**Can control of invasive vegetation improve water and rural livelihood security in Nepal?**

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**Abstract**

Nepal’s predominantly rural population depends on the ecosystem services of heterogeneous mountainous landscapes that are degrading under changing climate and development pressures. Invasive alien plants (IAPs) compound threats to ecosystem services including water resource security from mid-hill springs, though implications for Nepal’s water resources are under-researched. South Africa’s Working for Water (WfW) programme addresses linked policy priorities related to IAP management including water, biodiversity and employability. We use the STEEP (Social, Technological, Environmental, Economic, Political) framework to explore success criteria behind WfW and their potential translation into the geographically, culturally and politically different Nepali context, including local considerations at three sites in Kavrepalanchok district. An adapted WfW approach could potentially contribute to water, food, biodiversity, forest, soil, gender equity, community development and security outcomes in Nepal, delivering national and international policy priorities. Evidence from study sites suggests four priority IAPs – *Lantana camara*, *Ageratina adenophora*, *Chromolaena odorata* and *Pinus roxburghii* – of differing characteristics, extents of invasion and perceived impacts at selected sites requiring control. These initial observations warrant trial management of IAPs in a test area with monitoring to evaluate outcomes for water, food and livelihood security, with potential for subsequent regional or national roll-out of a management programme.

**Keywords**

Invasive species; water security; socio-ecological systems; sustainability; conflict; poverty

**Research highlights**

* Nepal’s scattered rural population subsists on local mountain ecosystem services
* Invasive alien plants (IAPs) may threaten water resource and food security in Nepal
* Four IAP species are widespread and problematic in 3 study sites in Kavrepalanchok
* IAPs have fewer beneficial uses than the native plant species they displace
* Initial evidence suggests further research needs and a pilot IAP management trial

**1. Introduction**

Biological invasions, arising from deliberate and/or accidental introduction into areas where species were formerly absent, can have major impacts on native biodiversity and ecosystem services (Collins *et al*., 2002; Gurevitch and Padilla, 2004; Ricciardi, 2007; Bezeng et al., 2017; Davis *et al*., 2011; Mason *et al*., 2017; Vaz *et al*., 2017), driving a global trend towards biotic homogenisation in human-modified landscapes (Smart *et al*., 2006). The impacts of invasive alien plants (IAPs) include competition with native species and degradation of resources, including water and soil minerals (Richardson and Van Wilgen, 2004; Ehrenfeld, 2010). Despite global concerns and often significant management efforts at local and regional scales, invasive species continue to proliferate (Sankaran *et al*., 2005; IUCN, 2011; Secretariat of the CBD, 2014).

IAPs generate multiple, potentially significant challenges including impacts on water security, particularly in water-stressed environments, affecting linked ecosystem services such as food production, soil erosion and fire risk, disproportionately affecting poorer and marginalised people especially in mountain regions (Asbjornsen *et al*., 2007). In Australia, evaporative loss from one hectare of alien willows (*Salix* spp.) equates to water use by 17 households (Doody and Benyon, 2011). Water security is one of the primary negative impacts associated with many IAPs in South Africa, particularly trees such as Australian *Eucalyptus* and *Acacia* species that have far greater evaporative loss compared to native species (Dye and Jarmain, 2004). Rooting depth is a key factor in depletion of water recharge (Seyfried and Wilcox, 2006). In South Africa, IAPs are conservatively estimated to use 2.9% of mean annual runoff (Le Maitre *et al*., 2016), with reductions of more than 25% in many catchments and a likelihood of increasing reductions if IAPs are allowed to spread unchecked (Van Wilgen *et al*., 2008). Species physiology, especially species-specific evapotranspiration rates in different environments, plays a major role in the likely impacts of IAP species on water resources (Le Maitre *et al*., 2015). Consequently, IAP removal can improve water yields, reducing impacts on ecosystem services such as grazing with associated benefits (van Wilgen *et al*., 2008). The significant role that native forests play in local regulation of the water cycle (Aragão, 2012) may also be disrupted by IAPs. Removal of invasive trees and protection of native forests may therefore be significant for water supply, flow regulation and other ecosystem services and associated livelihoods in heavily invaded tropical forests worldwide (Cavaleri *et al*., 2014). Notwithstanding the general global tendency for increasing invasion, there are significant regional successes in tackling IAPs for societal benefits. A particular effective example is the Working for Water (WfW) programme in South Africa, operating since 1995 as a resource protection and employment programme administered through the Department of Public Works with the support of multiple government departments.

The impacts of IAPs on water resources in mountainous areas, including in Nepal, have not received a great deal of research. The Federal Democratic Republic of Nepal (‘Nepal’) is a landlocked country located in the Central Himalayas, spanning a mountainous and substantially forested landscape of over 147,000 km² bordering China to the north, and India to the south, east and west. Central Asian Mountain Ecosystems (Yessekin, 2005) and forests (Shvidenko *et al*., 2005) benefit indigenous communities through provision of diverse ecosystem services. However, Nepal’s mountainous, forested ecosystems are degrading under climate change, population growth and development pressures, with significant consequences for many vulnerable and marginalized communities dependent on their services (Körner and Spehn, 2001; Chaudhary *et al*., 2016). Contemporary Nepal has become a fragile, low income country with high rates of population growth, poverty and male out-migration, compounded by gender inequality (Khadka *et al*., 2014). Impacts of a major earthquake in April 2015 and concurrent political instability exposed structural weaknesses, marginalised groups suffering disproportionately due to their inability to access water, forest and other ecosystem resources (The Conversation, 2015). These factors combine to threaten environmental sustainability and the flow of ecosystem services upon which rural livelihoods depend, potentially increasing civil unrest and the likelihood of conflict.

IAPs compound pressures on the natural environment and socio-ecological resilience. Lowe *et al*. (2000) catalogued “100 of the world’s worst invasive species” of which eleven IAP species occur in Nepal, six native and five alien, all of them potentially problematic (Budha, 2015; Shrestha, 2016). Sankaran *et al*. (2005) listed seven top IAPs in the Asia Pacific region, all noted as problematic in Nepal (*Chromolaena odorata* (siam weed); *Eichhornia crassipes* (common water hyacinth); *Lantana camara* (lantana, big-sage); *Leucaena leucocephala* (white lead tree); *Mikania micrantha* (bitter vine); *Ageratina adenophora* (crofton weed or kalobanmara); *Ageratum conyzoides* (tropical whiteweed, billygoat, or gandhe); and *Parthenium hysterophorus* (santa-maria)). Nepal ranks third among the countries most threatened by biological invasions, particularly impacting agricultural production (Paini *et al*., 2016). Invasive species colonising Nepal’s forests and agro-ecosystems continue to adversely affect forest regeneration, farm productivity and livestock health (Poudyal and Adhikari, 2013; Bhatta *et al*., 2015).

Nepal’s mid-hills support about 50% of the total national population, dependent on natural springs as fresh water sources for domestic consumption, irrigation and small hydropower. However, the reliability of these water resources is problematic, with mid-hill springs drying out or substantially decreasing in water flow over the past decade (Chapagain *et al*., 2016; ICIMOD, 2009; 2015; Dixit *et al*., 2009). The availability and quantity of water is a principal pressure upon communities and the environment (IPCC, 2007), though knowledge gaps about water resources in Nepal currently hamper objective assessment and appropriate management (WECS, 2011). The role of IAPs in compounding water insecurity in Nepal has not yet been thoroughly reviewed, though studies have been conducted on secondary effects including the implications of some species for agricultural productivity (such as Poudyal and Adhikari, 2013; Siwakoti *et al*., 2016), although evidence from other localities suggests that impacts may be significant in water-stressed situations. Further study is required into the likely impacts of priority IAPs and their management as a means to secure water and other natural resources underpinning societal wellbeing.

This paper reviews what is known about likely impacts of IAPs on water and livelihoods in Nepal’s mid-hills and explores the potential for translating principles underpinning South Africa’s WfW programme into the biogeographically, culturally and politically differing context of Nepal as a contribution to enhancing ecosystem services underpinning the needs of the rural community. It achieves this by: (1) characterisation of success factors underpinning the South African WfW programme using the STEEP (Social, Technological, Environmental, Economic, Political) model; (2) characterisation the Nepali context using the STEEP model; (3) observed and perceived relevance of IAPs for water management at local sites in Nepal; and (4) discussion of the potential for implementation of a WfW-based approach in Nepal.

**2. Methods**

An overview of South Africa’s WfW programme and some key outputs was derived from literature review and inputs from the Director of the WfW programme in South Africa. Key aspects of the programme were stratified using the STEEP model to explore some of the multiple, interconnected factors contributing to the success of the programme. Though STEEP was initially developed to assess global change issues (Morrison and Wilson, 1996), it has been applied to analyse systemic relationships in different domains of human activity including meeting sustainability goals (Steward and Kuska, 2011), including the deployment of appropriate technology and associated governance systems in management of water, ecosystem service flows and dependent development issues in South Africa, Europe and India (Everard *et al*. 2012; Everard 2013 and 2015). STEEP is also a suitable model for integrating different types of knowledge (Aretano *et al*., 2013). STEEP is used here as a basis for potential translation of WfW principles into Nepal’s significantly different context.

A field visit was made to three sites in the Jhiku Khola sub-catchment to the east of Kathmandu in Nepal: a rural farming community (Keraghari); a community forest (Tinpiple); and an intensively-cultivated river valley (Panchkhal), all in Kavrepalanchok District (Figure 1). The purpose of the field visit was to study livelihoods, IAP species and their locations, and the perceptions local people have about them. The sites were visited on Saturday 17th December 2016 in dry weather conditions. The field team spanned a range of expertise, including four of this paper’s authors (Everard, Gupta, Chapagain, Shrestha) with Himalayan ecological, climate change, socio-economic, botanical and ecosystem service expertise, also including a development scientist (Narendra Raj Khanal) and a manager of the NGO *Tuki Association Sunkoshin* that supports the development of rural communities (Hemanta Dangal).

*Figure 1: Location map of Keraghari, Tinpiple and Panchkhal sites in Kavrepalanchok District, Nepal, all altitudes point heights in a landscape of high topographical variability as indicated by the sinuosity of the road and river*



Primary evidence-gathering at the three field sites comprised: (1) meetings with representatives (N varying from 12 to 5 per site including approximately equal numbers of men and women) of resource-dependent communities; (2) empirical observations backed up by the knowledge of Nepali team members; and (3) opportunistic meetings with five rural people (three women and two men) encountered at sites interacting with food and water systems. A semi-structured approach was taken to information-gathering in interviews. The different dimensions of the STEEP model were introduced into interviews by conversation in locally relevant terms (e.g. food, water use, fuel, decision-making, subsistence versus cash crops, government support, etc.) and in a semi-structured way rather than through a rigid questionnaire, reflecting the cultural differences between researchers and local people and the diversity of views and perspectives of interviewees. Interviews commenced with a description of the purpose of our study and a request to use this information for research purposes, with ensuing dialogue revolving around people’s livelihoods and their relationships with the natural resources. Responses were recorded in writing by researchers, who subsequently stratified observations around the STEEP model. This approach enabled interviewees to respond freely and to refer to different values, uses and management approaches to resources, rather than asking them to stick to a rigid questioning framework. Once researchers judged that all relevant aspects of the STEEP model were exhausted in conversations, interviews were concluded with thanks.

*Figure 2: Farmer being interviewed at Keraghari, including input from a range of local residents of this rural, farmed area [Low resolution image only inserted here to aid review]*



**3. Results**

*3.1 The Working for Water (WfW) programme and assessment of success factors using STEEP*

WfW has operated since 1995 as a resource protection and employment programme administered by the Department of Public Works with the support of multiple South African government departments (Department of Environmental Affairs, Undated). WfW recognises IAPs as a major threat compounding climate change, land use conversion and other pressures impacting water security and biodiversity and imposing significant annual costs on the South African economy. To date, WfW has cleared more than one million hectares of IAPs (Department of Environmental Affairs, Undated). Table 1 lists linked aspects of WfW under the categories of the STEEP model.

*Table 1: Linked successful elements of WfW stratified by STEEP components*

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| **Social**:* Social dimensions are central to the design and delivery of WfW, relating to ‘real world’ social needs and involving people in delivery of personal development, employability skills and direct benefits to communities through enhanced water resources.
* Provision of jobs and employability training relating to IAP removal is a WFW priority, engaging approximately 20,000 people annually and prioritising the most marginalized sectors of society including targets for women, youth and the disabled.
* WfW delivery is supported by civil society organisations (Chitiga-Mabugu *et al*., 2013), working in collaboration with government departments and the national Expanded Public Works Programme (EPWP).
* Teaching people enrolled in the WfW programme to identify problematic species and match control measures to them builds employability skills.
* Social programmes such a HIV/AIDS programmes are built into WfW delivery.
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| **Technological**:* Technical solutions deployed by WfW programmes include a range of mechanical, chemical, biological and integrated vegetation management, reliant on basic tools but geared to the practical challenges of clearance of problematic species in the field.
* Improved targeting of removal of problematic species in the most impacted places has yielded significant benefits associated with improved water yields with collateral benefits including soil erosion, fire and flood control and the enhancement of agricultural productions from land, ecological functioning and ecosystem services (van Wilgen *et al*., 2008).
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| **Environmental**:* Consideration of environmental processes underpins the WfW approach, including the impact of invasive species on the ecosystem services of water regulation, erosion control and habitat for wildlife.
* Modification of the WfW approach supports conservation of native biodiversity.
* Education about native and invasive species, and the impacts of IAPs on a range of ecosystem services and their associated beneficiaries, underpins the whole programme.
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| **Economic**:* Enhanced run-off of water and development of employment skills are key economic returns from the WfW programme.
* Hydrological, employability, economic and other outcomes are audited to demonstrate multiple benefits resulting from WfW activities.
* WfW has been presented as an exemplar in the *Green Jobs for the Poor* paper by UNDP (Lieuw-Kie-Song, 2009).
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| **Political**:* WfW is designed to deliver on multiple, linked priority policy areas covered by different government departments.
* Although WfW outcomes benefit the individuals who carry them out and their communities, government support is vital to sustain the programme.

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It is important to recognize that all facets of the WfW programme are systemically connected across the STEEP model, rather than relying on any particular element in isolation. This contrasts with common historic flawed development assumptions, for example that big dams are universally good for water and hydropower energy supply (Word Commission on Dams, 2000), or that boosting economic growth will benefit all in society, when in reality these single-focus approaches tends to marginalise the least empowered (Everard, 2016).

*3.2 Characterisation of Nepali mid-hills community-ecosystem interdependencies using the STEEP model*

The social structure of Nepal is founded on its predominantly dispersed, agrarian communities, with 81.76% of the population living in rural areas spread across wide mountainous terrain (TradingEconomics, Undated) in which resources are not readily transported. Consequently, people have substantial and close dependence on locally heterogeneous geographical characteristics and resources. In common with many part of the developing world, women are primary natural resource stewards in Nepal’s mid-hills including assuming responsibility or fetching water and fodder which, under the influence of climate change, is increasing women’s workload in terms of distance covered, time spent and frequency of everyday water collection as springs progressively dry (Chapagain et al., 2016).

Technology choice in the Nepali policy environment tends to favour large dams as a source of energy and revenue, despite substantial tectonic instability (Buckley, 2015). However, large dam schemes often have multiple associated externalities that are frequently overlooked in planning (World Commission on Dams, 2000) including an asymmetry of benefits and negative outcomes across societal sectors with rural and poorer communities losing out both directly and indirectly through impacts on multiple ecosystem services (Everard, 2013). Protection and rebuilding of environmental resilience at local scale is vital for supporting the needs of rural people, including adaptation strategies to cope with the increasing effect of global environmental on mountain ecosystems through reduced and erratic precipitation and increased disease risk (Mishra *et al*., 2017) that have widespread consequences for climate-dependent sectors such as agriculture, water resources and health (Shrestha *et al*., 2015).

Environmental change therefore presents a major threat to rain-fed water sources in the Middle Himalayan Ranges across the Western and Eastern Himalaya. These sources are depleting rapidly, primarily due to resource exploitation, rapid urbanisation and resultant land use changes, and climate change affecting water, food, livelihood and health security (Valdiya and Bartarya, 1991; Sharma *et al*., 2007; Tiwari and Joshi, 2012a, 2012b, 2013, 2014a and 2014b). Climate change impacts are threatening established agro-ecosystem-based livelihoods in central Nepal (Bhatta *et al*., 2015). Various studies from different parts of the Nepali Himalayas demonstrate drying out of springs and water scarcity. A recent study from Sindhupalchok district in Central Nepal found that small springs with a discharge rate of less than 5l min-1 around settlements at elevations between 1000-2500m asl were most significantly affected, with a 30% reduction in spring water volume within recent decades, increasing the workload of women consequently required to travel increasing distance and to spend more time collecting water (Chapagain *et al*., 2016). The 2015 April earthquake compounded the situation, increasing vulnerability as 20% of the springs dried or disappeared after the earthquake and local people were compelled to relocate and travel longer distance for water (Chapagain *et al*., 2016). Declining spring reliability and flows are resulting in agricultural land abandonment and out-migration in eastern Nepal (Thakur and Upadhaya, 2014) and negative impacts on local livelihoods and ecosystems in various parts of the Koshi basin in Kavre District (Dixit *et al*., 2009; ICIMOD, 2015; Pradhan *et al*., 2015; Poudyal *et al*., 2015). Although springs play vital roles in the lives of rural people, their implications for livelihood and the environment is overlooked (ICIMOD, 2015) despite clear evidence of broad impacts on local ecosystems, biodiversity, agriculture, livelihoods and human wellbeing (Chaudhary *et al*., 2011; Becker and Bugmann, 2001; Ziervogel *et al*., 2006). Invasive shrubs are found to colonise first in degraded and landslide area in Nepal, with a positive role in soil protection but also degrading wildlife habitats, reducing the provisioning services of forests and associated ecosystems such as supply of forage and non-timber forest products (NTFPs) and hampering forest regeneration (Shrestha, 2016). Implications for local water resources are under-researched, yet local water resource security is fundamental to multiple dimensions of societal wellbeing from water supply, food production, health and community development.

Economically, the value of natural resources to the Nepali people is significant given the distribution and overwhelmingly rural nature of the population. One study in the upstream Koshi River Basin found that local communities derive a wide range of values from ecosystems, particularly the ecosystem services of water, agricultural products and various forest products (van Oort *et al*., 2015). Recognising, protecting or enhancing these ecosystem-derived values may be essential for securing community wellbeing. Investment to secure various aspects of wellbeing are spread across a range of government departments, including those pertaining to the supportive natural environment, community and personal development, agricultural, and forest and soil conservation as described below. Combining these budgets into programmes addressing the security of ecosystem resources underpinning the disparate policy aims is likely to yield significant synergies, multiple benefits and outcomes of greater net public value.

Governance in rural Nepal operates at multiple scales. A diversity of central Nepali government programmes address a wide range of environmental, social and economic outcomes, yet the role of water resources as an underpinning factor supporting these linked outcomes is not explicitly considered. Some of Nepal’s principal institutional responsibilities and supporting programmes are listed in Box 1. The Forest Sector Policy 2000 (MFSC, 2000) is the main document which guides sub-sectoral programmes relating to forests, wildlife and biodiversity, but the consequences of IAPs are not raised within it. Although the Government of Nepal instituted the Ministry of Water Supply and Sanitation (MWSS) in 2016, progress towards meeting the country’s basic water needs and promoting economic growth related to water resources development has been slow. In addition to these national priorities, IAP management could also contribute to Nepali initiatives to address international commitments outlined in Box 2.

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| **Box 1: Principal relevant institutional responsibilities and supporting programmes in Nepal**The Ministry of Forests and Soil Conservation (MFSC) is tasked with managing and coordinating forest resources, including a well-defined policy and legal framework such as:The Terai Arc Landscape StrategyThe Gender and Social Inclusion Strategy in the Forestry SectorThe Sacred Himalayan Landscape StrategyThe Nepal National Biodiversity Strategy and Action Plan 2014-2020 (MFSC, 2014), recognisiong that conservation and sustainable utilisation of biodiversity is fundamental for Nepal’s prosperityThe Department of Forest Research and Survey (DFRS) hosts the focal point for the Asia Pacific Forest Invasive Species Network of the UN Food and Agriculture Organization ([www.apfisn.net](http://www.apfisn.net)). This Department is also responsible for developing strategies for the management of invasive alien species in Nepal.The Government’s Climate Change Policy addresses the issues of climate change and the proper utilisation, promotion and conservation of forest resources as a means of alternative livelihoods.The Ministry of Federal Affairs and Local Development (MoFALD) promotes and provides financial assistance to local government and community development bodies:Across the 75 Districts into which Nepal is divided, the MoFALD is represented by District Development Committees (DDCs).The Local Governance and Community Development Programme II (LGCDP) was led in the period 2013-2017 by the MoFALD with technical and financial assistance of development partners (MoFALD, 2016). This national programme has the overarching goal of contributing towards poverty reduction through inclusive, responsive and accountable local governance and participatory community-led development. It provides an overall framework for strengthening decentralization, devolution and improved local governance systems, particularly making use of community structures such as Community Awareness Centres (CACs) and Ward Citizen Forums (WCFs), for the effective delivery of basic services and the empowerment of citizens, especially women, children and Disadvantaged Groups (DAGs) and their institutions. The goal of the LGCDP programme is aligned with the national goals of the Government of Nepal’s national plans with respect to effective service delivery and citizen empowerment.* The National Water Plan (NWP) of Nepal was prepared to operationalise a Water Resources Strategy (WRS) and maximize the sustainable benefits of water use.
* The Rural Water Supply and Sanitation Sector Policy deals with providing safe, convenient and adequate water supply, with specific focus on disadvantaged groups.
* The Water and Energy Commission Secretariat (WECS) of Nepal has also realized the importance of water and its linkage to livelihood and environment but it also has recommended research to establish a knowledge base through scientific study on water and its linkages to ecosystem services (WECS, 2011).
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| **Box 2: International policy priorities to which IAP management could contribute*** UN Sustainable Development Goals (SDGs)
* Disaster Resilience Reduction (DRR) under the Sendai Framework
* Climate commitments including those under the Paris Agreements 2015 pertaining to both adaptation (securing water resources in a changing climate) and mitigation (restoration of native vegetation sequestering carbon)
* Aichi Biodiversity Targets (CBD, 2010) which includes Target 9 “*By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment*”.
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Reflecting the scattered population and its high dependence on local natural resources, it is unsurprising that Nepal has a high degree of devolved governance at local scale. Many of national government policies and programmes are delivered through highly decentralised governance arrangements. Nepal’s Community Forest Act 1993 contained provisions for the delegation of authority and control of forests to local Community Forest Users’ Groups (CFUGs). About 18,000 CFUGs of varying sizes were established throughout Nepal by 2012, with approximately 28% of the Nepal’s total forest area under community forest management (USAID, 2012), an area gradually increasing over time. Localised CFUGs are linked up at both District level (Nepal is divided into 75 Districts) and National level. The national body representing the interests of CFUGs is FECOFUN (the Federation of Community Forestry Users Nepal: [www.fecofun.org.np](http://www.fecofun.org.np); accessed 26th April 2018), which has significant influence on government policy. The process for establishing a CFUG and its operating principles are outlined in Box 3. Development activities are coordinated by District Development Committees (DDCs) and a few non-government organisations such as CFUGs, which are very active in managing forest and local resources with the help of local community. IAPs are not explicitly mentioned in the Community Forest Act, so their management may represent a novel approach to community-based resource security.

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| **Box 3: Establishment and operation of Community Forest Users’ Group**If a community decides to establish a CFUG, it develops a baseline status report and operation management plan for its forest area, submitting them to the District Forest Office (DFO). The DFO evaluates plans and, if approved, devolves control. Once established, the local community is then responsible through the CFUG for management of the forest including consumption of forest goods, maintenance and replanting. Subsequent annual plans are prepared by the CFUGs, and the plans and their outcomes are monitored by DFOs. If forests decline locally or management plans are not followed, the DFO has the power to rescind authority from the CFUG and resume control of the forest. The total area of forest managed by CFUGs has increased since 1993.CFUGs raise their own funding through utilisation of forest resources within management plans. For some communities with richer forests and accessible markets, as in lower Himalayan elevations and river valleys where timber sales from Sal (*Shorea robusta* Gaertner f.) and Chir pine (*Pinus roxburghii* Sarg.) can be significant, substantial income can be achieved and reinvested in community infrastructure (e.g. schools and village roads) and poverty alleviation programs such as income generating activities for women and poor members. Elsewhere, particularly in the mid-hill region, where forests have low marketable outputs and where markets are remote, may suffer from out-migration by young males for employment, reducing manpower for cultivation and stock management further reducing dung production. These factors can combine to drive a cycle of village agricultural abandonment, in which people become increasingly dependent on imported food and fodder for livestock creating livelihood and societal fragility as seen elsewhere in the middle Himalayas (for example Everard *et al*., in press). |

By focusing on restoration of ecosystem functioning through targeted IAP removal, a linked suite of ecosystem services are likely to be protected spanning a range of beneficiaries. In theory, community engagement in IAP management in Nepal has the potential to yield significant self-benefits, and also contribute to higher-level national and international goals. Modification of the WfW approach therefore appears to have the potential to build significantly on water, food and other resource security, biodiversity and community development initiatives, potentially integrating policy priorities and associated budgets.

*3.3 Learning from site visits*

Diverse IAPs were observed at the three field study sites. Direct observation, traditional knowledge and the views of local people revealed four species currently perceived as particularly problematic: three invasive alien shrubs lantana (*Lantana camara*), Crofton weed (*Ageratina adenophora*) and Siam weed (*Chromolaena odorata*), and one native planted tree Chir pine (*Pinus roxburghii*). Although *Pinus roxburghii* is a native tree, it was introduced for timber production at this altitude where it was historically absent, but was considered problematic by local people as it displaces native trees which serve multiple purposes for the community. Other widespread IAPs found in study sites included *Bidens pilosa*, *Galinsoga quadriradiata*, *Ageratum conyzoides*, *Ageratum houstonianum*, *Parthenium hysterophorus*, *Amaranthus spinosus* and *Oxalis latifolia*. Botanical descriptions, and key features of each of the four perceived problematic IAPs are listed in Table 2.

*Table 2: Botanical descriptions, key features and assessment of invasion of field sites of observed IAPs*

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| **Latin name and authority – common name(s) – family*** **Growth form**
* **Field observation of four IAP species of local concern**
 |
| *Bidens pilosa* L. - black-jack, beggar-ticks, cobbler's pegs, Spanish needle – Asteraceae* Annual herb
* Not widely distributed or perceived as a problem in field sites
 |
| *Galinsoga quadriradiata* Ruiz & Pav. – Peruvian daisy, hairy galinsoga, fringed quickweed – Astereaceae * Annual herb
* Not widely distributed or perceived as a problem in field sites
 |
| *Ageratum conyzoides* L. - Billygoat-weed, chick weed, goatweed, whiteweed – Asteraceae * Medium-height herb
* Not widely distributed or perceived as a problem in field sites
 |
| *Ageratum houstonianum* Mill. – Blue Billy-goat – Asteraceae * Medium-height herb
* Not widely distributed or perceived as a problem in field sites
 |
| *Parthenium hysterophorus* L. – Santa-Maria, Fever weed – Asteraceae * Low-growing annual on disturbed ground
* Not widely distributed or perceived as a problem in field sites
 |
| *Amaranthus spinosus* L. - Spiny amaranth, Spiny pigweed, Prickly amaranth, Thorny amaranth – Amaranthaceae * Low-growing plant from a rosette on disturbed ground
* Not widely distributed or perceived as a problem in field sites
 |
| *Oxalis latifolia* Kunth – Garden pink-sorrel, Broadleaf woodsorrel – Oxalidaceae* Low-growing perennial plant
* Not widely distributed or perceived as a problem in field sites
 |
| *Lantana camara* L. – Lantana, ‘scourge of India’ – Verbenaceae* Woody-stemmed flowering plant
* Lantana was observed preferentially growing in dry soils where it formed dense stands in all three sites in the field study area.
 |
| *Ageratina adenophora* (Spreng.) King & H.Rob. – Crofton weed – Asteraceae* Perennial, semi-woody flowering shrub
* Crofton weed was widely observed in field sites and is reported as widely problematic in Nepal’s mid-hill region.
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| *Chromolaena odorata* (L.) R.M.King and H.Rob – Siam weed – Asteraceae * Rapidly growing perennial flowering plant
* This plant also hosts aphids during dry conditions, resulting in infestations of other vegetation when it emerges after rains.
 |
| *Pinus roxburghii* Sarg. – Chir pine – Pinaceae* A tall tree with needle-like leaves growing up to 30-50 m
* The reason for including the Chir pine in this priority list is that, under the Nepal-Australia Forest Project of the 1980s, many non-characteristic trees, fast-growing and hence potentially valuable timber-producing species were introduced into deforested and degraded forested areas. This programme was responding to the preceding mass clearance of forests, but is now perceived as causing many problems through replanting with inappropriate species with broad-leaved species constituting the native trees in these regions having been a more appropriate option (Sattaur, 1987).
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*Figure 3: Lady carrying a bundle of cut* Lantana *and* Chromolaena *stems at Panchkhal being interviewed by field team member [Low resolution image only inserted here to aid review]*



*Figure 4: Four Sal (*Shorea robusta*) trees shaped by regular lopping of lateral branches for fodder, mainly used during the dry season [Low resolution image only inserted here to aid review]*



Table 3 considers STEEP elements of WfW programme stratified in Table 1 in the context of the observed Nepali context.

*Table 3: Elements of the WfW programme considered in the Nepali context*

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| **STEEP dimensions, noting (✓) transferrable learning and (🖑) significant differences requiring further investigation or adaptation** |
| **Social**:* An IAP strategy based on ‘real world’ social needs, involving people in delivery of multiple goals, can ensure local buy-in and outcomes that are demonstrably beneficial.
* Nepal enjoys a diversity of NGOs and civil society organisations including CFUGs, providing a platform for collaboration with and delivery of government-led IAP management programmes.
* Other social and community development programmes can be co-delivered with an IAP management programme.
* Programme delivery can enhance the skills and employability of participants.
* HOWEVER, South African models must not be imposed blindly given significant contextual differences, requiring further adaptation to Nepali needs and context.
 |
| **Technological**:* Technical solutions, including mechanical, chemical, biological and integrated vegetation management reliant on basic tools, will be as relevant in Nepal as in South Africa.
* HOWEVER, clear targeting of effort and resource where it is likely to yield the greatest societal benefits will require further research.
 |
| **Environmental**:* Vegetation plays significant roles in water balances in all terrestrial environments, so a foundation in common environmental processes is likely to produce multi-beneficial outcomes including contributing to water resources.
* Nature conservation outcomes are likely to result from targeted IAP management.
* Education of communities about native and invasive species, and the impacts of IAPs on a range of ecosystem services and their associated beneficiaries, can promote community appreciation and engagement.
* HOWEVER, the South African approach is largely based on invasive woody vegetation, whereas the predominant invasive species in Nepal field sites were primarily herbaceous requiring significant modification of approach.
 |
| **Economic**:* Enhanced water run-off and development of employment skills could become important benefits in Nepal.
* HOWEVER, a business case spanning government programmes will need to be developed.
* Monitoring of outcomes is also necessary to audit and justify scheme investment.
 |
| **Political**:* An IAP management programme addressing water security as well as food, livelihood, erosion, biodiversity and other concerns could underpin benefit delivery under multiple policy areas, pooling support and possibly resources to yield net investment efficiencies.
* HOWEVER, government willingness and support will be required to initiate and perpetuate the programme over a timescale appropriate to assess effectiveness.
 |

**4. Discussion**

Consideration of potentially transferrable approaches and opportunities, but also areas of adaptation to the rather different geographical, biological and cultural contexts of Nepal, suggests that a structured IAP management programme could potentially represent a novel approach to natural resource management for a linked set of biodiversity, water, forest and soil, community development and security outcomes. Employment associated with an adapted WfW programme supporting enhanced stewardship and IAP management training would depend on promotion of societal change prioritising protection of water-based ecosystem services through IAP management, as found in South Africa. These outcomes span diverse policy goals, as well as making contributions to international commitments (see Box 2). As one example, gender equity and particularly female empowerment may be well-served by promotion of water security as women are primary natural resource stewards, for example fetching water and fodder which today, under the influence of climate change, is increasing women’s workload in terms of distance covered, time spent and frequency of everyday water collection as springs progressively dry (Chapagain *et al*., 2016). IAP management to secure water resources and native vegetation can relieve drudgery associated with more distant and time-consuming foraging, creating more time for productive purposes such as roles in community governance (as for example seen in restoration of water systems and food security in rural India: Everard, 2015). This is crucial in Nepal where gender-specific vulnerabilities are addressed as a cross-cutting issue throughout national policies. It is anticipated that linking up these and wider policy goals, and the departmental budgets that currently target them individually, will deliver economies in term of net societal and environmental benefits per unit of investment.

Initial evidence suggests that efforts in the study region of Nepal’s mid-hills should focus on a priority set of four species – *Lantana camara*, *Ageratina adenophora*, *Chromolaena odorata* and *Pinus roxburghii* – with their different extents of invasion and perceived impacts at different sites. Whilst initial exploration suggests that IAP management in different agricultural and community forest habitats is likely to yield benefits for water security and associated biodiversity and socio-economic outcomes, further study is required into the precise roles of key invasive species on water resources and the feasibility of an IAP management programme. Our findings are broadly consistent with those of Poudyal and Adhikari (2013) who, informed by a more extensive assessment of invasion particularly by *Ageratum conyzoides* and *Ageratina adenophora*, suggested a programme of ecosystem-based adaptation (EbA) including both extensive use and managed clearance of IAPs to protect ecosystems and associated livelihoods.

Distributional aspects also require further elucidation in terms of “who invests and who benefits”. If the societal distribution of benefits can be clearly demonstrated, this may promote any of a combination of three drivers for action: (1) management for self-benefit (e.g. as initiated through CFUGs in Sindhupalchok); (2) compulsions through legislation particularly to meet policy goals; and (3) measures achieved through payments, including potentially using ‘payment for ecosystem services’ (PES) mechanisms that may take the form of better targeting of existing policy-specific investments rather than requiring new money. Modelling likely and, wherever possible, actual outcomes of the IAP management approach across these interconnected drivers may help inform policy development, including both novel measures and refocusing of existing budgets, compulsions, technical advice or other forms of enabling support for community security and development. For example, the concept of IAP management can be integrated into a range of policy areas to enhance the effectiveness and co-benefits of protecting biodiversity and sustaining ecosystem service flows. It is possible that greater benefits may accrue from wider, inter-state regional knowledge integration and collaboration (Gupta *et al*., 2018), though this is likely only to follow demonstrable benefits flowing from pilot national or local implementation.

This study provides some initial evidence that translating the WfW approach to the significantly culturally and biogeographically different Nepali context is likely to yield water security and multiple linked beneficial outcomes across a range of ecosystem services and their associated beneficiaries and policy areas. Such an implementation would be novel and innovative for Nepal, presenting an additional approach to addressing water security and related livelihood needs through community engagement in IAP management. Transferring a resource security approach with a proven track record in South Africa to an Asian and mountainous/forested context would further demonstrate its validity as an addition to the armoury of socio-ecological development tools facing the increasingly water-stressed developed world confronted with linked challenges of poverty, climate change and socio-ecological resilience.

**5. Recommendations**

Further research effort could beneficially be expended on the potential transfer and modification of the WfW approach to Nepal as a strategic means to secure water, food and other ecosystem services underpinning sustainable livelihoods.

A more detailed, semi-quantified assessment is required of linked strategic national and international policy goals to which IAP management can contribute.

Pilot implementation in a target area, selected as most likely to yield benefits, will practically ground theoretical benefits, engaging with local people, relevant NGOs and government department to adapt the WfW model to Nepal’s unique context.

A monitoring regime to assess multiple ecosystem service benefits, including where relevant economic assessment and modelling to assess likely benefits of wider scheme implementation, can underpin future scheme modification and roll-out.

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