STATUS AND IMPACTS OF INVASIVE ALIEN PLANT SPECIES IN THE PARSA WILDLIFE RESERVE, CENTRAL NEPAL

A Dissertation

Submitted for the Partial Fulfillment of Master Degree in Botany, Institute of Science and Technology, Tribhuvan University, Kathmandu, Nepal.

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CERTIFICATE

This is to certify that the dissertation work entitled "**Status and Impacts of Invasive Alien Plant Species in the Parsa Wildlife Reserve, Central Nepal**" submitted by Mr. Raghu Nath Chaudhary has been carried out under my supervision. The entire work was based on the results of his primary fieldwork and has not been submitted for any other academic degrees. I, therefore, recommend this dissertation to be accepted for the partial fulfillment of Masters of Science in Botany from Tribhuvan University, Kathmandu, Nepal.

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LETTER OF APPROVAL

This dissertation paper entitled "**Status and Impacts of Invasive Alien Plant Species in the Parsa Wildlife Reserve, Central Nepal**" submitted to Central Department of Botany, Tribhuvan University by Mr. Raghu Nath Chaudhary, has been accepted for the partial fulfillment of requirements for Masters degree in Botany.

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Abstract

The study area is located in the tropical zone of Nepal where the forests are found more vulnerable due to invasive alien plant species (IAPS) infestation. The forest of Pars Wildlife Reserve (PWR) is dominated by *Shorea robusta*. This work was focused to study the status and impacts of IAPS in the forest ecosystem of PWR. Seven posts of the Reserve were taken as sampling sites; these were Adhabhar, Mahadev Khola, Charbhaiya, Gaduwaline, Nirmalvasti, Bhata and Pratappur post. In each post site, the stratified systematic sampling plots of 10m×10m were laid for the study. Different parameters such as coverage and frequency of IAPS, presence of flowering plant species, tree canopy cover, DBH of the trees and saplings, fire marks and stumping were measured from each plots. The flowering plants were enumerated; invasion level, species richness, factor governing IAPS and its impacts were analyzed.

Altogether 231 spp. of flowering plants, 51 spp. of naturalized plants and 14 species of IAPS were reported from the forest of PWR. *Ageratum houstonianum* Mill. was added to the list of IAPS listed by Tiwari *et al.* (2005). The coverage and species richness of IAPS in each sampling post areas were significantly different. The invasion of IAPS was found more near settlement than away from settlement in the Reserve. Among 7 sampling post areas, Bhata and Pratappur areas were reported as most problematic sites due to IAPS invasion followed by Adhabhar zone that were considered as sites near settlement. Among 14 spp. of IAPS, *Chromolaena odarata* was the most abundant and problematic species in each post areas except Bhata. In Bhata post area, *Mikania micrantha* was found most problematic species. The frequency and coverage of *Chromolaena odorata* was also the highest near the settlement than away from settlement. The highest number of IAPS belongs to family Asteraceae followed by Leguminosae.

The species richness of naturalized plants was found as the best factor to increase the richness and coverage of IAPS in reserve with strong and positive correlation having significant relationship. Similarly, the tree canopy cover of 10-50% was found to permit the best understory light intensity for the growth and reproduction of IAPS with negative trend of relationship. The richness of IAPS was increased by coverage of IAPS itself with positive relationship. Similarly, the impacts of IAPS in tree regeneration were found by suppressing the growth of saplings and seedlings. Native herb species also found to be affected by IAPS negatively.

List of Abbreviation and Acronyms

ANOVA	Analysis of Variance
asl.	Above sea level
Ave	Average
BPP	Biodiversity Profile Project
BRH	Biotic Resistance Hypothesis
ca.	Circiter; about
CABI	Centre for Agricultural Bioscience International
CBD	Convention on Biological Diversity
CNP	Chitwan National Park
CSUWN	Conservation and Sustainable Use of Wetlands in Nepal
DBH	Diameter at breast height
DNPWC	Department of National Park and Wildlife Conservation
e.g.	For Example
ERH	Enemy Release Hypothesis
et.al.	et alii/alia (used to denote other authors)
etc.	Exectra
FAO	Food and Agricultural Organization
GIS	Geographic Information System
GISP	Global Invasive Specie Program
GoN	Government of Nepal
ha	Hectare
i.e.	That is
IAAS	Invasive Alien Animal Species
IAPS	Invasive Alien Plant Species
IAS	Invasive Alien Species
IPCC	International Plant Protection Convention
ISSG	Invasive Species Specialist Group
IUCN	The World Conservation Union
KATH	National Herbarium and Plant Laboratory
km.	Kilometer

KTWR	Koshi Tappu Wildlife Reserve
m.	Meter
Max	Maximum
MEA	Millennium Ecosystem Assessment
MFSC	Ministry of Forests and Soil Conservation
Min	Minimum
mm/yr	Millimeter per year
MoAC	Ministry of Agriculture and Cooperatives
NBSAP	Nepal Biodiversity Strategy and Action Plant
NPK	Nitrogen, Phosphorus and Potassium
NWH	Novel Weapon Hypothesis
P.	Photo number
PCP	Participatory Conservation program
P^H	Negative Logarithmic Hydrogen ion
Pl.	Photo plate number
PWR	Parsa Wildlife Reserve
REDD	Reducing Emissions from Deforestation and Forest Degradation
S.E.	Standard Error
SCOPE	Scientific Committee on Problems of Environment
sp.	Single species
spp.	More species
SPSS	Statistical Package for Social Science
sq.km.	Square Kilometer
TUCH	Tribhuvan University Central Herbarium
UNCCD	United Nation Convention to Combat Dissertation
UNFCCC	United Nation Framework Convention on Climate Change
VDC	Village Development Committee
viz.	Namely
WHO	World Health Organization

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CHAPTER I

INTRODUCTION

1.1 Background

An alien species is "the species, subspecies or lower taxon, introduced outside its natural past or present distribution; includes any part, gametes, seeds, eggs, or propagules of such species that might survive and subsequently reproduce. " Any species, native to one area or region, that have been introduced into an area outside their normal distribution, either by accident or on purpose, and which have colonized or invaded their new home, threatening biological diversity, ecosystems and habitats, and human well-being are considered as the invasive alien species (IAS) and the process is biological invasion (CBD 2002, Gaertner *et al*. 2009). Such detrimental species, in terms of plants are considered as invasive alien plant species (IAPS) while in terms of animal considered as the invasive alien animal species (IAAS). There are a number of synonymous terms used to describe the alien species such as introduced, exotic, non-natives, immigrants, adventives, neophytes and non-indigenous.

The IAPS display strong vegetative growth, abundant seed production capacity, high seed germination rate, long-lived seeds, rapid maturation of a sexually reproductive stage and high ability to establish over large areas, phenotypic plasticity (ability to adapt physiologically to new conditions), and ability to survive on various food types and in a wide range of environmental conditions (Tiwari *et al*. 2005). These are today's most daunting environmental threats, wreaking havoc on ecosystems and people's livelihood. But, several alien species form a valuable part of the biodiversity and livelihood of people such as crops, ornamental plants etc. They do not cause serious environmental problems.

Most of the IAS were introduced in country intentionally for different purposes such as ornamental value (*Eichhornea crassipes, Lantana camara*), for food e.g. Tilapia (*Oreochromis mosambicus*), Catfish (*Clarias gariepinus*), fibers, habitat restoration, for soil stabilizing effect (*Ipomea carnea* subspecies *fistula*, *Leucaena leucocphala*) and even for commercialization (Alvey 2009), which later became problematic to native biodiversity and people's livelihood. It is considered that the common pathways for introduction of alien species in Nepal are porous border, road connections and international trade networks and air flows. Humans are a major vector for introducing the alien species from one part of the world to another in an attempt to satisfy various social, economic and cultural needs.

IAPS include herbs, shrubs, trees and vines that grow rapidly, form dense thickets and negatively impact native species and natural communities. The occurrence of invasive tree is relatively low. The presence of IAPS is higher near the road and anthropogenic disturbances (Kohli *et al.* 2009). The most of exotic plants can show the invasive character due to lack of natural enemies and competitors in the exotic lands e.g. species from tropical America to Nepal, due to which they can become fast growing and spreading invasive species (May 2007). Most of IAPS in Nepal are native to tropical America (Tiwari *et al.* 2005).

Not all introduced species are invasive, but are potential to be invasive (Tiwari *et al.* 2005, Siwakoti 2012) through invasion process (Figure 1) i.e. introduction, establishment and spread (Keam *et al.* 2009).

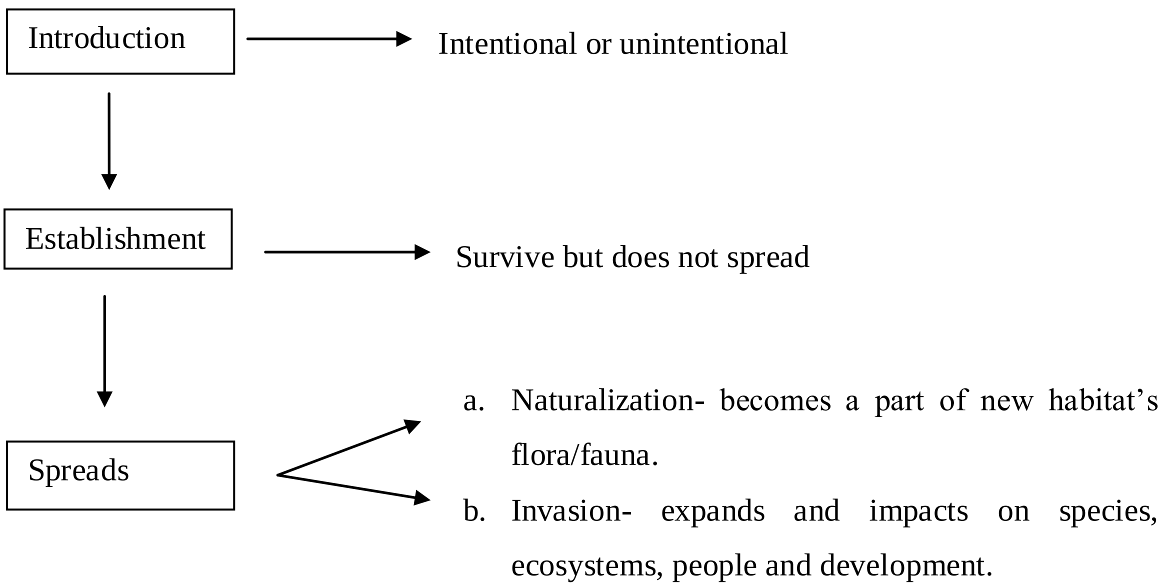

Figure 1: Process of Invasion by IAPS (Keam *et al.* 2009)

Richardson *et al.* (2000) proposed the simple conceptualization for the process of naturalization and invasion to clarify debate between the terms with separate terminology (Annex 8) considering the limiting factors that restrict the spread of introduced taxa in a region as a series of 'barriers'. The barriers are: exotic geography, exotic environment, reproduction, dispersal, disturbed environment, natural environment. By penetrating such barriers, an exotic species can become invasive. The concept of barriers was probably first used in connection with biological migrations by De Candolle (1820) and later by Cain (1944).

However, they follow the "rule of tens" to be invasive that suggests about 10% of introduced species will escape and survive in the wild, 10% of these will become naturalized & established and 10% of established species will spread and become invasive (Keam *et al*. 2009). Hence, only about 0.1% of introductions are likely to become invasive.

Many alien species naturalize and invade successfully by out competing native species and homogenizing ecosystems, changing hydrological characteristics, degrading gene pools through hybridization with native species (Richburg 2008), resulting biodiversity loss (Miththapala 2007, Gaertner *et al.* 2009, Hui *et al.* 2011). Furthermore, invasive species can degrade the productivity of agricultural lands and compromise significant cultural landscapes e.g. historic gardens (Richburg 2008). This damage is aggravated by climate change (Kriticos *et al.* 2003, Dukes and Mooney 2004), pollution, habitat loss and human-induced disturbance (Norbu 2004). The problem of IAPS continues to grow at great socio-economic, health and ecological cost around the world. Developing countries like Nepal are especially vulnerable to the impacts of IAPS, because they rely heavily on resource-based livelihoods such as agriculture, aquaculture, fisheries and forestry (Matthews and Brandt 2004). Furthermore, IAPS may now be the most significant drivers of population declines and species extinctions in island ecosystems worldwide (Donlan *et al.* 2003, Reaser *et al.* 2007). The apparent competition of IAPS with native species decreases the growth rate, changes habitat structure and breaks plant-consumer interactions and hence, it may cause selective extinction of species preferred by seed consumers (Dangermond *et al.* 2010).
Siwakoti (2012) listed 218 species of naturalized plant species which accounts about 3.39% of the reported 6419 species of flowering plants in Nepal. Among them, 21 species have been considered as IAPS, most of them are more abundant on lowland of the country. The invasive plants are more common in tropical and subtropical regions of Nepal with high species richness and invasion. However, a total of 282 flowering plant species are recorded as endemic to Nepal (Rajbhandari and Dhungana 2011), it can be estimated that most of them will be going to face with IAPS soon for their survivorship due to its upward shift.

1.2 Statement of Problems

The increasing volume of global trade and land use changes enhance the opportunity for global spreading of IAPS and are likely to become more severe in future. The large numbers of IAPS adversely affects the native biodiversity; now become an issue of global concern for its management. There remains a gap in understanding the invasive weeds in many areas of the world including Nepal.

Some IAPS, such as *Ageratina adenophora* (Joshi 1983, Chettri 1986), *Chromolaena odorata* (Norbu 2004) *Mikania micrantha* (Sapkota 2012, Rai and Scarborough 2012) *Lantana camara*, and *Hyptis suaveolens* are serious IAPS disrupting forests and shrub lands in the forest of Nepal (Tiwari *et al*. 2005). Except *Ageratina adenophora*, all these can be seen highly invaded the forest of Terai in Nepal. Similarly *Parthenium hysterophorus* has been expanding its distribution from urban areas and grasslands to forest ecosystems including the habitats of endangered mammals (Shrestha 2015) and increasing its abundance towards hardwood forest (Bhusal *et al.* 2014). The impacts of IAPS are experienced equally in both protected and outside the protected areas. The introduction and colonization of alien plant species is one of the serious threats to different protected areas of Nepal, particularly located in lowlands. The study site (Parsa Wildlife Reserve) is located in the Terai region of Nepal consisting tropical forest. Hence, it can be believed that such kinds of IAPS to be invaded the forest of PWR.

Anthropogenic activities are the best factor that responsible for increasing the invasion of IAPS e.g. *Chromolaena odorata* in reduced understory biomass and canopy opening caused by human activity (Joshi 2001, Norbu 2004), *Mikania micrantha* in afforested forest (Sapkota 2012) in lowland Nepal. Two villages i.e. Bhata and Rambhori was re-settled out of reserve before 10 years but the effects of settlement on this area have not been eliminated yet properly. Similarly, Pratappur village was also recently resettled out of the reserve. The longest Mahendra highway of Nepal runs at the margin of reserve. Hence, anthropogenic disturbance also can be seen in the study area.

Parsa Wildlife Reserve is contiguous with CNP (Chitwan National Park), in which *Mikania micrantha* was reported as high abundance with negative impacts on tree regeneration and altered species composition of the understory vegetation in forest (Sapkota 2012).

The biodiversity of Nepal is sensitive to IAPS due to its invasion in wide range of habitats and environmental conditions (Kunwar 2003; Tiwari *et al*. 2005). There is paucity of information on the distribution and impact of the invasive weed in Nepal. No any specific research about the IAPS in PWR has been done and published up to this date. Hence, Parsa Wildlife Reserve (PWR), Central Nepal was chosen for understanding the status and impacts of IAPS as it is located in lowland of the country.

1.3 Hypotheses and Objectives of the Study

The objectives of the study were based on the following hypotheses:

1. Open canopy in forest facilitates the infestation of IAPS.
2. Species richness of naturalized plants increases the richness of IAPS.
3. IAPS reduces the tree regeneration and species richness of native plants.

The main objective for overarching goal of this study is to assess the status and impacts of IAPS to the native biodiversity in PWR. Specific objectives include:

1. To determine the status and abundance of IAPS in PWR.
2. To assess the contribution of IAPS and other naturalized plant species in the flora of PWR.
3. To assess the impacts of IAPS on species richness and tree regeneration.

1.4 Limitations

High risk of wild animals in the PWR was the limitation of study, due to which:

1. Sampling was not possible in all core areas of PWR.
2. Sampling sites may not represent all forest types of PWR.

CHAPTER II

LITERATUR REVIEW

2.1 Invasive Alien Plant Species in Nepal

Nepal has a long list of alien plant species intentionally or unintentionally introduced for various purposes. A study conducted by IUCN (2005) reported that over 166 species of alien plants are naturalized in Nepal and Siwakoti (2012) added 51 species to this list from the different secondary resources such as web sites (http://www.issg.org/database/welcome) and published literature (Press *et al.* 2000, Kumar *et al.* 2009, Wu *et al.* 2010). Altogether 218 species of naturalized plants belonging to 46 families have recorded in Nepal, are considered as potential invaders. The 6 dominant families are Asteraceae (34 species), Solanaceae (23 species), Fabaceae (21 species), Euphorbiaceae (16 species), Cyperaces (10 species) and Amaranthaceae (10 species), which contribute more than 57% of total families. Herbs contribute about 76%, followed by shrubs 16%, climbers 6% and trees 2%. Among them, about 70% species are Neotropical origin (Tiwari *et al.* 2005, Siwakoti 2012).

Altogether 21 species of naturalized plants are considered as invasive and most problematic species (Tiwari *et al.* 2005), introduced from South America (Annex 7A & B). These were prioritized on the basis of invasiveness character such as *Ageratina adenophora, Chromolaena odorata, Lantana camara, Mikania micrantha, Eichhornia crassipes* and *Ipomoea carnea* subspecies *fistulosa* are considered as alien species with high threat to native species and ecosystems, followed by *Alternanthera philoxeroides, Myriophyllum aquaticum* and *Parthenium hysterophorus* with medium threats. Similarly, *Ageratum conyzoides, Amaranthus spinosus, Argemone mexicana, Cassia tora, Hyptis suaveolens, Pistia stratiotes* and *Leersia hexandra* considered as with low threat causing species as well as five species *Bidens pilosa, Xanthium strumarium, Cassia occidentalis*, *Oxalis latifolia* and *Mimosa pudica* were considered as species with insignificant threats, however, the status of the species is ever changing. Among these, the *Eichhornia crassipes, Ipomoea carnea* subspecies *fistulosa* , *Mikania micrantha, Alternanthera philoxeroides, Pistia stratiotes, Leersia hexandra, Myrophyllum aquaticum* (reported from the wetland of Kathmandu valley but potential invaders in Terai too) are major IAPS seriously invaded in core aquatic area, whereas the remaining species are mostly found in peripheral habitats of wetlands. The various ecosystems of Tarai, Chure (Siwaliks) and Midhills of Nepal are seriously threatened by IAPS (MFSC/CSUWN 2011). Alien species are more common in tropical and subtropical regions of Nepal with high species richness between 700 and 1500m asl. (Bhuju *et al.* 2013).

The world's 100 worst invasive aliens include 11 plant species (*Arundo donax, Chromolaena odorata, Eichhornia crissepes, Hedychium gardnerianum, Hiptage benghalensis, Imperata cylindrica, Lantana camara, Leucaena leucocephala, Mikania micrantha, Opuntia stricta* and *Rubus ellipticus*) that are found in Nepal (Lowe *et al.* 2000). However, they are not equally invasive and all are not alien species for Nepal. Seven top alien invasive in the list for Asia Pacific region include *Ageratina adenophora, Ageratum conyzoides, Chromolaena odorata, Eichhornia crissepes, Lantana camara, Mikania micrantha* and *Parthenium hysterophorus* (Sankaran *et al*. 2005). All these seven species are problematic in Nepal. Hence, it can be said that the species native to Nepal are invasive to other regions of the world e.g. *Rubus ellipticus, Imperata cylindrica*.

The documentation of IAPS in Nepal started since 1958, at present more than 43 studies conducted on IAPS; most of these were unpublished master level thesis (Poudel and Thapa 2012). Based on these studies, it found that still there is a sufficient data gap which is the major constraint for the management of IAPS in Nepal (Poudel and Thapa, 2012).

2.2 Causes of Invasion by IAPS

The success of invasive alien plants is due to presence of Novel weapon such as allelopathic feature (Rai and Tripathi 1982) and its evolution with increased competitive ability (Callaway and Ridenour 2004) - Novel Weapon Hypothesis (NWH). Recent research suggests conceptual parallels between the success of exotic human invasions and the success of exotic plant invasions – the possession of novel weapons (Callaway and Ridenour 2004).The naturalized species are more likely to become invasive when they are free from their natural enemies (Torchin *et al*. 2003, Eschtruth and Battles 2009) - Enemy release hypothesis (ERH). The diverse and dense forests with monospecific stands are vulnerable to biological invasion (Pimm 1984, Maron and Vila 2001, Norbu 2004) - Biotic resistance hypothesis (BRH). Anthropogenic and natural factors act together to facilitate the introduction and spread of alien species. Major causes of spread and invasion of alien species are modes of plant reproduction, small and large number of seed production, plant allelopathy, etc. as biotic factors and wind dispersal mechanism, land use change, depopulation, road and transportation, etc. were abiotic factors. Roads function as prime corridors for establishment and spread of invasive plant species (Kunwar and Acharya

2013). Less care about use of seeds, fertilizers, land and soil fertility and un-routinely control of weeds and invasive aliens led to rampant spread of invasive aliens. High nitrogen levels provide an advantage to invasive species (Brooks 2003).

2.3 Characteristics of Invasive Alien Plant Species

IAPS could exhibit one or many of the following characteristic features.

- They grow rapidly and reach maturity early.
- Many species are capable of vegetative reproduction *via* stolons (*Alternanthera philoxeroides*, *Eichhornia crassipes*), rhizomes, bulbs (*Oxalis latifolia*) and rooting at the tips of stem (*Ipomoea carnea*, *Mikania micrantha*) and root fragments (*Ageratina adenophora*).
- They are highly adapted for wind and insect pollinations.
- Their seeds get widely dispersed by winds, water, birds and other means enabling them to colonize in new areas at distances far from their original home.
- The spread rapidly and outcompete native plants.
- Quickly colonize in open spaces.
- Break plant-animal association.
- Changes natural ecological processes such as plant community succession.
- They often have a different phenology for leafing to dormant stages that provide better opportunities for taking nutrients from soil.
- They usually are not attacked by parasites, diseases, herbivores, etc. in the newly introduced area.
- Changes characteristics of the soil structure and chemistry.

2.4 Impacts of IAPS

Several negative impacts of IAPS on native biodiversity, ecosystems services and human livelihood were recognized.

2.4.1 Impacts on Biodiversity

IUCN 2005 considered IAPS as one of the greatest threats to natural ecosystems of the earth and is considered as the second biggest threat, after deforestation, to biodiversity conservation (Tiwari *et al*. 2005). They disrupt the ecology of a natural ecosystem, displace the native plant and animal species as well as degrade the landscape's unique and diverse biological resources. IAPS may reduce the amount of space, water, sunlight and nutrients that could otherwise be available to native species. They also alter hydrological flows and conditions as well as change characteristics of the soil structure and chemistry (Randall and Marinelli, 1996). IAPS are also considered as biological polluters (Westbrooks, 1991) and are capable of hybridizing with native plant relatives that result in unnatural changes to a plant's genetic makeup (Richburg 2008, Kunwar and Acharya 2013). Invasive Alien Species (IAS) as one of five major drivers of biodiversity loss in inland waters (MEA, 2005). IAPS invasion affected native species in almost every ecosystem on Earth and have caused hundreds of species extinctions (McNeely *et al*. 2001) through competition, predation, hybridization, transmission of pathogens and the disruption of local ecosystems and ecosystem functions and can recover its distribution after removal of IAPS (Andreu and Vila 2011). The IAPS has ecological and evolutionary as well as economic impacts. The ecological and evolutionary impacts include extinction of species, modification of ecosystem process (e.g. nutrient cycling, fire regime, hydrology), and evolution. For example, about 42% of the species on the threatened or endangered species list are at risk primarily due to alien species (Pimentel *et al.* 2000).

While all ecosystems have the potential to be invaded by IAPS, certain areas such as wetlands, mountains, agro-ecosystems and islands of the planet are more vulnerable than others. The freshwater species are the most threatened among of all taxa, whose rate of extinction is reported five times more rapid than that of terrestrial animals in North America and at a level similar to tropical forest species (Ricciardi and Rasmussen, 1999), approximately 20% of the world's freshwater fish species are at risk of extinction due to IAS in addition to other major drivers of biodiversity loss (Moyle and Leidy, 1992).

2.4.2 Impacts on Human Health

IAPS is also considered as an important source for human health hazard. A number of health related problems due to IAPS have been identified. The seeds of *Argemone mexicana* resemble mustard seed (*Brassica compestris*) and *Argemone maxicana* seed yields non-edible toxic oil and causes lethal dropsy when the oil is used for cooking (Tiwari *et al*. 2005). Another noxious weed is *Parthenium hysterophorus*, the pollens of which cause allergic types of diseases such as skin problem, asthma, hay fever (Mc Fadyen 1995, Cheney 1998). Seed, roots, leaves fruits of *Cassia occidentalis* is also reported as toxic and causes diarrhea, dark brown urine, etc. Smoke produced by burning the firewood of *Ipomoea carnea* causes throat problem. The latex of *Ipomoea carnea* causes vomiting and diarrhea and smell of *Hyptis suaveolens* might cause headache (Tiwari *et al*. 2005). IAPS may be reservoir of pathogens or may act as vector to transmit the diseases from one organism to another, the deadly new disease organisms, such as avian influenza A (H5N1), attack humans and animals, in both temperate and tropical countries is one of the examples (Tiwari *et al*. 2005). *Ageratum conyzoides* is allergic and produces foul smell, which often results in giddiness, vomiting, fever and headache (Kunwar and Acharya 2013).

2.4.3 Impacts on Animals

Further, many IAPS (*Ipomoea carnea*, *Xanthium strumarium, Ageratum houstonianum*, *Lantana camera*, etc.) are toxic to domestic cattle (Tiwari, *et al*. 2005). Grazing land was the most vulnerable to both *Ageratum* and *Ageratina* species invasion (Kunwar and Acharya 2013). *Ageratum houstonianum* is toxic to grazing animals, causing liver lesions (Sanchez and Durand 2004); sometimes cattle may die after feeding. A lysosomal storage disease induced by *Ipomoea carnea* was reported in goats in Mozambique, affected animals stagger and have head tumors causing eventual death (Tiwari *et al.* 2005). *Mikania micrantha* is considered as intermediate host for liver fluke; hence cattle grazing around it suffer from it (Tiwar *et al*. 2005). *M. micrantha* was detrimental to rhino forage availability by reducing native forage diversity and biomass (Subedi *et al.* 2014). *Xanthium strumarium* burs contain a highly toxic substance, Carboxyatractyloside capable of killing cattles, goats, sheep, and poultry (Parsons and Cuthbgertsonet 1992). *Lantana camara* cause food-web level impacts and decrease habitat suitability for wildlife in the forest (Prasad 2007).

2.4.4 Impacts on Agriculture

A study estimates about 8,000 species of plants traded or non-traded are expected to be agricultural weeds, out of which about 2,500 species are considered as potentially dangerous (Yaduraj *et al.* 2000). In agro-ecosystems, farmers have experienced remarkable loss in yields and quality of crop due to the invasion of various alien species. Agricultural crops particularly ginger, millet, rice and grasses were outcompeted by *Ageratum conyzoides* and their productivity was declined (Bhusal 2009, Kunwar and Acharya 2013). According to Oerke *et al.* (1994), there was a loss of 13% in agricultural output due to weeds. *Amaranthus spinosus* is common agricultural weed, competes with crops for nutrients (Tiwari *et al.* 2005). Harmful allelopathic effects of *Argemone maxicana* on germination and seedling of crops have reported, *Bidens pilosa*, *Cassia occidentalis* reduces soil fertility, *Xanthium strumarium* common in wheat field being problematic weed (Tiwari *et al*. 2005). The strong inhibitory effects of Leaf extract of *Parthenium hysterophorus* have observed on seed germination and seedling elongation of cereals and crucifers (Maharjan *et al.* 2007). Xanthinosin from *Xanthium strumarium* signinficantly affected seedling growth of *Amaranthus mangostanus* and *Lectuca sativa* (Shao *et al*. 2012)

2.4.5 Impacts on Wetland

Many wetland invaders form monotypic vegetation, which alter habitat structure, lower biodiversity (both number and quality of species), change nutrient cycling and productivity (often increasing it), and modify food webs (Zedler and Kercher, 2004). Floating type of aquatic IAPS such as *Eichhornia crassipes* and *Pistia stratiotes* form thick and extensive mats can block both sunlight and air for flora and fauna under water surface, increases loss of water through increase in evaporation (MFSC/CSUWN 2011). They disturb flow and navigation of water supply, canal and drainages, increase siltation, reduces water quality, alters habitat and provides an ideal breeding ground for mosquitoes. *Pistia stratiotes* can dominate where *Eichhornia crassipes* fails to dominate. *Pistia stratiotes* and *Leersia hexandra* also can be weed in rice fields, forms dense mats in aquatic habitats which hinder recreational activities (Tiwari *et al*. 2005). Single plant of *Pistia Stratiotes* is sufficient of its wide spread. Aquatic IAPS, such as *Pistia stratiotes,* in Bishazari, Godaghodi lake (MFSC/CSUWN 2011), *Eichhornia crassipes, Ipomoea carnea, Pistia stratiotes* in KTWR, *Myriophyllum aquaticum* in Taudaha Pond, Kathmandu, *Alternanthera phyloxeroides* in Kamalpokhari, Kathmandu are seen most problematic (Tiwari *et al*. 2005).

2.4.6 Economic Loss

High economic loss due to IAS has been reported from many countries, such as, in USA, an estimate indicates that invasive plants and animals entail US$20 billon direct economic losses each year in different sectors (Gould, 2004). The yearly losses caused by invasive alien species are as high as 200 billion yuan ($29.29 billion) in China (www.chinadaily.com.cn). A study in Benin demonstrated that the impact of the invasion of water hyacinth dropped the annual incomes of local people from US$ 1,984 to US$ 607. According to a case study in the Philippines, actual loss in production amounted to between 70,000 – 100,000 tons of paddy, valued at US$ 12.5 – 17.8 million in 1990. The economic damage caused by IAS has been estimated to be more than US$ 138 billion per year

(Pimentel 2011). According to a World Conservation Union report, the annual global economic loss caused by invasive alien species amounted to over $400 billion (www.chinadaily.com.cn/bizchina/2009-06/02/content_7964531.htm). Cost of damage to native species and ecosystems further increases the above figures (Gould, 2004). The rural farmers are willing to pay NRs. 2,382 per year for *Mikania micrantha* management in Nepal (Rai and Scarborough 2012). Adequate studies about the economic losses have not yet to be done in Nepal. It is difficult to say how many species are getting extinct or threatened due to the invasion of alien plant species.

2.5 Management Practices of IAS

2.5.1 Global scenario

The problem of IAS became so severe that one country's efforts can't be solved it, hence, IAS now becomes a major focus of International conservation concern and the subject of cooperative efforts (www. issg.org). Since 1990s, several global agreements and technical guidelines were developed to minimize the risk of invasive alien species. The Convention on Biological Diversity (CBD) through Article 8(h) requires it's Parties, to "prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats and species" (http;/www.biodiv.org). The sixth conference of parties of the CBD in decision VI/23 ratified by 188 countries (CBD, 2002). The seventh conference of parties in decision VII/13 recognized the need to strengthen further institutional coordination among international organizations and other conventions such as the United Nations Framework Convention on Climate Change (UNFCCC) and the United Nations Convention to Combat Desertification (UNCCD), the Collaborative Partnership on Forests and organizations such as the Food and Agricultural Organization of the United Nations (FAO), the World Health Organization (WHO) the Convention on International Trade in Endangered Species (CITES) and the International Plant Protection Convention (IPCC) (http;/www.biodiv.org). In seventh conference of parties decision VII/14, the Convention of Wetlands of International Importance, focused to manage IAS which could threaten to wetlands and wetland species (http://www.ramsar.org). Since 1952, the International Plant Protection Convention (IPCC) ratified by 111 countries, is designed to prevent the spread of plant pests and its standards are recognized by the World Trade Organization (WTO) (McNeely et al., 2001). Under the Species Survival Commission of IUCN, the Invasive Species Specialist Group (ISSG) brings together a group of 146 experts on IAS from 41 countries all over the world. This specialist group provides advice on IAS to, among others, managers and policy-makers.

The Global Invasive Species Program (GISP) is coordinated by the Scientific Committee on Problems of the Environment (SCOPE), in collaboration with the World Conservation Union (IUCN), and CAB International (CABI) for the awareness and increasing knowledge about IAS. The GISP toolkit recommends four major options for dealing with IAS: 1) prevention, 2) early detection, 3) eradication, and 4) control. The integrated pest management is often the most successful method of control (Wittenberg and Cock, 2001). In addition, IUCN (2000) designed guidelines for the prevention of biodiversity loss caused by IAS.

2.5.2 National Scenario

With several international agreements, Nepal itself formulated different policies and laws for the management of IAPS. Nepal formulated its Nepal Biodiversity Strategy 2002 (process of revision) and A National Wetland Policy 2003 (revised 2012) identified that IAS is one of the major causes for the loss of species and habitats and shows commitment to the protection and wise use of biological resources and habitats. Similarly, the fourth National Report to the Convention on Biological Diversity (GN/MFSC 2009) also identified that IAS is a serious problem for biodiversity loss and targeted for the control of pathways and preparation and implementation of management plan for at least 3 major species (*Eichhornia crassipes, Mikania micrantha* and *Parthenium hysterophorus*). Fifth National Report to CBD (2014), the Nepal Biodiversity Strategy and Action Plan 2006 (NBSAP) revised 2014 have formulated a number of strategies corresponding to the Aichi Targets. It describes by 2020, to develop Invasive Plant Atlas for identification, early detection, prevention and management of invasive alien plants (GoN/MFSC, 2014).

Besides, the country has also formulated several sectoral laws (Aquatic Life Protection Act, 1961; Plant Protection Act. 1972; The National Parks and Wildlife Conservation Act, 1973; Seed Act, 1988; Water resource act, 1992; The Forest Act, 1993, Local Self Governance Act, 1999; Agro biodiversity Policy 2008, revised 2013) to control and eradicate the germs, pests and weeds of agricultural crops may be native or alien species (MFSC/CSUWN 2011).

The Department of National Parks and Wildlife Conservation (DNPWC) is responsible to conserve the native biodiversity and natural ecosystem within the protected area systems.

DNPWC is also designated as a focal point for Ramsar Convention and Convention on International Trade of Endangered Species of Wild Fauna and Flora. The Department of Forests is responsible to manage the national forest ecosystems. Similarly, the Ministry of Agriculture and Cooperatives (MoAC) has established a Plant Protection Directorate (2000) in coordination with Plant Quarantine Section. There are 6 Quarantine Check Posts at different locations adjoining Indian boarders, i.e. Kakarbhitta, Biratnagar, Jaleshwor, Birganj, Bhairahawa and Nepalgunj) and one at a Tribhuvan International Airport, Kathmandu (MFSC/CSUWN 2011).

MFSC/CSUWN 2011 developed the Wetlands Invasive Alien Species Management Guidelines. It has proposed 10 strategic management guidelines to minimize the problem of IAS such as raise public awareness and increase support, promote scientific research, build capacity (institutions and human resources), formulate legislation and institution, promote alternate uses of IAS, prevent further entry of IAS, develop an early warning and a rapid response system, control/eradicate and manage problem species, increase international collaboration, support and networking and allocate fund for IAS related programs. Richburg 2008 proposed the general principles of IAPS management that includes:

- Prevention
- Early Detection and Rapid Response
- Control and Management
- Education and Public Awareness

Some classical measures such as mechanical method using traditional practices, like weeding, ploughing, burning, digging, flooding, etc., have been made to control the establishment of invasive plant species. Some herbicides, such as 2-4, D has been used to eradicate *Ipomoea carnea* subspecies *fistulosa* and some other broad leaved alien species, which is an effective means in short terms, but, due to their non selective nature they also harm other non targeted species and there are also reports of the negative impact on human health (MFSC/CSUWN 2011). Mechanical removals of weeds are the immediate steps to control invasion and reduce impacts and herbicidal applicaction in forest areas need to be avoided as far as possible (Sankaran *et al.* 2014).

Biological control is long term approach to controlling IAPS and it is effective only to slow down the invading process (Sun *et al*. 2004). For example *Procecidochares utilis* was the first used for suppression of Banmara (*Ageratina adenophora*) weed in 1945 in USA (Julien 1992). In 1987, fungi *Mycovelosiella* species and *Entyloma compositarum* were found to be effective than gall fly (Wan and Wang 2001). *Zygoramma bicolorata* is good bioagent to control the infestation of *Parthenium hysterophorus* weed (Shrestha *et al.* 20111). Biological control of *Ageratum conyzoides* by bioagents viz. *Liothrips mikaniae, Epiblema sternuana, Zygogramma bicolorata, Listronotus setosipennis, Puccinia* species, etc is widely introduced.

Although the scientific community does not encourage for using the IAPS for commercial utility for its management, "utility means to promote them" but the local community has utilized some of IAPS in limited amount. Similarly, the compost obtained from *Eichhornia crassipes* has acceptable composition of N, P, K and pH; and can be used in agricultural land (Kafle *et al.* 2009).

CHAPTER III

MATERIALS AND METHODS

3.1 Study Area

Parsa Wildlife reserve is located in the south-central lowland Terai of Nepal. The area of the reserve is 558.10 sq. km. having pristine tropical forest and the reserve extends between 27°13’52”N - 27°32’26”N latitudes and 84°40’22”E - 84°58’41”E longitudes (DNPWC/PCP 2003). It was gazetted as a wildlife reserve in 1984. It covers partially three districts – Parsa, Makawanpur and Bara districts (Figure 2) and is the largest Wildlife Reserve of the country. It is established to preserve the habitat for wild Asian elephant and a variety of other flora and fauna. The altitude ranges from 100m – 815m asl. Most of the Reserve’s landscape consists of Siwalik Hills. The soil is primarily composed of gravel and conglomerates susceptible to erosion. The foothills are very porous; hence water is scarce in this Reserve (Bhuju *et al*. 2007). It is contiguous with Chitwan national park in the west and extends to Birgunj - Hetauda highway in the west. The northern boundary is the Rapti River and the main Siwalik ridges and the cut-line (fire line) in the forest forms the southern boundary of the Reserve. The major river systems are Rapti River, Doharam Khola, Bakhariya Khola, Mahadev Khola, Bhatta Khola Bhalu Khola and Bhedaha Khola (DNPWC/PCP 2003). According to local people and staffs of the reserve, almost all the rivers except Rapti River, Doharam Khola and Bhalu Khola are seasonal which dry up during winter and summer.

The forest in the reserve mostly composed of Sal (*Shorea robusta*) mixed broadleaved vegetation. Along the banks of the rivers, riverine forests are found containing species like *Acacia catechu, Bombax ceiba etc*. Towards the north-eastern part of the reserve, at higher altitudes, *Shorea robusta and Pinus roxburghii* forests are occurring. Sabai grass (*Eulaliopsis binata*) is commercially important species, grows well on the southern face of the Siwalik Hills.

The Reserve is rich in biodiversity, consists of eight types of ecosystem and two types of forest vegetation (Bhuju *et al*. 2007) and estimated 919 species of flora in the Reserve (BPP 1995). The reserve includes 298 vascular plants, among them five pteridophytes, 1 gymnosperm, 234 dicotyledonous and 58 monocotyledonous plants were recorded (Bhuju *et al*. 2007). Chaudhary *et al.* (2002) recorded 59 plant species belonging to 51 genera

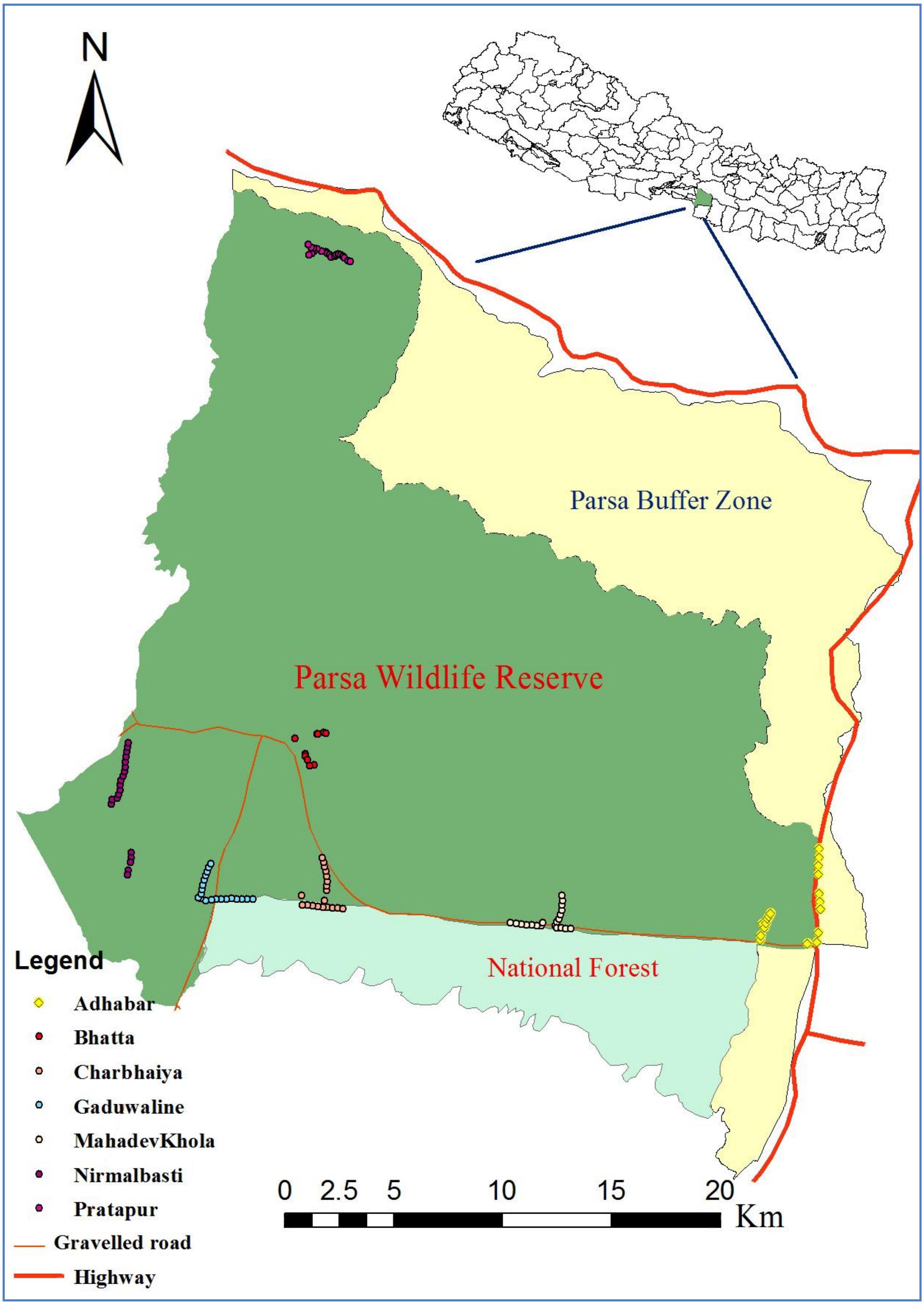

Figure 2: Map showing the sampling sites (Posts) and the location of plots at PWR.

and 39 families as the wild edible plants and 51 species belonging to 44 genera and 31 families reported as medicinal values. Similarly, 37 species of mammals, 503 species of birds, 8 herpeto and eight species of fish were recorded from the Reserve (Bhuju *et al*. 2007)). Mammal species such as wild Asian elephant (*Elephus maximus*), Royal Bengal tiger (*Panthera tigris*), Gaur (*Bos gaurus*), Hyena (*Hyaena hyaena*), Sloth bear (*Ursus ursinus*), Chittal (*Axis axis*) etc are symbolic of PWR.

There are 11 VDC area partially covered by buffer zones which are Manahari, Handi Khola, Padampokhari and Churiamai of Makawanpur District, Amlekhgunj, Pipra Simra and Jitpur of Bara district and Mahadevpatti, Subarnapur, Nirmalvasti and Sedhawa of Parsa District. The buffer zone covers almost 273.85 sq km (DNPWC/PCP 2003). These buffer zones also play very important role for the biodiversity conservation point of view. There are ten check posts in the PWR which are Adhabhar (Reserve HQ), Mahadev Khola, Charbhaiya, Gaduwaline, Nirmalvasti, Bhata, Amlekhgunj, Padampokhari, Ramauli and Pratappur.

There were two villages, named Bhata and Rambhori inside the Reserve near the Bhata Post, approximately 8 km towards the north core from the southern fire line and the area had occupied by dense settlements. These two villages were re-settled outside from the reserve before 10 years during reserve extension and re-settlement (DNPWC/PCP, 2003), but the effects of settlements can be seen yet. Similarly, Pratappur village also situated inside and on the northern margin of the reserve, had been also recently re-settled outside from the reserve. The Adhabhar post area covers the forest along the Mahendra highway.

Climate

Winter (Dec-Feb) provide cool and dry with pleasant temperatures and clear skies. During spring (March-May) temperatures rise and water becomes scarce with dry and hot environment. During monsoon (June-Aug) the days become hot and humid with temperatures rising up to 40°C. In summer (Sep-Nov), days are hot and bring cooling rains. Climatic data of Hetauda weather station for five years (2009-2013) was obtained from the Department of Hydrology and Meteorology. The average rainfall was 2256.1 mm/yr. Out of the annual precipitation, more than 90 % waterfalls seen during May-September (Figure 3). The rainfall was seen the highest during July and August. These months possess the rainy season in the Nepal. Similarly, monthly mean temperature ranges from minimum of 17.16°C to a maximum of 29.80°C. The monthly mean temperature was seen optimum during April-June (Figure 3). During these months, the environment is very hot; due to scares of humidity, flows dry and hot air.

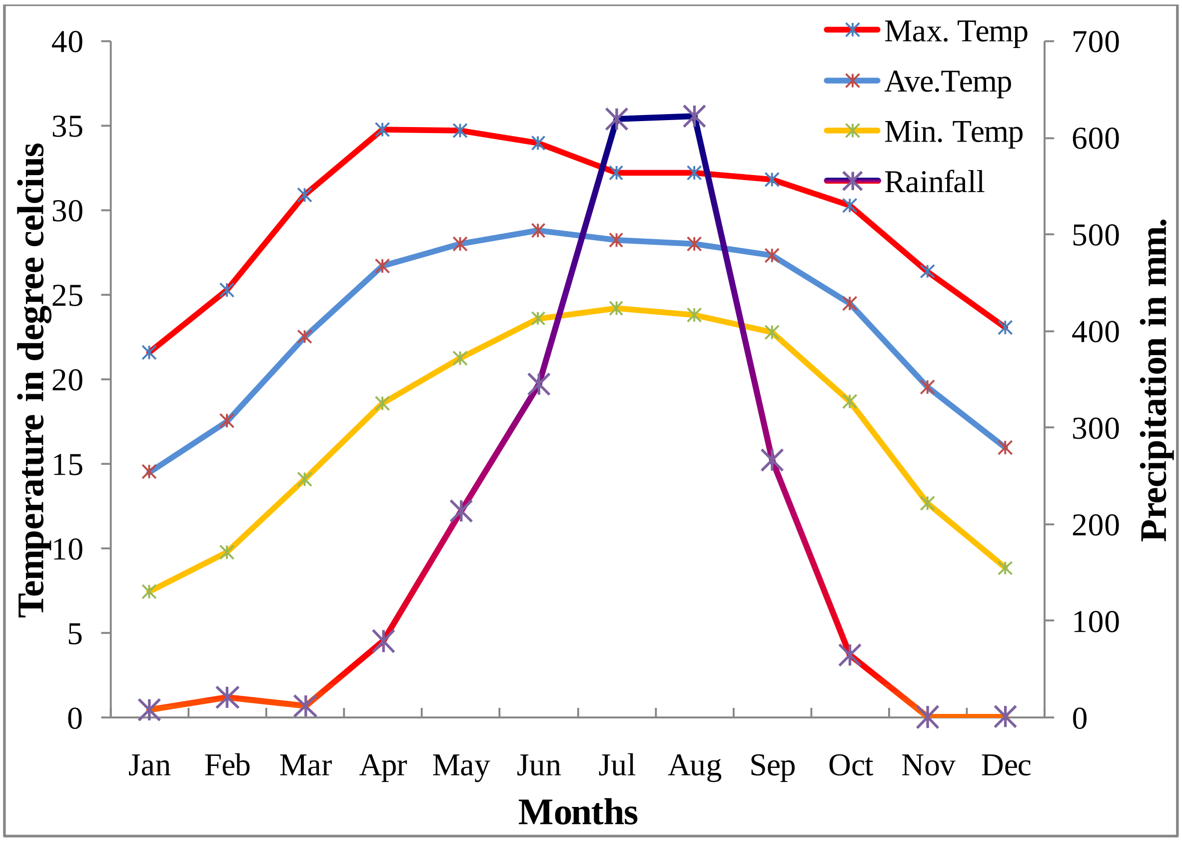

Figure 3: Five year (2009-2013) average of minimum, maximum, mean temperature and precipitation recorded at Hetauda weather station. (*Resource: Department of Hydrology and Meteorology/GoN*)

3.2 Data Collection Technique

3.2.1 Identification of IAPS

In Nepal, 21 naturalized plant species are identified as most problematic with high threat to native biodiversity and ecosystems which are considered as invasive alien plant species (Tiwari *et al*. 2005, Siwakoti 2012). These plant species are – *Ageratina adenophora, Chromolaena odorata, Lantana camara, Mikania micrantha, Eichhornia crassipes, Ipomoea carnea* subspecies *fistulosa, Alternanthera philoxeroides, Myriophyllum aquaticaum, Parthenium hysterophorus, Ageratum conyzoides, Amaranthus spinosus, Argemone maxicana, Cassia tora, Hyptis suaveolens, Pistia stratiotes, Leersia hexandra, Bidens pilosa, Xanthium strumarium, Cassia occidentalis, Oxalis latifolia* and *Mimosa pudica*. This study added 1 species i.e. *Ageratum houstonianum* Mill. to the previous list of IAPS by personal communication with my supervisors Prof. Dr. Mohan Siwakoti and Dr. Bharat Babu Shrestha during field survey. Out of 22 species, only 14 species of IAPS were found in forest of PWR (Table 4). These species were identified in the field by their morphological features with the reference of web site (www.issg.org/database/welcome/content.asp) and published literatures (Polunin and Stainton 1984, Stainton 1988, Malla 1986, Siwakoti and Varma 1999, Press *et al*. 2000, Tiwari *et al*. 2005, Gunasekera 2009, Wu *et al*. 2011, Kunwar and Acharya 2013, Bhuju *et al*. 2013, Kumar 2014) as given below.

Chromolaena odorata (L.) R. King & H. Robinson: A perennial herb or sub-shrub of 2.5 m tall in open forest. Stems soft but woody at base. In shady areas it becomes etiolated and behaves as a creeper, growing up to 10 m tall. The plant hairy and glandular. The leaves opposite, triangular to elliptical with serrated edges, 4–10 × 1–5 cm, pungent, aromatic odour when crushed. Flowers terminal, 10 to 35 in number. It produces prolific viable seeds up to 80000-90000/plant (Gunasekera 2009) and dispersed by winds, also by clinging to fur, hair, and cloths (Norbu 2004). Pl.1, P.1.

Lantana camara L.: Shrubs of up to 20 m (Prasad 2007), with long weak branches, armed with stout recurved prickles, pubescent. Leaf blade ovate to oblong, 3-8.5 × 1.5-5 cm, papery, wrinkled, very rough, with short stiff hairs, aromatic when crushed, base rounded to subcordate, margin crenate; lateral veins 5 pairs, very prominent. Capitula terminal. Flowers yellow or orange, often turning deep red soon after opening. Pl.1, P.2.

Mikania micrantha Kunth.: Vines, slender, branched. Stems yellowish or brownish, usually terete, glabrate to sparsely puberulent. Leaves opposite; blade ovate, both surfaces glabrate with numerous glandular spots, base cordate, margin entire to coarsely dentate, apex shortly acuminate. Inflorescence a corymbose panicle, capitula clustered; phyllaries oblong, ca. 3.5 mm, corollas white. Pl.1, P.3.

Alternanthera philoxeroides (Mart.) Griseb.: Perennial herbs. Stem creeping, length ca. 55-120 cm, branched; young stem and leaf axil white hairy; old ones glabrous. Leaf blade oblong-obovate, 2.5-5 × 0.7-2 cm, glabrous or ciliate, base attenuate, margin entire, apex acute or obtuse, with a mucro. Heads with a peduncle, globose. Pl.1, P.4.

Parthenium hysterophorus L.: Annual herbs, 30-120 cm tall. Leaf blade ovate-elliptic, 3-18 × 1-5 cm, pinnately (1-2) lobed, both surfaces sparsely scaberulose and gland-dotted. Stem fistular and pubescent (Prasad and Williams 2010). Inflorescences of open panicles. Capitula obscurely radiate; outer phyllaries 5(or 6), elliptic-lanceolate, 2-4 mm, inner 5(or 6) ovate to orbicular, 2.5-4 mm. Female florets 5(or 6); disk florets 12-30. Its leaves resemble with *Artemisia* spp. before flowering stage. Pl.1, P.5.

Ageratum conyzoides L.: Annual herbs, 50-100 cm tall, with inconspicuous main root. Stems robust, branched from middle, reddish, or green toward apex, white powdery puberulent or densely spreading long tomentose (Kunwar and Acharya 2013). Leaves densely white spreading villous; median leaves ovate, elliptic, 3-8 × 2-5 cm; upper leaves gradually smaller, oblong, both surfaces sparsely white puberulent and yellow gland-dotted, margin crenate-serrate, apex acute. Capitula small, 4-14; peduncle powdery puberulent; phyllaries 2-seriate. *A. conyzoides* L. sometimes confused with *A. houstonianum* Mill (Kunwar and Acharya 2013). Pl.1, P.6.

Ageratum houstonianum Mill.: Annual herbs, 30-70 cm tall. Stems erect, simple or branched from middle or lower part; purple-red, green, white tomentose. Leaves broadly or triangular ovate; median stem leaves 2-6 × 1.5-3.5 cm, or length equal to width; upper and axillary leaves smaller; all leaves basally 3-veined or inconspicuously 5-veined, both surfaces densely white pubescent, base cordate or truncate, margin crenate-serrate, apex rounded or acute. Inflorescence corymbose, peduncle densely pubescent. Capitula 5-15 or more. It has numerous sticky hairs on bracts surrounding its flower heads. The invulucral bracts are hairy, glandular and differ from those of *Ageratum conyzoides*. Each of the tiny flowers which make up the flower-heads has two short and narrow projections that are about 1-2 mm long. The bases of the flower-heads are relatively smaller (3-6 mm across) than that of *A. conyzoides* (5-8 mm across) (Kumar 2014). Pl.2, P.7.

Amaranthus spinosus L.: Annual herb. Stem erect, green, 30-100 cm tall, terete or obtusely angulate, much branched, glabrous. Leaf blade ovate-rhombic or ovate-lanceolate, 3-12 × 1-6 cm, base cuneate, margin entire, apex obtuse, with a mucro. Bracts very sharply spiny in proximal part of spike. Tepals green, apex acute, with a mucro, 2-2.5 mm; female flowers oblong-spatulate, ca. 1.5 mm. Seeds brownish black, subglobose. Pl.2, P.8.

Cassia tora L.: Annual herbs of 30-90 cm tall. Leaves obovate, 3-4.5 cm, apex obtuse, pungent smell when crushed. Flowers axillary to leaves, yellowish. Pods flattened or four angled, 10–15 cm long and sickle shaped, hence the common name sickle pod. There are 30-50 seeds within a pod. Pl.2, P.9.

Cassia occidentalis L.: Erect herb, 0.15-2 m high; stems subglabrous. Leaves paripinnate; leaflets in 4-5 pairs, ovate to ovate-elliptic, 5-12 × 2-4 cm, acute or acuminate at apex, glabrous with ciliolate margins. Inflorescence racemes; petals yellow. Pods linear, 8-12.5 ×

0.5-1.0 cm, brown, subglabrous, many-seeded; seeds compressed, grey-brown, ovate-suborbicular. Pl.2, P.10.

Hyptis suaveolens (L.) Poit: Annual herbs, aromatic, erect. Stems hispid. Leaf blade ovate to broadly ovate, 1.4-11 × 1.2-9 cm, adaxially olive green, abaxially pilose, base rounded to shallow cordate, margin serrulate, apex subacute to obtuse. Cymes (1- or) 2-5-flowered. Calyx ca. 5 × 3 mm, yellowish glandular. Corolla blue, 6-8 mm, puberulent. Pl.2, P.11.

Bidens pilosa L.: Annuals herbs. Stems 30-180 cm tall, glabrous or very sparsely pubescent in upper part. Leaf blade ovate-lanceolate, both surfaces pilosulose to sparsely hirtellous, bases truncate to cuneate, margin serrate or entire, usually ciliate, apices acute to attenuate. Inflorescence of solitary capitula or capitula in lax corymbs. Capitula radiate or discoid; phyllaries 7 -13, lanceolate to oblanceolate. Ray florets absent. Disk florets 20-40; corollas yellowish. Pl.2, P.12.

Xanthium strumarium L.: Perennial herbs, 20-120 cm. Leaves ovate-deltate, densely scabrid on both surfaces, base shallowly cordate to broadly cuneate, margin irregularly dentate, often 3-lobed, apex acute. Capitula monoecious. Male capitula in terminal umbels; corolla white, tubular. Female capitula axillary. Burs sessile, oblong, ellipsoid, 10-18 × 6-12 mm, densely puberulent, 2-beaked. Pl.3, P.13.

Mimosa pudica L.: Perennial herbs, shrubby, to 1 m tall. Stems cylindric, branched, with reflexed bristles and scattered, curved prickles. Leaflets sensitive; pinnae usually 2 pairs; leaflets 10-20 pairs, abaxially slightly hispid, adaxially glabrous, margin ciliate, apex acute. Heads solitar. Flowers numerous, pink, small. Legumes arranged in a star, slightly recurved, consisting of 3-5, 1-seeded segments. Seeds light brown, ovoid. Pl.3, P.14.

3.2.2 Sampling method

The survey was done from Friday, September 18, 2013 - Thursday, October 3 (15 days) at seven check post areas of the Reserve for the primary data; they were Adhabhar, Mahadev Khola, Charbhaiya, Gaduwaline, Nirmalbasti, Bhatta and Pratappur (Figure 2). These post areas were considered as the sampling sites for the field survey in PWR. Among the sites, Pratappur is located in Makawanpur district and remaining sites are located in Parsa district.

To study the current status and impacts of IAPS, 130 plots of 10m × 10m, were sampled by stratified systematic sampling method in seven different sampling sites (posts) with 20 plots at each sites except Bhata Post area where only 10 plots were sampled (Figure 2). The less number of plots in Bhata Post was due to the high wild animal risks. This site was considered as high movement zone of dangerous wild animals. Hence, our team couldn't sample far inside the forest from the check post. The sampling plots were laid by making transect, maintaining ca. 200-250m distance between the plot only in the forest ecosystem of PWR.

From each plot, the different parameters such as cover percent of IAPS by visual estimation, flowering plant species, DBH of tree and saplings in cm by DBH tape, tree canopy cover percent by visual estimation, fire mark, stump numbers, altitude and location point of plot were measured. A data collecting tool was prepared for collection of such information from field survey (Annex 1A & B).

To study the infestation level and intensity of IAPS along settlement, seven sampling sites (Posts) were categorized into two *viz*. near (around) settlement and away from settlement. For this, three sampling sites i.e. Adhabhar, Bhata and Pratappur post sites were considered as sites of near settlement and remaining four were away from settlement. The fire marks were recognized by the sign of fire on the base of trees or burnt materials seen on the grounds and if not seen sign of fire, considered as no fire marks.

3.2.3 Frequency and Coverage of IAPS

The frequency of the IAPS as well as all flowering species was evaluated by presence and absence method, recorded from each plot and its periphery approximately five meter away from plots. It was calculated by formula given below.

$$\textbf{Frequncy}\ (\%) = \frac{\textbf{No. of sampling plots in which species occurred}}{\textbf{Total no. of quadrat studied}} \times \mathbf{100}\%$$

Similarly, the coverage of IAPS in percent was evaluated by visual estimation method, considering each plot as 100 percent. Two types of cover i.e., species wise – by each species for all plots and plot wise – by all IAPS for each plot were calculated by formula given below.

Species wise cover:

$$\textbf{Cover}\ (\%) = \frac{\textbf{Total coverage of a species}}{\textbf{Total no. of qadrat studied}}$$

Plot wise cover:

$$\textbf{Cover}\ (\%) = \textbf{Sum of cover of all IAPS/plot}$$

The plot wise cover value 0-100% of IAPS was converted to Domin Cover Scale to minimize the errors and to normalize the data. Domin Cover Scale of IAPS is - 0=0%, 1=1-2 individuals with no measurable cover, 2=several individuals but less than 1% cover, 3=1-4%, 4=4-10%, 5=11-25%, 6=26-33%, 7=34-50%, 8=51-75%, 9=76-90%, 10=91-100% cover of IAPS (Kent and Coker 1994).

3.2.4 Density and Basal Area of Tree and Saplings

Tree and saplings were separated with the help of their DBH measure. The plants having DBH ≥ 10 cm were considered as tree while DBH < 10 cm, considered as saplings. Density of tree and saplings were estimated with the help of number of tree and sapling individuals and calculated by the formula given below.

$$\textbf{Density (stem/ha)} = \frac{\textbf{n x 10000}}{\textbf{p} \times \textbf{a}}$$

Here, n =number of individual in all quadrat, p = number of plot studied and a = area (m^2/plot).

Similarly, the basal area of tree and saplings also estimated with the help of DBH and calculated by the formula below.

$$\textbf{Basal Area (BA)} = \frac{\pi d^2}{4}$$

$$\textbf{Basal Area } (\mathbf{m^2/ha}) = [(\frac{\pi d^2}{4 \times 10000})/(\frac{a}{10000})] \quad \ldots\ldots \textbf{per individual}$$

$$\textbf{Total Basal Area } (\mathbf{m^2/ha}) = \textbf{Sum of Basal Area of each individual}$$

Here, π = 3.1415, is constant, d = DBH in cm, a = area (m^2/plot). (*Note: - DBH of dead fallen logs and stumped tree were not measured and neglected*)

3.2.5 Plant Collection, Herbarium Preparation and Identification

All the plant species encountered in sampling areas were collected for herbarium specimens, pressed by herbarium presser and then dried by paper exchange method. The dried plant specimens were mounted on herbarium sheet of 28cm × 42cm and labeled. The herbarium specimens were identified with the help of experts, and using literatures for reference: *Plant diversity of Eastern Nepal: Flora of Plains of Eastern Nepal* (Siwakoti and Varma 1999), *Flora of Kathmandu Valley* (Malla *et al.*1986), *Flora of China* (Wu *et al.* 2011), *Flowers of the Himalaya* (Polunin and Stainton 1984, 1988), *Annotated Checklist of the Flowering Plants of Nepal* (Press *et al*. 2000), *Flora of Bhutan* (Grierson and Long 1984, 1987, 1991, 1999, 2001). For the terminology Haris and Haris (2003) was used during identification. The collected specimens were tallied with specimens of TUCH and KATH for further confirmation. The collected species has been preserved in the Herbarium of Tribhuvan University (TUCH) by preparing herbarium specimens.

3.3 Data Analysis

The data obtained from field survey was analyzed with the help of statistical software: SPSS (Statistical Package for Social Sciences) version 16.0 and Ms-Excel.

The species number and cover value of the common IAPS was used to compare the species richness and infestation (invasion) among the sampling sites (posts) and different canopy ranges using ANOVA (analysis of variance). The species richness of the plants was measured by the numbers of species. Similarly, the coverage and species richness of IAPS among settlement status and fire mark status was compared by independent sample t-test. The site wise mean comparison of species richness of flowering plants, naturalized plant species and other various forms of life of vegetation and basal area and density of tree and saplings was also compared with the help of ANOVA test. The factor governing IAPS infestation and its impacts on native biodiversity had evaluated by linear regression model. The canopy caver, basal area, disturbance and species richness of naturalized plant were taken as factor governing IAPS and the impacts were studied in tree regeneration and species richness of native herb.

The normality testing and homogeneity of variance were tested by SPSS version 16.0. For the normality, Kolmogorov-Smirnov significant value was used (If $P>0.05$, data considered as normal) and for homogeneity of variance, Levene's test of homogeneity was observed (if $P>0.05$, the variances considered as homogenous). The analysis of variance (ANOVA), Independent sample t-test and regression analysis were performed by SPSS. All the plots were drawn by MS-Excel, office 2007 and map of the study area was made by ArcMap version 10.

CHAPTER IV

RESULTS

4.1. Enumeration of Plant Species

Altogether 231 species of flowering plant belonging to 63 families were recorded from different seven sampling sites (Posts) in PWR (Annex 2A-G and Table 1). Among them, 51 species of naturalized plant belongs to 20 families and 180 species of native plants belongs to 59 families were recorded from field survey in PWR. The result of the study represents ca. 23.5% species and ca. 43.48% families of naturalized plants of previous record in Nepal i.e. 218 species belonging to 46 families of flowering plants (Siwakoti 2012). Among the naturalized plants, altogether 14 species were recorded as invasive plant and remaining 37 species were recorded as non-invasive plants. The recorded species were categorized into different plant groups and plant life forms and their numbers are summarized below (Table 1&2).

Table 1: General status of dicotyledonous and monocotyledonous plants

Plant Group	Number of Species			
	Native Species	Naturalized species		Total
		Non-invasive species	Invasive species	
Dicotyledonous	147	36	14	197
Monocotyledonous	33	1	0	34
Total	180	37	14	231
No. of families belongs	59	20	5	63

Table 2: General status of different growth (life) forms of plants

Plant Growth (Life) forms	Number of Species			
	Native Species	Naturalized species		Total
		Non-invasive species	Invasive species	
Herb	57	24	11	92
Shrub	38	7	1	46
Climber	24	2	2	28
Tree	61	4	0	65
Total	180	37	14	231

Among the plant groups, all the invasive alien plant species were recorded as dicotyledonous plants. Similarly, among the plant life forms, 11 species of invasive plant were recorded as herbs while 2 species as climber, and only one species as shrub.

Among 7 sampling sites, species richness of flowering plants found the highest in the Adhabhar Post and least in Bhata Post site (Table 3 & Figure 4A). The mean number of flowering species in different sites were significantly different (*P<0.05*), from each other (Table 3).

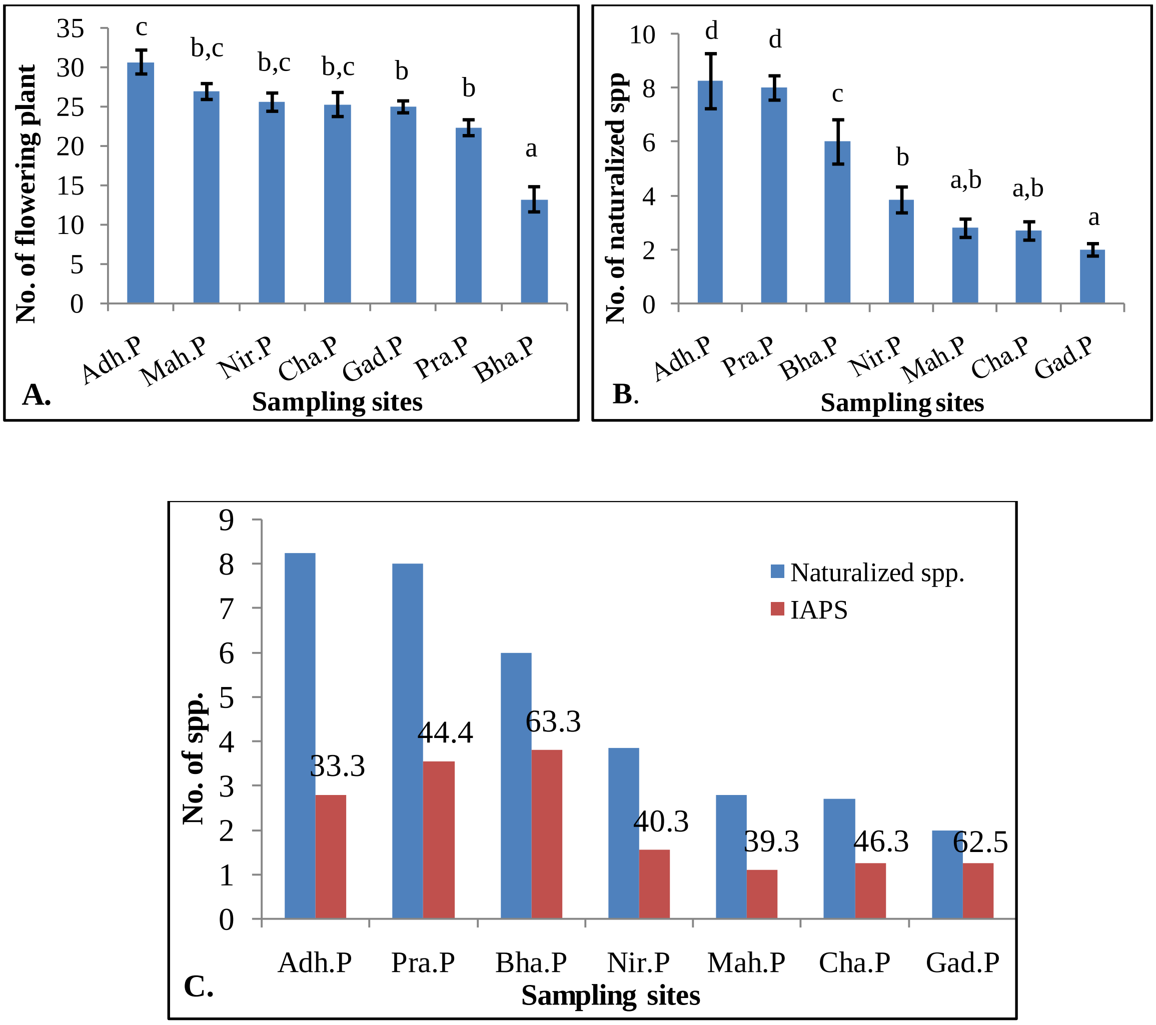

Figure 4: Species richness: **A.** Flowering plants, **B.** Naturalized plant species and **C.** Percentage of IAPS of naturalized plant spp. (***Note:*** *- Sampling Sites – Bha.P=Bhata, Pra.P=Pratappur, Adh.P=Adhabhar, Nir.P=Nirmalvasti, Cha.P=Charbhaiya, Gad.P=Gaduwaline, Mah.P=Mahadev Khola; the letters above error bar indicate the significant different in mean of species richness; the number above the IAPS bar indicates the percentage of IAPS of Naturalized Plant species*)

The highest richness of Naturalized Plant Species was found in the Adhabhar Post site and least richness in Gaduwaline Post site at PWR. The mean richness of naturalized plant species was found site wise significantly different (*P<0.05*) from each other (Table 3 & Figure 4B). Bhata Post Sites had significantly different species richness of naturalized plants from any others.

The richness percent of IAPS of naturalized plant species was highest in the Bhata Post site and least richness percent in Adhabhar Post sites (Figure 4C). Similarly, the mean species richness of Native spp., Shrub spp., Herb spp., Native herb spp. Climber spp. and Tree spp. are summarized in Table 3.

Top six families were ranked on the basis of number of species belonging to family found in the sampling post areas. The number of naturalized plant species were the highest belonging to family Asteraceae while least belonging to family Euphorbiaceae and Rubiaceae among six (Figure 5 and Annex 9).

The percent of naturalized plant species was reported the highest belonging to family Amaranthaceae while least percent belonging to family Euphorbiaceae (Figure 5).

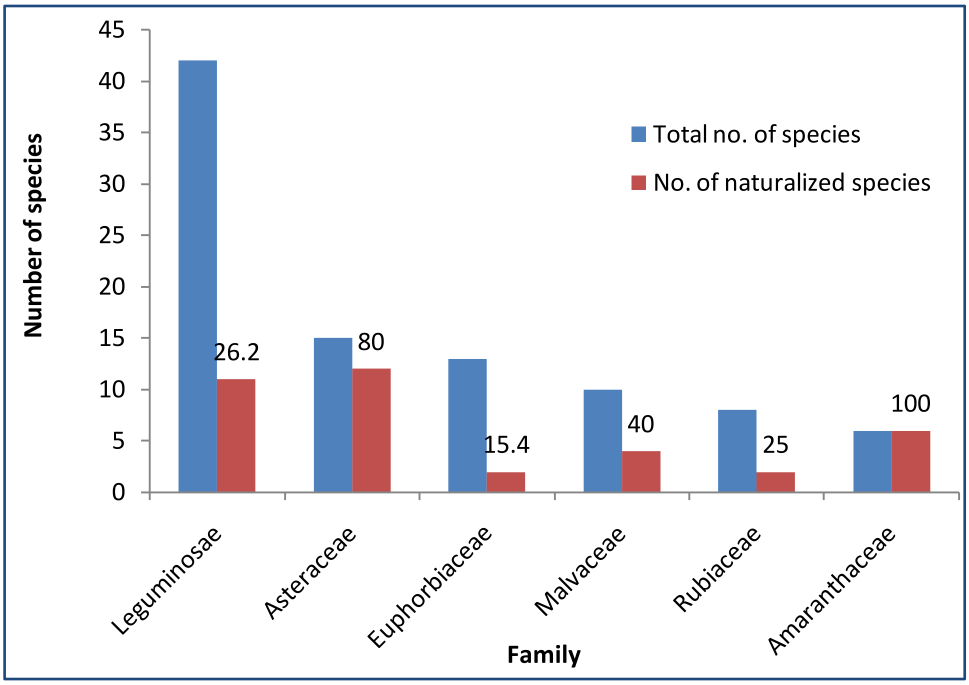

Figure 5: Percentage species richness of top six families of total recorded species. (***Note:** - The number above the Naturalized plant species bar indicates the percent of naturalized species of flowering plant species belonging to top six families*)

Table 3: Summary of Species Richness of different forms of species studied in PWR.

Sampling Sites (Posts)		Species Richness ($\overline{\chi}$ ± S.E.)							
		Flowering Plant Spp.	**Naturalized Plant Spp.**	**Native Spp.**	**Herb Spp.**	**Shrub Spp.**	**Native Herb Spp.**	**Climber Spp.**	**Tree Spp.**
Adhabhar Post		30.65 ± 1.52	8.25 ± 1.02	21.75 ± 1.17	10.1 ± 0.76	5.75 ± 0.70	4.85 ± 0.38	4.9 ± 0.36	9.45 ± 0.72
Mahadev Kohola Post		26.90 ± 1.01	2.80 ± 0.34	24.10 ± 1.05	6.15 ± 0.49	4.00 ± 0.42	4.70 ± 0.35	5.3 ± 0.44	11.65 ± 0.53
Charbhaiya Post		25.25 ± 1.53	2.70 ± 0.34	22.30 ± 1.25	6.39 ± 0.64	3.15 ± 0.38	4.25 ± 0.32	4.85 ± 0.44	10.7 ± 0.77
Gaduwaline Post		24.95 ± 0.76	2.00 ± 0.23	22.05 ± 0.97	5.55 ± 0.58	5.35 ± 0.42	4.00 ± 0.37	4.65 ± 0.4	10.3 ± 0.60
Nirmalvasti Post		25.55 ± 1.16	3.85 ± 0.48	21.55 ± 1.29	8.50 ± 0.70	4.30 ± 0.48	5.30 ± 0.49	3.75 ± 0.54	9.9 ± 0.86
Bhata Post		13.20 ± 1.60	6.00 ± 0.82	7.20 ± 0.84	7.4 0± 0.86	2.10 ± 0.72	3.40 ± 0.58	1.2 ± 0.25	1.7 ± 0.50
Pratappur Post		22.30 ± 1.01	8.00 ± 0.45	13.20 ± 0.88	11.35 ± 0.45	4.70 ± 0.49	4.35 ± 0.56	2 ± 0.29	4.35 ± 0.66
Homogeneity of Variance - Sig. value		0.193	0.070	0.134	0.058	0.053	0.077	0.147	0.137
ANOVA	F-value	13.214	18.492	22.749	12.559	5.121	1.638	14.932	21.989
	Sig. value	0.000	0.000	0.000	0.000	0.000	0.142	0.000	0.000

4.2. Frequency and Cover of IAPS

Among 14 species of invasive alien plant, the frequency and coverage of *Chromolaena odorata* was found to be the highest while *Amaranthus spinosus* was found to be the least in all cases i.e. on all samples, near and away from settlement are summarized in Table 4. On the basis of the presence, *Chromolaena odorata* is found as major IAPS, which is most frequent in the case of all samples, followed by *Cassia tora, Mimosa pudica, Ageratum conyzoides, Hyptis suaveolens, Ageratum houstonianum, Cassia occidentalis, Mikania micrantha, Alternanthera philoxeroides, Lantana camara, Bidens pilosa, Xanthium strumarium, Parthenium hysterophorus, Amaranthus spinosus* in PWR (Table 4, Figure 6A). Similarly, Coverage of *Chromolaena odorata* was highest and hence most dominant, followed by *Cassia tora, Mikania micrantha, Hyptis suaveolens, Ageratum conyzoides*, and *Mimosa pudica* and so on in PWR (Table 4 & Figure 6B).

Table 4: Frequency and Coverage of IAPS in PWR.

S. N.	Invasive Alien Plant Species	Frequency %			Cover%		
		On all samples	Near Settlement	Away from Settlement	On All Samples	Near Settlement	Away from Settlement
1	*Chromolaena odorata*	70.00	86.00	60.00	12.77	23.18	6.26
2	*Cassia tora*	23.08	46.00	8.75	2.44	6.08	0.16
3	*Mimosa pudica*	23.08	34.00	16.25	0.95	1.94	0.33
4	*Ageratum conyzoides*	19.23	34.00	10.00	1.12	2.56	0.23
5	*Hyptis suaveolens*	13.08	30.00	2.50	1.47	3.72	0.06
6	*Ageratum houstonianum*	7.69	18.00	1.25	0.58	1.46	0.03
7	*Cassia occidentalis*	6.92	18.00	0.00	0.39	1.02	0.00
8	*Mikania micrantha*	6.15	16.00	0.00	2.10	5.46	0.00
9	*Alternanthera philoxeroides*	6.15	8.00	5.00	0.26	0.42	0.16
10	*Lantana camara*	4.62	8.00	2.50	0.12	0.26	0.03
11	*Bidens pilosa*	2.31	6.00	0.00	0.31	0.80	0.00
12	*Xanthium strumarium*	2.31	6.00	0.00	0.36	0.94	0.00
13	*Parthenium hysterophorus*	1.54	4.00	0.00	0.13	0.34	0.00
14	*Amaranthus spinosus*	0.77	2.00	0.00	0.04	0.10	0.00

Frequency and cover of each IAPS near settlements was found greater than the sites away from settlements with significant differences. However, the frequency and cover of some invasive alien plant species i.e., *Cassia occidentalis*, *Mikania micrantha*, *Bidens pilosa*, *Xanthium strumarium*, *Parthenium hysterophorus*, *Amaranthus spinosus* was found to be null on the sites away from settlements, but their value near settlements found to be significant (Table 4 & Figure 6C&D).

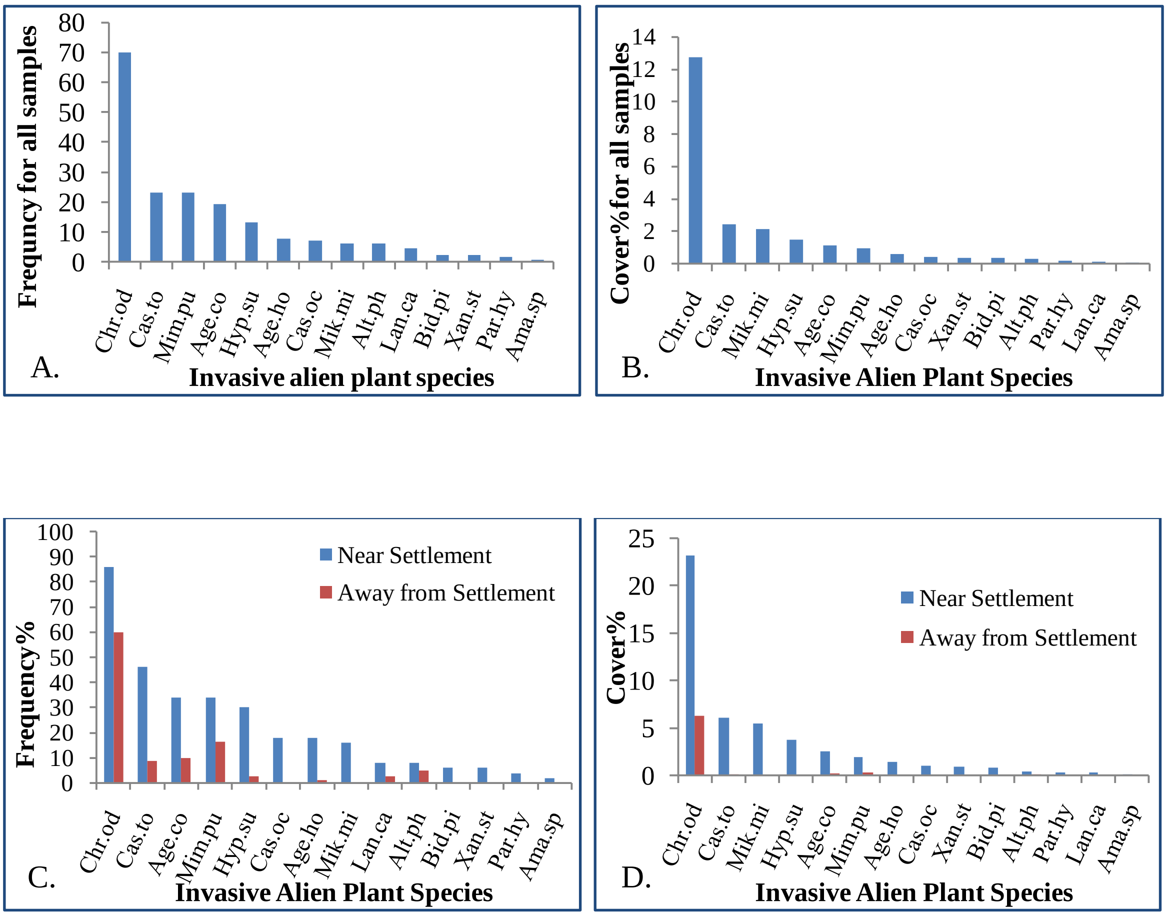

Figure 6: Frequency and coverage of IAPS in PWR. **A.** Frequency of IAPS on all samples, **B.** Coverage of IAPS on all samples, **C.** Frequency of IAPS near and away from settlement & **D.** Coverage of IAPS near & away from settlement. (**Notes**: *Chr.od=Chromolaena odorata, Cas.to=Cassia tora, Mim.pu=Mimosa pudica, Age.co= Ageratum conyzoides, Hyp.su=Hyptis suaveolens, Cas.oc= Cassia occidentalis, Age.ho=Ageratum houstonianum, Mik.mi=Mikania micrantha, Alt.ph=Alternanthera philoxeroides, Lan.ca= Lantana camara, Bid.pi= Bidens pilosa, Xan.st= Xanthium strumarium, Par.hy=Parthenium hysterophorus, Ama.sp=Amaranthus spinosus*).

The presence of *Mimosa pudica* and *Ageratum conyzoides* was recorded as equal frequent near (around) settlement. Similarly, *Alternanthera philoxeroides & Lantana camara* and *Bidens pilosa* & *Xanthium strumarium* were also equal frequent near the settlements while on away from settlement, frequency of *Chromolaena odorata* were followed by *Mimosa pudica, Ageratum conyzoedes, Cassia tora* and so on (Table 4, Figure 6C). The frequency of *Alternanthera philoxeroides* was found to be marginal difference between near and away from settlement.

The coverage of each IAPS in away from settlements was lower than near the settlements. The highest coverage of *Chromolaena odarata* was followed by *Cassia tora* and *Mikania micrantha*. Both of these had approximately equal coverage near settlements (Table 4 & Figure 6D).

The frequency and coverage of each IAPS along seven sampling sites (posts) were summarized in Table 5. *Chromolaena odorata* was found the most frequent with the highest coverage among 14 IAPS in all the sampling post areas except in Bhata site. In Bhata post area, *Cassia tora* found to be the most frequent, followed by *Mikania micrantha*, *Chromolaena odorata* and *Ageratum conyzoides* with equal frequency to this site. Although, *Cassia tora* was most frequent in the Bhata site, the coverage of *Mikania micrantha* found to be the highest. Hence, it can be said that Bhata site is most invaded by *Mikania micrantha* among 14 IAPS with highest dominance.

Among the seven sampling post areas, Adhabhar and Pratappur sites were found highly invaded by *Chromolaena odarata*, followed by Charbhaiya, Gaduwaline, Bhata, Nirmalvasti and Mahadeve Khola sites respectively. However, *Mikania micrantha* was recorded only from two sampling sites i.e. Bhata and Pratappur post areas with high difference of invasion; it was also seen on Charbhaiya post area out of the sampling plots with negligible invasions. Among 14 IAPS, 3 species – *Xanthium stramarium, Amaranthus spinosus* and *Parthenium hysterophorus* were only found in the Pratappur post site (Table 5). Bhata, Pratappur, and Adhabhar sites were seen most problematic due to invasion of IAPS among the 7 sampling post areas which were considered as the areas near the settlements. And *Chromolaena odorata* was seen the most dominant and the most problematic in PWR, not only near the settlement but also on the site away from the settlements.

Table 5: Summary of Site wise Frequency and Coverage of Invasive Alien Plant Species in PWR.

S. N.	Invasive Alien plant Species	Sampling Sites													
		Adhabhar Post		Mahadev Khola Post		Charbhaiya Post		Gaduwaline Post		Nirmalvasti Post		Bhata Post		Pratappur Post	
		Freq.	**Cov.**	**Freq.**	**Cov.**	**Freq.**	**Cov.**	**Freq.**	**Cov.**	**Freq.**	**Cov.**	**Freq.**	**Cov.**	**Freq.**	**Cov.**
1	*Chromolaena odorata*	95.00	21.20	50.00	2.95	75.00	7.30	60.00	5.10	55.00	9.70	60.00	16.40	90.00	28.55
2	*Mimosa pudica*	45.00	1.25	30.00	0.50	10.00	0.15	15.00	0.20	10.00	0.45	40.00	2.80	20.00	2.20
3	*Hyptis suaveolens*	40.00	1.05	0.00	0.00	0.00	0.00	5.00	0.10	5.00	0.15	10.00	4.00	30.00	6.25
4	*Cassia tora*	25.00	0.25	15.00	0.25	10.00	0.20	0.00	0.00	10.00	0.20	90.00	18.50	45.00	5.70
5	*Lantana camara*	20.00	0.65	5.00	0.05	0.00	0.00	0.00	0.00	5.00	0.05	0.00	0.00	0.00	0.00
6	*Alternanthera philoxeroides*	10.00	0.55	5.00	0.25	0.00	0.00	5.00	0.25	10.00	0.15	10.00	0.50	5.00	0.25
7	*Ageratum houstonianum*	10.00	0.25	0.00	0.00	5.00	0.10	0.00	0.00	0.00	0.00	30.00	3.40	20.00	1.70
8	*Ageratum conyzoides*	5.00	0.05	0.00	0.00	15.00	0.25	15.00	0.55	10.00	0.10	60.00	3.40	50.00	4.65
9	*Cassia occidentalis*	5.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.00	0.60	30.00	2.00
10	*Mikania micrantha*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	60.00	24.80	10.00	1.25
11	*Parthenium hysterophorus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.00	0.85
12	*Amaranthus spinosus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00	0.25
13	*Bidens pilosa*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.00	0.50	10.00	1.75
14	*Xanthium strumarium*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.00	2.35

The variances of mean coverage of all IAPS for settlement status, fire marks and sampling sites (posts) was found homogenous (*P>0.05*) (Table 6A, B & C). The mean coverage of IAPS and its invasion was found higher in near settlement than away from settlement (Figure 7A) and lower in fire marks than no fire mark (Figure 7B) with significantly different (*P>0.05*). The mean coverage of IAPS in different sampling post areas was also found significantly different (*P>0.05*) from each other. Bhata and Pratappur post areas were found highly invaded by IAPS than other sampling post areas among 7 sites (Figure 7E).

Table 6: Mean Comparisons of Coverage and Species Richness of IAPS
A. Near and away from settlements.

Samples & Tests		**Domin Cov. Scale of IAPS ($\bar{\chi}$ ± S.E.)**	**IAPS Richness ($\bar{\chi}$ ± S.E.)**
Settlement Status	Near Settlement	6.32 ± 0.29	3.3 ± 0.16
	Away from Settlement	2.72 ± 0.22	1.29 ± 0.11
Levene's Test for Equality of Variances	F-value	0.406	0.491
	Sig.-value	0.525	0.485
t-test	Sig.-value	0.000	0.000
B. In fire marks and no fire marks			
Fire Mark Status	No Fire Mark	4.7 ± 0.31	2.35 ± 0.16
	Fire Mark	3.2 ± 0.33	1.61 ± 0.18
Levene's test of Equality of Variances	F-value	2.041	2.260
	Sig.-value	0.156	0.135
t-test	Sig.-value	0.001	0.002
C. Different sampling Sites (Posts)			
Sampling Sites (posts)	Adhabhar Post	4.95 ± 0.45	2.80 ± 0.27
	Mahadev Kohola Post	2.00 ± 0.36	1.10 ± 0.19
	Charbhaiya Post	2.85 ± 0.47	1.25 ± 0.24
	Gaduwaline Post	2.70 ± 0.44	1.25 ± 0.22
	Nirmalvasti Post	3.35 ± 0.49	1.55 ± 0.23
	Bhata Post	8.00 ± 0.42	3.80 ± 0.25
	Pratappur Post	6.85 ± 0.38	3.55 ± 0.22
Leven's test of Equality of Variances	Sig.-value	0.465	0.691
ANOVA	F-value	22.578	22.047
	Sig.-value	0.000	0.000

(***Note:*** *Domin Cover Scale of IAPS - 0=0%, 1=1-2 individuals with no measurable cover, 2=several individuals but less than 1% cover, 3=1-4%, 4=4-10%, 5=11-25%, 6=26-33%, 7=34-50%, 8=51-75%, 9=76-90%, 10=91-100% cover of IAPS*)

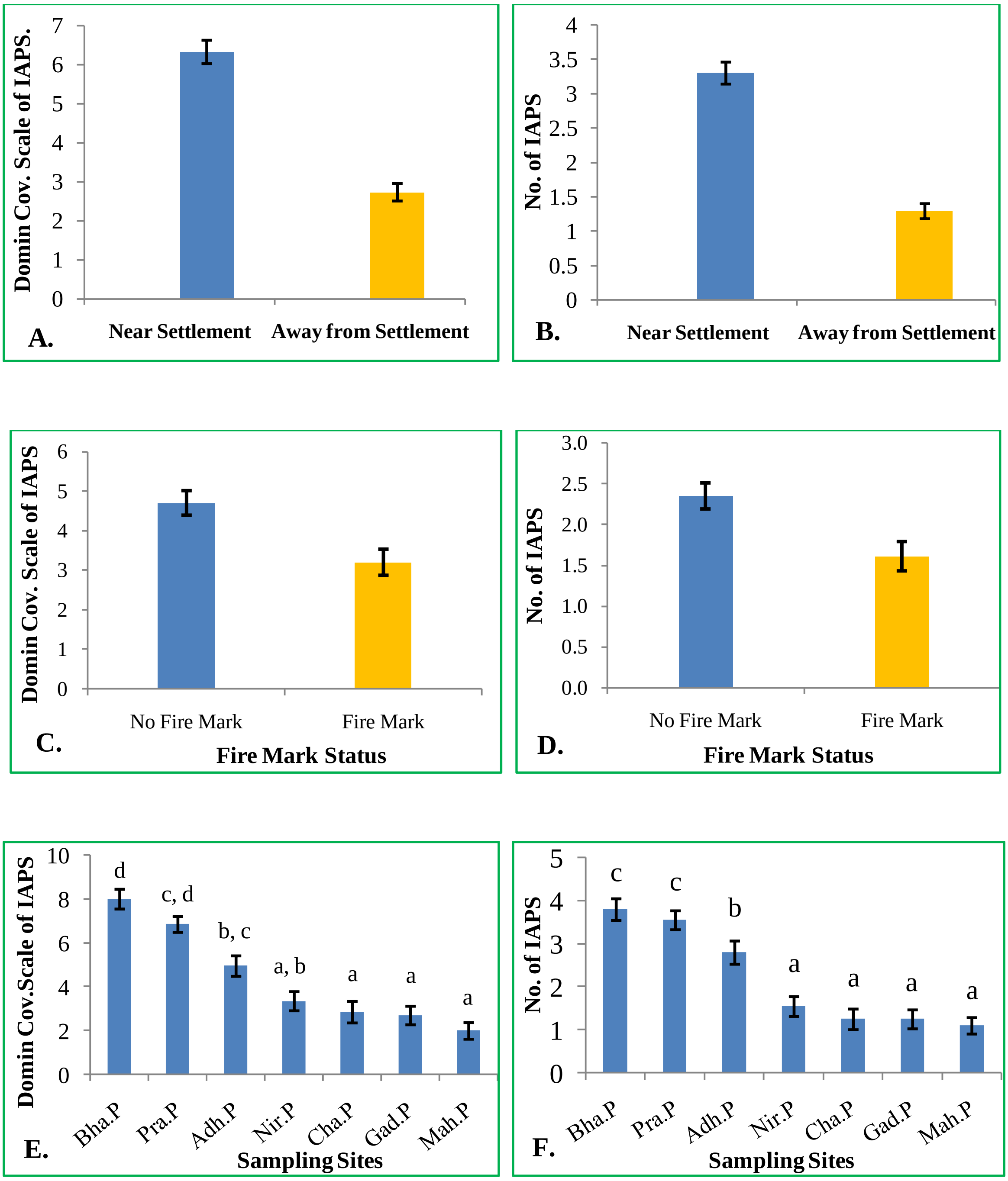

Figure 7: Domin Cover Scale of IAPS and its species richness: **A.** along settlement status, **B.** fire marks and **C.** sampling post sites. *(**Note:-** Domin Cover Scale of IAPS - 0=0%, 1=1-2 individuals with no measurable cover, 2=Several individuals but less than 1% cover, 3=1-4%, 4=4-10%, 5=11-25%, 6=26-33%, 7=34-50%, 8=51-75%, 9=76-90%, 10=91-100% cover of IAPS; Sampling Sites – Bha.P=Bhata, Pra.P=Pratappur, Adh.P=Adhabhar, Nir.P=Nirmalvasti, Cha.P=Charbhaiya, Gad.P=Gaduwaline, Mah.P=Mahadev Khola; letters above error bar indicate the significant different in mean value).*

Nirmalvasti, Charbhiya, Gaduwaline and Mahadev Khola Post showed the similar IAPS coverage, but significantly different from Bhata and Pratappur Post. IAPS coverage on Nirmalvasti and Adhabhar post areas showed no significant different from each other, but significant different from Bhata Post. Similarly Pratappur and Bhata showed no significant different in mean coverage of IAPS (Annex 4A).

4.3 Species Richness of IAPS

The variances of species richness of IAPS for all the three different types of samples (data groups) were homogenous ($P>0.05$) (Table 6A, B & C). The species richness of IAPS was found to be higher in near settlement than away from settlement (Figure 7B) and lower in fire marks than no fire marks (Figure 7D) with significantly different ($P<0.05$). Similarly the mean species richness in different sampling post areas were also found significantly different ($P<0.05$) from each other (Table 6A, B & C). The Bhata Post site was found highly rich in IAPS than other sampling post areas.

The IAPS richness on Nirmalvasti, Charbhaiya, Gaduwaline and Mahadev Khola Post were found approximately similar but significantly different from others. Adhabhar post showed significant different from all others and Bhata and Pratappur Post had the approximately similar species richness (Figure 7F and Annex 4B).

4.4 Factor Governing the IAPS

The factors that promote the growth, invasion of IAPS are considered as factors governing the IAPS. For this study, tree canopy cover, basal area and species richness of naturalized plant species were considered as the factor governing IAPS which were analyzed by linear regression model.

4.4.1 Relationship between tree canopy cover and coverage of IAPS

The relationship between the cover of canopy and invasive alien plant species was highly significant ($P<0.001$) with negative trend of relationship (r = -0.607). The tree canopy covers governs about 36.8% in the infestation and invasion of IAPS in the sampling sites of PWR (Figure 8).

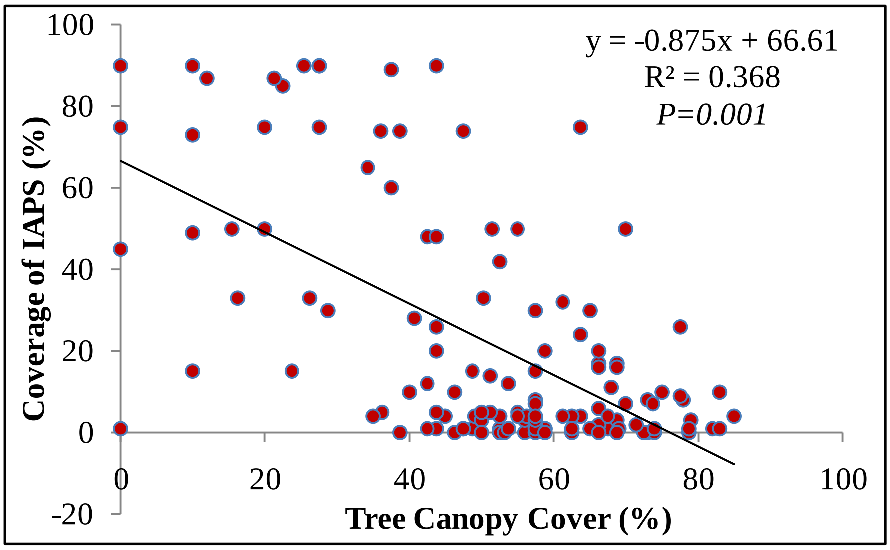

Figure 8: Variation of coverage of IAPS with tree canopy cover (%). (*Each point in the figure represents a sampling plot and the total number of sample plots was 130. Less number of points in the figure may be due to overlapping of the data among the plots. The fitted line is based on the linear regression model for sampling plots*.)

4.4.2 Relationship between tree canopy cover and number of IAPS

The relationship between the coverage of tree canopy and invasive alien plant species is very significant (*P<0.001*) with negative trend of relationship (r = - 0.503). The tree canopy cover explains about 25.2% of the species richness of IAPS in the sampling sites of PWR (Figure 9).

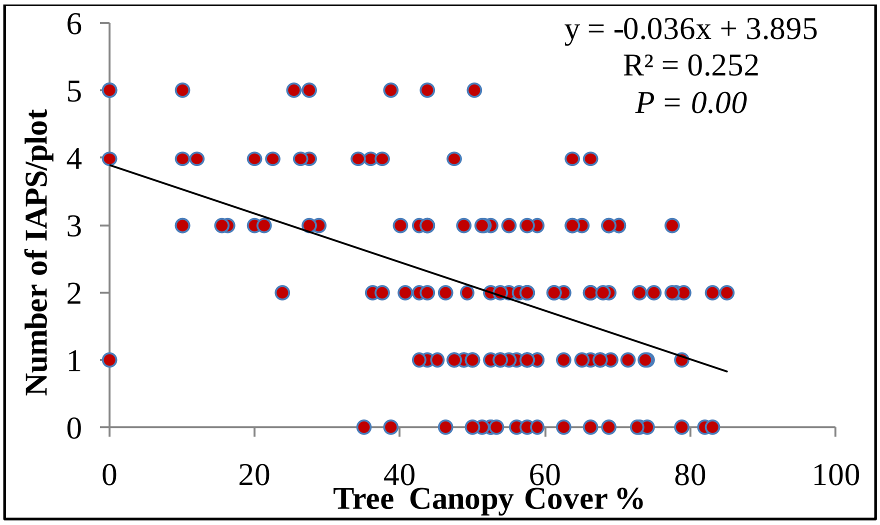

Figure 9: Variation of species richness of IAPS with Tree canopy cover (%). (*Each point in the figure represents a sampling plot and the total number of sample plots was 130. Less number of points in the figure may be due to overlapping of the data among the plots. The fitted line is based on the linear regression model for sampling plots*.)

4.4.3 Relationship between number of naturalized species and coverage of IAPS

The relationship between the numbers of naturalized plant species and coverage of invasive alien plant species is very highly significant (*P<0.001*) with positive trend of relationship (r = 0.618). The species richness of naturalized plant species play important role in governing the growth and infestation of about 38.2% for invasion of IAPS in the sampling sites of PWR (Figure 10).

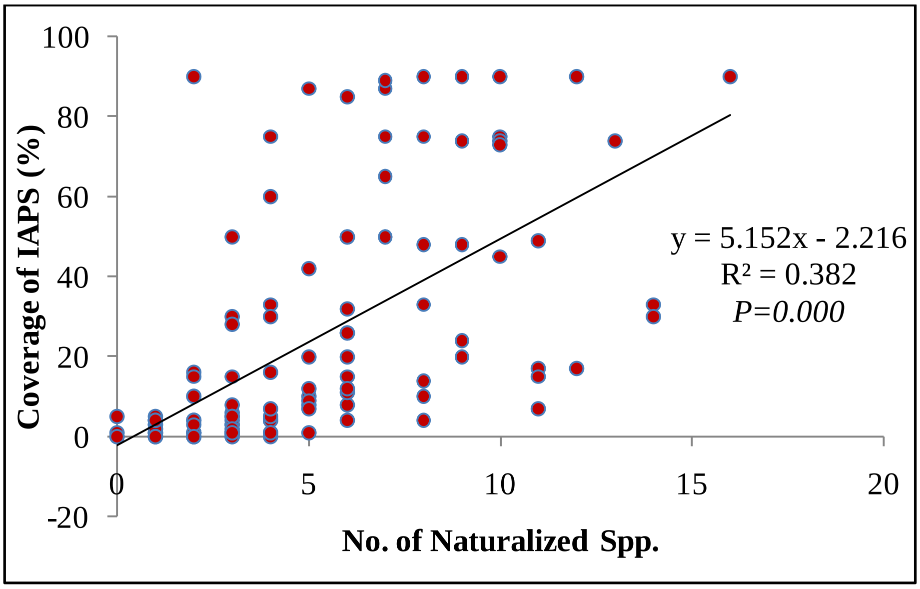

Figure 10: Variation of coverage of IAPS with species richness of naturalized plant spp. (*Each point in the figure represents a sampling plot and the total number of sample plots were 130. Less number of points in the figure may be due to overlapping of the data among the plots. The fitted line is based on the linear regression model for sampling plots.*)

4.4.4 Relationship between number of naturalized plant species and IAPS richness

The relationship between the numbers of naturalized plant species and number of invasive alien plant species is very significant (*P<0.001*) with positive trend of relationship (r = 0.8). The species richness of naturalized plant species governs of about 64% to increase the species richness of IAPS in the sampling sites of PWR (Figure 11).

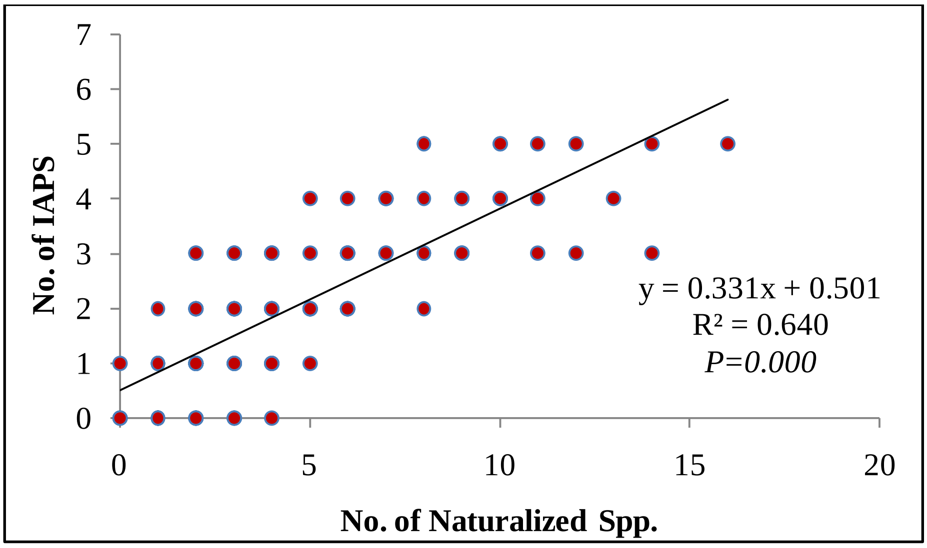

Figure 11: Variation of numbers of IAPS with numbers of naturalized plant spp. (*Each point in the figure represents a sampling plot and the total number of sample plots were 130. Less number of points in the figure may be due to overlapping of the data among the plots. The fitted line is based on the linear regression model for sampling plots*.)

4.4.5 Relationship between tree basal area and coverage of IAPS

The relationship between tree basal area and coverage of IAPS was poor but significant (*P<0.001*) with negative trend of relationship (r = - 0.411). Tree basal area explains about 16.8% coverage of IAPS in the sampling sites of PWR (Figure 12).

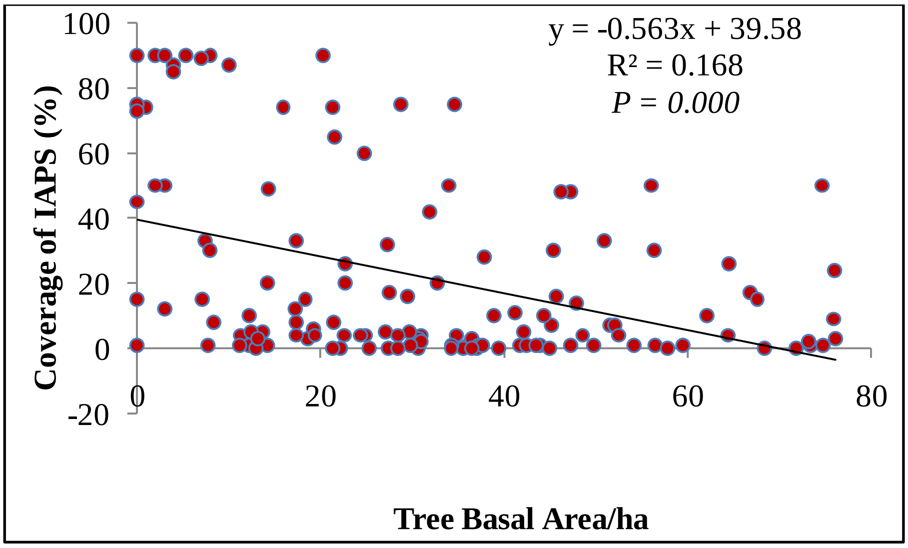

Figure 12: Variation of coverage of IAPS with Tree Basal Area/ha. (*Each point in the figure represents a sampling plot and the total number of sample plots was 130. Less number of points in the figure may be due to overlapping of the data among the plots. The fitted line is based on the linear regression model for sampling plots.*)

4.5 Impacts of IAPS

To evaluate the impacts, coverage of IAPS has been considered as predictor variable. The impacts of IAPS were seen in the sapling density and number of species of native herb species. The relationship between the predictor and response variable was determined with the help of linear regression model.

4.5.1 Relationship between coverage of IAPS and number of IAPS

There was highly significant relationship (*P<0.001*) between coverage of IAPS (%) and number of invasive alien plant species with positive trend of relationship (r = 0.804). The coverage of IAPS explains about 64.6% of variability of species of IAPS in the sampling sites of PWR (Figure 13).

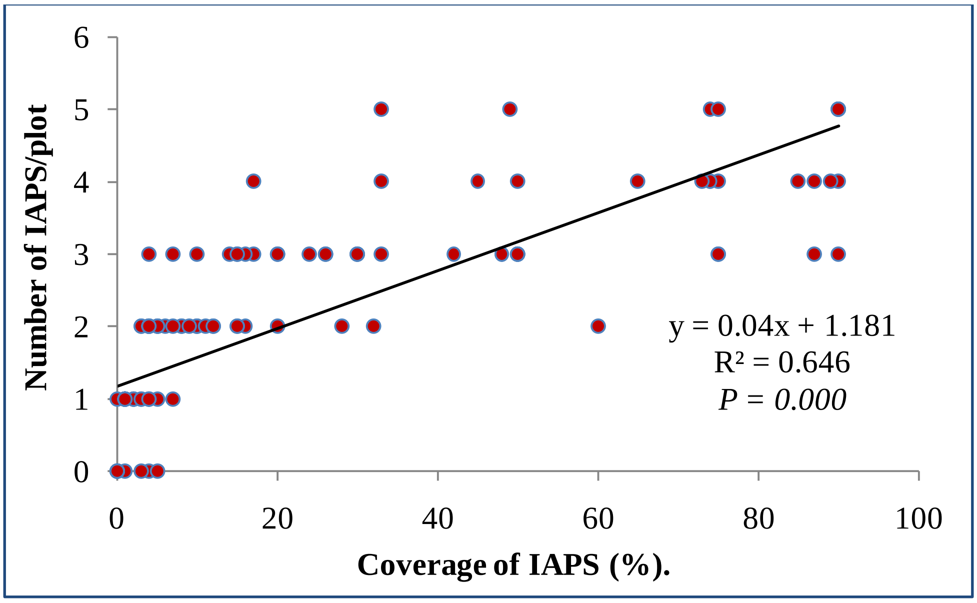

Figure 13: Variation of species richness of IAPS with coverage of IAPS. (*Each point in the figure represents a sampling plot and the total numbers of sample plots were 130. Less number of points in the figure may be due to overlapping of the data among the plots. The fitted line is based on the linear regression model for sampling plots.*)

4.5.2 Relationship between coverage of IAPS and sapling density

There was very significant relationship (*P<0.001*) between coverage of IAPS (%) and sapling density with negative trend of relationship (r = -0.451). The coverage of IAPS explains about 20.3% sapling density in the sampling sites of PWR (Figure 14).

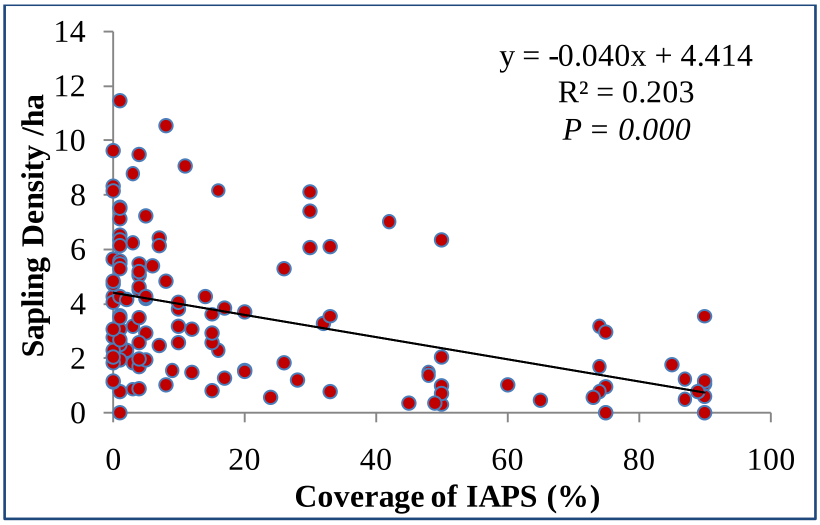

Figure 14: Variation of sapling density with coverage of IAPS. (*Each point in the figure represents a sampling plot and the total numbers of sample plots were 130. Less number of points in the figure may be due to overlapping of the data among the plots. The fitted line is based on the linear regression model for sampling plots*.)

4.5.3 Relationship between coverage of IAPS and numbers of native herb species

The relationship between coverage of IAPS (%) and number of native herb species was insignificant (*P>0.05*) with poorly negative trend of relationship (r = -0.088). The coverage of IAPS explains very few impacts ca. 0.7% on native herb species in the sampling sites of PWR (Figure 15).

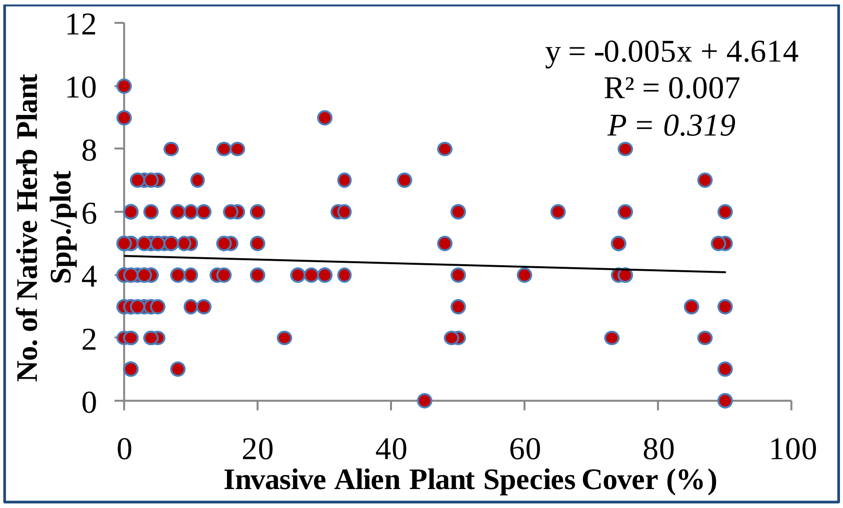

Figure 15: Variation of number of native herb plant spp. with coverage of IAPS. (*Each point in the figure represents a sampling plot and the total numbers of sample plots were 130. Less number of points in the figure may be due to overlapping of the data among the plots. The fitted line is based on the linear regression model for sampling plots*.)

CHAPTER V

DISCUSION AND CONCLUSION

5.1 Naturalized plant species in PWR

PWR consists of Hill Sal (*Shorea robusta*) forest and lower tropical Sal (*Shorea robusta*) mixed broad leaved forest and eight types of ecosystems (Bhuju, *et al*. 2007). The study was conducted only on forest ecosystem of PWR. The documentation of less number (231 spp.) of flowering plants (Annex 2A-G) in PWR than the record of Bhuju *et al*. 2007 (298 spp.) might be due to sampling only on lower tropical Sal (*Shorea robusta*) mixed broad leaved forest, the other forest types and ecosystems are avoided in the sampling sites due to high risk of wild animals.

Among the 7 sampling sites, the numbers of flowering plants and native plant species were found less in Bhata and Pratappur sites. It might be due to presence of higher numbers of naturalized plant species and invasion of IAPS (Table 3). As we know that all the naturalized plant species are not invasive but potential invasive plants at any time. The high number of naturalized plant species in Bhata, Pratappur and Adhabhar sites might be due to the effect of human activities. However, the number of naturalized plants not found less in Adhabhar site than Bhata and Pratappur, but no considerable effects was seen in number of native plant species (Table 3). It could be due to either in initial stage of spread of naturalized plant species or forest having high tree canopy cover (Annex 3) that dominate the effect of herbaceous and shrubby naturalized plant species.

The 6 dominant naturalized families in Nepal were Asteraceae (34 species), Solanaceae (23 species), Fabaceae (21 species), Euphorbiaceae (16 species), Cyperaces (10 species) and Amaranthaceae (10 species), which contribute more than 57% of total families of naturalized plants (Siwakoti, 2012). Approximately, similar result was found by this work as dominant families of naturalized plants. These were Asteraceae, Leguminosae and Amaranthaceae. In addition to Malvaceae, Rubiaceae and Euphorbiaceae were also reported as the dominant in the forest of PWR.

All 22 IAPS (Tiwari *et al.* 2005 and one from field survey) were dicotyledonous except *Pistia stratiotes* (Annex 7A-B). All the naturalized plants recorded in PWR also belong to dicotyledonous plants except *Cyperus difformis*. It can be said that the dicotyledonous plants are highly active in allelopathic nature (Callaway and Ridenour 2004).

5.2 Infestation of IAPS

The result approximately supports the previous study i.e. the frequency of *Chromolaena odorata* was 30.8%, followed by *Cassia tora (*7.3%), *Ageratum conyzoides (*17.2%), *Mimosa pudica* (2.3%) in forests of Terai in Nepal (Tiwari *et al.* 2005). Similarly, in previous study also showed that the coverage of *Chromolaena odorata* was highest (12.99%) followed by *Mikania micrantha* (11.6%) and *Ageratina adenophora* (8.20%) in forests of Tarai in Nepal. The high coverage of *Chromolaena odorata* might be due to small seed mass, prolific production, rapid growth, low nuclear DNA, high efficiency of competition for nutrition also promote invasion success (Hutsan 1994, Rejmanek 1995, 1996). *Amaranthus spinosus* was measured as the least dominant in PWR. It might favor the environments of agricultural land rather than forest land.

Among the 14 IAPS, *Chormolaena odaorata, Lantana camara* and *Mikania micrantha* were recorded in PWR are listed under the category of world's hundred worst invaders (Lowe *et al.* 2004). *Ageratum conyzoides, Chromolaena odorata, Imperata cylindrica, Lantana camara, Mikania micrantha* and *Parthenium hysterophorus* were identified in the list of seven top alien invasive plants of Asia Pacific region (Sankaran *et al.* 2005), were reported similarly by this work from sampling areas in PWR (Annex 2A-G).

The anthropogenic disturbance near settlement area was seen such as human movements, cattle grazing, stumping of tree, movement of vehicles, industrial product transportation, garbage waste, etc., while the area away from settlement was no anthropogenic disturbances or negligible disturbance. The invasion level of each IAPS near settlement favored more by the human activities rather than the allelopathic nature with high reproductive efficiency of invasive weed (Fugii *et al.* 2008). Anthropogenic activities and animal movement may help in arrival and distribution of IAPS propagules in exotic areas where they can easily colonize the niche and then start to alter ecosystem processes affecting native community. Each IAPS measured more dominant and more frequent in forest near settlement than away from settlement supporting the statement of Fugii *et al.* 2008. Hence, it can be said that the settlement zones are the favorable sites for the spreading of the IAPS. The level of invasion found to be decreased on decreasing the human interference gradually (Karki 2009) from sampling areas near settlement to away from settlements.

There is vigorous reproduction and growth of IAPS e.g. *Chromolaena odorata* after mild fires (de Rouw 1991). In South Africa, *Chromolaena odorata* is considered a fire hazard due to inflammability and is considered a potential threat to the persistence of coastal forests which are not resistant to fires (Witkowski 2000). But the infestation level of IAPS was recorded higher along no fire marks than fire marks. It was contradictory result with previous findings. The possible causes behind this result could be the fire might have eradicated IAPS propagules and seed bank. The infestation level and frequency of IAPS e.g. *Chromolaena odorata* might be governed by other factors such as light intensity, anthropogenic activities, etc rather than fires.

The cause of the most dominance and frequency of *Chormolaena odorata* among 14 IAPS in PWR might be due to high efficiency of reproduction and growth even in the low intensity of light. Close canopy cause low and grassland cause high light intensities. The coverage and frequency of *Chromolaena odorata* displays low under low light intensities, increased to intermediate light intensities and declined with high light intensities (Norbu 2004). Sal (*Shorea robusta*) forest of Terai of Nepal is best availability of such understory light intensity and displays a variety of reproduction, rapid growth and its spread (Joshi 2001). It is usually found in disturbed environments and due to its heliophilous nature capable of persistence in forests even in dense canopies (Joshi 2001).

Chromolaena odorata was found the most frequent and the highest coverage in each sampling sitesexcept at Bhata post areas. At Bhata site, there was approximately open canopy and wetlands and therefore *Mikania micrantha* found to be most frequent and the highest coverage. There are two wetlands viz. Lauki Daha and Devaki Daha and two streams Bhata Khola and Jalvayu Khola in the Bhata site that makes the area moist. The moist land with open canopy might be the best habitat for the growth, reproduction and rapid colonization of *Mikania micrantha*. It’s reporting from Koshi Tappu Wildlife Reserve (Siwakoti 2007) and from Chitwan National park (Sapkota 2012) further supports this statement. It could be the best cause for the highest coverage and infestation level of *Mikania micrantha* instead of *Chromolaena odorata* in Bhata post areas. However, *Mikania micrantha* recorded only from two sites i.e. Bhata and Pratappur post areas. It was seen with negligible cover out of sampling plot in Charbhaiya post areas.

Remaining 4 sampling sites viz. Mahadev Khola, Charbhaiya, Gaduwaline, and Nirmalvasti sites were away from the settlements and had dense tree canopy cover. The dense canopy checks the light intensity for growth and colonization of not only *Chromolaena odorata* but also the all IAPS. Hence, it might responsible for less coverage of *Chromolaena odorata* and other IAPS in these four sampling sites. The close canopy and high understory biomass might have prevented the infestation by *Chromolaena odorata* and other IAPS.

Similarly, the highest species richness and invasion of all IAPS in two sampling sites i.e. Bhata and Pratappur Post areas, followed by Adhabhar site (Table 6) might be due to three factors viz. anthropogenic cause, understory light intensity and species richness of naturalized plant. All these three areas were considered as sites near the settlements that promote the anthropogenic disturbance and such disturbance governs the infestation of IAPS. The mean tree canopy covers in Bhata and Pratappur found lower than other sites (Annex 3), that may permits appropriate understory light intensity for efficiency of reproduction and colonization of IAPS supporting the findings of Norbu 2004. Similarly, the species richness of naturalized plants found higher in these three sitesthan other. They may create suitable environments for the infestation and colonization of IAPS. Remaining four sites were far away from settlements and forest with high canopy covers (Annex 3) and less number of naturalized plant species (Table 3).

5.3 Factor Governing IAPS

With increasing tree canopy cover, both species richness and cover of IAPS was found to be decreasing (Figure 8 & 9) supporting the findings of Bhuju *et al.* (2013). Often the invasive alien plant species require direct light for growth and reproduction. In forests, the tree canopy determine the amount of light available on the ground surface. High tree canopy cover means low availability of light on the ground surface which is less favorable for the growth and reproduction of most of the invasive alien plant species. For example, abundance and reproductive efficiency of *Chromolaena odorata is* high in those micro habitats, where canopy cause intermediate light intensity (Norbu, 2004). Hence high tree canopy cover minimizes the infestation and colonization of IAPS in forest ecosystem. Result shows that the intensity of IAPS infestation can be seen higher and even faster in the forest having open tree canopy. The tree canopy cover found open and lower in Bhata, Pratappur and Adhabhar sites (Annex 3) due to which species richness and coverage of IAPS was found higher in these sites. Hence, the result supports the first hypothesis of the study that open canopy in forest facilitates the infestation of IAPS.

If the species richness of naturalized plant species increased the number of species and infestation of IAPS also found to be increased. The species richness of naturalized plant species found strongly correlated with species richness of IAPS that explained ca. 64.0%

variation with significant relationship (*P<0.001*) which is the highest among factor governing IAPS infestation (Figure 10 & 11). IAPS is subset of naturalized species and the later served as pool of species from which some species turn out to be invasive. It demonstrates that IAPS may favor the environments of naturalized species for their growth, reproduction and invasion. Another possible cause might be due to physiochemical properties of soil created by naturalized plant species e.g. phytotoxin (harmful for native vegetations), xanthinosin secreted by *Xanthium* sp. (Shao *et al.* 2012). These chemicals are allelopathic in nature. This nature of naturalized plants may promote the growth and invasion of IAPS (Callaway and Ridenour 2004). It can be said that the naturalized plant species play very important role for IAPS infestation. Hence, high species richness and infestation of IAPS in Bhata, Pratappur and Adhabhar sites also could be due to high species richness of naturalized plant species (Table 3). In conclusion, it can be said that the naturalized plants increase the richness and spread of IAPS. Therefore the result supported second hypothesis of the study that the species richness of naturalized plants increases the richness of IAPS.

With increasing of basal area of tree, IAPS was found the trend of decreasing. Higher the basal area, more the DBH, means the tree is also larger. Larger tree, have higher tree canopy cover. As we know that, invasive alien plant species require the understory light for their reproduction and growth while higher canopy check the more light intensity which might be less favorable for colonization and infestation of invasive alien plant species. The mean basal area was found least in Bhata sites (Annex 6), it also might be the possible cause for the highest species richness and invasion of IAPS in this post area (Table 6).

5.4 Impacts of IAPS

With increase of coverage of IAPS, there was increase of species richness of IAPS. More coverage of IAPS results secretion of high amounts of allelopathic and phytotoxic chemicals. Such chemicals can affect the species richness of other vegetation in one hand while on the other hand it would be favorable for species richness and infestation of IAPS.

Tree regeneration is affected by the abundance of IAPS. Seedlings are the pioneer for growth of saplings and tree regeneration. Sapling density was found to be declined with increasing coverage of IAPS with significant effects (*P<0.001*). High abundance of IAPS modifies the micro-habitat in such a way that it becomes hostile for seed germination and seedling growth due to which might results less density of saplings with increasing of coverage of IAPS. Besides changing physical environmental conditions, the IAPS release certain secondary metabolites i.e. allelochemical that makes the chemical environment of soil unsuitable for germination of seeds of other species (Inderjit e*t al*. 2008) and may suitable for germination and colonization of IAPS. The growth of seedlings into saplings was critical for tree regeneration under the high influence of invasive species. Once the individual grows to sapling, the effect of invasive alien plants species would be insignificant (Bhuju *et al.* 2013). Plants that have matured beyond the seedling stage with some potential to flower are only present in areas with more light and less competition. Plants in more stressful environments i.e. low light and high competition appeared as sterile (Norbu 2004). Hence it can be said that the impacts of abundance of IAPS might be either at the seedling stage or initial stage of saplings due to which there may be declination of sapling density with increasing infestation of IAPS.

IAPS further deteriorates the already degraded forests and prevent from natural regeneration. In other words, IAPS are the 'passengers' of deforestation and forest degradation at their early stage of colonization, which later change into 'drivers' by disrupting regeneration process (Dalal-Clayton *et al.* 2014). The situation could be more extreme if the forests infested by IAPS are also subjected to other kind of anthropogenic disturbances e.g. in Bhata and Pratappur post areas, there was very low sapling density (Annex 6). In the forests ecosystem of PWR, the reduced regeneration of tree species, as evident by low seedling and sapling density, is the most prominent impacts of IAPS (Figure 14). Hence, the result supported the second hypothesis of the study that IAPS reduces the tree regeneration of native plants.

The number of native herb plant species found decreasing with increasing of IAPS infestation but unexpectedly found to be affected insignificantly ($P=0.319$) by cover of IAPS. It might be due to still less impacts of IAPS on native herb regeneration. The understory light intensity and understory biomass may promote the native herb species regeneration. There was high coverage of litters on the ground that may fill up the required nutrition for native herb species regeneration. Hence, there would not be significant impacts on native herb species even due to high abundance of IAPS.

5.5 Conclusions

Altogether 231 species of flowering and 51species of naturalized plants were recorded from the sampling areas in PWR. Altogether 14 IAPS reported from PWR. The highest numbers of naturalized and IAPS were recorded belonging to family Compositae, followed by Leguminosae. Among these, *Chromolaena odorata* were most frequent with highest coverage in all sampling sites except Bhata. At Bhata site, *Mikania micrantha* recorded most dominant with the highest invasion. Frequency and coverage of each and all IAPS was seen more in the areas near settlement with high problematic than areas away from settlements. Bhata and Pratappur sites were found highly problematic due to invasion of IAPS.

The relationship of tree canopy with species richness and coverage of IAPS were significant having negative trend. The tree canopy covers of 10-50% permits the best understory light intensity for the growth and reproduction of IAPS in which the infestation found most problematic. The number of naturalized plant species was found to govern the invasion of IAPS with strong correlation and significant relationship. Coverage of IAPS can maintain the environment to increase the number of species of IAPS. The tree regeneration was found highly affected by infestation of IAPS negatively. It means less number of seeds overcome the impacts of IAPS due to which less number of seedlings to saplings overcome the infestation of IAPS. Similarly, the insignificant affect and negative relationship was found between coverage of IAPS and number of native herb species.

CHAPTER VI

RECOMMENDATION

Based on the results of the study, this work strongly recommends the following points to control invasion and management of IAPS in PWR.

1. To control the invasion of IAPS:

- Minimize the anthropogenic activities along peripheral regions of PWR so that further spread of IAPS can be reduced.
- Educate local communities to identify IAPS, understand their long term impacts on biodiversity and environment, their mode of spread and management options; encourage communities to control IAPS in their localities.
- This work refers the mechanical method to control the IAPS infestation in PWR.

2. Research in future:

- Preparation of detailed distribution map of major IAPS so that management can be focused to the most problematic areas and future monitoring would be possible.
- The researches on biological method to control the invasion of IAPS are necessary in PWR.
- Conduction of ecology and biological study of IAPS in PWR is essential to control its invasion as soon as possible.

3. Management policy:

- Develop national strategy for the management of IAPS in the protected areas of Nepal.
- Preparation of management plan for IAPS invasion and implementations in protected areas at local and national level.

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Annex-1A: First sheet sample for ecological data collection from the field

Status and Abundance of Invasive Alien Plant Species in Parsa Wildlife Reserve

SN. 5....... Date: 073-09-21 ... Site: Adhabar .... Aspect: ...x.......... U.P. 60

Latitude: 27.26243 .... Longitude: 84.98926 .... Elevation: 269 ..... Slope: ..x.......

Transect No. ...1....... Quadrat number: ...5......... Forest type: ..Tropical broadleaved Mixed

Tree canopy (%): 90/95/100/90.. = ... # stump: .... Fire marks: Y / N ✓

Inventory of selected IAS (among 21 species listed by Tiwari *et al*. 2005)

SN	IAS	Cover (%)	SN	IAS	Cover (%)
1	Chromolaena odorata (H)	15	6		
2	Mimosa pudica (H)	5	7		
3	Hyptis suaveolens (H)	2.	8		
4	Cassia tora. (H)	1	9		
5			10		

Inventory of tree species (height >1.3 m)

SN	Name of species	Diameter at breast height (cm)
1	Holarrhena antidysenterica	12.5, 14.5, 18.4
(H) 2	Croton roxburghii	22.7, 30, 13.5, 24, 13.4, 13.1, 4.5, 12, 11.1

1

Name of field investigator: ....

Annex 1B: Second sheet sample for ecological data collection from field

Inventory of shrubs and herbs (including climbers and ferns but excluding epiphytes and parasites)

SN	Name of species	Life form	SN	Name of species	Life form
1	Dillena pentagyna ([illegible])		16	Eleophantopus scaber	(N)
2	Desmodium ?(white flower)(area)		17	oplismenus burmanii	
3	Lagerstroemia parviflora		18	phyllanthus urinaria	(N)
4	shorea robusta		19	Icnocarpus frutescens	
5	Dalbergia sissoo ?		20		
6	Thespesia lampus		21		
7	phytopodium		22		
8	(Ban simi) (trifoliate)		23		
9	Dioscorea bulbifera		24		
10	Leea asiatica		25		
11	Triumpheta ? (Tiliaceae)		26		
12	Semicarpus anacardium		27		
13	Uraria lagopodioides ([illegible])		28		
14	Syzygium cumini		29		
15	euphorbia hirta	(N)	30		

Remarks: ……………………………………………………………………………………………

……………………………………………………………………………………………………

Summary (to be filled after returning from the field)

vascular plant species: …………………… # flowering plants: ……………………

dicotyledonous species: …………………… # monocotylenous species: ……………………

naturalized species: …………………… # IAS: ……………………

Name of field investigator: ……………………………………

2

Annex 2A: List of plant species recorded from sampling plots in PWR

S.N.	Name of species	Family	Habit	Freq.
1	*Peristrophe bicalyculata* (Retz.) Nees.	Acanthaceae	H	3.85
2	*Barleria cristata* L. *	Acanthaceae	S	9.23
3	*Strobilanthus capitata* (Nees.) T. Anders	Acanthaceae	H	53.08
4	*Justicia procumbens* (D. Don) T. Yamaz.	Acanthaceae	H	1.54
5	*Achyranthes aspera* L. *	Amaranthaceae	H	9.23
6	*Gomphrena celosioides* Mart. *	Amaranthaceae	H	6.92
7	*Achyranthes bidentata* Blume *	Amaranthaceae	H	1.54
8	*Alternanthera philoxeroides* (Mart.) Griseb.**	Amaranthaceae	H	6.15
9	*Alternanthera sessilis* (L.) DC. *	Amaranthaceae	H	1.54
10	*Amaranthus spinosus* L. **	Amaranthaceae	H	0.77
11	*Semecarpus anacardium* L. f.	Annacardiaceae	T	26.92
12	*Magnifera indica* L.	Annacardiaceae	T	3.85
13	*Spondias pinnata* (L.f.) Kurz	Annacardiaceae	T	2.31
14	*Miliusa tomentosa* (Roxb.) Sinclair	Annonaceae	T	20.77
15	*Miliusa roxburghiana* (Wall.) Hook.f. & Thomson	Annonaceae	T	3.08
16	*Holorrhena antidissentica* (Buch.-Ham.) Wall.	Apocynaceae	T	46.15
17	*Icnocarpus frutescenes* (L.) R. Br.	Apocynaceae	WC	41.54
18	*Wrightia arborea* (Dennst.) Mabb.	Apocynaceae	T	4.62
19	*Trachelospermum lucidum* (D. Don.) K. Schum.	Apocynaceae	WC	5.38
20	*Caladium bicolor* Vent.	Araceae	H	2.31
21	*Colocasia esculenta* (L.) Schott.	Araceae	H	1.54
22	*Calotropis gigantea* (L.) Dryand.	Asclepeiaceae	S	2.31
23	*Asparagus racemosus* Willd.	Asparagaceae	CS	37.69
24	*Impatiens exilis* Hook.f.	Balsaminaceae	H	0.77
25	*Garuga pinnata* Roxb.	Berseraceae	T	21.54
26	*Stereospermum personatum* (Hassk.) Chatterjee	Bignoniaceae	T	2.31
27	*Oroxylum indicum* (L.) Kurz.	Bignoniaceae	T	2.31
28	*Bombax ceiba* L.	Bombacaceae	T	6.92
29	*Cynoglossum lanceolatum* Forssk	Boraginaceae	H	0.77
30	*cynoglossum zeylanicum* (Vahl.) Thunb.ex. Lehm.	Boraginaceae	H	2.31
31	*Cannabis sativa* (Vavilov) Small & Cronquist	Cannabaceae	H	3.08
32	*Terminalia alata* Heyne ex. Roth.	Combretaceae	T	29.23
33	*Terminalia belerica* (Gaertn.) Roxb.	Combretaceae	T	13.85
34	*Terminalia chebula* Retz.	Combretaceae	T	0.77
35	*Cynotis cristata* (L.) D. Don.	Commelinaceae	H	25.38

(Note: - H=Herb, S=Shrub, T=Tree, WC=Woody Climber, CS=Climbing Shrub, CH=Climbing Herb, *=Naturalized spp. and **=IAPS, Freq. =Frequency %)

Annex 2B: List of plant species recorded from sampling plots in PWR

S.N.	Name of species	Family	Habit	Freq.
36	*Murdania scapiflora* (Roxb.) Royle	Commelinaceae	H	3.08
37	*Commelina paludosa* Blume	Commelinaceae	H	0.77
38	*Chromolaena odorata* (L.) King & Robinson**	Compositae	H	70.00
39	*Ageratum conyzoides* L. **	Compositae	H	19.23
40	*Synedrella nodiflora* Gaertn. *	Compsitae	H	10.00
41	*Elephantopus scaber* L. *	Compsitae	H	22.31
42	*Ageratum haustonianum* Mill.**	Compsitae	H	7.69
43	*Inula cuspidata* (DC.) C.B. Clarke	Compsitae	S	2.31
44	*Vernonia cinerea* L. *	Compsitae	H	6.92
45	*Spilanthes paniculata* Wall.ex. DC.	Compsitae	H	4.62
46	*Adenostemma lavenia* (L.) O. Kuntz. *	Compsitae	H	5.38
47	*Mikania micrantha* Kunth. **	Compsitae	CH	6.15
48	*Bidens pilosa* L. **	Compsitae	H	2.31
49	*Smallanthus sonchifolius* L.	Compsitae	H	1.54
50	*Parthenium hystenophorus* L. **	Compsitae	H	1.54
51	*Xanthium strumarium* L. **	Compsitae	H	2.31
52	*Tridax procumbens* L. *	Compsitae	H	0.77
53	*Argyria nervosa* (Burm.f.) Bojer	Convolvulaceae	CS	13.08
54	*Argyreia laotica* Roxb.	Convolvulaceae	CS	3.85
55	*Argyria setosa* (Roxb.) Choisy	Convolvulaceae	CS	0.77
56	*Ehretia acuminata* Roxb.	Coridaceae	T	2.31
57	*Cordia dichotoma* J.R. Forst.	Coridaceae	T	1.54
58	*Ehretia dicksonii* Hance	Coridaceae	T	0.77
59	*Zehneria indica* (Lour) Keraudren	Cucurbitaceae	CH	1.54
60	*Coccinia grandis* (L.) Boigt.	Cucurbitaceae	WC	3.08
61	*Trichosanthes ovigera* Blume	Cucurbitaceae	CS	0.77
62	*Cyperus rotundus* L.	Cyperaceae	H	0.77
63	*Cyperus difformis* L. *	Cyperaceae	H	0.77
64	*Cyperus esculentus* L.	Cyperaceae	H	0.77
65	*Kylinga brevifolia* Roxb.	Cyperaceae	H	1.54
66	*Dillenia indica* L.	Dilleniaceae	T	8.46
67	*Dillenia pentagyna* Roxb.	Dilleniaceae	T	4.62
68	*Dioscorea deltoidea* Wall.ex. Griseb.	Dioscoreaceae	CH	16.15
69	*Dioscorea bulbifera* L.	Dioscoreaceae	CH	54.62
70	*Dioscorea pentaphylla* L.	Dioscoreaceae	H	48.46

*(Note: - H=Herb, S=Shrub, T=Tree, WC=Woody Climber, CS=Climbing Shrub, CH=Climbing Herb, *=Naturalized spp.* and **=IAPS, Freq.=Frequency%)*

Annex 2C: List of plant species recorded from sampling plots in PWR

S.N.	Name of species	Family	Habit	Freq.
71	*Dioscorea Pyrifolia* Kunth	Dioscoreaceae	CH	0.77
72	*Dioscorea kamoonensis* Kunth	Dioscoreaceae	H	3.85
73	*Shorea robusta* Gaertn.	Dipterocarpaceae	T	70.00
74	*Diospyrus montana* Roxb.	Ebenaceae	T	10.00
75	*Diospyrus malabarica* (Desr.) Costel	Ebenaceae	T	16.92
76	*Diospyrus lotus* L.	Ebenaceae	T	3.08
77	*Trewia nudiflora* L.	Euphorbiaceae	T	10.77
78	*Bridelia pubescens* Kurz	Euphorbiaceae	T	0.77
79	*Mallotus phillipens* (Lam.) Mull.	Euphorbiaceae	T	39.23
80	*Croton bonplandianum* Baill. *	Euphorbiaceae	H	6.15
81	*Croton roxburghii* N.P. Balakr.	Euphorbiaceae	T	49.23
82	*Euphorbia hirta* L. *	Euphorbiaceae	H	5.38
83	*Phyllanthus emblica* L.	Euphorbiaceae	T	35.38
84	*Phyllanthus urinaria* L. *	Euphorbiaceae	H	11.54
85	*Breynia vitis-idaea* (Burm.f.) Fisch.	Euphorbiaceae	S	6.15
86	*Antidesma acidum* Retz.	Euphorbiaceae	T	2.31
87	*Bridelia retusa* (L.) Spreng.	Euphorbiaceae	S	1.54
88	*Phyllanthus amarus* Schumach & Thonn *	Euphorbiaceae	H	6.92
89	*Phyllanthus reticulatus* Poir	Euphorbiaceae	CS	3.85
90	*Imperata cylindrica* (L.) Beauv.	Graminae	H	23.85
91	*Oplismenus burmonii* (Retz.) Beauv.	Graminae	H	28.46
92	*Desmostachya bipinnata* (L.) Stapf.	Graminae	H	13.08
93	*Chrysopogon gryllus* (L.) Trin.	Graminae	H	3.85
94	*Saccharum spontaneum* L.	Graminae	H	6.15
95	*Cynodon dactylon* (L.) Pers	Graminae	H	3.08
96	*Hydrangea anomala* D. Don	Hydrangeaceae	T	0.77
97	*Curculigo orchides* Gaertn.	Hypoxidaceae	H	29.23
98	*Hyptis suaveolens* (L.) Poit **	Labiatae	H	13.08
99	*Plectranthus mollis* (Aiton.) Spreng.	Labiatae	H	3.85
100	*Salvia plebeia* R. Br.	Labiatae	H	3.85
101	*Pogostemon benghalensis* (Burm.f.) Benth.	Labiatae	H	10.77
102	*Pogostemon cablin* (Blanco) Benth.	Labiatae	H	1.54
103	*Colebrookea oppositifolia* Sm.	Labiatae	S	2.31
104	*Geniosporum coloratum* (D. Don) Kuntze	Labiatae	H	1.54
105	*Litsea salicifolia* (Roxb.ex. Nees.) Hook.	Lauraceae	S	33.85

(Note: - H=Herb, S=Shrub, T=Tree, WC=Woody Climber, CS=Climbing Shrub, CH=Climbing Herb, *=Naturalized spp. and **=IAPS, Freq. =Frequency %)

Annex 2D: List of plant species recorded from sampling plots in PWR

S.N.	Name of species	Family	Habit	Freq.
106	*Persea gambli* (King ex. Hook.f.) Kosterm	Lauraceae	T	1.54
107	*Corea arborea* Roxb.	Lecythidaceae	T	0.77
108	*Leea asiatica* (L.) Ridsdale	Leeaceae	S	66.92
109	*Leea alata* Edgew	Leeaceae	S	0.77
110	*Mimosa pudica* L. **	Leguminosae	S	23.08
111	*Flemingia strobilifera* (L.) Aiton	Leguminosae	S	23.85
112	*Cassia tora* L. **	Leguminosae	S	23.08
113	*Flemingia bracteata* (Roxb.) Wight	Leguminosae	S	1.54
114	*Desmodium laxifloraum* DC.	Leguminosae	S	9.23
115	*Mucuna ngricans* (Lour) Steud.	Leguminosae	WC	24.62
116	*Crotalaria pallida* Aiton *	Leguminosae	S	8.46
117	*Phyllodium pulchellum* (L.) Desv.	Leguminosae	S	20.77
118	*Crotalaria spectabilis* Roth.	Leguminosae	S	8.46
119	*Phaseolus vulgaris* L.	Leguminosae	CH	6.15
120	*Uraria lagopodioides* (L.) Desv.	Leguminosae	S	6.92
121	*Aeschynomene indica* L. *	Leguminosae	H	0.77
122	*Desmodium concinum* DC.	Leguminosae	S	1.54
123	*Dalbergia Sissoo* Roxb. *	Leguminosae	T	1.54
124	*Delonix regia* (Bojer ex. Hook) Raf. *	Leguminosae	T	1.54
125	*Dalbergia lattifolia* Roxb.	Leguminosae	T	20.77
126	*Cassia fistula* L.	Leguminosae	T	12.31
127	*Spatholobus parviflorus* (Roxb.) Kuntz.	Leguminosae	WC	26.92
128	*Alycicarpus rugosa* (Willd.) DC. *	Leguminosae	H	0.77
129	*Caesalpinia bonduc* (L.) Roxb. *	Leguminosae	T	2.31
130	*Bauhinia vahlii* Wight & Arn.	Leguminosae	WC	20.00
131	*Cassia occidentalis* L. **	Leguminosae	S	6.92
132	*Mimosa rubicaulis* Lam.	Leguminosae	T	20.00
133	*Albizia procera* (Roxb.) Benth.	Leguminosae	T	8.46
134	*Desmodium oojeinense* (Roxb.) Ohashi	Leguminosae	T	10.00
135	*Bauhinia purpurea* L.	Leguminosae	T	6.15
136	*Millettia extensa* (Benth.) Baker	Leguminosae	WC	19.23
137	*Desmodium Sp.*	Leguminosae	S	0.77
138	*Bauhinia varigata* L.	Leguminosae	T	20.00
139	*Desmodium gangetium* (L.) DC.	Leguminosae	S	22.31
140	*Albizia lebbek* (L.) Benth.	Leguminosae	T	13.85

(Note:- H=Herb, S=Shrub, T=Tree, WC=Woody Climber, CS=Climbing Shrub, CH=Climbing Herb, *=Naturalized spp. and **=IAPS, Freq. =Frequency %)

Annex 2E: List List of plant species recorded from sampling plots in PWR

S.N.	Name of species	Family	Habit	Freq.
140	*Albizia lebbek* (L.) Benth.	Leguminosae	T	13.85
141	*Flemingia macrophylla* (Willd.) Merr.	Leguminosae	S	5.38
142	*Butea minor* Buch.-Ham.ex. Baker	Leguminosae	T	3.08
143	*Crotalaria prostrata* Rottb.ex. Willd.	Leguminosae	H	0.77
144	*Indigofera pseudoreticulata* Grierson & Long	Leguminosae	S	10.00
145	*Acacia catechu* (L.f.) Willd.	Leguminosae	T	1.54
146	*Crotalaria calycina* Schrank	Leguminosae	H	1.54
147	*Dunbaria rotundifolia* (Lour.) Merr.	Leguminosae	CH	3.85
148	*Desmodium velutium* (Willd.) DC.	Leguminosae	CH	8.20
149	*Butea monosperma* (Lam.) Kuntze	Leguminosae	T	1.54
150	*Tadehagi triquertum* (DC.) Ohashi	Leguminosae	S	0.77
151	*Indigofera linifolia* (L.f.) Retz.	Leguminosae	H	0.77
152	*Lagestroemia parviflora* Roxb.	Lythraceae	T	68.46
153	*Woodfordia fruiticosa* (L.) Kuntze	Lythraceae	S	1.54
154	*Urena lobata* L. *	Malvaceae	H	41.54
155	*Sida rhombifolia* L. *	Malvaceae	S	5.38
156	*Sida acuta* Burm.f. *	Malvaceae	S	21.54
157	*Sida cordifolia* L. *	Malvaceae	S	32.31
158	*Thespesia lampas* (Cav.) Daizell & Gibson	Malvaceae	S	33.08
159	*Hibiscus cannabinus* L.	Malvaceae	H	27.69
160	*Abutilon indicum* L.	Malvaceae	H	23.08
161	*Sida veronicaefolia* Lam.	Malvaceae	S	1.54
162	*Kydia calycina* Roxb.	Malvaceae	T	15.38
163	Unidentified	Malvaceae	H	2.31
164	*Osbeckia chinensis* L.	Melastomataceae	H	2.31
165	*Melastoma malabathricum* L.	Melastomataceae	S	1.54
166	*Tinospora sinensis* (Lour.) Merr.	Menispermaceae	CS	3.85
167	*Cissampelos pereira* L. *	Menispermaceae	CS	27.69
168	*Ficus racemosus* L.	Moraceae	T	1.54
169	*Ficus hispida* L.f. Suppl.	Moraceae	S	1.54
170	*Ficus semicordata* Buch.-Ham.ex Sm.	Moraceae	T	0.77
171	*Syzygium cominie* (L.) Skeels	Myrtaceae	T	34.62
172	*Cleistocalyx operculata* (Roxb.) Merr.	Myrtaceae	T	1.54
173	*Psidium guajava* L. *	Myrtaceae	T	0.77
174	*Boerhavia diffusa* L. *	Nyctaginaceae	H	0.77
175	*Nyctanthus arbortristis* L.	Nyctanthaceae	T	2.31

(Note: - H=Herb, S=Shrub, T=Tree, WC=Woody Climber, CS=Climbing Shrub, CH=Climbing Herb, *=Naturalized spp. and **=IAPS, Freq. =Frequency %)

Annex 2F: List of plant species recorded from sampling plots in PWR

S.N.	Name of species	Family	Habit	Freq.
176	*Peristylus lawii* Wight	Orchidaceae	H	9.23
177	*Nervilia gammieana* (Hook.f.) Schltr.	Orchidaceae	H	1.54
178	*Oxalis curniculata* L. *	Oxalidaceae	H	3.08
179	*Phoenix acaulis* Roxb.	Palmae	S	11.54
180	*Martynia annua* L. *	Pedaliaceae	H	3.08
181	*Piper longum* L.	Piperaceae	CS	1.54
182	*Persicaria glabra* (Willd.) Gomez.	Polygonaceae	H	0.77
183	*Monochoria vaginalis* (Burm.f.) Presl.	Pontederaceae	H	1.54
184	*Zizyphus rugosa* Lam.	Rhamnaceae	T	47.69
185	*Zizyphus oenoplia* (L.) Mill.	Rhamnaceae	S	2.31
186	*Zizyphus xylopyrus* Edgew.	Rhamnaceae	S	2.31
187	*Zizyphus mauritiana* Lam.	Rhamnaceae	S	1.54
188	*Borreria articularis* (L.f.) Williams *	Rubiaceae	H	3.08
189	*Hedyotis diffusa* Willd.	Rubiaceae	H	5.38
190	*Adina cordifolia* (Willd.ex Roxb.) Benth. &Hook.	Rubiaceae	T	11.54
191	*Borreria alata* (Aubl.) DC. *	Rubiaceae	H	15.38
192	*Knoxia corymbosa* Willd.	Rubiaceae	H	3.85
193	*Xeromorphis spinosa* (Thunb.) Keay.	Rubiaceae	T	32.31
194	*Anthocephalus chinensis* (Lam.) Rich. & Walp.	Rubiaceae	T	20.77
195	*Mitragyna parviflora* Roxb. ?	Rubiaceae	T	6.15
196	*Clausena pentaphylla* DC.	Rutaceae	S	24.62
197	*Murraya koenigii* (L.) Spreng.	Rutaceae	T	3.08
198	*Aegle marmelos* (L.) Correa	Rutaceae	T	5.38
199	*Clausena heptaphylla* (Roxb.) Wight & Arn.	Rutaceae	S	9.23
200	*Clausena excavata* Burm.f.	Rutaceae	T	25.38
201	*Schleichera oleosa* (Laur.) Oken	Sapindaceae	T	16.15
202	*Aesandra butryracea* (Roxb.) Bachni	Sapotaceae	T	2.31
203	*Scoparia dulcis* L. *	Scrophulariaceae	H	6.92
204	*Smilax ovalifolia* Roxb.ex D. Don.	Smillacaceae	WC	32.31
205	*Physalis divarcata* D. Don.	Solanaceae	H	2.31
206	*Datura metal* L. *	Solanaceae	H	1.54
207	*Solanum verginianum* L.	Solanaceae	H	1.54
208	*Melochia corchorifolia* L. *	Sterculiaceae	H	3.85
209	*Sterculia vilosa* Roxb. ex Sm.	Sterculiaceae	T	17.69
210	*Helicteres isora* L.	Sterculiaceae	S	4.62

(Note:- H=Herb, S=Shrub, T=Tree, WC=Woody Climber, CS=Climbing Shrub, CH=Climbing Herb, *=Naturalized spp. and **=IAPS, Freq. =Frequency %)

Annex 2G: List of plant species recorded from sampling plots in PWR

S.N.	Name of species	Family	Habit	Freq.
211	*Helicteres elongata* Wall.ex Mast.	Sterculiaceae	S	0.77
212	*Triumfetta rhomboides* Jacq.	Tilliaceae	H	15.38
213	*Corchorus aestuans* L. *	Tilliaceae	H	18.46
214	*Grewia helictrifolia* Wall.	Tilliaceae	S	20.00
215	*Pouzolzia zeylanica* (L.) Benn. & R. Br.	Urticaceae	H	0.77
216	*Boehmeria macrophylla* D. Don.	Urticaceae	H	2.31
217	*Urtica ardens* Link	Urticaceae	H	1.54
218	*Lantana camara* L. **	Verbenaceae	CS	4.62
219	*Clerodendrum viscosum* Vent.	Verbenaceae	S	10.00
220	*Clerodendrum serratum* (L.) Moon	Verbenaceae	S	2.31
221	*Clerodendrum indicum* (L.) Kuntze	Verbenaceae	S	1.54
222	*Callicarpa macrophylla* Vahl.	Verbenaceae	S	0.77
223	*Ampelocissus latifolia* (Roxb.) Planch.	Vitaceae	WC	35.38
224	*Ampelocissus rugosa* (Wall.) Planch.	Vitaceae	WC	0.77
225	*Roscoea capitata* Sm.	Zingiberaceae	H	10.77
226	*Zingiber capitatum* Roxb.	Zingiberaceae	H	30.00
227	*Hedychium coccineum* (Buch.-Ham.) ex Sm.	Zingiberaceae	H	0.77
228	*Costus lacerus* Gangnep	Zingiberaceae	H	10.77
229	*Costus speciosus* (J. Koing) Sm.	Zingiberaceae	H	7.69
230	*Curcuma aromatica* Salisb.	Zingiberaceae	H	6.15
231	*Zingiber officinale* Rosc.	Zingiberaceae	H	1.54

*(Note: - H=Herb, S=Shrub, T=Tree, WC=Woody Climber, CS=Climbing Shrub, CH=Climbing Herb, *=Naturalized-non-invasive spp.* and ***=Naturalized-invasive, Freq. =Frequency %)*

Annex 3: Variation in tree canopy cover along sampling post areas

	Sampling Posts Areas						
	Adhabhar	Mahadev Khola	Charbhaiya	Gaduwaline	Nirmalvasti	Bhata	Pratappur
Mean Canopy cover%	61.48	67.62	48.73	51.92	60.16	20.37	30.72

Annex 4: Site wise significant value of mean comparison for-

A. Domin Cover Scale of IAPS

	Adh.P	Mah.P	Cha.P	Gad.P	Nir.P	Bha.P
Mah.P	0.000***					
Cha.P	0.011*	0.792				
Gad.P	0.005**	0.905	1.000			
Nir.P	0.116	0.277	0.981	0.932		
Bha.P	0.001**	0.000***	0.000***	0.000***	0.000***	
Pra.P	0.031*	0.000***	0.000***	0.000***	0.000***	0.705

B. IAPS Richness

	Adh.P	Mah.P	Cha.P	Gad.P	Nir.P	Bha.P
Mah.P	0.000***					
Cha.P	0.000***	0.999				
Gad.P	0.000***	0.999	1.000			
Nir.P	0.003**	0.798	0.966	0.966		
Bha.P	0.151	0.000***	0.000***	0.000***	0.000***	
Pra.P	0.232	0.000***	0.000***	0.000***	0.000***	0.995

(***Note:*** *- Significant codes - 0.000‘***’ 0.001‘**’0.01‘*’ 0.05‘’; sampling posts*-*Bha.P = Bhata Post, Pra.P = Pratappur Post, Adh.P = Adhabhar Post, Nir.P = Nirmalvasti Post, Cha.P = Charbhaiya Post, Gad.P = Gaduwaline Post, Mah.P = Mahadev Khola Post*).

Annex 5: Climatic data on maximum, minimum and average temperature in degree Celsius and rainfall in mm. of Hetauda weather station (2009-2013) taken from department of Hydrology and Metrology/GoN

Months	Temperature in degree Celsius			Rainfall in mm.
	Maximum	Minimum	Average	
January	21.62	7.44	14.53	8.34
February	25.3	9.76	17.53	21.54
March	30.96	14.08	22.52	12.4
April	34.8	18.62	26.71	79.36
May	34.74	21.3	28.02	213.92
June	33.98	23.64	28.81	345.56
July	32.26	24.24	28.25	619.26
August	32.22	23.84	28.03	622.58
September	31.82	22.82	27.32	266.42
October	30.3	18.7	24.5	64.82
November	26.42	12.68	19.55	0.88
December	23.12	8.84	15.98	1.02

Annex 6: Site wise Basal Area/ha and Density/ha of Tree and Saplings.

Sampling Sites		Basal Area/ha ($\overline{\chi}$ ± S.E.)		Density/ha ($\overline{\chi}$ ± S.E.)	
		Tree	Saplings	Tree	Saplings
Adhabhar Post		30.16 ± 4.02	1.23 ± 0.09	4.42 ± 0.42	3.43 ± 0.36
Mahadev Kohola Post		33.58 ± 6.56	2.09 ± 0.19	4.42 ± 0.37	5.67 ± 0.63
Charbhaiya Post		27.72 ± 5.96	1.22 ± 0.16	3.65 ± 0.58	3.66 ± 0.48
Gaduwaline Post		28.00 ± 3.49	1.75 ± 0.2	5.00 ± 0.58	3.81 ± 0.46
Nirmalvasti Post		46.29 ± 5.4	2.21 ± 0.24	4.31 ± 0.47	5.04 ± 0.58
Bhata Post		0.53 ± 0.53	0.20 ± 0.07	0.08 ± 0.08	0.74 ± 0.20
Pratappur Post		19.94 ± 5.77	0.39 ± 0.06	0.96 ± 0.23	0.88 ± 0.11
ANOVA	F-value	5.16	19.05	14.55	14.42
	Sig. value	0.00	0.00	0.00	0.00

Annexes

Annex 7A: Invasive Alien Plant Species of Nepal

S. N.	Name	Family	Local Name	Spread by	Habit/habitat	Alt. range	Native country	First report in Nepal
1	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	Jal Kumbhi	Seeds and stolons	H/aquatic	75-1500	South America/ Brazil	1966
2	I*pomoea carnea* subspecies *fistula* (Mart. Ex Choisy) Austin	Convolvulaceae	Besaram	Vegetative propagation	S/moist places	75-1350	South America	1966
3	*Mikania micrantha* Kunth	Compositae	Lahare Banmara	Seeds and stem	C H/moist forest	75-1200	South America	1963
4	*Alternanthera philoxeroides* (Mart.) Griseb.	Amaranthaceae	-	Stolons/stem fragments	H/moist places	75-1350	Brazil	1994
5	*Myriophyllum aquaticum* (Vell.) Verdc.	Haloragaceae	-	Rhizomes	H/wetlands	ca. 1350	South America	–
6	*Leersia hexandra* Swartz	Poaceae	Karaute ghans	Seeds, stolons and	H/Wet places	60-300	Tropical America	–
7	*Ageratina adenophora* (L.) King & Robinson	Asteraceae	Kalo Banmara	Seeds and roots	H/most places	650-2400	Mexico	1958
8	*Chromolaena odorata* (L.) King & Robinson	Asteraceae	Aule Banmara	Seeds and roots	S/forest & follow lands	75-1540	Tropical America	1825
9	*Lantana camara* L.	Verbenaceae	Masino kande	Vegetative propagation	S/forest & waste places	75-1700	Central America	1966
10	*Parthenium hysterophorus* L.	Asteraceae	Kanike ghans	Seeds	H/waste places	75-1350	Tropical America	1967
11	*Ageratum conyzoides* L.	Asteraceae	Boke Jhar	Seeds	H/moist places	75-2000	South America	1910
12	*Ageratum houstonianum* Mill.	Asteraceae	Ganaune Jhar	Seeds	H/moist places	-	Mexico	

Annex 7B: Invasive Alien Plant Species of Nepal

S.N.	Name	Family	Local Name	Spread by	Habit/habitat	Alt. range	Native country	First report in Nepal
13	Amaranthus spinosus L.	Amaranthaceae	Lunde	Seeds	H/moist, waste & cultivated field	75-1800	Tropical America	1955
14	Argemone mexicana	Papaveraceae	Satyanashi	Seeds	H/roadside & wet places	75-1400	Mexico	1910
15	Cassia tora L.	Leguminosae	Chakmake	Seeds	S/waste places	75-1300	South America	1910
16	Hyptis suaveolens (L.) Poit.	Labiatae	Tulasi Jhar	Seeds	H/forest floor	75-1000	Tropical America	1966
17	Pistia stratiotes L.	Araceae	Jalkobi	Stolons	H/wetland	75-600	Pantropical	1966
18	Bidens pilosa L.	Asteraceae	Kuro	Seeds	H/waste places	100-2100	Tropical America	1910
19	Cassia occidentalis L.	Leguminosae	Tapre	Seeds	S/waste lands	75-1400	Tropical America	1910
20	Mimosa pudica L.	Leguminosae	Lajjawati	Seeds	S/moist places	75-1300	Pantropical	1910
21	Oxalis latifolia Humb.	Oxalidaceae	Chari Amilo	Bulbils and seeds	H/open places	600-2200	Brazil	1966
22	Xanthium strumarium L.	Asteraceae	Bhede Kuro	Seeds	H/cultivated lands	75-2500	South America	1955

*Resource: Tiwari et al. 2005, MFSC/CSUWN 2011, Field survey 2013 (**Note**:- H = Herb, S = Shrub, CH = Climbing Herb)*

Annex 8: Terminologies used to describe the process of invasion are:

Alien plants: Plant taxa in a given area whose presence is due to intentional or accidental introduction as a result of human activity (synonyms: exotic plants, non-native plants; non-indigenous plants).

Casual alien plants: Alien plants that may flourish and even reproduce occasionally in an area, but which do not form self-replacing populations, and which rely on repeated introductions for their persistence (includes taxa labeled in the literature as 'waifs', 'transients', 'occasional escapes' and 'persisting after cultivation', and corresponds to De Candolle's (1855) usage of the term 'adventives'.

Naturalized plants: Alien plants that reproduce consistently (cf. *casual alien plant*) and sustain populations over many life cycles without direct intervention by humans (or in spite of human intervention); they often recruit offspring freely, usually close to adult plants, and do not necessarily invade natural, semi natural or human-made ecosystems.

Invasive plants: Naturalized plants that produce reproductive offspring, often in very large numbers, at considerable distances from parent plants (approximate scales: > 100 m; < 50 years for taxa spreading by seeds and other propagules>6 m/3 years for taxa spreading by roots, rhizomes, stolons, or creeping stems), and thus have the potential to spread over a considerable area and cause threat to native biodiversity and ecosystems.

Weeds: Plants (not necessarily alien) that grow in sites where they are not wanted and which usually have detectable economic or environmental effects (synonyms: plant pests, harmful species; problem plants). 'Environmental weeds' are alien plant taxa that invade natural vegetation, usually adversely affecting native biodiversity and/or ecosystem functionings (Humphries *et al.*, 1991; Randall, 1997).

Transformers: A subset of invasive plants which change the character, condition, form or nature of ecosystems over a substantial area relative to the extent of that ecosystem.

Resources: De Candolle (1855), Randall (1997), Richardson (1998), Richardson et al. (2000)

Annex 9: Percentage Species Richness of Top Six Families of naturalized plants

Family	Species Richness		
	Flowering Plant Spp. No.	Naturalized Spp. No.	Percent of naturalized spp.
Leguminosae	42.0	11.0	26.2
Asteraceae	15.0	12.0	80.0
Euphorbiaceae	13.0	2.0	15.4
Malvaceae	10.0	4.0	40.0
Rubiaceae	8.0	2.0	25.0
Amaranthaceae	6.0	6.0	100.0

PHOTOPLATE - 1

Photo 1: *Chromolaena odorata* (L.) King and Robinson

Photo 2: *Lantana camara* L.

Photo 3: *Mikania micrantha* Kunth

Photo 4: *Alternanthera philoxeroides* (Mart.) Griseb.

Photo 5: *Parthenium hysterophorus* L.

Photo 6: *Ageratum conyzoides* L.

PHOTOPLATE - 2

Photo 7: *Ageratum houstonianum* Mill.

Photo 8: *Amaranthus spinosus* L.

Photo 9: *Cassia tora* L.

Photo 10: *Cassia occidentalis* L.

Photo 11: *Hyptis suaveolens* (L.) Poit.

Photo 12: *Bidens pilosa* L.

PHOTOPLATE – 3

Photo 13: *Xanthium strumarium* L.

Photo 14: *Mimosa pudica* L.

Photo 15: Collecting data during field survey

Photo 16: Measuring DBH of Tree

Photo 17: Research team in PWR with Chief Warden Mr. Nilambar Mishara (middle)

Photo 18: Near Dewaki Daha with staffs of Bhata post in PWR

PHOTOPLATE – 4

Photo 19: Cattle grazing near Buffer Zone

Photo 20: Place of Old Pratappur Village

Photo 21: Old farmland of Bhata Villlage at Bhata Post site