands of Kanchanpur, district.

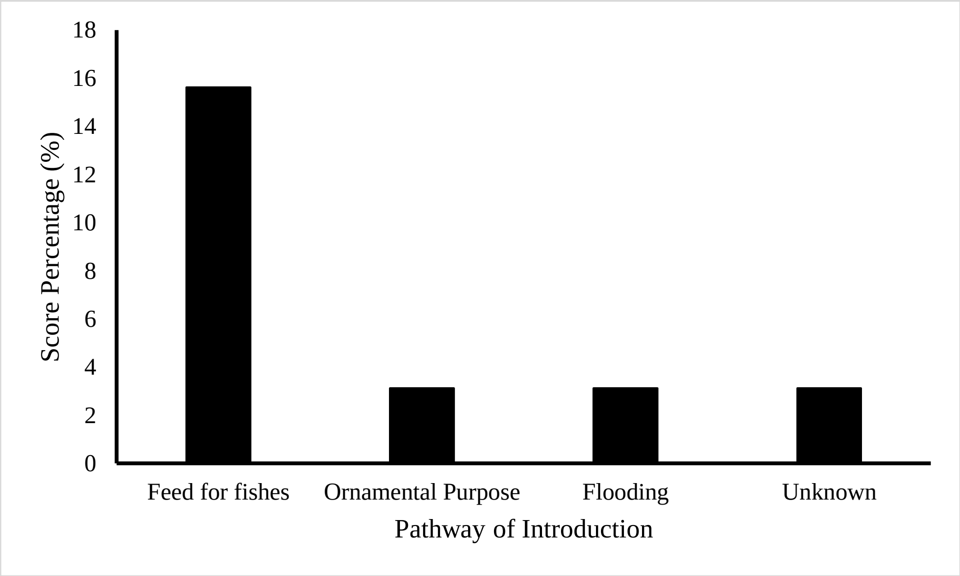

Fig 5. Bar- diagram showing score percentage of dispersal pathways of Eichhornia crassipes

The introduced pathway at Baijanath tal and Purani tal was for ornamental and flooding respectively. Of the 19 wetlands *Eichhornia crassipes* was found to be present in 8 wetlands. Among these 8 wetlands year of first introduction of *Eichhornia crassipes* in 4wetlands i.e., Kalikich, Kulla, Chauka and Puranii was not obtained through FGD, while year of introduction of *Eichhornia crassipes* in other 4 wetlands i.e., Baijanath, Shova, Pyara and Banda was found to be 2016, 2019, 1997 and 1998 respectively.

4.5.2 Use of and threats to wetlands

Among six utilization value of wetlands discussed during FGD, recreational activities was found to be most important with the highest score percentage i.e.,72% followed by fishing, religious activities, livestock, irrigation and boating with 42 , 41, 33, 21 and 3 score percentage respectively (Figure 6). Most of the wetlands of Kanchanpur, district are full of natural beauty and are picnic spots and other recreational activities. Wetlands situated at Chure range of district i.e., Jhilmila Tal, Bedkot Tal, Mudka Tal, Brhma Tal, Siddha Tal, Siddha-Baijanath Kunda, Sitaram kunda and Siddha Sarobar banda Tal are the religious places of district. Out of 19 wetlands, 11 are situated at terai region of district i.e. Baijanath Tal, Gadbijula Tal, Peli Tal, Kalikich Tal, Kulla Tal, Chauka Tal, Shova Tal, Puraina Tal, Purainii Tal, Banda Tal, Pyara Tal are used for fisheries and irrigation.

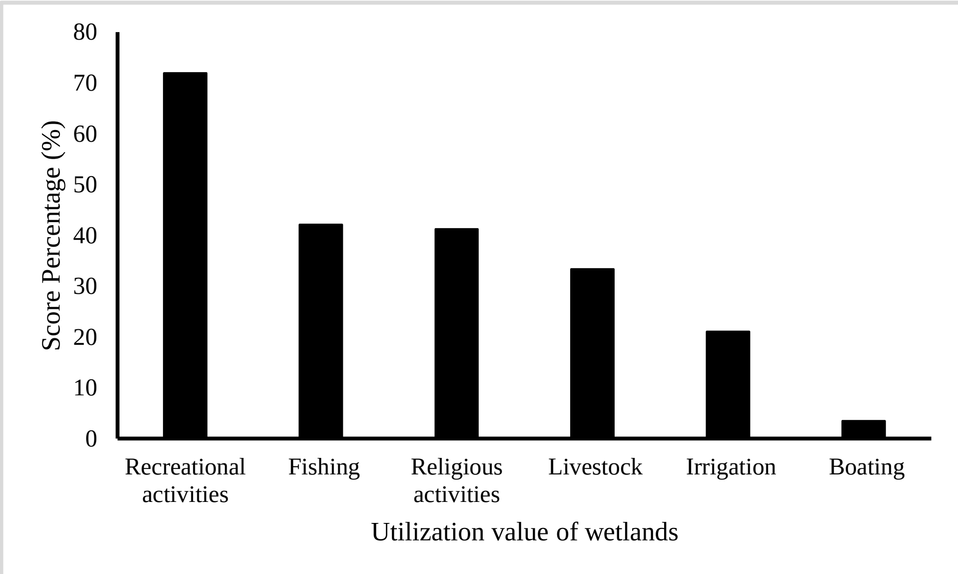

Figure 6. Local people's perception about Wetland utilization value

Among the seven wetland threats discussed during FGD, inappropriate wetland management have highest score with 82 % followed by wetland invasion, land use change, enchorachment, flood, pollution and connectivity to other water bodies with score percentage 30%, 29%, 28%, 27%, 21% and 9% respectively (Figure 7).

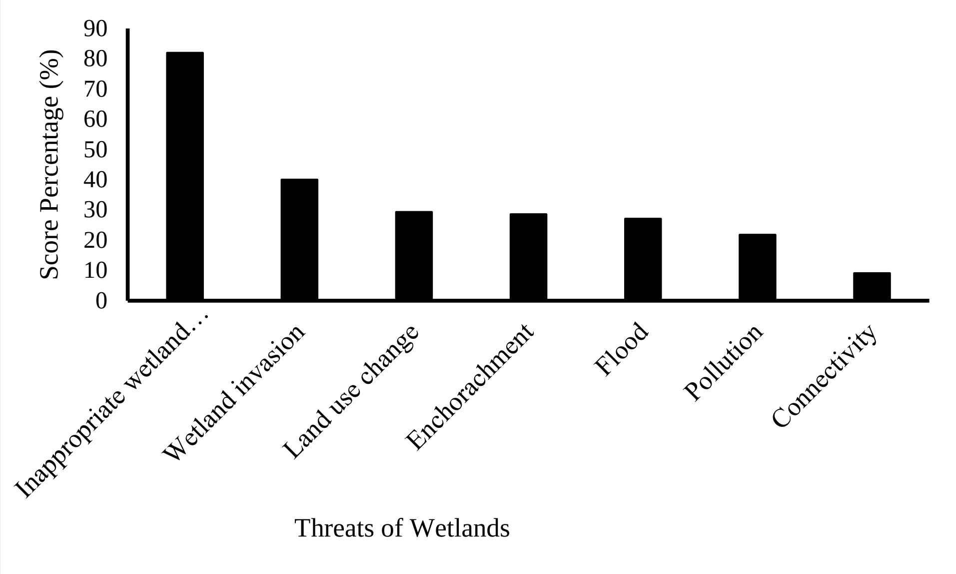

Figure 7. Score percentage of community perception of threats of Wetlands

4.5.3 Impacts of IAPS on Wetlands

Among six impacts of wetland IAPS discussed during FGD, high economic cost to remove IAPS in wetland have highest impact with percentage score 52.7 % followed by effect to native flora and fauna, biodiversity loss, difficulty in fishing, reduces the recreational value, loss of appetite in animals with percentage score 49 %, 37 %, 31 %, 25 % and 5 % respectively (Figure 8).

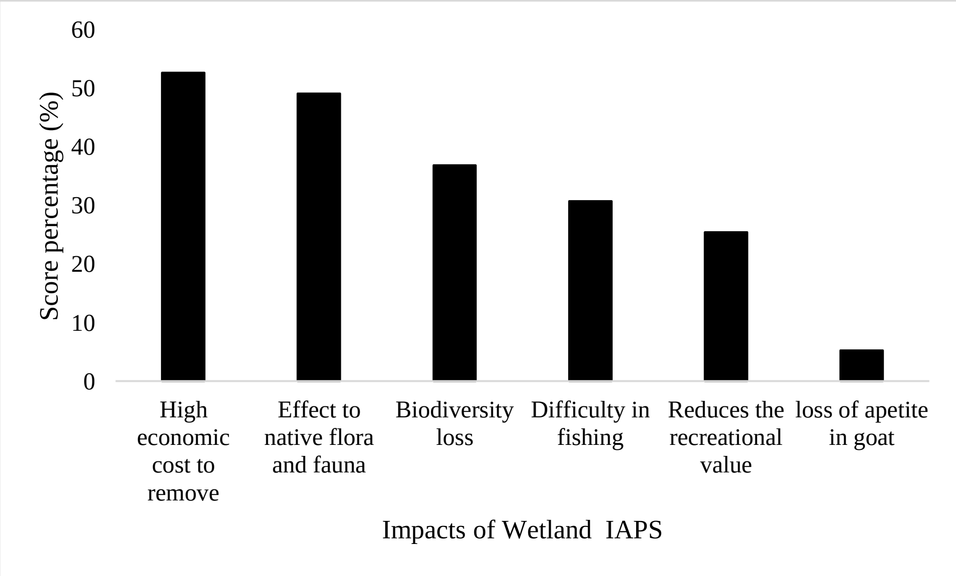

Figure 8. Community perception about impacts of Wetland IAPS

4.6 Major Drivers

Multivariate analysis was done in order to evaluate the effect of environmental variables such as distance from road, and distance from settlement, grazing, elevation, nitrate concentration, phosphate concentration, chloride, pH on abundance of IAPS and were presented by ordination analysis. Detrended Correspondence Analysis (DCA) ordination showed the relationship between species abundance, sampling plots and environmental variable with the Eigen values 0.469 and 0.179 on axes I and II respectively **(Table 4)**. The first axis of DCA have length of gradient 2.7 standard deviation (s.d) units. The data shows length of gradient more than 2.5 s.d. units. Thus direct gradient analysis i.e. Canonical Correspondence Analysis (CCA) was performed **(Table 5)**.

The CCA ordination explained the relationship of wetland invasive alien plant species with wetlands and environmental variables **(Figure 9)**. Nitrate concentration ($p=0.0105$), Phosphate concentration ($p= 0.0472$) and elevation ($p= 0.0365$) were the most significant variables that affect the distribution of aquatic invasive alien plant species in different wetlands **(Table 6)**. However, other environmental variables such as Chloride, pH, distance from road and distance from settlement and grazing had less significance over the distribution of aquatic invasive plant species in the present study.

Table 4. Detrended Correspondance Analysis (DCA) ordination summary for wetland IAPS and different environmental variables

Axes	**1**	**2**	**3**	**4**	**Total inertia**
Eigen values	0.47	0.18	0.02	0.00	1.122
Length of gradient cumulative %	2.79	2.78	1.50	0.00	
Variance of species data	4.18	57.7	59.2	0.0	
Sum of all Eigen values					1.122

Table 5. Canonical Correspondance Analysis (CCA) ordination summary for wetland IAPS and environmental variables

Aves	1	2	3	4	Total Inertia
Eigen values	0.42	0.32	0.19	0.13	1.122
Species-environment correlations	0.95	0.86	0.91	0.00	
Cumulative % variance of species data	37.9	66.0	82.7	94.6	
Cumulative % variance of Species-environment relation	45.8	79.8	100	0.0	
Sum of all Eigen values					1.122
Sum of all Canonical Eigen values					0.928

Table 6. Importance of environmental variables on distribution of wetland IAPS analyzed based on CCA analysis F and p values were obtained using Monte Carlo Permutation test with 9999 replicates.

S.N	Environmental Variables	Abbreviation	F-value	p-value *
1.	Elevation	El	4.185	**0.0365**
2.	Nitrate	Ni	4.034	**0.0105**
3.	Phosphate	Ps	2.932	**0.0472**
4.	Grazing	Gz	1.903	0.1573
5.	Chlorine	Cl	1.594	0.2051
6.	Distance from road	Dis_rd	1.194	0.2856
7.	Distance from settlement	Dis_Set	0.997	0.3802
8.	pH	pH	0.113	0.9236

***** Bold letter represents statistically significant values.

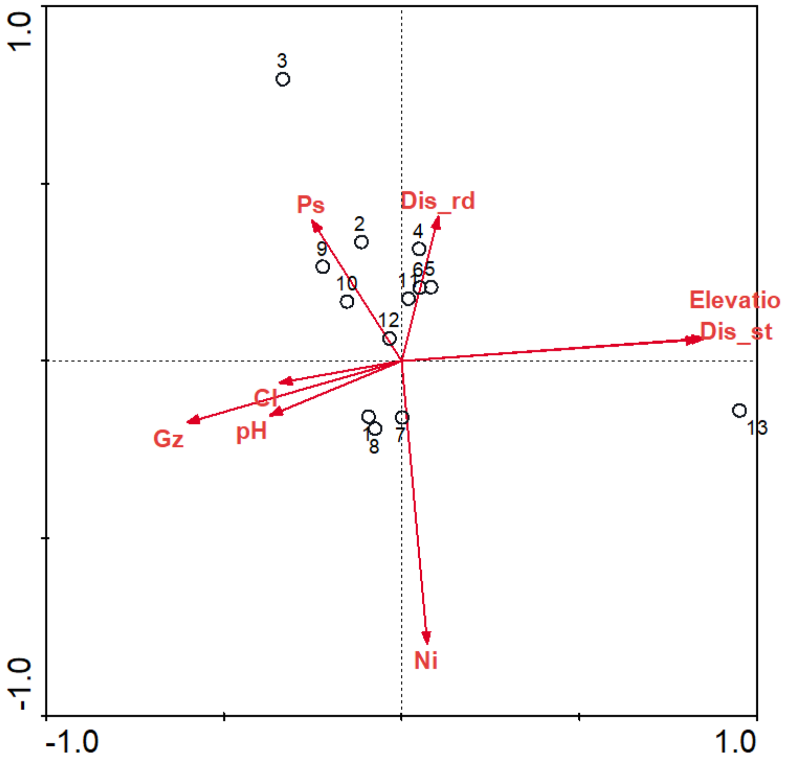

Figure 9. CCA bipolt for Wetland and environmental variables (Wetlands are represented by open circles with number 1- 19 and their names are presented in Table 3. Arrows indicate environmental variables that are significantly correlated with the distribution of IAPS).

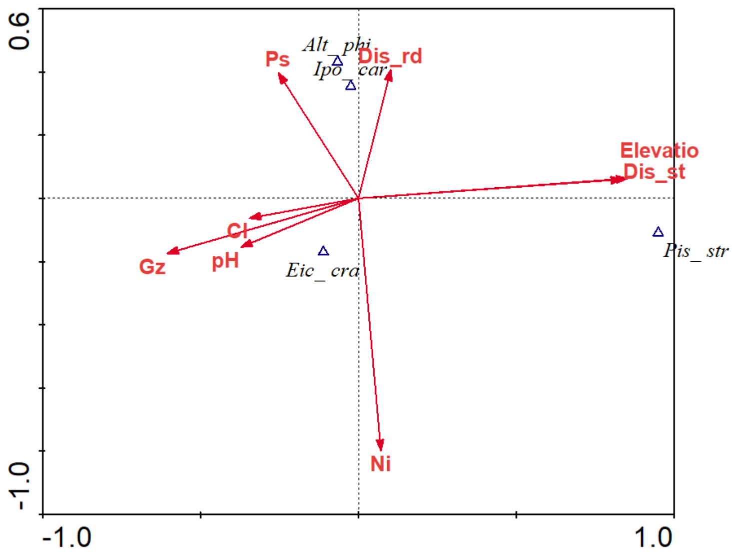

Figure 10. CCA biplot for Environmental Variables and Wetland IAPS. Species abbreviations represent concatenated forms of first three letters of generic and specific epithet, as presented in Annex (XIII).

Approximately, 37.9% variance of species data and 45.8% variance of species-environment relationship were explained by axis I while approximately 66% variance of species data and 79.8% of variance of species-environment relationship were explained by axis 2 **(Table 5)**.

From CCA diagram, it is clear that wetland far from settlement and at higher elevation have low intensity of grazing and chloride concentration is also low. Environmental variables like elevation and distance from settlement (Dis_st) and phosphate and Distance from road (Dis_rd) showed closer connection with each other‘s. Likewise, Chlorine (Cl), pH and grazing also showed nearer correlation with each other. This means correlated environmental variables have similar type of influence on distribution of aquatic invasive alien plant species.

CCA diagram showed that the probability of occurrence of *Eichhornia crassipes* (Eic_cra) increases with increase in concentration of nitrate (Ni), chloride (Cl) and higher intensity of grazing and decreases with increasing phosphate concentration. Whereas, the probability of occurrence of *Ipomoea carnea* ssp. *fistulosa* (Ipo_Car) seemed to increase with increasing phosphate concentration and in wetlands situated nearer to road. The probability of occurrence of *Pistia stratiotes* (Pis_str) was found to be high in wetlands nearer the settlement and in higher concentration of nitrate. *Pistia stratiotes* is also found at higher elevation **(Figure 10)**.

CHAPTER 5. DISCUSSION

5.1 Inventory of Wetland Invasive Alien Species

It has been found that 26% of the wetlands of Kanchanpur district were highly invaded (i.e., Cover of IAPS > 50%) by these IAPS, 42% were moderately invaded (cover <50%) and 31% were free of invasion. *Eichhornia crassipes*, a species that falls in list of 100 of the world's worst invasive species (Lowe et al., 2000), was dominant invasive species in study area by coverage. Several attributes of *Eichhornia crassipes* have contributed to its success as a worldwide invader of aquatic habitat. These includes a prolific capacity for multiplication through clonal reproduction, the high mobility of its free floating life form (Wright & Purcell 1995) and very high growth rates under appropriate environmental conditions (Zhang et al. 2010). Of the 6 IAPS recorded from different wetlands of Nepal by Shrestha (2019), 4 aquatic invasive species were recorded from different wetlands of Kanchanpur district; namely, *Eichhornia crassipes, Ipomoea carnea* ssp. *fistulosa, Pistia stratiotes* and *Alternanthera philoxeroides*. Almost all invaded wetlands of Kanchanpur district have *Ipomoea carnea,* which is followed by *E. crassipes, Pistia stratiotes* and *Alternanthera philoxeroides*. These IAPS are also recorded from the different Ramsar sites of Nepal. In Ramsar sites of Tarai, Siwalik and middle mountains, the major IAPS are *Eichhornia crassipes*, *Ipomoea carnea* ssp. *fistulosa*, *Pistia stratiotes* and *Leersia hexandra* (Siwakoti & Karki, 2009; Shrestha et al. 2016*). Eichhornia crassipes*, the most damaging wetland IAPS globally has been reported from different Ramsar sites of Nepal like Koshi Tappu, Beeshajari and Pokhara lake cluster but not from Mai Pokhari, Jagdishpur and Ghodaghodi lakes (Shrestha et al. 2019). *Eichhornia crassipes* is now present on all continents except Antarctica, and has invaded all tropical and sub- tropical countries as well as some parts of Mediterranean basin (Parsons & Cuthberston; 2011). In India also *Eichhornia crassipes* and *Alternanthera philoxeroides* are considered as serious aquatic IAPS (Masoodi & Farred; 2010). *Alternanthera philoxeroides* is known as invasive species in many parts of the world (Julien et al. 1995) is originally from South America (Vogt et al. 1979) and is now widespread throughout the world (Buckingham 1996). In India *Alternanthera philoxeroides* was reported for the first time from Kashmir (Pramod et al. 2008).Now, this species has been reported from Assam, Bihar, West Bengal, Tripura, Manipur, Andhra Pradesh, Karnataka, Maha- rashtra, Delhi & Punjab in India (Pramod et al. 2008). According to Jha (2017), different aquatic habitat of Jharkhand state of India are also infested by different type of aquatic weedy flora like *Eichhornia crassipes*, in association with other plant species like *Ipomoea* sp., *Pistia* sp., etc. adversely affecting the fish pond and agricultural fields. Similarly, in China, Weber (2008), identified 270 IAPS corresponding to 0.9% of the flora of China. In China the most widespread species included ornamentals like *Ipomoea purpurea.* According to Wu & Ding (2019), among 55 species of alien aquatic plants in China, 10 species are invasive such as *Eichhornia crassipes*, *Alternanthera philoxeroides*, and *Pistia stratiotes*. Disturbance can enhance the invasion of exotic species by increasing the availability of a limiting resources such as light, water or nutrients (Hobbs 1989). As these wetlands are disturbed by agricultural runoff, eutrophication, flooding; these disturbances helps in the dispersal of IAPS in wetlands and make suitable habitat for establishment.

5.2 Distribution Pattern

Spatial distribution mapping of IAPS enabled to identify the wetlands invaded by IAPS. Spatial information from maps & extensive field work identify *Eichhornia crassipes* as the most problematic species in invaded wetlands. Disturbed ecosystems are highly disturbed through grazing, fire and flooding which help in the dispersal of seeds and propagules on these ecosystems and make suitable habitat for establishment of IAPS (Siwakoti et al. 2016), by increasing the alien and invasive species cover in the disturbed habitat (Rodgers & Parker, 2003). Similar to these findings we also found that, disturbed wetlands had higher cover of IAPS. Richness of IAPS was high in wetlands situated near settlement and roadside is also similar to the finding of Spellerberg 1998; Parendes & Jones 2000; Trombulak & Frissell 2000. Roads represent the primary pathway for the introduction of alien plant species, especially for generalist species, with short life cycles and high reproductive rates. Roadsides act as reservoirs of alien plant propagules that can be liberated in disturbance events (Parendes & Jones 2000). Elevation and landuse also influences the abundance and distribution of IAPS (Pauchard & Alaback, 2004). Most alien species are invasive in human-disturbed landscapes at low elevations (Hobbs 2000). Plant propagules of IAPS can also reach to the wetlands at higher elevation and relatively undisturbed environments by natural means of dispersal. Thus wetlands at higher elevation and undisturbed environment can also be susceptible to invasion by alien plants (*Deferrari* & Naiman, 1994; Heckman 1999; Stohlgren et al. 1999; Pauchard et al. 2003). Similar to these findings, we also found that most of the studied wetlands situated at lower elevation are invaded by IAPS and Siddha Sarobar Banda Tal, which is situated at higher elevation (i.e., 414 m) in comparison to other wetlands was also found to be severely invaded by *Pistia stratiotes*.

Wetland IAPS threaten ecosystems due to their excessive growth and have both ecological and economic impacts (Husner et al., 2017). To minimize these impacts effective management of wetland IAPS is required. Prevention of the introduction of IAPS is considered the cost effective management option. The major pathway responsible for introduction of *Eichhornia crassipes* in study area was found to be use of this plant as fodder for fishes. There is a lack of awareness among local people and stakeholders about the cost of invasive species and the benefits of their prevention and control. Thus awareness program for fisherman who are mainly responsible for introduction of *Eichhornia crassipes* to non-invaded wetlands is highly recommended. Wetland invasion has influenced the livelihood of the local population who are dependent on the goods and services provided by the wetlands. Although, wetland IAPS of Kanchanpur district are causing evident damage to ecosystem and livelihood of local people, no any science based management of these IAPS has been initiated by national and regional government. However, some efforts have been made by communities, partners and local government for mechanical removal of *Eichhornia crassipes* in some wetlands (e.g., Kalikich Tal & Baijanath Tal). In Nepal physical method has been used to control of wetland IAPS. For example, *Eichhornia crassipes*, *Pistia stratiotes*, *Leersia hexandra* are being periodically removed from Beeshajari lake system (WWF Nepal, 2013) and *Eichhornia crassipes* from lake cluster of the Pokhara Valley. Use of chemicals for the control of IAPS in natural ecosystems has not been observed in Nepal. In agroecosystems, use of glyphosate and 2, 4-D for *Alternanthera philoxeroides* (Ranjit, 2013) has been recommended. The 2, 4-D has been also used to control *Ipomoea carnea* ssp. *fistulosa* in Jagdishpur Reservoir (Siwakoti & Karki, 2009). In Nepal, biological control agents have not been released officially through quarantine screening for any of the IAPS (Shrestha, 2019). From the field observation it has been found that *Eichhornia crassipes* have been spread covering most of the area of wetland in Kalikih Tal, Kulla Tal, Chauka Tal, Pyara Tal and Baijanth Tal. So in these wetlands complete eradication of *Eichhornia crassipes* seems impossible. So, we suggest the manual control of *Eichhornia crassipes* in these wetlands to maintain its low cover. But in wetlands like Shova Tal, Banda Tal, Puranii Tal, complete eradication of this species may be possible if effective management strategies will be applied. Thus it is time to develop and implement management strategy for wetland IAPS to prevent their further spread to non-invaded wetland and to maintain their low cover in wetlands where they have already invaded. Invaded wetlands should be prioritized for management in order to reduce its impact and to protect other wetlands of being invaded.

5.3 Dispersal Pathways

Dispersal is one of the most important factor in determining a species spatial distribution. Human mediated dispersal is a key process in plant invasions and identifying and assessing the dispersal pathway helps to set priorities in prevention and management (Carlton & Ruiz, 2005; Kowarik and Von der Lippe, 2007; Hulme et al. 2008). Global trade (particularly aquarium and ornamental trade) has been identified as the major pathway for aquatic alien plant introductions and the rapid spread of propagules and/or seedlings of invasive aquatic alien plants caused by trade may accelerate their invasions worldwide (Ding et al. 2008). Dispersal pathways for *Eichhornia crassipes* were identified by Focus Group Discussion (FGD). During the FGD, we mainly focuses on the time of first introduction of a wetland IAPS in study area. The minimum residence time, i.e., the date or the estimated date of introduction of an invasive alien plant species is acknowledged to be a highly relevant information in plant invasion studies (Pysek & Jarosik 2005, Lambdon et al. 2008). Although the exact date of the first introduction of *Eichhornia crassipes* is unknown in most of the wetlands, records of its use as an feed for fishes in Pyara Tal, Banda Tal and Shova Tal date back to 24, 23 and 1 years respectively and for ornamental purpose in Baijanath Tal about 4 years ago, while in other invaded wetlands i.e., Kalikich, Chauka and Kulla Tal the exact date of introduction of *Eichhornia* is unknown. *Eichhornia crassipes* is used as an ornamental plant in garden ponds. This attribute has certainly helped its spread (Center et al. 1999). Species dispersal is one of the major component of invasion process, so for proper management of wetland IAPS we need to know their dispersal.

From prioritization of these dispersal pathways obtained through FGD *Eichhornia crassipes* as a source of food for fishes is the most important pathway of dispersal from invaded area to non-invaded area. This shows that *Eichhornia crassipes* was either introduced intentionally (i.e., feed for fishes (16%) & for ornamental value (3%)) in some wetlands by local people and fisherman for their benefits and accidently (i.e., by flooding (3%)) in some wetlands and introduction was unknown for some wetlands (i.e., 3%). **(Fig. 5)**. In China also the most widespread wetland invasive species were introduced intentionally for Ornamental purpose or for other benefits. For example, three aquatic IAPS *Alternanthera philoxeroides*, *Eichhornia crassipes* and *Pistia stratiotes* have been planted extensively throughout China in the 1950s because they were regarded as beneficial (Ding & Xie, 1996). Thus the distribution of any plant species cannot be understood without knowing their history. After the wide spread of *Eichhornia crassipes* local peoples and fisherman have realized the negative impact of this species and physical removal has been practiced in some wetlands. But due to its prolific capacity for multiplication and high growth rate as well as its higher capacity to regenerate and spread, this is not being effective for its control. Similar techniques are also practiced in other wetlands of Nepal. For example, *Eichhornia crassipes* is being periodically removed from Bishajari lake system (a Ramsar site) of Chitwan, Phewa and Begnas lake of Pokhara valley, Taudaha of Kirtipur municipality in Kathmandu valley, etc. (Shrestha, 2016).

It has been found that local peoples are accelerating intentional introduction of IAPS for ornamental purpose, feeding fishes and also to prevent soil erosion. According to Wu & Ding (2019), 55 aquatic alien plant species were intentionally introduced into china for different purposes like ornamental, aquatic landscaping, water purification and forage through human involvement. However, 10 species among them (nearly 18%) later became invaders i.e., *Alternanthera philoxeroides, Eichhornia crassipes, Pistia stratiotes, Myriophyllum aquaticum,* etc. Among these *Alternanthera philoxeroides*, which is considered as one of the worst invader, has invaded 18 provinces followed by *Eichhornia crassipes*, which has invaded 16 provinces, *Pistia stratiotes* and *Myriophyllum aquaticum* also have wide distributions and occur in more than nine provinces, while in Nepal *Myriophyllum aquaticum* has been only reported from Kathmandu valley (Shrestha, 2016). Introduction of IAPS for ornamental purpose and for preventing soil erosion was also recorded in China. In expanding its horticultural industry, China introduced about 150 Ornamental plant species between 1997 and 2001 (Xu and Qiang 2004). A field survey from 2001 to 2002 indicated that 11 of these ornamental plant species had already escaped in Shanghi Suburb (Yin et al. 2003). Reichard 1997, also recorded introduction of majority of IAPS for ornamental purpose and few were for soil erosion control in United States. Species such as *Eichhornia crassipes* were introduced for aquatic gardening and escaped with serious consequences (Williams 1980). Because of the interconnected nature of many aquatic systems, species can spread quickly and become very expensive to control. Participants of FGDs were unaware of the dispersal pathway of the remaining three species, namely; *A. philoxeroides, Ipomoea carnea* ssp. *fistulosa* and *P. stratiotes*. However, intentional introduction of *P. stratiotes* for ornamental values and *I. carnea* ssp. *fistulosa* for controlling soil erosion along roadside and as hedge plant in agroecosystem have been reported in different parts of Nepal (Shrestha, 2016). It appears that local people and stakeholders in the study area were not aware of the environmental damage that *E. crassipes* would have after its introduction in wetlands. Inability of FGD participants to explain the introduction pathways of three of the four IAPS found in the study areas would also mean that local people do not pay much attention to the spread of these IAPS. Therefore, awareness program on introduction, dispersal, impact of IAPS and their prevention measures can play important role in preventing the introduction and spread of IAPS.

Thus, researchers should examine primary pathways of species introduction and local peoples should be aware of these pathways and impacts to prevent introduction of IAPS and their further spread.

5.4 Major Drivers

In the present study cover of IAPS shows a significant relation ($p<0.05$) with certain environmental variables such as elevation ($p= 0.0365$), nitrate ($p= 0.0105$), phosphate ($p= 0.0472$) **(Table 5)**. Thus we found that these parameters were primarily associated with the distribution of aquatic invasive alien plant species in the study area. We found that the cover of IAPS in the study area increases with increasing grazing is similar to finding of Anderson et al. (2015). The probability of occurrence of IAPS increases with decreasing distance from settlement area is similar to finding of Seipel et al., 2012. Land use, disturbance and climate are driving factors of alien plant invasion (Lonsdale 1999). The most relevant predictors of wetland invasion include factors that influence water quality and proximity to roads (Buchan and Padilla 2000); distance to nearest waterway, lake size and lake depth (Roley and Newman 2008); debris (Maezo et al. 2010); and native species present (Oslon et al. 2012). Although the environmental variables such as distance from road and distance from settlement affect the abundance and distribution of IAPS, in our study we found that these factors have relatively less effect to explain the distribution of IAPS in comparison to other environmental variables in wetlands. This finding is Similar to the finding of Bellerd et al. (2016). However, Bellerd et al. (2016), concluded that these environmental variables are important predictors for terrestrial invertebrates and plants.

Nitrate and Phosphate concentration of different wetlands of Kanchanpur district were examined to assess the effects of invasion on nitrate and phosphate concentration of wetlands. Increase of soil nutrients is contributing to the invasion by exotic plants (King & Buckney, 2002). In plant communities, nutrient enrichment of soil can increase susceptibility to invasion of exotic plants directly, independent of physical disturbance (Huenneke et al. 1990). Our result shows that cover of *Eichhornia crassipes* and *Pistia stratiotes* increase with increase in nitrate concentration of wetland water and cover of *Ipomoea carnea* ssp. *fistulosa* is found to be higher with increasing phosphate concentration of wetland water. Similar to our finding Nicholas et al. (2006), also found that sediments in the invaded wetland showed higher concentrations of soluble nutrients, including ammonium, nitrate and phosphate. Increased soil phosphorus creates conditions suitable for exotic invasion (Rose & Fair Weather 1997). A field survey in Southeast China found that *Alternanthera philoxeroides* dominates in microhabitats with high soil nutrients and water availability, whereas the cover of its native congeners *A. sessilis* was relatively high in habitats with low soil nutrient and water availability. High resource availability therefore appear to facilitate by *Alternanthera philoxeroides* (Pan et al. 2006). Elevation is an important indicator of microclimatic variation which may physiologically constrain alien plant invasion (Forcella & Harvey 1983; Wilson et al. 1992). Similar to this, our result also indicate that low elevation areas are more invaded than higher ones. Of the all studied wetlands, only one wetland (i.e., Siddha Sarobar Banda Tal) situated at higher elevation was found to be invaded by wetland IAPS (*Pistia stratiotes*). Richard et al. (2013) also found lake elevation as important predictor of IAPS richness. They also found that changing level of runoff, infiltration, temperature and nutrients (Phosphorus and nitrogen) amplify lake invaders.

5.5 Implications for management

Compiling alien species for a given country has proved to be a useful approach for understanding plant invasion pattern (Khuroo et al. 2007) and is the first step towards developing a management strategy for invasive species. Inventory and spatial mapping of IAPS with their potential dispersal pathway and drivers are necessary to draw a conclusions on the invasion process. There is a lack of awareness among local people and stakeholders about the impact of IAPS and benefit of their prevention and control. Thus an increase of awareness and knowledge of invasive species in Nepal is pre-requisite for setting up a national, regional and local management strategy. Intensified research on the ecology of invasive species in Nepal and the development of proper control techniques seems necessary. There is unavailability of data regarding diversity, potential dispersal pathways, major drivers as well as their impacts of IAPS in freshwater ecosystems and management practices are also limited to mechanical removal only. This study provides detailed information on diversity, distribution, potential dispersal pathways and drivers of introduction IAPS in study area which are required for the long term and systematic management planning in wetlands.

CHAPTER 6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Four wetland IAPS were recorded from different wetlands of Kanchanpur district. *Eichhornia crassipes* and *Ipomoea crassipes* ssp. *fistulosa* were found to be most abundant IAPS in study area. It has been found that 26% of the wetlands of Kanchanpur district were highly invaded (i.e., Cover of IAPS >50%) by these IAPS, 42 % were moderately invaded (Cover < 50%) and 31% were free of invasion. Of the severely invaded wetlands all are situated at lower elevation except Siddha Sarobar Banda Tal which is situated at 414m was severely invaded by *Pistia stratiotes*. Spatial distribution of IAPS in different wetlands is useful for identification of the highly invaded wetland. The major factors responsible for distribution of wetland IAPS were also identified. Elevation, phosphate and nitrate concentration of wetland water were found to be the major drivers of wetland invasion with significant p- value ($p < 0.05$). Intentional introduction of *Eichhornia crassipes* as a fodder for fishes was found to be major dispersal pathway (16%), followed by introduction for ornamental purpose, accidently by flooding each with 3% and for some wetland dispersal of *Eichhornia crassipes* was unknown. Our analysis provides empirical evidence that the introduction and spread of aquatic invaders is impacted by a multitude of environmental parameters and anthropogenic activities. Thus, effective early detection and rapid response program are essential for proper management of IAPS.

6.2 Recommendations

Based on the result of the study, this work strongly recommend the following points to control plant invasions in wetlands and management of IAPS in wetlands.

- Since intentional introduction by fish farmers was found to be a major dispersal pathway of *Eichhornia crassipes* in the study area, educating these and other local communities of the potential risks associated with IAPS introduction is highly recommended to prevent IAPS invasion in the IAPS-free wetlands.
- Our data revealed that eutrophic lakes with high nutrient content were likely to have high abundance of IAPS. Thus, any effort to prevent wetland eutrophication is recommended, which may also indirectly help in IAPS control.

- Season round removal of IAPS should be practiced to reduce abundant cover of IAPS in wetlands.
- Regular monitoring should be carried out in wetlands so as to prevent the introduction of IAPS in non-invaded wetlands and to reduce the cover of IAPS in invaded wetlands.

- The community based education materials related to biological invasion should be promoted by the national and local government.

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APPENDICES

Appendix I. Climatological statistics of Mahendranagar Station

S.N	Months	Maximum Temperature	Minimum Temperature	Precipitation
1	Jan	19.599	7.873	28.04
2	Feb	25.164	9.808	40.17
3	Mar	30.755	13.613	20.88
4	Apr	35.803	18.598	17.38
5	May	37.245	22.923	43.42
6	Jun	36.246	25.184	273.41
7	Jul	32.942	25.674	659.29
8	Aug	33.1545	25.532	602.93
9	Sep	33.316	24.385	282.4
10	Oct	31.609	19.236	92.3
11	Nov	27.412	13.029	5.2
12	Dec	22.953	8.681	14.19

Source: (Source: Department of Hydrology and Meteorology, Government of Nepal; data obtained on November, 2019)

Appendix II. Field data collection sheet for identifying drivers of plant invasions in wetlands of Kanchanpur district, western Nepal

Field Data Sheet

SN: ……Date:…………...............**Name of Wetland:………………………………..**

Latitude (N):……………………….. Longitude (E): ………………………….…

Elevation (m)…………………… Slope……….…… Aspect …………………..

Nagarpalika/ Gaunpalika ……………………………Ward No………….……….…

Locality…………………………………………………………………..……..

East	West	North	South

Surrounding Land use

Recreational Activity

Recreational Activity	East	West	North	South
Picnic spot				
Resting spot				
Swimming				
Boating				
Fishing				

Grazing: Yes, No Intensity of grazing: Low/Moderate/High

* High; > 80% grazed or >80% Trampling area, Moderate; 20-80% grazed or 20-80% trampling area, Low; <20% grazed or <20% Trampling area

Other disturbance factors:

Distance from road (m): ……………………….

Distance from settlement (m): ………………………..

Water

Source:……………………..……..Outlet:…………………………..……..…

Estimated Depth (m): …………Connection with other water bodies: ………………

Enumeration of IAPS

S.N	Name of the species	Habitat	Phenology
1.	*Alternanthera philoxieroides*		
2.	*Eichhornia crassipes*		
3.	*Ipomoea carnea* ssp. *fistulosa*		
4.	*Leersia hexandra*		
5.	*Pistia stratiotes*		
6			
7			
8			
9			
10			
11			

Note: **Habit:** A (Aquatic), S (Shoreline and Shallow aquatic), T (Terrestrial)

Phenology: Fb (Floral bud), Fl (Flowering), Fr (Fruiting),Resprouting (Re), Senescence(Sn)

No of grids; ……..

Cover of species in different grids

Species	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	Average
Alt.phi.											
Eic.cra.											
Ipo.car											
Lee.hex											
Pis.str.											

Photo no. ………………………………..

Name of researcher: ……………………………

Appendix III. Field data collection sheet for Identification of potential dispersal pathways

SN: ……………Date…………….FGD start time…..………End time…………

Name of wetland …………………………Locality…………………………….

Wetland type…………………………Ownership………………………………..

Nagarpalika/ Gaunpalika………………Ward no… Locality…………………….

Management responsibility……………………………………………………

Wetland dependent community………………………………………………

Management plan: Yes/No

Date of management plan implementation……………………………………….

Implementing organization………………………………………………….

Focus group discussion

Questionnaire

1. **Utilization value of wetland**

S.N.	**Utilization**	**Priority order**
1.	Irrigation	
2.	Livestock	
3.	Swimming	
4.	Boating	
5.	Fishing	

***1- Highest/ Most important**

2. Threats of wetlands

S.N.	Threats	Priority order
1.	Land use change	
2.	Enchroachment	
3.	Pollution	
4.	Flood	
5.	Connectivity	
6.	Inappropriate wetland management	
7.	Wetland invasion	

3. How many aquatic IAPS present and what are they?

S.N.	Name of spp.	Present (+)	Absent (-)
1.	*Alternanthera philoxieroides*		
2.	*Eichhornia crassipes*		
3.	*Ipomoea carnea* ssp. *fistulosa*		
4.	*Leersia hexandra*		
5.	*Pistia stratiotes*		
6.			
7.			
8.			
9.			
10.			

4. How first time wetland IAPS arrived here? Intentionally or Accidently.

S.N	Species	Intentionally		Accidently
		Year of introduction	Purpose of introduction	Probable agent or pathway
1.	*Alt.phi.*			
2.	*Eic. Cras.*			
3.	*Ipo.car.*			
4.	*Lee. hex.*			
5.	*Pis. str.*			
6.				
7.				

5. Can the invaded lakes be source of propagules for further invasion to new wetlands? ....

6. What are the impact of IAPS?

S.N.	Impacts	Priority order
1.	High economic cost to remove	
2.	Effect to native flora and fauna	
3.	Biodiversity loss	
4.	Difficulty in fishing	
5.	Reduces the recreational value of Wetlands	
6.	Loss of appetite in livestocks	

7. How the local people use these IAPS?

8. Is there any control measures taken to control the spread of IAPS or not? Yes/ No

If yes what are they? ....

9. Details of Participants

S.N.	Name	Gen.	Edu.	Add.	Phone	Remark
1.						
2.						
3.						
4.						
5.						
6.						
7.						
8.						

Photo no……………………………………………………………………….

Name of Researcher………………………………………………………..

Appendix IV. Data collection sheet for water analysis

1. **Name of wetland:**

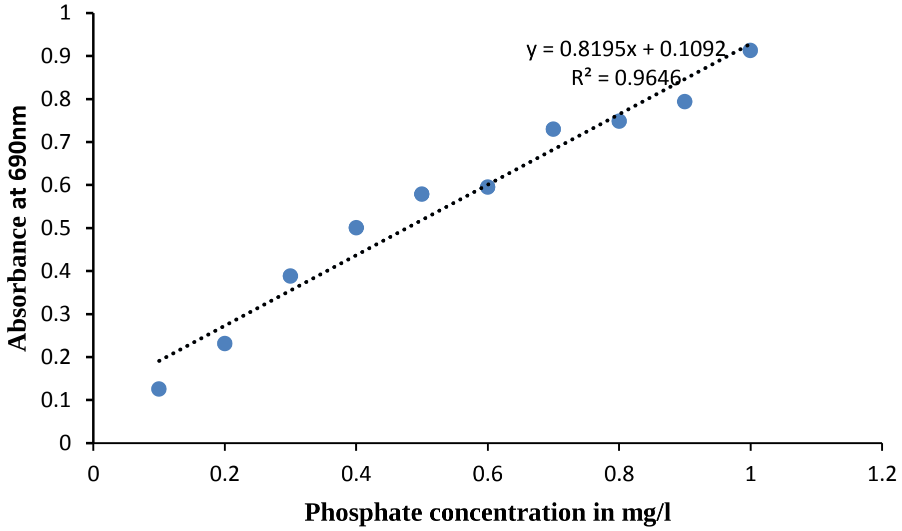
Date	Sample No.	Time
Longitude	Latitude	
No. of subsamples	PH	
Sample collector:		**Volume:**

Appendix V. Cover of wetland IAPS in different wetlands

S.N.	Name of Wetlands	Cover of wetland IAPS			
		Eichhornia crassipes	***Ipomoea carnea* ssp. *fistulosa***	***Pistia stratiotes***	***Alternanthera philoxeroides***
1.	Baijanath Tal	56.25	5	0	0
13.	Banda Tal	1.9	2.5	0	2.5
6.	Betkot Tal	0	0	0	0
15.	Brhma Tal	0	0	0	0
10.	Chauka Tal	85	1.5	0	0
2.	Gadbijula Tal	0	19.5	0	0
5.	Jhilmila Tal	0	0	0	0
8.	Kalikich Tal	32.2	17.2	9.25	5
9.	Kulla Tal	32.5	13.7	10.4	0
3.	Mudka Tal	0	0.8	0	0
7.	Peli Tal	0	19.5	0.6	0
4.	Puraina Tal	0	14.4	0	0
12.	Puranii Tal	4.7	2.5	0	4.06
14.	Pyara Tal	50.2	25.1	0	0
11.	Shova Tal	0.4	0.8	0	0
19.	siddha Baijanath Kunda	0	0	0	0
17.	Siddha sarobar banda	0	0	14.3	0
16.	Siddha Tal	0	0	0	0
18.	Sitaram Kunda	0	0	0	0

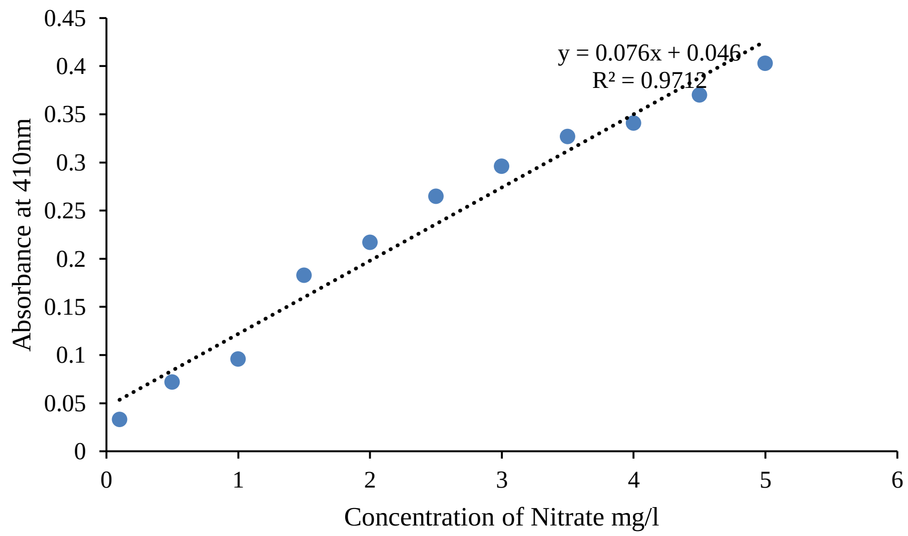
Appendix VI. Calibration Curve for phosphate

S.N	Concentration (mg/l)	Absorbance
1	0.1	0.125
2	0.2	0.231
3	0.3	0.388
4	0.4	0.5
5	0.5	0.578
6	0.6	0.595
7	0.7	0.729
8	0.8	0.748
9	0.9	0.793
10	1	0.912



Appendix VII. Calibration Curve for Nitrate

S.N	Concentration (mg/l)	Absorbance
1	0.1	0.033
2	0.5	0.072
3	1	0.096
4	1.5	0.183
5	2	0.217
6	2.5	0.265
7	3	0.296
8	3.5	0.327
9	4	0.341
10	4.5	0.37
11	5	0.403



Appendix VIII. Prioritization of utilization value of wetlands

S.N.	Utilization value	Score percentage (%)
1	Recreational activities	71.92
2	Fishing	42.10
3	Religious activities	41.22
4	Livestock	33.33
5	Irrigation	21.05
6	Boating	3.5

Appendix IX. Prioritization of Wetland Threats

S.N	Threats	Score Percentage (%)
1	Inappropriate wetland management	81.95
2	Wetland invasion	39.09
3	Land use change	29.32
4	Encroachment	28.57
5	Flood	27.06
6	Pollution	21.80
7	Connectivity	9.02

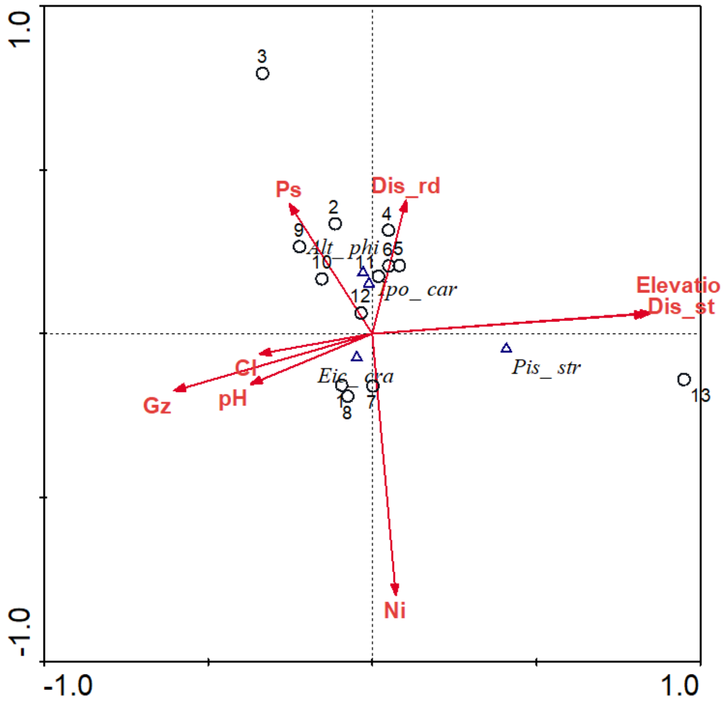
Appendix X. Prioritization of Impacts of IAPS on Wetlands

S.N	Impacts	Score percentage (%)
1	High economic cost to remove	52.63
2	Effect to native flora & fauna	49.12
3	Biodiversity loss	36.84
4	Difficulty in fishing	30.70
5	Reduces the recreational value	25.43
6	Loss of appetite in goat	5.27

Appendix XI. Prioritization of dispersal pathway of *Eichhornia crassipes*

S.N.	Pathway of introduction	Score percentage (%)
1	Ornamental purpose	3.125
2	Feed for fishes	15.625
3	Flooding	3.125
4	Unknown	3.125

APPENDIX XII



CCA plot for Wetlands, environmental variables and wetland IAPS

APPENDIX XIII. Name of the plant species and their abbreviation.

S.N.	Species Name	Abbreviation
1.	*Alternanthera philoxeroides*	Alt_ phi
2.	*Eichhornia crassipes*	Eic_cra
3.	*Ipomoea carnea* ssp. *fistulosa*	Ipo_car
4.	*Pistia stratiotes*	Pis_str

PHOTOPLATES

Field work and data collection in Study area

Baijnath Tal invaded by *Eichhornia crassipes*

Ipomoea carnea ssp. fistulosa at Kalikich Tal

Eichhornia invasion at Chauka Tal

Pistia stratiotes at Kalikich Tal

Eichhornia at Kulla Tal

Eichhornia crassipes at Pyara Tal

Alternanthera philoxeroides at Kalikich tal

Lab Work: Water Analysis