Conference Proceedings

International Conference on Natural Resources, Agriculture and Society in Changing Climate

NRACC 2019

Kathmandu, Nepal

17-19 August 2019

PROCEEDINGS

of

International Conference on

Natural Resources, Agriculture and Society

in Changing Climate

Kathmandu University

Editors

Smriti Gurung, Bishal Sitaula, Roshan Man Bajracharya,

Nani Raut, and Bed Mani Dahal

August, 2019

Proceedings of International Conference on Natural Resources, Agriculture and Society in Changing Climate

17 to 19 August 2019

Held at the Hotel View Bhrikuti, Godavari, Lalitpur, Nepal

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Department of Environmental Science and Engineering, School of Science, Kathmandu University (KU), Nepal
Norwegian University of Life Sciences (NMBU), Norway
Institute of Forestry (IOF), Tribhuvan University (TU), Nepal
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Citation for this Publication

Gurung, S., Sitaula, B.K., Bajracharya, R.M., Raut, N. and Dahal, B.M. Editors (2019) Proceedings of International Conference on Natural Resources, Agriculture and Society in Changing Climate, Kathmandu, Nepal, pp. 317

ISBN 978-9937-0-7329-5

ISBN 978-9937-0-7329-5

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Preface

The International Conference entitled "Natural Resources, Agriculture and Society in a Changing Climate" was successfully conducted in Kathmandu, Nepal during the period 17-19 August 2019. This multi-stakeholder interdisciplinary conference represents an important milestone of the NORAD funded NORHED project entitled, ***"Sustainable natural resource management for climate change adaptation in the Himalayan region: A collaborative project among Norway, Nepal, Pakistan and Bhutan***". The Project was a joint effort of the Norwegian University of Life Sciences, Royal University of Bhutan, Karakorum International University and Kathmandu University who were project partners. The objectives of the institutional collaboration were to enhance the capacity and relevance of higher education and research related to climate change, natural resource management, and environment in a coordinated network of four universities in South Asia. The overall aim has been to develop institutional and human capacity and positively influence the formulation and implementation of policies focused on sustainable resource management and climate change related issues in the Southern partner countries. The international conference served as a forum for dissemination of project-related research along with sharing of findings from other studies conducted on related themes within the region and beyond. The papers and posters presented herein have been organized into several sub-thematic focus areas, namely, agriculture and soil management, forest resource management under changing climatic conditions, biodiversity, water security and resource management, policies and governance an economic strategies for livelihood security, and, disaster, resilience, and transformation in a changing climate. All the sessions were conducted in active participation of professionals from the policy arena as well as the professional/academic community. Key persons from both arenas were instrumental in formulating the conference declaration with a commitment for policy uptake of relevant findings from the project. Furthermore, it is anticipated that the state of the art and the findings of research studies disseminated through refereed publications and in this conference, proceedings will serve as a valuable knowledge base and literary resource to students and researchers working in the Himalayan region and abroad. Funding support provided by NORAD through the NORHED project (QZA-0485, NPL-13/0022) making the international conference possible is, hereby, gratefully acknowledged.

Bishal K. Sitaula

Nani Raut

Roshan M. Bajracharya

Godavari declaration on "pathways for climate adaptation and resilience"

International Conference on Natural Resources, Agriculture and Society in a Changing Climate

17-19th August 2019

We feel that it is our moral obligation and ethical duty to hand over the earth to the future generations at least as good as it was what we inherited if not in a better condition. It is obvious that the daunting interrelated challenges that face the world will require a concerted, multi-dimensional global effort on the parts of all nation states and individuals. We, the participants of the International Conference on Natural Resources, Agriculture and Society in a Changing Climate, in full recognition of the urgency and existential threat of the myriad of inextricably interlinked global environmental crises, hereby make the following declaration on this nineteenth day of the month of August of the year two thousand and nineteen A.D.:

- Reconfirming that natural resource degradation is ever increasing, which strongly demand the practice of sustainable use including approaches to replenish, reuse, recycle and restore forests, soils, biodiversity, water, mineral and ores.
- Understanding that land and soil resources restoration will require an improved, holistic and regenerative approach in various land uses such as agriculture and forestry.
- Realizing that the Mountain regions are more prone to extreme climate events and climate change induced disasters calling for a coordinated approach among all stakeholders to ensure pathways for climate adaptation and resilience.
- Recognizing that the solutions must be pro-poor and women centered with consideration on their livelihood security.
- Considering conservation, protection, and efficient use of the water sources along with rain water, surface and ground water.
- Appreciating that natural resource use and economic development are highly influenced by the population pressure which increase consumption needing stark mitigation strategies such as sustainable land management mainstreaming land, water, forest, tourism, etc.
- Utilizing all forms of media to raise awareness and understanding on the climate change related crises.
- Agreeing to encourage more and effective collaboration between Government, Non-Government, Industries and educational institutions in national priority research.
- Distinguishing the value of personal transformation, individuals engaged in education, research, and policy making will adopt this approach through context responsive interventions.

Table of Contents

The Regenerative Approach: Beyond Sustainable Land Management?

Prof. Roshan M. Bajracharya, Ph.D.

Paper presented at the International Conference on Natural Resources, Agriculture and Society in a Changing Climate

Held in Kathmandu, 17-19 August, 2019

Abstract

The 21st Century is witness to ever-increasing pressures of a ballooning human population upon the natural resource base of our planet. Land, which, as yet, is the primary medium for large-scale food and fiber production needed to sustain the growing population, is fast approaching the limits of its ability to support life on Earth. Moreover, the destructive and exploitative human activities, such as, deforestation, intensified commercial agriculture, industrialization and ever-expansive urbanization, continue to not only ravage and degrade the land and its resources, but also pollute the atmosphere and water bodies. In addition, climate change exacerbates the adverse effects of human activities and becomes both the effect and cause of further environmental degradation. It is, therefore, amply evident that sustainable land management practices alone are unlikely to effectively enable us to tackle and solve the myriad of interlinked global crises. A regenerative approach to agricultural, range, and forest lands worldwide may offer a way out of this existential crisis by simultaneously enhancing the productivity of these land and increasing carbon capture and sequestration, while concurrently helping to reduce further carbon emissions. This approach involves a range of practices including improved composting, no-till farming, cover crops, controlled grazing, reforestation, agroforestry, permaculture and application of soil enhancing amendments such as biochar. Only by focusing on improving soil health through nature-based techniques and utilizing waste products leading to the closing of the loop among humans, livestock, plants, air, water and soil, can we hope to solve the global climate and pollution crises in the long-run.

***Keywords*:** Biochar, Climate change, Holistic management, Pollution, Urbanization

Introduction

Modern times have seen ever-increasing stresses upon the natural environment with the insatiable demands of a growing population that continues to strive for higher standards of living. The quest for advancement of societies with increasingly sophisticated technologies fuels the constantly expanding need for food, energy, water and building materials. This in turn has led to the over-exploitation of all forms of natural resources causing their depletion, degradation and pollution by wastes and undesirable by-products of technological activities and rapidly growing densely populated urban areas. While the impacts of early human communities following the advent of settled agriculture, some 10,000 to 13,000 years ago, was typically insignificant (Braidwood, 1960; Piggot, 1961), modern societies have had devastating impacts on the environment with lasting global-scale consequences causing notable alteration of the Earth (Thomas et al., 1956; Darlington, 1969). The industrial revolution of the mid-1800s brought about advances in science and technology resulting in large-scale industrial and agricultural development along with ever-expansive urbanization, transportation and communication networks, all of which demand evermore energy generation, water and raw materials extraction (Boserup 1965; Carswell, 1997; Du Pisani, 2006; Bajracharya and Dahal, 2012). Indeed, it can be said that the scale and magnitude of global ecological crises have become an existential threat to humankind.

Key Causes of the Problem

The root cause of the global environmental crises can undoubtedly be attributed to the burgeoning world population that has placed ever-growing pressures upon the natural resource base of the planet. This indisputable fact coupled with major advances in technology which fuelled industrial manufacturing, modern input-intensive agriculture, global trade and transportation, as well as the quest for high economic standards of living have led to the constantly increasing requirements of societies for fossil fuels, minerals, ores, construction materials, water and land. Thus, the period of exploitative extraction of resources and clearing of vast tracts of land for cultivation of food crops and pastures for livestock rearing since the late 1800s has had devastating impacts on natural ecosystems and global climatic patterns.

Modern agricultural production systems using large-scale mono-culture cropping, chemical fertilizers and pesticides along with excessive tillage and manipulation of the soil leads to loss of soil organic carbon to the atmosphere, low floral and faunal diversity, reduced soil fertility as well as productivity, and ultimately, degradation of the land. Coupled with changing climatic patterns, such land degradation can culminate in desertification of vast tracts of land as seen in parts of Africa, the Middle East and Asia (Bajracharya, 2018; Lal, 2011). Moreover, energy generation, heavy industries, manufacturing, the transportation sector and rapidly spreading unplanned urbanization (in less developed countries) lead to all forms of waste production and environmental pollution. These result in air, water and land pollution from municipal solid waste, sewage, industrial effluents, gaseous emissions, toxic chemical contamination, dust, smoke and volatile compounds causing acid rain, etc.

Hence, the over-exploitation of resources, driven by reckless quest for profit and short-term gains, and maintaining unsustainable lifestyles without consideration for long-term consequences, is leading to escalating and converging global environmental crises. There is no doubt that the myriad of problems and issues are inextricably interlinked; i.e., energy production and industrialization, water and mineral extraction, land clearing, agriculture, urbanization and pollution, greenhouse gas emissions and climate change, etc. It is becoming ever more evident that simply maintaining the ‘status quo’ or merely achieving ‘sustainable’ production will not be sufficient to tackle climate change and the numerous interrelated global-scale problems. Future agriculture and land management will need to adopt a *regenerative* approach if we are to ensure food production levels required to meet the growing demands while also simultaneously preserving ecosystem balance and resilience to climate change impacts (Bajracharya, 2018; Ohlson, 2014).

Potential Solutions

The regenerative approach to soil and land management entails a set of practices and techniques that enhance soil health, fertility and productivity of the land. Over time, these practices lead to enhanced soil fertility and health; increase in water percolation and retention; increased biodiversity, ecosystem health and resilience; and, contributes to reversing climate change by rebuilding soil organic matter and restoring degraded soil biodiversity leading to carbon sequestration and improving the water cycle (Savory, 1999; RAI/TCU, 2017). Regenerative Agriculture is defined by RAI/TCU (2017) as “a holistic land management practice that leverages the power of photosynthesis in plants to close the carbon cycle, and build soil health, crop resilience and nutrient density”. It includes various practices that improve soil biodiversity and ecosystem integrity, such as, minimum or zero tillage, application of organic residues, biochar, compost and animal manure, crop rotations and cover crops, agroforestry and permaculture systems, and well-managed grazing practices like agri-silvopastoral systems (Roberts, 2017; Regeneration International, 2018; Novak et al., 2016; Penn State, 2018). The beneficial effects of various regenerative land management practices are shown in Table 1.

A regenerative approach to pasture and grassland management has be demonstrated in South Africa by Savory (1999). At the Africa Center for Holistic Management near Victoria Falls, he promotes “Holistic management – a new framework for decision making” (Savory, 1999). He demonstrated that rotational grazing of large cattle herds in 180 small parcels of land for 2 days per parcel trample the ground and incorporates plant and animal litter into the soil. This method simulates natural grazing herds, whereby, “under natural conditions in the past, large herds of ruminant herbivores roamed the prairies and savannas in close groups, constantly moving for protection against predators; they ate only the tops of the grass/plants encouraging rapid regeneration.” Over time such an approach leads to vast improvements in the pasture land soil quality, species composition, biodiversity and ultimately ecosystem health.

Minimum or zero tillage is the method of producing grain crops on large tracts of land with a minimum of disturbance to the soil. Seeds are planted into the ground by no-till seed drill that only pierces a hole in the soil and drops the seed into it. If done manually, the seed are simply scattered over the soil surface by hand-tossing or dropped into a hole in the ground made using a pointed stick or rod. By avoiding over-turning of the soil or other major manipulation, soil biological communities and microorganisms are preserved while disturbance to the physical structure of the soil is reduced. The method of crop cultivation reduces the soil respiration and emission of carbon dioxide to the atmosphere, as well as, maintains good soil aggregation and porosity which enhances water percolation (RAI/TCU, 2017; Bajracharya et al., 2014; Lal, 2009).

The use of organic instead of chemical forms of fertilizers for meeting plant nutrient requirements has multiple benefits. Organic fertilizers include crop residues, animal manure, biogas slurry, and compost made from farmyard wastes like weeds and leaf-litter. Nutrients released from the decomposition of organic materials become gradually available to plants throughout the course of the cropping season. Thus, leaching losses in storm water runoff is minimized and any excess or residual nutrients remain available for subsequent crops. The use of organic fertilizers also lead to an increase in the organic matter (humus) content of soils rendering them more stable, porous and fertile. Moreover, high organic matter and readily available organic residue in the soil enhances and supports microbial and biological activity, which promotes nutrient cycling (RAI/TCU, 2017; Lal, 2009).

Along with the application of organic manures or farmyard manure, the use of biochar as a soil amendment has gained considerable accolade in recent years as a potential means of enhancing the carbon storage capacity and longevity in soils, while simultaneously increasing the soil’s fertility and productive capacity (Regeneration International, 2018; Novak et al., 2016; Bajracharya et al., 2014) . Biochar, a pyrolysis product of biomass, has been used by ancient civilizations in the Amazon, North West Europe and the Andes (Downie et al. 2011; Sandor and Eash 1995). It has gained scientific attention as a simple yet potentially powerful tool for climate change mitigation while contributing to sustainable agricultural production (Downie, et al., 2011; IBI 2012). The benefits of biochar reportedly result from its high stability, porosity and resistance to microbial breakdown, thereby, acting as sites for enhanced microbial activity along with increased water and nutrient retention (Novak et al., 2016; Sohi, 2012). Thus, biochar acts as a catalyst for biochemical reactions in the soil which improve plant nutrient availability.

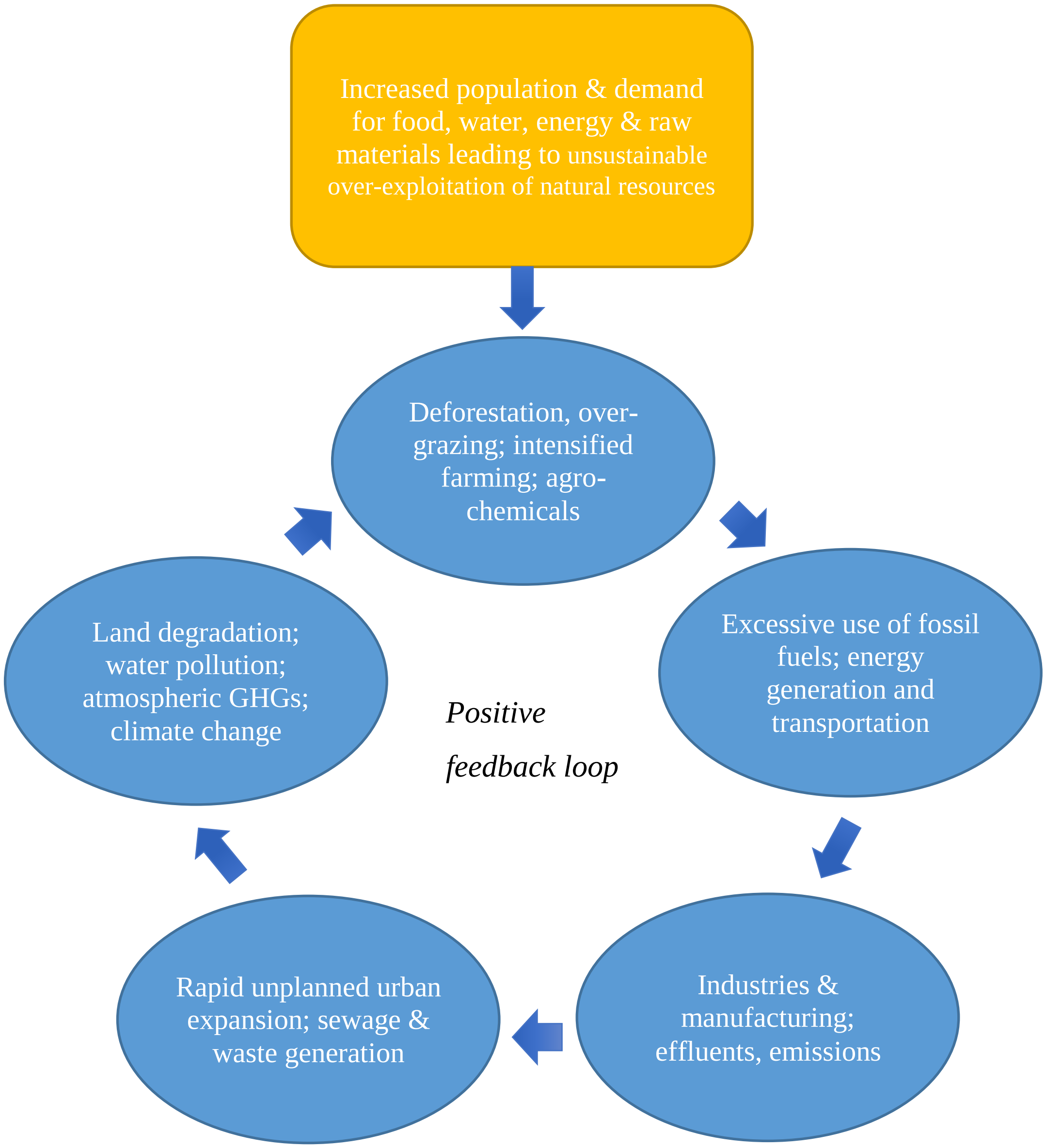

Figure 1. *Cycle of degradation driven by the ever-increasing demands of a ballooning population.*

Table 1. *Effects of regenerative land management practices compared to conventional farming (modified from Bajracharya, 2018).*

Land Mgmt. Practice	**Beneficial regenerative effects of land management practice:**					
	Increases SOM & C-sequestration	Enhances biological activity/diversity	Improves structure & stability	Increases water percolation	Boosts nutrient availability	Increases fertility & productivity
Conventional farming	--	--	--	--	--	--
Minimum or zero-tillage	++	++	+++	++	+	++
Compost, FYM, organic residue	+++	++	+++	++	+++	+++
Biochar amendment	++	+++	++	++	+++	++
Crop rotation, cover crops	++	++	++	++	+	+
Agroforestry & permaculture	+++	+++	++	++	++	+++
Agri-silvo-pasture	+++	+++	++	++	++	++
Holistic pasture management	+++	+++	+++	+++	++	++

Note: -- indicates that the practice does not have beneficial effects; + indicates slightly beneficial; ++ moderate beneficial effects; +++ highly beneficial.

Crop rotations and cover crop plantation involves careful selection and planting of different types of crops during a cropping cycle (typically annual). This practice offers the opportunity to incorporate leguminous crops (able to fix atmospheric nitrogen making it available to plants) into the rotation which is highly beneficial in managing plant nutrients and reduces the need for chemical fertilizer additions. Moreover, changing the type of crops planted breaks the cycle of continuous cropping and, thereby, offers protection and resilience against crop pests, such as, insects, diseases and weeds. Cover crops, on the other hand, provide protection for the soil and prevent exposure of bare soil in between major cropping periods. Therefore, cover crops are not harvested, rather they cultivated into the soil prior to planting of the next crop and serve as a source of organic manure that eventually decomposes and releases nutrients for the subsequent crop (Bajracharya et al., 2014; Sherchan and Karki, 2006).

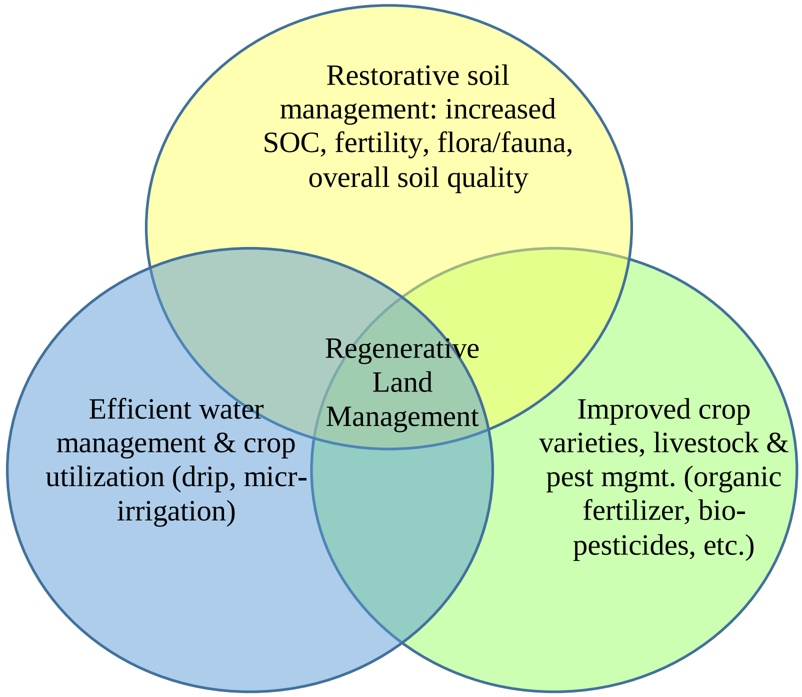

Figure 2. *Three-pronged approach to regenerative land management for enhanced ecosystem health and resilience*.

Agroforestry and permaculture systems have good potential to serve as both a climate adaptive strategy, as well as, a climate change mitigation option, particularly in mountainous regions (Gautam et al., 2017; Nair, 2011). These systems incorporate perennial trees or shrubs into farm plots along with other annual crops, thereby, diversifying the production. In the event of severe weather such as droughts or floods, such diversification leads to the possibility that all the crops will not fail, hence a total loss can be prevented. Furthermore, tree and shrub crops can lead to accumulation of carbon, both in the biomass and in the soil, thereby contributing to climate change mitigation. The tree or shrub crops may be of high value species, like fruits or medicinal plants, or be used as fodder for livestock, which augment the farm income enabling improved livelihood (Penn State, 2018; Gautam et al. 2017).

Pasture cropping or agri-silvopastoral systems also hold promise as an integrated and holistic land management approach that combines livestock grazing with crop production. After harvesting of the main crop, the livestock are allowed to graze freely on the plant stubble and residues. This practice leads to the control of weeds and utilization of crop residues while simultaneously fertilizing the field through the urine and manure depositions by the animals. Therefore, dual benefits of improved crop yields along with gains in animal products can be obtained through these integrated practices (Roberts, 2017; White, 2012).

Table 2. *Simultaneous approaches and technologies necessary to achieve sustainable land management. SOURCE: Modified from Bajracharya et al. (2014).*

Category	Approaches and Technologies
Soil/land resource – restorative soil management	Enhanced soil fertility and quality through improved composting, use of adequate farmyard manure and urine application. Increased soil organic matter and soil carbon sequestration. Use of bio-fertilizers and optimization of rhizosphere microbial activity. Use of biochar and zeolite amendments to improve soil bio-physical properties and water retention. Adoption of minimum or zero tillage, crop residue management, and other conservation practices. Holistic pasture land management and controlled grazing
Water resource management and use efficiency	Increased water use efficiency through micro-irrigation and timing of application; use of laser level to improve irrigation/water productivity. Water harvesting and ground water recharge; proper drainage of excess water runoff/overland flow. Improved water retention in soil through the application of biochar, zeolites and mulching. Water recycling, waste water reclamation and re-use, de-salinization.
Crop/agro-biodiversity resource management	More efficient and risk averting crop production systems, such as, agro-forestry with high value crops; mixed, relayed and inter-cropping. Improved crop varieties with drought, cold, and pest resistance; high-yielding varieties enhanced through genetic modification. Forage species/crop rotation with legumes and planting of fruit and fuel wood tree species on private land. Integrated and natural pest control approaches; use of bio-pesticides.
Policy and institutional initiatives	Adequate investment in agricultural research. Technical support to farmers through extension and outreach services. Institutional support and strengthening of capacity. Policies and incentives to encourage conservation and support sustainable production. Carbon tax and disincentives for emissions

The Way Forward

While the realization that proper management of the land, water and other natural resources is essential for sustained productivity and ecological balance is not new, but rather dates back to the early 1900s, the need for a concerted global effort to solve the numerous interconnected environmental problems has never been more urgent than at present. According to various BBC and CNN reports, vast tracts of land have been laid to waste through the devastating effects of coal and mineral mining; half of all coral reefs have become bleached; 60% the ocean's fish stock have been over-harvested; the oceans are being choked with plastic pollution from millions of tons dumped per year; an area the size of a football field of rain forest is clear-felled approximately every minute; the polar ice caps and glaciers of Greenland are melting at unprecedented rates causing sea-level rise which threatens to inundate islands and coastal areas; large areas of Asia, Africa and the Middle East are experiencing desertification due to prolonged droughts; 20 out of the past 22 years have seen record high annual average global temperatures. And all the while we continue to release tremendous amounts of greenhouse gases though our industries, power generation, farming activities and transportation sector.

It has become undeniably evident that the "business as usual" approach to capitalist economies in pursuit of ever-greater wealth and extravagant standards of living, oriented to short-term gains without taking into account future consequences, can no longer be sustained by the limited resources and capacity of the Earth. Indeed it is "all hands on deck" time! Only through a massive, coordinated global effort with simultaneous action on several fronts will we be able to overcome the many converging ecological crises that threaten the very existence of humankind. A multi-faceted approach to tackle the above issues is required including: wholesale changes to the global economy and way business is done; phasing-out of fossil fuels for both energy generation and transportation; switching to renewable energy sources; changing many aspects of our lifestyles including the way we travel, the types of food we eat, and even adopting sustainable fashion (clothing); and, minimizing pollution through reducing, reusing, and recycling all types of materials. While many of the above actions focus on reducing emissions and pollution, equally important are activities that can take carbon out of the atmosphere and store it in the Earth. The regenerative approach to land management can achieve this through the variety of practices that adopt nature-based solutions and restore the soil fertility and biodiversity as outlined in Table 2. Indeed, eliminating deforestation and simply planting more trees can counteract more than 20% of the global carbon emission to the atmosphere (Velasquez-Manoff, 2018). Finally, policy measures and enforcement mechanisms to ensure that governments, businesses and individuals follow such sustainable and regenerative practices while minimizing adverse impacts to the environment are needed. These could include investment in research, extension and technical support, incentives and subsidies, carbon taxes and fines for violators (Table 2). It is only through nature-based and regenerative approaches to improving soil health, land productivity and minimizing pollution by utilizing waste leading to a closing of the loop among humans, livestock, plants, air, water and land can we hope to solve the environmental degradation and pollution crisis (Ohlson, 2014; Velasquez-Manoff, 2018). Thus, clearly we possess the ways and means to halt and reverse the global ecological crises and climate change; the question is, *do we have the political will and perseverance to achieve it*?

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Rice Farmers' Understanding to Intervention on Climate Change Adaptation: A Case from Rural Nepal

Niranjan Devkota[1*], Ram Kumar Phuyal[2], Durga Lal Shrestha[3] and Udbodh Bhandari[4]

[1]Quest Research Management Cell, Quest International College, Pokhara University, Nepal
[2]Associate Professor, Center for Economic Development and Administration, Tribhuvan University, Nepal
[3]Professor of Economics, Tribhuvan University, Nepal
[4]Nepal Commerce Campus, Minbhawan, Tribhuvan University, Nepal

*Corresponding author: mailto:niranjan@quest.edu.np

Abstract

Rice is an important crop of Nepal where farmers have complained over the years about increasing difficulties to plant rice due to delay monsoon. Definitely, farmers involved in rice production are facing climate change related barriers and it is high among the rural rice farmers. The assumption is that rice farmers are unable to cope rice related climatic anomalies in many cases. This study analyzes the dynamics of change adaptation on rice production in Nepal and the cost associated with it. The survey was conducted in 7 districts of Nepal balancing provincial geography, rural rice cultivated area and country coverage using a multi-stage sampling technique. By using structured questionnaire, a total 773 farmers from 28 Primary Sampling Unit (PSU) were interviewed irrespective of gender, farm size or tenancy status through a farm household survey. About 81% and 90% of the farmers perceived climatic variations in temperature and decrease in rainfall in 30 years period. 77% of them responded that rice production and yield has decreased due to such changes which force them to the adoption of available adaptation options. The study shows overall 71% of the farmers have adopted available adaptation options to protect themselves from the perceived risk. There are 13 major adaptation options rice farmers practice in order to protect them from climatic risk. It is observed that adoption practice is more with non-poor rice farmers compared to poor and the people lived in Terai region. Also, surprisingly, farmers who do not adopt any adaptation options are able to receive the highest income from per unit production. The research indicates there is a need for greater investment to remove the barriers of institutional setup.

Keywords: Climate change adaptation, Perception, Determinants, Cost and benefit, Adaptive capacity, Barriers, Rural rice farmers, Nepal

Introduction

In the last decades, Nepalese farmers' awareness on climate change has been well captured through varied research. Rice farmers in various part of Nepal have already been suffering from the climatic anomalies. Studies by Karn (2014), Devkota et al (2018), Budhathoki & Zander (2019) show that climate change in Nepal has already reduced crops and created threats on future production. Farmers are already in pressure to cultivate rice production and if further pressure would appear, in terms of change in temperature and rainfall patterns, its consequences would be more devastated.

Paddy is one of the most important food grains and occupies the first position in terms of area (42.2%) and production (51.7%) (MoAC, 2017). CBS (2011) record shows paddy cultivation area has decreased by 129 thousand hectares and now only 72.3% households cultivate paddy. Erratic weather pattern, decrease in soil organic carbon reserve and nutrients, non-uniform distribution of rainfall, increase in temperature; and rainfall are considered as major causes of such reduction (Swain & Yadav, 2009). Since1980s till date, temperature increased by overall 1.8°C and differs in Terai by 0.04°C and Himalayas by 0.09°C (Shrestha et al., 1999; Malla, 2008; Devkota & Phuyal., 2016). Rainfall in the region was observed decreasing in both volume and pattern (Malla, 2008; Aryal, 2015). It is evident that lands in Nepal are getting drier, which in turn restrict water availability to the farmers and ultimately reduce the production (Devkota et al., 2017). A number of studies have been conducted to measure the climatic effect on paddy production in Nepal. Joshi et al (2011) observed positive influence of climatic variation in rice production whereas Karn (2014), Adhikari et al (2017) and Devkota et al (2018) detected inverse influence of climatic increase in rice production in Nepal. Similarly, several cross-sectional researches by Sapkota et al (2010), Rai et al (2011) revealed similar negative relationship between rice productions.

Government of Nepal has taken numerous steps in the development of agricultural sector. Adaptation and mitigation issues have been well discussed, in national and regional plans such as the National Adaptation Programme of Action (NAPA), Local Adaptation Plans of Action (LAPA), and climate change policy. However, many empirical studies are still concentrated to understand the farmers' perception, determinants, limitations and impact assessment. Issues related to economy are less explored that demand immediate research. Therefore, the present study offers improved understanding of economics of climate change adaptation by rice farmers in Nepal. This empirical study disentangles the issue of economics of climate change adaptation among rural rice farmers.

Economics of Climate Change Adaptation

Different choices are associated with different levels of utility (Mengistu & Haji, 2015). Therefore, individual households generally reflect their preferences for different coping strategies based on their understanding. However, Deressa et al (2008) and Gbetibouo (2009) opined that the decision regarding whether or not to adopt any adaptation options is considered to be under the general framework of utility and profit maximization. Furthermore, it is assumed that a rational farmer uses adaptation methods only when the net benefit from using such a method is significantly greater than the cost of not doing so (Mendelsohn, 2012). Although the benefit is not directly observed, the action of economic agents is observed through the choices they make (Deressa et al., 2008).

Costs and Benefits of Adaptation

Agrawala & Frankhusher (2008) pointed out that adaptation is inherently local problems, and costs and benefits falls largely to each private actors and local government (Mendelsohn, 2012). Therefore, adapting to farmers' own farm to climate change helps the farmers because the benefits are local and can be captured with adaptation by local farmers. Studies by Enete et al (2011), Mohammed et al (2013), Shongwe et al (2014), Mugula et al (2015), Devkota et al (2017) analyze cost and benefit of major strategies practiced by the rice farmers to cope with climate change. Devkota et al (2017) identified that alternative irrigation practice, denser plantation of local seeds and climate smart varities are three costly adaptation options with average adaptation cost of $69.95, $20.69 and $18.06 respectively per farmer. Devkota et al (2017) further observed that 88% farmers practice multiple adaptation options on the same farm. The per unit total cost ranges from $28.34 to $32.79 depending on the location they adapt to whereas per unit total revenue ranges from $33.4 to $49.2. Surprisingly, farmers who do not adopt any adaptation options are able to receive highest income from per unit production.

Materials and Methods

The research was conducted in Mid-hill and Terai regions in 7 districts - 3 from Terai and 4 from the Mid-hills. Terai region is considered as the grain basket of Nepal and has fertile agricultural land (Devkota et al., 2017). Multistage sampling technique has been applied for this study, where, the 7 rice producing districts, one from each province, was randomly selected. Similarly, 14 Village Development Committees (VDCs), two from each district, were selected based on rice pocket area as per communication with district agriculture offices. Further inquiry was made to each VDC secretary and social mobilizer for the selection of 28 rice pocket wards as primary sampling unit (PSU), two wards from each VDC. Thus altogether 28 farmers were selected from each ward.

The interviews were conducted in the year 2016 during the main rice cultivation season in Nepal that falls on June/July to October/November of each year. A total of 773 farmers, irrespective of gender, farm size or tenancy status, were interviewed by using structured questionnaire. Prior to the study, a pretesting of the questionnaire was performed to avoid missing of any important information and overcome fallacy in question setting. The enumerators were provided with field training about the study objectives and farm household survey.

Results and Discussion

Adaptive Capacity

Adaptive capacity is the capacity of system to adopt the changing environment to adjust to climate change anomalies (Smit & Wandel, 2006; IPCC, 2007). It is vector of resources such as financial, social, human, economic and natural capital by which adaptation actions can be taken (Smith et al., 2001; Brooks & Adger, 2005; Vincent, 2007). According to Brooks & Adger (2005), adaptive capacity depends on the ability of community and society. Farm community has a strong kinship network, which helps them to increase adaptive capacity through collective actions and conflicts resolution process between its members (Brooks & Adger, 2005; Pelling & High, 2005; Smit & Wandel, 2006). Farmers having better adaptation or changes on the system can deal well with problematic exposures (Smit & Wandel, 2006). In Nepal, many farmers are coping spontaneously to reduce current stress (Dixit, 2011; Khanal et al., 2018). The effective adaptation helps to maximize net benefit (Mendelsohn, 2012) but adaptation of new technology depends upon the farmers' capacity (Mendelsohn, 2000, 2012). Adaptation option depends on how wealthy a farmer is because poor farmers have less choice in comparison to wealthier ones (Mendelsohn, 2000, 2012). Devkota et al (2018) observed that farmers' adaptive capacity differs in their level of wealth. Poor farmers' choice of adaptation differs as per their capabilities. Their result observed that rural rice farmers are in moderate level (.048), whereas the score was 0.41 for poor households and 0.50 for non-poor households. Besides, total farmland, access to credit and distance from road significantly influence poor farmers' choice of adaptation.

Barriers to Climate Change Adaptation

Barriers are factors, conditions or obstacles that decrease the effectiveness of adaptation strategies (Moser & Ekstrom, 2010; Van et al., 2015). Overcoming challenges of barriers is often one of the primary targets of every adaptation efforts (Archie, 2014). Barriers can be overcome with effort, creative management, and change of thinking, prioritization and related shift in resources, land use and institution (Moser & Ekstrom, 2010). Identifying such barrier is a promising approach to overcome these barriers

(Gurney et al., 2016). Hence, in climate change research, understanding - where, when and how barriers and limits to adaptation arise has become important frontier (Barnett et al., 2015). Phuyal et al (2017) found that Nepalese rice farmers face various hindrances when adapting available options best for them. Inadequate capital, poor access to weather forecast and climate change information, inadequate awareness programs on climate change from government and non-government agencies were major barriers for more than 90% of the farmers. Further, 80% farmers state that the high cost of improved seeds, fertilizer and irrigation, the inadequate knowledge of coping mechanism and resiliency; and inadequate access to credit facilities were hindrances to rice farmers (Devkota et al., 2018). Insufficient manpower, inadequate government policies and primitive farming technology and equipment are several other barriers. Ndnami & Watanabe (2015) also agree that unpredictability of weather, high farm input cost, and lack of access to timely weather information and lack of access to water resources are the most important barriers to farmers. Thus, farmers' major adaptation barriers are socio-ecological factors, psychological factors and resource constraints which are due to poverty level (Deressa et al., 2009; Van et al., 2015). Lack of focus on adaptation at the national level has in turn led to a lack of attention to these issues at the local level.

Role of Information and Communication Technologies (ICTs)

Studies of George et al (2011), Sylvester (2013) and Chavula (2014) recognized the arrival of ICTs as well timed and a solution to improve agricultural production in developing countries. Recently the use of ICTs in the form of Mobile phones and internet has been increasing (Devkota & Phuyal, 2018). In Nepal, the number of mobile subscribers reached 27.07 million by 2016, which is 102.18% of the total population of the country. Similarly, internet penetration has reached 44.89 percent of the total population (Nepal Telecom, 2016). ICT can assist farmers to understand better adaptation techniques and enhance their knowledge regarding new adaptation options. In these days, ICT tools are increasingly becoming popular among farming communities. Upadhyaya & Baijalwan (2015) argued such ICT tools are playing an important role in disseminating the knowledge on adaptation and fighting against climate change. In the Nepalese context, Devkota & Phuyal (2018) found that 65% farmers perceived climate related information from various ICT devices that they possess. Mostly rural farmers receive information from radio (71%), T.V. (69%) and mobile phones (62%). Farmers argued the devices are more prominent, easily accessible and practical to receive farm related information. 86% farmers use such devices daily whereas 71% receive climate change related information and 61% of them receive agro-based information. Majority of the farm respondent argued that such available information is very much informative and supportive for resiliency against climate change and use of available adaptation options.

We assume that rice farmers, in the different ecological zone in Nepal, are aware of the issue regarding climate change and will often ascribe change in farm productivity to changes in temperature and rainfall patterns. A number of studies have revealed that farmers are aware of climate change and coping pattern in their farm as per their best judgment (Mertz et al., 2009; Okonya et al., 2013; Minh et al., 2014); the nature of climate variation depends on how people perceive climate change and variability (Deressa et al., 2008).

The impact of climate change depends on the vulnerability, temperature and rainfall and magnitude, from irrigated to rainfed rice production (Mugula et al., 2015). The impact can be negative if climate variable results in high temperature, low rainfall, occurrence of floods, low crop yields and so on. Some studies such as those of Malla (2008), Thapa-Parajuli & Devkota (2016), Devkota & Phuyal (2016) revealed that Nepal is likely to be affected by climate change in both positive and negative ways. Understanding such impacts determine what adaptation options (short-term or long- term adaptations) farmers should take to protect themselves from the effect of climate change and variability. Adaptation options for rice production include selecting short duration crop varieties, planting drought-resistant crops, use of chemical fertilizer, irrigation, changing nursery date, changing the plantation date and so on (NAPA, 2010; Le Dang et al., 2014). Though the bulk of adaptation options are available to cope with climate-induced vulnerability, our assumption is that, farmers do not behave irrationally while choosing adaptation options available in the market (Mendelsohn, 2012). They judge the better options, based on their perception, and choose the one which provides them with maximum satisfaction (Maddison, 2006; Deressa et al., 2011). Further, the decision whether to adopt or not to adopt new adaptation options available to farmers depend upon the costs and benefits derived from adaptation options (Pant, 2011).

Increase crop yields, income generation are considered as benefits from adaptation options, but the costs for adaptation options involve the cost of investment, cost of maintenance and operation (World Bank, 2010; Sova et al., 2012; Mugula et al., 2015). It depends on their ability to adopt technology and capital (Smith et al., 2001; Brooks & Adger, 2005; Adger et al., 2007; De Silva & Phuong, 2011). A common assumption in the adaptation literature is that rich farmers have more technology and capital to choose from more options than poor farmers (Pender, 2007; Mendelsohn, 2012). And, we believe that having more substitutes allow wealthier farmers to adapt more readily.

Better adaptation options help sustainable livelihood and also help to mitigate the problem of climate change (Mitin, 2009). Therefore, understanding the ongoing adaptation options and decision-making process is important (Maddison, 2006; Van et al., 2015). Similarly, to know the determinants, perception and barriers to adaptation options is very important (Abid et al., 2015). Besides, understanding the income level of farmers plays crucial role in decision-making process (Deressa et al., 2009; Deressa et al., 2011). Appropriate adaptation options can be promoted and popularized by having the farmers timely informed by various means (Fankhauser et al., 1997; Yadav et al., 2011). It also helps policymakers to promote successful adaptation on rice production and reduce the effect induced by climate change (Sarker et al., 2013; Mugula et al., 2015). In this regard, Callaway (2004) rightly remarked that the benefits of adaptation are, in fact, local in nature and it is important to focus on local adaptation because it is related with both technology and policy. It also provides information to them regarding the place where they are planning to promote adaptation options which further promote successful adaptation on rice production and reduce the effect induced by climate change (Mudombi et al., 2014). It also allows proper allocation of scarce resources with efficient management. Further, it helps policymakers to promote successful adaptation on rice production which is affordable and popular with the farmers (Mugula et al., 2015). Similarly, adaptive capacity plays crucial role to adopt better adaptation options by the farmers and helps in their decision-making process (Mendelsohn, 2012; Le Dang et al., 2014).

Policy and Technical Measures for Farmer Adaptation

Policy and supportive environment guide development stakeholders in planning and executing adaptation intervention enable farming community to adapt to climate change (Ampaire et al., 2017). Government should consider mainstream barriers to, and choice of factors of adaptation practice to climate change related projects and programs (Ndamani & Watanabe, 2015). The government also should make information more available on climate change and find possible ways to overcome barriers to adaptation (Ifeanyi-Obi & Issa, 2013). Furthermore, it shows the need for multi-level governance framework in which the national government gives the clear rise to municipalities through setting goals, creating regulations and financing adaptation process for the local governments to implement where necessary (Amundsen et al., 2010). Poor information on climate change is identified as a barrier to adaptation strategies. Hence, government and other development actors should create useful meteorological centers in the rural areas to make accessible climate information to farmers via radio and television. This will reinforce farmers' adaptability to climate change (Kim et al., 2017).

Phuyal et al (2017) observed that for the removal of the hindrances for the adoption of climate change adaptation options by rural rice farmers, the role of policy makers and other relevant stakeholders is crucial. Among the total respondents, 69.4% of rural rice farmers argued that making timely availability of improved seeds as per required quantity could be one of the most important policy and strategic interventions to adopt climate change adaptation options. 56% farmers opined quality fertilizer whereas 55% mentioned training and proper information at local level help for the successful adaptation. Besides, 50% and 30% of farmers argued that managed irrigation and Junior Technical Assistant (JTA) service respectively are responsible for better adaptation (Phuyal & Devkota, 2018). Along with this, farmers also mentioned that supports such as flood control, soil test, labor, bullock and tractor management, credit facilities through banking channel are better adaptive options. In addition, pest and disease control facilities, determination of proper price of the paddy during sales, proper market facilities with easy access, rightful ownership of land to the farmers, storage facilities help them to practise proper rice farming. Beyond all these, there are several other policy interventions farmers mentioned which are required for the better farming on the verge of climate change. Such interventions can be the promotion of rural farmers' targeted program, proper road access, follow up of the implemented policy and programs, inflation control, mitigation and elimination of middleman and corruption.

Recommendations

Following recommendations are put forward for the consideration of policymakers:

Irrigation and Flood Control: Irrigation seems more urgent for farmers to develop their field that result in timely production. That indicates farmers with proper irrigation facility have better adaptive capacity to cope with existing climatic stimulus. With the successful implementation of irrigation (regardless of its nature), more production is possible with the same land area due to economies of scale and/or high level of productivity. Many farmers complained about either not having a proper canal or damaged existing canal or cost of alternative irrigation process (Phuyal & Devkota, 2018). In this regard, proper irrigation facility provided to the farmers from the government and concerned authority could help them to cope with changing climate without any impact on production. Flood control, with the application of river training structure, is another important demand of the farmers as most of the rice farmland in Nepal is situated on the river banks. Inability to control such floods results in their land being swiped away during rice plantation period leaving the rural poor farmers with insufficient food throughout the year.

Quality Fertilizer and Improved Seeds: Farmers demand timely availability of quality and advanced seeds for their land as they argued that seeds are not available as per their need and on time, which is hampering their overall production as well as adaptation practice. National Agriculture Research Council (NARC) is involved in research activities related to different issues related to agricultural sector in Nepal including those on new and modern techniques associated with agriculture. However, such research outcomes have not yet reached to the rural farmers and village level as it was supposed to be. Therefore, for proper research dissemination, there should be the huge utilization of ICTs, local media and the existing extension centers that can play a vital role to promote awareness at the village level. Cost of seeds and fertilizer is another important concern of the farmers as they mentioned that high yielding varietiy (HYV) seeds and fertilizer are very costly restricting poor rice farmers to use local seeds available to them, which are less productive in nature (Devkota et al., 2017). Farmers, therefore, demand subsidy on such seeds and fertilizer inputs. The demand for the local fertilizer (also called compost fertilizer) among the rice farmers in Hilly area is higher. As such manure is more fruitful and keeps their land safe from contamination, serious attention and possible action must be taken from concerned authority to promote the organic product. The use of fertilizer is random and farmers are using more fertilizer on their land on the belief that additional fertilizer can increase productivity. The consequences of such malpractices are already being observed in many places. The yield is still less even after the use of HYV seeds and chemical fertilizer. Therefore, a manual for fertilizer use and appropriate training to the farmers is of prime importance with regard to application of proper fertilizer dose. ICTs can play a vital role to disseminate such information to the farmers timely (Devkota & Phuyal, 2018)

Training & Information at Local Level: Rural rice farmers still adopt traditional methods of farm practice due to lack of training and other means of information. Therefore, providing training to the rural, poor and marginal farmers is necessary. Farmers argued that if trainings are available, only influential and educated farmers get priority. Therefore, rural and poor farmers demand such training at the local level and want the inclusion of all the farmers regardless of their caste, class, education and geography. They believe that such training will help them practice better farming. Farmers are also unaware of the possible damage due to climate change. Even though they are aware of such climatic change, they do not know how to cope with such changes. Therefore, they demand proper training and information systems to help them act timely. Providing such training and information could help farmers protect themselves from possible unforeseen loss and make improvement in their livelihoods.

Soil Test and JTA Services: Soil test is another important demand of the farmers. Most of the farmers mentioned that they do not know the status of their soil. As a result, they are not sure about which varieties of crops suitable for their land. A proper soil measurement and test system at local level could help them towards modern and climate-smart farm practices. The demand for JTA in the village is very high among the farmers, since the latter can act as a proper counselor and technical advisor at the village level. Farmers opined that most of the time, in the absence of JTA, they practice conventional methods which harms their production and are not even able to return the cost that incurred in their field. Therefore, it is recommended that government should mobilize JTAs effectively in every village and make them available every time as per the need of the farmers. However, the number of JTAs is very less and the facilities received by them are not sufficient for the long hours they work. Furthermore, they have fear of snake bites and attacks from other animals particularly at night and rainy seasons. Therefore, the government should increase the vacancies and provide basic facilities like umbrellas, boots, torch lights, medical toolkits and other basic facilities to existing JTAs. Providing such basic facilities could help to increase the efficiency and willingness to work as JTAs.

Labour and Land: Rice farmers, even in the rural area, argued that labour shortage is another major challenge of today's agricultural practice. They argued, due to labour shortage the cost of labour has soared up that is hindering them to cultivate their land and force them to leave their agricultural land fallow (Phuyal et al., 2017). Therefore, provision of incentives and facilities to farmers may help labour force to engage in farming activities. Farmers further argued that these days, poor and landless farmers are not willing to take others' land on lease and rent as a result many lands remains fallow. Such unwillingness emerges out of the high cost of agricultural inputs, shortage of labour and insecure production. In this context, the government can provide some attractive packages or offers to farmers such as free crop insurance, subsidized seeds and creating an atmosphere of purchasing farmers' product without any complex procedures.

Bullock and Tractor: Other agricultural inputs like bullock are costly to the farmers so farmers are demanding for suitable tractors – i.e., power tillers in Hilly areas and tractors in Terai region for plowing their land. Farmers opined that use of tractor helps them to reduce cost, time and number of labour heads. Therefore, proper investment on the tractor is beneficial to promote better and timely farming and it can also compensate labour shortage to some extent. Additionally, providing a subsidy for petroleum product to use such tractors encourages and motivates farmers to cultivate their land in the better way.

Bank and Financial Facilities: Farmers argued that there is no provision and practices of proper bank loan for the rural and marginal farmers. Similarly, even well-off farmers are having many difficulties to receive an agricultural loan. Therefore, there should be a clear policy to disburse loan to the rice farmers. Timely with less procedural complexities, transparent and suitable interest rate loan available to all the needy farmers, regardless of their location and status, encourage and motivate them to do better farming. One possible and most effective way to provide loan to rural farmers is through cooperative and microfinance as they are the most effective means to provide services to the rural farmers at the community level. Though cooperative and microfinance have provisions to invest a certain amount in the agriculture sector, such provisions are not in practice in its full-fledged state. So, there is an urgent need of formulating provisions, including the legal framework for cooperatives and bank to allocate certain percentage of loan for the betterment of agriculture activities.

Insurance Facilities: Seasonal rice crop insurance is another important aspect for better cultivation. Most of the farmers show their concern about agriculture insurance. Farmers' who have already insured their crop are disappointed in the unclear insurance pattern and demand government to take care of such insurance. Therefore, the government should provide crop insurance schemes to the rice farmers through extension centers existing in the village and ward levels. This could also increase trust and credibility of the farmers.

Pest and Disease Control: Farmers complained about the increase in new diseases and pests in their rice field in recent years in comparison to the earlier years particularly with HYV seeds. Therefore, there should be proper diagnosis and treatment of such pest management from concerned research institution(s) and agricultural centers to protect agriculture farm and increase the productivity.

Price of the Commodity and Market facilities: Price of rice is a major concern to the farmers. They mentioned that during the time of harvesting, the price of rice decreases to nominal, whereas during cultivation period, its price becomes more than double. This situation leaves poor and marginal rice farmers worried and de-motivated towards mass production as they are not getting the proper price of their product. In this respect, government should determine stable and reasonable price of rice. Connectivity of the rural road network to nearby market centers, elimination of price cartel developed by local sellers, formation of established government market centers in different places and imposition of uniform and scientific price system in a district or a region help farmers to get better price of the product.

Ownership of Land: Farmers who cultivate others' land are having a problem due to the land ownership problem. They opined for legal provision to ensure the security of land holding for cultivation by marginal farmers who cultivate others' land.

Storage Facilities: Storage house is another important requirement for the farmers to keep their product secured for the long term. Poor and marginal rice farmers, especially from the Terai region are having a problem due to the lack of storage house. This situation forces farmers to sell their product at lower cost. Therefore, there should be at least a storage house, even in the rural area, that helps farmers to store their product till the soaring of the price, provided that such storage house should be maintained either by the private sector or by community level or by government agencies for better functioning.

Recognition of Real Farmer: Many farmers argued that there is no recognition of actual farmers and want the real farmers to be encouraged and recognized. For this, they view, there should be the best farmers' award at the district or even local level, as per farmers' performance, which motivates and encourages agricultural farmers to work and devote in farming. Although, the news regarding the provision of pension system for actual and long-term farmers highly encouraged and motivated the farmers initially, such agenda remained a political slogan and people are not sure about its implementation. The government should form an expert team to make some criteria for the identification of the actual farmers. Successful implementation of the pension or incentive systems not only enhances the productive capacity of the farmers, but also attracts many new farmers to enter into agriculture system. It could be a rational strategy to reduce food insecurity of the nation. It is recommended to provide real farmers' card to the year-round farmers and provide facilities based on the availability of that card. The government also can categorize farmers on the basis of primary, secondary and tertiary and provide facility accordingly. For that agricultural extension center can be utilized.

Health Facilities to the Farmers and their Families: Many farmers opined when their family members suffer from any disease, they face various problems mainly due to economic conditions. Other problems include inaccessible roads and lack of bridges to get access to hospitals. It is therefore recommended that farmers and their family should be provided with minimum health facilities along with other infrastructural facilities such as accessible roads.

Utilization of ICTs: Another important issue is how to disseminate available information to the rural farmers. It is observed that most of the farmers possess ICTs – T.V., Radio and Mobile phone and almost every district has installed at least a local FM station (Devkota & Phuyal, 2018). Such FM stations can be utilized for timely information dissemination to the grass root level, like information related to the distribution of local seeds, fertilizer and other incentives to the farmers. It is also possible by broadcasting agricultural programs daily via local and national channels. More importantly, it could also help farmers to cope with climate change and its anomalies.

Agricultural Internship for Graduate Students: To encourage people towards the agricultural sector, agricultural institutions and universities can introduce an internship program to their undergraduate and graduate students. Such programs could be beneficial to farmers as well as the latter could get highly capable and enthusiastic manpower from and the farmers could learn many new tricks, techniques and receive proper information. We believe that it can be very cost-effective and productive step to develop the agricultural sector of short, medium and long-term nature. It also helps to collect reliable information via their theses (or project reports) of the diverse area, which government further can utilize for policy formulation and implication.

Agriculture as a Major Curriculum at the School Level: Another long-term impact can be generated by introducing agricultural studies curriculum in school level. Being an agrarian country, agricultural studies must be introduced as a major subject in school level curriculum. Such curriculum will widen the importance of agriculture to the coming generation; reduce the labour shortage in agriculture and help to mitigate food insecurity.

Conclusion

This study revealed that farmers' adaptation strategies differ with the adaptation options and the knowledge they perceive regarding such adaptation options. The adaptation options are very costly, and the adaptive capacity of the farmers is not satisfactory. Poor farmers are more vulnerable to changing climate calling for immediate actions to improve their wellbeing. Investment in education, the supply of enough agricultural inputs, providing awareness about the use of chemical fertilizers and other adaptation options can be used as appropriate policy options in order to minimize the effect of climate change simultaneously resulting in higher agricultural yield on rural farmlands in Nepal.

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An Assessment of NTFPs Contribution to the Livelihoods of Rural People: A Case Study from Kalika Community Forest of Surkhet District, Nepal

Arati Budhathoki[1], Bikram Manandhar [2]*

[1] Kathmandu Forestry College, Kathmandu
[2]Tribhuwan University, Institute of Forestry, Hetauda Campus

*Corresponding author: bmanandhar@iofhc.edu.np

Abstract

Non Timber Forest Products (NTFPs) are all forest extracts excluding timber. This study explores the status of NTFPs and their contribution towards the livelihoods of Kalika Community Forestry User Group (CFUG) of Surkhet District, Nepal. Primary data were collected through household questionnaire survey, focus group discussions, key informant interviews, direct observation, preference ranking and resource inventory. Matrix ranking and Pair Wise ranking was conducted to identify the most preferred NTFPs. The study identified *Zanthoxylum armatum* (Timur), *Swertia Chirayita* (Chiraito), and *Berberis aristata* (Chutro) as the three most preferred NTFPs and have higher financial contribution, i.e., 60%, 20% and 15% respectively, to the household due to high market demand and price. The financial contribution of NTFPs to the livelihood of CFUG is only 15% compared to agriculture, livestock, etc. Regular monitoring of NTFPs in the study area is recommended in order to uplift the livelihoods of users and status of the NTFPs.

Keywords: Non timber forest products, Community forest user groups, Livelihood, Timur, Chiraito, Chutro.

Introduction

Non-timber forest products (NTFPs) are all goods of biological origin derived from forests or any other land under similar use excluding timber of all forms. Harvesting of NTFPs has had a long history in the human civilization (Delgado et al., 2016). NTFPs are the most important provisioning services people obtain from forest ecosystems (MEA, 2005). Over the last two decades, the importance of NTFPs has been increasingly recognized as a key component of health care, biodiversity conservation and people's livelihood. The importance of NTFPs in rural livelihoods and forest conservation is well recognized. NTFPs provide income generating opportunities to millions of people around the world (Rasul et al., 2008; Steele et al., 2015), and these also serve as a major source of supplementary food, medicines, fiber, and construction materials (Shackleton & Shackleton, 2004). In developing countries, NTFPs contribute 20–25 % of income to rural people (Vedeld et al., 2007). However, the economic potential of NTFPs is highly contextual and depends upon a combined set of socio-economic, cultural, ecological and geo-political conditions (Uprety et al., 2016).

Nepal harbours only 3.2% of the world's total flora i.e. 11971 species (GoN, 2014) but it's diverse topographic and climatic variations ranging from tropical to alpine tundra of high Himalaya offer a variety of high value NTFPs throughout the country. The plant species found in Nepal have different medicinal values. The utilization and development of NTFPs is identified as one of the most important feasible solutions for sustainable management of forests and uplifting of local economy (Rijsoort, 2000; Wiersum et al., 2005). People near to forests and associated frequency of forest visits have direct influence on livelihood dependency on NTFPs. Thus, the higher the custody of these variables the higher will be the collection and consumption and sale of NTFPs. To reduce the degradation and depletion rates of NTFPs, there is a need for quantification of density, frequency and abundance of species for the sustainable management of the resources.

Surkhet district in west Nepal with elevational range of 198 masl to 2347 masl is rich in natural resources. Forest coverage of Surkhet is about 71.4% followed by agriculture and settlement (26.4%). The district is rich in natural resources and different types of medicinal value possessing NTFPs can be found such as 'Sal', 'Kafal', 'Katus', 'Laligurans', 'Timur', 'Sughandhawal', 'Chuttro', 'Uttis', 'Bajh', 'Kaulo; etc. Community Forest User Groups (CFUGs) depend upon NTFPs to support everyday livelihood of people as supplementary foods during food scarcity periods and to generate additional household income during off-farm seasons. Despite this, very little research on NTFPs has been carried out in the district.

Hence this study focuses on the status of NTFPs and their contribution in the livelihood of Kalika CFUGs in west Nepal.

Materials and Methods

Study Area

This study was conducted in Kalika Community Forest of Surkhet. The forest lies in Birendranagar Municipality- 15 with a total population of 303 (154 male and 149 female).The community forest is a natural type of forest covering an area of 140.60 ha. It was handed over to the local community in 2003 (Figure 1).

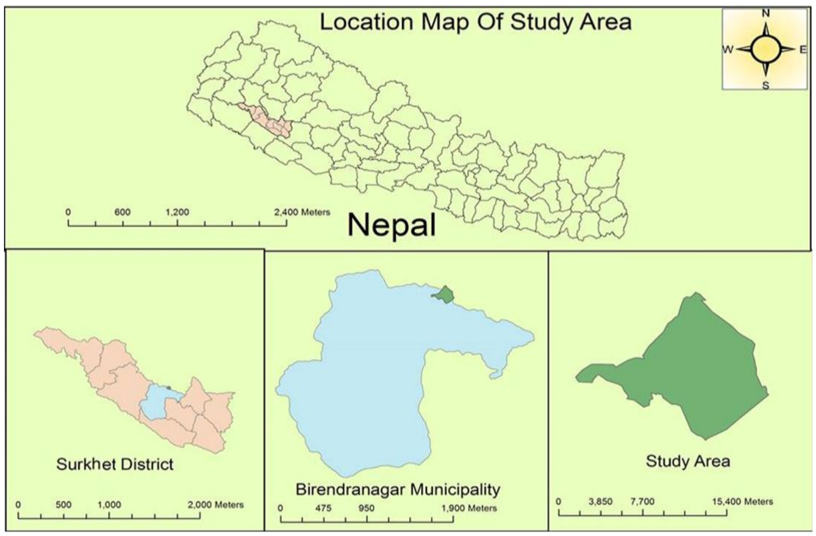


Figure 1 *Map of the study area (Source: Operational Plan of CFUG*

Primary data were collected through Households(HHs) Questionnaire Survey, Focus Group Discussions (FGDs), Key Informant Interviews (KII), Participatory resource mapping, Direct Observation, and NTFPs Inventory; while secondary data were collected from journals, District Forest Office, the operational plan of the CF, constitutions and reports of CF and other published and unpublished sources, websites, etc.

Primary Data collection

Household Questionnaire Survey:

HHs survey was conducted with HHs involved in NTFPs collection, use and trade using snowball sampling method through a semi-structured questionnaire. Out of 67 households 35 (52% of total

Households) were surveyed. The characteristics of the respondents were categorized on the basis of gender composition, age structure, ethnic composition, and education level which were discussed below.

Focus group discussion

FGD was carried out with selected CFUG members, NTFPs collectors and traders, etc. FGD was conducted with users group during their annual general assembly. The listing of the NTFPs, their uses, habit, existing income generating activities based on NTFPs and preference ranking of prioritized NTFPs with the set criteria for income generating activities was done during the discussion.

Key Informant Interviews (KII)

This included interviews with NTFPs harvesters and traders, technician and VDC representative. The information about NTFPs resources and their existing condition, market price and pattern was collected.

Participatory resource mapping

The participatory resource map showing forests was delineated roughly with the help of local informants to find out the effective area of the major NTFPs species.

NTFPs Inventory

Inventory of only three highly preferred NTFPs were done with the sampling intensity 0.05%. The plot size was taken as 5m*5m for shrubs and herbs using a random sampling method following the NTFPs Inventory Guideline (2069 BS).

Data Analysis

The qualitative socioeconomic data was analyzed and interpreted in the form of text and tabular presentation while quantitative data was analyzed in simple diagrams such as pie charts and bar diagrams. The quantitative biophysical data was analyzed following using following formula (DoF, 2012; NTFPs Inventory Guideline- 2069):

$$Density\ of\ `A'\ Species\ = \frac{Total\ number\ of\ plants\ of\ `A'\ species}{Total\ number\ of\ plots\ taken * \ area\ of\ sample\ plot} * 10000....Eqn1$$

$$Relative\ Density\ of\ "A"\ species = \frac{No.\ of\ individuals\ of\ species\ A\ in\ all\ plots}{Total\ no.\ of\ individuals\ of\ all\ species} * 100.......Eqn2$$

$$Frequency\ of\ "A"\ species = \frac{No.\ of\ plots\ where\ species\ "A"\ occurs}{Total\ no.\ of\ sample\ plots\ taken} * 100........Eqn3$$

$$Relative\ Frequency\ of\ \text{"}A\text{"}\ species = \frac{Frequency\ of\ one\ species}{Sum\ of\ all\ frequency} * 100......Eqn4$$

$$Abundance\ of\ \text{‘}A\text{’}\ Species = \frac{Total\ number\ of\ plants\ of\ \text{‘}A\text{’}\ species}{Total\ number\ of\ plots\ in\ which\ spp.\ Found * size\ of\ plot} * 10000..Eqn5$$

$$Relative\ Abundance\ of\ \text{‘}A\text{’}\ species = \frac{Abundance\ of\ individual\ species}{Total\ Abundance\ of\ all\ species} * 100.....Eqn6$$

Analysis of Contribution to Livelihood

Contribution of NTFPs to local livelihood was analyzed based on the Sustainable Livelihood Framework (DFID, 1999) in which qualitative and quantitative assessment of the indicators of only three out of five livelihood- assets were carried out in this study.

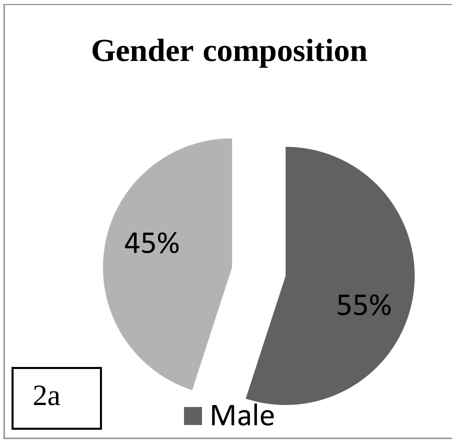
Preference Ranking

Preference ranking was used to determine the most preferred NTFPs from the study area. Matrix Preference was carried out where Matrix Ranking was done by assigning value against characteristics of potential NTFPs.

Results and Discussion

Socio-economic characteristics of respondents

The gender and age structure of the respondents are shown in Figure 2a and 2b. As compared between male and female participation, female participation was about 10% lower than male participation (Figure 2). Respondent's age was categorized into two groups i.e., youth (15 to 40 years) and adult (41 to 65 years) with youths representing the major group. Youth were highly engaged in the collection and selling of the NTFPs as compared to adult ones. Lower women participation in collection, trade and various programs regarding NTFPs is attributed to women’s involvement in household chores. According to the women respondents, NTFPs play an important role in their livelihood because it provides food and money for them. They further highlighted that this situation can be improved by promoting women empowerment programs such as training and visits regarding NTFPs harvesting and marketing and even domestication of some of the important NTFPs which are mainly used for household purpose such as ‘Timur’, ‘chiraito’ etc. in barren farm lands as well as in community lands. Majority of them were Chettris, followed by Brahmin and Thakuri (Figure 3a) The education of respondent was categorized into four groups (Figure 3b) namely illiterate, primary education (class 1 to 7), secondary education (class 8 to 10) and higher education (above S.L.C). Among the respondents, 61.02% were literate as shown in Figure 5. They highlighted that it is very important to introduce NTFPs development, cultivation and management practice in a demonstrate way to have effective diffusion in study area.



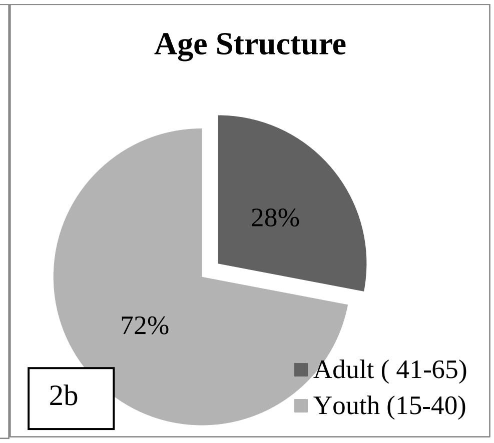
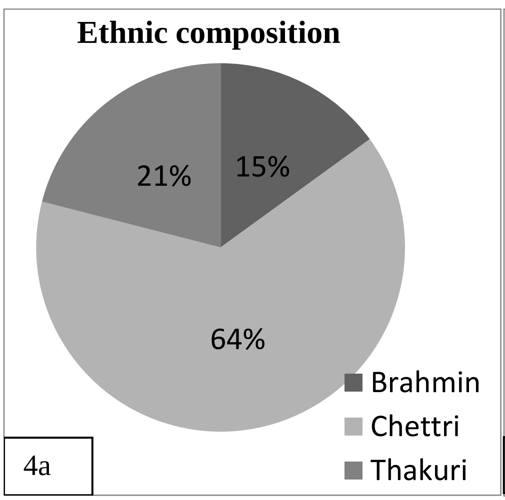


Figure 2a *Gender status of the respondents* **Figure 2b** *Age structure of respondents*



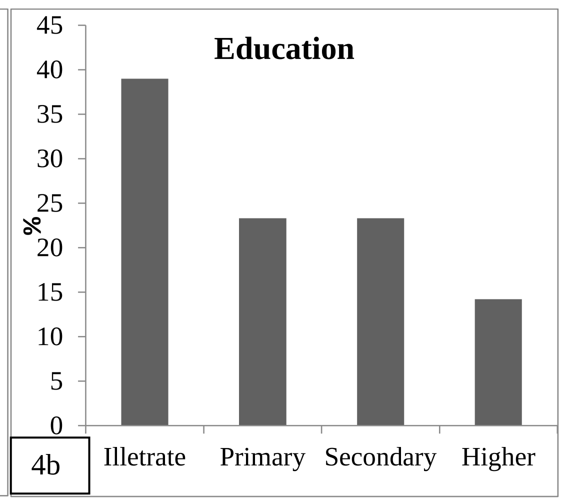


Figure 4a *Ethnic composition of the respondents* **Figure 4b** *Education level of respondent*

NTFPs in Kalika CF

List of available NTFPs obtained through resource inventory survey, household questionnaire survey, FGD, KII is tabulated as below. Altogether33 species of NTFPs were recorded.

Table 1 *List of NTFPs and their common uses*

S.N.	Local name	Scientific name	Elevation (m)	Habit	Common uses
1	Amala	*Phyllanth usemblica*		Tree	Fruit is edible and eaten as pickle or directly. Root is used for dye, softening the skin.
2	Ainselu	*Rubus ellipticus*	1700-2600	Shrub	Bud is used in the treatment of gastric and diabetes; root is used in pneumonia and all parts are used in diarrhea; root and stem are used to prepare gun powder. Fruit is used as food.
3	Allo	*Girardinia diversifolia*	1700-3000	Herb	An insecticide; root juice is used in snake bite. Fiber extracted from bark of stem is used to make threads, ropes and strings. Stem bark is used to make rough clothes.
4	Bisphej	*Polypodioum vulgare*		Orchid	Whole part of it is used. Used to relocate fractured and injured bone.
5	Banderkera Orchid			Orchid	Fruit is used to make energy drinks.
6	Chutro	*Berberis aristata*	1800-3500	Shrub	Fruit is edible and are used to cure diarrhea. Used in treatment of jaundice, enlargement of spleen. Root barks used to cure malarian fever.
7	Chiuri	*Aesandra butyracea*	200-1500	Tree	Fruit, leaf, seed and bark of the plant is used for making soap, oil and ghee. Leaf is also used for making ‘duna’ and' tapari’.
8	Chiraito	*Swertia chirayita*	1200-3000	Herb	Whole plant is used for curing fever, stomachache, diarrhea and cancer. Color is also extracted from plant
9	Chhatechayau			Fungi	

S.N.	Local name	Scientific name	Elevation (m)	Habit	Common uses
10	Geethi	*Dioscores bulbifera*			
11	Gucchichyau	*Morchellaconia*		Fungi	Used as vegetables.
12	Indreni	Trichosanthes Wallichiana.	1200-2300	Climber	Roots and fruit: Extract used to treat gonorrhea, asthma; tender shoots used for vegetable.
13	Jhyau	*Parmelia nepalensis*		Lichen	Useful in diseases of blood and heart, biliousness, leprosy, bleeding piles. Oil is also extracted from it.
14	Kurilo	*Asparagus racemosus*	300-2200	Herb	Root used in gastric and fever. Root and fruits have veterinary values. Fruits also sometimes used as a substitute of soap; young shoot used as vegetable
15	Kaulo	*Persea odoratissima*	1000-2000	Tree	Bark is used to make incense and also used to make soap.
16	Kafal	*Myrica esculenta*	1200-2300	Tree	Used in dysentery and headache. Fruit is edible.
17	Kalikafal			Tree	Used in fractured and dislocated bone.
18	Kachur	*Curcuma zedoaria*		Herb	Used in fractured and dislocated bones; swelling
19	Lokta	*Daphne papyracea*	1500-2400	Shrub	Bark of the stem is used for making ropes and strings. Roots are used for intestinal disorder and parasites. Fibers from plants are used for Nepali paper production.
20	Liligurans	*Rhododendron arboretum*	1400-3600	Tree	Bark is used in the preparation of a kind of snuff. Tender leaves are applied to the forehead to relieve headache, fish poison. Flowers are chewed in case of fish bone stuck in the throat.
21	Majitho	*Rubiamanjith*	1200-2100	Climber	Roots are taken as tonic, alternative and an astringent. Root used to cure cough, uterine and vaginal diseases, eye, and ear problem, jaundice and piles. Leaves are used to increase appetite and cure biliousness
22	Okhar	*Juglans regia*	1000-2000	Tree	Warm decoction of stem bark is drunk for its anthelmintic property. Walnut oil is also used for coloring, printing inks, varnishing and making soap. Fruit used as an alternative in rheumatism.
23	Pakhenbedh	*Bergenia ciliata*	900-3600	Herb	Rhizomes are helpful in dissolving kidney stone. Juice from the rhizome is taken to get relief from fever. Rhizome paste and powder are taken to get rid of round worms.

S.N.	Local name	Scientific name	Elevation (m)	Habit	Common uses
24	Pilajadi			Herb	Used to cure fever and headache.
25	Rittha	*Sapindus mukorossi*	1000-1200	Tree	Fruit, bark and seed has a saponins element which with medicinal values and used in cough an anemia.
26	Sughandawal	*Valeriana officinalis*		Herb	The dried rhizomes are used in perfumes, incense and to a lesser extent as medicine. It is prescribed as remedy for hysteria, hypochondriasis, nervous unrest and emotional troubles.
27	Setakchini	Smilax spp.		Herb	Used to make juice
28	Samalata (Butterfly orchid)	*Encyclia tampensis*		Orchid	
29	Sikakai	*Acacia rugata*		Shrub	
30	Sisno	*Urtica dioica*	1000-4000	Shrub	Young leaf and bud are eaten as vegetable and bark fiber is used for making cloth and rope.
31	Timur	*Zanthoxylum armatum*	1100-2500	Shrub	Seeds are used in Spices and pickle. Bark is pungent and used to clean teeth. The fruit and seeds are used as an aromatic tonic in fever and dyspepsia.
32	Tejpat	*Cinnamomum tammela*	450-2000	Tree	Leaf and bark have a medicinal value for the treatment of diarrhea, vomiting and stomach ache.
33	Titepati	*Artemisia indica*	1500-3800	Shrub	The oil from plant has been found to be good larvicide like kerosene and a feeble insecticide. The freshly extracted essential oil from the air-dried leaves shows anti-bacterial and antifungal activities.

Preferred NTFPs

Though the study area had a number of NTFPs, not all the NTFPs were found to hold an equal potential for regular harvesting and income generation. Such species were eliminated from potentiality examination owing to their restricted use, low or no monetary value and/or minimum ecological availability after their identification from KII and FGD. Only ten high market potential and high availability NTFPs were examined using the matrix ranking with the given criteria and pair-wise ranking. The score given were 3 for highest, 2 for moderate and 1 for the lowest. These values were summed separately for each individual species and compared with that of each other's. The results above show that Timur has got the highest score and is placed in first order followed by 'Chiraito' and 'Chutro' (Table 2).

Status of Most Preferred NTFPs

Based on the NTFPs Inventory guideline, density, relative density, frequency, relative frequency of three most preferred NTFPs have been calculated (Tables 2, 3, 4 and5). The results show shows that Chiraito have higher density and relative density among the other preferred NTFPs (Table 4). Chutro had the highest abundance and relative abundance than other plants (Table 5).

Matrix Ranking of Ten Potential NTFPs

The matrix ranking provided the results presented in the table below:

Table 2 *Matrix ranking of Ten potential NTFPs*

CRITERIA	SPECIES									
	Timur	Chutro	Kaulo	Sughandawal	Pakhenved	Chiraito	Geethi	Amala	Kafal	Lokta
1. Economy/Marketing										
i. Market demand	3	2	3	3	1	3	1	1	1	1
ii. Competition	3	2	2	2	1	2	1	1	1	1
iii. Profitability	3	3	3	3	1	2	1	1	2	1
2. Ecology/Environment										
i. Availability (in time)	1	3	2	2	3	1	3	1	1	2
ii. Availability (in Forest)	2	3	1	1	3	3	2	1	2	3
iii. Amount of time needed to find & harvest	2	1	2	2	2	2	2	2	2	1
iv. Impact of harvesting in survival of species	3	3	1	2	2	3	2	1	1	1
v. Regenerative potential	2	3	1	1	3	3	2	2	2	3
3. Social/Institutional										
i. Contribution to income	3	2	2	2	2	3	2	2	2	1
ii. Potential for income generation/ employment	3	3	2	2	1	2	2	2	3	1
iii. Equal benefit distribution to the community	2	2	2	2	2	2	2	2	2	1
iv. Women's participation in business &use	3	1	1	1	2	3	1	2	3	2
4. Science/Technology										
i. Processing technology	3	2	2	2	2	3	2	2	1	3
ii. Expertise needed for using processing technology	3	2	3	1	3	3	2	2	2	2
Total	36	32	27	26	28	35	25	22	24	23
Ranking	1st	3rd	5th	6th	4th	2nd	7th	10th	8th	9th

Table 3 *Density and Relative Density Table*

S.N.	Species	Total no. of Plants	Total no. of plots taken	Area of the sample plot (m2)	Density (no./ha)	Relative Density (%)
1.	Timur	20	28	25	285.71	20.41%
2	Chiraito	40	28	25	571.43	40.82%
3	Chutro	38	28	25	542.86	38.77%

Table 4 *Frequency and Relative Frequency*

S.N.	Species	Total no. of sample plot	No. of sample plots in which species occurred	Frequency (%)	Relative Frequency (%)
1.	Timur	28	18	64.28%	29.99%
2	Chiraito	28	22	78.57%	36.66%
3	Chutro	28	20	71.42%	33.35%

Table 5 *Abundance and Relative Abundance*

S.N.	Species	Total no. of plants	No. of sample plots in which species occurred	Area of the sample plot (m2)	Abundance (no/ha)	Relative Abundance (%)
1.	Timur	20	18	25	444.44	23%
2	Chiraito	40	22	25	727.27	37.65%
3	Chutro	38	20	25	760	39.35%

Contribution to the Livelihood

Contribution to the financial, social, physical assets of Livelihood

NTFPs accounts for 15%, which acts as supplementary support during the deficient months as income from livestock. Agricultural production was not sufficient to fulfill users' needs (Figure. 5). Male population have higher participation in planting NTFPs than female population as female users were busy with in their household chores only (Figure.6). Decisions regarding NTFPs, forest rules such as fee, product distribution are mostly decided in the general assembly. Committee members set the price according to the NTFPs through the general assembly but they couldn't get the satisfied price from the local traders. Consultation with CFUG members and executive member study found that little financial contributions have been made by CFUGs for infrastructural construction listed below. Incomes generated from NTFPs revenue collection were used for construction of infrastructures such as school, mini health post, drinking water pool and foot trails etc.

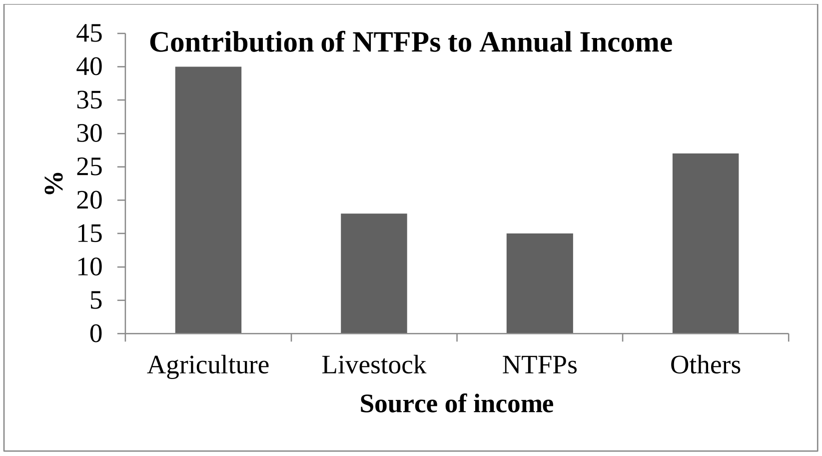


Figure 5 *Contribution of NTFPs in the Household Income*

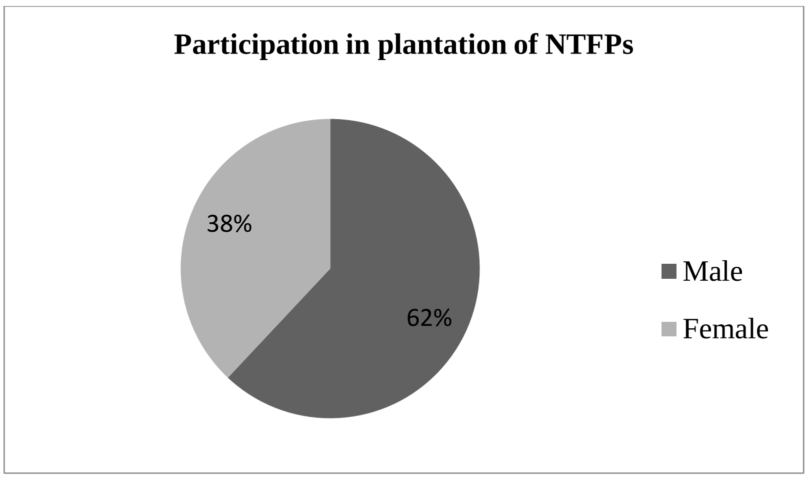


Figure 6 *Participation of people in plantation of NTFPs*

NTFPs TREND OF PAST FIVE YEARS IN KALIKA CF

Harvesting and price trends of NTFPs

Harvesting trend of NTFPs from private lands shows that 'Timur', 'Chutro', and others ('Pakhenved',' Kaulo', 'Sughandawal' etc.) were harvested. 'Timur' harvest was highest in 2013 (1204 Kg), lowest in 2016 (671 Kg) but increased to 1200 Kg in 2017. In contrast, 'Chutro' was not harvested for four years from 2013 to 2016and only harvested in 2017 with a yield of 4000 Kg. Harvesting trend of NTFPs from CF revealed that 'Chiraito' and 'Chutro' were the common species harvested. Harvested quantity of 'Chiraito' increased from 100 Kg in 2013 to 300 Kg in 2017. 'Chutro' was not harvested for three years from 2013-2015 but 500 Kg of 'Chutro' was collected from Kalika CF in 2016-2017

'Timur' was sold at highest price and its price increased from Rs 100/Kg in 2013 to Rs. 500/Kg in 2017. In contrast, 'Chutro' was sold at the lowest price of only Rs. 12/Kg. 'Timur' had the greatest contribution to the income than other NTFPs. The price of ‘Chiraito’ also increased from Rs.40/Kg in 2013 to Rs. 60/Kg in 2017. ‘Chutro’ from CF was sold at Rs. 18/Kg during 2016-2017.

Conclusion

A total of 33 NTFPs were found in Kalika Community Forest and among them 10 species were selected as potential NTFPs. Among the 10 selected potential NTFPs ‘Timur’ (*Zanthoxylum armatum*) was found to be the most preferred NTFPs followed by ‘Chiraito’ (*Swertia chirayita*) and ‘Chutro’ (*Berberis aristata*) because of their demand and local use; and these species also had higher abundance and density in Kalika CF. NTFPs have contributed only 15% to the overall household income of local people. Harvested quantity of ‘Timur’, ‘Chutro’ and ‘Chiraito’ was higher than other NTFPs because of high market demand and local use. Price of ‘Timur’ was higher those of ‘Chiraito’ and ‘Chutro’ because of the former’s high socio- economic values. This study indicated that as Kalika CF has a huge potential of NTFPs, thus the Operational Plans of CFUGs should be prepared with better emphasis on its economic management. Regular monitoring and promoting cultivation as well as management operations of NTFPs on public and private lands in the study area is recommended in order to uplift the livelihoods of users and status of the NTFPs.

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Physico - Chemical Characterization of Soils in Rara Lake Catchment

Preety Pradhananga[1], Roshan Man Bajracharya[1*], Nani Raut[1], Bishal Sitaula[2], Smriti Gurung[1]

[1]Department of Environmental science and Engineering, Kathmandu University, Nepal
[2]Norwegian University of Life Sciences, Norway

*Corresponding author: rmbaj@ku.edu.np

Abstract

The physico-chemical characteristics of soils under forest and grazing land were studied in Rara Lake catchment of Mugu district. Soil samples were collected from two depths (0-15 cm and 15-30 cm) respectively and soil profiles were studied. Soil physico-chemical parameters, including Soil Organic Carbon (SOC) and micronutrients were determined and analyzed by following the standard methods. This study revealed the bed rocks and parent material found under the soil profile were derived from micaceous and metamorphic rocks; mainly schist, phyllite and quartzite. Land use types significantly affected ($p<0.05$) soil temperature, moisture, pH, Mn and SOC under varying depths. The soil texture in the grazing land and forest land was found to be silt loam indicating similarity in the parent material. Within the lake catchment, the forest soil had higher total carbon stock than grazing land i.e. 200,472 tonnes in forest, 46,723 tonnes in grazing land. The micronutrients in all land use types with depth were above the critical levels indicating that there is no deficiency of these micronutrients in the study area. Our study concluded that soil quality varies under different land uses at varying depths. Very little research has been done in the higher physiographic region of the Himalaya and further work should be done for establishing baseline records. Such information would be of value for proper sustainable use and management of the land and water resources of the high mountain regions of the Himalaya.

Keywords: Soil quality, Land use, Carbon stock, Micronutrients

Introduction

Soil quality is a complex concept which was introduced during the late 1970s and evolved during the 1990s in response to the increased global emphasis on sustainable land use and soil management. It is considered to have three main aspects reflecting physical, chemical and biological soil properties which varies in space and time (Reddy et al., 2012) and is affected by a number of threats driven by a range of man-made and natural processes including climate change, land use practices, soil erosion processes. The growing population is increasing pressure on forests leading to decline in soil fertility and forest productivity (Ives & Messerli, 1989). Every year, an estimated 12 million ha of soil is lost through soil degradation (FAO, 2015). Conversion from forest to other land uses has been shown to result in higher bulk density, lower hydraulic conductivity, and higher erosion (Spaans et al., 1989) thereby, promoting soil degradation. On the other hand, tree plantation or keeping the land under vegetative fallow can help increase the fertility of degraded soils (Phiri et al., 2001). Minimizing soil disturbance leads to soil organic carbon (SOC) accumulation, while high intensity of cultivation causes SOC decline (Bajracharya et al., 1997). Owing to greatly varied geographical, geomorphological, and climatic conditions, Nepal comprises one of the most diverse ecosystems in the world. Reduction in biodiversity and degradation of land and soil are often viewed as major threats (Solbrig, 1991) to mountain ecosystems. Also, mountain soils are susceptible to global changes including climate change, land use changes, deforestation, overgrazing that are affecting the area in an unprecedented way thereby triggering land degradation, desertification, natural calamities such as flood, erosion, landslides.

The anthropogenic activities such as land use conversion, overgrazing, deforestation and farming practices transform soil properties. Mountain soils are vulnerable to these changes and in turn, affect the livelihood of mountain people (Solbrig, 1991). In addition, Himalayan catchments have a serious problem in terms of decline in soil organic carbon (SOC) pool primarily due to deforestation, land use changes, forest degradation, soil erosion and fertility decline (Sitaula et al., 2005). Summing up, anthropogenic activities like land use conversion, overgrazing, deforestation and farming practices transform soil properties. The impacts that have been of primary concern are the effects of land use change on biological diversity, soil degradation and the ability of biological systems to support human needs.

Rara Lake catchment, located in the Rara National Park of the Mugu district in western Nepal, is one of the remote high altitude watersheds of Nepal. The lake and its catchment have a relatively low number of visitors due to its remoteness (Nepal Tourism Statistics, 2016). However, with the recent plans to improve and construct roads in the region with an upcoming plan to build a large-scale hotel (Bom, 2015 pers.comm.) near the lake catchment, there could be a significant rise in the number of tourists visiting the area. The number of domestic tourists has already risen in recent years (Bom, 2015) which in turn could lead to more anthropogenic impacts on the lake catchment affecting its ecosystem services. Grazing is one of the activities practised in the study area. In a study by Franzluebbers et al (2001), it is reported that the intensity of grazing affects soil quality of grazing land. In Lake Rara, studies on some physico-chemical features of the lake, bathymetry (Okino & Satoh, 1986) have been studied. A recent study on the hydrochemistry of Lake Rara with particular focus on the major ions (Gurung et al., 2018) was conducted. However, studies on soil physical and chemical properties have not yet been conducted in the study area. Upon the conversion of natural forest into grazing land; agriculture, hotels are very significant to distinguish early variation in soil quality. Therefore, soil quality assessment is necessary for proper planning and management of the catchment. Our study would provide the baseline data for the future study and also can give an idea of the present status of the catchment for the sustainable conservation and management of the protected area.

Materials and Methods

Study area

The study was conducted in Rara lake catchment within Rara National Park. The Rara National Park is one of the most remote and smallest high-altitude national parks established in 1976 covering an area of 106 Km^2 in Mugu and Jumla districts in west Nepal. Lake Rara is the largest lake of Nepal within the national park situated at the southern part of the Lesser Himalayan of the western side of the country. It is located at 29°32’N and 82°05’E at an altitude of 3000m (Nakamura et al., 2012). The lake has an area of 9.8 Km^2, a maximum water depth of 168m and catchment area of only 30km^2 (Okino & Satoh, 1986). The forest is dominated by several conifer species. The slopes below 3,150 m are predominantly covered by Himalayan Pine (*Pinus wallichiana* A.B. Jacks) (ICIMOD, 2015). The north-facing slopes are covered with Himalayan Fir (*Abies spectabilis*) and Himalayan Birch (*Betula utilis*) forest, Rhododendron scrubs and alpine meadows; while the southern slopes have West Himalayan Spruce (*Picea smithiana*), Himalayan pine and Brown oak (*Quercus semecarpifolia*) forests (Yasuda & Tabata, 1988). The lake and its catchment lie within the temperate subalpine climatic zone. The temperature can drop to -4°C in the winter and rise to 27°C in the summer. The area receives an annual average precipitation of 462 mm (ICIMOD, 2015). Settlement in the catchment area comprises of an army barrack and two hotels.

Soil sampling and analysis

Five transects (S1, S2, S3, S4 and S5) were selected in two land uses (three from grazing land and two from forest) and the four replicates were sampled based on increment on the basis elevation in every 20 m contour interval. Both loose samples and core samples were taken from two depths (0-15 cm and 15-30 cm) respectively. Soil profiles for each transect was studied by excavating pits and describing the various horizons and morphological features. Soil physical and chemical parameters were determined by following the standard methods in the laboratory.

Figure 1 *Sampling sites in Rara lake catchment*

All the data regarding soil physico-chemical properties were analyzed using appropriate statistical tools. To test the soil quality parameters of different land use under varying depths, one way analysis of variance (ANOVA) followed by Tukey HSD was performed by using Sigma Plot 12.3. The map of current land use of Rara lake catchment was prepared using GIS software.

Results and Discussion

Table 1 shows the different physico-chemical properties of the soil. The soil profile descriptions of the sites studied were pine forest, grazing land, shrubs with few settlements which comprised the major land uses in the study area. The bed rocks and parent material found under the soil profile were derived from micaceous and metamorphic rocks; mainly schist, phyllite and quartzite. The United States Department of Agriculture (USDA) taxonomic order of soil was noted to be Inceptisol. The temperature was found to be significantly different under grazing land and forest at 0-15 cm depth ($p<0.05$) but not at 15-30 cm depth. The significant difference in temperature at 0-15 cm could be because the grazing land is exposed to sunlight and has the lowest soil moisture content due to evaporation of the soil water whereas the high canopy pine forest coverage in the forest blocks the sunlight and maintain highest moisture content. Although, soil bulk density did not show significant difference with respect to land uses at varying depths, bulk density was found to be higher in 15-30 cm depths in both land uses than 0-15 cm depth, indicating the tendency of bulk density to increase with depth (Wang et al., 2014). Soil moisture was found to be significantly higher ($p<0.05$) in forest than in grazing land at 0-15 cm depth. The highest canopy coverage in the forest blocks the sunlight, retaining water and maintaining highest moisture. Hence, the forest soils had higher moisture content. The results are in agreement with a study conducted by Kalu et al (2015). The soil texture of both the land uses was found to be silt loam indicating similarity in parent material. The soil texture analysis showed that, in most of the soils, the proportion of silt fraction was high followed by sand fraction. Considering the effects of land use under varying depths, the highest silt (81%) and sand (31%) were recorded at 0-15 cm depth in grazing land than forest. In contrast, the highest silt (68%) and sand (20%) were recorded at 15-30 cm depth in forest than grazing land. The soil pH ranged from 5.2-7.2 under both land uses under varying depths. The pH of forest was found to be higher than that of the grazing land. As Rara Lake catchment is dominated by pine trees and the soils of pine forest are usually acidic in nature due to decomposition of fallen pine leaves. The lower pH in the grazing lands could be attributed to the removal of basic cations by over grazing. The results are similar to a study carried out by Schumann & Glover (1999). Soil total nitrogen did not show significant variation between different land uses as well as different depths (Table 1) and the differences in total nitrogen was fairly small. However, it was observed that with the increasing depth, the content of nitrogen decreased in both land types. The total nitrogen was higher in both the land uses because large amounts of nitrogen are bound in organic matter.

Table 1 *Soil physical and chemical quality parameters under different land use*

Land use types		**Grazing land**		**Forest**	
Depth (cm)		**0-15**	**15-30**	**0-15**	**15-30**
Physical and chemical parameters of soil analyzed (Mean±SD)	Temp (°C)	15.6±3.1*	13.21±2.6	12.4±3.1*	11.6±1.9
	Bulk density (g/cm3)	0.93±0.17	1.18±0.10	0.97±0.22	1.31±0.25
	Soil moisture (%)	24.74± 9.72*	19.21± 5.75	30.52± 7.91*	19.17± 2.25
	Clay (%)	15.2±3.35	20.5±3.20	14.5±2.98	17.2± 5.6
	Sand (%)	18.05±8.6	18.22±9.2	19.75± 3.7	14.02±3.2
	Silt (%)	66.78±9.26	61.28±8.68	65.75±6.13	68.73±6.21
	pH	6.05± 0.20*	6.53± 0.64*	6.56± 0.63*	6.02± 0.27*
	Total Nitrogen (%)	0.25± 0.07	0.19± 0.07	0.26± 0.05	0.25± 0.09
	Available Phosphorus ($mgkg^{-1}$)	390.5± 137.5	269±97	269± 126	186.5±132
	Available Potassium ($mgkg^{-1}$)	153.64±90.88	100.1±64.17	160.53±72.53	117.29±48.5

Note: *represents significance at ($p<0.05$)

Available phosphorus concentration of soil of grazing land and forest was highly variable (Table 1) though no significant difference in available phosphorus among the land use types at varying depths was observed. All of the sampled soils from every site had very high rating of available P. The reason for high level of P in all the sites could be attributed to large amounts of organic depositions in the catchment area. Available potassium concentration in the protected forest was medium; low in the open grass and grazing lands; and did not vary significantly with respect to land use under varying depths. It indicates that the lower available potassium in the open grass land and grazing land could be probably due to soil degradation and losses by leaching as the open grassland and grazing land were denuded of vegetation cover (Moges et al., 2013).

Soil organic carbon (SOC) content and carbon stock

The SOC content in 0-15 cm depth of grazing land and pine forest were similar (Figure 2). High SOC in the surface layer of grazing land suggests that livestock influence on grassland may be favorable for enhancing carbon storage in topsoil. A similar result was found in the study carried out in Mardi watershed by Shrestha (2002). This may be attributed to the rapid turnover of vegetation and animal excreta. Reeder & Schuman (2002) also noted higher SOC contents in the top 60 cm depth of grazing land than at lower depths. The SOC content in 0-15 cm depth of the pine forest could be attributed to organic input from the litter fall. A decreasing trend in SOC content was observed with increased soil depths under different land uses. As the soil depth increased, steep fall in SOC content was found which is an indication of higher biological activity or anthropogenic disturbances associated with surface soil. The results are in line with other studies that justify the higher concentration values of SOC in 0-15 cm depth (eg. Wang et al., 2004; Alamgir & Amin, 2008).

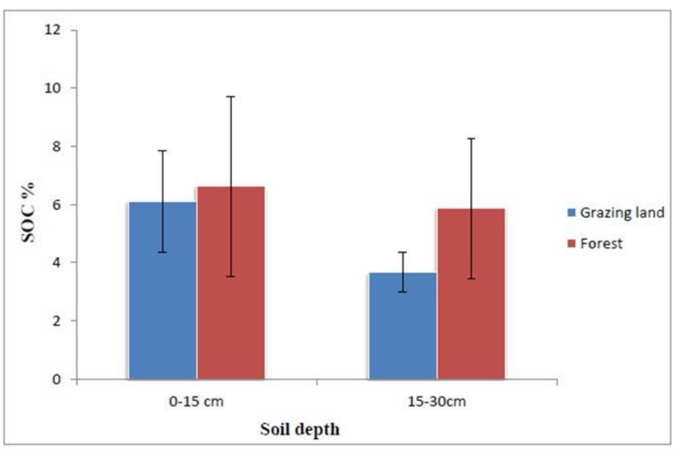

Figure 2 *Soil organic carbon in different soil depths of various land uses*

Table 2 shows the soil organic carbon stock in different soil depths of grazing land and forest. The SOC stock was observed to be higher at 0-15 cm depth in both the land uses. The total SOC stock in the soil profile in the entire watershed was estimated to be 247,194 tonnes with higher values in forests (81%) than in grazing land (18%). This result attributes to both the SOC content and the area covered by the respective land uses. The overall estimated SOC stock at varying depths for the watershed was observed to be 55 % in 0-15 cm and 45 % in 15-30 cm respectively. This is consistent with observed decreasing trend in SOC stock with soil depth for all the land uses. Forest shares the higher SOC stock compared to grazing in each depth. From the above result, we can say that forest shares higher SOC stock than other land uses.

Table 2 *Total Soil Organic Carbon Stock*

Land use system and area covered	Soil depth (cm)	SOC content (%) (mean ± SD)	Mean C stock (tonnes per hectare)	C stock (Tonnes)	SOC content (%) (mean ± SD)	Mean C stock (tonnes per hectare)
Grazing land	0-15	6.09±1.73	84.23	26,448.6	6.09±1.73	84.23
(315 ha)	15-30	3.67±0.68*	64.57	20,274.2	3.67±0.68*	64.57
Forest	0-15	6.62±3.08	86.53	109,717.0	6.62±3.08	86.53
(1268 ha)	15-30	5.86±2.40*	79.05	90,754.2	5.86±2.40*	79.05
Total Carbon Stock (tonnes)						**247,194**

Note * represents significance at ($p<0.05$)

Soil micro- nutrients

Table 3 shows the concentrations of selected soil micro-nutrients of the study area

Table 3 *Concentration of soil micronutrients analyzed*

Land use types		**Grazing land**		**Forest**	
Depth (cm)		**0-15**	**15-30**	**0-15**	**15-30**
Soil Micro-nutrients analyzed (Mean±SD)	Iron (Fe) (ppm)	145.62±103.17	104.91±73.50	96.67±32.59	82.09± 19.34
	Zinc (Zn) (ppm)	1.41 ± 0.97	1.09± 0.85	0.93± 0.90	0.45±0.38
	Manganese(Mn) (ppm)	34.98±22.37**	23.71±21.75**	68.56±24.70**	55.86±24.21**
	Copper (Cu)(ppm)	4.96± 3.43	5.5± 2.66	5.78±4.79	6.12±4.05

Note ** represents significance at ($p<0.05$)

The concentrations of all the micronutrients were higher at the surface (0-15 cm) layer than in the subsoil layer (15-30cm) of all land use types. This can be due to the lower contents of exchangeable bases in the surface layer which is decreased as the result of leaching. According to the ratings of Sims & Johnson (1991), the critical level of soil available (DTPA extractable) Fe, Cu, and Mn are 2.5-4.5, 0.1-2.5, and 1-50 mg/kg, respectively The concentrations of extractable Mn was significantly ($p<0.05$) (Table 3) affected by land use under varying depths while those of Fe, Zn, Cu did not show significant variations at different depths. The concentrations of Zn was the lowest than those of Fe, Mn and Cu and this result is in agreement with the studies on available micro-nutrients in western and eastern Nepal where low concentrations of Zn has been observed (Tripathi, 1999; Andersen, 2000). The deficiency level of Zn in soils is 0.5 - 1.0 mg/kg. The soil concentrations of extractable micronutrients in all land use types with depth were above the critical levels indicating that there is no deficiency of these micronutrients in the study area.

Conclusion

The study showed that land use types influenced soil quality, which was reflected in differences in key soil physical and chemical properties. Within the lake catchment, the forest soil comprised higher total carbon stock than grazing land. The micronutrients in all land use types with depth were above the critical levels indicating that there is no deficiency of these micronutrients in the study area. There was considerable variation in soil quality among land uses which reflects difference in prior to land use practices, age of land use and vegetation cover effects. This study has generated a baseline data on physico-chemical parameters, carbon stock potential and soil micronutrients in Rara Lake catchment. Such data could be used for sustainable management and conservation of these ecologically significant mountain ecosystems.

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Status and Impact Assessment of Invasive Alien Plant Species (IAPS): A Case Study from Galyang Municipality, Syangja Nepal

Ashish Neupane[1] and Keshav Raj Acharya[1]

Tribhuvan University, Institute of Forestry, Hetauda, Nepal

*Corresponding author: acharya_keshav@hotmail.com

Abstract

Invasive alien species are non-native species of plants or animals which spread and dominate new areas and are believed to cause harm to the environment, ecosystems and human well-being. Present study was conducted in Ward 11 of Galyang Municipality in Syangja district of Nepal to document the status of invasive alien plant species (IAPS) and find out the impact of such IAPS to local livelihoods through ecological assessment, household survey and regeneration survey in different land use types. A total of sixteen different IAPS were recorded, but were dominated by *Ageratum houstonianum, Bidens pilosa, Chromolaena odarata*. The present study showed that the diversity of IAPS was inversely proportional to altitude and dense forest stand. The regeneration density of desired species was found to be 5107/ha in invaded areas and 11556/ha in non-invaded areas. Fallow land and rangeland were observed to be most invaded land use types with greatest economic loss in rangeland. In case of forest, the impact on regeneration was high in open canopy and areas having high levels of grazing impact. Local people are responding to increasing invasion through hand removal and use of IAPS biomass as mulch and fuel wood for controlling the invasion in the study area.

Keywords: Ecological assessment, Invasive alien plant species (IAPS), Regeneration density, Land use type, Syangja

Introduction

Invasive Alien Species (IAS) are understood as those non-native species of plant or animal origin, having a tendency to spread and dominate in a new area and are believed to cause harm to the environment, ecosystems and human well-being (Ehrenfeld, 2010). The introduction of alien species to a new location can either be accidental or intentional (Enserink, 1999). Accidental introductions are propagated by travel across countries and continents and import of various items such as timber, food grains, fodder etc. (Shimono & Konuma, 2008). Intentional introductions are for a variety of purposes such as agriculture, horticulture, forestry and ornamental plant cultivation (Cremer, 2003).

Non-native invasive plants species are also known as exotic pest plants or invasion exotics. These exotic pest plants alter the structure and function of an ecosystem resulting in major threats to native plant communities and cause major changes in vegetation at global levels (Vitousek et al., 1996; Mack et al., 2000). Invasive plants usually possess traits that make them effective invaders, such as short life cycles, high growth rate, large number of seeds with good dispersal ability, and good colonizing capacity (Bisht et al., 2016). The globalization of trade, travel, and transport is greatly increasing the diversity and number of IAPS around the world, as well as the rate at which they are moving. At the same time, changes in climate and land use are rendering some habitats more susceptible to biological invasions (Meyerson & Reaser, 2003).

Since 17th century, IAPS have been the agents for nearly 40 percent of different animal extinctions for which cause is known (CBD, 2002). The CBD (1992) has set global priorities, and guidelines on collecting information and on coordinating international actions on invasive alien species. The fifth IUCN World Park Congress in 2003 underlined the need for managing IAPS as an “emerging issue”, which was further emphasized at the sixth World Park Congress in 2014. Nepal, being a signatory of the Convention on Biological Diversity (CBD), is required to prevent the introduction of IAPS and to control or eradicate those IAPS that threaten ecosystems, habitats and species (CBD, 1992).

Large numbers of invasive plant species have been recorded in Nepal due to its diverse altitudinal, climatic and geographic features. There are at least 219 alien species of flowering plants found in Nepal (Tiwari, 2005; Siwakoti, 2012). An assessment of invasive alien plant species (IAPS) was undertaken the first time by IUCN Nepal during 2002/2003 and reported 21 naturalized (i.e. alien species with self-sustaining population) flowering plant species to be invasive in Nepal (Tiwari, 2005). Most of these species are found in the Terai, the Siwalik and the Mid-hills of Nepal. Among the 100 worst invasive plant species of world, 11 plant species are found in Nepal (Lowe et al., 2000). Of these, seven most invasive species are on the list of Asia Pacific Region and these include *Ageratina adenophora*, *Ageratum conyzoides, Chromolaena odorata, Eichhornia crissepes, Lantana camara, Mikania micrantha and Parthenium hysterophorus* (Sankaran et al., 2005). However, limited research has been carried out in Nepal based on the status and impact assessment of invasive alien plant species on different ecosystems. Galyang Municipality also has noticeable invasion by such plant species over the past few years; however, no systematic study has been conducted on the status of such species. Therefore, this study has been proposed to list such IAS, find out the status, and assess the impact on regeneration in Galyang Municipality. The study also intends to evaluate the perception of local people on such invasive species and suggests management options to control these identified species in the study area.

Materials and Methods

Study Area

The study was conducted in Galyang Municipality of Syangja district which is located in central mid-hill region of Nepal covering the area of 122.69 km^2 (Figure 1). Within the municipality, intensive study was conducted in Ward 11, Tulsibhanjyang area. The area was selected for the study due to topographic and elevational variation, high level of out-ward migration, expanse of degraded forest and fallow land and record of invasion from the past. It is located between latitudes 27.93°N, and longitudes 83.63° E. This area includes rivers like the Kaligandaki and the Aadhikhola. The elevation of the area ranges from 385-1085m from sea level and variation in elevation coupled with topography has contributed to occurrence of riverine forest dominated by *Acacia catechu* and tropical mixed deciduous forest dominated by *Shorea robusta*.

Sample Design

The distribution of the IAPS differs by aspect, elevation ranges, and land use type; thus in order to cover all aspects, the research was conducted by stratifying the study site into 200 m elevation range wise strata as shown (Figure 2). Sample locations were situated in each stratum at an interval of about 1km in such a way that those plots could cover all the land use types, elevation ranges and aspect. Altogether, 23 sample plots were selected for data collection.

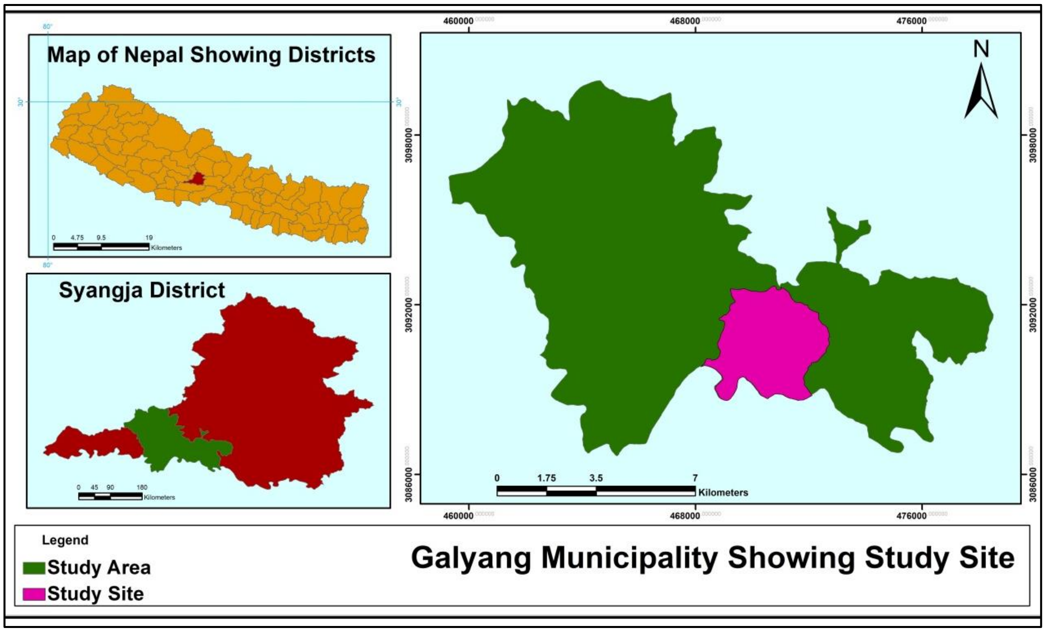

Figure 1 *Map of Nepal showing the study area*

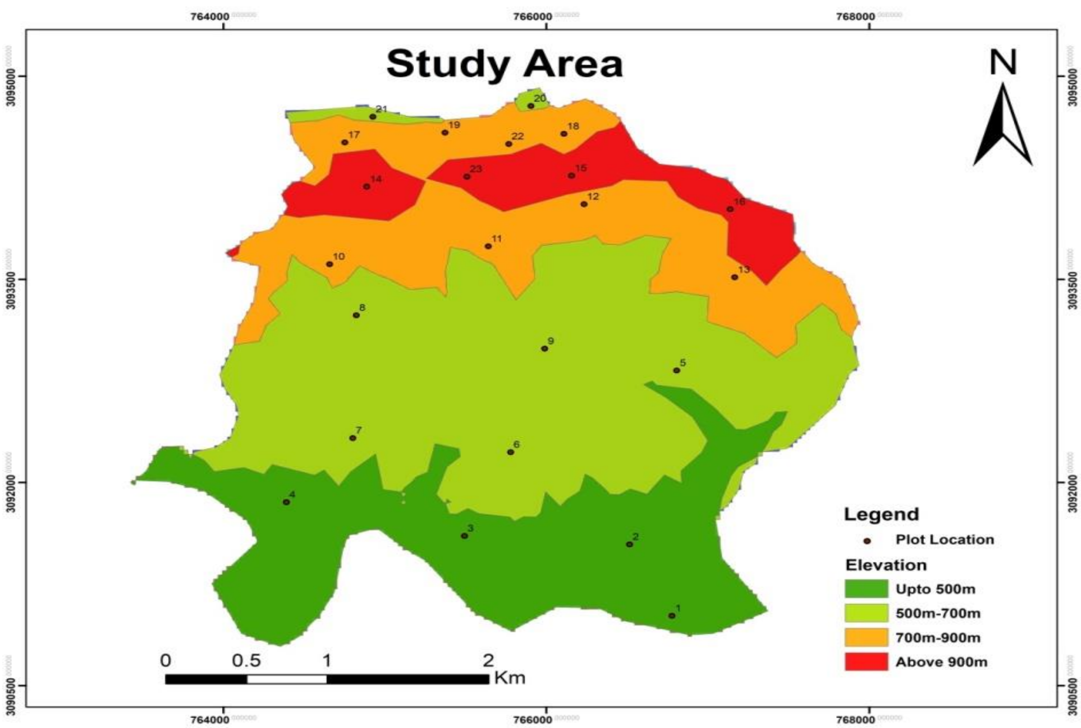

Figure 2 *Study Area showing sampling plots*

Ecological Assessment

In each plot, quadrat dimensions of 10m*10m was used for the inventory of the invasive plant species and within the same location two quadrats of 1m*1m for IAPS with heights of less than 1meter and 2m*2m for species with heights of more than 1 meter were laid (Fig.3). Rapid ecological assessment was carried out in different sites as per different aspects, ecosystems, elevation ranges and location.

Household Survey

In order to find the status, impact of invasive plants on biodiversity, socio-economy of locals, household survey was conducted at different sites of the study site. A total of 45 households were surveyed through questionnaire and information were collected from people belonging to different sex, age group, caste, family status, education status etc.

Regeneration Survey

Regeneration survey was carried out in invasive plant invaded and few non-invaded regions from forest and rangeland ecosystems selected with a circular plot of radius 1.78m.

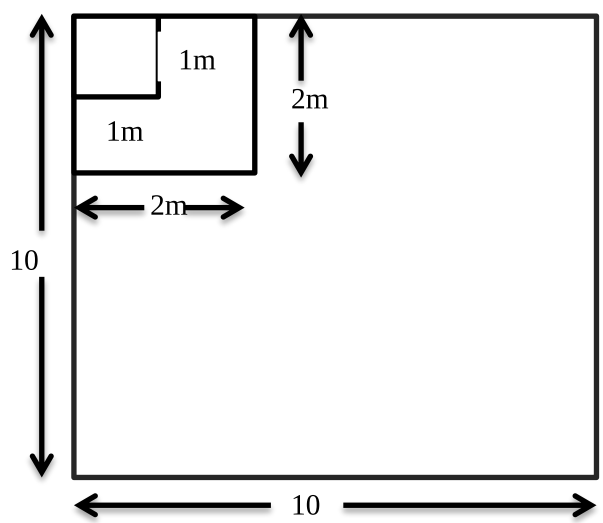

Figure 3 *Quadrat dimension*

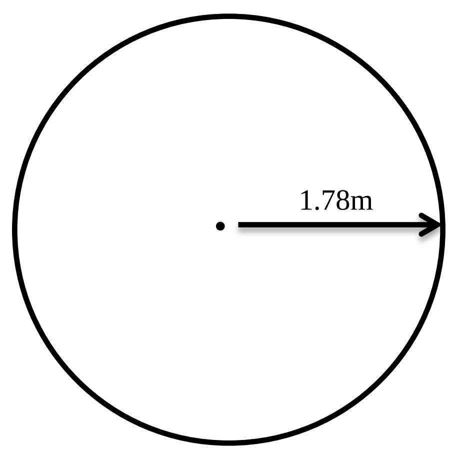

Figure 4 *Circular plot*

Data Analysis

Data was analyzed by both quantitative and qualitative methods. Quantitative methods were used to find the current status of IAPS, regeneration analysis. Analysis of species distribution was carried out through Important Value Index (IVI) method (Cottam & Curtis, 1956) which was introduced for comparison of species dominance. The IVI provides a quantitative basis for the classification of community, which reflects the overall importance of a species; the IVI for a species is calculated as the sum of its relative frequency, relative density and relative abundance, as follows:

IVI= Relative Frequency (%) + Relative Density (%) + Relative Abundance (%)

Results and Discussion

Status of IAPS

A rapid ecological assessment identified sixteen different IAPS from the sites, which are among the 219 IAPS found in Nepal. Listing of those invasive plants as per aspect, elevation, land use types with respect to study site are shown in Table 1.

Table 1 *Listing of IAPS of Study Area*

Invasive Plant Species of Study site with Local Name	Naturalized IAPS found in Study Site	Aspect	Elevation (m)	Land use types
Chromolaena odarata (Seto Banmara)	*Chromolaena odarata*	S	385-1085	F, FL, RL
Ageratina adhenophora (Kalo Banmara)	*Ageratina adhenophora*	N	500-1085	F, Ag, FL, RL
Ageratum houstonianum (Nilo Ganne)	*Ageratum houstonianum*	S,N	385-1085	Ag, FL
Ageratum conyzoides (Gandhe)	*Ageratum conyzoides*	S,N	385-1085	Ag, FL
Parthenium hysterophorus (Pati Jhar)	*Parthenium hysterophorus*	N	500-1085	F, Ag, FL, RL
Bidens pilosa (Kalo Kuro)	*Bidens pilosa*	S, N	385-1085	F, Ag, FL, RL
Rubus elliptius (Aaiselu)		S, N	385-1085	F, RL
Amaranthus spinosus (Kande Lude)	*Amaranthus spinosus*	S	385-1085	AG, FL
Argemone mexicana (Thakal)	*Argemone mexicana*	N	500-1085	FL, RL
Senna tora (Tapre)	*Senna tora*	S	385-700	FL
Senna occidentalis (Panwar)	*Senna occidentalis*	S, N	385-700	FL
Hyptis suaveolens (Ban Tulsi)	*Hyptis suaveolens*	S	385-700	F, FL
Mimosa pudica (Lajjawati)	*Mimosa pudica*	S	385-1085	FL,
Oxalis latifolia (Chari amilo)	*Oxalis latifolia*	S	385-1085	FL
Xanthium stromarium (Bhende Kuro)	*Xanthium stromarium*	S	385-700	FL, RL
Urena lobata (Nalu Kuro)		S	385-700	F, FL, RL

Where, N = Northern Aspect; S = Southern Aspect; F = Forest; Ag = Agriculture land; FL = Fallow Land; RL = Range Land

Among the 100 worst IAPS of world (Lowe et al., 2000), 14 worst species are prevalent in Nepal, and among them, five species were recorded in Tulsibhanjyang, Ward-11 of Galyang Municipality. Similarly, among seven worst invasive alien plant species of Asia Pacific regions (Sankaran et al., 2005), five (*C odarata, A adhenophora, A conyzoides, P hysterophorous, R ellipticus*) were recorded from the study site. Based on household survey response, invasive plant species like *Ageratum conyzoides, Oxalis latifolia, Amaranthus spinosus* were present from the past, but, *C odatata* is reported to have recently appeared and most widely impacting the site. About half of the surveyed people responded that *C odarata* appeared around only 20 years ago, while only a few respondents said that it appeared around 10 years ago. Among the 21 important IAPS of Nepal, those that were present in Syangja district were *Ageretina adhenophora*, *Mimosa pudica*, *Amaranthus spinosus and Oxalis latifolia* (Tiwari, 2005). in addition to this, ten more invasive species that are under 25 important IAPS (Shrestha et al., 2016) of Nepal were recorded in this study and those include *C. odarata, B. pilosa, P. hysterophorus, A. conyzoides, A. mexicana, S. tora, S. occidentalis, H. suaveolens, X. strumarium, A. houstonianum* .

Detail analysis of IVI in the study area showed that *Bidens pilosa*, *Ageratum houstonianum* and *Chromolaena odarata* had high species dominance while *Xanthium stromarium*, *Senna tora* and *Argemone maxicana* had the lowest species dominance in the study area (Table 2).

Table 2 *Status of identified IAPS*

S.N	Species	RD (in %)	RF (in %)	RA (in %)	IVI (in %)
1	*Chromolaena odarata* (Seto Banmara)	12.93	14.29	10.71	37.93
2	*Ageratina adhenophora* (Kalo Banmara)	11.11	8.16	8.05	27.33
3	*Ageratum houstonianum* (Nilo Ganne)	20.50	14.29	8.49	43.27
4	*Ageratum conyzoides* (Gandhe)	2.68	4.08	3.89	10.65
5	*Parthenium hysterophorus* (Pati Jhar)	7.09	8.16	5.14	20.39
6	*Bidens pilosa* (Kalo Kuro)	15.90	16.33	5.76	37.99
7	*Rubus elliptius* (Aaiselu)	1.92	6.12	1.85	9.89
8	*Amaranthus spinosus* (Kande Lude)	3.83	2.04	11.11	16.98
9	*Argemone mexicana* (Thakal)	1.53	3.06	2.96	7.56
10	*Senna tora* (Tapre)	1.34	2.04	3.89	7.27
11	*Senna occidentalis* (Panwar)	1.92	5.10	2.22	9.24
12	*Hyptis suaveolens* (Ban Tulsi)	3.83	4.08	5.55	13.47
13	*Mimosa pudica* (Lajjawati)	3.64	6.12	3.52	13.28
14	*Oxalis latifolia* (Chari amilo)	8.43	3.06	16.29	27.78
15	*Xanthium stromarium* (Bhende Kuro)	1.15	2.04	3.33	6.52
16	*Urena lobata* (Nalu Kuro)	4.98	4.08	7.22	16.28

Based on people's perception from the economic point of view *C odarata, A conyzoides, A houstonianum* were most problematic. The distribution of these problematic species on different land use shows that fallow land was highly invaded by these species in natural environment followed by rangeland (Figure 5).

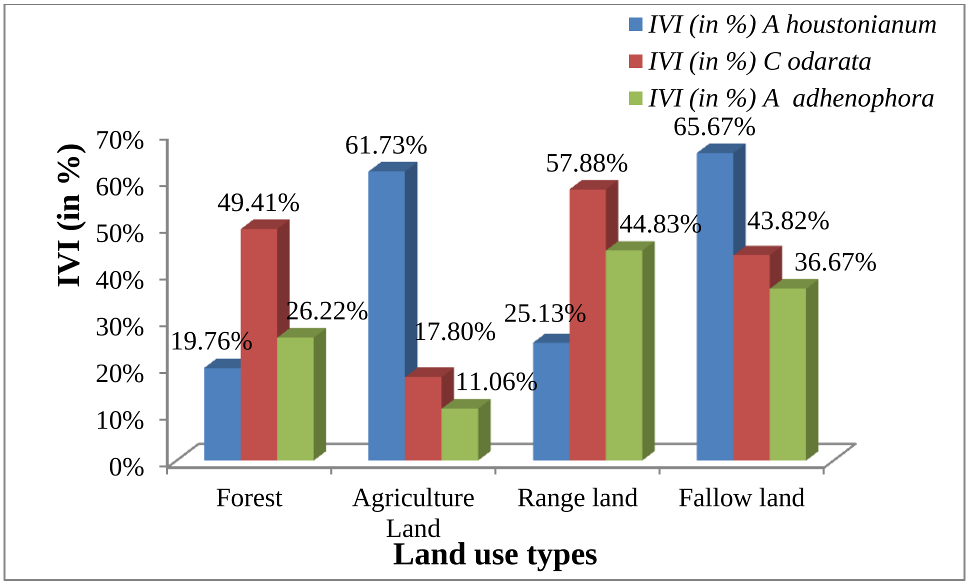

Figure 5 *The importance value index for key invasive species on different land use types*

The household survey conducted on 45 households revealed that the most invaded land use type was found to be range land followed by fallow land. This is probably because, in agriculture land tillage is carried out at least annually. Thus, there is no invasion in close canopy of forest as opposed to range land and fallow land where management activities are not carried out.

Impacts on Regeneration of Desired Species:

On calculating the average regeneration per hectare, there were only 5107 individuals/ha in IAPS invaded areas and 11556 individuals/ha in non-invaded areas. Impact on regeneration of some of high value species of that area are shown in Figure 6.

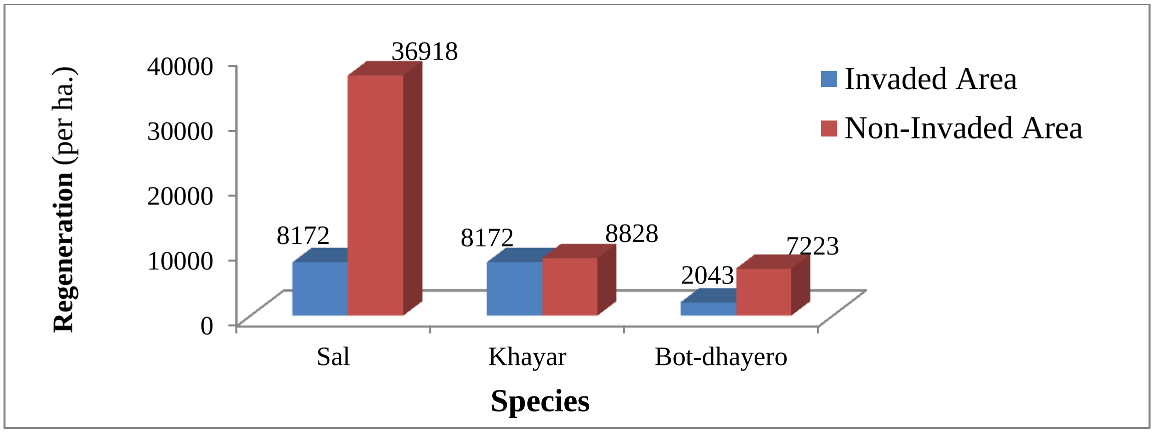

Figure 6 *Impacts on Regeneration of Desired Species*

The impact of IAPS seems to be high in degraded or open canopied forest while in case of rangeland high impact were seen in IAPS invaded region (Table 3).

Table 3 *Average regeneration in different land use*

Average Regeneration in Forest		**Average Regeneration in Rangeland**	
Open Canopy (/ha.)	Closed Canopy (/ha.)	Invaded region (/ha.)	Non-Invaded Region (/ha.)
4943	14232	5296	11938

Management of IAPS:

IAPS have both positive and negative impacts. These plants supply a variety of forest products and services including fuel wood, animal feed, soil conservation, rehabilitation of degraded lands and cultural values. But the negative impacts of IAPS are far more than those of benefits thus, these species must be managed. Management of invasive species involves three basic strategies: prevention, eradication and control (Radosevich et al., 2009). As the study area is already invaded by invasive species, prevention and eradication is not possible. Thus, the only strategy is to control them such they further they cannot invade more areas. 68.89% of respondents engage mechanical removal of IAPS; 17.78% respondents take no action for management while remaining 13.33% were observed to use chemicals to control these species

Conclusion

In the study area, a total of sixteen IAPS were recorded. Among the recorded IAPS, *Ageratum houstonianum, Bidens pilosa, Chromolaena odarata* had high species dominance. Economically *C odarata* was reported to be the most problematic with higher impact in range land, while ecologically, fallow land was found to be a highly invaded land use type. Regeneration of desired species is affected by invasion of IAPS in forest and rangeland type and in average regeneration in invaded region was 5107/ha while 11556/ha in non-invaded region. Distribution and diversity of IAPS was found higher in southern aspect compared to northern aspect. Similarly, in altitudinal variation, it was observed that the invasion of IAPS decreased with an increase in altitude. Most of the people were unaware about the IAPS and their impact on native species, so awareness among local people particularly for identification and control measure has been recommended. Mechanical control measure could be applied for removal by uprooting manage the number. Last but not least, enrichment plantation in degraded forest and open canopy has been recommended for reducing the rate of invasion as the numbers of invasive species were observed to be higher in open canopy areas.

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Water quality of Ghodaghodi Lake: a Ramsar site in western Nepal

Rita Bhatta[1*], Shrija Tuladhar[2], Dikshya Regmi[3], Smriti Gurung[2], Rajendra Joshi[1], Bed Mani Dahal[2], Nani Raut[2], Kumud Raj Kafle[2], Rabindra Kayastha[4], Archana Prasad[5], Lekhendra Tripathee[6], Chhatra Mani Sharma[3]

[1]Department of Chemical Science and Engineering, School of Engineering, Kathmandu University
[2]Department of Environmental Science and Engineering, School of Science, Kathmandu University
[3]Central Department of Environmental Science, Institute of Science and Technology, Tribhuvan University, Kirtipur, Kathmandu
[4]Department of Mathematics, School of Science, Kathmandu University
[5]Central Department of Zoology, Institute of Science and Technology, Tribhuvan University
[6]State Key Laboratory of Cryospheric Science, Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences

*Corresponding author: ritu_chem@ku.edu.np

Abstract

Wetlands are one of the most dynamic ecosystems that provide unique ecological functions and economic values such as water purification, ground water recharge, nutrient retention and bio-diversity conservation. This study was conducted at Ghodaghodi lake- one of the Ramsar sites in Nepal to generate baseline information on a range of physico-chemical parameters and to assess the suitability of lake water for irrigation and aquaculture. A total of 13 different sites representing diverse land uses in the vicinity were chosen. The results showed that the lake water is characterized by circum neutral to alkaline pH (7.97 ±0.516), moderate dissolved oxygen (6.63 ±1.15 mgL^{-1}) and low conductivity (160.42±46.35 μS/cm). The concentrations of major cations followed the order $Ca^{2+}>K^{+}>Na^{+}>Mg^{2+}$. Similarly, the anions were in the order of $HCO_3^{-}>SO_4^{2-}>Cl^{-}>NO_3^{-}$. Cations and anions are dominated by Ca^{2+} and HCO_3^{-}, respectively which is an indication of crustal derived materials. Furthermore, most of the trace metals were found to be below the detection limit in most of the sampling sites except Fe and Mn. Water quality of Ghodaghodi lake seems to be suitable for irrigation and aquaculture.

Keywords: Water quality, Major ions, Ghodaghodi lake, Wetlands

Introduction

Water pollution is one of the major concerns of the world today. Rapid deterioration of water resources in many countries are mainly due to population growth and associated impacts which in turn affect the quality and quantity of water for various purposes. The sewage wastewater, industrial effluents, and municipal wastewater are directly and indiscriminately discharged into rivers and lakes and thus is a primary cause of water pollution (Bhatta et al., 2015). The major threats to aquatic bodies like lakes and reservoirs, worldwide seems to be chemical pollution, eutrophication, alien plants and animal species (Herschy, 2012), acidification, heavy metal contamination (Mustapha, 2008), long range transport of pollutants (Schlesinger, 2004) and overharvesting of aquatic resources. The increasing contamination of aquatic bodies by the spreading of inorganic pollutants such as trace metals are of great concern for the quality and the sustainable use of freshwater resources (Ngelinkoto et al., 2014). Trace metals are elements such as iron, chromium, copper, cobalt, magnesium and zinc that normally occur at very low levels in the environment. Living beings require very small amount of some trace metals, but high concentrations of these metals can be toxic. Metals may accumulate in sediments, bioaccumulate in aquatic organisms and the food chains and eventually reach the human body through the consumption of fish and other aquatic organisms (Ikem et al., 2003; Ngelinkoto et al., 2014). Therefore, water quality assessment based on physico-chemical parameters of lakes and reservoirs have been largely used all over the world which provides an idea of the status, productivity and sustainability of such water bodies.

Wetlands are most diverse ecosystems in the world providing unique ecological functions and economic values. They support various ecological functions such as water purification, nutrient retention, ground water recharge, biodiversity conservation, food supply. Besides, they provide a unique habitat for a wide variety of biota. They also perform as a biological safety net serving as environmental insurance against the impacts of climate change and ecosystem degradation (Baral et al, 2015; Ramsar Handbook, 2016; DoF, 2017).

In context of Nepal, information on the water quality and concentrations of different major ions and trace metals in water, sediment and biota in wetlands is still scant. Some scientific contributions regarding environmental status of the Himalayan range are there in recent period (Loewen et al., 2005; Sharma et al., 2012, 2013, 2015; Tripathee et al., 2014a; Tripathee et al., 2014b; Kang et al., 2016; Paudyal et al., 2016; Pandey et al., 2017), yet, there is less information on the western part of Nepal regarding water pollution and quality, and this work could be a source for baseline data. The objectives of this study were generate baseline information on a range of physico-chemical parameters and to assess the suitability of lake water for irrigation and aquaculture of Ghodaghodi lake- a Ramsar site in west Nepal.

Materials and Methods

Study Area

The study was conducted in the Ghodaghodi Lake complex (28°41'17"N, 80º 56'47" E) – a Ramsar site in Kailali district of Far Western Terai in Nepal (Figure 1). It covers an area of 2,563 ha (6,330 acres) and is located at an altitude of 205 m on the lower slopes of the Siwalik Hills (Lamsal et al., 2014; Joshi & KC, 2017). The lake complex consists of a system of around 14 large and shallow oxbow lakes and ponds with marshes and meadows, streams and swamps. It is surrounded by tropical deciduous mixed *Shorea robusta* forest in the lower slopes of Siwalik Hills. One of the major lakes of the complex is Ghodaghodi Lake which covers an area of 138 ha (Lamsal et al., 2014). The lake system is connected with extensive forests along the Siwalik Hills to the north and falls between the Royal Bardia National Park and the Shuklaphanta Wildlife Sanctuary and functions as an important corridor for the movement of wildlife (Lamsal et al., 2014). The lake is fed by atmospheric inputs and surface flows. It has no inlet but has two outlets along the Mahendra highway. It has sub- tropical monsoonal type of climate with dry winter and rainy summer.

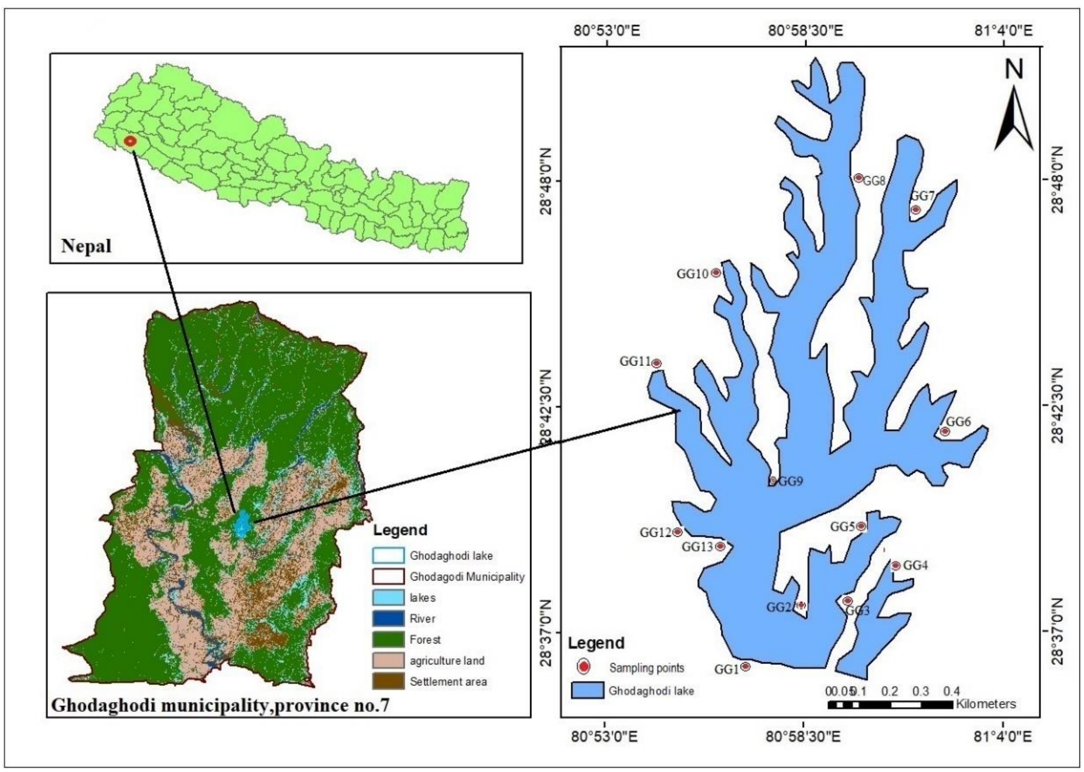

Figure 1 *Location of Ghodaghodi Lake complex and different sampling sites in Ghodaghodi Lake.*

Sampling and analyses

The study was conducted during 15-17 January 2019 (winter). Water samples were collected from 13 different sites (Fig. 1) based on diverse land use pattern, accessibility and stressors. Two replicate samples were collected from each site. Samples were collected in 500 ml plastic bottles and preserved following standard procedures (APHA, 1989). A total of 28 parameters were analyzed that include physico-chemical parameters focusing on major ions and heavy metals. Temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO) were measured on site with a Multimeter probe. Samples were analyzed in the laboratory of Kathmandu University and Water Engineering laboratory following standard methods (APHA, 1989). The obtained results were compared with Nepal standard for irrigation and aquaculture (Environmental Statistics of Nepal, 2019).

Results and Discussion

The results of on-site water parameters, major ion and trace metal analyses are shown in the Tables 1, 2 and 3 respectively. All the sites were characterized by neutral to slightly alkaline pH and moderate DO values (Table 1). A number of surface water bodies in Nepal are known to have alkaline pH (Jones et al., 1989; Lacoul & Freedman, 2005). The observed DO values are suitable for sustaining/survival of most of the aquatic biota.

Table 1 *Site wise concentration of onsite parameters of water of Lake Ghodaghodi*

Site	Temp (°C)	pH	EC (µS/cm)	TDS (mgL^{1})	DO (mgL^{1})
GG1	15.73± 0.12	8.15± .09	156.8±1.67	83.83±0.87	8.4±0.17
GG2	19.47± 0.46	8.07±0.33	157.1±3.38	82.6±2.16	5.7±0.10
GG3	14.57± 0.06	7.73±0.03	142.43±2.87	75.23±0.97	5.9±0.44
GG4	21.37± 0.06	8.20±0.03	269.33±0.58	143±0.00	6.2±0.78
GG5	18.8± 0.35	7.61±0.38	160.67±11.92	82.83±7.08	5.69±0.06
GG6	14.07± 0.15	7.58±0.03	168.73±2.46	89.73±0.67	5.3±0.10
GG7	18.87± 0.21	7.59±0.01	243.67±5.51	131±2.65	6.33±0.23
GG8	21.43± 0.06	7.94±0.11	159.26±2.96	84.3±0.36	6.5±0.17
GG9	22.43± 0.06	9.11±0.09	139.93±0.60	79.6±3.08	9.37±0.06
GG10	16.33± 0.35	8.84±0.15	127.1±2.10	67.63±0.80	7.37±0.12
GG11	19.13± 0.42	7.84±0.08	109.17±5.40	57.57±2.99	7±0.10
GG12	15.43± 0.15	7.69±0.10	127.3±3.38	67.23±1.27	6.03±0.25
GG13	14.8± 0.1	7.28±0.05	124.03±0.70	65.97±0.31	6.46±0.02

The mean concentrations of major cations was in the order of $Ca^{2+}>K^{+}>Na^{+}>Mg^{2+}$ whereas those of the major anions follow the order $HCO_3^{-}>SO_4^{2-}>Cl^{-}>NO_3^{-}$ (Table 2). Cations and anions are dominated by Ca^{2+} and HCO_3^{-} respectively which is an indication of crustal derived material (Wetzel, 2001). Bedrock geology is often recognized as the source of different ions and minerals in water bodies (Das & Dhiman, 2003) although for some ions, sources via anthropogenic activities also explain their elevated concentrations. Calcium is often the dominant cation in most freshwater bodies across the earth (Wetzel, 2001) and several studies in Nepal has also reported similar findings (e.g., Khadka & Ramanathan, 2012; Gurung et al., 2015). Presence of chloride ions in water is naturally associated with the processes of leaching from minerals, from rocks (Nikanorova & Brazhnikova, 2009). However, anthropogenic sources such as long-range transport, sewage and fertilizer run off have also been confirmed to be the sources of Chloride (Schlesinger, 2004) in water bodies.

The concentrations of most of the trace metals (B, Al, Cr, Co, Ni, Cu, Zn, Cd, Pb, As, Hg) were found to be below detection limits (Table 3) in all the sites except for Fe and Mn. The mean concentration of Fe was 0.31±0.33 $mgL^{-1}$and whereas that of Mn was 0.03±0.04 mgL^{-1} (Table 2). Generally, the concentrations of trace metals in different environmental compartments of wetland systems are found in the order of sediment> macrophytes> water (eg., Zhang et al., 2014). This probably explains low concentrations of these trace metals in Ghodaghodi Lake.

Site GG4 was observed to have highest values of EC, TDS, nitrate, bicarbonate, calcium, magnesium, iron, and manganese. This site is near the Mahendra Highway with maximum human influence. Therefore, the probable reason for such a high level of these parameters could be due to anthropogenic activities.

Table 2 shows the mean values of different parameters and Nepal Standard values for irrigation (2019) and aquaculture (2019). All the parameters are in compliance except iron for aquaculture and manganese for irrigation.

Table 2 *Mean concentration and range of different parameters of water of Lake Ghodaghodi*

Parameters	Mean concentration	Range	Nepal Standard for irrigation (2019)	Nepal Standard for aquaculture(2019)
Temp(°C)	17.88±2.88	14.07-22.43		4-30°C
pH	7.97±0.52	7.28-9.11	6.5 -8.5	6.5-9
EC (μScm^{-1})	160.42±46.35	109.17-269.33	<40000 μScm^{-1}	
TDS (mgL^{-1})	85.42±24.78	57.57-143.0		<2000 mgL^{-1}
DO (mgL^{-1})	6.63±1.15	5.3-9.37		5-9 mgL^{-1}
Nitrate (mgL^{-1})	1.45±0.90	0.79-4.35		<300 mgL^{-1}
Total Phosphorus (mgL-1)	0.9±0.07	0.76-1.00		
Sulphate (mgL^{-1})	16.12±1.15	8.26-21.74		
Bicarbonate (mgL^{-1})	219.42±63.44	155.00-377.5		
Chloride (mgL^{-1})	5.65±0.99	4.00-7.50	<100 mgL^{-1}	<600 mgL^{-1}
Sodium (mgL^{-1})	3.00±1.60	1.08-6.55	<70 mgL^{-1}	
Potassium (mgL^{-1})	3.35±0.69	2.3-4.5		
Calcium (mgL^{-1})	26.58±10.38	15.05-54.95		
Magnesium (mgL^{-1})	2.29±0.90	1.4-4.55		<15 mgL^{-1}
Iron (mgL^{-1})	0.31±0.33	0.12-1.38	<5 mgL^{-1}	<0.01 mgL^{-1}
Manganese (mgL^{-1})	0.03±0.04	0.01-0.14	<0.02 mgL^{-1}	<0.1 mgL^{-1}
Ammonia (mgL^{-1})	1.73±0.25	1.44-2.20		0-30 mgL^{-1}

Table 3 *Site wise concentration of different trace metals of water of Lake Ghodaghodi (mgL^{-1})*

Site	Fe	Mn	Cu	Ni	Zn	Cd	Cr	Pb	Hg	B	Co	Al	As
	<0.01*	<0.01*	<0.01*	<0.01*	<0.01*	<0.003*	<0.05*	<0.01*	<0.001*	<0.02*	<0.01*	<0.01*	<0.005*
GG1	0.18	0.02	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
GG2	0.22	0.02	0.025	BDL	1.325	BDL	BDL	BDL	BDL	BDL	BDL	0.015	BDL
GG3	0.21	0.02	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
GG4	1.38	0.14	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
GG5	0.14	0.015	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
GG6	0.22	0.02	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
GG7	0.34	0.025	0.01	BDL	1.34	BDL	BDL	BDL	BDL	BDL	BDL	0.01	BDL
GG8	0.29	0.01	0.01	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
GG9	0.21	0.01	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
GG10	0.32	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
GG11	0.27	0.01	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
GG12	0.12	0.01	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
GG13	0.17	0.01	BDL	BDL	1.1	BDL	BDL	BDL	BDL	BDL	BDL	0.01	BDL

Note: Detection Limit*

Conclusion

A preliminary water quality assessment was conducted in Ghodaghodi Lake. The lake water is characterized by circum neutral to alkaline pH and moderate DO concentration suitable for the survival of most of the aquatic biota. Calcium and Bicarbonate were the most dominant cation and anion respectively derived from bedrock while the concentrations of most of the trace metals were low and many were below the detection limit. Water quality of the lake seems to be suitable for irrigation and aquaculture.

Acknowledgements

This study was funded by University Grants Commission (Grant # CRG-73/74S&T-04). Gratitude to Ghodaghodi Municipality and Ghodaghodi conservation committee for providing permits for this research and local people of the area for their kind cooperation.

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Physicochemical Characterization of Water Samples from Lake Phewa and Kulekhani Reservoir, Nepal

Babi Kumar Kafle[1], Bed Mani Dahal[2*], Chhatra Mani Sharma[3], Kumud Raj Kafle[2], Smriti Gurung[2], Nani Raut[2] and Sushma Manandhar[2]

[1]Department of Chemical Science and Engineering, Kathmandu University, Dhulikhel, Nepal
[2]Department of Environmental Science and Engineering, Kathmandu University, Dhulikhel, Nepal
[3]Central Department of Environmental Science, Tribhuvan University, Kirtipur, Nepal

[*]Corresponding author: bedmani@ku.edu.np

Abstract

The water quality of lakes and reservoirs worldwide are being affected by eutrophication, sedimentation, acidification, and invasive species. Thus, water quality monitoring with the aim to develop effective management strategies for sustainable use of lakes and reservoirs is important. However, Nepalese lakes and reservoirs in terms of their water quality and activities affecting them are less studied. Water quality assessment of Lake Phewa of Kaski and Kulekhani Reservoir of Makawanpur districts of Nepal, serving a number of ecosystem services, was carried. Selected physico-chemical parameters such as pH, DO, conductivity, temperature, turbidity and TDS were measured on-site with a portable probe. Nine water samples (from five inlets and four lake samples) from Kulekhani and ten water samples (from six inlets and four lake samples) from Phewa were collected and analyzed for major ions following standard procedures. Lake Phewa had circum-neutral pH (6.83±0.76) and low conductivity (50.04 ± 40.82μScm^{-1}) whereas the Kulekhani Reservoir water had circum-neutral to alkaline pH (8.08±0.64) with higher conductivity (168.64 ± 63.57μScm^{-1}). The concentrations of major cations were in the order of $Ca^{++}>Na^{+}>Mg^{++}>K^{+}$ and those of the anions were in the order of $Cl^{-}>HCO_3^{-}>SO_4^{--}>NO_3^{-}$ in both water bodies. Higher concentrations of Cl^{-} probably indicate agricultural runoff and untreated sewage from the catchment. Water quality of both the water bodies meets the criteria of Nepal standard for irrigation and aquaculture.

Keywords: Lakes, Reservoir, Water quality, Major ions, Phewa, Kulekhani

Introduction

Water quality in reservoirs and lakes is an important issue for a number of reasons such as water supply, flood control, hydropower, fish and wildlife conservation, recreation etc. (Stefan et al., 1989). However, the existing water resources are being subjected to intense multi-objective demands as a result of which the quality of surface water including those of lakes and reservoirs has deteriorated in many countries (Otiang'a-Owiti & Oswe, 2007; Tessema et al., 2014) including Nepal (Burlakoti & Karmacharya, 2004; Gautam & Bhattarai, 2008).

Major threats to lakes and reservoirs include eutrophication, chemical pollution, growing alien plant and animal species (Herschy, 2012); acidification and heavy metal contamination (Mustapha, 2008). Consideration of water quality is particularly important when fishery resource issues, drinking and recreation purposes come into account (Chapman, 1996). In Nepal, water from Lake Phewa is used for irrigation, fishery and recreation (Pokharel, 2008). Tourism and fishery from the lake forms the basis of livelihoods for local communities (Aryal et al., 2010). Similarly, Kulekhani reservoir initially built for generation of hydroelectricity and considered as a success story, generates not only hydroelectricity but also supports cage fishery (Gurung et al., 2010). However, increasing number and volume of fish cages and use of agro-chemicals in the catchment area are the major causes of water pollution. Therefore, water quality assessment becomes crucial in planning and developing management strategies of water bodies for their sustainable use. Therefore, this study attempts to assess the water quality of Lake Phewa and Kulekhani Reservoir in Nepal especially focusing on their physico-chemical characterization and suitability of lake water for irrigation and aquaculture.

Materials and Methods

Study area

The study was conducted in Kulekhani Reservoir and Lake Phewa in Nepal (Figure 1).

Kulekhani Reservoir

The Kulekhani Reservoir is located in the Makwanpur District, Central region of Nepal, about 30 Km southwest of Kathmandu. It is a manmade reservoir which was built by the construction of 406 m long, 114 m high rock fill dam in Kulekhani river at Kulekhani village. The Kulekhani is locally named as Indra-Sarovar. The reservoir receives the water during the rainy season and the water is utilized during the dry season through cascade system of Kulekhani No. I at Dhorsing, Makwanpur Power Station (60

MW) and Kulekhani No. II Power Station (32 MW) at Bhainse VDC, Bhainse, Makawanpur (Sthapit, 1996). The climate of Kulekhani watershed varies from subtropical at lower elevations to temperate at higher elevations. The watershed experiences four distinct seasons: pre-monsoon (March to May), monsoon (June to September), post-monsoon (October to November) and winter (December to February). The warm temperate humid zone is found between 1500 and 2000 masl and the cool temperate humid zone lies above 2000 masl. The average annual precipitation over the watershed is about 1500 mm. About 80 % of the total rainfall occurs between June to September. The average temperature in the warm temperate humid zone is 15 °C to 20 °C and in the cool temperate it is 10 °C to 15 °C (Ghimire, 2004). Tasar, Bisingkhel and Chitlang Khola are the major streams that empty into the reservoir. The average slope of the tributaries ranges from 1.2% to 21.3%. Agriculture constitutes about 42% of the watershed area; forestry constitutes about 44%; shrubland covers about 9% and grazing land about 2%. The reservoir, rock field, landslides and residential area cover about 3%. Out of 42 % agricultural land, about 82 % is sloped ("Bari" land) terrace and about 18 % is flat and valley terraces ("Khet" land). Around 9 % of the watershed area is steeper than 60 % slope and about 52 % of the watershed area falls into the slope category 31-60 %. Of the remaining area, 28 % has slopes of 16-30 %, 9 % has slopes of 3-15 % and 2 % is lake and wetland (Dhital et al., 2014).

Lake Phewa

Lake Phewa is a stream- fed dam- regulated, semi- natural freshwater subtropical mountain lake (maximum depth 24m and mean depth 7.5 m), lying at an altitude of 796 masl in Pokhara valley of Nepal. It occupies an area of 5.23 km^2 and watershed area of 110km^2 (Lamichhane, 1996). The climate in the region is humid subtropical monsoon to cool temperate monsoon. Mean average temperature varies between 12°C in the winter to 30°C in the summer. Rainfall pattern is monsoon type and more than 80% of the total rainfall occurs during the period of May to September. Landuse pattern in the immediate lake catchment include agriculture and dense urban areas in the north; forest with sparse rural settlement in the south; silt trap zone in the western side; and an outlet in the eastern side. The main inlet is Harpan Khola in the west and there are number of seasonal inlets emptying into the lake particularly on the northern side.

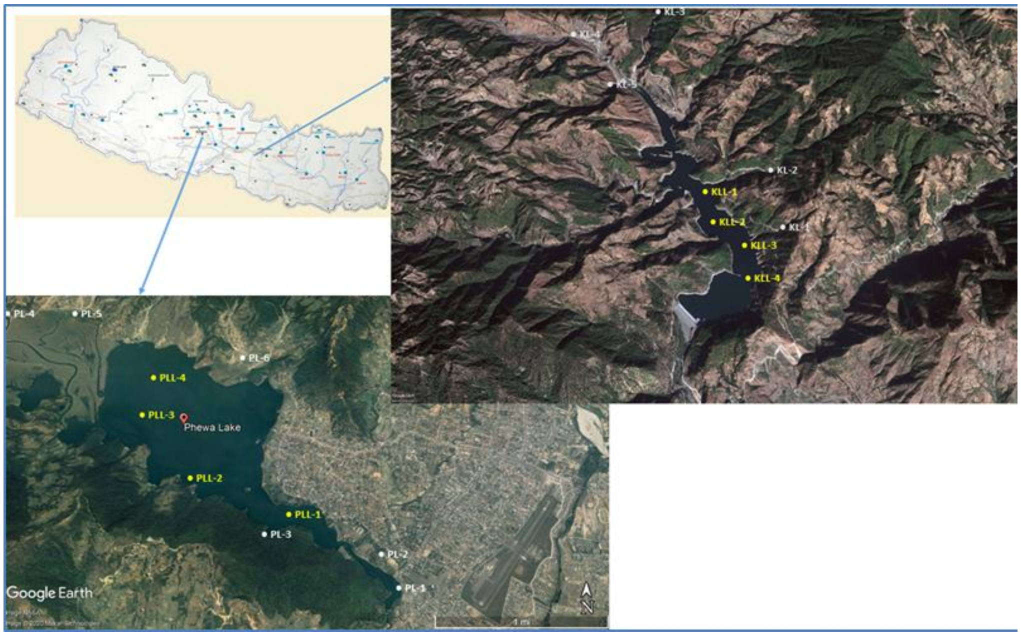

Figure 1 *Location Map of the study area showing Kulekhani reservoir and Phewa lake*

Sampling and analysis

Nine water samples (from five inlets and four reservoir samples) from Kulekhani and ten water samples (from six inlets and four lake samples) from Phewa were collected during July 2017. Therefore, a total of 19 water samples were collected from two water bodies. The geographical coordinates and the elevation of the sampling sites are presented in Table 1.

Selected physico-chemical parameters such as the dissolved oxygen (DO), pH, conductivity, temperature, turbidity and total dissolved solids (TDS) were measured on-site with portable probes. At each site, three replicates were taken. 1000 ml of water samples were collected in high density polyethylene (HDPE) bottles from each sampling site for the analysis of the major ions *viz*. HCO_3^-, SO_4^{--}, PO_4^{---}, NO_3^-, Cl^- Ca^{++}, Mg^{++}, Na^+, K^+ and NH_4^+, The sampling bottles were rinsed with the lake water (for samples from the lake), and inlet water (for samples from the inlets) and the outlet (for sample from the lake outlet in Phewa Lake) before the samples were collected. The samples were immediately stored in icebox until they were transported to the laboratory for further analysis. Concentrations of the major ions were estimated following the standard procedures at the Laboratory of the Department of the Environmental Science and Engineering, Kathmandu University and Water Engineering Lab at Kathmandu following standard methods (APHA, 1998).

Table 1. *Geographical details of the sampling sites in Kulekhani Reservoir and Lake Phewa*

Kulekhani Reservoir			Lake Phewa		
Site code	**Geographic Coordinates**	**Elevation (masl)**	**Site code**	**Geographic Coordinates**	**Elevation (masl)**
KL-1	27°35’59.21” N; 085° 10’1.37” E	1565	PL-1	28°11’50.73” N; 083°58’9.75” E	800
KL-2	27°36’27.20” N; 085°0 9’56.29”E	1502	PL-2	28°12’01.72” N; 083°58’3.32 E	797
KL-3	27°37’53.79” N; 085°08’57.77” E	1598	PL-3	28°12’9.37” N; 083° 57’21.3”	800
KL-4	27°37’43.17” N; 085°8’12.63” E	1529	PL-4	28°13’54.9” N; 083°55’7.65” E	803
KL-5	27°37’12.7” N; 085°8’36.40” E	1496	PL-5	28°13’56.38” N; 083°55’42.17” E	782
KLL-1	27°36’19.8” N; 085°09’26.55” E	1514	PL-6	28°13’28.4” N; 083°57’05.49” E	800
KLL-2	27°36’5.12” N; 085°09’28.72” E	1495	PLL-1	28°12’17.30” N; 083°57’30.03” E	785
KLL-3	27°35’53.55” N; 085°09’46.51” E	1507	PLL-2	28°12’30.98” N; 083° 56’49.26” E	796
KLL-4	27°35’40.62” N; 085°09’46.19” E	1510	PLL-3	28°12’57.9”N; 083°56’25.73” E	795
			PLL-4	28°13’.18” N; 083° 56’28.36” E	794

Results and Discussion

The results of on-site estimation of selected physico-chemical parameters of Lake Phewa and Kulekhani Reservoir are presented in Table 2 and Table 3 respectively.

Table 2. *Concentration of selected parameters of water of Phewa Lake*

Lake Phewa						
Site code	**Temperature (°C)**	**DO (mgL^{-1})**	**pH**	**TDS(ppm)**	**Conductivity (μScm^{-1})**	**Turbidity (NTU)**
PL1	25.70±0.00	8.40±0.10	7.27±0.01	27.47±1.72	57.90±0.61	31.53±0.57
PL2	24.23±0.06	9.27±0.06	6.25±0.04	78.83±0.70	158.50±0.53	15.34±1.96
PL3	22.50±0.52	10.10±0.10	5.12±0.02	8.86±0.04	17.89±0.13	1.16±0.08
PL4	27.90±0.20	9.17±0.15	7.02±0.02	14.20±0.17	28.40±0.17	51.13±0.50
PL5	26.20±0.10	10.27±0.25	6.75±0.05	12.40±0.17	25.07±0.21	3.16±0.29
PL6	23.83±0.32	10.03±0.32	6.45±0.05	33.30±0.26	66.93±0.25	2.52±0.49
PLL1	27.50±0.10	9.33±0.21	6.87±0.06	19.70±0.52	39.87±0.15	27.40±0.56
PLL2	28.20±0.10	10.50±0.10	7.53±0.01	18.53±0.21	36.23±2.28	24.33±0.06
PLL3	27.77±0.06	10.20±0.10	7.520±.07	17.00±0.70	34.33±1.67	27.60±0.26
PLL4	27.90±0.00	10.60±0.10	7.57±0.15	17.57±0.06	35.30±0.17	23.63±0.32

Table 3. *Concentrations of physicochemical parameters of Kulekhani Reservoir*

Kulekhani Reservoir						
Site code	**Temperature (°C)**	**DO (mgL^{-1})**	**pH**	**TDS(ppm)**	**Conductivity (μScm^{-1})**	**Turbidity (NTU)**
KL1	19.20±0.00	11.20±0.00	7.99±0.03	137.67±4.51	283.00±5.57	4.29±0.57
KL2	20.35±0.35	11.03±0.42	7.78±0.04	108.00±1.00	217.67±1.15	21.93±0.31
KL3	20.75±0.31	10.40±0.10	7.77±0.06	124.33±1.53	250.50±6.35	3.56±1.09
KL4	21.57±0.21	10.40±0.10	8.07±0.01	62.40±0.70	123.87±0.67	9.84±0.90
KL5	19.20±0.10	11.40±0.60	6.75±0.15	69.87±0.51	137.80±2.34	1.95±0.22
KLL1	26.03±0.06	14.80±0.10	8.29±0.07	63.33±0.21	126.83±0.15	13.80±0.62
KLL2	26.10±0.17	14.00±0.17	9.14±0.03	62.93±0.06	125.57±0.40	13.73±0.52
KLL3	26.17±0.12	13.07±0.06	8.56±0.04	63.33±0.49	126.07±0.21	10.14±0.27
KLL4	26.23±0.06	13.70±0.00	8.18±0.05	63.30±0.17	126.47±0.31	10.49±0.26

Lake Phewa had circum-neutral pH (6.83±0.76) and low conductivity (50.04 ± 40.82μScm^{-1}) with moderate DO values whereas the Kulekhani Reservoir water had circum-neutral to alkaline pH (8.08±0.64) with higher conductivity (168.64 ± 63.57μScm^{-1}) and rich DO values (Table 1 and Table 2).Table 4 and Table 5 show the site-wise concentrations of different major ions of Lake Phewa and Kulekhani Reservoir respectively.

Table 4. *Site-wise concentrations (mgL^{-1}) of major ions in Lake Phewa*

Lake Phewa										
Parameters	**Sites**									
	PL1	**PL2**	**PL3**	**PL4**	**PL5**	**PL6**	**PLL1**	**PLL2**	**PLL3**	**PLL4**
Sulphate	7.42	7.71	5.66	7.27	4.74	8.00	8.44	9.36	8.87	7.37
Bicarbonate	58	14	50	10	8	24	8	16	18	16
Ammonia	0.44	0.48	0.160	0.70	0.01	.0.45	1.75	2.71	1.20	0.39
Chloride	113.3	111.6	114.3	113.3	108.3	106.6	111.6	111.6	113.3	115
Nitrate	0.05	0.06	0.02	0.06	ND	0.15	0.03	ND	0.04	0.02
Total Phosphorus	0.02	0.02	0.03	0.02	0.03	0.02	0.04	0.02	0.03	0.02
Sodium	5.15	7.51	4.81	4.23	5.98	6.11	4.96	4.83	4.89	5.62
Potassium	1.46	3.04	2.26	1.05	0.96	1.39	1.51	1.32	1.37	1.77
Total Hardness	60	37.5	60	20	27.5	20	5	7.5	5	2.5
Calcium	10.4	12.8	2.4	3.2	3.2	8	0.8	4.8	6.4	3.2
Magnesium	2.4	6.3	0.97	1.9	1.4	2.4	0.5	2.4	3.9	1.9

Note: ND Not detected

Table 5. *Site-wise concentrations (mgL^{-1}) of major ions in Kulekhani Reservoir*

Kulekhani Reservoir									
Parameters	**Sampling sites**								
	KL1	KL2	KL3	KL4	KL5	KLL1	KLL2	KLL3	KLl4
Sulphate	10.92	7.71	7.17	10.19	10.33	8.83	7.76	8.14	7.85
Bicarbonate	120	142	82.6	112	32	62	6	56	58
Ammonia	0.45	0.64	2.21	1.33	0.29	1.46	1.14	0.57	0.75
Chloride	111.6	115	111.6	115	111.6	116.6	120	115	111.6
Nitrate	0.09	0.21	0.24	0.03	ND	0.20	0.20	0.01	0.02
Total Phosphorus	0.03	0.02	0.02	0.02	0.06	0.09	0.02	0.03	0.02
Sodium	9.04	9.3	9.75	5.26	9.34	9.3	9.14	9.23	8.7
Potassium	3.23	2.01	2.15	1.26	2.76	2.67	2.53	3.03	3.48
Total Hardness	55	37.5	42.5	15	17.5	10	12.5	12.5	15
Calcium	40	28.0	33.66	10.4	12.8	0.8	15.2	13.6	12
Magnesium	9.7	8.7	8.2	3.9	6.8	0.5	4.8	4.3	6.8

Note: ND Not detected

The concentrations of major cations were in the order of Ca^{++}> Na^{+}> Mg^{++}> K^{+} and those of the anions were in the order of Cl^{-}> HCO^{-}_{3}> SO^{--}_{4}> NO_3^{-} in both water bodies. Calcium is often the dominant cation in most freshwater bodies across the earth (Wetzel, 2001) and a number of water bodies in Nepal have been reported to have Calcium and Bicarbonate as the most dominant cation and anion respectively (eg. Jones et al., 1989; Khadka & Ramanathan, 2013; Gurung et al., 2015). In general, weathering of minerals from rocks releases mobile elements (alkali and alkaline earth) and trace elements into the waters (Salbu & Steinnes, 1995). For instance, presence of chloride ions in water is naturally associated with the processes of leaching from minerals (e.g. gallite, sylvite, carnallite, schofite), from rocks (e.g. nephelines) (Nikanorov & Brazhnikova, 2009). The sources of Bicarbonates are various carbonate rocks such as limestones, dolomites, magnesites from which dissolution takes place with the precipitation of carbon dioxide (Mustapha, 2008). However, anthropogenic sources such as long-range transport, sewage and fertilizer run off have also been proven to be the sources of chloride (Schlesinger, 2004; Tripathee et al., 2014). Bicarbonate concentrations in both water bodies were variable (Table 4 and Table 5). It's concentration is pH dependent and form a carbonate system of chemical equilibrium. When the pH of a water system is 7 to 8.5, the predominant ion is hydrogen carbonate. When pH is less than 5, the content of hydrogen carbonate ions is close to zero. Carbonate ions dominate when pH>8 (Wetzel, 2001). Higher concentrations of hydrogen carbonate in Kulekhani probably explain higher pH value than that of Lake Phewa. Both the water bodies had higher concentrations of Chloride ions (Table 4 and Table 5). Higher concentrations of chloride in these water bodies probably reflect the anthropogenic sources particularly from agricultural run-off and untreated sewage.

Table 6 shows the comparison of the concentrations of selected physico-chemical parameters with Nepal Standard for irrigation and aquaculture (Environment Statistics of Nepal, 2013).

Table 6. *Comparison of selected parameters with Nepal standard for irrigation and aquaculture*

Parameters	Kulekhani Reservoir	Phewa Lake	*Nepal Standard for irrigation	*Nepal Standard for aquaculture
Temp(⁰C)	19.20 - 26.23	22.50 -28.20		4-30
pH	6.75-9.14	5.120-7.57	6.5 -8.5	6.5-9
EC(µScm^{-1})	123.86 - 250.50	17.89 - 158.50	<40000	
TDS (mgL^{-1})	8.86-78.83	62.40-137.66		<2000
DO (mgL^{-1})	10.4-14.80	9.16-10.60		5-9
Nitrate (mgL^{-1})	0.02 - 0.24	0.02 - 0.15		<300
Chloride (mgL^{-1})	111.63 - 119.96	106.63 - 114.96	<100	<600
Sodium(mgL^{-1})	5.26 - 9.75	4.81 to5.91	<70	
Ammonia(mgL^{-1})	0.45 - 2.21	0.44 - 2.71		0-30

**Source: Environmental Statistics of Nepal (2013)*

Water quality of both water bodies is found to be suitable in relation to national Nepal Standards for irrigation and aquaculture.

Conclusion

A preliminary study water quality assessment was conducted in Lake Phewa and Kulekhani reservoir in Nepal. Calcium and Chloride were the most dominant cation and anion in both the water bodies. Higher concentrations of Cl^- probably indicate agricultural runoff and untreated sewage from the catchments. The water quality meets the criteria of Nepal standard for irrigation and agriculture.

Acknowledgement

The authors acknowledge the University Grants Commission, Nepal (UGC Institutional Grant 2073) for the financial support to conduct this study.

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Preliminary Eutrophication Status Assessment in Kulekhani Reservoir and Lake Phewa, Nepal

Milina Sthapit[1], Smriti Gurung[1*], Babi Kumar Kafle[1], Bed Mani Dahal[1], Chhatra Mani Sharma[2], Kumud Raj Kafle[1], Nani Raut[1] and Sushma Manandhar[1]

[1] Department of Environmental Science and Engineering, Kathmandu University, Nepal
[2]Tribhuvan University, Nepal

*Corresponding author: smriti@ku.edu.np

Abstract

Eutrophication assessment is an important component of water quality assessment of lakes and reservoirs. A preliminary assessment of trophic status in Kulekhani Reservoir in Makwanpur and Lake Phewa in Kaski district was conducted in July 2017. Water samples were collected for chlorophyll-a and total phosphorus (TP) determination from 4 sites in both the water bodies. Water transparency was measured on-site using Secchi disk. Trophic State Index was estimated following Carlson (1977). Low Secchi values of 0.51m and 0.37m in Kulekhani Reservoir and Lake Phewa respectively were observed whereas the TP concentration was 0.047mg L^{-1} and 0.027 mg L^{-1} in Kulekhani Reservoir and Lake Phewa respectively. The average Trophic State Index value was observed to be 62.03 in Kulekhani Reservoir and 58.77 in Lake Phewa and based on these values both the water bodies were categorized as eutrophic in nature. Agricultural runoff, nutrient loading associated with untreated sewage and rapid urbanization (particularly around Phewa) could be the probable reasons for high phosphate concentration leading to eutrophication of these freshwater bodies.

Keywords: Water quality, Chlorophyll-a, Secchi depth transparency, Eutrophication, Trophic state index

Introduction

Eutrophication is a process of nutrient addition which causes growth of primary producers and changes the water quality with taste, odor, and toxicity problems associated with cyanobacterial blooms (Dodds et al., 2013). Although eutrophication is a natural process, anthropogenic activities are known to cause considerable increase in nutrient concentrations in aquatic ecosystems especially nitrogen and phosphorus leading to the process of cultural eutrophication (Callisto et al., 2014). The enrichment of surface water with excessive nutrients correspond to high productivity of autotrophs which leads to high respiration rates resulting anoxia in poorly mixed water (Khan & Ansari, 2005). Eutrophication increases biomass of phytoplankton and macrophyte vegetation which decrease the water transparency and causes reduction in species diversity (Smith, 2016). There is a loss of economic value of a water body due to eutrophication as it decreases the aesthetic value of the water body which in turn reduces the recreational activities and result in difficulty in fishing and navigation due to heavy growth of plants (Khan & Ansari, 2005; Dodds et al., 2009). Eutrophication causes increased growth of undesirable algae and aquatic weeds which breaks the natural equilibrium of the aquatic ecosystem thereby restricting the water use for fisheries, recreation, industries and drinking (Smith, 2016). Trophic status of a lake or reservoir gives us the information about the productivity which is measured by knowing the amount of phosphorus, algae abundance and depth of light penetration. In Nepal also, a number of studies conducted on lakes and reservoirs such as Phewa, Mai Pokhari, Ghodaghodi, Beeshazar, and Jagadishpur have shown that these water bodies suffer from eutrophication (Thapa & Saund, 2014). Therefore, eutrophication assessment is an important component of water quality assessment and this study is aimed to assess the eutrophication status of Lake Phewa and Kulekhani reservoir in Nepal.

Materials and Methods

Study area

The study was conducted in Lake Phewa in Kaski district and Kulekhani Reservoir in Makwanpur district in Nepal (Figure 1). The sampling was conducted in July 2017. Lake Phewa is a tourist hotspot and also supports cage fishery (Gurung et al., 2010). Kulekhani Reservoir is important for hydroelectricity generation and cage culture. However, in recent times, the reservoir attracts local visitors and thus it is also becoming a recreational centre.

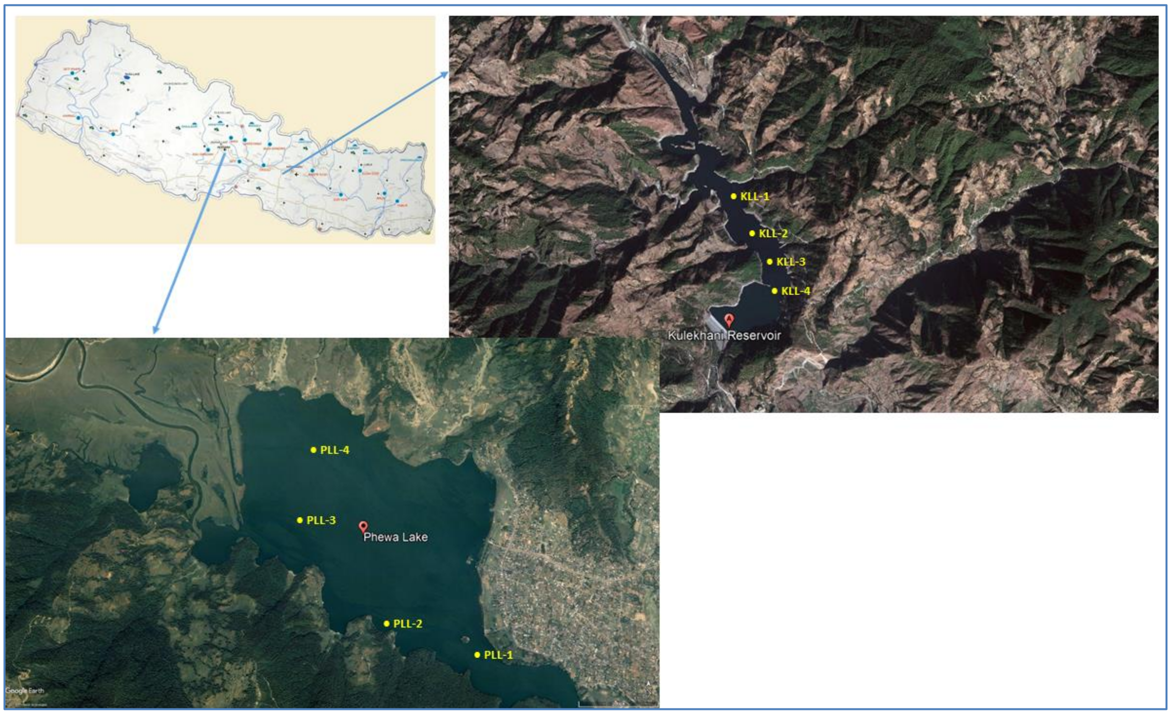

Figure 1 *Map of Nepal showing Kulekhani Reservoir and Lake Phewa with sampling sites*

Table 1: *Table showing geographical coordinates and elevation of the sampling sites*

Kulekhani Reservoir			Lake Phewa		
Site code	**Geographic Coordinates**	**Elevation (masl)**	**Site code**	**Geographic Coordinates**	**Elevation (masl)**
KLL-1	27°36’19.8” N; 085°09’26.55” E	1514	PLL-1	28°12’17.30” N; 083°57’30.03” E	785
KLL-2	27°36’5.12” N; 085°09’28.72” E	1495	PLL-2	28°12’30.98” N; 083° 56’49.26” E	796
KLL-3	27°35’53.55” N; 085°09’46.51” E	1507	PLL-3	28°12’57.9”N; 083°56’25.73” E	795
KLL-4	27°35’40.62” N; 085°09’46.19” E	1510	PLL-4	28°13’.18” N; 083° 56’28.36” E	794

Four sampling sites were selected in each water body during the sampling carried out in July 2017.Water samples of 1000mL were collected from each site of the lake and reservoir for chlorophyll-a estimation. These samples were filtered immediately through nylon membrane filter paper with the pore size of 0.45μm. At the end of filtration, few drops of Magnesium carbonate was added in order to preserve the sample. The filter paper was then folded and wrapped in aluminum foil and kept in an ice box during transportation. At each site, 1000mL surface water was additionally collected for analysis of Total Phosphorus (TP). The samples were immediately kept in an icebox to preserve the sample during transportation. Secchi depth transparency was measured with an 8-inch diameter Secchi disc. The transparency was measured by lowering the Secchi disk slowly into the water body until it disappeared.

This depth was noted then the disk was slowly raised until its reappearance. The second reading was also noted and the average of these two readings were taken as Secchi depth transparency.

In the laboratory, TP concentration was determined following standard procedure (APHA, 2012) and Chlorophyll-a estimation was done by acetone extraction method (Lorenzen, 1967). The filter paper with chlorophyll was grinded in 90% aqueous acetone solution. The extracted slurry was made to 10mL with 90% acetone solution which was then centrifuged. This solution was used for chlorophyll-a estimation using spectrophotometer. The concentration of Chlorophyll–a was estimated using the following formula:

$$\text{Chlorophyll-a}(\text{mg m}^{-3}) = [26.7 \times (663b - 665a) \times V1] / (V2 \times L)$$

Where V1= Volume of extract (L); V2= Volume of sample (m^3); L= Light path (cm); 663b= Corrected optical density of 90% acetone extract before acidification; 665a= corrected optical density of 90% acetone extract after acidification.

Carlson's Trophic State Index (Carlson, 1977) was used for the study. The following equations can be used to compute Carlson's TSI:

$$\text{TSI-P} = 14.42 \times \ln[TP] + 4.15 \text{ (in µg L-1)}$$

$$\text{TSI-Chl-a} = 30.6 + 9.81 \ln[\text{Chl-a}] \text{ (in µg L-1)}$$

$$\text{TSI-S} = 60 - 14.41 \times \ln[SD] \text{ (in meters)}$$

$$\text{Average TSI} = [\text{TSI (P)} + \text{TSI (Chl-a)} + \text{TSI (SD)}] / 3$$

Where TP is total phosphorus, Chl-a is chlorophyll-a and SD is Secchi depth.

Results and discussions

The average values of Secchi depth, Total Phosphorus, Chlorophyll-a and TSI in Kulekhani Reservoir and Lake Phewa are presented in Table 2.

Table 2: *Mean Secchi depth transparency, Total Phosphorus, Chlorophyll-a, TSI*

Parameters	**Kulekhani Reservoir**	**Lake Phewa**
Secchi depth (m)	0.51±0.01	0.14±0.07
Total Phosphorus (mg L^{-1})	0.047±0.03	0.027±0.01
Chlorophyll-a (µg L^{-1})	8.02±4.63	21.38±9.64
Average TSI	62.03	58.77
Trophic State	**Eutrophic**	**Eutrophic**

The low Secchi depth and high chlorophyll-a values indicates phytoplankton growth in both the water bodies as eutrophication causes the water bodies to become rich in plant biomass and decrease in transparency (Smith, 2016). The average TSI value was found to be 62.03 and 58.77 in Kulekhani Reservoir and Lake Phewa respectively. On the basis of Carlson's TSI (Carlson, 1977), the observed TSI values indicated the eutrophic nature of both the water bodies. Studies have found water quality of Kulekhani Reservoir to be moderately polluted (Adhikari et al., 2017) and Lake Phewa has changed from oligotrophic to mesotrophic to eutrophic (Maeda & Ichimura, 1973; Nakanishi et al., 1988). The catchment of Kulekhani Reservoir consists of heavily agricultural area and thus it receives the higher phosphate concentrations due to the runoffs from fields which use agricultural fertilizers loaded with phosphates and other animal wastes (Adhikari et al., 2017). The nutrient loading in Lake Phewa is a result from agriculture, landslides, untreated sewages and rapid urbanization in the surrounding areas which has caused eutrophication of the lake (Rai, 2000).

Conclusion

Kulekhani Reservoir and Lake Phewa both were found to be eutrophic in nature based on the Carlson's TSI. The input of plant nutrients such as nitrogen and phosphorus has been increasing due to anthropogenic sources. These are the preliminary findings and a comprehensive water quality and eutrophication status assessment encompassing seasonal variation is underway.

Acknowledgement

This study was supported by fund from University Grant Commission (UGC Institutional Grant 2073)

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Potential of Multiple Use Water System in Addressing Water Scarcity: A Case Study in Annapurna Gaunpalika, Kaski District, Nepal

Aashna Shakya[1]*, Nani Raut[1], Smriti Gurung[1], Bed Mani Dahal[1]

[1]Department of Environmental Science and Engineering, Kathmandu University, Nepal

*Corresponding author: nani.raut@ku.edu.np

Abstract

Multiple use water system (MUWS) is considered to be a participatory, integrated and poverty-focused approach to water resource management that accommodates both domestic and productive water use in order to meet multiple livelihood potential. This study assessed the implications of MUWS in terms of water accessibility, availability and quality in Annapurna Gaunpalika of Kaski district in Western Nepal. Data collection was done through key informant interviews and questionnaire survey in five MUWS and two drinking water schemes. A total of 11 water samples representing six natural water sources and five MUWS water supply tanks, were assessed for drinking and irrigation water quality in pre-monsoon season (April 2018) following standard procedures. The results suggested that MUWS benefited rural livelihoods through improved water availability, equitable distribution, economic benefits from vegetable production, health benefits and women's involvement in income generation activities. Gender, water collection time, education, and economic benefits were found to have positive influence on the adoption of MUWS. However, despite being involved in income generation activities, majority (63%) of the respondents reported that women still have no access to financial decision making within their households. Water supplied by MUWS was found to be suitable for irrigation without any alkali hazard however faecal contamination was found to be the key problem with drinking water.

Keywords: Multiple use water system, water accessibility, water availability, water quality

Introduction

Most of the peri-urban and rural areas of the developing countries whose major occupation is agriculture, heavily depend upon water for their livelihood (Soussan, 2003; Renwick et al., 2007). However, they depend on one single scheme for all their water needs irrelevant of the supply design structure (Van Koppen et al., 2006; Mikhail & Yoder 2008). Majority of the households rely on single use water systems for multiple purposes in rural Africa, Latin America and Asia including Nepal (Van Koppen & Koppen, 2002; Hall et al., 2014) introducing conflicts over water use among the water users, inefficiency, risking water shortage and even causing premature system failure and breakdown (Van Koppen et al., 2006). As a response to this situation, more emphasis has been placed on the challenge of changing the sectoral boundaries within water sector to provide multiple use services since 1980s (Van Koppen et al., 2006). Accordingly a number of programmes such as the Challenge Program on Water and Food (CPWF), the MUWS innovator and the lead organization for MUWS development, began in 2003 and conducted action-research project named as "Models for multiple water use supply systems for enhanced land and water productivity, rural livelihoods, and gender equity" to develop and test guidelines for community-level implementation and upscaling of Multiple Use Water Systems in eight countries in five CPWF benchmark basins globally (Van Koppen & Hussain, 2007; Smits et al., 2010). MUWS is defined as "water services planning and design of new systems or rehabilitations that start with people's multiple water uses and reuses and needs at their preferred sites within communities" (Van Koppen et al., 2006). The construction of MUWS is same as any other drinking water scheme (Van Koppen et al., 2007). The only difference is the water quantities through design and infrastructure to supply additional water for small holder irrigation to meet multiple livelihood potential (Rautanen & White, 2013; Sharma et al., 2016), particularly in terms of health, freedom from drudgery, food and income (Van Koppen et al., 2007).

Nepal is one of the pioneering countries for MUWS planning and implementation with the first implemented MUWS in Palpa in 2003 by International Development Enterprise (IDE) Nepal with the objective of capacity building on high-value crop production, through micro-irrigation technologies and connection to markets for sale of the products, rather than developing water sources for farmers (Clement et al., 2015). Nepal has a number of MUWS being implemented particularly in the mid-hills of western, mid-western and far-western Nepal and a number of literatures and reports have indicated its benefits in the mid-hills of Nepal (Pant et al., 2007; Khawas & Mikhail, 2008; Mikhail & Yoder, 2008). However, there are few studies regarding equitable distribution of water supplied by MUWS in terms of caste, class and gender. Furthermore, MUWS studies on water quality are mostly on perception and incidences of water borne diseases (Pant et al., 2007). Although, the theoretical characteristics of MUWS implies that water quality is taken into account in the design of MUWS (Sharma et al., 2016), there are no scientific reports concerning water quality aspects of MUWS in Nepalese context. Water quality is equally important as water quantity as it determines the suitability of water for various purposes and affects the health and well-being of human beings to a great extent (Subramani et al., 2005). Besides, in recent years it has become clear that the condition of water resources in Nepal are deteriorating which further necessitates assessment and monitoring (Sharma et al., 2009) to ensure a safe and sustainable water supply system in Nepal (Adhikary, 1998; Whittingtonet et al., 2002). Therefore, pragmatic analysis of the performance of MUWS in its existing condition with different socio-economic settings and water quality for various purposes is necessary to confirm the effectiveness of MUWS. The present study is an attempt to analyze the implications of MUWS in terms of availability, accessibility, and quality in respect of drinking and irrigation water supplied by MUWS.

Materials and Methods

Study Area

The study was conducted in Annapurna Gaunpalika of Kaski District in Western Nepal. According to Dhikurpokhari Development Association, there are altogether nine functioning MUWS in Kaski District concentrated in Annapurna Gaunpalika. For our study, five MUWS and two drinking water schemes were selected with three MUWS located in Lumle and the rest located in Dhikurpokhari in Annapurna Gaunpalika (Figure 1). The total area of Annapurna Gaunpalika is 419 km^2. Dhikurpokhari and Lumle are situated 24 km and 32 km west from Pokhara respectively. Lying in the subtropical region, Lumle receives highest precipitation in Nepal with an average of 3551 mm/year. Agriculture remains the main source of income followed by remittance. Figure 2 shows the location of water supply tanks and natural sources of MUWS.

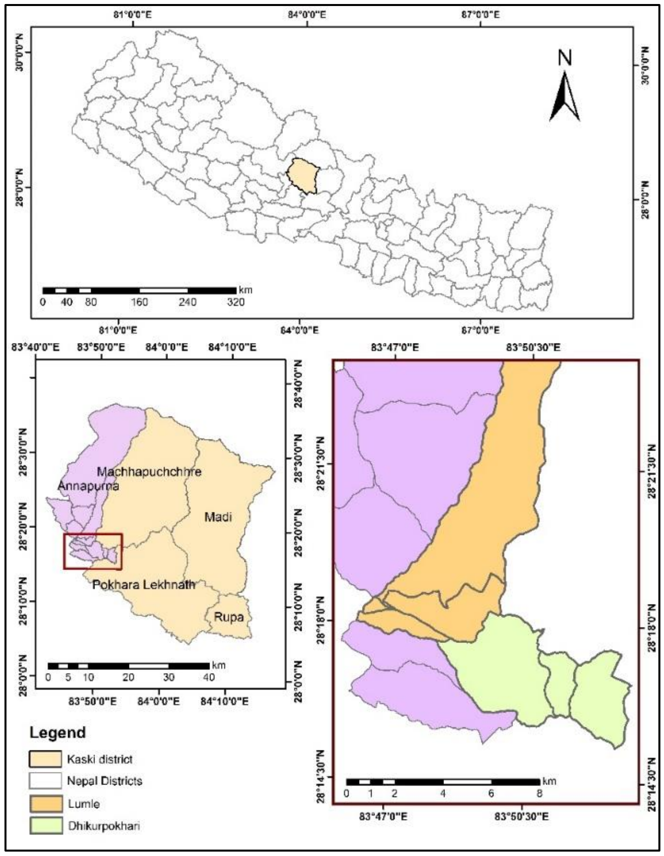

Figure 1 *Map of Nepal showing the study area*

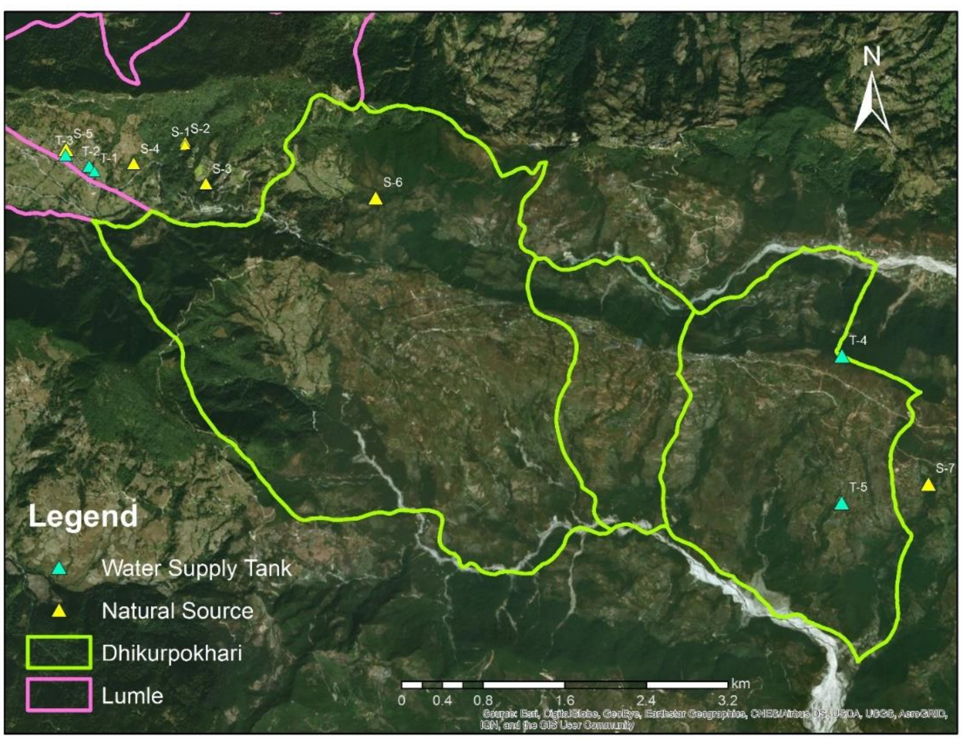

Figure 2 *Map of water supply tanks and natural sources of MUWS*

Data collection

At least 30% of the total households were randomly selected and surveyed for each water supply system using semi-structured questionnaire. A total of 150 households were surveyed among which 92 households were MUWS users and remaining 58 households were drinking water scheme users. Sample size distribution of MUWS and drinking water schemes are shown in Table 1 and Table 2 respectively. Key informant interviews were also carried out to understand the basic layout of the community; the institutional functioning of the water supply system; identify the beneficiaries of water supply system; natural water sources and water supply tanks of MUWS. The key informants for the study were program coordinator of Dhikurpokhari Development Association and water user committee members.

Data on water use, water access, food security, economic and health benefits before and after MUWS adoption were compared using descriptive statistical analysis and inferential statistical analysis whereas binomial logistic regression was performed for the comparison between MUWS and drinking water scheme. Statistical Package for the Social Sciences (SPSS, Version 18) was used to process and analyse the data obtained from questionnaire survey.

Table 1 *Sample size distribution of MUWS water user committee*

S.N.	Name of water user committee of MUWS	Village Development Committee	Total number of households using the scheme	Sample size
1	Subhakamana MUWS Samiti	Lumle	20	75%
2	Kalika Bahu Udeshya Khanepani Upabhokta Samiti Majhkhola	Lumle	36	47%
3	Batiko Dhara MUWS Samiti	Lumle	20	50%
4	Dalit Basti Sichaai Tatha Khanepani Upabhokta Samiti	Dhikurpokhari	72	39%
5	Majuwa Adhikari Dada Bahu Udeshya Khanepani Yojana	Dhikurpokhari	46	50%
Total number of households			194	48%

Table 2 *Sample size distribution of water user group of drinking water scheme*

S.N.	Name of water user group of Drinking water scheme	Village Development Committee	Total number of households using the scheme	Sample size
1	Namuna Khanepani Tatha Sarsafaai Upabhokta Samuha	Dhikurpokhari	56	77%
2	Lakuribot Khanepani Tatha Sarsafaai Upabhokta Samuha	Dhikurpokhari	26	58%
Total number of households			82	71%

Table 3 *Description of the studied MUWS*

Name of the scheme	Subhakamana MUWS	Kalika MUWS	Batiko Dhara MUWS	Maranchhe MUWS	Adhikari Danda MUWS
Gaunpalika and Ward no.	Annapurna-6	Annapurna-6	Annapurna-6	Annapurna-1	Annapurna-1
Technology	Gravity	Gravity	Gravity	Gravity	Gravity
Installation year (B.S.)	2067	2066	2069	2070	2072
Water source	Spring		Spring	Stream	Stream
Names of natural water sources	Gairi khoriya muhan (S-1) Paani khalta muhan (S-2) Melbot muhan (S-3) Syani padheri muhan (S-4)		Batiko dhara/padhero (S-5)	Maranchhe khola (S-6)	Majuwa khola (S-7)
Capacity of water supply tanks (litre)	T-1: 3000	Domestic (T-2): 6000 Irrigation: 6000	T-3: 8,000	T-4: 18,000	T-5: 20,000
Number of tapstands	20	Irrigation offtakes: 6 Domestic offtakes: 18	20	13	46
Monthly water tariff rate (Rs)	--	--	--	50	50
Financial contribution	iDE Nepal, community	iDE Nepal, community	iDE Nepal, VDC, community	Mount view church, ICCA/iDE, Peter Needhem, community	iDE Nepal, community
Initial investment per HH	NRs 2000+20 days labor	NRs 3,500+26 days labor	NRs 16,000 including labor	NRs 2,000+1 month labor	NRs 6,000+43 days labor
Water user committee members	Male: 0 Female: 7	Male: 8 Female: 3	Male: 5 Female: 2	Male: 9 Female: 4	Male: 6 Female: 3
Average daily water use (lpcd)	57	84	65	63	65
Type of MUWS	Intermediate MUWS				

Water Sample Collection

A total of 11 water samples, representing six natural sources and five water supply tanks of five MUWS, were collected from the study area during the dry season. The selected physical parameters such as pH, turbidity, temperature, total dissolved solids and electrical conductivity were measured using multi-parameter meters at the site right before water sample collection. GPS coordinates were recorded at each sampling site. Presence/Absence (P/A) vial test was performed to assess presence or absence of coliform. Water samples were analyzed for the parameters included in Nepal Drinking Water Quality Standard (NDWQS) (2005) applicable for rural surface water supply system following the procedure recommended in APHA (1995). Sodium Adsorption Ratio (SAR) value was calculated to determine the suitability of water for irrigation using the formula given below (Oster & Sposito, 1980).

$$\mathrm{SAR} = \frac{Na^{+}}{\sqrt{1/2(Ca^{2+} + Mg^{2+})}}$$

where the concentrations are reported in meq/l.

Results and Discussion

Implications of MUWS

The conventional design norms in domestic water supply system designed to cater domestic uses is 20-30 liter per capita per day (lpcd) which allows for hardly any productive use of water (Smits et al., 2010). However, due to lack of adequate water supply from domestic water scheme to meet domestic water needs i.e. 20-30 lpcd, the households obtained water from multiple sources such as stone water taps, well, streams, '*mul'*, and '*kholsa'*. The respondents had to make an average of 4 trips per day and even had to spend 2-3 hrs to collect water. They had to limit their basic domestic water needs, such as cleaning, washing and managing livestock which created unsanitary condition in the household. Vegetable production was rain-fed based and was sufficient for less than six months. Lack of maintenance of the previous water supply systems, particularly unrepaired pipelines and water outlets, and limited number of public taps resulted into lack of adequate water supply. Moreover the *Dalits* - the less privileged group- were facilitated with only one public tap stand while the *Brahmins* an*d the Chhetris* -the privileged groups- were provided with one tap stand for every six households. However, the implementation of Maranchhe MUWS in *2070 BS* (2014 AD) improved the situation of the *Dalits* with 13 public tap stands shared among 72 households.

The average daily water use increased from 25 lpcd to 61 lpcd. 50-100 lpcd or more is required to support multiple uses of water at a significant scale (Smits et al., 2008). Based on the MUWS ladder proposed by MUWS project (Van Koppen & Hussain, 2007), all the studied MUWS can be categorized as intermediate MUWS (Table 3). After MUWS adoption, majority of respondents (71%) reported to use water beyond domestic uses. MUWS have enabled proper hygiene and sanitation which decreased the incidence of water borne diseases. The availability of water by MUWS made the vegetables sufficient for 9-12 months (Figure 3). IDE introduced micro-irrigation technologies in conjunction with MUWS in hills to utilize limited water to grow small plots of vegetables for home consumption and for commercial purpose both on season and off season (Pant et al., 2007; Mikhail & Yoder, 2008; GC & Colavito, 2015).

However, only 3% of the respondents were found to apply water saving practice of drip irrigation. 30% of the respondents, who did not grow vegetables before MUWS adoption, started cultivating vegetables after MUWS adoption. Broccoli, zucchini, and carrot were newly introduced vegetables. Production of high-value crops, particularly cucumber, brinjal, cauliflower, tomato, cabbage and coffee increased to a greater proportion. Vegetable gardening is considered to be a cost effective way to fight food insecurity at the household level, by assuring a basis of home-grown food always accessible to the household's members (Bertelli & Macours, 2014). MUWS facilitated home vegetable production which improved nutrition level of the diet. Vegetable production also contributed to economic benefits which covered grocery expenses and even livestock purchase.

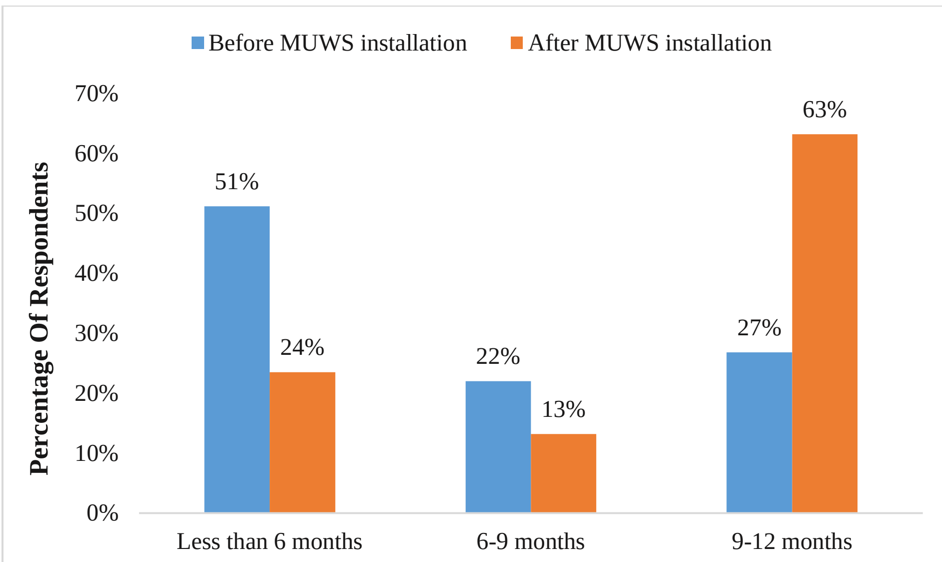

Figure 3 *Food sufficiency from own production before and after MUWS adoption*

After MUWS adoption, communities spent only 1-5 minutes for water collection. The respondents admitted that their water carrying efforts had decreased and they perceived decrease in their back pain. Time saving in turn benefitted women in particular since women are primarily responsible for water collection. Time saved was utilized for agriculture, household chores, managing livestock and childcare. However, despite being involved in income generation activities, majority (63%) of the respondents reported that women still have no access to financial decision making within their households. Smallholder Irrigation Market Initiation (SIMI), a collaboration of IDE and Winrock, recommends women to hold key positions such as chairperson, secretary, and treasurer in MUWS water user committee (Mikhail & Yoder, 2008). The inclusion of women in water user groups was seen as members but the only women entitled to participate in water users group in key leadership positions were found to be those with absence of adult male in the house. This is in contrast with the findings of GC &

Colavito (2015) who reported that women had access to financial decision-making, key leadership positions in MUWS user committee and even empowered to link with other agencies in the hills of Nepal.

MUWS considerably reduced drudgery of women and enabled to utilize their saved time in vegetable production, marketing and commercial activities, involvement in other income generation activities such as service, wage labor and shop; participation in different local development groups or associations and meetings held by water user committee, continuation of their studies, and learning skills such as sewing for income.

The respondents found the allocation of water equitable and fair for all ethnic groups. Since, there are no specific rules for water allocation in terms of quantity in the studied MUWS, water is used as per the need. It is only during the dry season when the discharge of some springs decrease and the maintenance period of MUWS when water users have to limit their water use. Basic domestic needs were found to be prioritized under scarcity and only after that, minimum water supplies for both domestic and productive activities for all. The core concept behind MUWS approach is that all domestic water needs must be satisfied before water is delivered for productive use (Mikhail & Yoder, 2008) and this basic norm of MUWS was observed to be followed in this study.

Factors Influencing adoption of MUWS

Different factors affecting the adoption of MUWS in the study area and the maximum likelihood estimates of the MUWS adoption model is presented in Table 4.

Table 4 *Maximum likelihood estimates of the MUWS adoption model*

Variables	Coefficient	S.E.	Sig.	Odds ratio
Caste	-0.073	0.353	0.001*	0.930
Gender	0.310	0.356	0.016**	1.363
Education of the respondent	0.224	0.240	0.002**	0.799
Occupation	-0.124	0.824	0.880	0.884
Area of land under vegetable production (Between 0.25 to 0.5 *ropani*)	-0.004	0.004	0.000*	0.596
Water storage facility	0.021	0.125	0.879	0.072
Time spent in water collection (min)	0.157	0.173	0.005**	2.170
Economic Benefit	0.002	0.001	0.020**	1.002

Hosmer and Lemeshow Test: Chi-square= 4.144, d.f. = 8, Sig. = 0.736, -2 Log likelihood = 211.763, Cox & Snell r^2 = 0.750; Nagelkerke r^2 = 0.72; overall percentage of right prediction = 83%; sample size = 150
* p<0.001, ** p<0.05

The results of the binary logistic regression model showed the indicators, magnitude and statistical significance of the estimated parameter for adoption of MUWS using the logistic regression model. The log likelihood is 212 and overall, the model correctly predicted 83% of the variation in the adoption behavior of the local people.

Four out of eight significant variables had a positive influence on the adoption namely: gender, education, time spent in water collection and economic benefit from vegetable (Table 4). Female respondents and respondents facing longer water collection time showed an inclination to adopt MUWS. The tendency of women to adopt MUWS can be attributed to reduction in women's work load and water collection time, a task typically assigned to women. This is in line with the study by Yehdego (2006) which revealed that women have strong inclination towards MUWS because the latter minimizes their water collection time and work load. Likewise, economic benefit from vegetable production and education level motivated the farmers to adopt MUWS. In contrast, the landholdings under vegetable production and ethnic group had a significant negative influence on the behavior of farmers towards the adoption of MUWS. The farmers having landholding for vegetable farming between 0.25 to 0.5 *ropani* showed the tendency to adopt MUWS. However, the less privileged ethnic group – the *Dalits*- owned landholding less than 0.25 *ropani* and showed lesser inclination towards MUWS adoption. This might be explained by the small total landholding (less than 0.5 *ropani*) with small landholding under vegetable production (less than 0.25 *ropani*), and the dependency of majority of respondents from *Dalit* group on remittance as the main source of income.

Water quality

Out of 11 water samples analyzed, values of all the physical and chemical parameters were within the permissible limits of the NDWQS (2005) and World Health Organization (WHO) except turbidity in water source of *Batiko Dhara* MUWS (S-5) and water supply tank of *Maranchhe* MUWS (T-4), and pH in water source of *Adhikari Danda* MUWS (S-7) (Table 5). Majority of the respondents (n=11) likewise perceived the water supplied by T-4 to be turbid. Microbial parameters were in compliance with those given by DWSS (2005) and WHO (2017) except in four sites where microbial contamination was observed. The presence of faecal pollution might be attributed to the vulnerability of distribution system to infiltration of faecally contaminated, non-potable water, including sewage. Considering the poor condition of water supplies and sources, it is likely that water collected and stored become contaminated due to unhygienic practices of collection, storage conditions and practices within the households (Faldetta et al., 2014).

Questionnaire survey also revealed that among those who suffered from diarrhoea in the previous month, majority of the respondents (n=7) were the consumers of *Subhakamana* MUWS. Likewise, the highest incidence of diarrhoea (n=9) in children under five was also observed in children who consumed water of *Subhakamana* MUWS. The incidence of typhoid was reported in all five MUWS with majority (n=4) being the consumers of *Kalika* MUWS. The incidence of diarrhoeal diseases and typhoid can be attributed to the lack of effective water treatment practices by consumers. A significant ($p>0.05$) relationship between willingness to treat drinking water and perception of water quality was observed. Hence, majority of the respondents perceived water to be good (n=68) and consumed water directly without using any treatment method (n=56) which might explain the probability of incidence of diarrhoea and typhoid.

SAR values were within the permissible guideline values of National irrigation water quality standards by CBS (2014). According to the classification of water given by Fipps (2003), all the water samples of our study fall in the low sodium hazard (Table 8). This implies that alkali or saline hazard is not anticipated to the crops. Therefore, water of the study area can be used for irrigation purpose on almost all soil without any hazard.

Table 5 *Parameters for drinking water quality*

Parameters	Units	Range	Mean ± SD	NDWQS (2005)	WHO
Turbidity	NTU	0.96-9.84	2.7 ± 2.65	5(10)	5
pH		6.1-7.3	6.85 ± 0.34	6.5-8.5	6.5-8.5
EC	µS/cm	33-57	42.42 ± 9.23	1500	--
TDS	mgL^{-1}	17.4-34.5	22.92 ± 5.05	1000	1000
Fe	mgL^{-1}	0.04-1.2	0.46 ± 0.33	0.3(3)	0.3
Mn	mgL^{-1}	0.01-0.08	0.02 ± 0.03	0.2	0.3
Cr	mgL^{-1}	0.05	0.05	0.05	0.05
Fl	mgL^{-1}	0.02-0.23	0.13 ± 0.08	0.5-1.5	1.5
NH_3	mgL^{-1}	0.84-1.51	1.01 ± 0.19	1.5	1.5
NO_3^-	mgL^{-1}	0.08-0.84	0.4 ± 0.34	50	50
Total Hardness	mgL^{-1}	15.8-29.9	19.82 ± 4.6	500	500
Ca	mgL^{-1}	3.2-6.4	4.22 ± 1.02	200	75
E. coli	MPN/100 ml	Present	Present	0	0

Table 6 *Parameters for irrigation water quality*

Parameters	Units	Range	Mean ± SD	NIWQS
pH		6.1-7.3	6.85 ± 0.34	6.5-8.5
EC	mS/m	3.3-5.7	4.24 ± 0.92	< 40
Fe	mg/l	0.04-1.2	0.46 ± 0.33	< 5
Mn	mg/l	0.01-0.08	0.02 ± 0.03	0.02(0.05)
Cr	mg/l	< 0.05	< 0.05	< 0.1
Fl	mg/l	0.02-0.23	0.13 ± 0.08	< 2
Na	mg/l	0.02-0.32	0.12 ± 0.08	< 70
SAR	meq/l	0.25-0.52	0.42 ± 0.09	< 2
Faecal coliforms	< 1 count/100 ml	Present	Present	0

Table 7 *Quality of irrigation water based on EC (Fipps, 2003)*

EC (μS/cm)	Classes of water	Water samples
< 250	Excellent	All water samples
250-750	Good	Nil
750-2,000	Permissible	Nil
2,000-3,000	Doubtful	Nil
3,000	Unsuitable	Nil

Table 8 *Alkalinity hazard classes of the water samples (Fipps, 2003)*

SAR	Sodium hazard of water	Classes of water	Water samples
1-10	Low	Excellent	All water samples
10-18	Medium	Good	Nil
18-26	High	Doubtful	Nil
>26	Very High	Unsuitable	Nil

Conclusion

All the studied MUWS were intermediate MUWS which fulfilled the water requirement required to support multiple uses of water at a significant scale. The adoption of MUWS has benefitted rural livelihood through better water availability, equitable distribution, increased water use, food security, economic benefits from vegetable production, health benefits, women involvement in income generation activities and local development groups. However, women lacked access to financial decision making within their households and key leadership positions in water user committee. Despite having equal access to water supplied by MUWS, the less privileged ethnic group, *Dalit* group, might not be able to make complete utilization of the productive use of water supplied by MUWS due to ownership of small land. Female respondents, respondents facing longer water collection time, farmers seeking economic benefit from vegetable production and respondents with higher education level have an inclination to adopt MUWS. Water supplied by MUWS was found to be suitable for irrigation but faecal contamination was found to be the key problem with drinking water.

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An Assessment of the Spatio-temporal Variation in Water Quality in Tinau River, Nepal

Bibek Shrestha[1,2], Samikshya Chhetri[1,2], Nischal Shrestha[1], Rajendra Bhandari[*1,2], Joyanto Routh[3], Subodh Sharma[1,2]

[1]Department of Environmental Science and Engineering, School of Science, Kathmandu University, Nepal
[2]Aquatic Ecology Center, Kathmandu University, Nepal
[3]Department of Thematic Studies – Environmental Change, Linköping University, Linköping, Sweden

[*]Corresponding Author: rajendra.vandari@gmail.com

Abstract

Tinau is a perennial rain-fed river which traverses the Mahabharat and the Siwalik ranges to reach the Terai in western Nepal. The river is affected by a number of stressors including riverbed extraction, damming, agricultural run-off and effluents from urban area including Butwal city. The study focused on select physical-chemical water quality characteristics and their spatio-temporal variation in six sampling stations in the river over three seasons in 2017-18. Temperature, pH, dissolved oxygen, turbidity, total hardness, orthophosphate, total phosphorus, lead, and zinc concentrations showed significant seasonal variations ($p<0.05$). Total nitrogen showed a statistically significant spatial variation ($p=0.016$). Higher monsoon runoff influences the concentration of chemical constituents of geogenic as well as anthropogenic (agricultural, urban) origins in river water. Compared with relevant national standards for water quality, the water was determined to be generally suitable for irrigation, generally unsuitable for drinking and unsuitable for aquaculture in terms of total hardness, ammonia, iron, lead, and zinc concentrations.

Keywords: Tinau river, Water quality, Spatio-temporal variation

Introduction

Tinau, a perennial rain-fed river originating in the Mahabharat hills in Palpa, traverses the geologically fragile Chure range to reach the lowlands of Terai in western Nepal (Kharel, 2002). Tinau watershed harbours large urban, commercial and industrial centres. The river meets 30% of Butwal's water demand (Pandey & Devkota, 2016). The river is affected by fragile geology and mass wasting processes (Dahal & Guragain, 2013) and anthropogenic stressors including intensive riverbed extraction (Dahal et al., 2012a), damming, agricultural run-off and effluents (Dahal et al., 2012b). Tinau is "in a degrading state before it reaches Butwal" and effluents from Butwal lead to further degradation of the river resulting in significantly high concentrations of some parameters such as lead, arsenic, and total dissolved solids downstream of Butwal (Dahal et al., 2012b).

Previous studies on the water quality of Tinau reported a favorable water condition (suitable DO, pH, temperature and total hardness) for diverse indigenous fish species for the stretch between Damkada and Chidiya Khola (Sharma, 1996). Jha et al (2007) assessed the immediate upstream and downstream of Tinau Dam to study the impact of dam on fish. Dahal et al (2012a) reported a decline in fish species richness and abundance mainly due to riverbed extraction and poisoning activities in an impacted stretch of the river. Dahal et al (2012b) studied water quality with respect to riverbed extraction in the stretch between the dam and Bethari and expressed concerns over the potability of water due to some key parameters such as arsenic, lead and TDS exceeding WHO (2006) standards. Meanwhile, Pandey & Devkota (2016) limited their study between Jhumsa and Butwal (near Chidiya Khola) inferring a general potability of river water. These studies have failed to consider spatial and temporal variations in water quality. This study focuses on the assessment of select physical-chemical characteristics of the river water and their spatio-temporal variation from the headwater to the lowland stretch, while including some sites unassessed in the previous studies.

Materials and Methods

Study Area

Tinau watershed has an area of about 562 km^2 ranging in altitude from 85 m (at Bangai) to 1,940 m above sea level (near Amile) and extending from 27°41' N to 27°52' N and 83°18' E to 83°42' E (Kayastha et al., 2012). It is a Class II (Adhikari, 2013), third-order river (Kharel, 2002; Guragain, 2012) flowing down south through the gorges in the fragile Chure hills to enter the Terai below Butwal (Dahal et al., 2012b). Dobhan Khola in the west, Bhainskatta Khola in the center-west and Jhumsa Khola in the east of the watershed are its major tributaries (Kayastha et al., 2012).

The drastic elevational range in the watershed has resulted in diverse climatic conditions with two broadly-categorized climatic zones – a subtropical zone (150-1,200 masl with average annual temperature of 20-35°C) and a warm temperate to humid zone (above 1,200 masl with average annual temperature of 10-30°C) with the annual rainfall varying from 1,500 mm in the north to 2,400 mm in the south, more than 80% of which occurs in the monsoon (June to September) (Kayastha et al., 2012). The discharge, highly influenced by the run-off during rainfall largely determines the river water quality (Dahal et al., 2012b). Heavy monsoon rains trigger mass wasting in this mountainous watershed, particularly due to its fragile and forming geology–alternate bands of hard and soft rocks, highly fractured rocks and deeply incised riverbanks (Kayastha et al., 2012).

Sampling and Analysis

Water samples were collected from six stations (selected based on accessibility and presence of stressors) in the river over three seasons – monsoon (28-29 July 2017), winter (1-2 January 2018) and pre-monsoon (22-24 March 2018) (Figure 1) (Table 1).

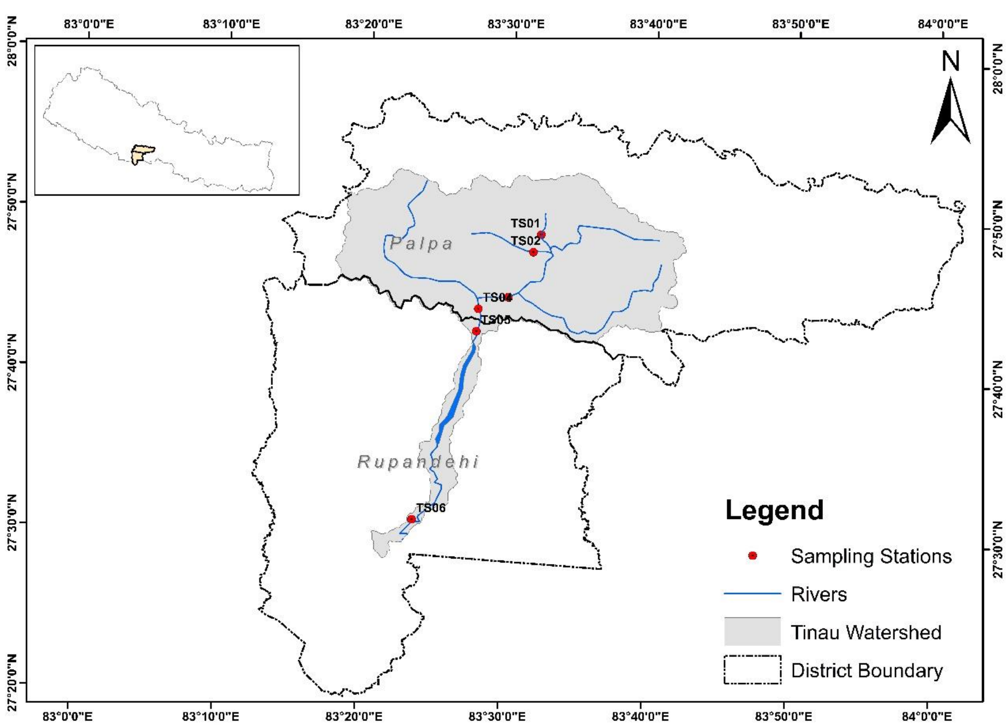

Figure 1 *Map of study area showing the sampling stations in Tinau watershed located in Palpa and Rupandehi districts*

Table 1 *Sampling stations and geographical coordinates*

Station	Location	Coordinates	Altitude
TS01	Bhalebas, Palpa	27.81500°N, 83.53555°E	755 m
TS02	Dumre Khola, Palpa	27.79805°N, 83.52689°E	634 m
TSO3	Jhumsa, Palpa	27.74950°N, 83.49947°E	294 m
TS04	Siddhababa, Palpa (Upstream of Dam)	27.73688°N, 83.46471°E	225 m
TS05	Chidiya Khola, Rupandehi	27.71315°N, 83.46323°E	165 m
TS06	Bangai, Rupandehi	27.51555°N, 83.39391°E	85 m

Selected physico-chemical water quality parameters such as pH, temperature, DO, EC and TDS were determined in-situ with pre-calibrated instruments. Water samples were collected in sterilized detergent-free sample bottles. Three 500 ml samples from each site were collected – without preservative, with 1.5 ml conc. HNO_3 (for trace metals) and; with 1.5 ml conc. H_2SO_4 (for total nitrogen and total phosphorus). The samples were labeled, stored and transported in an ice-box for further analyses. The samples were analyzed within one week of the collection at Aquatic Ecology Centre, Kathmandu University following standard laboratory protocols (APHA, 1998) (Table 2).

Table 2 *Chemical parameters analyzed in the laboratory and methods used*

Parameters	Preservative	Method used
Total Hardness as $CaCO_3$	Without preservative	EDTA titration
Calcium Hardness as $CaCO_3$	Without preservative	EDTA titration
Nitrite Nitrogen	Without preservative	Argentometric analysis
Nitrate Nitrogen	Without preservative	Screening and UV Spectrophotometry
Ammonia Nitrogen	Without preservative	Nesslerization and Spectrophotometry
Total Nitrogen	Conc. H_2SO_4	Kjeldahl method
Total Phosphorous	Conc. H_2SO_4	Potassium persulphate digestion and Spectrophotometry
rthophosphate	Without preservative	UV-Spectrophotometry (Colorimetry, Ascorbic acid)
Trace metals (Fe, Zn, Pb, Cd)	Conc. HNO_3	Atomic Absorption Spectrometry

The Shapiro-Wilk test was conducted to check for normal distribution of the datasets. As most of the datasets did not show a normal distribution, non-parametric Kruskal-Wallis H-test was carried out for assessing the significant seasonal and site-wise variation in water quality parameters followed multiple pairwise comparisons.

Results and Discussion

The results of the physical-chemical water quality parameters are presented in

Table **3**.

Table 3 Concentrations of physico-chemical water quality parameters of Tinau river

Parameters	S	Range	Mean ±SD	Parameters	S	Range	Mean (±SD)
Temperature (°C)	M	25.6-34.4	29.5±3.00	Calcium Hardness as $CaCO_3$ (mg/L)	M	62-136	96.333±31.53
	W	13.2-17.1	15.367±1.28		W	94-168	126.67±33.48
	P	20-25	22.9±1.909		P	76-172	99.333±36.85
pH	M	6.7-8.6	7.967±0.66	Nitrate-N (mg/L)	M	0-1.29	0.382±0.598
	W	8.22-8.7	8.527±0.18		W	0-1.13	0.348±0.54
	P	8.08-8.6	8.373±0.22		P	0-0.67	0.187±0.26
DO (mg/L)	M	8.58-12.85	10.828±1.99	Nitrite-N (mg/L)	M	0.001-0.006	0.002±0.002
	W	9.8-13	11.483±1.083		W	0.001-0.02	0.009±0.008
	P	7.7-11.2	8.967±1.3		P	0.004-0.03	0.01±0.012
Turbidity (NTU)	M	19.2-349	91.2±126.87	Ammonia-N (mg/L)	M	0.435-0.84	0.622±0.16
	W	1.4-5	2.667±1.28		W	0.14-0.96	0.462±0.35
	P	1.7-224	39.65±90.315		P	0.2-0.36	0.243±0.063
EC (µS/cm)	M	250.1-467	318.48±75.36	Total Nitrogen (mg/L)	M	0.28-2.12	1.012±0.78
	W	282-440	330.67±55.84		W	0.28-1.8	0.82±0.597
	P	279-411	338.67±57.75		P	0.28-3.39	1.688±1.36
TDS (ppm)	M	168-312.9	213.38±50.5	Orthophosphate (mg/L)	M	0.006-0.018	0.012±0.004
	W	195-292	222.67±35.22		W	0.002-0.006	0.002±0.002
	P	187-275	226.81±38.59		P	0.002-0.006	0.003±0.002
Total Hardness as $CaCO_3$ (mg/L)	M	114-184	147.33±24.58	Total Phosphorous (mg/L)	M	0.01-0.32	0.17±0.124
	W	184-274	230.33±34.77		W	0.15-0.3	0.227±0.07
	P	154-216	180±24.43		P	0.003-0.048	0.023±0.019
Iron (mg/L)	M	0.2-0.94	0.528±0.28	Zinc (mg/L)	M	0.04-0.07	0.053±0.014
	W	0.01-2.64	0.55±1.05		W	0.01-0.03	0.023±0.008
Lead (mg/L)	M	0.11-0.15	0.135±0.02	Cadmium (mg/L)	M	0-0.03	0.013±0.014
	W	0.09-0.11	0.102±0.01		W	0-0.02	0.012±0.01

M (Monsoon); W (Winter); PM (Pre-monsoon) for the seasons (S); SD denotes Standard Deviation

Water temperature increased progressively towards the downstream sites and increased seasonally from winter to pre-monsoon and monsoon; the water remained warm (above 20°C) except in the winter. The pH remained in a range of 6.7-8.7 over the seasons and along the length of the river. However, from winter to the monsoon, the average pH decreased slightly (from 8.37 to 7.96) in contrast to the generally lowest pH in the winter reported by Pandey & Devkota (2016) and Dahal et al (2012b). Also, the drop in pH observed by Dahal et al (2012b) which they attributed to massive riverbed extraction and increased pollution after 2002, especially in the stretch downstream of Butwal (Chidiya Khola) is supported by the lower pH observed for Chidiya Khola-Bangai stretch in 2017-18. The DO generally remained over 8.0 mg/L in all the stations round the year. Although there appears to be a declining trend of DO from the upstream to the downstream reaches in the winter and monsoon, such a trend is not apparent in the pre-monsoon when the average DO is the lowest for the river. Although the highest DO levels in the winter correspond with the lowest water temperatures in winter, the lowest DO levels do not occur in the monsoon when the average water temperature was the highest. EC was consistently the highest in the most downstream site as it increased progressively from the upstream stretches in all the seasons, indicating a general increase in the load of pollutants from agricultural run-off, effluents and the effect of flushing of minerals from the riverbed mining activities from the upstream reaches. This observation is in agreement with that by Dahal et al (2012b). However, the observed EC values were much higher (250-467 µS/cm) compared to all the previous data (below 100 µS/cm) by Dahal et al (2012b) and by Pandey & Devkota (2016). TDS showed trends similar as EC in all respects. However, in stark contrast to EC, the observations by Dahal et al (2012b) were higher (mean: 468.50 mg/L; range 200-1200 mg/L) compared to the observed range of 168-312 mg/L. Average turbidity was much higher in the monsoon than in pre-monsoon and winter confirming the high sediment load associated with the drastically higher monsoon discharge and consequently increased erosion and mass wasting processes in the Chure catchment. In other seasons, the water remained fairly clear (turbidity below 5 NTU) at all the stations except in the lowermost station in the pre-monsoon, probably because of the direct influence of riverbed mining in the Chidiya Khola-Bangai stretch of the river during the low-flow period.

Calcium hardness was found to be the highest in winter followed by pre-monsoon and then monsoon; total hardness showed a similar trend across the seasons (Figure 2). Calcium hardness was found to be the major cause of hardness of the river water (contributing to at least about 50% of the total hardness).

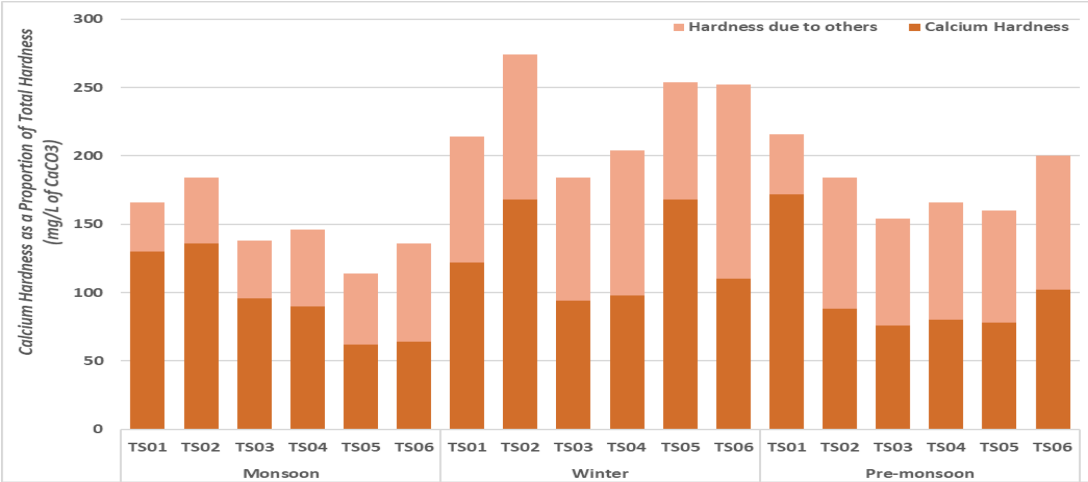

Figure 2 *Calcium hardness as a proportion of total hardness in the sampling stations in three seasons*

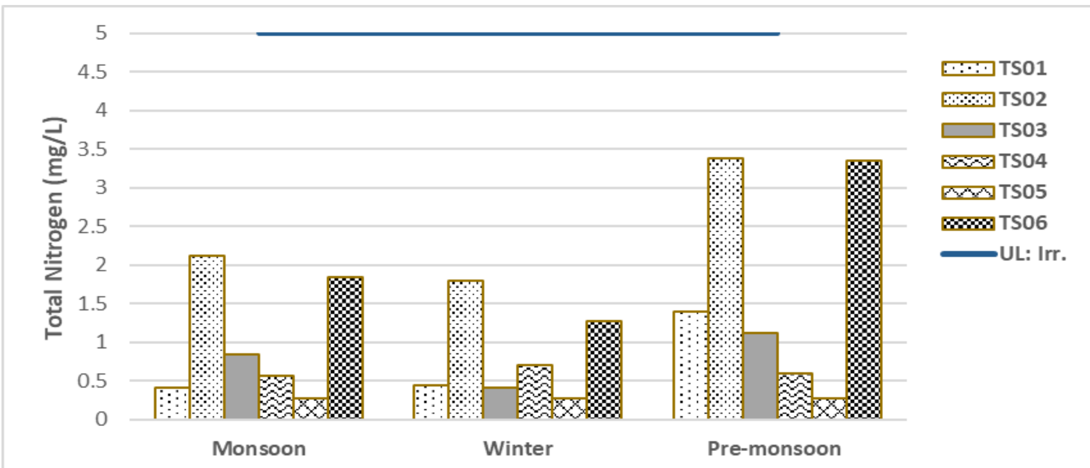

Figure 3 *Total Nitrogen concentration in the sampling stations in three seasons*

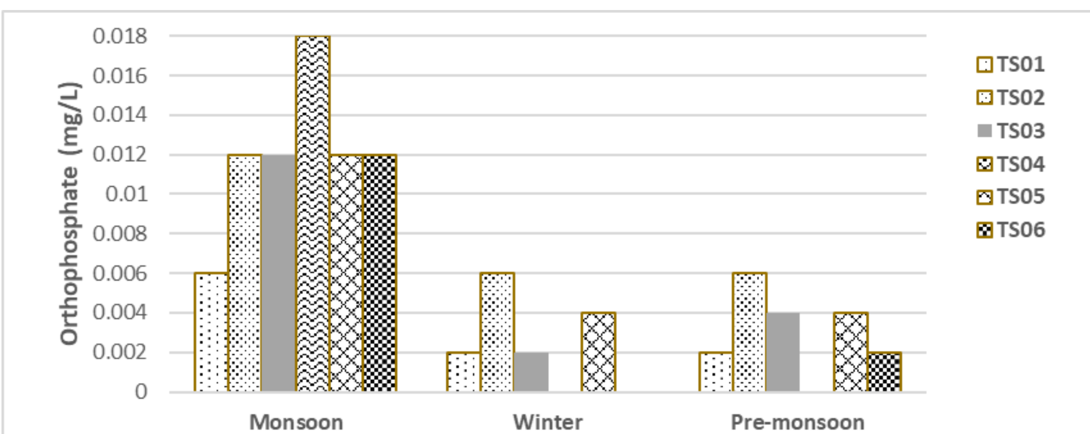

Figure 4 *Orthophosphate concentration in the sampling stations in three seasons*

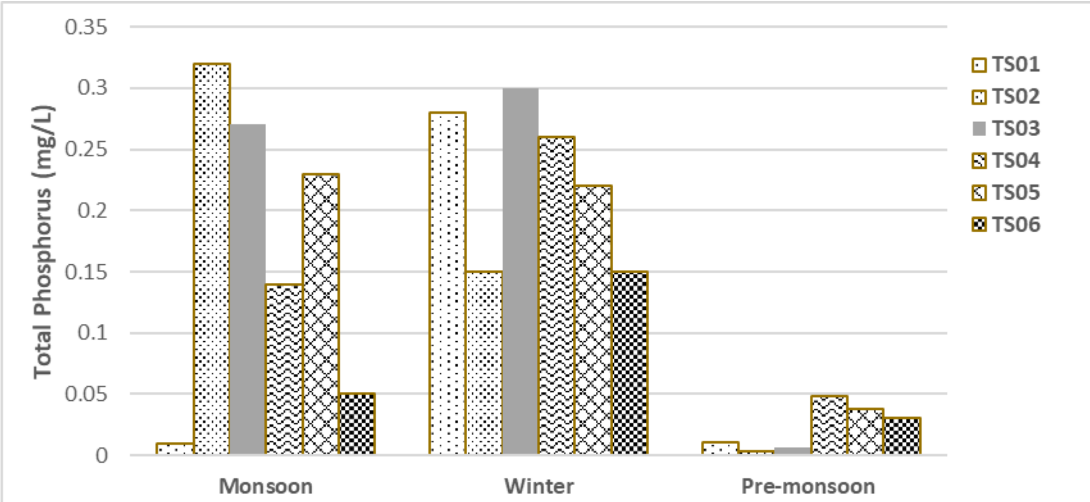

Figure 5 *Total P concentration observed in the sampling stations in three seasons*

Nitrate-N was observed below detection limits (<0.05 mg/L) for 11 observations out of 18. It was detected in all the seasons at TS06, in monsoon and winter at TS02 and in pre-monsoon at TS01 and TS04 which were both affected by impoundment of widely varying degrees. The average concentration was the highest in monsoon (0.382±0.598 mg/L) which may be attributable to the agricultural run-off from the farms (WHO, 2006), especially because monsoon coincides with the cultivation of paddy – a major crop in river basins and plains which demands input of chemical fertilizers and organic manure like animal waste, the major sources of nitrate (WHO, 2006). Nitrite concentration was the highest in pre-monsoon followed by winter and lowest in monsoon while ammonium-N concentration was the highest in monsoon followed by winter and the lowest in pre-monsoon. Total nitrogen concentration was the highest in pre-monsoon and the lowest in winter (Figure 3). Pandey & Devkota (2016) observed that nitrogen concentration in the river showed lower average values (0.76±0.15, 0.66±0.14 and 0.629±0.34 mg/L in monsoon, winter and pre-monsoon respectively). Remarkably, total nitrogen was the only parameter that showed a statistically significant (p=0.016) station-wise variation (especially between TS02 and TS05).

Orthophosphate concentration was the highest in monsoon and lowest in winter. The stations TS02, TS03, TS05 and TS06 showed same levels of orthophosphate in monsoon which was higher than the overall average of 0.006±0.005 mg/L (Figure 4). These concentrations were much lower than those reported by Pandey & Devkota (2016) (1.135±0.18, 1.10±0.25 and 0.76±0.06 mg/L from monsoon to pre-monsoon through winter). In contrast to orthophosphate, total phosphorus showed the highest concentration in winter followed by monsoon and pre-monsoon (Figure 5). Dahal et al (2012b) reported the maximum concentration in post-monsoon, followed by similar average values in winter and pre-monsoon and the lowest average in monsoon.

The mean concentrations of the assessed trace metals were generally higher in the monsoon than in the winter. Dahal et al (2012b) reported lower iron concentrations with a mean of 0.28 mg/L (range 0.01-0.6 mg/L) but higher lead concentrations (range 0.008-0.075 mg/L) with the maximum concentration at Bethari (near the most downstream site) in the winter.

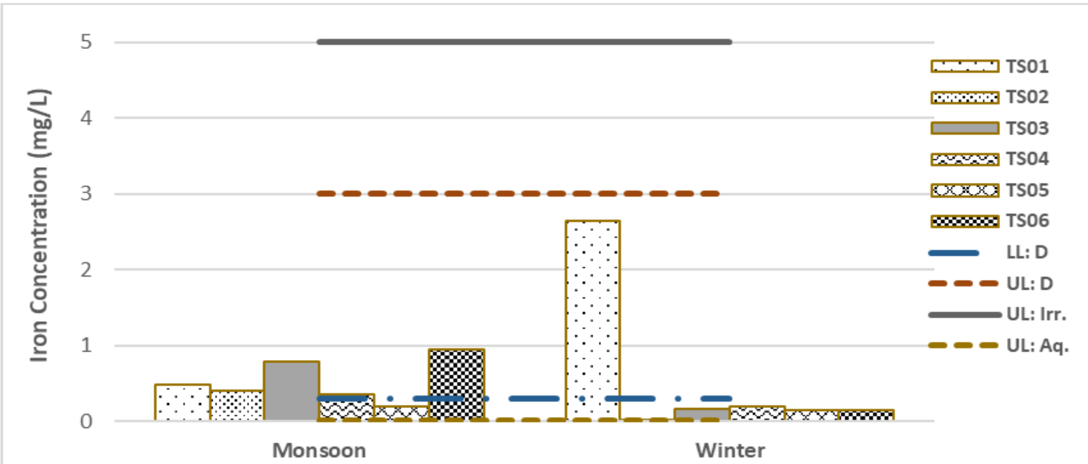

Figure 6 *Iron concentration in the sampling stations in two seasons*

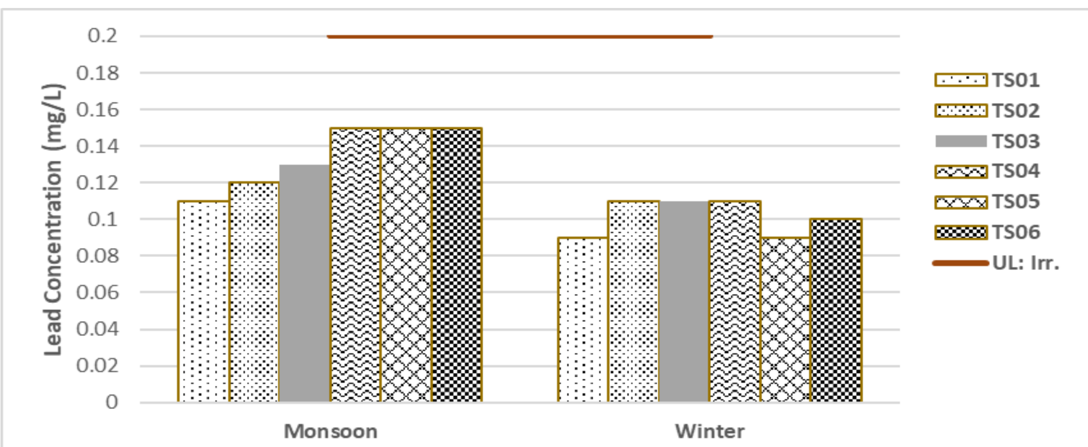

Figure 7 *Lead concentration in the sampling stations in two seasons*

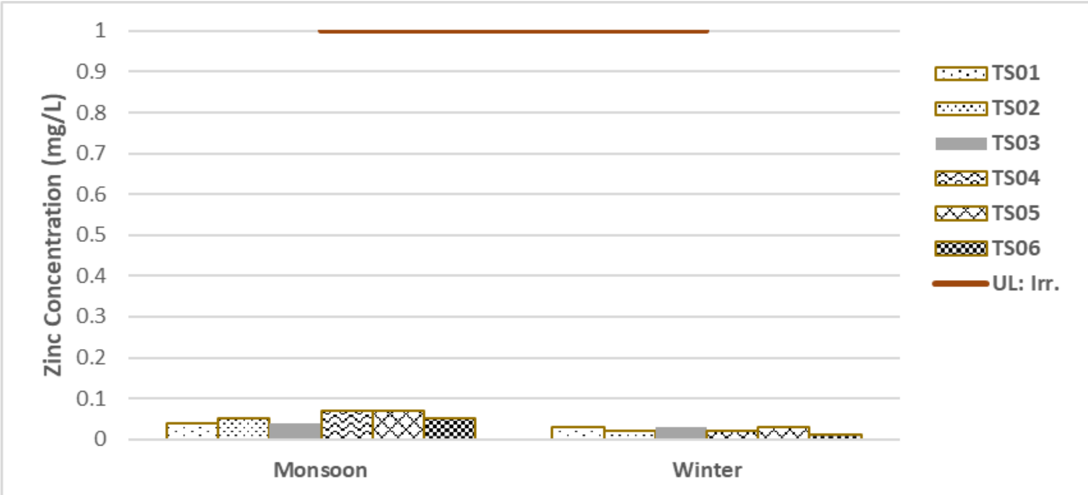

Figure 8 *Zinc concentration in the sampling stations in two seasons*

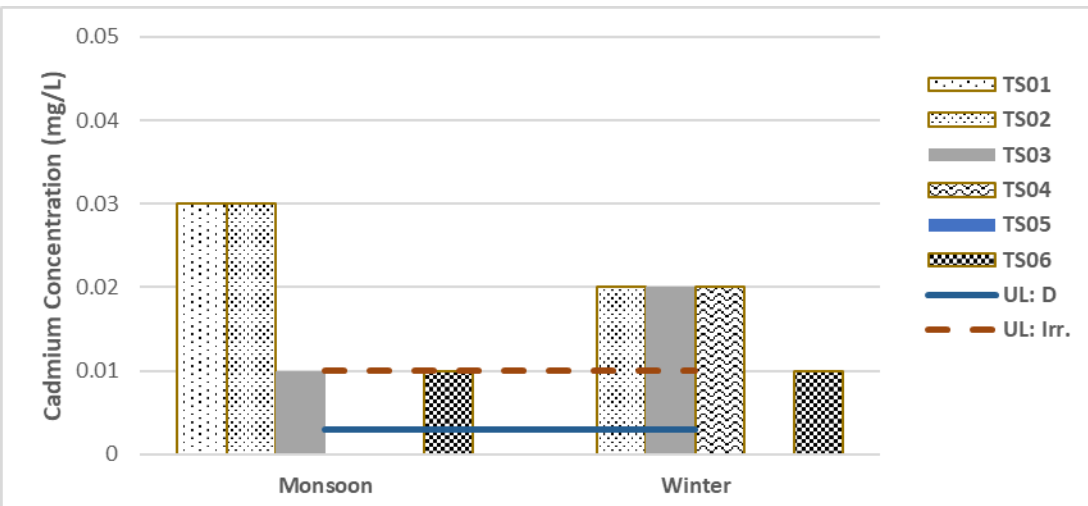

Figure 9 *Cadmium concentration in the sampling stations in two seasons*

The temporal variation (among the seasons) was statistically significant ($p<0.05$) for nine parameters assessed – temperature, pH, DO, turbidity, total hardness, orthophosphate, total phosphorus, lead and zinc. Seasonal variation in discharge – higher runoff and consequently high sediment load in the monsoon largely influences the concentration of chemical constituents of geogenic as well as anthropogenic (agricultural, urban) origins in the river water. However, spatial variation (among the stations) was statistically significant ($p<0.05$) only for total nitrogen which may be linked to the variation in surrounding land-use summed with the combination of natural and anthropogenic nitrogen-rich inputs (agricultural fertilizers and effluents) in various sampling sites. The reason for non-significant spatial variation for most other parameters could be the smaller spatial coverage (smaller size of the watershed) resulting in a low retention time of the river water in the catchment.

Conclusion

The water quality of Tinau river varied widely over the three seasons (monsoon, winter and, pre-monsoon in 2017-18) in terms of pH, temperature, DO, turbidity, total hardness, orthophosphate, total phosphorus, lead, zinc showed statistically significant seasonal variations. A significant variation across the stretch of the river from Bhalebas, Palpa to Bangai was observed only for total nitrogen. Among the parameters assessed, turbidity, lead and cadmium concentrations exceed the prescribed limits for drinking water in Nepal's National Drinking Water Quality Standards, 2005 (GoN, 2013) making the water unfit for drinking without treatment. The water was determined generally suitable for irrigation as per the standards in Nepal Water Quality Guidelines for Irrigation Water, 2008 (GoN, 2013) but unsuitable for aquaculture of fish due to total hardness, ammonia, iron, lead and zinc concentrations exceeding the prescribed limits in Nepal Water Quality Guidelines for Aquaculture, 2008 (GoN, 2013).

Acknowledgment

The authors would like to acknowledge the support of Swedish Research Council for funding the research project 'FOCOS' (The Fate of Organic Carbon in Small Mountain Rivers in the Himalayas: Implications for Soil Erosion and Climate Change) administered by Aquatic Ecology Center, Kathmandu University, under which this research was carried out.

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Seasonal Variation of Functional Feeding Groups and Notation of Its Corresponding Stream Ecosystem Attributes in the Headwaters of Bagmati River, Nepal

Anu Rai[1], Ram Devi Tachamo-Shah[1], Carol Milner[2] and Deep Narayan Shah[3*]

[1]Aquatic Ecology Center, Kathmandu University, Dhulikhel, Nepal.
[2]Biosphere Association, UK.
[3]Central Department of Environmental Science, Tribhuvan University, Kirtipur, Nepal.

*Corresponding author: dnshah@cdes.edu.np

Abstract

The ecological integrity of rivers is often assessed by using a range of river health assessment approaches involving both biological and physico-chemical parameters. Especially, the Functional Feeding Groups (FFGs) of macroinvertebrate communities can be used as surrogates for ecosystem attributes to assess the ecological conditions of streams. The FFGs ratio change as the relative dominance of various food resource changes spatially or temporally. So, seasonal change in ecosystem attributes can be noted by studying the seasonal change in FFGs. This study was conducted to study the seasonal variation in FFGs in the headwaters of Bagmati River lying in Shivapuri Nagarjun National Park, Nepal and to relate these to differences in ecosystem attributes as predicted by macroinvertebrate assemblages. The samples were collected following multi-habitat sampling approach; identified and assigned FFG category. The composition of Functional Feeding Groups was in agreement with the predicted stream function. A balance between predators to prey was seen in all sites in both seasons except one site where an overabundance of predator was found. Seasonal change in FFGs ratio and their notation of ecological attribute was found but none of the relationship was statistically significant however; the change in season have often led to changes in flow and temperature in aquatic system which has greatly influenced the biological timing, growth and development of many macroinvertebrates Overall, in all sites and in both seasons, strongly to very strongly heterotrophic nature was found. Since, the macroinvertebrates are critical part of the food web, the changes in its composition can have important implications to river health.

Keywords: Benthic macroinvertebrates (BMIs), Functional feeding groups (FFGs), River continuum concept, Ecosystem attributes, Heterotrophic nature, Predator to prey relationship.

Introduction

Described almost 50 years ago, the Functional Feeding Groups (FFGs) are a classification approach of benthic macroinvertebrates that categorizes taxa according to their morpho-behavorial adaptation to food acquisition (Cummins, 1973). The basic food categories of invertebrates include Coarse Particulate Organic Matter (CPOM) - particles greater than 1 mm in size and include leaf litter and other terrestrial plant parts; Fine Particulate Organic Matter (FPOM) - particles ranging between 0.5 µm to 1 mm size and includes particles reduced through physical and/or biological reduction of CPOM; periphyton - algae attached to stones, wood or plant surfaces and prey which predominantly includes small invertebrates consumed by predators. Functional Feeding Groups consume different food resource so, the FFG approach can give a direct link between availability of food resource and the invertebrates dependent on them (Merritt & Cummins, 1996; Merritt et al., 2002; Cummins et al., 2005). The food availability is itself a result of ecosystem attributes of a stream. So, the Functional Feeding Groups (FFGs) of macroinvertebrate community can also be used as surrogates for ecosystem attributes to assess the ecological conditions of streams (Merritt et al., 2002; Cummins et al., 2005).

Based on the food categories, the FFGs include scrapers which consume periphyton; shredders which consume riparian derived plant litter; filtering-collectors which consume FPOM from the water column; gathering-collectors which consume FPOM from the stream bottom; and predators feeding on other consumers (Figure 1). Assigning FFG category to a macroinvertebrate requires taxonomy only to the level to detail sufficient for categorization (Merritt & Cummins, 1996; Merritt et al., 2002; Cummins et al., 2005; Cummins, 2016). For instance, all Odonata are predators but the classification of other macroinvertebrates may require lower level of taxonomic resolution with some key features making it easier for assignment such as Ephemeroptera with an oval, dorso-ventrally flattened body are scrapers (Cummins, 2016).

As the relative dominance of various food resource changes, there also occurs associated change in the corresponding ratios of the Functional Feeding Groups. Both spatial and temporal changes in functional organization of invertebrates occur. This is the central theme of the River Continuum Concept (RCC) (Vannote et al., 1980). On spatial front, RCC assigns different sections of a river into three rough classifications – headwaters, mid reaches and lower reaches. Theoretically, in the headwaters, shredders are hypothesized to be co-dominant with collectors; in the mid reaches the collectors and grazers should make up the majority of the macroinvertebrate structure; and the lower reaches should be mostly composed of collectors. Likewise, on the temporal front, the change in season often lead to changes in flow and temperature in aquatic systems. Such changes can accentuate differences in water quality and habitat characteristics which can influence structural and functional organization of macroinvertebrates basically through change in Functional Feeding Groups (FFGs). For instance, as predicted by RCC, the shredders are hypothesized to be high in winter whereas scrapers are predicted to be high in summer season (Vannote et al., 1980). Such change occurs because the macroinvertebrates capitalize the availability of different food resources.

Likewise, the ratios of various FFGs can be used as surrogates for ecosystem attributes to assess the ecological conditions of streams such as balance between autotrophy and heterotrophy; linkage between riparian inputs and stream food webs; availability of different forms of Fine Particulate Matter (FPOM); channel stability; and top-down control among others (Vannote et al., 1980; Cummins et al., 2005; Merritt et al., 2017). The ratios can be compared with proposed thresholds to produce a qualitative evaluation of stream ecosystem health. The ecosystem attributes are difficult and time-consuming to measure directly so, the use of FFGs ratios serves as a rapid and integrating technique of characterizing the ecological condition of stream which can provide critical data with much less effort. The objective of the study was to compare the seasonal differences in macroinvertebrate FFGs ratios and relate these to differences in ecosystem attributes as predicted by macroinvertebrate assemblages.

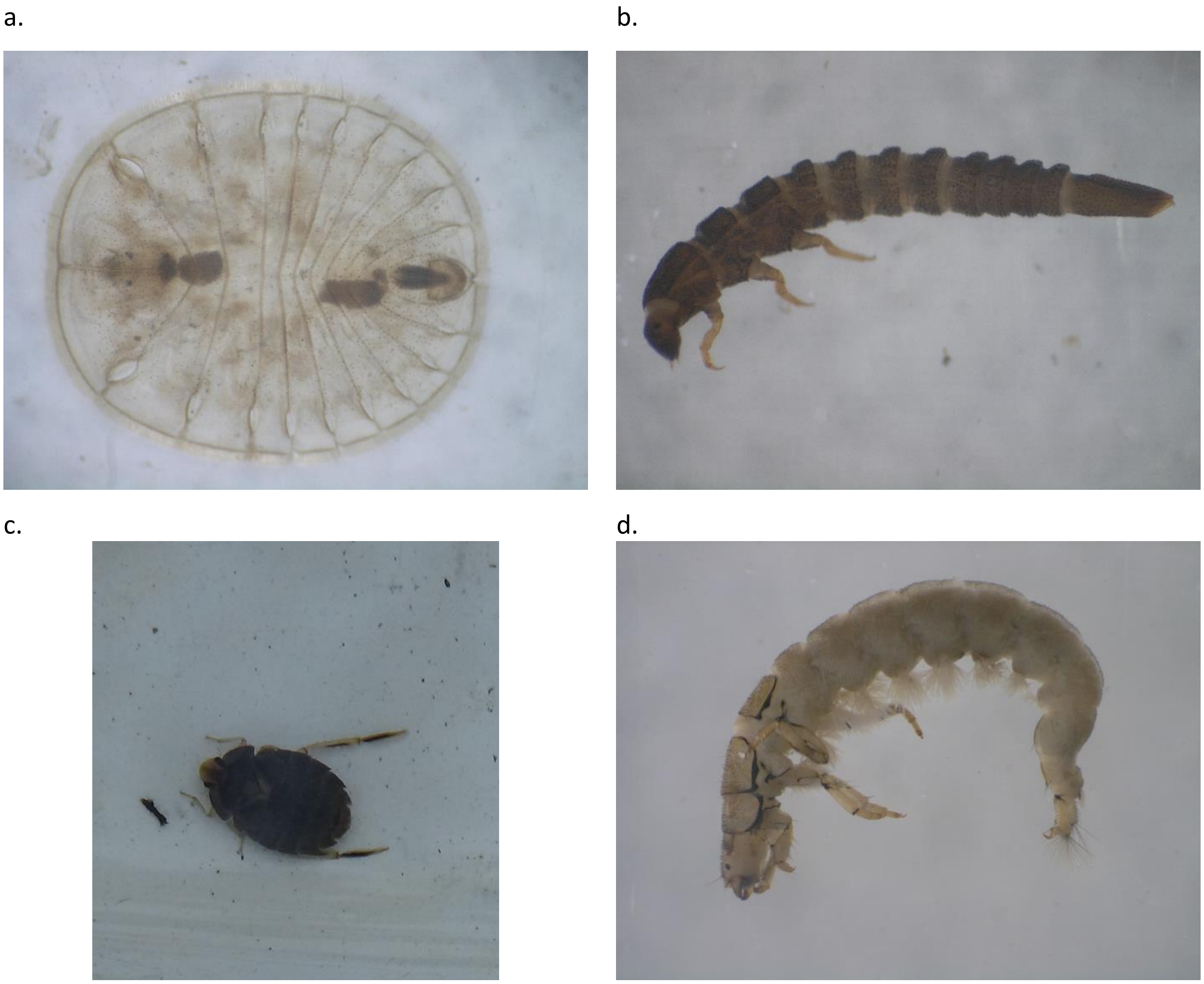

Figure 1 *Representative stream Functional Feeding Group taxa.*
a. Scraper (Coleoptera: Psephenidae), b. Collector-Gatherer (Coleoptera: Elmidae), c. Predator (Heteroptera: Aphelocheridae) and d. Collector-Feeder (Trichoptera: Hydropsychidae)

Materials and Methods

Study Area

The study was conducted in the headwaters of Bagmati river in its two tributaries - Bagmati (sampling points BA01 and BA02) and Nagmati (sampling points NA01 and NA02) (Figure 2). The average temperature of the study sites range from 12-13 °C (a data produced from a one-year average, collected using temperature logger placed at the study sites) (unpublished data (Him Bio Clic, 2019)). The catchment area of the study sites are 12.7 km^2 for site NA02, 9.15 km^2 for site NA01, 14.2 km^2 for site BA02, 2.7 km^2 and for site BA01 (Rai, 2018). The average water discharge of Bagmati stream was 0.16

m^3/s in pre-monsoon and 0.51 m^3/s in post-monsoon season (based on three months average in 2016) while the average water discharge of Nagmati stream was 0.19 m^3/s in pre-monsoon and 0.43 m^3/s in post-monsoon season (based on three months average in 2016) (unpublished data (Him Bio Clic, 2019)). The dominant land cover type in the study sites is forest with a mean coverage of 86.79% followed by cultivated, developed and barren land cover types covering 3.86%, 3.65% and 1.46% respectively (Rai, 2018). A more thorough description of the sites is given in Rai et al (2019).

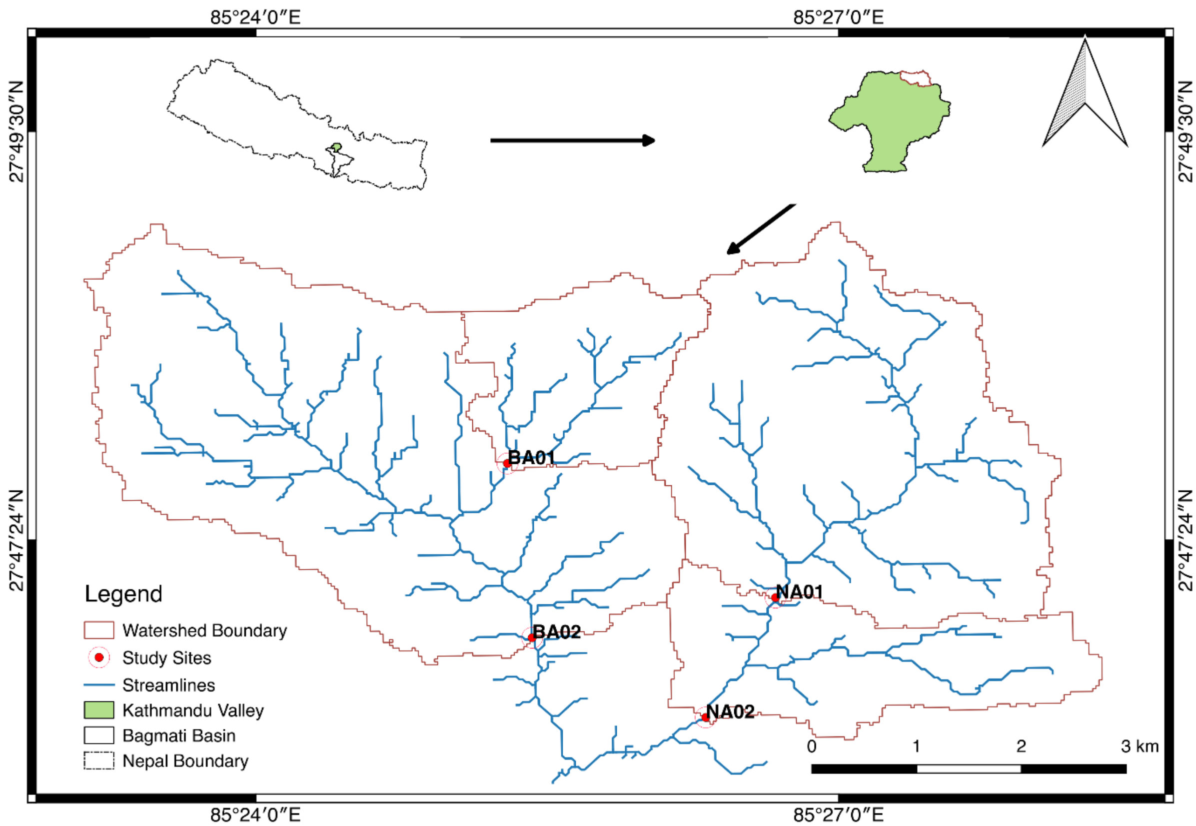

Figure 2 *The locations of the four sampling sites distributed in Nagmati (NA01, NA02) and Bagmati (BA01, BA02) Streams*

Data collection

Benthic macroinvertebrates (BMIs) sampling was conducted in pre-monsoon in May and post-monsoon period in November, 2016. Multi-habitat sampling (Moog, 2007) approach was adopted. It is an enhancement over the traditional sampling procedures as it involves sample collection across all major habitats (Barbour et al., 2006). Before sampling the river bed habitat coverage within 100 m of the river stretch was estimated. Substrate consisting of at least 5% habitat coverage were sampled and the sampling effort was proportionally allocated across all major habitat types present in the study sites. The BMIs were collected by using a kick net of 500µm mesh size. In total, samples from 20 micro-habitats were collected and composited into a single sample. The samples were spread out in a tray and washed thoroughly. The large organic matters like twigs and other material like cobbles or stones were removed. These samples were then transferred to a plastic container and labelled with site codes and date. The samples were then preserved using 5% formaldehyde in the field.

Laboratory analysis

In the laboratory, the BMIs samples were sorted and identified to Family level following Bouchard (2004), Nesemann et al (2007) and Nesemann et al (2011). Then they were counted and preserved in 90 percent ethanol.

The Functional Feeding Groups were assigned following Merrit & Cummins (1996) and Cummins (2016). The richness of different FFGs were calculated using filter function (dplyr package and count_ if function in expss package) and abundance was calculated using the sum function in RStudio Version 1.1.463. The ratios of various FFGs based on numerical abundance was calculated and ratios were used as surrogates for ecosystem attributes.

Table 1 *Ecosystem attributes denoted by various FFGs ratio*

S.N.	Ecosystem attribute	FFGs ratio	Threshold
1	Production [P]/Respiration [R] index - balance between autotrophy and heterotrophy	The ratio of scrapers to (shredders + total collectors)	>0.75 - Autotrophic
2	Course Particulate Organic Matter (CPOM)/ Fine Particulate Organic Matter (FPOM) - linkage between riparian inputs and stream food webs	The ratio of shredders to total collectors	>0.25 – Normal shredder association with riparian zone
3	FPOM in transport (suspended) (TFPOM)/ FPOM storage in sediments (deposited in benthos) (BFPOM)	The ratio of filtering collectors to gathering collectors	>0.5 – FPOM in transport suspension greater than normal particulate loading in suspension.
4	Channel stability	The ratio of (Scrapers +Filtering collectors) to (Shredders + Gathering collectors)	>0.5 – Stable substrate plentiful.
5	Top-down predator control	The ratio of predators to prey (total of all other groups).	0.1 - 0.2 - a normal predator-to-prey balance, >0.2 - an overabundance of predators.

(Merritt & Cummins, 1996; Merritt et al., 2002; Cummins et al., 2005)

Results and Discussion

Change in Functional Feeding Groups

The post-monsoon season had higher abundance as well richness of FFGs though the increase was very small. In both seasons, the relative richness and abundance of collectors were found to be the highest (Figure 3 and Figure 4). But the co-dominance of collectors and shredders as hypothesized (Vannote et al., 1980; Cummins, 2016) was not found. The co-dominance of shredders and collectors were also not found in a study conducted by Bunn (1986) with explanation of such deviance arising through restriction of sampling riffle areas as opposed to pools and debris dams where CPOM accumulate. Similar substrate types have similar faunal assemblages. For instance, in a study by Oliveira & Nessimian (2010), collector-gatherers were found dominant in pool substrates along with shredders whereas collector-filterers and scrapers were dominant in riffle and hard substrate respectively. Perhaps the FFG study requires sampling with equal distribution of substrates rather than a proportional one.

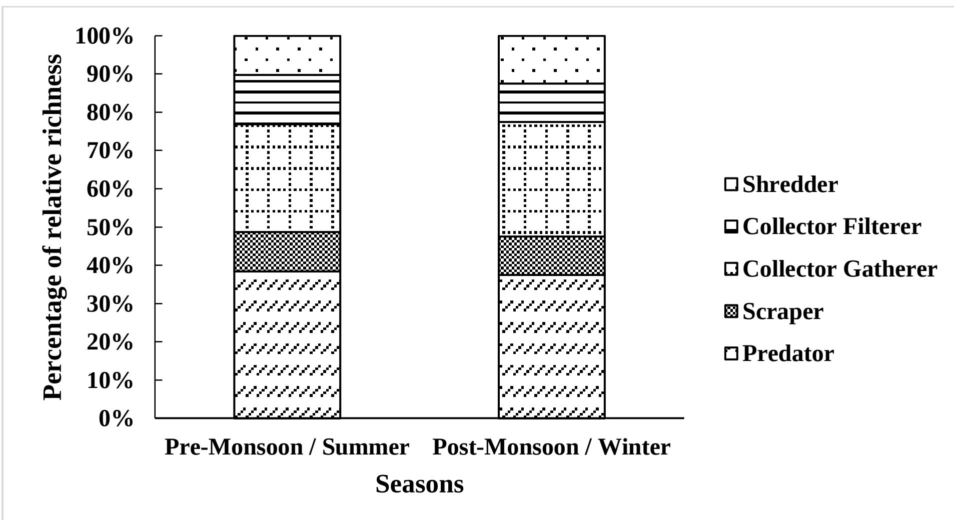

Figure 3 *The relative richness of various Functional Feeding Groups found in the study sites in pre-monsoon and post-monsoon season*

Besides, overall abundance wise, the highest change was seen in Collector-Feeder FFG having increased to 343% in post-monsoon season as opposed to pre-monsoon season and least change was seen in predator FFG having increased only 51% in post-monsoon season as opposed to pre-monsoon season. Only the scraper FFG seems to have declined in post-monsoon with decline of 56% in comparison to pre-monsoon.

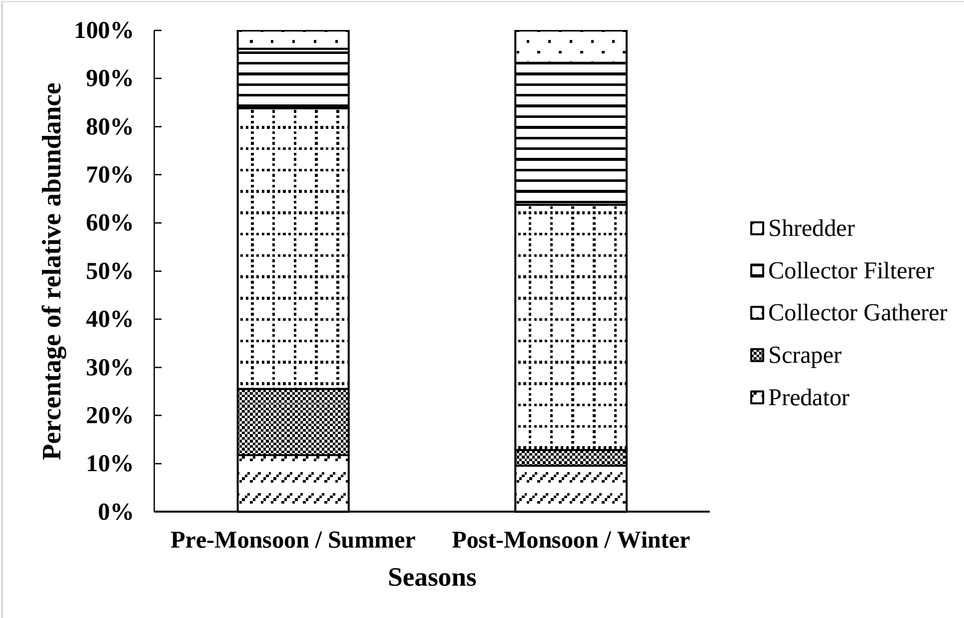

Figure 4 *The relative abundance of various Functional Feeding Groups found in the study sites in pre-monsoon and post-monsoon season*

The temporal changes in the composition of FFGs were in agreement with the predicted stream function (Cummins, 1973; Vannote et al., 1980). The abundance of shredder was high in the winter season capitalizing on the leaf fall. The collectors were found to be comparatively higher in post-monsoon especially collector-filterer had higher net increase in post-monsoon because when flow is high the particulate matter would be suspended in water column providing more food source to this FFG. Likewise, the abundance of scraper was high in the summer season as predicted by RCC. The primary production is stimulated in the summer due to higher water temperature and light intensity which should have increased the scraper abundance (Minshall, 1978; Vannote et al., 1980). Similarly, the abundance of predator was comparatively higher in post-monsoon than pre-monsoon perhaps due to higher abundance of other FFGs in the post-monsoon as well. But the relative abundance of predators seems low in post-monsoon because of the overwhelming increase in collectors.

Ecosystem attributes as predicted by macroinvertebrate assemblage

All sites in both seasons, were found to be strongly to very strongly heterotrophic (Table 2). This result is consistent with the River Continuum Concept which states that headwaters are mostly heterotrophic in nature. A very strong heterotrophic nature was mostly seen in winter or post-monsoon season meaning the productivity of stream declines in winter. The amount of light could probably be the reason of such seasonal difference. The availability of light has shown to be a driver of such seasonal variation (Mulholland et al., 2001; Bernot et al., 2010; Lupon et al., 2016). Likewise, in both seasons, shredders had either poor or very poor link with the riparian. This represents a problem in the riparian litter supply but sites being surrounded by forest and having a heterotrophic nature contradicts this assessment. Perhaps the litter was not suitable for shredder food source because of conditioning time. But the study was seasonal and this error would have been highly unlikely. Hence, a comprehensive long-term study is required to investigate on this phenomenon. Another explanation could be the bias of biomass-based surrogate. There can be potential bias in biomass-based surrogates for measures of ecosystem functioning when large-bodied shredders are dominant (Masese et al., 2014).

In site BA01, the channel stability was low in both seasons most probably because of sand mining in the site. Collector-Filterers require stable substrate for attachment, but the sand mining disturbs this stability. In all other sites, above normal suspended load was found in post-monsoon. Hence, material transformation is high in post-monsoon. Besides, mostly higher substrate channel stability was found in post-monsoon which accounts for more invertebrates that cling to surface of stone in post-monsoon (Cummins et al., 2005). It can also be interpreted that compared to invertebrates that have the adaptation to avoid unstable substrate by swimming or the invertebrates that can live in unstable substrate the invertebrates that require stable substrate are high (Cummins et al., 2005).

A balance between predators to prey was seen in all sites in both season except site NA01 where an overabundance of predator was found. However, in sites BA01 in the pre-monsoon season, the ratio is still high (>0.15) which would reflect the dominance of prey having short life cycles therefore, populations that turn over rapidly to continuously renew the food supply for the longer-lived predators (Merritt et al., 2017). But the change in FFGs with season was not significant for Production/Respiration, Course Particulate Organic Matter / Fine Particulate Organic Matter, FPOM in transport (suspended) / FPOM storage in sediments (deposited in benthos), Channel stability and Predator/Prey ($p > 0.05$). This could have been because of the limitation of the number of study sites or that the seasonal change in macroinvertebrate abundance is simply not variable in the study area. Hence, a further study is required to investigate this phenomenon.

Table 2 *Results of invertebrate Functional Feeding Group (FFG) analysis from the study sites. (See table 1 for ratio calculation and bold highlights indicate threshold has been crossed.)*

Site	Ecosystem parameter	FFG ratio Pre-monsoon	FFG ratio Post-monsoon	Threshold	Interpretation
BA01	P/R	0.07	0.02	>0.75	Very strongly heterotrophic in both seasons
BA02		0.19	0.04		Strongly heterotrophic in pre-monsoon but very strongly heterotrophic in post-monsoon
NA01		0.22	0.22		Strongly heterotrophic in pre-monsoon but very strongly heterotrophic in post-monsoon
NA02		0.18	0.04		Strongly heterotrophic in pre-monsoon but very strongly heterotrophic in post-monsoon
BA01	CPOM/ FPOM	0.24	0.01	>0.25	Poor Shredder link with riparian in pre-monsoon but very poor shredder link with riparian in post-monsoon
BA02		0.03	0.11		Very poor shredder link with riparian in pre-monsoon but Poor Shredder link with riparian in post-monsoon
NA01		0.06	0.07		Very poor shredder link with riparian in both season
NA02		0.04	0.22		Very poor shredder link with riparian in pre-monsoon but Poor Shredder link with riparian in post-monsoon
BA01	TFPOM/ BFPOM	0.20	0.33	>0.5	Reduced suspended loading of FPOM or poor quality of FPOM in both seasons
BA02		0.19	**0.78**		Reduced suspended loading of FPOM or poor quality of FPOM in pre-monsoon but above normal suspended load or good quality of FPOM in post-monsoon
NA01		**0.71**	**0.99**		Above normal suspended load or good quality of FPOM in both seasons
NA02		0.09	**0.67**		Very light suspended load or very poor quality of FPOM in pre-monsoon but just above suspended load or good quality of FPOM in post-monsoon
BA01	Channel stability	0.24	0.35	>0.5	Stable substrate sub-adequate in pre-monsoon but Stable substrate marginal in post-monsoon
BA02		0.41	**0.72**		Stable substrate marginal in pre-monsoon but Stable substrate adequate in post-monsoon
NA01		**1.01**	**0.96**		Stable substrate abundant in both seasons
NA02		0.28	**0.56**		Stable substrate sub-adequate in pre-monsoon but Stable substrate adequate in post-monsoon
BA01	Predator/ Prey	0.20	0.05	0.1 - 0.2 - a normal predator-to-prey balance, >0.2 - an overabundance of predators.	Normal predator to prey balance in pre-monsoon but abundance of prey on post-monsoon
BA02		0.09	0.07		Abundance of prey in both seasons
NA01		**0.21**	**0.31**		Normal predator to prey balance in pre-monsoon but overabundance of predator in post-monsoon
NA02		0.11	0.07		Normal predator to prey balance in pre-monsoon but abundance of prey in post-monsoon

Conclusion

The composition of Functional Feeding Groups in the study sites were found to be in agreement with the predicted stream function. The abundance of shredders, collectors especially collector-filterers and predators were high in winter or post-monsoon season. This seasonal variation in FFGs also led to an interpretation of various ecological attributes even though the variation was not statistically significant. In both seasons, the study sites were found to be strongly to very strongly heterotrophic. Likewise, in both seasons, shredders had either poor or very poor link with the riparian. Mostly, suspended load was found above normal in post-monsoon. Besides, mostly high substrate channel stability was found in post-monsoon. Moreover, mostly a balance between predators to prey was seen in all sites in both seasons.

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Drinking water quality of Sagarmatha National Park, Nepal

Siddhartha Sapkota[1], Suman Prakash Pradhan[1], Kirsten Nicholson[2,*], Klaus Neumann[2], Subodh Sharma[1]

[1]Department of Environmental Science and Engineering, Kathmandu University, Nepal
[2]Department of Geological Sciences, Ball State University, USA

*Corresponding author: knichols@bsu.edu

Abstract

Access to safe drinking water is essential for a healthy life and considered as the basic human rights. This study assessed the quality of drinking water in Sagarmatha National Park and illustrates the status of drinking water and its health impacts on people. Samples were taken from the water sources which are common sources of drinking water used by tourists, porters, guides and local residents of the villages on the trekking route from Lukla to Milingoo. A total of 15 samples from 15 sampling stations were taken in June 2018 and analyzed for physical, chemical and biological parameters on the basis of standards provided by National Drinking Water Quality Standards (NDWQS, 2005) of Nepal. Physical parameters like pH, turbidity and electrical conductivity do not exceed the permissible limits whereas biological parameters; *E. coli* and Total coliforms are present in all the samples. Chemical parameters such as fluoride, calcium, iron and chromium exceed the permissible NDWQS limits. The results show that the drinking water quality is not suitable for drinking purposes due to the bacterial and chemical contamination, and therefore water treatment prior to consumption is recommended.

Keywords: Sagarmatha national park, Drinking water quality, Contamination

Introduction

Water is one of the principal constituents of all living beings and is a vital component for their survival which regulates the physiology of the body (Lang & Waldegger, 1997; Humayun et al., 2015). The quality of water is essential to both the natural ecosystem, human development, and welfare (Mirzabeygi et al. , 2017; Soleimani et al., 2018). Access to safe drinking water is essential for the health and well-being of all living beings (Khan et al., 2013). Unsafe water supply, sanitation, and hygiene are the keys to the global burden of diseases (WHO, 2002). The environment report of Government of Nepal has also identified water pollution as a major cause of public health issues (Manfredi et al., 2010).

The physical, microbial and chemical contamination in water is an important issue regarding human health which plays vital role in changing the quality of water (ADB, 2006; Radfard et al., 2019). In addition, various anions and cations in water influence the contamination with harmful effects on human health (Muhammad et al., 2010). Therefore, water resource protection through water quality monitoring is crucial. The World Health Organization (WHO) has established international standards on water quality and human health which is regarded as the basis for regulation and standard setting (WHO, 2017). The guidelines for drinking-water quality promote the protection of public health by the adoption of preventive risk management approaches (Cotruvo, 2017). The government of Nepal has also established the National Drinking Water Quality Standards (NDWQS) from the Ministry of Physical Planning and Works in the year 2005 by establishing concentration limits for different physical, chemical, and biological parameters.

Sagarmatha National Park (SNP) is the world's highest altitude Protected Area and it was declared as a World Heritage Site in 1979. It covers the catchment of the Bhote Koshi and Dudh Koshi river basin, which are respectively fed by Nangpa and Ngozumpa glaciers (Bhuju et al., 2007). The Sherpas are the primary ethnic groups residing in SNP and its buffer zone. Along with one of the world's highest ecological flora and fauna, it preserves the rich culture of the Sherpa tribe (Nepal, 2002). Nowadays, tourism is one of the leading occupations of people living in this area (Panzeri et al., 2013). Although tourism is the major source of economy, many people still depend on agro-pastoral activities in this region (Nicholson et al., 2016). The increasing pressure of tourists on SNP face problems of open defecation and water pollution along the tracking trail. In this study, we mainly focused on the assessment of drinking water quality of different check posts and villages of SNP to assess the drinking water quality of SNP particularly along the tourist trail.

Materials and Methods

Study Area

Our study area covers Sagarmatha National Park (SNP); established in 1976 is the first National park of Nepal which is situated in Solukhumbu District of Nepal. It ranges in latitude from 27°30’19” N to 27°06’45”N; and longitude from 86°30’53”E to 86°99’08”E (Figure 1), covering an area of 1,148 Km^2 ranges in elevation from 2,610 masl (Phagding) to 8,848 masl at the summit of the Mount Everest. It is the highest altitude National Park in the world with the high mountains, glaciers, deep valleys and rivers. The climatic zones range from lower alpine to nival (Balestrini et al., 2014).

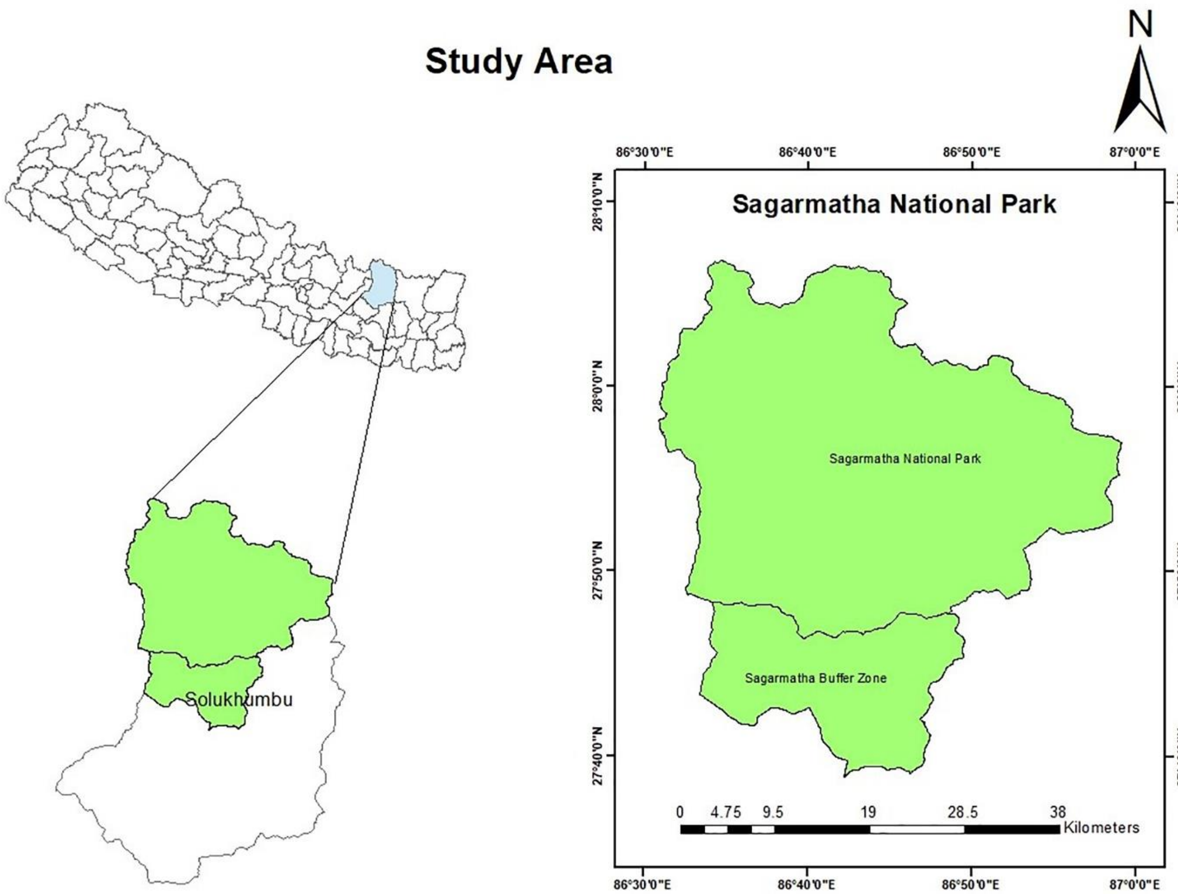

Figure 1 *Map of Nepal showing Sagarmatha National Park*

Sampling and analysis

A total of 15 sites were selected from Lukla (27.68858˚N & 86.73125˚E) to Milingoo (27.84353˚N & 86.77872˚E) focusing on the trekking route (Table 1). The sampling sites were selected on the basis of the availability of the water that the local populations, tourists, porters, and guides use for drinking purposes. 500 ml of two replicates were collected from each site a sterile sample bottle and preserved for further analysis.

Table 1 *Sampling sites with geographical coordinates*

Sample Code	Sampling Site	Latitude	Longitude
S1	Lukla	27.68858˚N	86.73125˚E
S2	Chaurikharka	27.70761˚N	86.71798˚E
S3	Phagding	27.74030˚N	86.71236˚E
S4	Jorsalle	27.77807˚N	86.72201˚E
S5	Namche Check Post	27.79972˚N	86.72401˚E
S6	Namche Bazar	27.77777˚N	86.72108˚E
S7	SNP Headquarter	27.80290˚N	86.71468˚E
S8	Kyangjuma	27.82287˚N	86.73106˚E
S9	Tasinga	27.82880˚N	86.73807˚E
S10	Lawi Schyasa	27.82991˚N	86.73972˚E
S11	Phurte	27.81170˚N	86.69054˚E
S12	Fungithanga	27.83236˚N	86.69054˚E
S13	Tyangboche	27.83555˚N	86.76203˚E
S14	Deboche	27.84043˚N	86.77672˚E
S15	Milingoo	27.84353˚N	86.77872˚E

The pH and electrical conductivity were measured on site using calibrated standard pH/conductivity meter (accumet® 13636AP71 and 13636AP72) whereas the turbidity was measured using calibrated turbidity meter (HANNA, HI-88703, Turbidimeter) in the laboratory. The colour was also noted on-site by observing. Different chemical parameters such as manganese, chromium, nitrate, ammonia, total hardness, fluoride, calcium, and iron were analyzed quantitatively by following standard methods (APHA, 2005). The water samples for microbial contamination analysis followed those of Nicholson et al (2016). The samples were collected in sterile 100 mL Whirl-Pak bags and kept at temperatures below 20˚C prior to analyses. A standard Hach® portable water test kit was used for the analysis of fecal coliform (APHA, 2005). The collected samples were filtered through sterile 0.45 micron filter using a hand vacuum pump and placed into a dish treated with Hach® m-ColiBlue24® broth medium and placed in a Hach® portable field incubator at 35˚C ± 0.5˚C for 24 hours and the sample counts were done using a magnifying glass and a 10X geological hand lens. The presence of royal blue pigment confirms *E.coli* while the crimson red pigment confirms coliform bacterial colonies. The results were presented whether *E.coli* and total coliform were present or absent in the samples.

Results and Discussion

Physical and biological parameters

The concentration of pH usually has no straight influence on water consumers but it is considered as one of the most important operational water-quality parameters because this parameter can indirectly affect some water quality characteristics, such as ion solubility, the survival of pathogens, and other contaminants (WHO 2003a; Khan et al., 2013). High turbidity can cause gastrointestinal illness (Robert et al., 2016). Due to the presence of particulates such as clay, silt, organic matter, algae, and other microorganisms water loses its transparency and become turbid (Patel & Vashi, 2015). The physical parameters such as pH, turbidity, and electrical conductivity do not exceed the standard limits provided by NDWQS (2005). The summary of results on physical parameters are presented in the Table 2.

All the samples were found to be contaminated with *E. coli* and total coliform (Table 2). Consumption of drinking water contaminated with pathogenic microbes of faecal origin is a significant risk to human health in the developing countries (Davies-Colley et al., 2001; Mohammed et al., 2018). In particular, faecal coliforms are serious indicators of the presence of sewage and waste in the environment (Kacar, 2015). Since *E. coli* is mainly found in faeces (Edberg et al., 2000), their presence in drinking water indicates the presence of disease-causing pathogens in the water system (Hassan et al., 2016). Recent work on bacterial contamination on the water sources also confirm that all river and water sources contain *E. coli* and coliform bacteria in SNP (Ghimire et al., 2013). The results of the analyses of some selected physical and biological parameters are summarized in Table 2.

Table 2 *Results on physical and biological parameters*

Station	pH	Conductivity (μS/cm)	Turbidity (NTU)	Color	*E. coli*	Total Coliform
S1	6.40	28.40	8.80	NO	+	+
S2	6.58	47.60	1.57	NO	+	+
S3	6.13	32.40	4.25	NO	+	+
S4	6.55	23.60	3.11	NO	+	+
S5	6.77	26.00	3.50	NO	+	+
S6	6.97	36.40	3.47	NO	+	+
S7	6.76	41.10	3.82	NO	+	+
S8	6.49	39.00	2.02	NO	+	+
S9	6.77	26.00	2.41	NO	+	+
S10	6.62	31.40	1.71	NO	+	+
S11	6.98	31.20	3.09	NO	+	+
S12	6.61	55.50	1.58	NO	+	+
S13	6.36	12.37	1.52	NO	+	+
S14	6.80	44.60	0.88	NO	+	+
S15	6.30	52.60	16.93	NO	+	+
WHO Limits, 2017	6.50-8.50	750	10	5	0	0
NDWQS Limits, 2005	6.50-8.50	1500	10	5	0	0

NO: Non Objectionable, +: Presence

Chemical Parameters

The concentration of different chemical parameters is shown in Figures 2 and 3. Manganese (Mn^{2+}) are introduced into surface and ground waters from soils and bedrock as well as anthropogenic activities (Heal, 2001; Ljung & Vahter, 2007). In early life development, manganese is an essential element for it functions as a cofactor in a number of enzymes and in certain antioxidants (Mistry & Williams, 2011) while there is an increasing concern about its effect on central nervous system, particularly in children and neurodevelopment (Zoni & Lucchini, 2013; Yu et al., 2014). Although, animal and epidemiological studies have consistently found inorganic Cr(III) to be nontoxic and non-carcinogenic (Zhitkovich, 2011), some other form of chromium such as Cr(IV) causes the lungs cancer in human (Smith & Steinmaus, 2009). Chromium is also a naturally occurring metal in drinking water with concentrations less than 10 mg/L has no effects on human health (Hem, 1985). The high concentration of nitrate (NO_3^-) and nitrite (NO_2^-) causes health problems such as Methemoglobinomia (Yang et al., 2006), risk of abortion, and reduction in oxygen transfer to the foetus through the mother's blood (Gamao et al., 2015; Chetty & Prasad 2016).The nitrate present in both surface water and groundwater is a consequence of agricultural activity, wastewater treatment and human and animal excreta which leads to various human ailments (WHO, 2003b). The ammonia (NH_3) in drinking water sources may originate from human activities, metabolic, agricultural and industrial processes, and disinfection (Fu et al., 2012) and it is an important indicator of faecal pollution (WHO, 2004). Ammonia has health implications along with taste and odour problems in drinking water sources. It also indicates the possible contamination with bacterial, sewage and animal (WHO, 2003a).

Both calcium and magnesium ions are essential minerals and beneficial to human health in several respects and are the main source of hardness of water. An inadequate intake of either nutrient can result in adverse health consequences (WHO, 2009). Fluoride (F^-) is found in all natural waters at some concentration and has beneficial effects on human health especially in protection of teeth but excessive exposure to fluoride in drinking water can give rise to a number of adverse chronic effects such as dental, skeletal, neurological, and Alzheimer problems (Fawell et al., 2006; Asghari et al., 2017; Mohammadi et al., 2017; Mirzabeygi et al., 2018; Yousefi et al., 2018). The weathering of primary rocks and leaching of fluoride-containing minerals in soils is the source of fluoride in drinking water (Ayoob & Gupta, 2006).

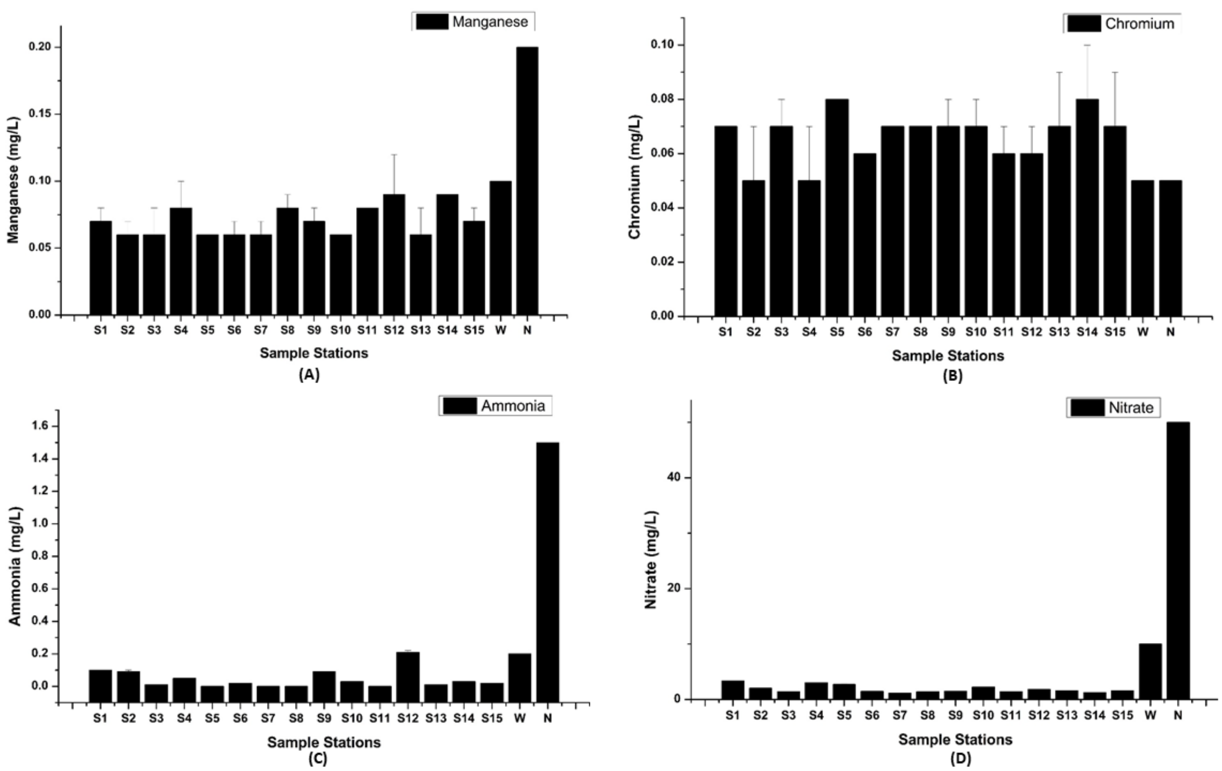

Figure 2 *Concentrations of (A) Manganese, (B) Chromium, (C) Ammonia and (D) Nitrate in water samples*

Calcium (Ca^{++}) is abundant in drinking water and mainly helps in building bones and keeping them healthy and also enables blood clots, muscles and heart functioning and lack of this ion causes cardiovascular disease (Radfard et al., 2019). However, a high level of calcium consumption leads to nausea, vomiting, weakness, and muscle cramp and bone pain (Ferguson, 2017). The concentration up to 2 mg/L of iron does not possess any hazard to health (WHO, 2004) but the threshold limit of NDWQS (2005) is 0.3 mg/L and if there is not any alternative. 3 mg/L is considered as the threshold limit. The total iron (Fe^{2+}& Fe^{3+}) contamination as a result of corroded pipes is very common in the drinking water supply system (Colter & Mahler, 2006). Chemical parameters such as fluoride, calcium, iron and chromium exceed the permissible NDWQS (2005).

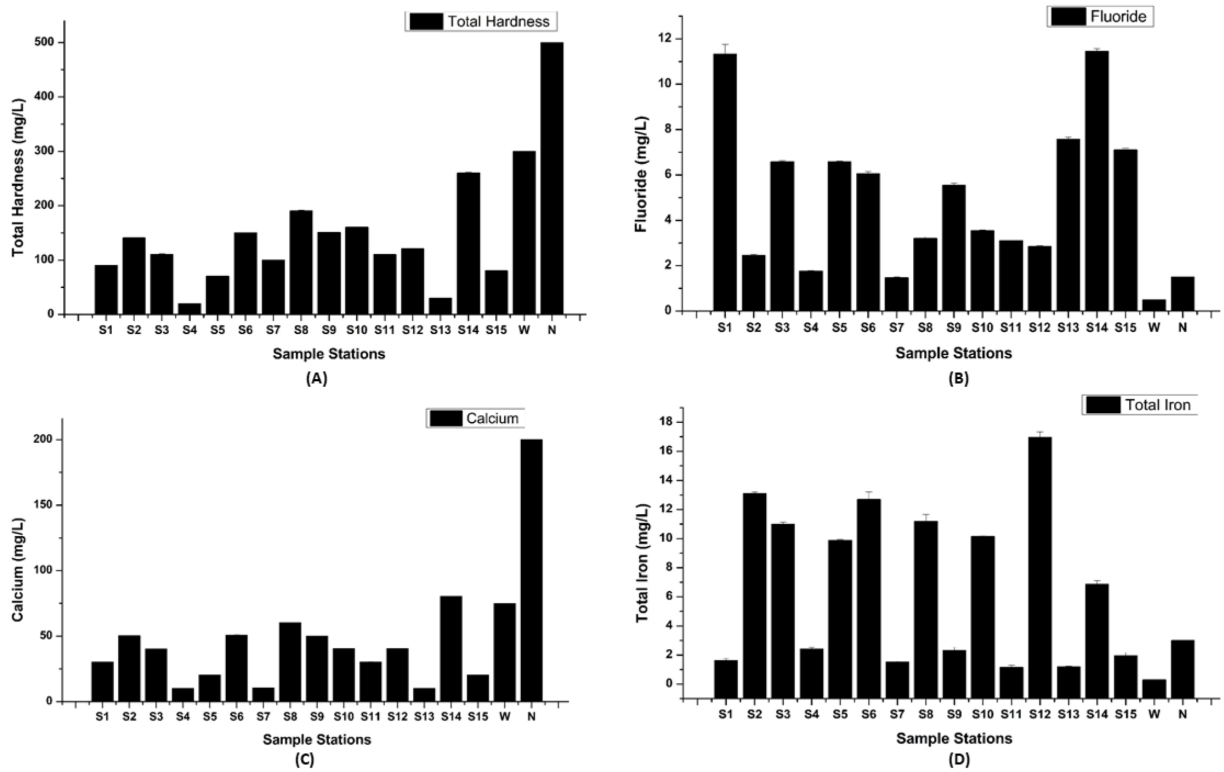

Figure 3 *(A) Total hardness, (B) Fluoride, (C) Calcium and (D) Total iron of the samples*

Our overall results revealed that total coliform, *E. coli*, fluoride, chromium, calcium and total iron exceeded the permissible limit of NDWQS (2005) and other parameters are within the permissible level in most of the sampling stations (Table 3) The overall results was complementary to those of previous investigators, which indicates the contamination of water (Manfredi et al., 2010; Nicholson et al., 2016) and such type of contaminations in water directly affecting the health condition of people living over there (Kafle & Khanal, 2010).

Conclusion

Drinking water quality assessment was conducted in Sagarmatha National Park along the trekking trail. The significant results in physical and chemical parameters reflect that the water is drinkable to the some extent but the bacterial contamination in water sample of all the sampling stations shows that the water is highly contaminated with the microbial pathogens such as coliform bacteria. The highest degree of contamination in drinking water was found in S14-Deboche from all aspects and least in S7- SNP Headquarter as compared with other sampling sites. The water in the SNP area is not suitable for drinking without basic treatment. The bacterial contamination might lead to severe acute and chronic illness which could ultimately lead to people with severe health problems and disabilities. Social and educational awareness about the importance of drinking water quality and its improvement; introduction and encouragement for water treatment prior to before consumption; construction of public toilets in trekking routes to reduce the open defecation are some of the measures to mitigate pollution and protection of water sources in the SNP region.

Acknowledgment

The fund for this study was provided by Ball University, USA. We would like to thank the Department of National Park and Wildlife Conservation (DNPWC), Nepal for providing permits to carry out our research in Sagarmatha National Park. We are thankful to all the research team from Ball State University, USA. We would like to give our sincere gratitude to all the field supporters and local people for their immense help during the field and lastly we are great full to Aquatic Ecology Center (AEC) and KU-SNU B&W Core Facility Center, Kathmandu University for analyzing some of the chemical parameters.

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Habitat Analysis and Distribution of Chinese Pangolin in Community Forests of Dolakha District, Nepal

Anuradha Rai[1], Shyam Sharma[2], Suveksha Shrestha[1], Ashish Bashyal[2], Sandeep Shrestha[1*], Sanjay Nath Khanal[1]

[1]Department of Environmental Science and Engineering, Kathmandu University,Nepal
[2]Biodiversity Conservancy Nepal

[*]Corresponding author: sandeep@ku.edu.np

Abstract

Habitat preference and distribution of Chinese Pangolins (*Manis pentadactyla* L.) has been assessed through this study in Chaletropakha and Bisesh Community Forests of Dolakha. This particular animal is a burrowing mammal with scarce information in Nepal on their ecology, distribution and behaviour. Two transects were laid in each block of 100 X 100 meter and around 84% of the blocks were investigated. Indirect signs of pangolin presence - dimensions and image documentation of burrows, scratch marks, termite mounds, elevation, slope, aspect, ground cover, crown cover and soil characteristics of burrows- were recorded. Suitable habitat was predicted using MaxEnt modelling. A total of 302 burrows from 149 blocks were observed out of which 277 were old and 25 were new having clumped distribution pattern. Their preferred habitat ranged from 1500-1700 masl with mostly south and south west facing burrows at 20-30° slope. Dark reddish brown clay loam soil with moisture 4-8% was preferred due to its soft layers where digging burrows is easy. Habitat modelling predicts their suitable ecological niches in the country providing information for strengthening conservation efforts for this animal in those particular areas.

***Keywords*:** Pangolins, Habitat, Burrows, Modelling, Conservation

Introduction

Nepal is home to 212 mammal species (Amin et al., 2018), 886 bird species (DNPWC & BCN, 2018), 137 reptiles and 53 amphibian species (Shah, 2013). Among these, some are globally recognized and listed under the IUCN Red List in different categories. Out of four Asian pangolin species, Chinese pangolin (*Manis pentadactyla*) is one of the species that is found in Nepal and has been listed as critically endangered by IUCN Red List (IUCN, 2017). This mammal is listed under Appendix I of CITES (CITES, 2017) and in Nepal, they are protected by Government of Nepal under the National Park and Wildlife Conservation Act, 1973 (Thapa et al., 2014).

Pangolins (*Manis sp*.) are largely terrestrial and their bodies are protected by thick scales (Sapkota, 2016). They are shy animals (Kaspal, 2008; Suwal, 2011) and dig their own burrows with the help of their sharp claws (Heath, 1992). This species is nocturnal and tends to spend the day in their underground burrows (Sapkota, 2016). Due to their specialized diet, pangolins are able to perform an important ecological role in regulating insect populations (Challender et al., 2014). Their main food sources are ants and termites and studies show that an adult pangolin can consume more than 70 million insects annually which helps in controlling forest termites (Shi & Wang, 1985). Due to their soil digging nature, they are considered to be good soil tenders helping in improvement of soil nutrient quality.

In Nepal, presence of Chinese pangolins have been reported from Annapurna Conservation Area, Makalu Barun National Park, Taplejung, Ilam, Panchthar, Ramechhap, Sindhuli, Panauti (Beber area), Bhaktapur, Kavre, Nagarjun forest of Shivapuri National Park, Sundarijal, Barabise, Baglung (Shrestha, 1981; Majupuria & Majupuria, 2006; Kaspal, 2008; Suwal, 2011; Bhandari & Chalise 2014; Thapa et al., 2014). Chinese Pangolins are one of the most illegally trafficked animals in the world due to their high economic values (Hua et al., 2015) with their population decreasing primarily due to hunting, poaching and habitat destruction (Challender et al., 2014). Their trade has been increasing due to low economic status of the people and weak law enforcement (Katuwal et al., 2013). Pangolin scales are used in traditional Chinese medicines (TCM) for treating skin conditions, promoting blood circulation, accelerating milk secretion in lactating mothers, for pus elimination, reducing swelling and rheumatism and their meat is considered a delicacy in countries like China and Vietnam (Heath, 1992; Hua et al., 2015). Habitat destruction, rampant economic development and conversion of forest to plantation are some threats causing decline in pangolin population.

Based on some collected information showing presence of this animal in the central and eastern parts of Nepal (Baral & Shah, 2008), this particular study has been conducted in Dolakha which also lies in the central region of Nepal.

Materials and Methods

Study Area

The study was conducted in two community forests-Chaletropakha and Bisesh of Dolakha district. Dolakha is a district in Province No. 3 covering an area of 2191 km^2. Chaletropakha community forest has an area of 16 hectares (0.16 km^2) whereas Bisesh community forest has an area of 172 hectares (1.72 km^2) and both the community forests are located in Baiteshwor Village Municipality of Dolakha district (Figure 1). These two sites were selected based on the information from District Forest Office, Dolakha about these forests being some of the prime habitats of Chinese pangolins.

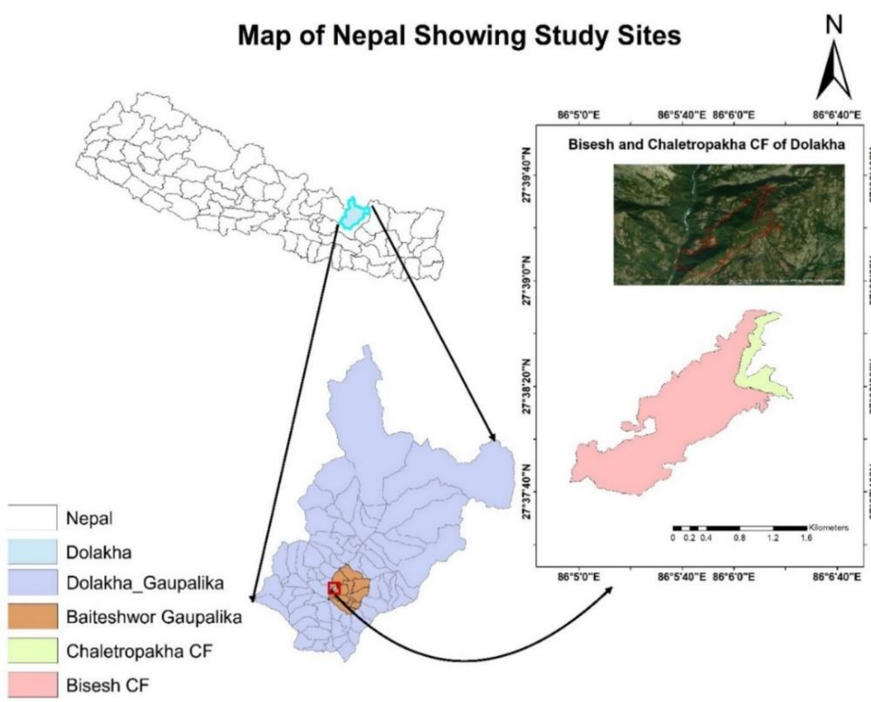


Figure 1 *Map showing the study sites*

Data Collection

Data collection was done from 13th April to 1st May, 2018. The shape files of the two community forests were prepared based on the GPS points of the areas. Each community forest was divided into 100m X 100m grids using Fishnet function in Arc GIS 10.2.2. Line transect method was followed where two transects of 100m each were laid at an interval of 33m in each grid.

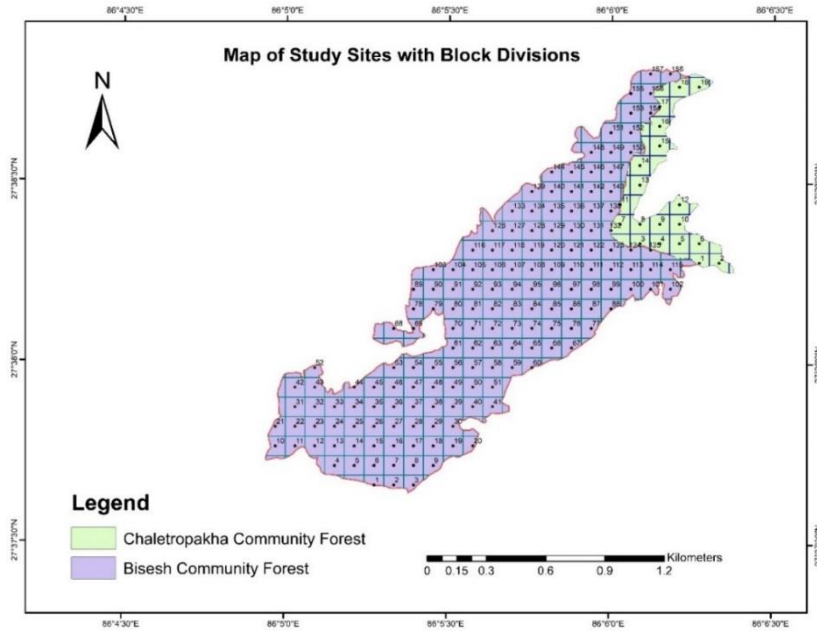


Figure 2 *Map showing study sites with block divisions*

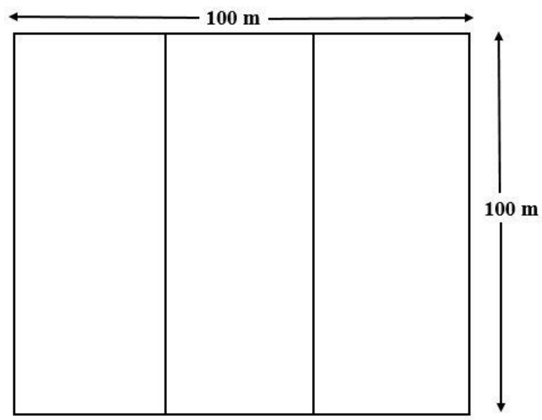


Figure 3 *Block Design showing transects*

In Chaletropakha Community Forest, all 19 blocks were investigated whereas in Bisesh Community Forest, a total of 130 out of 158 blocks were investigated. Around 84% of the total number of blocks was covered. Every block couldn't be investigated due to steep hills and difficult terrain. Burrows were searched in the community forests with the help of local guides and burrows with height and width of more than 15 cm and depth of more than 50 cm were taken as burrow inclusion factors. These recorded burrows were identified as new and old burrows. Wider burrows with presence of freshly dug soil and termite mounds nearby the burrows were characterized as new burrows whereas burrows with spider webs at the entrance and dried leaves blocking the entrance were characterized as old burrows. Soil samples (approx. 500-600 gm) from the burrows were collected in zip lock bags and brought to the laboratory for further soil analysis. An intensive search of other indirect signs like scats, footprints, scales and scratches was also conducted in each plot to assess the habitat of the animal.

Table 1 *Instruments/Methods used for data collection*

S.N.	Data	Instruments/Methods
1.	Burrow locations	GPS (Garmin GPS Map 60 CSx)
2.	Soil moisture (onsite)	MS300 Digital Moisture Meter
3.	Aspect of the burrows	Silva Expedition 4 Compass
4.	Elevation	GPS (Garmin GPS Map 60 CSx)
5.	Slope	Clinometer (Sokkia Abney Level Clinometer)
6.	Canopy Cover	Densiometer (Spherical Densiometer, Model-A, Lemmon)
7.	Ground Cover	A 2-meter profile board (Mitchell & Hughes, 1995).

Laboratory Analysis

The collected soil samples were brought to the laboratory at the Department of Environmental Science and Engineering, Kathmandu University for further analyses. First the unwanted impurities such as dried leaves, plant roots, twigs etc. were removed. Soil pH was analyzed using a pH meter (Lutron BPH-231). Soil colour was analyzed using Munsell’s Colour Chart while soil texture and type were analyzed using a Hydrometer.

Data analysis

Descriptive statistics, data arrangement and pie charts were created using Windows Excel 2013. Regression was performed to find out the relationship between the dependent variable (number of burrows) and independent variables (the environmental parameters) using SPSS 20.

Chinese Pangolin distribution pattern in the study area was determined by calculating the ratio of variance and mean (S^2/a) (Dhakal, 2016) of the number of burrows found in different blocks.

If $S^2/a = 1$ i.e. there is a random distribution.

If $S^2/a < 1$ i.e. it has a regular distribution.

If $S^2/a > 1$ i.e. it has clump distribution.

ArcGIS 10.2.2 was used for processing the shape files and spatial layers and Maximum Entropy Species Distribution Modelling Software (MaxEnt) 3.4.1 (Phillips & Dudík, 2008) was used for running the model. MaxEnt is a computer program that estimates the probability distribution for a species and predicts potential suitable habitat range of mammals (Dorji, 2017). Altogether 19 environmental layers were downloaded from www.worldclim.org and were converted from raster format to ASCII format with a standard cell size of 30 m x 30 m based on the resolution of the Digital Elevation Model (DEM). The presence data used for the modelling are from Dolakha (based on our study), Kavre and Bhaktapur based on the ongoing research on Pangolins), Taplejung (Thapa et al., 2014), Makwanpur (Upadhyaya, 2015) and Udayapur (Bhandari, 2017). The database excel spread sheet containing the presence data of Chinese Pangolins was converted to comma-separated value (csv) format which was imported to MaxEnt software. The presence data of the animal was uploaded under 'Samples box' and all the spatial layers in ASCII format were brought under the 'Environmental layers box' and the model was run (Dorji, 2017).

Results and Discussion

Burrow Characteristics

149 blocks with 302 burrows were recorded among which 72 burrows were observed in Chaletropakha Community Forest and 230 burrows were observed in Bisesh Community Forest. The general characteristics of the burrows encountered in both the forests are given in Table 2 and the habitat preference of the Chinese pangolin in the study area is given in Table 3. The overall burrow distribution pattern was clumped type in the study site since the value obtained from calculation (ratio of variance and mean of the number of burrows observed in different blocks) was 4.25 which is greater than 1.

Table 2 *Table showing the Burrow Characteristics*

Burrow Type	Name of the Forest	No. of Burrows	Total No. of Burrows	Average Width (cm)	Average Height (cm)	Average Depth (cm)
Old	Chaletropakha	67	277	22.63 ± 3.94	19.53 ± 4.11	124.01 ± 61.53
	Bisesh	210				
New	Chaletropakha	5	25	24.28 ± 4.39	21.98 ± 3.68	177.68 ± 47.57
	Bisesh	20				

Habitat Preference

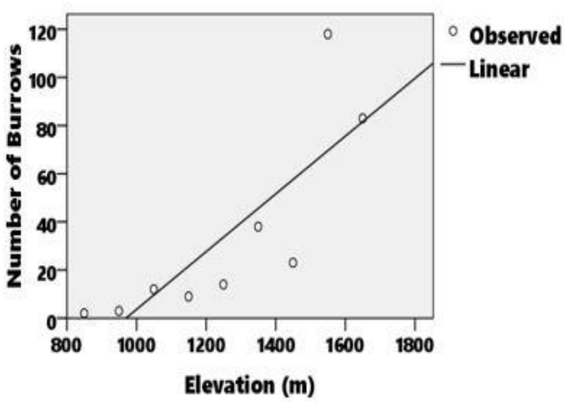
Table 3 *The preference range of different environmental parameters of Chinese pangolin in the study area*

Environmental Parameters	Preference Range	R^2 value
Elevation	1500-1700m	0.660
Ground cover	0-25%	0.947
Crown cover	50-75%	0.677
Slope	20-30°	0.467
Soil pH	5.5-7	0.843
Soil moisture	4-8%	0.678

The best suited curve estimation model for regression analysis of elevation and number of burrows is Linear (Figure 4); for ground cover and number of burrows it is logarithmic (Figure 5); for crown cover and number of burrows it is quadratic (Figure 6); for slope and number of burrows it is quadratic (Figure 7); for soil pH and the number of burrows it is quadratic (Figure 8); and for soil moisture and number of burrows it is logarithmic (Figure 9).

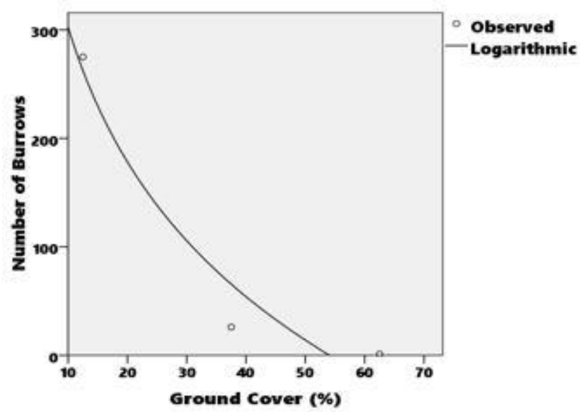
The highest number of burrows was recorded at an elevational range of 1500-1599m with 118 burrows followed by at 1600-1699m with 83 burrows. Highest number of burrows in similar altitudinal range has also been reported in Nagarjun Forest of Shivapuri National Park where highest number of burrows have been recorded at 1450-1650m (Bhandari & Chalise, 2014) and Bhutan (Dorji, 2017). The numbers of burrows in the lower elevations are rare which might be due to presence of human settlements nearby. Dorji (2017) recorded maximum number of burrows within ground covers of 51-75% and 76-100% in Bhutan. Pangolins prefer dense ground cover layers in order to hide from the predators. Wu et al (2004) reported the use of dense ground cover by pangolins for protecting their burrow entrance. However, this does not match with current observations as our study site had more open forests with less ground coverage and also croplands and shrub lands nearby. Areas with more canopy cover tend to be moist and termite occurrences are higher in dry area than wet area. But this does not match with current results as in our study sites the highest number of burrows is found within crown cover of 50-75% and least within 0-25%. This could be because the study site was an open forest with low ground coverage and so the crown cover did not affect the area for its dryness or wetness. The obtained results coincided with those of Dorji (2017) who also found majority of the burrows at slopes of 20-45° and Bhandari (2017) who recorded the presence of 99 burrows at the slope of 20-30°. This could be due to the soft clayey loam soil found at slope of 20-30° in the study area which is suitable for digging burrows.

The result for soil pH is similar to those obtained by Sapkota (2016). This shows pangolins prefer burrows in soil having acidic and more or less neutral pH value. Most termites prefer mounds in acidic and weakly alkaline soils with pH values between 3.5 and 8.7 (Li et al., 2017). According to Bhandari (2017), majority of the burrows had soil moisture of 10-20% followed by 0-10% which partially coincides with the present result. Very less number of burrows is found in soil with high moisture because water molecules hold more tightly on soil particles and termites which are the main food source of pangolins, can successively colonize only in relatively drier soils where they can move around easily (Cornelius & Osbrink, 2010).



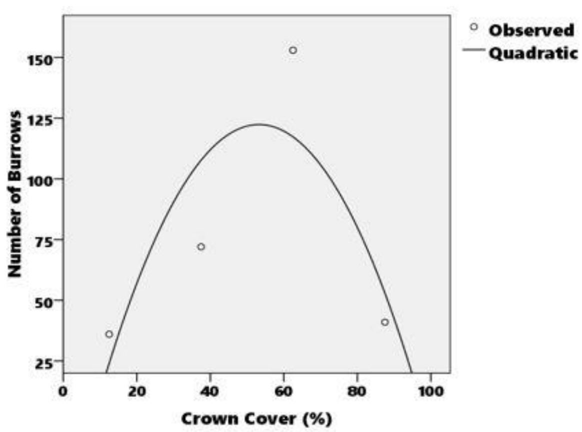
$R^2 = 0.660$

Figure 4 *Relationship between Number of Burrows Elevation*



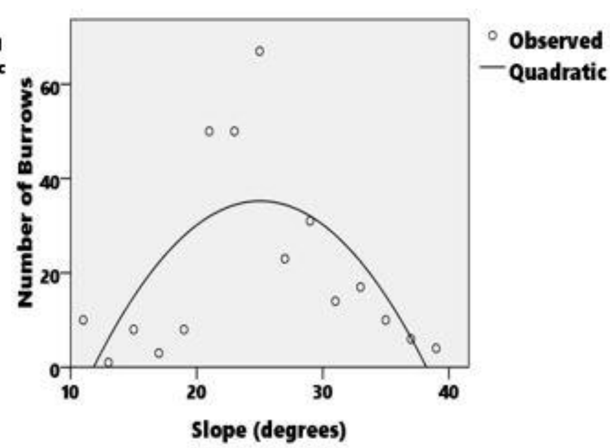
$R^2 = 0.947$

Figure 5 *Relationship between Number of Burrows and and Ground Cover*



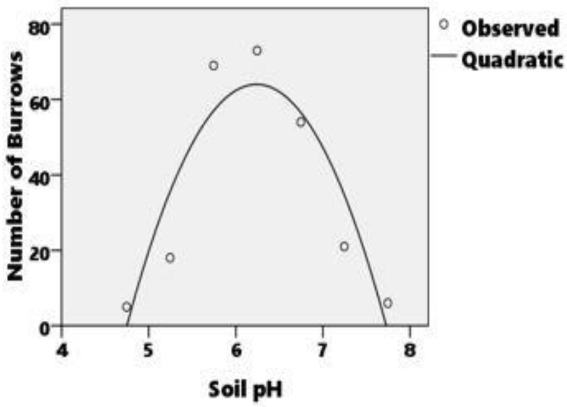
$R^2 = 0.677$

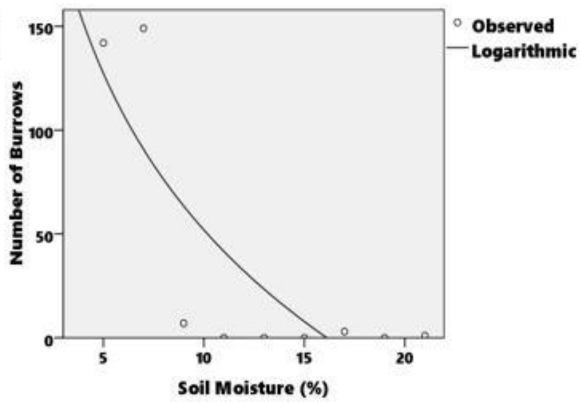
Figure 6 *Relationship between Number of Burrows and Crown Cover*



$R^2 = 0.467$

Figure 7 *Relationship between Number of Burrows and Slope*





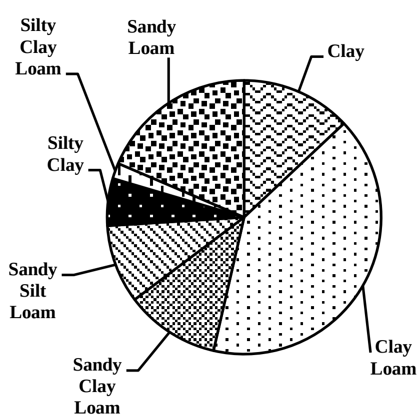
$R^2 = 0.843$ $R^2 = 0.678$

Figure 8 *Relationship between Number of Burrows and Soil pH*

Figure 9 *Relationship between Number of Burrows and Soil Moisture*

Majority of the blocks that had the presence of burrows showed the occurrence of clay loam type of soil (40.5%) followed by sandy loam (18.5%) (Figure 10). Similar results were obtained by Dorji (2017) in Bhutan. According to Wu et al (2004), pangolins mainly choose clayed loam and sandy loam soil that have soft layers, where they can easily dig burrows.

Majority of the blocks that had the presence of burrows showed the occurrence of dark reddish brown soil (39%) (Figure 11). This result coincided with the study done by Suwal (2011) and Dhakal (2016) who recorded burrows in brown soil in Bhaktapur and Gorkha in Nepal. Reddish brown coloured soil is usually the clay loam soil which has soft layers making it easy for the pangolins to dig (Wu et al., 2004). Maximum number of burrows were recorded in forest areas (86%) with South aspect (37%) followed by the South West aspect (19%) (Figure12). Pangolins are known to prefer south and south west aspect (Gurung, 1996; Suwal, 2011; Bhandari, 2017) as these aspects are warmer than other aspects thereby providing warmth to tide over the cold winter months (Dorji, 2017).



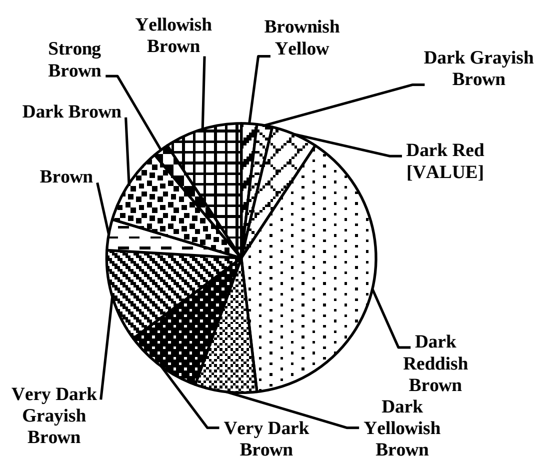


Figure 10 *Burrow occurrence in different Soil Types*

Figure 11 *Burrow occurrence in different Soil Colours*

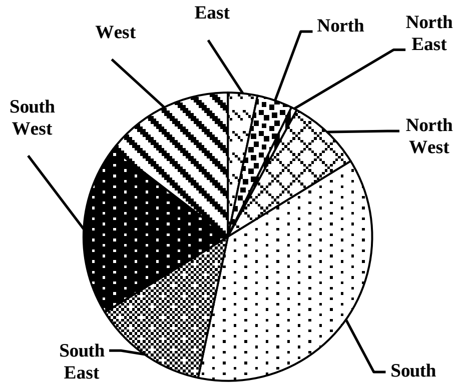


Figure 12 *Burrows in different aspects*

Predicting Suitable Habitat of Chinese Pangolins using MaxEnt Modelling

The MaxEnt model predicted potential suitable habitat of Chinese Pangolins (indicated by red area in Figure 13). The model shows that in Nepal, the Chinese Pangolins are mostly found in the hilly areas compared to the high Himalayan region which might be due to lesser availability of food sources (ants/termites) as termite diversity starts decreasing as elevation increases (Dorji, 2017). The suitable habitat shown by the model matches with previous findings in Bhaktapur (Kaspal, 2008); Kavre (Suwal, 2011) and Nagarjun (Bhandari & Chalise, 2014).

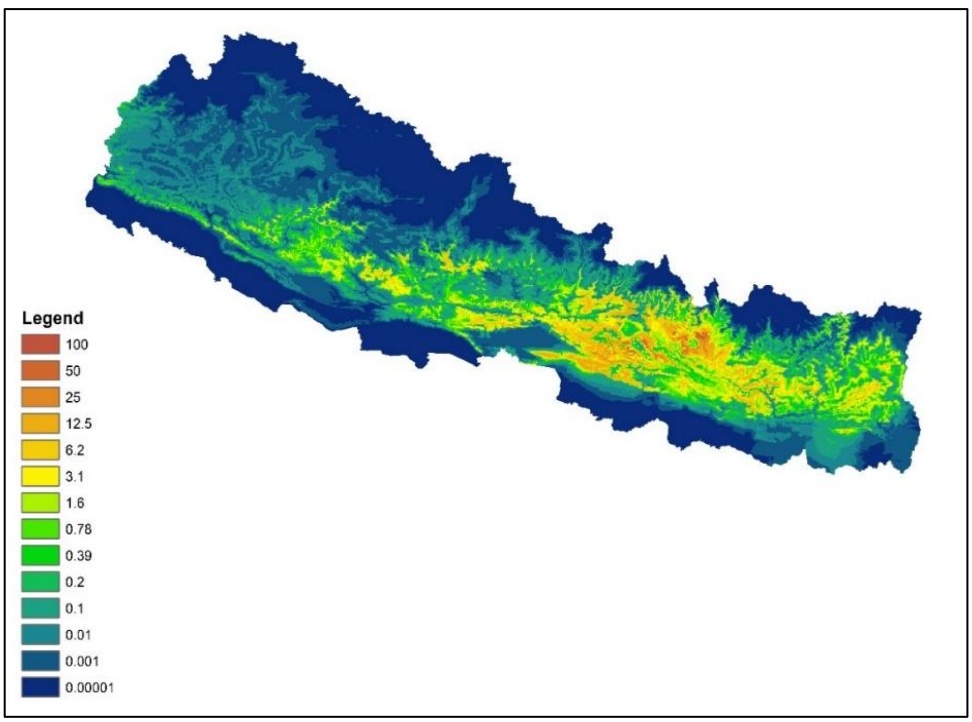


Figure 13*MaxEnt Model Performance/Output* showing suitable pangolin habitat area in Nepal

Conclusion

This study revealed that most of the Pangolin burrows were found at an elevation of 1500-1700m and a slope of 20-30° with south and south west facing aspects. The burrows were found to have clumped distribution pattern. The baseline information generated from this study might be helpful in further studies and in formulating future scientific management plan for conservation of Chinese pangolins in the study area.

Acknowledgement

The authors would like to thank Kathmandu University for providing the opportunity to conduct this research and Russell E. Train Education for Nature (EFN), WWF, USA, University Grant Commission, Nepal, and Arizona Center for Nature Conservation (ACNC)/Phoenix Zoo Conservation & Science Grant Program, USA for funding this work.

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Altitudinal Vascular Species Richness Pattern in West Nepal

Babu Ram Nepali[1, 2 *], John Skartveit[3], Chitra Bahadur Baniya[1]

[1] Central Department of Botany, Tribhuvan University, Kirtipur
[2]Butwal Multiple Campus, Tribhuvan University
[3] University College, NLA, Bergen, Norway

[*]Corresponding author- nepalibaburam7@gmail.com

Abstract

Altitudinal species richness pattern is a known phenomenon among biogeographers across the world including Nepal. However, no cross-sectional richness pattern on large scale so far has been studied in Nepal. Thus, this present study has been initiated to understand the vascular species richness pattern in the west (80˚04' to 83˚E) Nepal. All available information related to vascular plants of the west Nepal were collected first and then interpolated. A total of 3291 vascular species were enumerated from different literatures from altitude below 100 masl around Dhangadi to above 7100 masl around Api mountain, west Nepal. The interpolated vascular species richness was regressed against their respective altitude through an application of generalized linear model (*GLM*). Statistically highly significant unimodal species richness pattern ($p < 0.001$ & $r^2=0.957$) with maximum richness of 1360 species was obtained at 2200 masl. Similar unimodal richness pattern was observed for endemic and non-endemic vascular plants with maximum richness at 3700 masl and 2200 masl respectively. This study resembled general pattern in some extent and differed with specific pattern. There would be many reasons behind these patterns but more likely driven by much drier westerly weather condition.

Key words: Endemic, Interpolation, Maximum richness, Regional, Unimodal

Introduction

Species richness, the number of species confined per unit area, is not uniform in this earth (Gaston, 2000). It is the most widely used, studied, simplest and easily interpretable indicator of biological diversity which is determined by a complex of environmental factors (Whittaker, 1977; Brown et al., 2007). Many factors including geographic (e.g. species pool, dispersal), biotic (e.g. competition, predation, facilitation) and abiotic (e.g. resource availability, environmental heterogeneity, disturbance frequency and intensity) variables affect small-scale species richness (Brown et al., 2007). In general, species richness shows four patterns: decreasing, low plateau, low plateau with a mid-elevation peak and broad mid-elevation peak (McCain, 2009; Zhang et al., 2016).

Numerous hypotheses have been proposed to explain the altitudinal species richness pattern, especially variation between habitats and large scale regions (e.g., the latitudinal diversity gradient) (Mittelbach et al., 2007), area (Wang et al., 2007), disparity of temperature and rainfall (Stevens & Fox, 1991; Acharya et al., 2011), complex topography (Ghazal, 2015), aspect (Sharma et al., 2014), soil composition (Dölarslan et al., 2017). Rahbek (1995, 1997) analyzed three patterns in altitudinal species richness: a monotonic decline, a hump-shaped with a maximum at mid-elevations, and a monotonic incline. Rahbek's (1995) review on altitudinal species richness pattern showed that a large number of species show mid altitudinal peak in species richness pattern. Unimodal altitudinal species richness distribution pattern seems to be a universal. According to Grytnes & Vetaas (2002), unimodal pattern of species richness with respect to altitude is typical in many mountainous regions, even in Nepal Himalaya. The mid domain nature produces a peak at mid elevation which disrupts the increasing pattern of species richness against altitude resulting into hump shaped unimodal or polymodal forms. Every species has its own life span which is limited in certain distribution range according to their tolerant capacity. The species richness first increases along altitude due to continuous addition of new species and overlapping of their elevation range. But, it decreases after certain altitude due to termination of elevation range of more species and introduction of less species or species accumulation curve according to Ugland et al (2003). Many evidences show that time and ecological influences on diversification rates on both large and small scale species richness patterns (Wiens, 2011).

Nepal's rich biodiversity is reflection of its unique geographic position (the longest bioclimatic elevation gradients extending from 67 m to 8848 m) within 150–200 km south to north, diverse climatic conditions and great habitat variation (Grytnes & Vetaas, 2002). The occurrence of the east Himalayan vegetation in East Nepal and west Himalayan elements in west Nepal, or the transitional zone between the eastern and western Himalayas make rich in biodiversity (Banerji, 1963; NBS, 2002). Although, the country occupies only about 0.1 percent of global area, yet harbours 3.2 percent and 1.1 percent of the world's known flora and fauna, respectively (MFSC, 2014).

History of botanical explorations in the country shows that such explorations are concentrated in Central and East Nepal (Rajbhandari et al., 2016). The western part of the country with fragile soil structure, more steep and rocky hills and less rain fall are likely to harbour different and unique biodiversity than in other regions. For instance, acidic soil resulted due to dense gymnosperm species (Thomson, 2014) of this region may create unfavorable condition for other species. Moreover, information on biodiversity is crucial to prepare sound development plans that integrate biodiversity conservation issues. Therefore, this study was conducted with aims to (i) generate a baseline on species richness pattern of different taxa of vascular plants in west Nepal. (ii) compare altitudinal species richness pattern of the endemic species with non-endemic vascular plant species.

Materials and Methods

Study Area

This study was conducted in west Nepal. The altitudinal range in west Nepal ranges from below 100 m to above 7100 masl, occupying about 20 % of total land in Nepal. Climatologically, it is warmer and drier than other parts of the country because monsoon in Nepal starts from Bay of Bengal which gradually decreases towards central and western Nepal. The west Nepal (mainly former mid-western and far western development regions) receives decreasing trend of monsoonal rainfall only up to 4 mm during pre-monsoon; up to 30 mm in monsoon and up to 7 mm per year in post monsoon. Some areas in the northern parts of west Nepal observed decreasing trend of rain even in winter (Marahatta et al., 2009). The maximum and minimum rainfall was recorded at Dhandgadi (1888.1 mm/yr) and Jumla (811.4 mm/yr) respectively. The average maximum temperature (30-36° C) and minimum temperature (-10 to -20°C) have been recorded in Nepalgunj and Simikot, Humla respectively in west Nepal (DHM, 2017). So, soil in west Nepal is more fragile and dry which results in some different types of vegetation than the rest of the country. Terai and Siwalik regions (below 1000 masl) consist of tropical forest, containing *Shorea robusta*, *Dalbergia sissoo, Acacia catechu*, *Adina cordifolia* etc. Sub-tropical region (1000-2000 masl) is occupied by *Schima walichii*, *Pinus roxburghii*, *Castonopsis indica* etc. Above 2000 m, most parts of west Nepal is covered by gymnosperms (*Pinus wallichiana*, *Cedrus deodara*, *Juniperus* spp., *Abies pindrow*, *Picea smithiana*, *Castonopsis*, *Quercus*, *Rhododendrons* etc. Between 3000 to 4000 m the hills of inner and outer Himalayas are dominated by conifers and *Rhododendron* forests containing *Rosa sericea, Salix bhutanesis, Daphne volua, Prunus cornuta, Picea smithiana* etc.

Above 4000 m, trees are absent and vegetation covers mainly consists of grasses, herbs and dwarf shrubs such as *Juniperus indica*, *Potentilla fruticosa*, shrubby Rhododendrons etc.

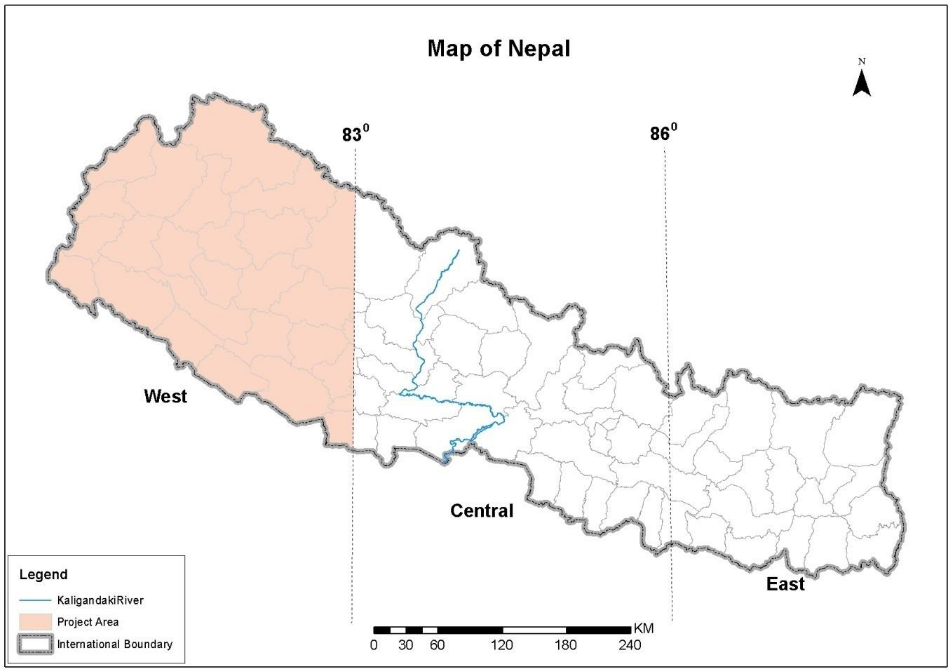

Figure 1. *Map of Nepal showing East, Central and West parts.*

Data sources

Plant Species Resources collection and interpolation

The plant species information of west Nepal were collected from various published research articles (Bartolucci & Dhakal, 1999; Thapa, 2001; Grytnes & Vetaas, 2002; Panthi & Chaudhary, 2002; Bajracharya & Shrestha, 2004; Rajbhandari & Dahal, 2004; Jha, 2007; Rajbhandari & Suzuki, 2008; Rijal, 2008; Bhatta & Chaudhary, 2009; Shrestha & Jha, 2009; Rokaya et al., 2010; Ohba & Akiyama, 2010; Adhikari et al., 2012a; Adhikari et al., 2012b; Satyal & Setzer, 2012; Shrestha & Rai, 2012; Semwal et al., 2014; Pradhan & Bajracharya, 2014; Shaheen et al., 2016; Sangraula et al., 2017); research books and reports and some unpublished data (Niroula, 2004; Baniya, 2010; Singh, 2014). The collected information was corrected on the basis of web pages www.theplantlist.org. and www.catelogueoflife.org.

The altitudinal gradient of west Nepal (80-6200 m) from where plants were reported were divided equally into 62 bands. Between upper and lower elevation limits, the species were counted at each 100 m interval. In this study, total number of species present in each 100 masl band represents as species richness. Species recorded at only a single site were subjectively given an altitudinal range of 100 m.

Similarly, species number of plants on the basis of taxa (dicot, monocot, gymnosperm and ferns or pteridophyte), non-endemic and endemic plants were also determined. This is a macro-scale study that covers the entire elevation range of west Nepal.

Data Analysis

The patterns related to species of different taxa (dicot, monocot, gymnosperm and ferns) and total species of vascular plants as respondents and their altitudes as a predictor variable were analyzed within the framework of Generalized Linear Model *(GLM).* The quasi-poisson family error distribution was applied to remove over dispersion. The assumption of normal distribution of error was conformed after Q-Q diagnostic plots plotted against residuals. The change in deviance follows the F-distribution. R mgcv 1.8-2.2 was used to analyze the non-parametric data of endemic plant species and smoothers were fitted with library *GLM* (Baniya, 2010). Similarly, a Pearson correlation was used to show correlation between altitude and plant species.

Results and Discussion

Vascular Plant Species Richness

A total of 3291 species of vascular plant belonging to 200 Families and 1245 Genera comprising of 2045 herbs, 415 shrubs, 336 trees and 195 climbers were recorded (Table 1). This indicates rich floral diversity in the region. Dicot, monocots, gymnosperms and ferns were represented by 2331, 644, 16 and 300 species respectively. The dicot showed broad elevational distribution range while the gymnosperms had the lowest distribution range (Table 1).

Table 1 *Taxonomic account of floristic diversity of West, Central and East Nepal*

SN	Region	Taxa	Species number	Altitudinal range (m)
1	West Nepal	Total vascular species	3291	<100-6200
		Dicot	2331	<100-6200
		Monocot	644	<100-5800
		Gymnosperm	16	300-4500
		Pteridophyte	300	<100-4800
2	Central Nepal	Total vascular species	5101	<100-8000
3	East Nepal	Total vascular species	4294	<100-8100

Correlation of different vascular taxa, endemic and non-endemic species with altitude

The species of vascular taxa (dicot, monocot, gymnosperm, ferns) and total species showed significant negative relationship (-0.8 to -0.34) with altitude (Table 2). Likewise, endemic species of vascular plants showed significant positive relation (0.30) but non-endemic species showed significant negative relationship (-0.71) with elevation (Table 2).

Table 2 *Summary of correlation of different taxa, endemic and non-endemic vascular plants with respect to altitude*

	Alt	**Dicot**	**Monocot**	**Gymno**	**Ferns**	**Tot_spp**	**Endem**	**Non-end**
Alt	1	-0.65	-0.8	-0.34	-0.65	-0.69	0.3	-0.71
Dicot	-0.65	1	0.96	0.86	0.87	0.99	0.3	0.99
Monocot	-0.8	0.96	1	0.74	0.89	0.98	0.05	0.98
Gymno	-0.34	0.86	0.74	1	0.83	0.85	0.4	0.84
Ferns	-0.65	0.87	0.89	0.83	1	0.91	-0.06	0.92
Tot_spp.	-0.69	0.99	0.98	0.85	0.91	1	0.21	1
Endem	0.3	0.3	0.05	0.4	-0.06	0.21	1	0.18
Non-end	-0.71	0.99	0.98	0.84	0.92	1	0.18	1

Species Richness Pattern of Vascular taxa

Species richness in terms of all taxa and total species of vascular plants increased first when altitude increased. Then, it started to decrease after optimum elevations showing unimodal structure. The total vascular species (r^2=0.957), dicot (r^2=0.939), monocot (r^2=0.931), gymnosperm (r^2=0.945) and ferns (r^2=0.989) attained the maximum richness with 1360 species at 2200 m (Figure 2 E); 965 at 2300 masl (Figure 2 A); 246 species at 2000 (Figure 2 B); 10 species at 2600 m (Figure 2 C) and 156 species at 2100 m (Figure 2 D) respectively.

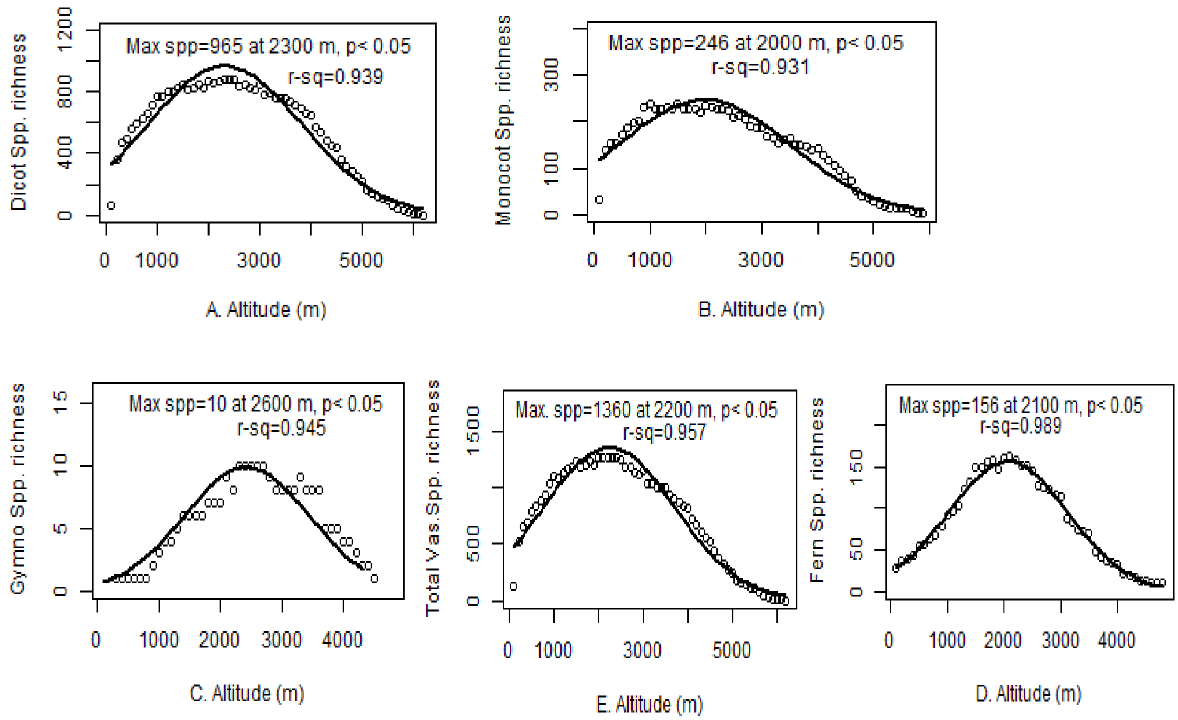

Figure 2 *Pattern of interpolated (E) - total vascular plant species, (A) - dicot, (B)- monocot, (C)- gymnosperm & (D)- ferns species in relation to altitudinal gradient in west Nepal.*

Richness pattern and distribution range of endemic and non-endemic species

A total of 86 endemic and 2982 non-endemic vascular plants were observed which represented respectively 27.6% of total endemic and 51.9 % of total non-endemic vascular plants of Nepal (Table 4). The richness of both endemic species and non-endemic vascular species showed unimodal pattern against elevation. The endemic species (r^2=0.940) attained maximum species (37 spp.) at 3700 masl altitude with right skewedness (Figure 3 A) but the non-endemic species showed maximum species (1339 spp.) at 2200 m with left skewedness (Figure 3 B). The altitudinal distribution range of endemic vascular plant was found less (900-5900 m) than non-endemic species in west Nepal.

Table 4 *Comparison of Species Richness, Elevation distribution range and Elevations of maximum Endemic and Non-endemic species of West Nepal with overall Nepal.*

S.N.	Taxa	Species richness		Elevation range (m)		Elevation of maximum species (m)	
		West Nepal	Overall Nepal	West Nepal	Overall Nepal	West Nepal	Overall Nepal
1	Endemic species	86	312	900-5700	<100-5900	3700	3600
2	Non-endemic species	3205	6174	<100-6200	<100-8100	2200	2100
3	Total vascular species	3291	6486	<100-6200	<100-8100	2200	2100

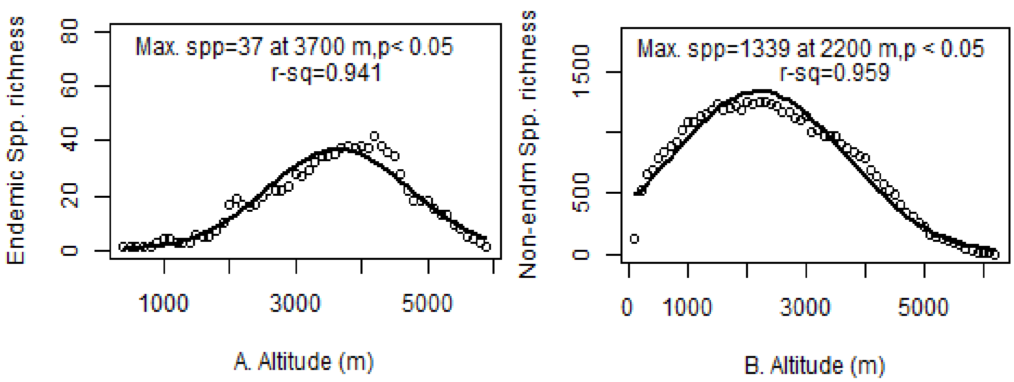

Figure 3 *Pattern of interpolated (A) endemic species& (B) non-endemic species in relation to altitudinal gradient in west Nepal*

This study shows that west Nepal is as rich (3291 species) as East and Central region in floral diversity. The altitudinal range of west Nepal is lower (highest elevation up to 7100 m Api Mountain) in comparison to east and central Nepal which mirror images in occurrence of less altitude of distributional range (up to 6200 m) and less diversity. This coincides with distributional range of plant species which is proportional to overall altitudinal range. Plant growth depends on two important natural resources - soil and water. Soil acts like a reservoir that holds water and nutrients plants need to grow. Soil conditions like soil texture, salinity, soil pH, nutrients etc. are major physical factors that affect plant distribution (Wu et al., 2011). Arid and semi-arid environments which are responsible for fragile ecosystems and certain degree of desertification support low vegetation cover (Zare et al., 2011). Fragile soil structure, more steep and rocky hills and less rain fall in west Nepal could be the main cause for less richness of diversity than other regions. Similarly, acidic soil formed due to dense gymnosperm species of this region may create unfavorable condition for other species. There is significant negative relationship of species of different vascular taxa and non-endemic species with elevation in west Nepal. Only endemic species show the positive relationship against altitude. Sharma et al (2014) found that a positive linear relationship between the native species and altitude. Driessen (2013) also found positive relation of endemic species and negative relation of non-endemic species against altitude in the islands of New Guinea and Borneo. The deviation of species richness with elevation might be associated with the reduction of temperature and productivity (Rahbek, 1995), which results into negative relation between species and elevation.

The richness of all taxa, endemic and non-endemic species of vascular plant show hump shaped pattern with peak richness at the lower half or upper half of the elevation gradient. Similar richness pattern follows in species of most of the mountain regions (Oommen & Shanker, 2005). The skewedness of peak richness is positive in many vascular taxa- dicot, monocot, ferns and total species of vascular plants- but negative in gymnosperm. In general, mountains presenting greater elevation extent are more likely to display unimodal patterns (Guo et al., 2013).

The peak richness altitude of vascular taxa appears between 2100-2600 m in west Nepal. This result coincides with peak richness elevation (1500 to 2500 for flowering plants; 1900 m for ferns) for Nepal (Grytness & Vetas, 2002; Oommen & Shanker, 2005, Bhattarai & Vetas, 2006). Different taxonomic groups exhibit peak at different elevations due to different hard boundaries for individual species (Bhattarai & Vetas, 2006) which probably reflects both physical and physiological constraints. The result concludes that the peak elevation of any plant group is directly proportional to altitudinal distribution range of most species of that group than overall distribution range. The differences in elevation diversity peaks among plants and animals and among their subgroups probably reflect differences both in physiological tolerance and niche partitioning among species groups (Guo et al., 2013).

The peak richness of endemic species appears in 3700 m in west Nepal. It is supported by highest richness of endemic lichen in 4000-4100 masl (Baniya, 2010) and bryophytes at 4250 masl altitude in Nepal. Both endemic and non-endemic species express unimodal structure against altitude. There was negative skewedness in endemic but positive skewedness in non-endemic species. The endemic vascular plant species shows very short elevation distribution range or in narrow ecological amplitude (Bhattarai &

Vetas, 2006) on higher altitudes than non-endemic species (Driessen, 2013). The mid-domain effect (MDE) theory predicts that endemic species show more peak elevation than non-endemics (McCain, 2009). There was no overlap between the peak of endemic species (at 3700 masl) and non-endemic species (at 2200m) with a striking 1500 m difference between the peaks with similar results of endemic and non-endemic species in overall Nepal (Grytnes &Vetaas, 2002). The range of endemic species is constricted due to high anthropogenic pressure, unable to invade in fresh areas (Stevens, 1992) or being isolated due to unfavorable conditions of evolution and assault of new exotic species. Multiple factors are responsible for distribution patterns of different taxa on different places at different spatial and temporal scales.

Conclusion

Altitude was found to have a significant relation with species richness of all vascular taxa, endemic and non-endemic species. Species richness of vascular taxa and non-endemic species showed significant negative relation but endemic species showed significant positive relationship with elevation. The species of all taxa had a unimodal response to altitude. However, the peak elevation having maximum species richness is diverse in different taxa in west Nepal, which is less than those of Nepal and is proportional to the altitudinal range of species. The result concludes that the peak elevation of any plant group is directly proportional to altitudinal distribution range of most species of that group than overall distribution range.

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Appendix 1. Summary of regression of statistics when species richness of each taxon of vascular plants is regressed against elevation. Polynomial first order (1) and second order (2) were tested against the null model

Model	Predictor	Response	Resid DF	Resid. Dev	Df	Deviance	F	Pr(>F)
0	Altitude	Dicot species	61	5630448				
1			60	9453	1	5620995	45210	< 2.2e-16
2			**59**	**1035**	**2**	**5629414**	**194917**	**< 2.2e-16**
0	altitude	Monocot spp	57	360884				
1			56	1801	1	359083	14193	< 2.2e-16
2			**55**	**237**	**2**	**360647**	**48355**	**< 2.2e-16**
0	Altitude	Gymno spp	44	456.31				
1			43	92.59	1	363.72	201.4	< 2.2e-16
2			**42**	**6.46**	**2**	**449.85**	**1702.7**	**< 2.2e-16**
0	Altitude	Fern species	48	147446				
1			47	1625	1	145821	4604.1	< 2.2e-16
2			**46**	**20**	**2**	**147426**	**161480**	**< 2.2e-16**
0	Altitude	Total spp Richness	61	11800329				
1			60	13243	1	11787086	67029	< 2.2e-16 *
2			**59**	**1110**	**2**	**11799219**	**379636**	**< 2.2e-16 ***
0	Altitude	Endemic spp	59	38915				
1			58	1097	1	37819	2183.4	< 2.2e-16
2			**57**	**130**	**2**	**38785**	**6722.5**	**< 2.2e-16**
0	Altitude	Endemic spp	50	3049.33				
1			49	254.52	1	2794.8	606.67	< 2.2e-16
2			**48**	**18.35**	**2**	**3031**	**3736.4**	**< 2.2e-16**

Impact of Invasive Alien Plant Species (IAPS) on Native Flora in Barandabhar Forest Corridor, Nepal

Jyoti Dhakal[1*], Keshav Raj Acharya[1] and Saroj Raj Poudel[2]

[1] Tribhuvan University, Institute of Forestry, Nepal
[2] Forest Research Institute (Deemed to be University), Dehradun, India

*Corresponding author: jyoti.dhakal.27@gmail.com

Abstract

Chitwan National Park is currently under invasion by different Invasive Alien Plant Species (IAPS) thereby increasing threat to native flora and fauna. This study was conducted in southern part of Barandabhar Forest Corridor to list out IAPS, identify the occurrence of IAPS, and calculate various ecological indices of flora and also to explore local IAPS control practices. Nine Buffer Zone Community Forests (BZCFs) of Chitwan National Park were selected for transect walk to list out IAPS. Vegetation sampling and key informant survey were conducted in two community forests that were highly influenced by invasion (realized during transect walk). A total of 14 IAPS were found invading the habitat. Highest occurrence was recorded for *Chromolaena odorata* which was dominant in *Shorea robusta* forest with open canopy cover. Vegetation analysis reveals high invasion in Milijuli BZCF than Tikauli BZCF. Simpson's diversity Index and Shannon-Wiener diversity Index for Milijuli were 0.32 and 1.51 respectively; and for Tikauli it was 0.26 and 1.75 respectively. Various local control measures were practised by each community forests such as cutting, uprooting and fire to resist the IAPS but were not effective. Early detection and uprooting of IAPS before flowering was recommended for controlling in initial stage of its invasion.

Keywords: Barandabhar corridor, BZCFs, Diversity index, IAPS, Native flora, Occurrence

Introduction

Challenging era of "invasion" has already started in globe following human activities. Nepal is also suffering from the introduction of Invasive Alien Plant Species (IAPS). As many as 179 species of these plants are naturalized (Shrestha et al., 2018) in different ecosystems with higher invasion in eastern and central parts of the country than the western region (Bhattarai et al., 2014) with majority of concentration lying in Terai and Siwalik regions (Poudel, 2016). Most of these invasive species are natives of the Americas. For Asia Pacific region, top invasive species include *Ageratina adenophora, Ageratum conyzoides, Chromolaena odorata, Eichhornia crassipes, Lantana camara, Mikania micrantha and Parthenium hysterophorus* (Sankaran et al., 2005). Nepal has a long history of introduction of such species and pioneer contributors were the British who brought economically important plants from almost all continents to the Indian sub-continent and later introduced in Nepal (Nurul Islam, 1991). Moreover, gardeners, horticulturists, foresters and the retired British Gorkha soldiers have also facilitated introduction of IAPS in Nepal (Kunwar, 2003). IAPS have potentiality to rapidly colonize range of habitats, which in turn modify plant community and ecological processes like nutrient cycling, energy flow or hydro-dynamic properties of the native ecosystem (Huston, 2004). Numerous natural or agri-ecosystems are damaged by forest invasive species which includes native forests and biodiversity (Srivastava & Singh, 2009). Not only loss of biodiversity but commercial value of biodiversity also deplete due to invasion. There are great concerns to production forestry because IAPS are associated with economic impacts (Padmanaba & Corlett, 2014). Many researchers have raised concerns of IAPS colonization at the boundary between protected areas and human-dominated areas (Alston & Richardson, 2006). Although IAPS are exerting serious pressures in conservation of native ecosystems in CNP and its Buffer Zone, these problems are not being taken seriously (Sapkota, 2007). Considering the importance of CNP as a protected area coupled with its importance as globally renowned conservation of biological richness, this study on biological invasion was conducted at its buffer zones as the latter have management implications as entry point to extend in entire areas.

Materials and Methods

Study Area

The study was conducted in Barandabhar forest which is a trans-boundary corridor that connects two important protected areas to Mahabharat range namely the Chitwan National Park (CNP), Nepal; and the Valmiki Tiger Reserve, India in the south and is intersected by east-west Mahendra Highway. The corridor is surrounded by Bharatpur sub-metropolitan city in the west and Ratnanagar and Kalika municipality in the east.

Barandabhar forest comprises of vegetation dominated by *Shorea robusta* and partly by tall and short grassland. Winter, summer and monsoon are the notable seasons. Temperature can vary from minimum at 8° C during January to maximum of 37°C during April (DNPWC, 2015). Nine Buffer Zone Community Forests namely Ban Devi Barandabhar (254.25 ha), Nawa Jyoti (62.05 ha), Dakshinkali (165 ha), Batuli Pokhari (67.07 ha), Belsahar (204.40 ha), Tikauli (79.35 ha), Milijuli (45.66 ha), Chitrasen (185.01 ha) and Baghmara (215 ha) were selected as study area and among the nine Buffer Zone Community Forests, Tikauli and Milijuli were selected for vegetation analysis and key informants survey.

Vegetation Sampling

Systematic sampling was carried out in Tikauli and Milijuli BZCFs. 25*20 m^2 quadrates were allocated in front and left side of the sample plot for trees and nested plots of 5*5 m^2 and 1*1 m^2 quadrates were allocated within the big quadrants for shrubs and herbs respectively (Figure 1). One percent sampling intensity was used for the study. All the species in the plot were counted for the analysis.

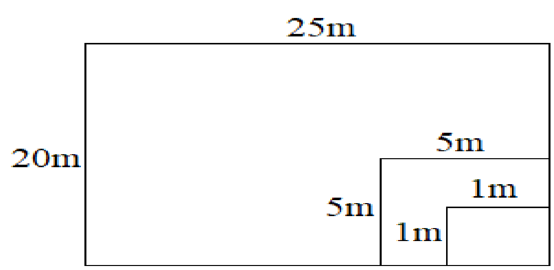

Figure 1 *Layout of sample plot*

Transect walk was started from 100m inside the forest boundary and at every 200m interval, IAPS, canopy cover, and habitat type were observed and recorded in the data sheet. The level of IAPS was measured using a simple ranking of cover within the area through ocular estimation as: 0- absence; 1 - present but coverage < 50%; 2 - High coverage i.e. >50% (Lamichhane et al., 2014). Manual on invasive alien plant species (Bisht et al., 2016) and unpublished field guides were followed along with taxonomic expert's consultation to identify the invasive species. A total of 115 transect segments were intercepted during this study.

Key Informant Survey

Nine key informants were interviewed using set checklists to document local management practices for IAPS control and history of invasion of IAPS in particular forests. Presidents, members and forest guard were key informants and one of these informants in each Buffer Zone Community Forests was interviewed to deduce information.

Data Analysis

The collected data were tabulated, processed and analyzed using Microsoft Excel 2015. The following quantitative characteristics of the vegetation were determined using following formulae.

Frequency=$\mathrm{J}/\mathrm{I} \times 100$, J = No. of quadrates in which the species occurred, I = Total quadrates studied.

Density=$\frac{\mathrm{H}/\mathrm{I}}{\mathrm{A}}$, H= Total no. of individual of a species in all the quadrates, I = Total quadrates studies, A= Area of the quadrates.

Abundance=H/J , H = Total no. of individual of a species in all the quadrates, J= No. of quadrates in which the species occurred.

Simpson's index (D) =$\frac{\sum n(n-1)}{N(N-1)}$, n = the total number of organisms of a particular species, N = the total number of organisms of all species (Simpson, 1949).

Shannon-Wiener index or α diversity (H′) = $-\sum$ pi ln pi**,** H′ = Shannon's diversity index, pi= proportion of total sample belonging to the ith species, ln= log of natural numbers (Shannon's & Weaver, 1963).

Results and Discussion

Altogether 14 IAPS belonging to nine Families were recorded. This requires urgency in management focus for such diverse number of alien plants. *Asteraceae* was the largest family with six species; remaining eight Families namely *Verbenaceae, Mimosaceae, Pontederiaceae, Araceaesaceae, Papaveraceae, Caesalpiniaceae, Convolvulace* and *Lamiaceae* were represented by only one species each (Table 1).

Table 1 *List of IAPS and their local names*

S.N.	Scientific Name	Local Name	Family
1.	*Chromolaena odorata*	Seto Banmara	Asteraceae
2.	*Ageratum houstonianum*	Nilo Gandey	Asteraceae
3.	*Ageratum conyzoides*	Seto Gandey	Asteraceae
4.	*Ageratina adenophora*	Kalo Banmara	Asteraceae
5.	*Mikania micrantha*	Lahare Banmara	Asteraceae
6.	*Lantana camara*	Kande Banmara	Verbenaceae
7.	*Parthenium hysterophorus*	Pati Jhar	Asteraceae
8.	*Mimosa pudica*	Lajjawati Jhar	Mimosaceae
9.	*Eichhornia crassipes*	Jalkumbi	Pontederiaceae
10.	*Pistia stratiotes*	Kumbhika	Araceaesaceae
11.	*Argemone mexicana*	Gaida Kanda	Papaveraceae
12.	*Senna ocidentalis*	Panwar	Caesalpiniaceae
13.	*Ipomea carnea*	Besaram	Convolvulace
14.	*Hyptis suaveolens*	Tulsi Jhar	Lamiaceae

Out of the total segments (n=115) under transect walk, highest occurrence was of *Chromolaena* (in 97 segments), followed by *Ageratum houstoniaum* (in 82 segments), *Mikania* (in 64 segments) and *Ageratum conyzoides* (in 37 segemnts). Maximum observed species with above 50% occurrence was *Mikania* (15) followed by *Chromolaena* (13) (Figure 2). Grassland, wetland and mixed forest were lowest intercepted habitat types. Table 2 shows the occurrence of IAPS and their frequency in different canopy cover. Table 3 shows the occurrence of IAPS and their frequency in different habitats. Occurrence of *Mikania*, *Chromolaena*, *A conyzoides*, *A houstonianum* and *Parthenium* prevailed in both grades of canopy cover density Presence of *L camara* in the study area is in contradiction to previous study (Dangol & Maharjan, 2012) which indicated its presence in the forested area along the Narayani river of CNP. Severe management implications have been always stressed upon *Mikania micrantha* as the most problematic weed for immediate measures to control the species in CNP (Sapkota, 2007). This study has shown *C odorata* and *A houstonianum* need equal management focus for immediate control measures which also agrees with the findings of Shrestha et al (2019) in Chitwan-Annapurna Landscape. Heavy infestation of *C odorata* and *A houstonianum* was observed in both open and closed canopy covers of *Shorea robusta* forest during the transect walk. Barandabhar corridor is invaded by *Lantana* and *Parthenium* at very low extent in comparison to that of *Mikania*, *Chromolaena* and *A conyzoides* under several habitat types and both grades of canopy cover and their presence indicate that they may be possible threat in the future. *Mikania* can occur in wetlands in seepage areas of both perennial and seasonal types (Siwakoti, 2007) and it was found to be dominant in the wetlands of study area. It has been realized that at the moment *Mikania*, *Chromolaena*, *A houstonianum* and *A conyzoides* need intensive management focus for control. In general, forest with open canopy covers have maximum occurrence of IAPS. Most alien plant species are open-habitat species, probably because most introductions have occurred through agriculture and gardening (Rubino et al., 2002). Many authors have stressed that open forest canopy favours alien species where they germinate and develop more rapidly in such micro-sites than in closed canopy (Brothers & Spingarn, 1992; Forrest Meekins & McCarthy, 2001; Meiners et al., 2002). This is due to two mechanisms operated at two scales. At localized scale, germination and growth of IAPS is favourable whereas at landscape scale, open canopy increases seeding rate resulting in rapid colonization in such sites (Charbonneau & Fahrig, 2004).

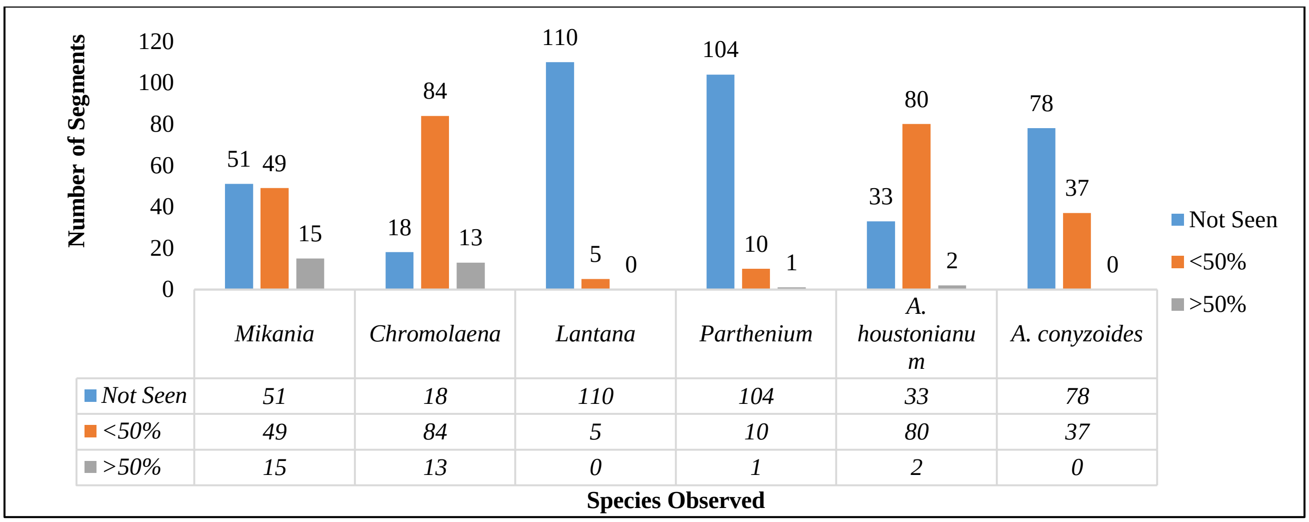

Figure 2 *Occurrence of IAPS in number of segments*.

Table 2 *Occurrence of IAPS and canopy Cover.*

Species	Canopy Cover	Not seen	<50%	>50%
Mikania micrantha	Closed	30	23	6
	Open	21	26	9
Chromolaena odorata	Closed	11	30	3
	Open	7	54	10
Lantana camara	Closed	59	0	0
	Open	51	5	0
Parthenium hysterophorus	Closed	54	4	0
	Open	50	7	0
Ageratum houstonianum	Closed	23	36	0
	Open	10	44	2
Ageratum conyzoides	Closed	42	17	0
	Open	36	20	0

Table 3 *Occurrence of IAPS vs Habitat Types.*

Species	Habitat type	Not seen	<50%	>50%
Mikania micrantha	Grassland	1	3	0
	Mixed	1	1	0
	Riverine	0	9	13
	Wetland	5	12	2
	Sal	44	24	0
Chromolaena odorata	Grassland	1	3	0
	Mixed	1	1	0
	Riverine	5	17	0
	Wetland	1	3	0
	Sal	10	60	13
Lantana camara	Grassland	4	0	0
	Mixed	2	0	0
	Riverine	22	0	0
	Wetland	2	1	0
	Sal	80	4	0
Parthenium hysterophorus	Grassland	2	2	0
	Mixed	2	0	0
	Riverine	13	8	1
	Wetland	5	0	0
	Sal	82	0	0
Ageratum houstonianum	Grassland	2	2	0
	Mixed	0	2	0
	Riverine	15	7	0
	Wetland	0	10	2
	Sal	15	59	1
Ageratum conyzoides	Grassland	4	0	0
	Mixed	2	0	0
	Riverine	18	4	0
	Wetland	3	10	0
	Sal	51	23	0

Vegetation analysis data shows that high density of flora in Milijuli than that of Tikauli. However the density of invasive species is high in Milijuli than non-invasive species Total density of flora was higher in Milijuli than in Tikauli BZCF (Figure 3; Table 4). In *Shorea* dominated forests, *C odorata* and *A conyzoides* were found to be most invasive plants invading Milijuli and Tikauli forests in general (however only record of *C odorata* in Tikauli). Both these forests are close to each other under similar management regime i.e. under hands of community. However, in Tikauli BZCF, both Simpsons and Shannon-Wiener diversity index is higher to that of Milijuli (Table5). This is due to low infestation of invasive species and greater number of non-invasive species in the forest than Milijuli BZCF.

It is clearly shown that under similar management status how invasive species are varying in infestation at spatial scale in forest. There is urgent requirement of suitable control methods to be adopted in Milijuli BZCF to minimize invasive species and enhance native flora of the forest in intensive scale to that of Tikauli.

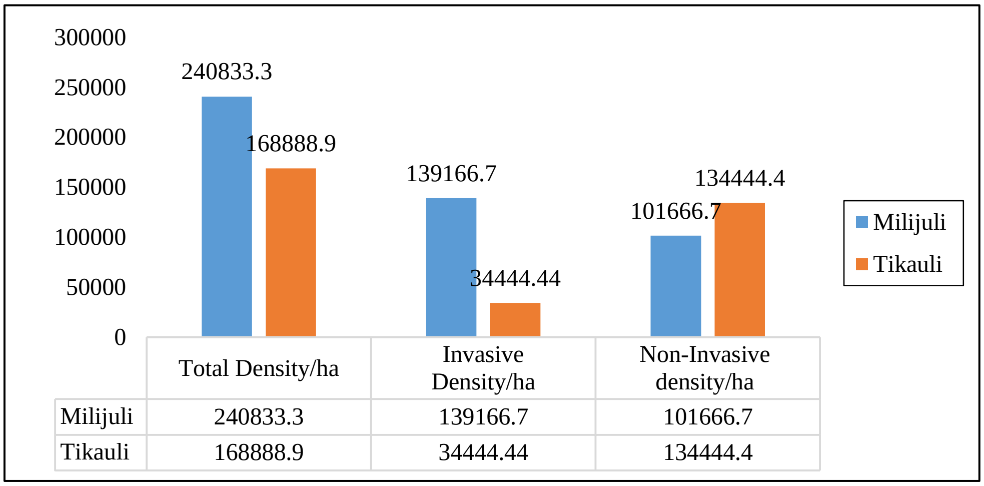

Figure 3 *Comparison of density of flora of both community forests*

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Table 2 *Ecological indices of Milijuli and Tikauli Buffer Zone Community Forest.*

Milijuli Buffer Zone Community Forest					Tikauli Buffer Zone Community Forest				
Species	**Numbers**	**Density**	**Frequency**	**Abundance**	**Species**	**Numbers**	**Density**	**Frequency**	**Abundance**
Chromolaena odorata	112	93333.33	75	12.44	*Chromolaena odorata*	7	7777.78	33.33	2.33
Mikania micrantha	15	12500	8.33	15	*Shorea robusta*	93	103333.33	100	10.33
Hyptis suaveolens	12	10000	8.33	12	*Clerodendron infortunatum*	23	25555.56	55.56	4.6
Ageratum conyzoides	20	16666.67	8.33	20	*Flemingia spp*	19	21111.11	33.33	6.33
Shorea robusta	81	67500	91.67	7.364	*Maesa chisia*	1	1111.11	11.11	1
Terminalia tomentosa	3	2500	8.33	3	*Myrsine semiserrata*	1	1111.11	11.11	1
Clerodendron infortunatum	35	29166.67	33.33	8.75	*Argemone mexicana*	2	2222.22	11.11	2
Hymenodictyon exelsum	4	3333.33	8.33	4	*Pogostemon benghalensis*	2	2222.22	11.11	2
Maesa chisia	6	5000	8.33	6	*Lallea coromegelica*	4	4444.44	11.11	4
koenigii	1	833.33	8.33	1					

Table 3 *Diversity Index*

Diversity index	Tikauli BZCF	Milijuli BZCF
Simpson's Diversity Index (D)	0.26	0.32
Shannon-Wiener Diversity index (H')	1.75	1.51

Control measures

Various control measures such as cutting, uprooting and fire were practised by the users in both but most of these measures seem to have failed in controlling the invasive species. Figure 4 and 5 respectively show the existing applied control measures and suggested control measures in the study area.

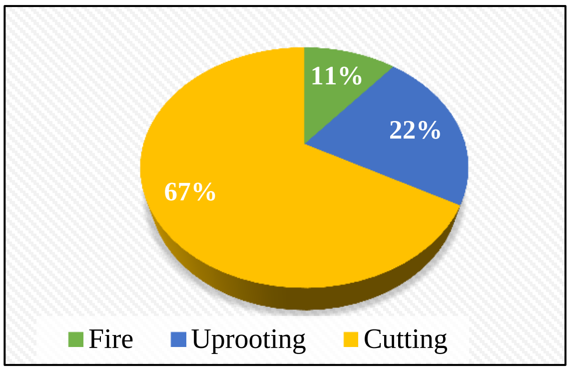

Figure 4 *Existing applied control measures*.

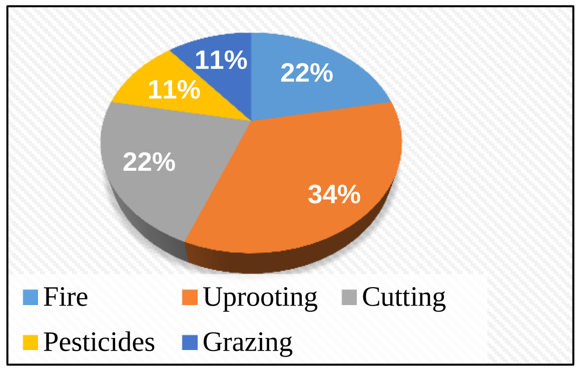

Figure 5 *Suggested control measures.*

Uprooting has been suggested to be most effective method by respondents and it should be exercised at regular interval particularly before flowering and fruiting season. Some of the respondents shared that invasive species were not found in large scale like present days before the introduction of community forestry. This may be because of the trampling effects which restrict the species to grow by making the soil compact. They also believe that transportation or road access may have brought the weed in their localities while some of them shared that weeds originates after the flood of 2050 BS (1993 AD).

Conclusion

Altogether 14 species of IAPS were recorded in the study site. The occurrence of *C odorata* is the highest. Diversity of Tikauli is higher to that of Milijuli BZCF. *Shorea* forest with open canopy has maximum hold of two species; *Chromolaena* and *A houstonianum*. High invasion was seen in Milijuli to that of Tikauli BZCF but the density of regeneration of native species was higher in Tikauli BZCF. This study shows that invasive plants reduce the regeneration which was evident by low density of non-invasive plants in highly infested area. Most of the control measures are not effective. Regular assessment and monitoring of the IAPS is necessary to understand the problem and their impacts. Early detection of IAPS by user groups of BZCFs in order to apply best control practices and prevent the further invasion is crucial. Permanent experimental plots can be established at different sites invaded by highly problematic IAPS to assess the effectiveness of restoring native species after removal of the IAPS. Identification and awareness program by CNP authority to local community about impacts and their control measures are recommended with this study.

Acknowledgement

We are thankful to the Department of National Park and Wildlife Conservation (DNPWC) for the permission to undertake this study. We are indebted to National Trust for Nature Conservation-Biodiversity Conservation Center for the financial support. Gracious thanks to Anil Prasai and Babu Ram Lamichhane for their mental investment to shape this article. Cordial thanks to Ruchi Timilsena for her help.

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Fish Diversity and Distribution Status in Bheri and Babai River, Mid-Western, Nepal.

Kumar Khatri[1,2*], Bibhuti Ranjan Jha[2], Smriti Gurung[2], Udhab Raj Khadka[1], Saru Pokharel[2], Anish Adhikari[2] and Anuj Khoju Shreshta[2].

[1] Mahendra Ratna Campus, Tribhuvan University, Nepal
[2] Department of Environmental Science and Engineering, Kathmandu University, Nepal

*Corresponding author: khatriku.kk@gmail.com

Abstract

A baseline study on fish assemblages of the Bheri and the Babai rivers in mid-west Nepal in the wake of first inter-basin water transfer under the Bheri Babai Diversion Multipurpose Project (BBDMP) was conducted. A total of 10 sites were sampled in these rivers and their upstream tributaries during January 2018 (Winter). To supplement the study selected physico-chemical parameters *viz*. pH, conductivity, dissolved oxygen (DO), temperature, turbidity was measured on-site using a multi-meter probe taking three replicates at each site. Fish assemblages were sampled with standard electrofishing gear with two runs of 20 minutes each. Fish were identified up to species level following standard literature. Fish abundance was measured in temporal unit called Catch Per Unite Effort (CPUE), expressed as the number of fishes collected per 10 minutes of electro fishing. The species diversity was analyzed using the Shannon- Weiner index (H), Evenness (E). All the sites were characterized by alkaline pH (8.21-8.68); rich DO values (8.15- 10.94mgL^{-1}) suitable for fish survival. Conductivity and water temperature were higher in rain-fed Babai (302.33 to 468±2 µScm^{-1}; 14.17 to20.98°C) than in glacial-fed Bheri (230.33 to 410 µScm^{-1}; 11.86 to 16.58°C). A total of 1763 fish individuals belonging to five Orders, 11Families and 28 species were recorded. Cyprinidae was most dominant Family. The most common species were *Barillus vagra* and *Schistura beavani*. *Neolissochilus hexagonolepis*, *Schizothorax richardsonii* and *Tor putitora* are enlisted under IUCN Red List. The Shannon Weiner Index ranged from 0.03 to 1.95 and the Evenness values of 0.48 to 0.9 indicating fairly rich fish diversity. The result of this study could be useful information to assess the influence of inter-basin water transfer from Bheri to Babai.

Keywords: Fish diversity, Inter-basin water transfer, Electrofishing, Bheri, Babai

Introduction

Freshwater fishes are important components of global biodiversity representing approximately 15000 species (Reid et al., 2013). An estimated 3000 species are found in Asia (Lundberg et al., 2000) with Carps (Cypriniformes) and Cat fishes (Siluriformes) representing the major freshwater fish taxa from South Asia (Berra, 2007). Nepal with its rich freshwater resources (WECS, 2011) and varied topographical features with different climatic and ecological zones is also known to support rich fish diversity (Shrestha, 2000). Fish studies in Nepal started as early as early 1800s (Hamilton, 1822) and a number of contributions have been made by scholars in the field of Ichthyology since then (Jha, 2006 and references therein). However, most of these studies have focussed on fish inventory (eg. Edds, 1993; Shrestha et al., 2009; Jha et al., 2015; Shrestha, 2016). Different studies have reported different number of fish species. For example, Rajbanshi (2005) reported 187 species whereas Shrestha (2008) reported 232 species and Shrestha (2011) reported 206 fish species. In contrast, studies related to seasonal variations and impact of different environmental variables are still scarce (Jha et al., 2018; Pokharel et al., 2018). These studies have revealed Cyprinidae to be the most dominant taxa in Nepalese freshwaters and fish assemblages show spatio-temporal variations influenced by a range of environmental variables (Edds, 1993; Jha et al., 2018; Pokharel et al., 2018).

The Government of Nepal (GoN) has started the construction of Bheri Babai Diversion Multipurpose Project (BBDMP) - the first of its kind of inter-basin water transfer project in Nepal. Being classified as a "Project of National Pride" by the GoN, BBDMP aims to divert water from glacial-fed River Bheri to rain-fed Babai, for irrigation of 51000 hectares of agricultural land in Bardiya and Banke with generation of 46 MW hydropower (www.bbdmp.gov.np). While such projects are crucial for the prosperity of a developing nation like Nepal, the current state of knowledge elsewhere indicates that large dams, inter-basin water transfers and water withdrawal from rivers have impact on aquatic ecosystems and ecosystem functions (Lakra et al., 2011) with socio-economic consequences (Das, 2006). These include upstream as well as downstream impacts on habitat for aquatic communities such as fish and macroinvertebrates, water quality and quantity (Pelicice et al., 2015). Considering the importance of freshwater fishes and the environmental and socio-economic impacts of inter-basin water transfer, this study aims to generate baseline information on the fish assemblages in two different river systems of Mid-Western Nepal – glacial-fed (Bheri) and spring/rain-fed (Babai) in the wake of inter-basin water transfer. The result of this study could be useful information to assess the influence of inter-basin water transfer on fish diversity from Bheri to Babai.

Materials and Methods

Study Area

The study was conducted in selected stretches of the Bheri River and the Babai River in mid-west Nepal. The Bheri is a glacial-fed perennial river originating from the Dhaulagiri range (Mishra et al., 2018) whereas the Babai River is a rain-fed river with low flow during dry seasons (Khanal, 2001) originating from the Mahabharat region (Jha, 2010). A preliminary study for site selection was conducted in October 2017 and the sampling was conducted in January 2018 (winter) on 10 selected stretches over the Bheri and the Babai and their tributaries (Figure 1; Table 1). Site selection was based on upstreams and downstreams of water diversion and water release of the Bheri and the Babai, their tributaries and accessibility. Accordingly, upstream and downstream of water diversion site at Bheri and upstream and downstream of water release at Babai together with three upstream tributaries of the Bheri and two upstream tributaries of Babai were sampled. Necessary permission to conduct the study was obtained from Department of National Parks and Wildlife Conservation (DNPWC) before the commencement of the field visits.

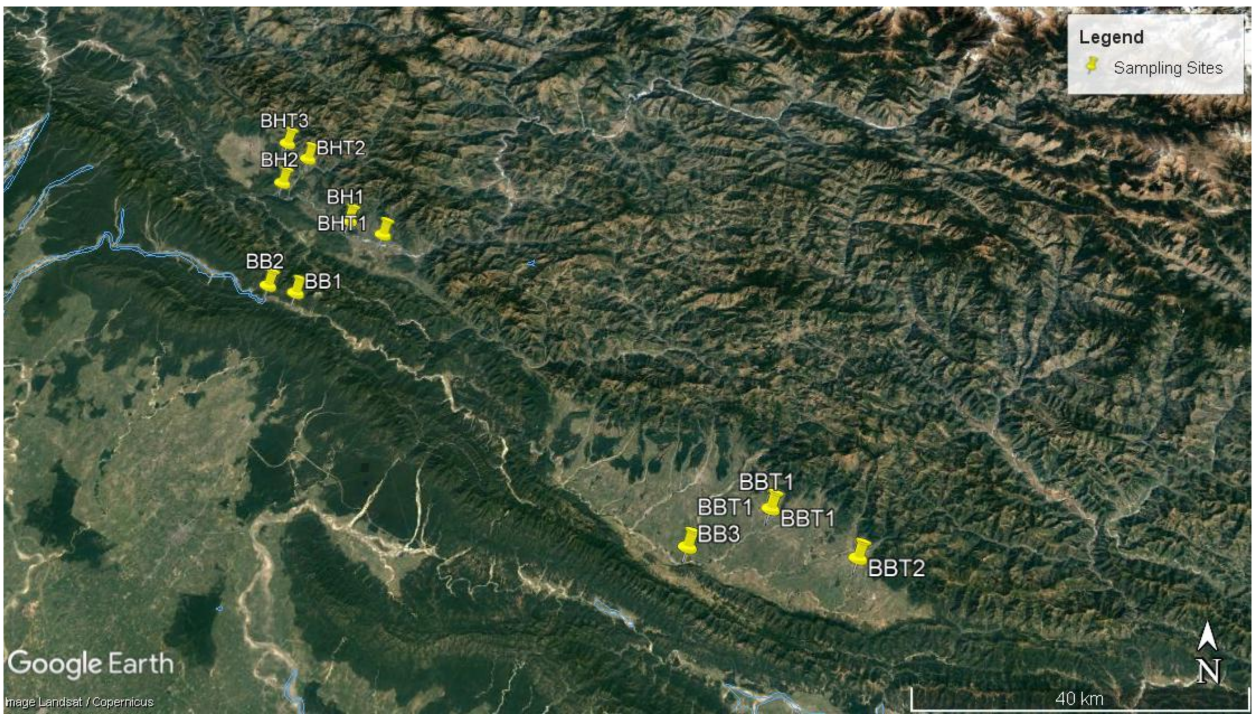

Figure 1 *Sampling sites at Bheri and Baba*

Table 1 *Sampling sites showing elevation and geographical coordinates*

River	Site Code	Place	Elevation (masl)	Latitude	Longitude	Remarks
Bheri	BH1	Surkhet	436	28.45742°N	081.78235°E	Upstream of water diversion at Bheri
Bheri	BH2	Surkhet	403	28.51468°N	081.67520°E	Downstream of water diversion at Bheri
Goche	BHT1	Mehelkuna, Surkhet	475	28.43677°N	081.83489°'E	Tributary of Bheri
Chingad	BHT2	Gangate,Surkhet	466	28.55361°N	081.70715°E	Tributary of Bheri
Jhupra	BHT3	Surkhet	497	28.57791°N	081.67207°E	Tributary of Bheri
Babai	BB1	Chepang Ghat, Surkhet	293	28.35160°N	081.72109°E	Upstream of water release at Babai
Babai	BB2	Mul Ghat, Bardiya	287	28.36127°N	081.68044°E	Downstream of water release at Babai
Babai	BB3	Bel Takura, Dang	561	28.03095°N	082.26972°E	Upstream of Babai
Patre	BBT1	Majh Gaun, Dang	594	28.07607°N	082.37733°E	Tributary of Babai
Katuwa	BBT2	Ghorahi, Dang	625	28.01966°N	082.48380°E	Tributary of Babai

Data Collection and Analysis

Selected physico-chemical parameters such as the temperature, dissolved oxygen (DO), pH and conductivity were measured on-site with a multimeter probe (Hannah). Three replicates were taken at each site. For fish sampling, standard electro-fishing by wading method was adopted (Jha, 2006). This method involves the coordination of four persons; the first one with the standard gear wading the river and electro-shocking the fish, while the next two behind carry dip nets to collect the shocked fish. The fourth person carries a bucket to empty the contents of the dip nets. Fish sampling was done in two runs of approximately 20 minutes which was later used to calculate the Catch Per Unit Effort (CPUE), expressed as the number of fishes collected per 10 minutes of electro fishing. The captured fishes were identified up to species level in the field itself following Shrestha (2008) and pictures of the fishes were also taken. The identified fishes were released back to their natural habitat once the necessary information was collected. Unidentified fish specimens were preserved in formalin and brought to the Department of Environmental Science and Engineering, Kathmandu University.

Shannon- Weiner index (H), Evenness (E) was calculated to estimate fish diversity and following the formulae:

Shannon-Weiner index

$H = – \Sigma pi \ln pi$

Evenness index

$E = H / \ln S$

Where, H= diversity index

Pi = relative abundance (s/N)

s = the number of individuals for each species

N = the total number of individuals

S = the total number of species

E = the similarity or evenness index

Ln = natural logarithm

The fish species were categorized into different IUCN categories to know about their status.

Results and Discussions

Physico-Chemical Parameters

The values of selected physico-chemical parameters for the investigated sites are summarized below (Table 2).

Table 2 *Physico-chemical parameters of the sampling sites*

Site	Season	pH	DO mgL^{-1}	Conductivity μScm^{-1}	TDS mgL^{-1}	Temperature °C	Turbidity NTU
BB1	Winter	8.53±0.03	8.77±0.41	340.67±0.58	170.67±0.58	14.29±0.01	2.57±0.15
BB2	Winter	8.68±0.19	9.65±0.14	342±1.73	171.33±1.55	16.59±0.34	3.05±0.04
BB3	Winter	8.28±0.02	8.55±0.17	410	205	14.50±0.01	1.25±0.01
BBT1	Winter	8.58±0.01	10.94±0.07	302.33±0.58	151	20.98±0.05	12.14±0.05
BBT2	Winter	8.21±0.01	9.08±0.32	468±2.00	23. ±1.00	14.17±0.08	3.76±0.05
BH1	Winter	8.59±0.01	9.24±0.29	262.67±0.58	131	12.23±0.06	3.03±0.12
BH2	Winter	8.61±0.01	9.92±0.24	264.67±4.04	133	11.86±0.01	3.38±0.11
BHT1	Winter	8.21±0.37	8.27±0.18	410±6.93	205±3.46	14.57±0.19	6.82±0.04
BHT2	Winter	8.44±0.02	8.48±0.10	230.33±2.08	115±1.00	13.25±0.02	7.87±0.06
BHT3	Winter	8.52±0.03	8.15±0.11	241.67±0.58	121	16.58±0.06	5.57±0.06

All the sites were characterized by alkaline pH with highest value at BB2 (8.68±0.19) and the lowest value at BBT2 (8.21±0.01). Water temperature ranged from 20.98±0.05°C (BBT1) to 11.86±0.01°C (BH2). Conductivity was highest at BBT2 (468±2.00 μScm^{-1}) and lowest at BHT2 (230.33 ±2.08 μScm^{-1}). Dissolved oxygen (DO) ranged from 8.15±0.11 (BHT3) to 10.94±0.07 (BBT1) indicating rich DO concentrations. Two sampled t- test revealed a significant variation in conductivity and TDS ($p<0.05$); Conductivity and temperature were comparatively higher in Babai river system (Table 2). Fresh water bodies in western Nepal have relatively higher conductivity values (Sharma et al., 2005; Gurung et al., 2018) in contrast to the eastern part of the country (Shrestha et al., 2009; Jha et al., 2015). Glacial-fed rivers are known to have low temperatures (Fuereder et al., 2001) and the Bheri being glacial-fed river is bound to have lower surface temperature in contrast to the Babai and its tributaries. Relatively lower surface temperatures in winter in Bheri with its larger numbers of riffles in the sampled stretches probably explain higher DO values than those observed in the Babai. Alkaline pH values in streams and rivers in western Nepal including the Bheri and the Babai have also been reported in previous studies as well (Sharma et al., 2005; Matangulu et al., 2017).

Fish Assemblages and Distribution

A total of 1763 fish individuals belonging to 5 Orders, 11 Families and 28 species were recorded during the study. Of this, a total of 776 individuals representing 16 species were observed from the Bheri and its tributaries while a total of 987 individuals representing 22 species were observed from the Babai and its tributaries (Table 3). Of the 28 species observed in these sites, three species *viz. Neolissochilus hexagonolepis*, *Schizothorax richardsonii* and *Tor putitora* are enlisted under IUCN Red List (https://www.iucnredlist.org/) as near threatened, vulnerable and endangered respectively (Table 3). The Shannon Weiner Index ranged from 0.03 (BBT1) to 1.95 (BH2) (Fig. 2) indicating fairly rich fish diveristy; and Evenness ranged from 0.9 (BH2) to 0.48 (BBT1).

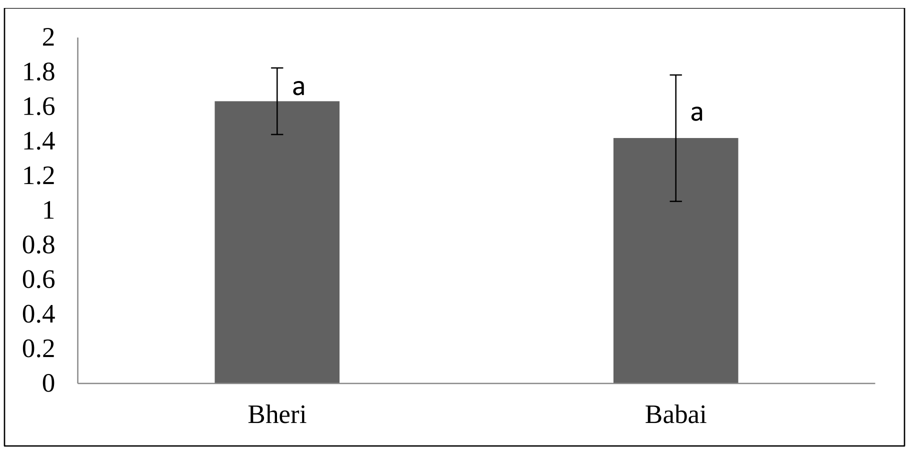

Figure 2 *Shannon Weiner Diversity in Bheri and Babai*

Table 3 *Fish taxa, Catch Per Unit Effort values and their current IUCN status*

SN	Order	Family	Name of the species	Bheri	Babai	IUCN Status
1	Cypriniformes	Nemacheilidae	*Acanthocobitis botia*	3.7	0.812	LC
2	Siluriformes	Amblycipitidae	*Amblyceps mangois*	0	1.3	LC
3	Cypriniformes	Cyprinidae	*Barilius barila*	10.45	2.3	LC
4	Cypriniformes	Cyprinidae	*Barilius barna*	0	0.1	LC
5	Cypriniformes	Cyprinidae	*Barilius bendelisis*	1.9	0.05	LC
6	Cypriniformes	Cyprinidae	*Barilius vagra*	7.8	22.77	LC
7	Perciformes	Channidae	*Channa punctate*	0	0.6	LC
8	Cypriniformes	Cyprinidae	*Crossochelius latius*	0.1	0	LC
9	Cypriniformes	Cyprinidae	*Danio rerio*	0	0.5	LC
10	Cypriniformes	Cyprinidae	*Esomus danricus*	0	0.05	LC
11	Cypriniformes	Cyprinidae	*Garra gotyla gotyla*	4.4	2.59	*LC*
12	Siluriformes	Sisoridae	*Glyptothorax telchitta*	0.25	0.55	*LC*
13	Siluriformes	Erethistidae	*Hara jerdoni*	0	0.05	*LC*
14	Cypriniformes	Cyprinidae	*Labeo dero (Bangana Dero)*	0	0.1	*LC*
15	Cypriniformes	Cyprinidae	*Labeo macmahoni*	0.15	0	Not Evaluated
16	Cypriniformes	Cobitidae	*Lepidocephalus guntea*	0	2.87	LC
17	Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	0.05	0.25	LC
18	Siluriformes	Bagridae	*Mystus tengara*	0	0.1	LC
19	Cypriniformes	Cyprinidae	*Neolissochilus hexagonolepis*	0.25	0	NT
20	Siluriformes	Sisoridae	*Pseudeheneis sulcatus*	1.75	0	LC
21	Cypriniformes	Psilorhynchida	*Psilorhynchus pseudecheneis*	0	0.20	LC
22	Cypriniformes	Cyprinidae	*Puntius conchonius*	0	0.95	LC
23	Cypriniformes	Cyprinidae	*Puntius sophore*	1.25	2.6	LC
24	Cypriniformes	Nemacheilidae	*Schistura beavani*	4.45	12.15	LC
25	Cypriniformes	Nemacheilidae	*Schistura rupecula*	1.25	0	LC
26	Cypriniformes	Cyprinidae	*Schizothorax richardsonii*	0.1	0	VU
27	Cypriniformes	Cyprinidae	*Tor putitora*	0.95	0.7	EN
28	Beloniformes	Belonidae	*Xenontodon cancila*	0	0.05	LC

LC: Least Concern, VN: Vulnerable, NT: Near threatened, EN: Endangered

Cyprinidae was the most dominant Family comprising 53.57% followed by Nemacheilidae (10.71%) and Sisoridae (7.14%). Cyprinids were represented by 15 species followed by Nemacheilidae with three species; Sisoridae with two species whereas Amblycipitidae, Bagridae, Belonidae, Cobitidae, Channidae, Erethistidae and Mastacembelidae were represented by only one species each. *Schizothorax richardsonii*, *Pseudecheneis sulcata*, *Neolissochilus hexagonolepis*, *Labeo macmahoni* and

Crossochelius latius were observed in Bheri and its tributaries while *Amblyceps mangois*, *Barilius barna*, *Channa punctata*, *Danio rerio*, *Esomus danricus*, *Hara jerdoni*, *Labeo dero (Bangana Dero)*, *Lepidocephalus guntea*, *Mystus tengara*, *Psilorhynchus pseudecheneis*, *Puntius conchonius* and *Xenontodon cancila* were observed only in Babai and its tributaries (Table 3). Species like *Schizothorax richardsonii* are characteristics of cold water with rich dissolved oxygen concentration (Saund et al., 2012) and are found in Himalayan and sub-Himalayan regions (Pathak et al., 2014). Cyprinids represent the largest freshwater fish taxon globally and this taxon is found to occur in Eurasia, Africa, North America but absent in South America and Australasia (Berra, 2007). China and South Asia are considered to be the largest diversity centres of this taxon (Berra, 2007) and the dominance of Cyprinids in a number of studies in Nepal (Gautam et al., 2010; Jha et al., 2015; Jha et al., 2018; Limbu & Gupta, 2019) including in this study also corroborates this fact.

Conclusion

This study was conducted to generate baseline data on fish assemblages in the wake of inter-basin water transfer from Bheri to Babai. A total of 28 species were observed indicating fairly rich fish diversity and Cyprinidae was the most common fish taxa in both the river systems. The result of this study could be useful information to assess the influence of inter-basin water transfer from Bheri to Babai. A comprehensive study encompassing different seasons and other environmental variables are underway.

Acknowledgement

The authors acknowledge the University Grants Commission, Nepal (UGC Institutional Grant 2073) for the financial support to conduct this study.

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Variations in Host-epiphytes Relationship in Temperate Forest of Chandragiri Hill, Kathmandu, Central Nepal

Ram Saran Dani[1,2*] and Chitra Bahadur Baniya[2]

[1]Trichandra Multiple Campus, Tribhuvan University, Ghantaghar, Kathmandu
[2]Central Department of Botany, Tribhuvan University, Kirtipur, Kathmandu

*Corresponding author: rsdani2001@yahoo.com

Abstract

This study focused on the relationship between epiphytes (74 species belonging to 33 Genera of 7 Families) and characters of phorophytes (25 species of 14 Families) species in mature forest of Chandragiri Hill, central Nepal. We established 10 vertical transects along elevation gradient from 1400 to 2300 masl. For every 100 m increment in height, one grid point was designed in search of all host trees and associated epiphytes around diameter of 25 meter from grid point. We analyzed physical as well as chemical properties of each host tree like diameter at breast height (DBH), pH of bark, their rugosity and water-holding capacity. Our result show that epiphyte diversity was found correlated with host DBH, bark pH and water holding capacity of bark. The mean pH of the bark was found 6.6. Bark pH and water holding capacity were observed to have poor correlation ($p>0.12$) with epiphyte diversity. Water holding capacity of phorophytes with 70-80% was best selected by epiphytes.

Keywords: Epiphytes, Host-epiphyte relation, Microhabitat, Phorophytes

Introduction

Epiphytes spend their entire life cycle perched on other plants and receive all mineral nutrients from non-terrestrial sources (Kress, 1986). Vascular epiphytes usually prefer to grow luxuriously in humid tropical to temperate forests (Hietz, 1999). About 10% of the earth's total vascular flora are vascular epiphytes and limited to tropical and subtropical forests with most diverse life form in high humidity (Madison, 1977; Benzing, 1987). Harrison et al (2003) found the most determining factor for determining variation in epiphytes colonization is host size Host size is a complex factor that integrates several ecological processes affecting epiphytes. Larger host is directly related with wider diameter, more surface area, more canopy covering, more diverse micro-habitat, greater ranges of illumination, water holding capacity and longer life span for durability for easy colonization by epiphytes (Wyse & Burns, 2011). Bark texture is another host trait for determining variation in epiphytes. The texture of bark determines surface for growth, water holding capacity, chemical retention properties. Studies by Miyata & Forsyth (1984) showed that the water-shedding effect of smooth bark in decreased drought resistance; and consequently decreased moss abundance on smooth-barked trees. Trees with rough bark are conducive to small vines that use tendrils to cling to crevasses.

Rationale of the study

Phorophyte species provide shelter for several epiphytes. The nature of bark plays important role in growth and species diversity of epiphytes. The present study tried to analyse some features of phorophytes suitable for epiphytes growth.

Materials and Methods

Study area

Our study was conducted in south to east aspects of Chandragiri Hill, western boarder of Kathmandu valley (Figure 1). The study area has annual mean temperature of 17.67°C and annual rainfall ranges between 7-378 mm and 80% precipitation falls between June to September. It represents typical temperate forest elevation ranging from 1365 to 2524 metres above sea level (masl) and dominated by *Schima wallichii* - *Alnus nepalensis* forest in lower region and upper region dominated by *Rhododendron* - *Berberis* forest. We conducted research on lower to upper region from basal entry point at 1400 masl to upper exit point at 2400 masl.

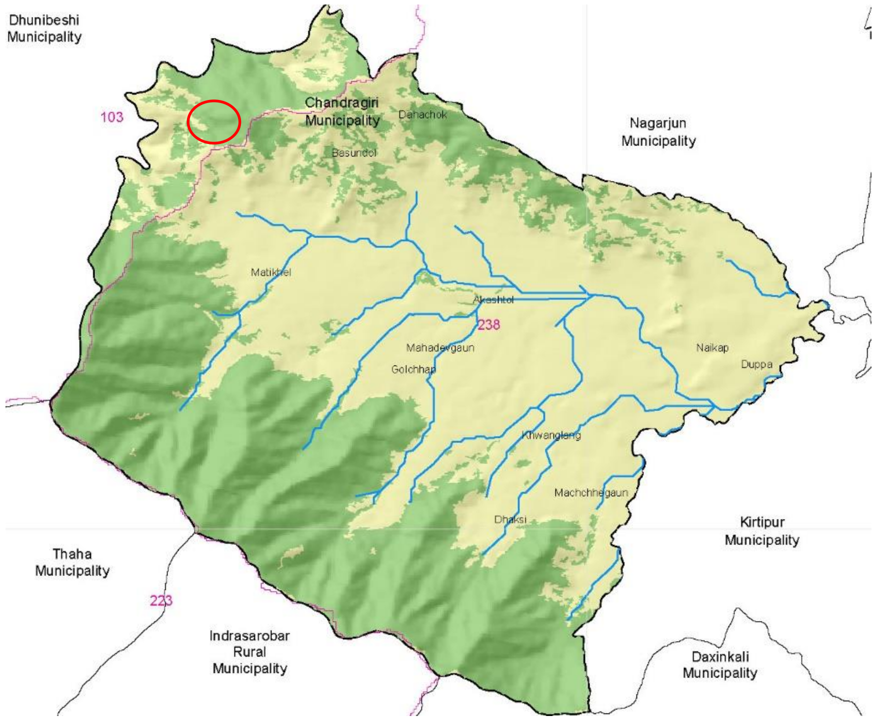

Figure 1 *Map showing study area*

Field work was conducted in January to March 2019. Vascular epiphytes were surveyed in ten plots located in main forests starting from basal altitude 1400 masl. Vertical transect was designed from base to top of the hill and ten grid points were selected by using GPS unit (Garmin etrex10) for every 100m vertical increment. From central grid point a single circular plot of 25m diameter was established. From this quadrat, we surveyed all trees (having >10cm DBH) having epiphytes or without epiphytes. We examined host traits and environmental factors for every epiphyte and host plant. Host size (DBH and tree height), bark rugosity, elevation and rugosity were included. Chemical parameter like pH of bark was also recorded by using single flat head electrode (Farmer et al., 1990). For water holding capacity of bark, small piece of bark was brought to laboratory and standard method (Mehltreter et al., 2005; Köster et al., 2011) was applied.

Tree height and stem height were measured using 5 m pole (using linear measuring tape). For stem rugosity, three categories were made: (1= smooth having <1cm fissure width); 2 = medium (having 1-2 cm fissure width); and 3 = rough having > 3cm fissure width (Callaway et al., 2002).

Among several environmental factors, uncorrelated factors were eliminated by using Spearman’s rank correlation coefficient with threshold value of $p < 0.5$. Final data were organized into a species by site matrix, with qualitative and quantitative variable of elevation, phorophytes and epiphytes.

Results and Discussion

The epiphytes observed in 10 vertical transects was 74 species belonging to 33 Genera of 7 Families and phorophytes were 25 species of 14 Families with 38.93% host mean occupancy. Along elevation gradient, the number of epiphytes, standing density of phorophytes, host occupancy and species richness showed similar midpoint apex (Figure 2). Among phorophytes, only 6 species held more than 70% epiphytes. Only 14 epiphytic species are specific to single host plants and 4 phorophyte species bear single epiphyte.

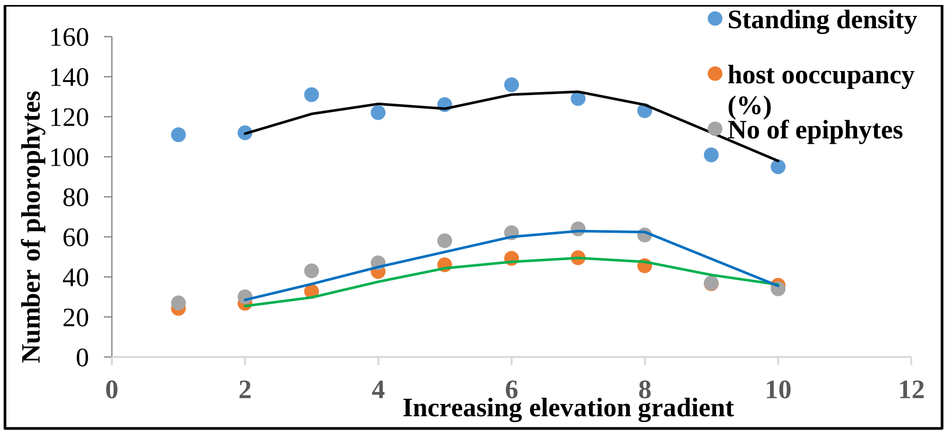

Figure 2 *Standing density, host occupancy and species richness of epiphytes along increasing elevation*

Regarding pH of bark, there is very poor relationship with elevation. Acidic pH is common to all types of epiphytes ranges from 5.6 to 6.8 with mean pH 6.6. More than half (about 60%) epiphyte prefers to grow in the pH ranging from 6.1 to 6.5 (Figure 3).

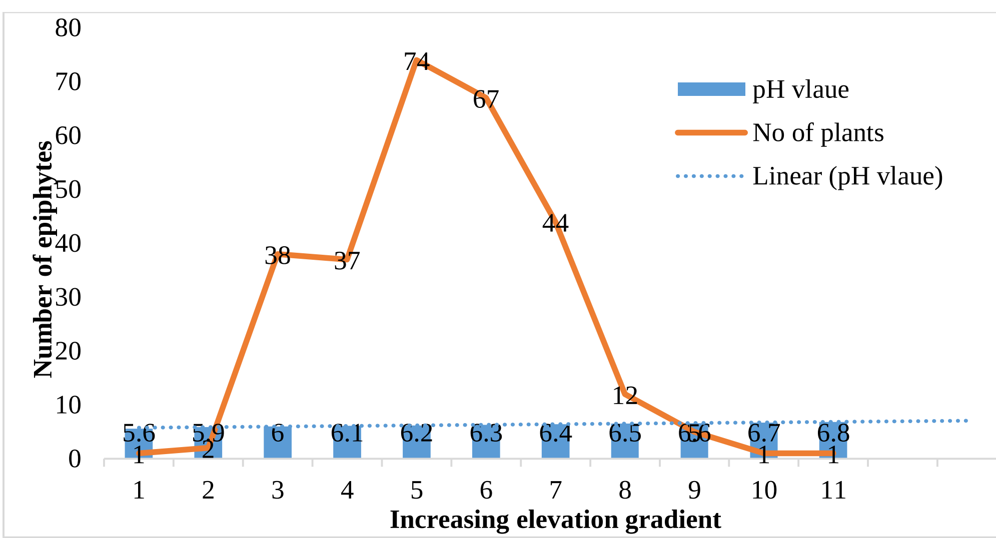

Figure 3 *Variation of pH of barks of phorophytes along increasing elevation*

Diameter at breast height (DBH) is another character chosen by epiphytes for their growth. Several studies showed the positive correlation between the increasing DBH and species richness (Figure 4). Present study showed that there are specific ranges of DBH for optimum growth of epiphytes. Medium sized trees are usually selected by epiphytes for their growth.

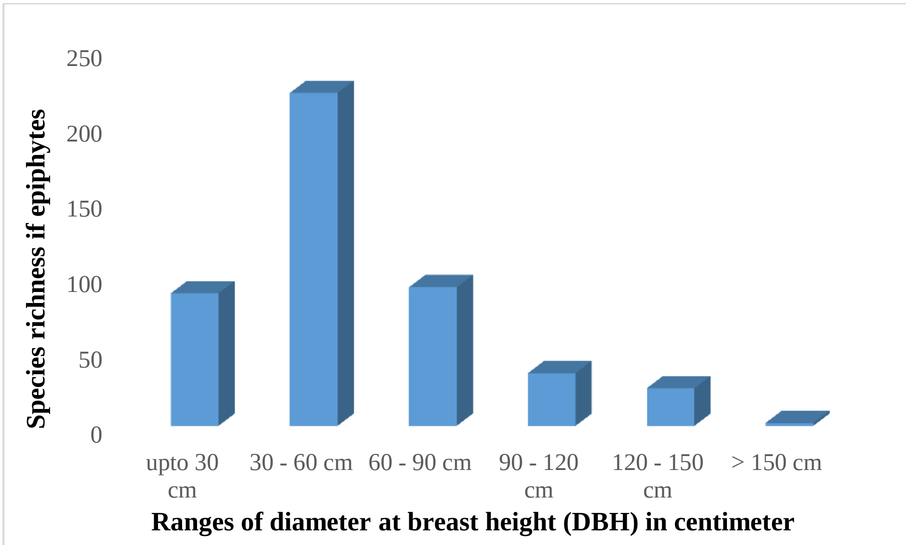

Figure 4 *Ranges of DBH of phorophytes and species richness of epiphytes*

Usually epiphytes prefer to grow in rough medium textured bark. Rough rugosity of barks can hold large amount of water for growth of epiphytes (Figure 5). Very few individual epiphytes prefer to grow in smooth barks like Rhododendrons whereas the barks of *Schima* and *Quercus* provide sufficient rough texture for decomposition of litters and maintain suitable water moisture. Epiphytes get sufficient water and minerals from barks of phorophytes. Usually epiphytes luxuriously grow in those barks where water holding capacity of bark maintained around 70-80% (Wyse & Burns, 2011) (Figure 6).

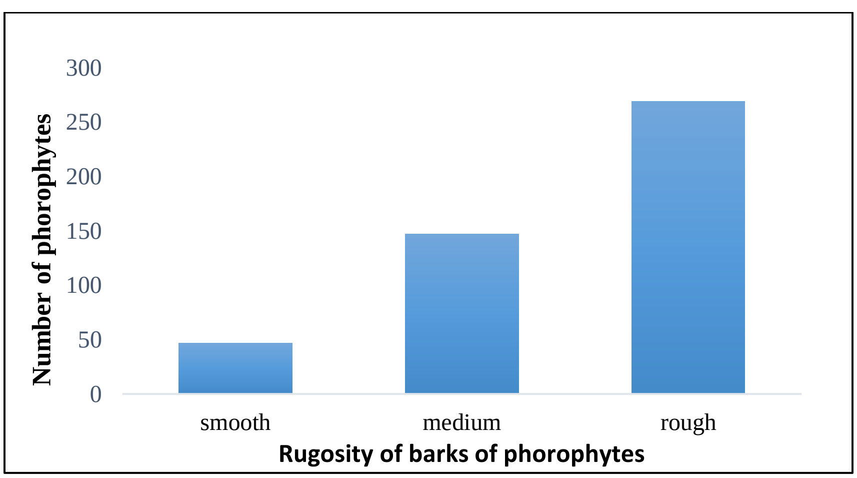

Figure 5 *Preferences of rugosity (smoothness) of bark of epiphytes*

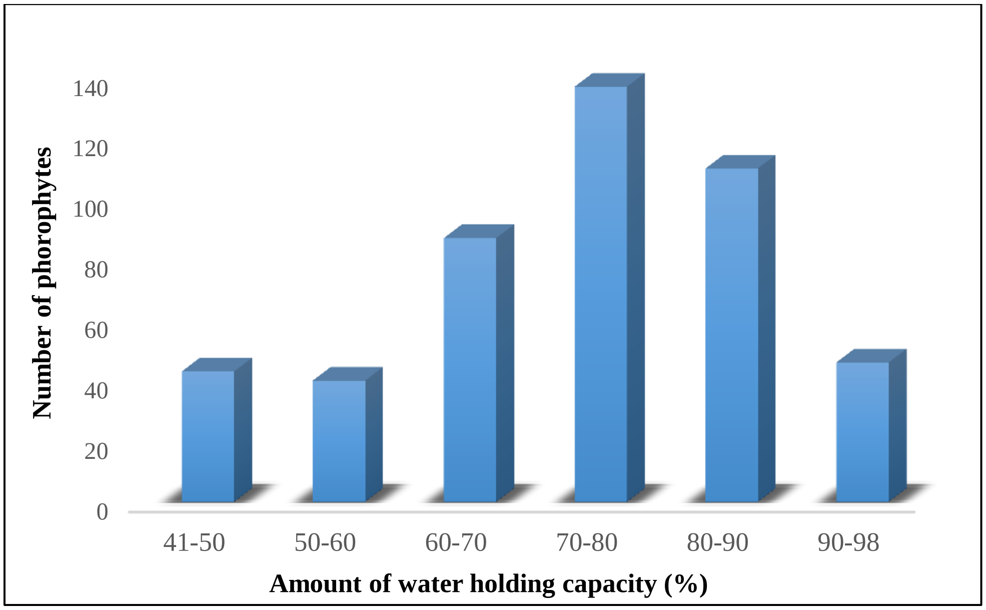

Figure 6 *Presence of water holding capacity (%) of bark for growth of epiphytes*

Conclusion

The distribution of epiphytes depends on habit of phorophytes as the latter provide suitable environment for growth and development of epiphytes. Usually, host occupancy of epiphytes is about more than one third as compared to potential phorophytes. Trees with a rough or fissured bark are more likely to show high species richness. Therefore, conservation of phorophytes not only retain species richness also increases epiphytic species diversity.

Acknowledgement

Authors are grateful to Trichandra Multiple Campus, Central Department of Botany, TU, field guides and concerned authorities for their helps.

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Study of Phytochemical, Antimicrobial, Antioxidant and Cytotoxic activity of Some Medicinal Plants of Nepal.

Sameer Mudbhari[1], Sudati Shrestha[1], Sarun Jonchhe[1], Nabin Timsina[1], and Bhupal Govinda Shrestha[1]*

[1]Department of Biotechnology, Kathmandu University, Dhulikhel, Nepal

*Corresponding author: bgs@ku.edu.np

Abstract

Nepal being a locale to multitudes of geographical landforms and variable environmental features support prominent diversity of life forms and the evolution of myriads of plant species with utmost medical significance. The study was undertaken to examine the curative values of *Gaultheria fragrantissima*, *Taxus wallichiana* and *Bergenia ciliate*. Plant extracts were prepared with ethyl acetate maceration, methanol soxhlet and methanol maceration and then examined for the proportion of the bioactive compounds with different phytochemical tests *viz* antioxidant properties via 2, 2-diphenyl 1-picryl hydrazyl (DPPH) free radical scavenging assay; cytotoxic activity via Brine Shrimp assay; and their antimicrobial potentials. All three plants exhibited a strong antimicrobial activity against four potent human pathogenic microbial strains. Similarly, methanol extracts of *T wallichiana* and *B ciliate* showed promising antioxidant activity with Inhibitory Concentration 50 (IC50) values of 1.23µg/ml and 3.76µg/ml respectively. *T. wallichiana* and *G. fragrantissima* had lethal concentration 50 (LC50) value of 289.81ppm and 441.42ppm respectively in Brine Shrimp Cytotoxicity assay.

Keywords: Medicinal plants, Phytochemical, Antimicrobial, Antioxidant, Cytotoxic.

Introduction

Human beings rely on plants for many purposes- for the source of energy in the form of food, making clothes, curing different diseases and many more (Shoemaker, 1994). Medicinal plants are the plants which have some chemical components in them that can either help prevent the onset of diseases or help cure them. The importance of medicinal plants to prevent and cure different types of diseases is known to human for a long period of time. Many holy books like the Vedas in Hindu scripture seem to have given them a huge importance by mentioning many plants with their benefits in curing different diseases. In one of the stories of the Ramayana- a major Sanskrit epic- Lord Hanuman has been said to bring a mountain full of plants which also had a very special plant called "*Sanjeevani buti"*, a magical herb which had helped cure Lakshmana who was nearly killed (Kalra et al., 2016). Nowadays, there has been a lot of interest throughout the world to carry out research for the purpose of finding novel chemical compounds in medicinal plants for the purpose of finding cure for different diseases. Drugs like Paclitaxel have been discovered which are frequently used in modern day medicines to cure some of the life threating diseases like the cancer. Hundreds of research articles are published every year with the finding on some kind of medicinal plant extracts which has the capacity to fight some kind of disease (Slichenmyer & Von, 1991).

Nepal has a huge variety of plants found in some extremely high-altitude areas to very low 'Terai' belts. Most of the plants located in high altitude are especially given high priority for carrying out investigation on the phytochemicals that could have some special medicinal value. Plants such as *Ophiocordyceps sinensis*, which is natively called as "Yarsagumba" in Nepal are highly valued locally and internationally because it is highly effective for the treatment of kidney dysfunction and male sexual problems (Shrestha et al., 2012). However, there are still many unidentified plants in Nepal which are yet to be screened for the possibility of finding novel phytochemicals that could have a huge medicinal value. Therefore, this study aims to assess the curative values of three plants *viz. Gaultheria fragrantissima*, *Taxus wallichiana* and *Bergenia ciliate*.

Materials and Methods

Collection of plant materials

Gaultheria fragrantissima and *Bergenia ciliate* were collected from Ilam, east Nepal whereas *Taxus wallichiana* was collected from regions near Dhorpatan Hunting Reserve, west Nepal. Collection was done in summer in the month of May. The selections of the plants were based on the ethnobotanical knowledge and the prescription of the local inhabitants. Plants were collected in Ziplock bags. The plant samples were identified following standard literature. The samples were washed using tap water and shade dried for about a week. The dried plants were then grinded to a fine powder and sieved with 80 mesh sieve. All the reagents and chemicals were purchased from Thermo Fisher Scientific, India.

Extraction of metabolites

The plant extracts were prepared with three different approaches for each sample. Soxhlet extraction with methanol as an extractant; Ultrasonication followed by overnight shaking extraction in two different solvent systems -ethyl acetate and methanol.

Phytochemical screening and antioxidant assay

The Phytochemical analysis was performed following the standard protocol (Thapa et al., 2016). The antioxidant activity was measured with DPPH (2, 2-diphenyl 1-picryl hydrazyl) (Sigma Aldrich, USA) assay modified from Kim (2005).

Antibacterial activity

Disk-diffusion anti-microbial susceptibility test was performed to determine antibiotic sensitivity of pathogens following Bauer et al (1959).

Brine Shrimp cytotoxicity assay

The extract with potent antimicrobial and antioxidant activities were analyzed for cytotoxicity The Brine shrimp cytotoxicity test was performed following Solis et al (1993).

Results and Discussion

Phytochemical Screening

Table 1, 2 and 3 show the different phytochemicals obtained from methanol maceration, methanol soxhlet and ethylacetate maceration. The phytochemical screening revealed the presence of various active biomolecules which is in a good agreement with the potent antioxidant and antimicrobial activities of the plant extracts. The phytochemicals present exhibit such antioxidant properties based on their redox properties which facilitate as a reductant, hydrogen donor, singlet oxygen quencher, metal quencher, metal chelator. The significant amount of antioxidant activity shown by the plant extracts reveal its importance in developing medical and herbal products.

Table 1 *Phytochemical screening of Plant extracts produced with methanol as solvent and maceration as the extraction process.*

		Methanol maceration							
S.N.	Plant samples	Steroids	Quinones	Terpenoids	Reducing sugars	Coumarins	Resins	Tannins	Phenols
1	*G. fragrantissima*	+	+	+	-	+	-	+	+
2	*T. wallichiana*	+	+	+	+	+	-	+	+
3	*B. ciliate*	+	+	+	+	+	-	+	+

+ indicates the presence of phytochemicals;- indicates the absence of phytochemicals

Table 2 *Phytochemical screening test result with methanol as solvent and soxhlet as the extraction process.*

		Methanol soxhlet							
S.N.	Plant sample	Steroids	Quinones	Terpenoids	Reducing sugars	Coumarins	Resins	Tannins	Phenols
1	*G. fragrantissima*	-	+	+	+	+	-	+	-
2	*T. wallichiana*	+	+	+	-	+	-		+
3	*B. ciliate*	-	+	+	+	+	-	+	+

+ indicates the presence of phytochemicals;- indicates the absence of phytochemicals

Table 3 *Phytochemical test result with Ethylacetate as solvent and maceration as the extraction process.*

		Ethylacetate maceration							
S.N.	Plant sample	Steroids	Quinones	Terpenoids	Reducing sugars	Coumarins	Resins	Tannins	Phenols
1	*G. fragrantissima*	+	+	-	-	+	+	-	-
2	*T. wallichiana*	+	+	+	-	+	+	-	-
3	*B. ciliate*	+	+	+	+	+	+	+	-

+ indicates the presence of phytochemicals;- indicates the absence of phytochemicals

Results for Antimicrobial Susceptibility Test

Figures 1-8 show Zone of Inhibition (ZOI) against four microorganisms and concentrations of plant extracts obtained through different solvents and extraction processes. Extracts showed a range of inhibition against the microorganisms used in the concentration range of 25µg/ml-200µg/ml. ZOI of 18 mm was obtained against *Bacillus cereus* and *Citrobacter freundi* in methanolic maceration extract of *Bergenia ciliate* (Figure 2) whereas ZOI of 17 mm was obtained against *Bacillus cereus* in methanol soxhlet extract

of Bergenia ciliate at 200 µg/ml concentration (Figure 5). *Taxus wallichiana* methanol maceration extract at 200µg/ml concentration had a ZOI of 15mm against *Bacillus cereus* (Figure 1). Ethylacetate extract of *Gaultheria fragrantissima* had a ZOI of 14mm at a concentration of 200µg/ml against *S. aureus* and *Shigella* (Figure 6).

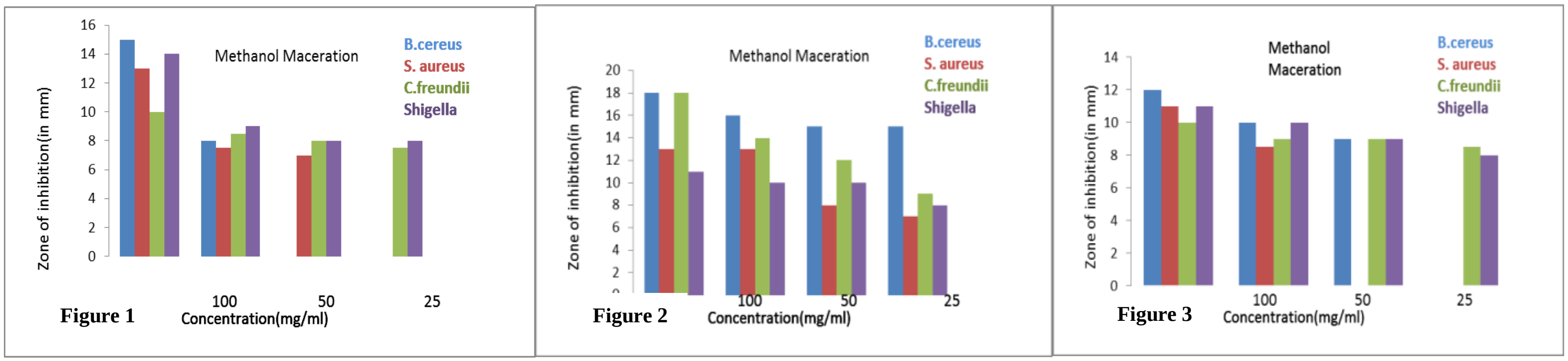

Figure 1-3 *Antimicrobial susceptibility test result for extract produced with methanol as solvent and maceration as the extraction process. (From left: Taxus wallichiana, Bergenia ciliate, Gaultheria fragrantissima)*

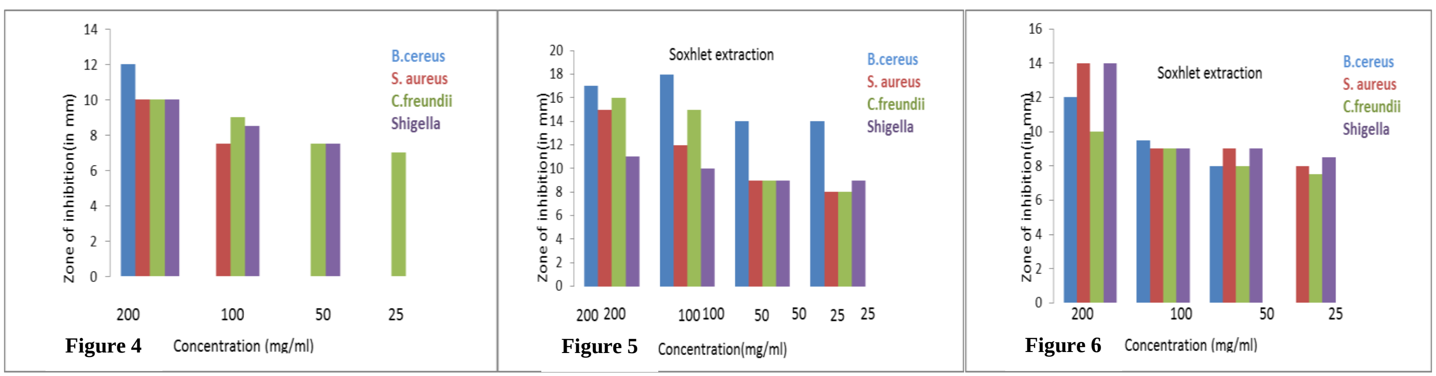

Figure 4-6 *Antimicrobial susceptibility test result for extract produced with methanol as solvent and soxhlet as the extraction process. (From left Taxus wallichiana, Bergenia ciliate, Gaultheria fragrantissima)*

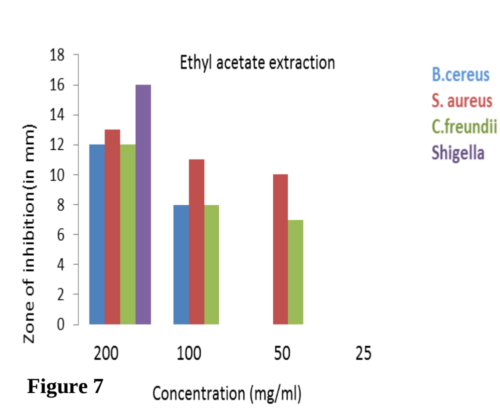

Figure 7

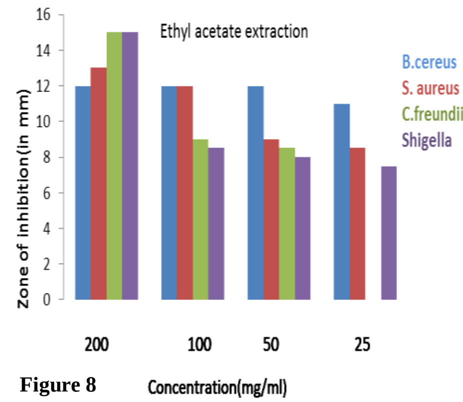

Figure 8

Figure 7-8 *Antimicrobial susceptibility test result for plant extract produced with Ethylacetate as solvent and maceration as the extraction process. (From left: Taxus wallichiana, Bergenia ciliate)*

Result for DPPH free Radical Scavenging Assay (IC50 values)

Table 4 shows the antioxidant potential of plant extracts with different solvent and extraction processes. The results showed higher radical scavenging activity of Ethylacetate maceration for *Gaultheria fragrantissima*. Methanol maceration and ethylacetate maceration based plant extract had good scavenging activity in *Taxus wallichiana*. For *Bergenia ciliate* the methanol maceration extract had the better scavenging activity (Table 4).

Table 4 *Antioxidant potential of plant extract with different solvent and extraction process expressed as IC50 value in µg/ml.*

Plant sample	Methanol Maceration IC50 value(µg/ml)	Ethylacetate maceration IC50 value(µg/ml)	Methanol Soxhlet IC50 value(µg/ml)
G. fragrantissima	60.32	13.43	29.79
T. wallichiana	1.23	4.43	22.84
B. ciliate	3.76	54.39	13.07

Result of Brine Shrimp cytotoxicity assay

The extracts were not toxic upto 200ppm except *Taxus wallichiana* maceration-based extract which had LC50 value of 289.81(Table 5).

Table 5 *LD50 value of different plant extract obtained with cytotoxicity assay expressed in ppm.*

S.N.	Plant	Solvent and Method of extraction	LC50(ppm)
1.	*Bergenia ciliate*	Ethylacetate	>1000
2.	*Bergenia ciliate*	Methanol maceration	655.40
3.	*Taxus wallichiana*	Methanol maceration	289.81
4.	*Taxus wallichiana*	Ethylacetate	604.54
5.	*Gaultheria fragrantissima*	Methanol soxhlet	533.06
6.	*Gaultheria fragrantissima*	Methanol soxhlet	798.14

The extraction solvent used and the method of the extraction process plays a crucial role in the results based on the affinity of the bioactive compounds towards the extractants and their relation with the respective curative properties and is thus the reason for the variability that has been observed for antioxidant, antimicrobial and cytotoxic activity of the same plant. The Brine Shrimp cytotoxicity carried out in *Artemia vulgaris* showed no significant toxicity except for *Taxus wallichiana* revealing that the extracts are well tolerated and test doses are safe for the animals and further in-vitro tests on cancer cell lines as well as in-vivo animal models could be carried out to study its therapeutic use for medical drug development.

Acknowledgement

We would like to acknowledge Department of Biotechnology, Kathmandu University for providing the funding as well as laboratory facility to conduct the experiments. We would also like to acknowledge Dr. Uttam Budathoki, Department of Pharmacy, Kathmandu University for his support with 96well plate reader and Dr. Rajendra Gyawali, Department of Pharmacy, Kathmandu University for helping us identify plant samples.

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Habitat and Distribution Assessment of Chinese Pangolin *(Manis Pentadactyla*, Linnaeus, 1758*)* in Thulo Shivalaya Community Forest in Dolakha, Nepal

Suveksha Shrestha[1], Shyam Sharma[2], Anu Rai[1], Sandeep Shrestha[1*], Ashish Bashyal[2], Sanjay Nath Khanal[1]

[1]Department of Environmental Science and Engineering, Kathmandu University
[2]Biodiversity Conservancy Nepal

*Corresponding author: sandeep@ku.edu.np

Abstract

Chinese pangolin (*Manis pentadactyla L.*) is a critically endangered Mammal with surprisingly a smaller number of information about its habitat, distribution and behavior. The study was carried out to assess the habitat preference, current distribution and threats to Chinese pangolins in Thulo Shivalaya community forest in Dolakha District, Nepal. Two transects were laid in each block of 100m X 100m within which, indirect signs of Chinese pangolin such as the dimensions and image documentation of the burrows, footmarks, scats and termite mounds were recorded. Other abiotic factors such as soil texture, colour, moisture, pH of the burrows, crown cover, ground cover and vegetation near the burrows were also recorded. A total of 182 burrows were recorded from 35 blocks. The number of old burrows was 145 and the number of new burrows was 37. The maximum number of the burrows was found in the elevations of 900−1000 masl; 5.5%−6.0% moisture; and the slopes with 25˚−30˚ and 30˚−35˚. The study suggested that the Chinese pangolins preferred sandy loam soil for easy burrowing and availability of food (termites). The distribution of burrows was highly affected by the construction works and soil extraction. These data will provide preliminary baseline to predict the viability of Chinese pangolin in Dolakha. Similar studies must be carried out in other parts of Nepal to fully substantiate the total population, distribution and range of Chinese pangolin.

Keywords: Chinese pangolin, Burrows, Distribution, Community forest

Introduction

Globally, there are eight species of pangolin, among which two species - Chinese pangolin and Indian pangolin are found in Nepal (Kaspal, 2009). The Chinese pangolin *(Mains pentadactyla*) is a "Critically Endangered" (IUCN, 2014) insectivorous mammal which is scarcely distributed in foothills of eastern and central Himalayas of Nepal (Challender et al., 2016). The species occupies a number of different habitats within its range including primary and secondary forests, tropical forests, bamboo forests, grassland and agricultural fields (Katuwal et al., 2015). In Nepal, Chinese pangolins have been reported from Taplejung, Ilam, Makwanpur, Panchthar, Ramechhap, Dolakha, Dhading, Sindhuli, Panauti (Beber area), Barabise and other places of Kavre, Bhaktapur, Sundarijal of Kathmandu, Baglung (Majupuria & Majupuria, 2006; Kaspal, 2008; Suwal, 2011), Shivapuri Nagarjun National Park (Bhandari & Chalise, 2014) and Chitwan Annapurna Landscape (CHAL) Area (WWF, 2013). This mammal is listed under Appendix I of Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, 2017) and in Nepal, they are protected by Government of Nepal under the National Park and Wildlife Conservation Act, 1973 (Thapa et al., 2014). Chinese Pangolins are also ranked 91st on Evolutionarily Distinct and Globally Endangered (EDGE) Mammalian list (www.edgeofexistence.org).

Chinese pangolins are called "scaly anteaters" as they are covered with tough overlapping scales and feed only on different species of ants and termites and. They are nocturnal, shy, non-aggressive, defensive and solitary in nature (Thapa et al., 2014). Chinese pangolins are of great significance in the control of forest termite disaster (Hua et al., 2015) and help in the improvement of soil nutrient quality and in healthy ecosystem functioning (Pappin, 2011). Besides their ecological value, pangolins are extremely important economic animals with the value as medicine and food due to which their illegal hunting is increasing excessively along with their habitat destruction is (Hua et al., 2015) resulting in decreasing population (Challender et al., 2016).

Despite being listed as a critically endangered Mammal, information on its population levels is very scant (Challender et al., 2016). Conservation and management of endangered species require information on their population size (Sutherland, 2006). But this is difficult to obtain for elusive species like the Chinese pangolins. Furthermore, it is very risky to apply trapping-based methods for the study purposes because it can cause injury to the animal, so, to avoid such risks, non-invasive methods should be applied which do not require observation and handling of the animal (Höss et al., 1992). Lack of detailed study about its distribution and habitat is a major obstacle for its conservation. There are very few scientific studies that have been carried on the habitat and distribution of pangolins in Nepal (Katuwal et al., 2015). Chinese pangolins were speculated to also be found in Dolakha (Kaspal, 2008), but no any specific study on the species has been conducted in Dolakha. Therefore, this research intends to fulfill gaps by studying more about habitat, distribution and threat assessment in this district.

Objectives

The main objective of the study was to collect baseline data on burrow ecology and population status of Chinese pangolins in the Thulo Shivalaya Community Forest in Dolakha.

Study Area

The study was conducted in Thulo Shivalaya Community Forest of Dolakha district, Nepal. The district lies in Province No. 3, covering an area of 2191 km^2. Thulo Shivalaya Community Forest has an area of 1.1 km^2 located in Baiteshwor Gaupalika of Dolakha located 29.2 km east from Charikot (Figure 1). This forest is the prime habitat of Chinese pangolins (Division Forest Office).

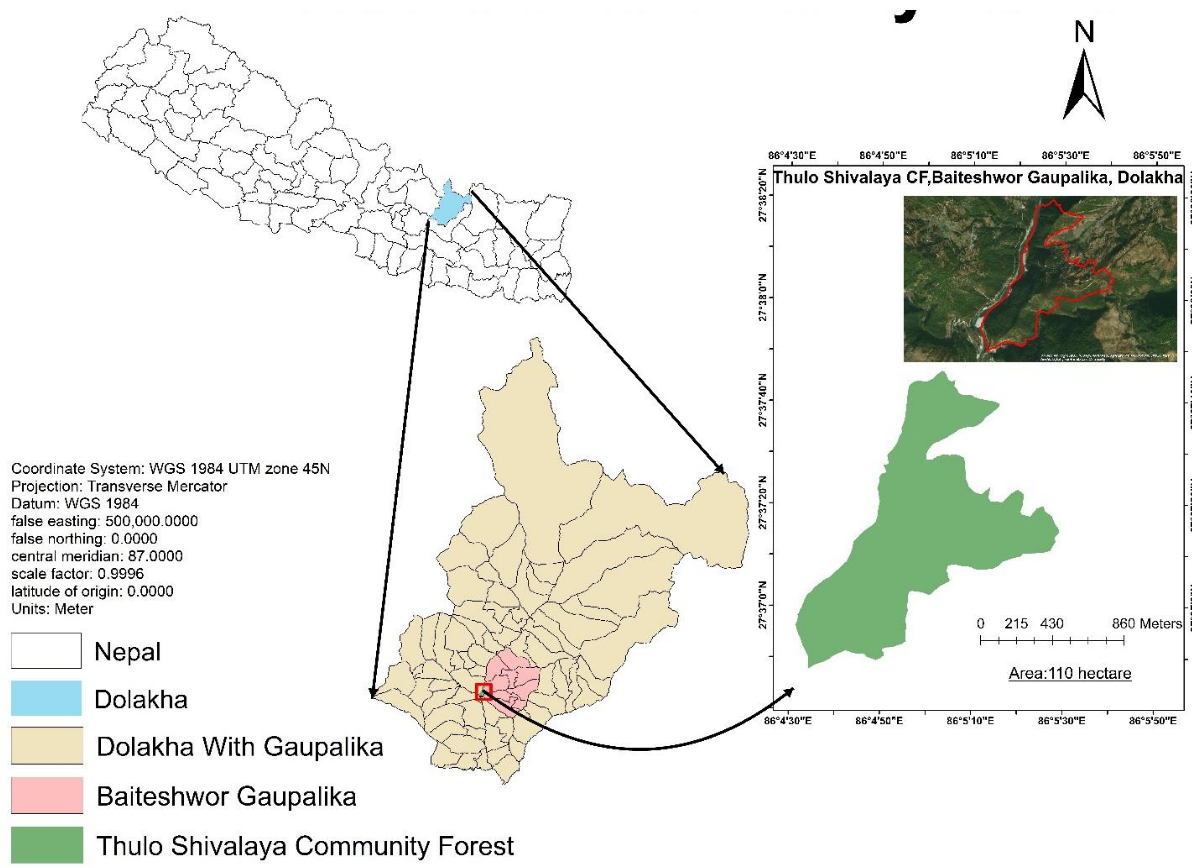

Figure 1 *Location of Study Area*

Data Collection

Indirect method of counting was adopted. First of all, a shape file was prepared for boundary of the community forest undertaken for the study, based on GPS points of areas. Then the community forest was divided into 100m X 100m blocks using a fish netting tool in ARC GIS 10.2.2 (Figure 2). Two transects of 100m were laid and was intensively searched for burrows within 10m width on either side (Figure 3).

Figure 2 *Study Site Showing Blocks*

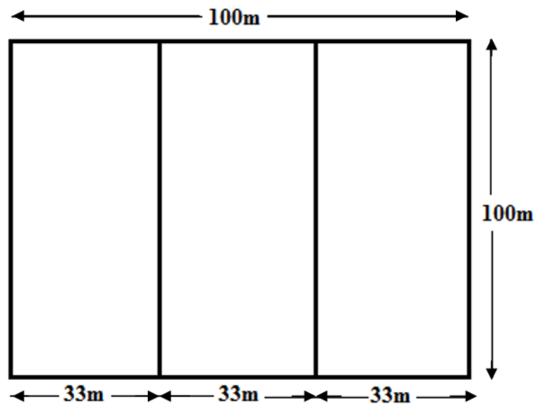

Figure 3 *Block with two transects*

An intensive search was conducted for the indirect signs of species, such as the burrows (dimensions and image documentation), footmarks, scats and termite mounds were recorded. Crown cover, ground cover, elevation, aspect at location of presence of Chinese Pangolin's burrows was recorded. Soil samples (approx. 500-600 gm) from the burrows were collected in zip lock bags and brought to the laboratory for further soil analysis. Searched burrows were identified as new or old and active or non-active on the basis of the soil conditions around the burrow, presence of spider webs and the presence of the footmarks. Following instruments and methods were used for data collection (Table 1).

Table 1 *Instruments used for data collection*

S. N.	**Data**	**Instruments**
1.	Burrow locations	GPS (GPS Map 60 CSx)
2.	Burrow dimensions (length, breath, depth)	Measuring Tape
3.	Soil moisture (onsite)	MS300 Digital Moisture meter
4.	Aspect of the burrows	Silva Expedition 4 Compass
5.	Elevation	GPS (Garmin GPS Map 60 CSx)
6.	Slope	Clinometer (Sokkia Abney Level Clinometer)
7.	Canopy Cover	Densiometer (Spherical Densiometer, Model-A, Lemmon)

Data Analysis

ARC GIS 10.2.2 was used for mapping. MS Excel 2016 was used for data arrangements and charts. Regression analysis between dependent and independent variables was performed using SPSS 25.0 version. MaxEnT 3.4.1 (Phillips et al., 2004) was used for niche modelling for entire Dolakha district. The MaxEnT is a computer program that estimates the probability distribution for a species and predicts potential suitable habitat for a range of mammals (Jennings & Veron, 2011). Altogether 19 environmental layers were downloaded from www.worldclim.org and were converted from raster format to ASCII format with a standard cell size of 30 m x 30 m based on the resolution of the Digital Elevation Model (DEM). The database excel spread sheet containing the presence data of Chinese pangolins of Thulo Shivalaya Community Forest was converted to comma-separated value (csv) format which was imported to MaxEnt software. The presence data of the animal was uploaded under 'Samples box' and all the spatial layers in ASCII format were brought under the 'Environmental layers box' and the model was run following Dorji (2015). The collected soil samples were brought to the laboratory at the Department of Environmental Science and Engineering, Kathmandu University for further analyses. Soil samples were analyzed for pH, color and texture following standard methods (Table 2).

Table 2 *Instruments and methods for laboratory analysis*

S. N.	Soil parameters	Quantity	Instruments/Methods
1.	pH	10gm	Lutron BPH-231
2.	Color	>5gm	Munsell Colour Chart
3.	Texture	50gm	Hydrometer method (Bouyoucos, 1962)

Results and Discussion

A total of 182 burrows were recorded. The types of the burrows and detailed dimensions about the burrows are given below (Table 3). Figures 4a and 4b show the distribution of old and new burrows in the study area. Figures 5, 6,7, 8 and 9 show the distribution of burrows based on slopes, crown cover, ground cover, elevations and soil moisture. The highest number of the burrows was recorded in the ground cover 25%−50% dry soil, canopy cover 25%-50%, with relatively undecomposed leaf litter layer and with a greater amount of dry dead sticks and branches. It's easier to dig in those sorts of soils. Wu et al (2003) has stated that Chinese pangolins avoid too high vegetation density above 75% and too low less than 30%, which corroborates with this finding.

The best suited curve estimation model for regression analysis of burrows for slope (R^2=0.947), crown cover (R^2=0.807), elevation (R^2=0.456) and pH (R^2=0.294) were quadratic whereas those for ground cover (R^2=0.778) and soil moisture (R^2=0.272), it was linear (Figure10a, 10b, 10c, 10d, 10e and 10f).

Table 3 *Number of Burrow Type and Size Recorded*

S. N.	Burrow Type	No. of Burrows	Average width (cm)	Average height (cm)	Average Depth (cm)
1.	Old & Inactive	145	22.24±2.39	19.09±2.82	79.95±42.01
2.	New & Active	37	21.57±3.02	18.05±3.08	75.95±39.60

Figure 4a *Distribution of old burrows*

Figure 4b *Distribution of new burrows*

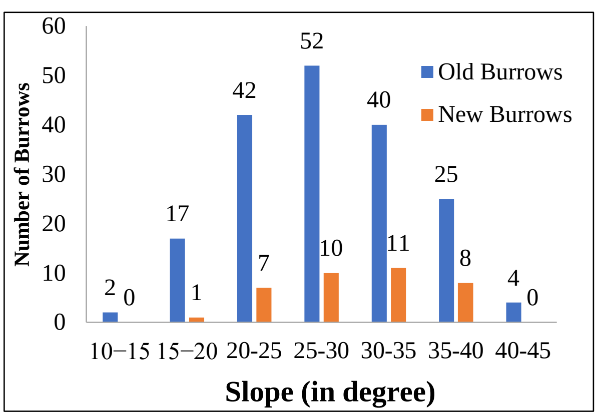

Figure 5 *Distribution of burrows in different slopes*

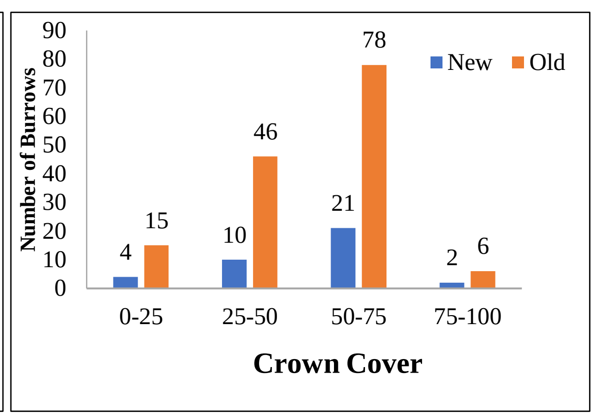

Figure 6 *Distribution of burrows in different crown*

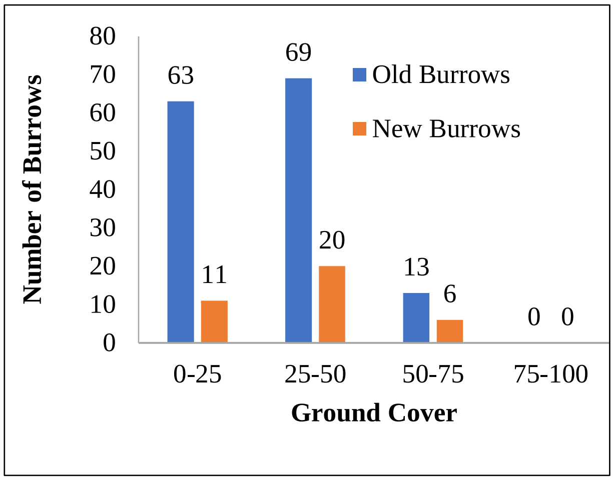

Figure 7 *Distribution of burrows in different Ground Cover*

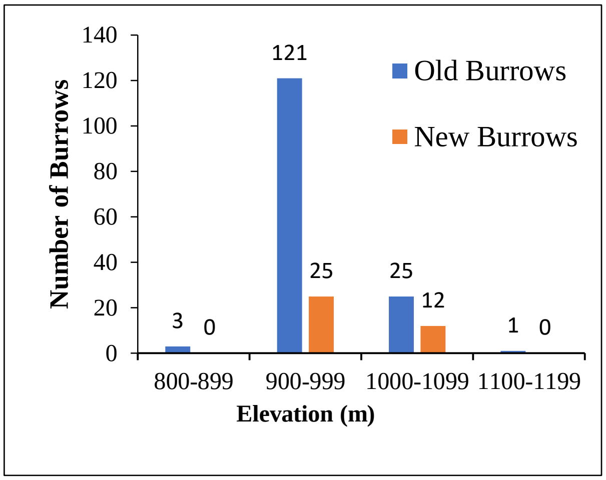

Figure 8 *Distribution of burrows in different elevation*

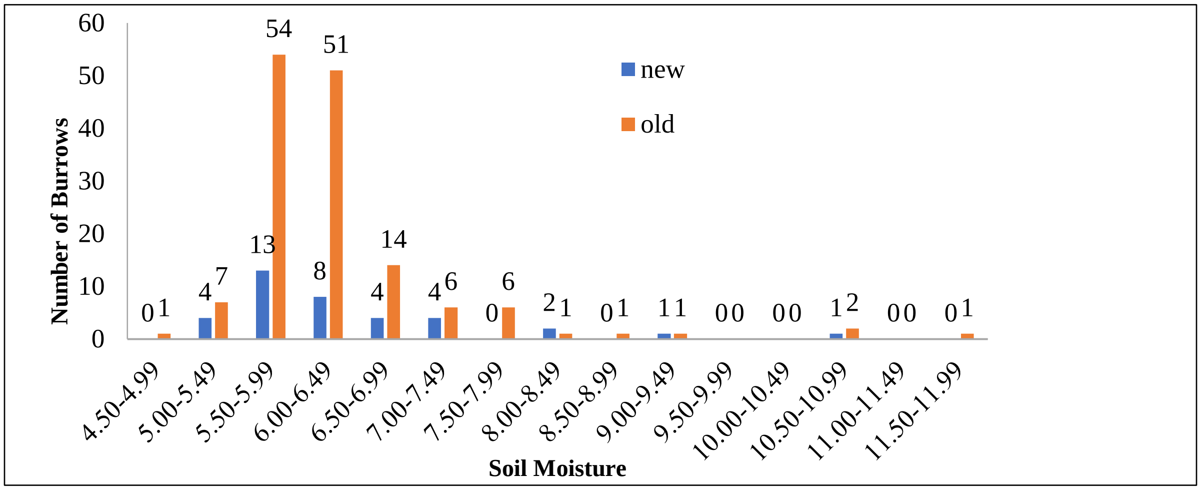

Figure 4 *Distribution of burrows based on soil moisture*

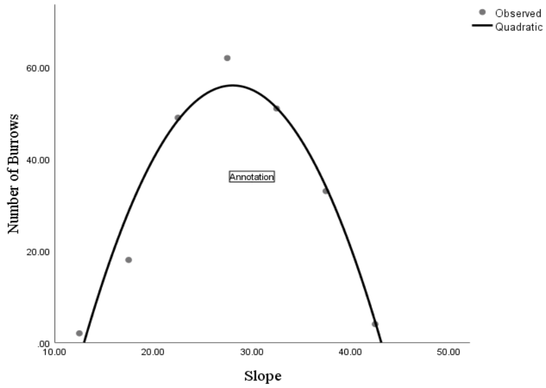

Figure 5a *Relationship between number of burrows and slope*

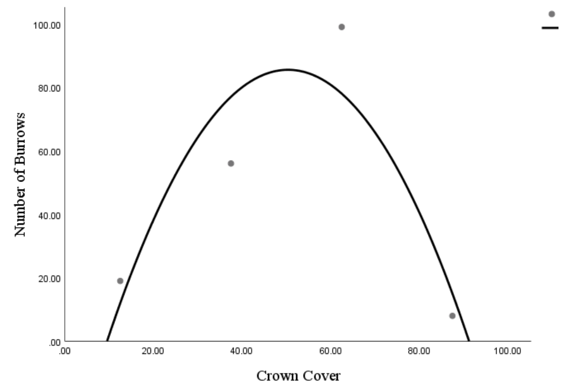

Figure 10b *Relationship between number of burrows and Crown Cover*

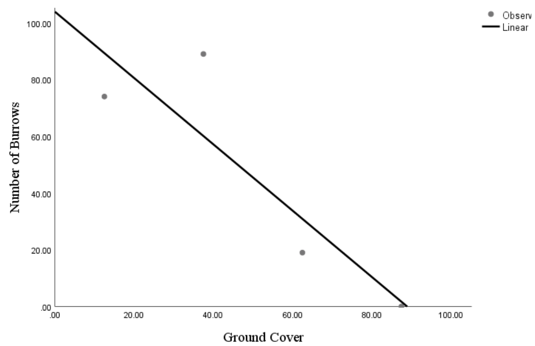

Figure 10c *Relationship between number of burrows and Ground Cover*

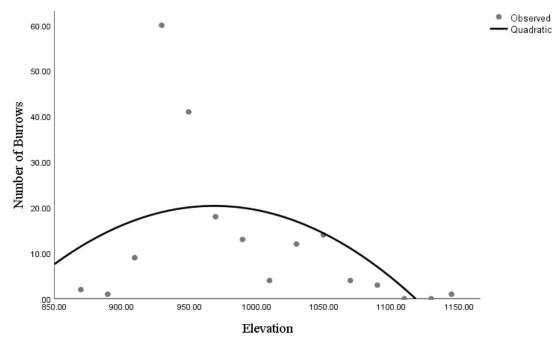

Figure 10d *Relationship between number of burrows and Elevation*

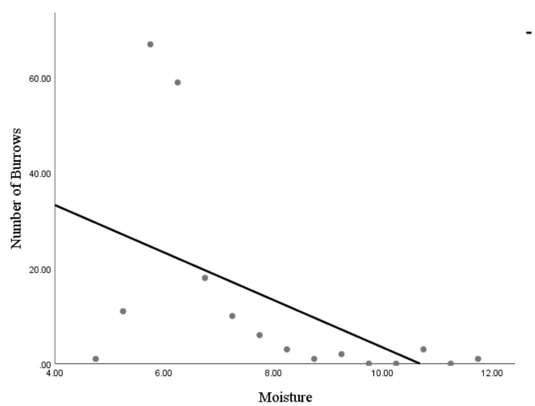

Figure 10e *Relationship between number of burrows and Moisture*

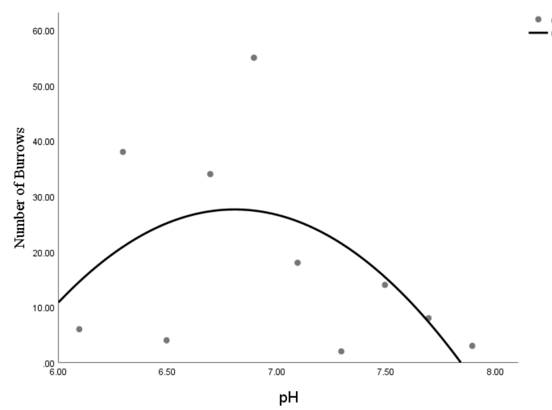

Figure 10f. *Relationship between number of burrows and pH*

Wu et al (2003) recorded the elevation preference by pangolin up to 1550 masl while Chao (2002) and Chakraborty et al (2002) recorded the presence of burrows up to 2000 masl. According to study by Bhandari & Chalise (2014) burrows were mostly distributed at the range of 1450-1550 masl but were also recorded beyond 2000 masl in Nagarjun forest. In this study the highest number of burrows were recorded in the elevation between 900-1000 masl.

The highest number of the new burrows was recorded in west aspect with 24% to 25% and lowest in the south- east aspect with 3% (Figures.11 and 12). As Chinese pangolins are nocturnal, there are high chances that they prefer shade during the day. And if their burrow is west facing then the burrow will be in the shade during most of the time on the day and this might be the reason for maximum burrows facing towards west. However, Gurung (1996) stated that the pangolins preference is more to the south facing slopes. Burrow distribution is non- uniform in all aspects (Suwal, 2011) and this was the case in this study. Preference for certain aspect in different areas might be influenced by the climatic condition, availabilities of food and degree of human interference.

Maximum number of burrows were found to be in dark yellowish-brown soil (26%) followed by dark brown colour (23%) (Figures. 13 and 14). Soil colour is affected by the mineral content of soil or the presence of organic matter content in the soil. Chinese pangolins prefer dark brown soil with high concentrations of organic matter harbouring ants in symbiotic relationship. Suwal (2011) also recorded more burrows in brown soil which supports findings of this study. The texture of the soil was sandy loam (Figure 14). Chinese pangolins are known to prefer loamy soil but the highest presence of burrows in the sandy loam soil type in the study indicate that this species can survive in sandy soil as well.

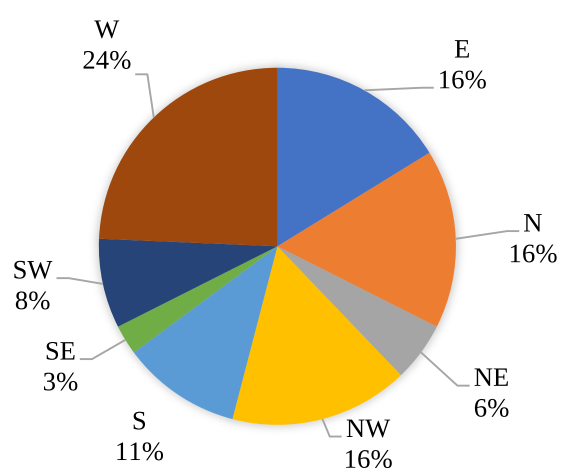

Figure 11 *Distribution of new burrows in different aspects*

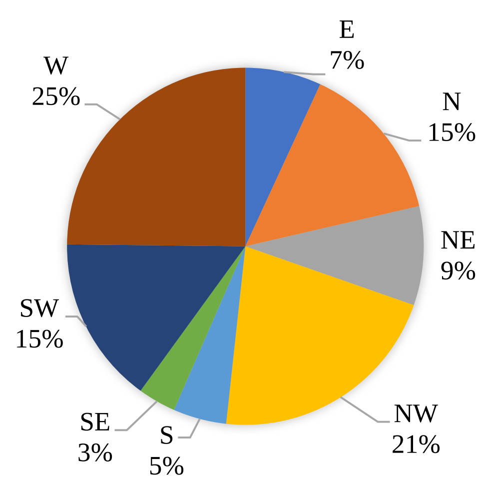

Figure 12 *Distribution of old burrows in different aspects*

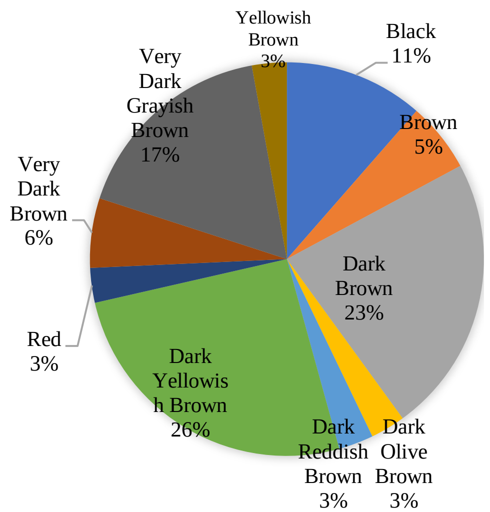

Figure 13 *Distribution of burrows in different soil colour*

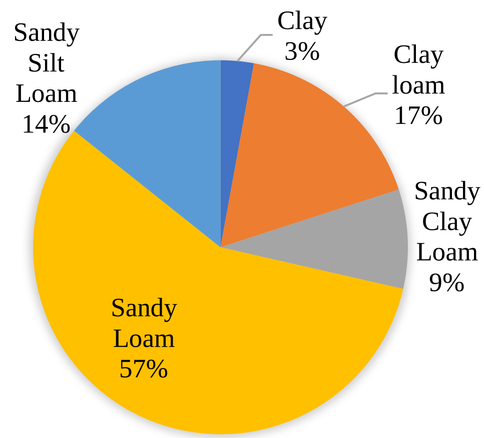

Figure 6 *Distribution of number of burrows with the soil texture*

Prediction of Suitable Habitat of Chinese Pangolin in Dolakha using MaxEnt Modeling

The MaxEnt model predicted potential suitable habitat of Chinese pangolin as indicated by red area (Figure 15). The model predicted suitable habitat for Chinese pangolin in Dolakha district which lies in close proximity to Busti, Namdu, Mirge, Bhirkot, Jhule, Dandakharka, Melung, Gairimudi, Pawati and Fasku.

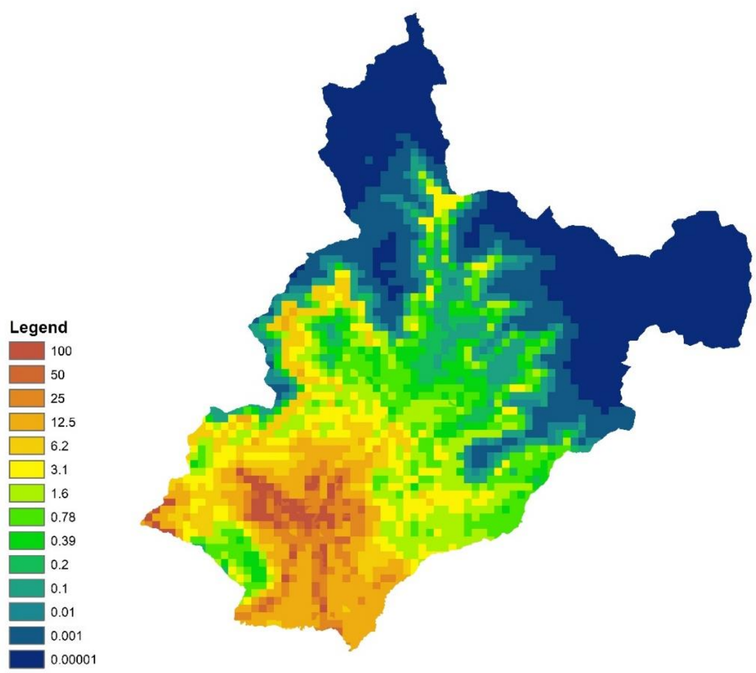

Figure 15 *MaxEnt model performance/output for Dolakha district, Nepal*

Conclusions

The study revealed that Chinese pangolin burrows were not uniformly distributed in Thulo Shivalaya Community Forest and the distribution was highly influenced by altitude, aspect and availabilities of food and water. Number of burrows was maximum at elevation range between 900 – 1000 masl. Comparison between the aspects show that Chinese pangolins was mostly found in west facing slopes. The MaxEnt model predicted suitable habitat for Chinese Pangolin in Dolakha district which lies in close proximity to Busti, Namdu, Mirge, Bhirkot, Jhule, Dandakharka, Melung, Gairimudi, Pawati and Fasku.

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Effect of Silicon on Growth and Salinity Stress of *Trigonella foenum-graecum* L. var. Pusa Early Bunching

Riti Thapar Kapoor[1]*

[1]Plant Physiology Laboratory, Amity Institute of Biotechnology, Amity University, Noida, Uttar Pradesh, India

*Corresponding author: rkapoor@amity.edu

Abstract

Salinity is a major abiotic stress that adversely affects cultivated land worldwide and reduces crop yield. The present investigation was conducted to find out the changes in germination, biomass and biochemical characteristics of *Trigonella foenum-graecum* var. Pusa Early Bunching (PEB) exposed to different concentrations of salt solution and potassium silicate. The role of potassium silicate in growth and its effectiveness in salt stress alleviation was investigated. In the present study it was observed that plant growth attributes such as germination, radicle and plumule length, fresh and dry weight, chlorophyll and protein contents were significantly improved with potassium silicate (3 mM) as compared to control. NaCl solution (20 mM) significantly decreased growth of fenugreek seedlings but addition of potassium silicate to salt stressed seedlings substantially alleviated the adverse effects of salinity. The increase in seed germination and growth characteristics followed the order: K_2SiO_3 > Control > NaCl + K_2SiO_3 > NaCl. Current study suggests that potassium silicate application alleviates the detrimental effect of salinity stress on the growth and development of *Trigonella foenum-graecum.*

***Keywords*:** Potassium silicate, Salinity, *Trigonella foenum-graecum.*

Introduction

Soil salinity is a global problem that adversely affects approximately 20% of irrigated land and reduces crop yield (Qadir et al., 2014). Soil degradation caused by salinity is a major challenge and problem as saline soil has serious implications in agricultural systems (Qadir et al., 2008). The presence of salt reduces the water potential of soil solution and decreases ability of plants for water uptake. The inescapable excessive absorption and accumulation of salts in plants causes ion imbalance and toxicity (Parida & Das, 2005). Salinity stress in plants results in morphological and biochemical changes such as reduction in plant growth, membrane dysfunction, reduced photosynthesis, increase in oxidative stress and enzyme activity (Tester & Davenport, 2003). Silicon is considered as a beneficial quasi-essential nutrient for the growth and development of plants particularly when plants are grown under adverse environmental conditions (Bakhat et al., 2017). It is also known as stress reliever as it enhances tolerance capacity of plants against abiotic and biotic stresses (Etesami & Beattie, 2017; Etesami & Jeong, 2018). Silicon increases 35-40% water retention capacity in plants via the formation of better soil structure and improvement in water utilization efficiency in plants (Cooke & Leishman, 2011). Potassium is another important nutrient which plays an important role in water relation, osmotic adjustment and stomata movement (Ibrahim et al., 2015). Aown et al (2012) reported that potassium improves plants' tolerance capacity to environmental stresses. The positive correlation was observed between potassium silicate with nutrient content of bean plant under salt stress (Abou-Baker et al., 2011). Shedeed (2018) reported significant increase in growth parameters such as plant height, leaf area, number of leaves and fresh and dry weight of leaves and stem of maize by potassium silicate.

Trigonella foenum-graecum L. popularly known as Fenugreek or 'Methi' belongs to the family Fabaceae. It is a multipurpose crop being used as a spice, leafy vegetable and as a medicinal plant. The leaves and shoots of fenugreek plant are rich in protein, minerals and vitamins (Arya, 2000). The leaves and seeds of fenugreek are widely used as a spice and condiment to enhance the taste of food. The fresh and dried leaves have aromatic properties which are used for seasoning of food (Prajapati et al., 2017). Fenugreek leaves and seeds contain saponin, diosgenin and alkaloids and can be used in pharmaceutical industries for the treatment of diabetes, cardiovascular diseases, gastric inflammation and cancer etc. The literature reveals that no study has been done till date to study the effect of potassium silicate on the mitigation of adverse effect of salt stress on fenugreek plant. Hence, present investigation was conducted to compare the growth and biochemical parameters of *Trigonella foenum-graecum* L. grown under saline condition and potassium silicate and role of potassium silicate in alleviation of the adverse effect of salt stress on fenugreek.

Material and Methods

The experiment was conducted at the Plant Physiology Laboratory, Amity Institute of Biotechnology, Amity University, Noida, India. The certified, healthy and uniform fenugreek seeds (*Trigonella foenum-graecum* L. var. Pusa Early Bunching) were procured from Indian Agricultural Research Institute (IARI), New Delhi. Seeds were stored in sterilized polythene bags to avoid contamination. The effect of different concentrations of salt solution (20 mM) and potassium silicate (3 mM) and their combined effect (20 + 3 mM) were studied on the growth and biochemical parameters of *Trigonella foenum-graecum* L. variety Pusa Early Bunching.

Experimental design

Preparation of different concentrations of salt solution and potassium silicate

Different concentrations of salt solution (20mM) and potassium silicate (3mM) (Formula: K_2O_3Si, molecular weight: 154.28 g/mol] LOBA Chemie Private Limited, Mumbai) were prepared with distilled water and used for the treatment.

Petri plate experiments

Seeds of fenugreek were thoroughly washed with tap water to remove dirt and dust for 5 minutes. To avoid the effect of toxins produced by fungi or bacteria, seeds were surface sterilized with 10:1 distilled water/ bleach (commercial NaOCl) solution for 5 minutes and then washed 6-7 times with distilled water. Thirty seeds were divided into three replicates of 10 seeds each and were soaked for 5 hours in 10 ml of different concentrations of salt solution (20 mM) and potassium silicate (3 mM). Control seeds were soaked in 10 ml distilled water. The fenugreek seeds were allowed to germinate in 20 cm diameter petri dishes with a tight - fitting lid and seedling were maintained in a growth chamber under the controlled temperature (24±2°C) and photoperiod of 16/8 hrs. Petri dishes were kept moist by adding 1 ml of different concentrations of salt solution, potassium silicate or distilled water as and when required according to the treatment. Seed germination was determined by counting the number of germinated seeds at 24 hours interval till 10 days.

Determination of growth parameters

Different growth characteristics of fenugreek seeds (*Trigonella foenum-graecum* L. var. Pusa Early Bunching) such as germination percentage, relative germination rate, germination index, seedling length, biomass and vigour index were determined in control and treatment following Li (2008). Following formulae were used for calculation:

(1). Germination percentage (G%) = Total number of seeds germinated / total number of seeds taken for germination x 100

(2). Relative germination rate (RGR) = germination percentage in treatment/ germination percentage in corresponding control.

(3). Germination index (GI) = $\Sigma Gt / Dt$

Where, Gt is the number of seeds germinated in t days; Dt is the number of corresponding germination days.

(4). Seedling length: The radicle and plumule length of fenugreek seeds were measured with a measuring scale and values were expressed in cm (ISTA, 2008).

(5). Vigour index: Vigour index of the fenugreek seedlings was estimated by following Abdul-Baki & Anderson (1973).

Vigour index (VI) = Total seedling length (mm) x germination percentage

(6). Biomass estimation: Fresh weight of the fenugreek seedlings in control and treatment was measured after 10 days of seed sowing. After that, the seedlings were oven dried at 65°C for 72 hours and dry weight was also estimated.

Relative water content (RWC)

Fresh weight (FW) of the fenugreek seedlings was measured and these seedlings were immediately floated on distilled water at 25°C in the darkness. After 12 hours, the turgid weight (TW) was measured and then seedlings were dried in an oven at 80°C for 48 hours for the estimation of dry weight (DW). The relative water content was calculated by the modified method of Bars & Weatherly (1962).

$$RWC\ (\%) = (FW-DW) / (TW-DW) \times 100$$

Estimation of photosynthetic pigment

The amount of chlorophyll was determined in the fenugreek seedlings following Lichtenthaler (1987). The leaves (10 mg) of control and treatment were grounded with 10 ml of 80% acetone and centrifuged at 3000 revolutions per minute for 10 minutes. The optical density of the supernatant was measured at 645 and 663 nm and the amount of chlorophyll a, chlorophyll b and total chlorophyll was analyzed by applying the following formula:

Total chlorophyll (mg/g) = $20.2 \times OD645 + 8.02 \times OD663 \times V / 100 \times W$

Chlorophyll a (mg/g) = $12.7 \times OD663 - 2.69 \times OD645 \times V / 100 \times W$

Chlorophyll b(mg/g) = $22.9 \times OD645 - 4.68 \times OD663 \times V / 100 \times W$

Where, V = volume of the supernatant in ml, W = fresh weight of the leaves in g and OD = optical density.

Chlorophyll stability index (CSI*)*

Chlorophyll stability index (CSI) was determined according to the method of Sairam et al (1997) and calculated by the formula: CSI = Total chlorophyll under treatment/ Total chlorophyll under control x 100

Estimation of sugar content

The sugar content was quantified according to the method of Hedge et al (1962). Fenugreek seedlings (100 mg) were homogenized in 5 ml 95% ethanol. The homogenate was centrifuged at 4000 revolutions per minute for 15 minutes and supernatant (0.1 ml) was mixed with 0.9 ml distilled water and 4 ml anthrone solution. The reaction mixture was boiled in the water bath for 15 minutes. Absorbance was recorded at 620 nm after cooling and the amount of sugar was calculated with reference to standard curve prepared from glucose.

Estimation of free proline

Determination of proline was done according to the method of Bates et al (1973). Fenugreek leaves were extracted with 3% sulphosalicylic acid. An aliquot was treated with acid-ninhydrin and acetic acid and boiled for 1 hour at 100°C. The reaction mixture was extracted with 4 ml of toluene. The absorbance of chromophore containing toluene was determined at 520 nm and proline content was expressed as μmol g^{-1}FW using a standard curve.

Estimation of protein

Quantitative estimation of protein was done following Lowry et al (1951). The dried fenugreek seedlings of control and treatment were homogenized with 1 ml of 1 N NaOH for 5 minutes at 100°C. Alkaline copper reagent (5 ml) was added to it and the mixture was allowed to stand at room temperature for 10 minutes. Folin - Ciocalteu reagent (0.5 ml) was added immediately and the contents were mixed in the test tube. The absorbance of the solution was measured at 650 nm after 30 minute. The amount of protein was calculated with reference to standard curve of lysozyme.

Total antioxidant content

The total antioxidant content in fenugreek seedlings was evaluated following Prieto et al (1999). Total antioxidant capacity was quantified in a sample solution containing 0.1 ml of sample prepared by incubating fenugreek seedlings (150 mg) in 3 ml of ethanol, 3 ml of reagent solution (0.6 M Sulphuric acid, 28 mM Sodium phosphate and 4 mM Ammonium molybdate). The absorbance of the test sample was measured at 695 nm.

Statistical analysis

All the treatments were arranged in a randomized block design with three replications. Data were statistically analyzed using analysis of variance (ANOVA) by using SPSS software (Ver. 10; SPSS Inc., Chicago, IL, USA). The treatment mean was analyzed by Duncan's multiple range test (DMRT) at $p < 0.05$.

Results and Discussion

Seed germination and growth parameters

Significant differences ($p < 0.05$) were observed among various treatments for all the growth parameters studied i.e. seed germination, relative germination rate, radicle and plumule length, vigour index and fresh and dry weight of fenugreek seedlings. 88% fenugreek seeds were germinated in control. Significant increase ($p < 0.05$) in seed germination and growth parameters of fenugreek was observed with potassium silicate. Maximum seed germination (96%) was observed with potassium silicate and it was 8.3% more than control. Germination index was also higher in K_2SiO_3 treatment in comparison to other treatment and control (Table 1).

Table 1 *Effect of potassium silicate and salt on the seed germination of Trigonella foenum-graecum L. variety Pusa Early Bunching.*

Treatment	Concentration (mM)	Germination (%)	Relative germination rate (RGR)	Germination Index (GI)
Control	0	88a ± 0.98	-	8.8a ± 0.09
NaCl	20 mM	54c ± 0.43	0.61c ± 0.08	5.4b ± 0.07
K2SiO3	3 mM	96a ± 0.85	1.09a ± 0.92	9.6a± 0.24
NaCl + K2SiO3	20 + 3	83b ± 0.71	0.94a ± 0.14	8.3a± 0.05

Mean ± SD values followed by different letters in each group show significant differences at $p < 0.05$

Table 2 shows the effect of potassium silicate and salt on the growth parameters of *Trigonella foenum-graecum* L. variety Pusa Early Bunching. The highest vigour index was observed in fenugreek seedlings treated with potassium silicate

Table 2 *Effect of potassium silicate and salt on the growth parameters of Trigonella foenum-graecum L. variety Pusa Early Bunching.*

Treatment	Concentration (mM)	Radicle length (cm)	Plumule length (cm)	Vigour index
Control	0	5.2b ± 0.03	8.9a ± 0.26	12408
NaCl	20 mM	2.1c ± 0.05	4.5c ± 0.39	3564
K2SiO3	3 mM	7.8a ± 0.18	12.6a ± 0.82	19584
NaCl + K2SiO3	20 + 3	6.3a ± 0.26	7.9b ± 0.48	11786

Mean ± SD values followed by different letters in each group show significant differences at $p < 0.05$

Table 3 shows the effect of potassium silicate and salt on the biomass of *Trigonella foenum-graecum* L. variety Pusa Early Bunching. The fresh and dry weight of fenugreek seedlings significantly ($p< 0.05$) decreased with NaCl application but enhanced with potassium silicate (Table 3). Higher relative water content was observed with potassium silicate treatment in comparison to control and other treatment. Increase in seed germination percentage and other growth characteristics followed the order: K_2SiO_3 > Control > NaCl + K_2SiO_3 > NaCl.

Table 3 *Effect of potassium silicate and salt on the biomass of Trigonella foenum-graecum L. variety Pusa Early Bunching.*

Treatment	Concentration (mM)	Fresh weight (gm)	Dry weight (gm)	Relative water content (%)
Control	0	$9.48^b \pm 0.92$	$5.29^a \pm 0.15$	$85.19^a \pm 0.83$
NaCl	20 mM	$6.22^c \pm 0.61$	$1.83^c \pm 0.92$	$71.86^b \pm 0.54$
K_2SiO_3	3 mM	$11.83^a \pm 0.12$	$6.96^a \pm 0.42$	$92.62^a \pm 0.81$
NaCl + K_2SiO_3	20 + 3	$8.54^b \pm 0.05$	$3.05^b \pm 0.27$	$75.07^b \pm 0.64$

Mean ± SD values followed by different letters in each group show significant differences at $P < 0.05$

Chlorophyll, sugar, proline and protein content

The amount of chlorophyll decreased in the fenugreek seedlings treated with NaCl (20 mM). The Chlorophyll Stability Index (CSI) was highest with K_2SiO_3 treatment. The increase in total chlorophyll content in fenugreek seedlings followed the order: K_2SiO_3 > Control > NaCl + K_2SiO_3 > NaCl (Table 4).

Treatment with potassium silicate significantly increased sugar content in Trigonella foenum-graecum L. The sugar content 93.89 mg/g was recorded in fenugreek seedlings with potassium silicate as compared with 78.89 mg/g in control. Maximum increase 19% in sugar content was observed in fenugreek seedlings with potassium silicate treatment over control (Table 4). The significant reduction in sugar content 42.88% was observed with NaCl treatment. The analysis of proline content in fenugreek seedlings showed that NaCl application significantly increased proline content whereas under potassium silicate treatment, proline content in fenugreek seedlings markedly decreased. The increase in proline content showed the following trend: NaCl > NaCl + K2SiO3 > Control > K2SiO3 (Table 4).

Significant increase ($p< 0.05$) in total protein content in fenugreek seedlings has been reported with potassium silicate. The total protein content 69.32 mg/g was recorded in fenugreek seedlings with potassium silicate as compared with 61.05 mg/g in control. Maximum reduction (37.36 %) in protein content was recorded in fenugreek seedlings with 20 mM NaCl over control (Table 4).

Table 4 *Effect of potassium silicate and salt on the biochemical components of Trigonella foenum-graecum L. variety Pusa Early Bunching.*

Treatment	Concentration (mM)	Total chlorophyll content (mg/g)	Chlorophyll Stability Index (CSI)	Sugar (mg/g FW)	Proline (µmol/g FW)	Protein (mg/g FW)
Control	0	1.97b ±0.94	-	78.89b ± 0.58	0.98b ± 0.09	61.05a ±0.59
NaCl	20 mM	1.03c ±0.87	0.52	45.06c ± 0.24	1.65a ± 0.97	38.24b±0.42
K2SiO3	3 mM	2.88a ±1.05	1.46	93.89a ± 0.92	0.92b ± 0.83	69.32a ±0.53
NaCl+ K2SiO3	20 + 3	1.62b ±0.71	0.82	69.77b ± 0.35	1.03b ± 0.82	56.87b±0.36

Mean ± SD values followed by different letters in each group show significant differences at $P < 0.05$

Total antioxidant content

Total antioxidants can be considered as plant defense against oxidative stress. Significant increase in total antioxidant content in fenugreek seedlings was observed with potassium silicate treatment and it showed the following order: K_2SiO_3 > NaCl + K_2SiO_3 > Control > NaCl (Figure 1).

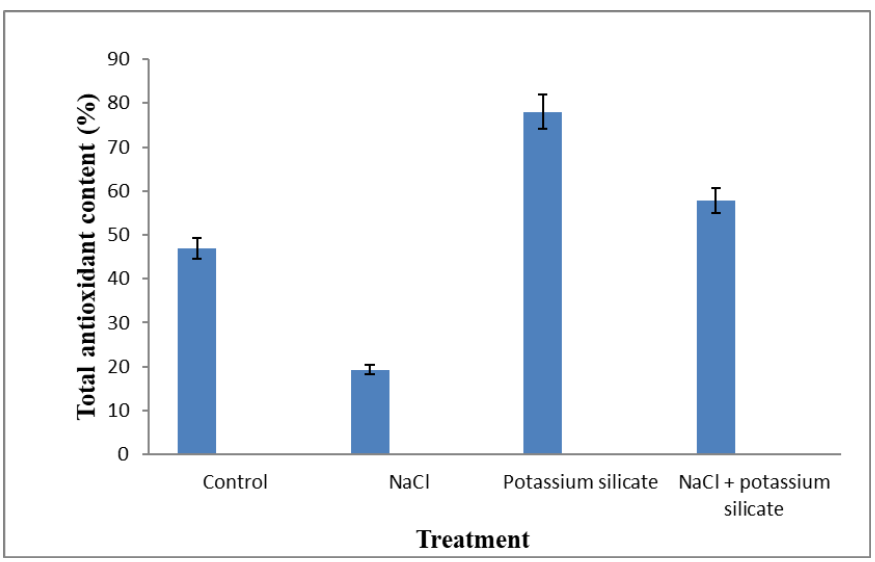

Figure 1 *Effect of different treatment on the total antioxidant content of fenugreek seedlings.*

During seed germination, germination is initiated by water absorption followed by biochemical events in the seed (Greipsson, 2001). The absorbed water in the seed is used for activation of hydrolytic enzymes, which breaks the complex seed reserves into the simple molecules required for various metabolic activities such as cell division and elongation (Groot & Karssen, 1992). Earlier reports revealed that salt stress can delay, reduce or prevent seed germination (Zhou et al., 2005). The excessive absorption and accumulation of salt in plants decreases plant ability for water uptake and it also causes ion imbalance and toxicity in plant cells (Parida & Das, 2005). Salt treatment (20 mM) resulted significant reduction in fresh and dry weights of fenugreek seedlings (Table 3). Decreased relative water content showed water deficit due to reduction in water absorption under saline condition (Soleimannejad et al., 2018). The reduced radicle and plumule length of fenugreek seedlings appears as a strategy to manage water demand under saline condition (Acosta-Motos et al., 2017). Positive correlation was observed between the concentration of potassium silicate and seed germination and other growth parameters of fenugreek in the present study (Table 1 and 2). It may be due to the nutritional properties of potassium silicate which helps in division, elongation and expansion of the cells which is a prerequisite for seedling growth. The improvement of salt tolerance capacity by silicon nutrition has been reported in barley, rice and canola plant as well (Farshidi et al., 2012). Silicon has been also considered as a plant growth regulator which promotes cell division and expansion (Hwang et al., 2007) and plays a defensive role against wide range of environmental stresses (Tripathi et al., 2013).

It is well known fact that increased photosynthetic rate leads to increased plant growth. The chlorophyll content declined with NaCl but significantly increased with potassium silicate in fenugreek seedlings suggested that potassium silicate alleviated the negative effects of NaCl on chlorophyll content. The reduction in chlorophyll content due to salt stress has been observed in other plants such as wheat (Ashraf et al., 2002), rice (Anuradha & Rao, 2003) and pea (Ahmad & Jhon, 2005). The increase in biochemical constituents such as chlorophyll and protein under the influence of high concentration of potassium silicate might cause increase in germination and growth of the tested crop. Donega (2009) found that use of silicon improves plant architecture and increases photosynthesis. The deposition of silicon in the cell wall maintains stability of the leaves and increases leaf surface area that may provide more availability of light for photosynthesis. The increase in fenugreek seedling growth might be due to increase in CO_2 - fixing efficiency or promotion in germination capacity coupled with higher efficiency in dry matter production. An improvement in growth of salt stressed fenugreek seedlings under the influence of potassium silicate in the combined treatment may be due to the improved photosynthesis, enhanced chlorophyll content and ribulose biphosphate carboxylase activity. Ribulose biphosphate carboxylase (Rubisco) is an enzyme which is involved in the carbon fixation, a process by which the atmospheric CO_2

is converted by plants to energy-rich molecules such as glucose. Similar observations have been reported in plants like barley and cucumber (Liang, 1998). Talebi et al (2015) found that exogenous application of potassium silicate had a positive effect by increasing carbohydrate and protein contents in the potato leaves.

Proline accumulates in high concentration in fenugreek seedlings under NaCl treatment and it plays an important role in osmotic adjustment (Ullah et al., 1997), detoxification of reactive oxygen species and maintenance of membrane integrity (Demiralay et al., 2013). Due to the accumulation of sugar and proline, the osmotic potential of the cell is lowered, which in turn attracts water into the cell and tends to maintain turgor pressure. Proline is also considered as a potent antioxidant and inhibitor of programmed cell death (Johari-Pireivatlou, 2010). Earlier studies reported that proline contents significantly increased in soybean (Chon et al., 2003), corn (Yoon et al., 2005) and bean (Khadri et al., 2006) under salt stress. Current results also suggest that proline contents decreased with potassium silicate application, which show favourable role of potassium silicate in mitigating the adverse effects of salt stress on fenugreek seedlings.

Potassium silicate attenuates salt stress symptoms as evidenced by low proline content and stimulation of protein accumulation (Table 4). The decrease in Na^+ uptake under salinity stress in fenugreek seedlings supplied with potassium silicate might be related to its reduction of apoplastic transport in the cell wall and endodermis due to potassium silicate deposition or increase in exclusion mechanism at the root surfaces by high H^+- ATPase activity (Gong et al., 2006). The increase in protein content in response to exogenous application of silicon may be due to its role in protein (Soundararajan et al., 2014) and DNA formation and functioning of mRNA (Abbas et al., 2015). Silicon plays a protective role by scavenging Reactive Oxygen Species (ROS) in plants (Manivannan & Ahn, 2017). The increased concentration of total antioxidants acts as damage control system and provide protection to the cells from oxidative stress, lower lipid peroxidation and maintain membrane stability in fenugreek seedlings. The results are in agreement with earlier findings of potassium silicate offsetting the negative impacts of NaCl stress by raising antioxidant content (Al-Aghabary et al., 2004). Qutab et al (2017) stated that plants utilize antioxidant enzymes in order to cope with the oxidative stress.

Conclusion

Potassium silicate supplementation acts as stimulating agent and enhances seed germination, growth and biochemical parameters of *Trigonella foenum-graecum*. It alleviates the detrimental effect of salinity stress on the growth and development of *Trigonella foenum-graecum.* However, further, field experiments under saline condition should be performed with the optimum level of potassium silicate before its application at commercial scale.

Acknowledgement

The author is thankful to Prof. Chanderdeep Tandon, Director, Amity Institute of Biotechnology, Amity University, Noida for providing the laboratory facilities to carry out this study.

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Comparative Analysis on Effects of Introducing Mechanical Hood Ventilation System on Indoor Air Quality

Kundan Chaudhary[1*], Sujata Karki [1], Dhiraj Pokhrel [2], Avash Bhandari,[2] and Amod Kumar Pokhrel [2,3]

[1] Kathmandu University, Dhulikhel, Nepal
[2] LEADERS Nepal, Putalishadak, Kathmandu, Nepal
[3] University of California, Berkeley, CA 94720-7360, USA

*Corresponding author: kundanchaudharynp@gmail.com

Abstract

While outdoor air pollution gets considerable attention from the public or policymakers, indoor air pollution, which affects the majority of people´s health and livelihood in developing countries is often neglected. Generally, people spend more time indoors than outdoors. Notably, the susceptible groups are children and the elderly who spend most of their time indoors and thus could be exposed to a very high-level indoor air pollution, if households use an open fire to cook family and animal food or heat home. This study focused on determining whether a mechanical hood ventilation system can provide a significant improvement to indoor air quality with regard to $PM_{2.5}$ and Carbon monoxide (CO) concentration relative to natural ventilation without hood. For the experimental setup, the mechanical hood was designed and installed in a traditional kitchen without inbuilt ventilation system. A light scattering air pollution monitor, Particles and Temperature Sensor (PATS+) was used to measure real-time exposure to $PM_{2.5}$ and CO under three conditions viz. without hood, hood with no fan and hood with a fan.The experiment for all tests was carried for 35 minutes (average). During the experiment, 4 L of water was boiled in a traditional cook-stove to compare the variation of pollutant concentration between the assigned conditions. The mechanical hood was placed at the optimal height for a user, and door to the kitchen was left open during all tests. PATS+ was placed in the kitchen at the height of the breathing zone of the cook. The air flowrates of the duct were measured only when the test had a fan on. The average concentration of $PM_{2.5}$ and CO for three different conditions were 1315.54 $\mu g/m^3$ and 65.01 ppm (without hood); 800.16 $\mu g/m^3$ and 48.29 ppm (Passive hood with no fan) ; 301.50 $\mu g/m^3$ and 9.44 ppm (Active hood with a fan) respectively. National Indoor Air Quality Standard Implementation Guideline (2009) has framed Nepalese standard for the indoor concentration of $PM_{2.5}$ and CO are 100 $\mu g/m^3$ and 35 ppm for 1hr-average time. Hence the study concludes that introducing proper mechanical hood ventilation with a fan in the kitchen can significantly improve indoor air quality in terms of $PM_{2.5}$ and CO concentration.

Keywords: Indoor air quality, Hood ventilation system, Solid fuels, $PM_{2.5}$, CO

Introduction

Solid fuels such as firewood, cattle dung and agricultural residues are commonly used biomass in the rural parts of Nepal as a traditional source of domestic energy. Households consume solid fuels to cook animal and family food, water heating and space heating. The Biomass Energy Strategy (MoPE, 2017) reported that 77% of Nepalese rely on traditional biomass energy and has targeted to develop households indoor emission at a national permissible level by year 2022 through promoting clean cooking technologies, which is regarded as a tough task as it requires huge investment and personal-level awareness (MoPE, 2017). According to the National Household Census (CBS, 2011), almost 74% of households rely on traditional energy from biomass (CBS, 2011). A special report on global exposure to air pollution and its disease burden prepared by Health Effect Institute called "State of Global Air 2019" estimates nearly 47% of the global population (3.6 billion people) were exposed to indoor air pollution mainly in sub-Saharan Africa, South Asia, and East Asia due to solid fuels used for cooking (HEI, 2019). The use of solid fuels has declined from 64% to 47% within 12 years period (2005-2017) but less developed countries like Nepal still persists inequalities and continue to suffer from indoor air pollution exposure while fulfilling the demand for household energy (MoPE, 2017).

The indoor air pollution is considered as a major health hazard in developing countries and numerous studies found a strong linkage between exposures to indoor air quality and health impacts. Millions of people worldwide suffer and lose their lives because of indoor air pollution-related diseases, such as acute lower respiratory infection, chronic obstructive pulmonary disease, chronic lung malignancy (mainly due to exposure to coal), pulmonary tuberculosis, asthma and several cardiovascular disarrays. A cross-sectional study conducted in rural mountainous region of Nepal on the interrelationship between indoor air quality and its associated health impact also found a significant relationship between exposure level to poor indoor air quality and respiratory disorders in both adults and children who spend the majority of their time in the house (Joshi et al., 2009).

Burning biomass is a major source of unsafe smoke that mostly contributes to indoor air pollution and causes detrimental health effects because this smoke contains fine particulates, sulfur and nitrous oxides, carbon monoxide, volatile organic compounds, poly-aromatic hydrocarbons including carcinogens such as benzopyrene (De Koning et al., 1985). A cross-sectional study performed in rural part of Sunsari District (Nepal) to identify consequences of indoor air pollution among housewives (n=157) who were involved in kitchen for more than 5 years reported that 87.3% of sampled population had prevalence of health illness such as difficulty in breathing, teary eyes and productive cough. These symptoms were found common among housewives who use unrefined biomass for cooking on traditional mud stoves (Ranabhat et al., 2015). A survey carried out in Dhading District in Nepal reported that about 87% of households consume solid biofuels as key source of household fuel with 50% acute lower respiratory infection or pneumonia attributed to fuel burning (Dhimal et al., 2010). A study conducted in India reported that biomass combustion for cooking is associated with reduced infant birth weight independent of infant gender, birth order, maternal literacy, living standard and care during pregnancy (Mishra, 2004). Prevalence of tuberculosis was aslo observed among housewives using solid-fuels while cooking (Mishra et al., 1999). A case-control study (n=206) carried in the Nepal-India border provides clear evidence on association of prevalence of cataract among women performing cooking on unvented solid-fuel stove compared to the stoves that use liquid fuel, gas or at least vented solid-fuel stove (Pokhrel et al., 2005). A study based on analytical statistical modeling conducted in southern part of India to analyze association between indoor air pollution and domestic energy use revealed that the average household exposure concentration of indoor smoke is subjected to on different aspects of cooking conditions such as fuel type, stove type, kitchen type and type of ventilation system (Balakrishnan et al., 2002).

Some studies have found that cooking activity itself is a source of most fine indoor particles because fine particles are emitted as a result of the combustion of the solid fuels and the food itself as a result of the burning of food and oil (Kamens et al., 1991; Ozkaynak et al., 1996; Nazaroff, 2004; Dennekamp et al., 2011). Exposure to these breathable particles can be deposited in the lungs via the respiratory system and can accelerate the incidence of lung cancer and multiple respiratory diseases among cooking operators who spend more time cooking (Ko et al., 2000; Pope, 2000). While cooking, a strong buoyancy occurs in the kitchen and the particles can be rapidly distributed to other areas, causing adverse effects not only in the cooking operators but also on other people in the living room and adjacent areas (Lai & Ho, 2008; Yu et al., 2015). An experimental study conducted in South Korea to analyze the concentration of indoor air particles generated from cooking on different conditions (natural ventilation, cross-ventilation and mechanical ventilation) and to evaluate the adverse health hazards on the occupants living in the other space of house found that the concentration of particles was slightly greater in living room than that in the kitchen as a result of particle diffusion. The concentration of $PM_{2.5}$ exceeded 24-hr standard (50 g/m3) by 3.8 times increasing the health risk by 30.8% more than the base situation. However the higher emission was during natural ventilation compared to cross-ventilation and mechanical ventilation (Kim et al., 2018). The exposure to increased concentration of air pollutants is strongly correlated with health hazards, mainly suffering from respiratory and cardiovascular events, including myocardial infarction, arrhythmias, stroke, increased blood viscosity and blood pressure, decreased heart rate inconsistency and changes in the repolarization patterns including discharges of implanted cardioverter-defibrillators (Peters, 2005). Therefore, in order to monitor and evaluate the interventions applied to improve air quality, to more complex exposure and epidemiological studies, the need to strengthen research capacity and development must be prioritized by central and local authorities.

Materials and Methods

Measurement of $PM_{2.5}$ and CO exposure on different cooking conditions

The study was conducted to assess the effects of mechanical hood ventilation on indoor air quality through field measurement. The mechanical hood was designed and installed for the experimental set-up in a traditional kitchen (three-stone cooking stove) without an integrated ventilation system located near the Kathmandu University in Dhulikhel Municipality, Nepal. In this comparative study, the reduction effect of $PM_{2.5}$ and CO under three different conditions were investigated based on alteration in ventilation system as Condition A: Without hood ventilation system; Condition B: Passive hood ventilation system (without fan); and Condition C: Active hood ventilation system (with fan). In condition B and C, the airflow was measured through the hood on both locations on the duct in the beginning and end of the tests. In order to minimize the influence of outdoor air, the whole kitchen was left ventilated for an hour before the experimental tests were carried out. The test was conducted on three different days to avoid influence of indoor air pollution occurred due to previous tests. A light scattering air pollution monitor and Particles and Temperature Sensor (PATS+) were used to measure real-time exposure to $PM_{2.5}$ and CO. The monitor was placed at the breathing zone of the stove operator at a logging interval of 10 seconds. PATS+ ranges upper particulate matter detection limit of $PM_{2.5}$ from 30,000 to 50,000 $\mu g/m^3$ and lower particulate matter detection limit ranges from 10 to 20 $\mu g/m^3$. The optical sensor for CO can measure up to 500 ppm (parts per million) concentration. PATS+ can log PM concentration, temperature, humidity, movement, and battery voltage simultaneously. A kitchen schematic diagram showing mechanical hood placement and PATS+ relative to stove and operator is shown in Figure 1.

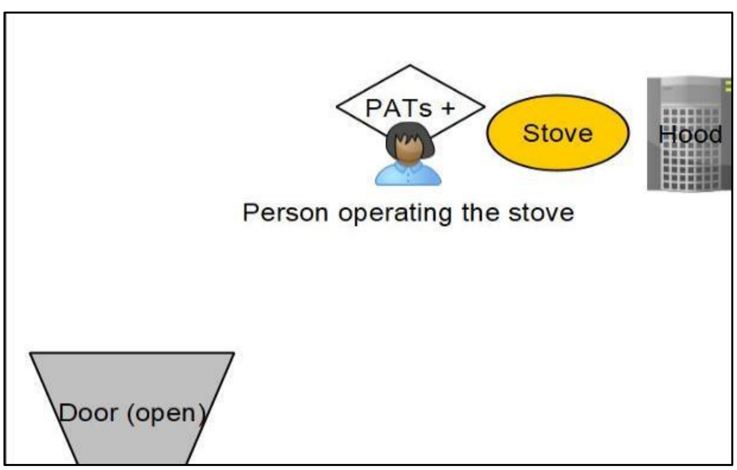

Figure 1 *Schematic diagram of a kitchen showing placement of Mechanical hood and PATS+ relative to the stove and the operator*

Figure 2 *Position of PATS+ in the kitchen*

Figure 3 *Experimental setup for condition A (without hood ventilation system) using plastic cover*

Measurement condition

In average, the experiment for all three tests was carried on for 35 minutes. In a traditional three-stone cook-stove, 4 Litres (L) of water was boiled to compare the variation in indoor air pollutant concentration between the specified conditions. The kitchen air temperature ranged from 21.38 °C to 23.06 °C and relative humidity ranged from 50.36% to 53.83% respectively for different tests throughout the measurement duration. The average airflow rate (m/s), wood moisture (%), relative humidity (%), temperature (°C) and fuel used (kg) in different conditions is presented in Table 2. For accurate analysis, particle concentration analysis for the different cooking recipe over various cooking conditions is required, however, in the exploratory phase, it is difficult to measure varieties of cooking recipes. Therefore, in this study, the particle concentration analysis was analyzed by boiling 4L of water on the traditional cooking stove. The PATS+ was turned on to record measurement a few minutes beforehand the stove was fully fired. From the start time, after 18 minutes water started to boil and was fully boiled after 30 minutes as presented (Table 1). At the start of the test, 4L tap water was put into saucepan of depth and width 20 cm and 40 cm.

Table 1 *Measurement schedule of the cooking period*

Time (min) →																		
0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36
Test start	Pot heating									Water starts to boil						Fully boiled		Test stop

Table 2 *Average airflow rate (m/s), wood moisture (%), relative humidity (%), temperature (°C) and fuel used (kg) during different conditions*

Conditions	**Ventilation system**	**Average**				**Fuel used (kg)**
		Airflow rate (m/s)	**Wood moisture (%)**	**Relative humidity (%)**	**Temperature (°C)**	
A	Natural, without hood	N/A*	10.86	52.82	21.38	1.22
B	Passive hood (no fan)	Start:1.62 End:1.59	11.36	50.36	22.09	0.92
C	Active hood (with fan)	Start:2.59 End:2.28	12.64	53.83	23.06	1.25

**N/A= Not Attempt*

Results and Discussion

$PM_{2.5}$ and CO particle scattering by cooking conditions

The scattering of the $PM_{2.5}$ and CO concentration by different cooking conditions in the kitchen are presented in Figures 4 and 5. After three minutes of cooking fine particulates started to emit and concentration steadily arose during cooking and reached maximum concentration when water started to boil fully, and then decreased with the end of cooking (Figure 5). The concentration of $PM_{2.5}$ exposure was found comparatively higher with an average 1315.54 µg/m^3 in without hood ventilation condition compared to the passive hood and active hood ventilation conditions (Table 3; Fig. 4). The $PM_{2.5}$ exposure concentration, however, was greater in the condition due to the poorly-ventilated traditional kitchen where particles suspend for a prolonged duration and inflow of outdoor particles by wind also contribute to it.

Table 3 *Descriptive Statistics of $PM_{2.5}$ concentration (µg/m^3)*

Conditions	Without hood (Condition A)	Passive hood (Condition B)	Active hood (Condition C)
Mean	1315.54	800.16	301.50
Median	713.00	657.30	156.46
Std. Deviation	1811.21	515.64	361.41
Minimum	29.00	22.76	10.29
Maximum	9338.00	2588.93	1954.52

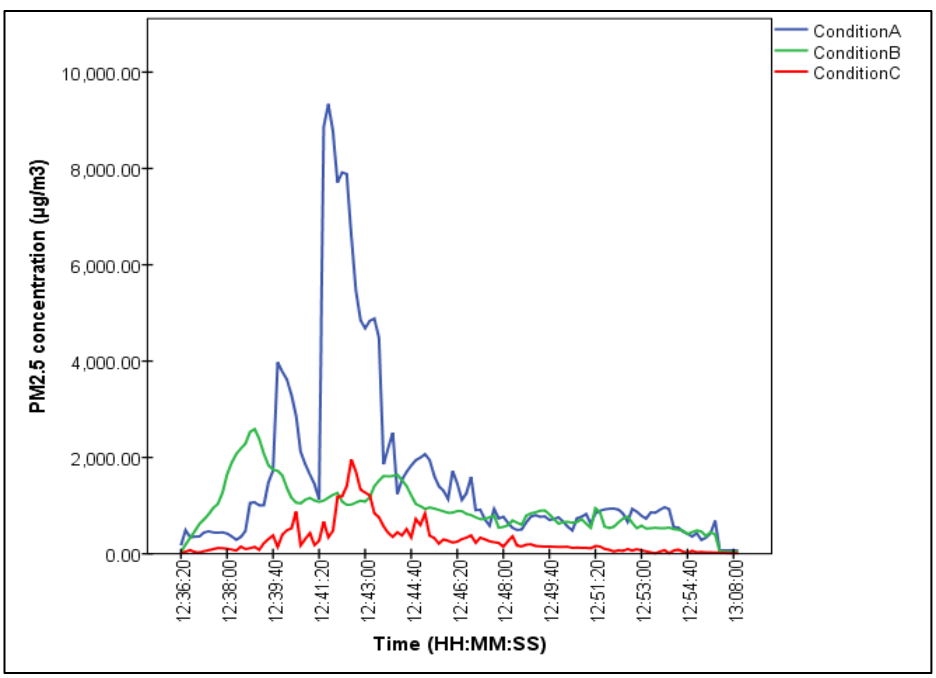

Figure 4 *Emission concentration of $PM_{2.5}$ by different cooking conditions*

The scattering and concentraitions of CO under different test conditions are presented in Table 4 and Figure 5. The mean concentration for CO exposure was higher in condition A (Table 4). National Indoor Air Quality Standard Implementation Guideline (2009) has framed Nepalese standard for the indoor concentration of $PM_{2.5}$ and CO at 100 µg/m^3 and 35 ppm respectively for 1hr-average time**.** Therefore, introducing the proper mechanical hood ventilation with a fan in the kitchen can significantly reduce exposure to the higher levels of $PM_{2.5}$ and CO, and hence improve quality of health of susceptible groups by mitigating chronic health issues caused due to long-term exposure to indoor air pollution.

Table 4 *Descriptive Statistics of CO concentration(µg/m^3)*

Conditions	Without hood (Condition A)	Passive hood (Condition B)	Active hood (Condition C)
Mean	65.01	48.29	9.44
Median	65.47	48.49	3.91
Std. Deviation	20.90	18.02	8.89
Minimum	8.11	1.89	0.10
Maximum	114.88	84.17	43.25

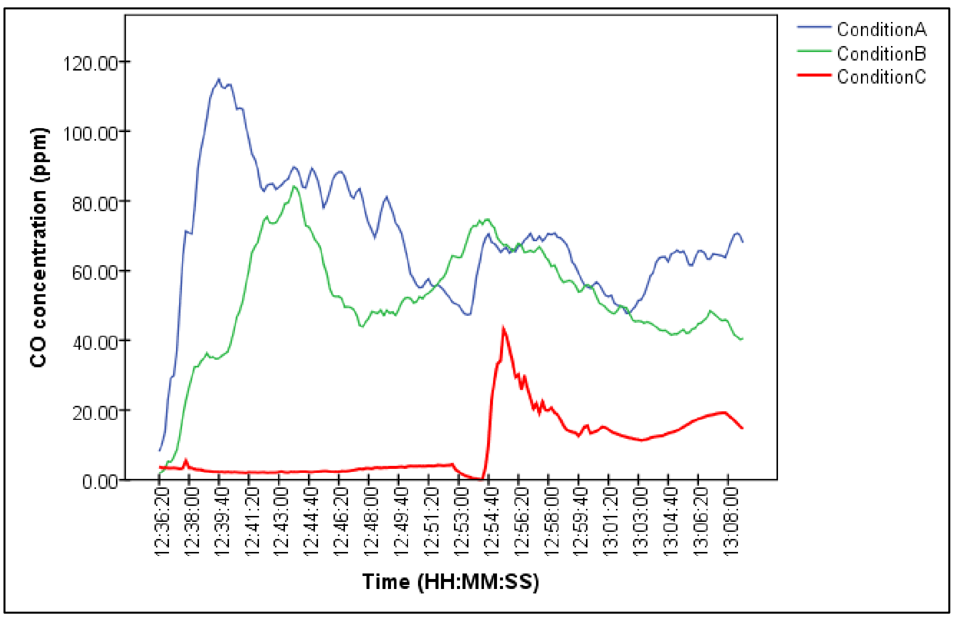

Figure 5 *Emission concentration of CO by different cooking condition*

Study Limitations

The limitation of the exploratory phase of this study are as follows:

- The relationship between a dependent (Particles concentration) and independent variables (fan size, hood height from the ground and dimension of the hood) were not measured by altering the independent variables.
- The removal efficiency of the particles given a mechanical hood ventilation system was not evaluated.
- The long-term measurement was not performed rather was limited to 35 minutes and with a similar cooking method.
- The real-time PM monitor was only placed at breathing zone of a cooking operator, thus concentration on various parts of the room was not monitored.
- The cost and feasibility of deploying a hood system to achieve the desired benefit were not analyzed.

Conclusion

The result of the study shows a significant improvement in indoor air quality in terms of $PM_{2.5}$ and CO concentrations with mechanical hood ventilation. However, small intervention cannot be replicated without appropriate policies, hence it is recommended to review existing policies and further policy recommendations on household energy, health and enhanced indoor air quality in order to minimize the negative impact on human health and the environment.

Acknowledgement

This study is supported by Clean Cooking Alliance (Nepal) and Leaders, Nepal (Putalishadak, Kathmandu).

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Community- based Ecotourism Sustainability Measurement: A Case study of Ghorepani-Ghandruk Trekking Trail (GGTT)

[1*]Sneha Rai and [1]Dr. Subodh Sharma

[1]Department of Environmental Science and Engineering, Kathmandu University, Dhulikhel

*Corresponding author: snehakhaling23@gmail.com

Abstract

The sustainability of ecotourism on hilly and mountain regions are of critical issue around the world due to increased environmental degradation and globalization. The sustainability of ecotourism in *Ghorepani- Ghandruk Trekking Trail (GGTT)* was assessed through sustainability indicators of social, economic and environment aspects. The present study utilized both qualitative and quantitative data which were collected from questionnaire survey. It exhibited a strong socio-cultural element resulting from improved awareness of community towards benefits of tourism (local employment and infrastructure development). However, concerns were seen regarding some effects of tourism such as increase in price of local goods, minimum participation of women in tourism related activities and; training and skill development of staff and communities. Likewise, economic consideration was found to be strong and measured through tourist's satisfaction. The study also focuses on the analysis of drinking water quality along the trekking trail. Both microbial and physico-chemical parameters were tested for drinking water quality analysis. It showed no obvious harm in consuming the Community Safe Drinking Water (CSDW) but showed coliform contamination in tap water that were not CSDW. In addition, seasonal variation was observed with high risk of both total and fecal coliform during the monsoon season compared to pre-monsoon in tap water. Majority of the visitors rated Ghorepani-Ghandruk trekking trail as excellent destination of tourist satisfaction. However, from the sustainability perspective, it is also crucial to attain progress and balance in all three aspects-social, economic and environmental dimensions for a meaningful ecotourism sustainability

Keywords: Ecotourism, Sustainability, Drinking water quality

Introduction

The rapid growth in tourism have created adverse negative impacts on environmental and socio-economic conditions resulting in exploitation of natural resources, waste management problem, influence on the indigenous culture and tradition. In addition, tourism has also been identified as the contributor to climate change (Gossling, 2009), thus, efforts are made for encouraging ecotourism and sustainable tourism all over the world in the recent years. Ecotourism is a sub-component of sustainable tourism which considers three pillars of sustainability- environment, social and economic aspects (Satarat, 2010). The concise and widely used definition of Ecotourism is given by The International Ecotourism Society **(**TIES) as *"Responsible travel to natural areas that conserves the environment, sustains the well-being of the local people, and involves interpretation and education"* (TIES, 2015). The assessment of tourism sustainability is vital for the addressing the emerging issues for better decision making and long-term survival of the tourism destination through identification of impacts (WTO, 2004).

Tourism in Nepal mostly involves traveling to natural areas for adventure to experience varying socio-cultural and environmental settings. Thus, the bulk of tourism in Nepal encompasses 'ecotourism' or 'nature tourism' (MoFSC, 2014). Community-Based Ecotourism (CBET) not only considers the environmental aspect of sustainability but also ensures the participation and empowerment of host community, by allowing them to get involved in conservation, business enterprise and community development (Fiorello, 2014). Thus, participation of the local communities in any development activities is crucial for long term sustainability.

Besides various benefits, tourism also has severe adverse effects such as unwanted pressure on natural resources, environmental pollution, cultural erosion; and growth of criminal activities (Yogi, 2010). As a result of these negative influences, the demand of eco tourist and rapid rise of the tourist industry pose serious threat to sustainability (Weaver & Lawton, 2002). We aim to explore the sustainability question in Ghorepani- Ghandruk Trekking Trail by examining people’s perception and environmental indicators such as drinking water quality and its seasonal variation in a tourist trail in Nepal. The objective of this study was to characterize the socio-economic, cultural and environment aspects in GGTT from people’s perception; to assess the seasonal variation of the quality of drinking water at Point of Use (PoU) along the GGTT.

Materials and Methods

Study Area

The study was conducted in Ghorepani- Ghandruk Trekking Trail area (Figure 1). Ghorepani-Ghandruk Trek is one of the most popular eco-treks in Annapurna Conservation Area of Nepal (NTNC Brochure, 2013). Ghorepani and Ghandruk lies at the latitude and longitude of 28°24'02.84" N and 83°41'59.95" E and 28°27'47.80" N and 83°49'33.92" N respectively. Along with the spectacular scenic beauty of Annapurna, the area gives an opportunity to acquaint and enjoy culture and traditions of Nepal.

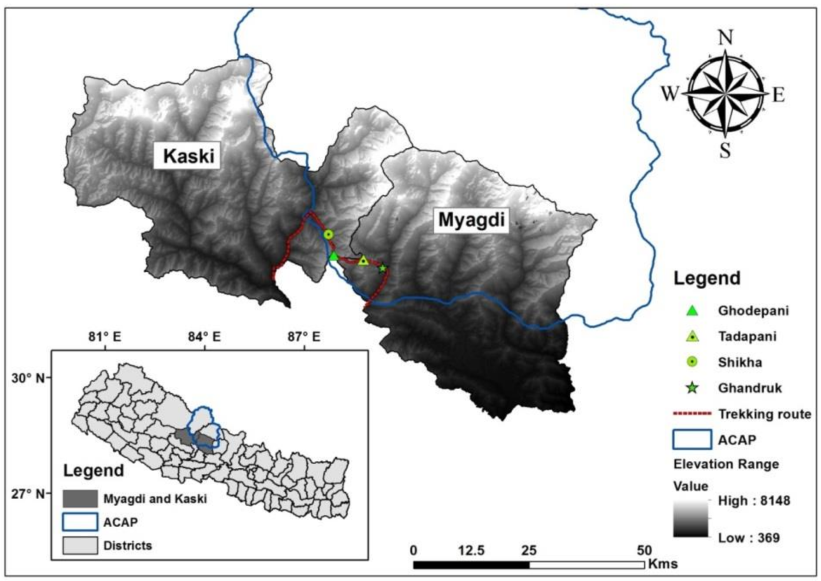


Figure 1 *Study area map of Ghorepani-Ghandruk trekking trail*

Evaluation framework

The evaluation framework for this research was based on the ecotourism sustainability indicator framework of Mearns (2010). The use of sustainability indicators provides an objective way of measuring and monitoring sustainability of the selected ecotourism ventures and the destination (Mearns, 2011). The issues and indicators used are linked to the three pillars of sustainability namely - social, economic and environmental sustainability - in order to achieve economic prosperity, environmental quality and social justice. Nine issues with 18 sustainability indicators (Table 1) were selected for the study from Mearns evaluation framework. These selected indicators were measured through questionnaire surveys, interviews and drinking water quality analysis.

Table 1 Ecotourism sustainability indicators adapted from Mearns (2010)

Issues and Sustainability Indicators	
Issues	**Indicators**
Local satisfaction with tourism	Local satisfaction with tourism
	Local community complaints
Effects of tourism on communities	Percentage who believes that tourism brings new services or infrastructures
	Other effects of tourism on the community
Education	Education of tourists
	Education of Community
	Training and skills development of staff
Community decision making	Community decision making structures
Culture	Cultural appreciation and conservation
Sustaining tourist satisfaction	Level of tourist satisfaction
	Perception of the value for money
	Percentage of return visitors
	Perception of sustainability
	Tourist complaints
Waste management	Waste disposal
Biodiversity and Conservation	Local community involvement in conservation projects in the area
Drinking water quality	Water quality analysis: Microbial and Physio-chemical parameters

Data collection

Questionnaire survey and Interview

A total of 162 questionnaire survey was conducted among tourists (59), hotel managers (21), employees (32) and local community people (52) in different ventures along the trekking trail. The responses were colour coded into five categories and positively and negatively stated responses were differentiated for separate analyses. Likert score was used to assess the response(s) and perception of the community and staff.

Water sample collection

Water samples were collected from the point of use (PoU) of randomly selected ventures of four different locations in the trekking trail. The basis of selection of drinking water quality variables are according to WHO guidelines. These variables include turbidity, temperature, pH, nitrate, phosphorous, sulfate, total hardness, Ca2+, Mg2+, Cl-, fecal coliform, total coliform. The venture name and GPS coordinates were recorded during the field visit. Presence Absence (PA) sampling field kit was used for testing of bacteriological contamination. The confirmatory test was later done in laboratory using standard membrane filter technique.

Data analysis and interpretation

The results obtained from the questionnaire survey were analyzed and interpreted using SPSS and Excel. The drinking water samples were analyzed using various methods and instruments (Table 2).

Table 2 *Methods/Instruments used for Physico-chemical parameter analysis*

S.N.	Parameter	Test method/Instrument
1	pH	pH meter
2	Temperature	Temperature meter
3	Turbidity	Turbidity meter
4	Chloride	$AgNO_3$ titration
5	Total hardness	EDTA titration
6	Ca hardness	EDTA titration
7	Mg hardness	EDTA titration
8	Nitrate	Atomic Absorption Spectrophotometer
9	Phosphate	Atomic Absorption Spectrophotometer
10	Sulfate	Atomic Absorption Spectrophotometer

Results and Discussion

Social sustainability

Table 3 shows the colour coding categories of selected responses. The satisfaction levels of staff and community members with tourism. The level of local satisfaction with tourism was high among the staff and community. Majority of the respondents mentioned that tourism create jobs. However, 20% community respondents complained about increase in the price of goods because of tourism (Figure 2).

Table 3 *Color coding categories of selected responses for analysis*

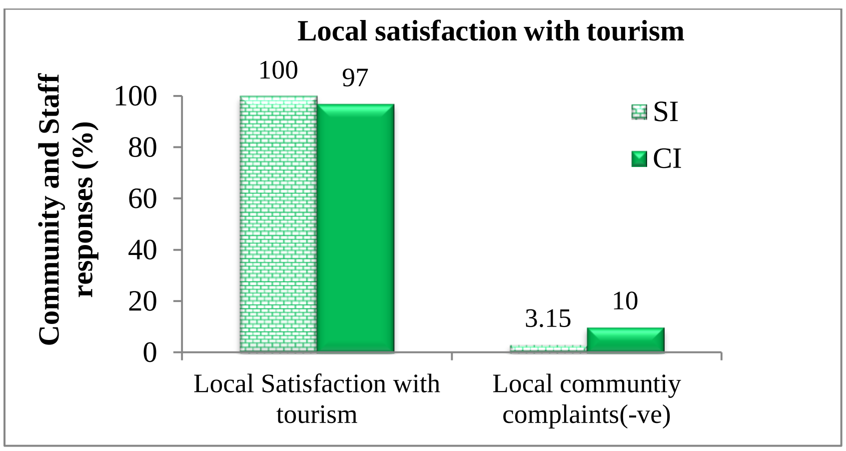
Color coding	%responses (positive statements)	%responses (negative statements)	Cumulative Likert scale (positively stated)	Cumulative Likert scale (negatively stated)
Excellent	81-100	0-20	4.21-5.0	1.0-1.8
Good	61-80	21-40	3.41-4.2	1.81-2.6
Average	41-60	41-60	2.61-3.4	2.61-3.5
Below average	21-40	61-80	1.81-2.6	3.41-4.2
Cause of concern	0-20	81-100	1.0-1.8	4.21-5.0

With regard to different effects of tourism on communities, a large portion of community and staff members think tourism does not help for any development activities. The reason could be because very little amount is spent by the owners for adding new infrastructures and services. In contrast, an average percentage of both staff (53.1%) and community (46%) responded that tourists do employ local youths. However, all the community respondents (100%) and majority of the staff (87.5%) agreed that tourism increase the price of the local goods. The reason is that community and staff have to pay nearly equivalent price for the goods. A below average percentage of staff (62.5%) and community (66%) believe tourism changes the behavior of community while others believe it is influenced by media, internet, and modernization rather than tourism. One respondent said, *"Because of tourism we are aware and focused towards our culture preservation which is the positive side of behavioral change due to tourism."*. Majority of the respondents believe that tourists do not damage or destroy the resources. 74% of community and 90.6% of staffs agreed that local community can also visit or use tourism facility but could not afford it due to high price (Figure 3).

On the issue of whether the tourists, staff and community members receive any education, training or skill development, it was observed from the managers' interview that not much attention is given to the education of tourists by the ventures as many come with their own guides. However, it was vital for Free Independent travelers (FIT). Very few staff (15.4%) responded that they have received training, but not by the venture. Few other staffs responded that the venture provided them training

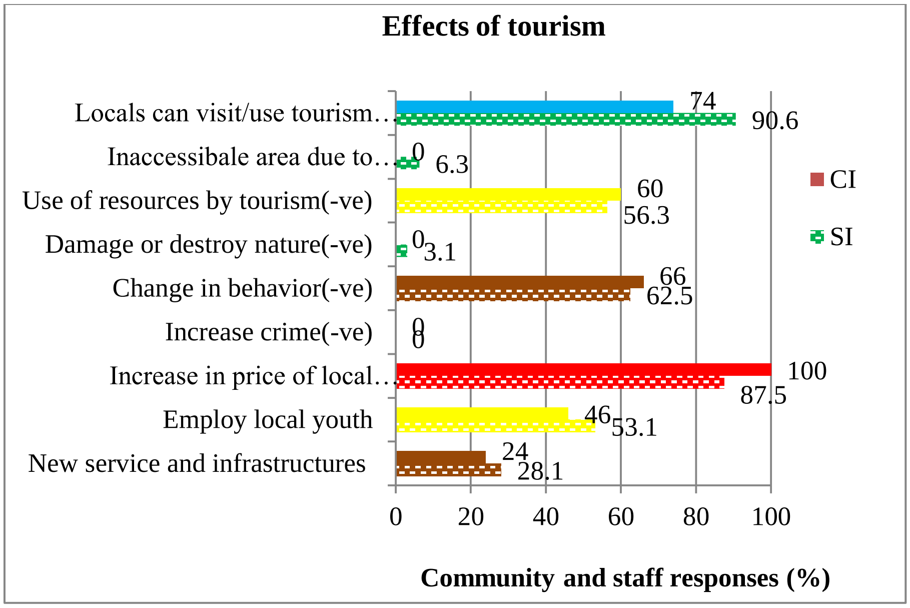
(9.4%) but these especially include the training for head chefs for cooking. Training on nature and culture is very less because communities have no influence on decision making by the ventures and since the latter are all privately owned, training to staffs and community are not the priority of the ventures (Figure 4). It is important to realize the fact that nature and culture are the foundation of tourism development and so improvement of education is important for communities involved in tourism. The staffs and community indicated that the communities have no control over tourism. The decision making are done solely by the owners of the ventures (Figure 5).

Visitors gave a suitable rank on culture, supporting that they were satisfied (Figure 6) with the local culture (Average Score =4.41) experienced through cultural singing and dancing conducted by 'Aama Samuha' (Women community group), display of culture and tradition through cultural museum, shops for local crafts like 'Gurung' shawl (Bhangra) and local carpets. The uniqueness of the Ghandruk village is maintained by prohibiting the RCC (Reinforced Cement Concrete) buildings and encouraging the traditional stone roofed houses.



Note: SI Staff Interview; CI Community Interview

Figure 2 *Percentage of staffs and community showing local satisfaction with tourism*



Note: -ve Positive response; -ve Negative response

Figure 3 *Percentage of community and staff responses to the effects of tourism*

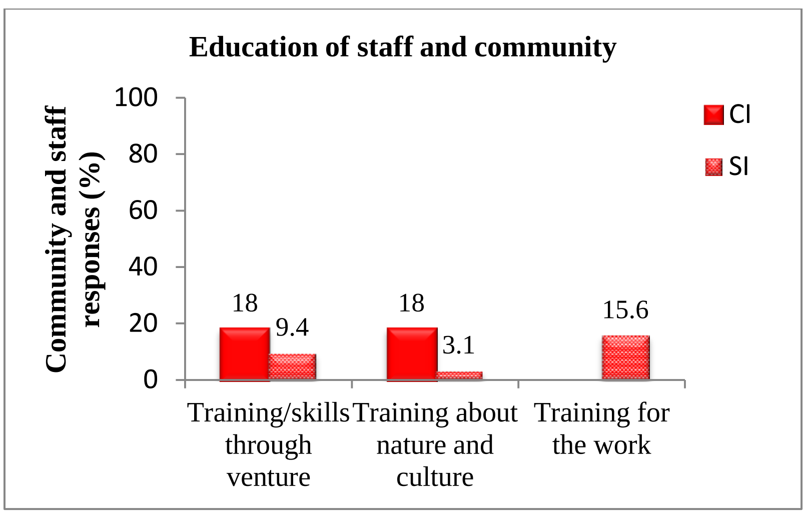


Figure 4 *Percentage of community and staff responses to education issue*

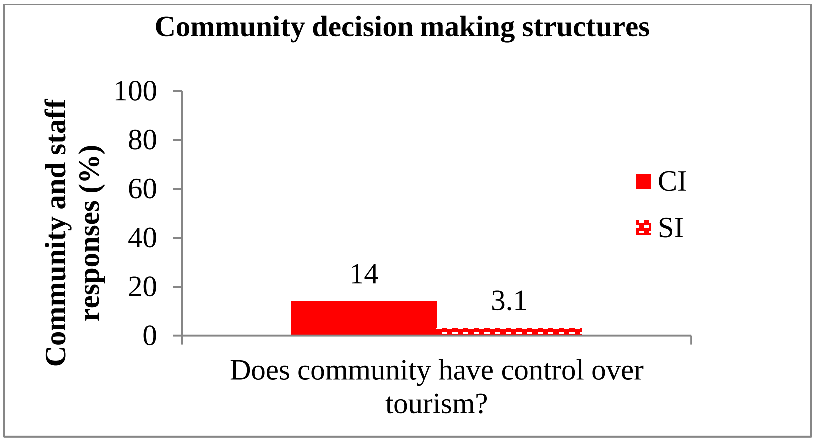


Figure 5 *Percentage of staffs and community showing community decision making structures*

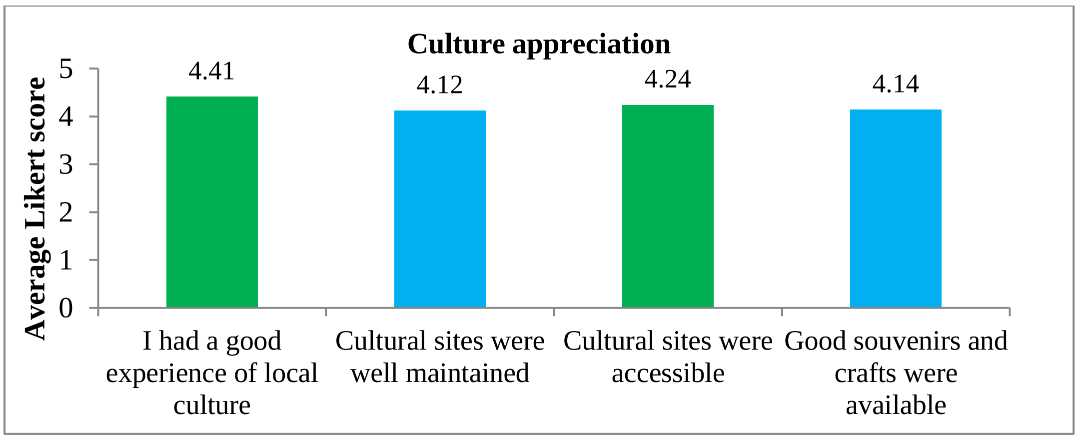


Figure 6 *Visitor responses on cultural appreciation and conservation in Likert scale*

Economic sustainability

The visitors provided a good to excellent score to the overall satisfaction indicators (Figure 7). The visitors' perception regarding the accessibility of the local destination was not so good and rated as average to the state of roads and signage (Average Score = 2.73 and 3.37 respectively). One responded, *"It is really difficult to visit the destination during monsoon because the roads are often hit by landslides and it is dangerous and causes long traffic"*. Many tourists complained about the solid wastes seen in the trekking route and gave an average score of only 2.6. However, they were satisfied with the local cuisine, accommodation and the service provided by the ventures. Few FIT tourists with no guides complained about the interaction with the staffs for not understanding the English language. This calls for attention towards the language and conversation skill trainings of the staff members. The tourists felt highly safe and secure during their visit (Figure 7). The visitors gave an excellent score (Average Score = 4.32) on the perception of value of money received (Figure 8). Few complained about the price being too high in the destination. The indicator of return visitors is an important aspect to measure the percentage of return visitors. The percentage of tourists who visited the destination for the first time and wanted to visit again is high (Average Score = 4.36). The visitors perceived the destination is sustainable (88.1%). Some added *"Sustainability could be maintained if the trekking route is free of rubbish and the natural environment is maintained and wildlife is not harmed."* Some visitors indicated the destination is environment friendly with good opportunity to experience local food and culture.

Out of the total, 49.16% tourists responded for the improvement of their visit. Some suggestions by the tourist are: more cultural activities and chance to interact with the local people, maintenance of nature, clean hotel rooms, kitchen and toilets, more dustbins on the trekking route, detailed maps and signage. Only 6.3% staff interviewed showed awareness about the tourist complaints. The reason behind low staff awareness is could be due to the lack of conversation skills and education of the staffs which needs to be addressed.

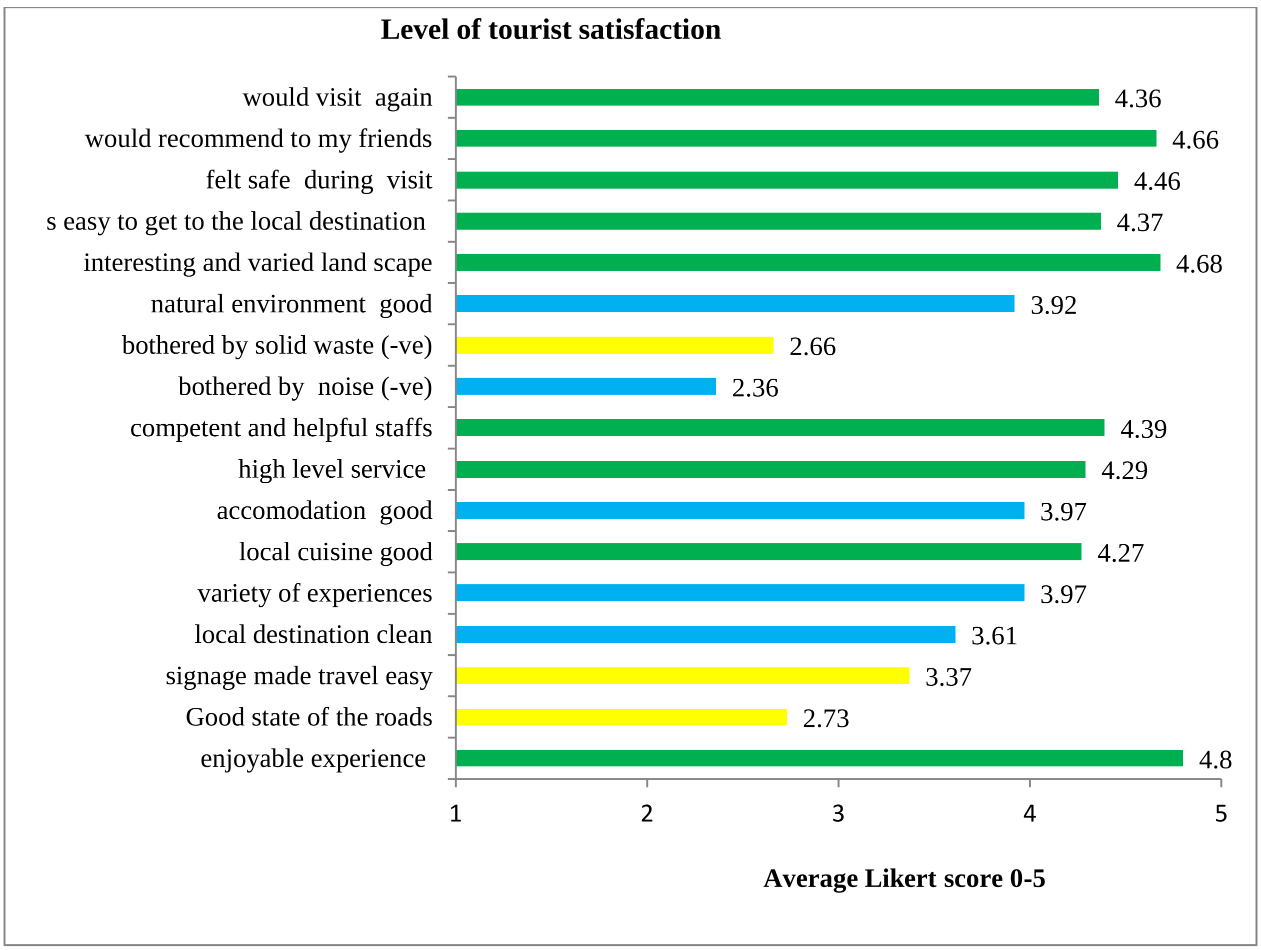


Figure 7 *Visitor responses on level of tourist satisfaction in Likert scale*

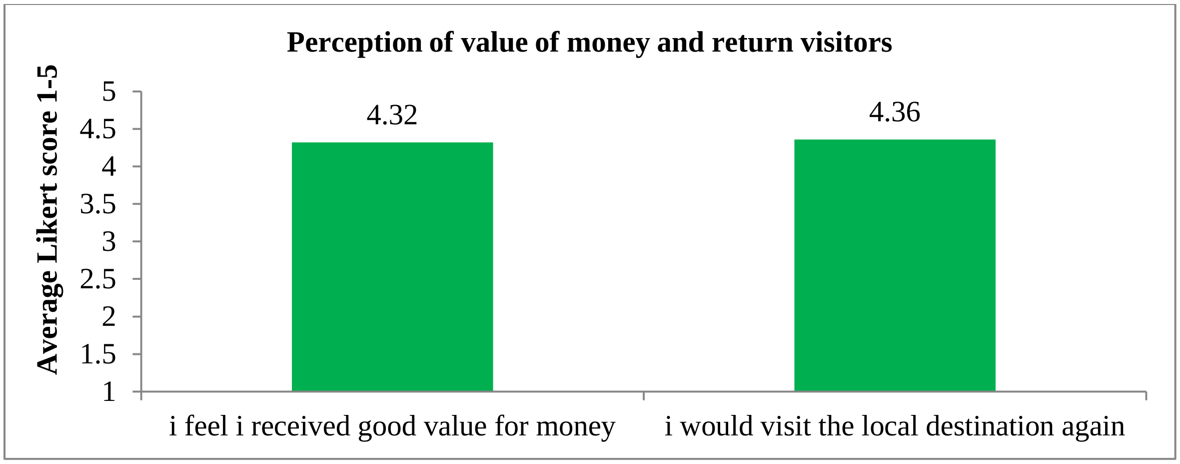


Figure 8 Visitor responses on perception of value of money and return visitors in Likert scale

Environment sustainability

Waste management

The managers' interviews indicated that all the biodegradable and kitchen waste is composted while other non-biodegradable wastes are burned or buried. Out of the total managers interviewed, 43% replied that they manage the waste by burying, 33% burning and 24% being managed by collection in the waste collection center. It was informed by the waste collector that once the landfill is filled, another pit is dug for burying the non-biodegradable waste. This type of waste management is not sustainable on long run and is a cause of concern as this can affect the soil, water and vegetation of the area.

Biodiversity and conservation

The involvement in conservation projects is significant as this helps to see whether efforts are made to protect and conserve the valuable resources in which the destination is built upon. The staff members show below average percentage (28.1%) of involvement while the communities are involved in good proportion (64%).

Drinking water quality

Table 4 and 5 show the results of the microbial analysis and the associated risk grade of the drinking water in the study area.

Table 4: *Total coliform risk in Pre-monsoon and Monsoon*

Total coliform	**Risk Grade**	**Pre-monsoon (n=12)**	**Monsoon (n=16)**
(cfu/100mL)	%		
0	No Risk (A)	25	6.25
1-10	Low Risk (B)	33.33	6.25
11-100	High Risk (C)	41.67	43.75
101- >1000	Very High Risk (D)	0	43.75

Table 5 *Fecal coliform risk in Pre-monsoon and Monsoon*

Fecal coliform	**Risk Grade**	**Pre-monsoon (n=12)**	**Monsoon (n=16)**
(cfu/100mL)	%		
0	No Risk (A)	83.33	18.75
1-10	Low Risk (B)	8.33	25
11-100	High Risk (C)	8.33	50
101- >1000	Very High Risk (D)	0	6.25

The presence of total coliform in 24 (85.71%) of 28 samples and fecal coliform in 15 (53.57%) of 28 samples exceeded WHO standard (0 cfu/ 100mL) thereby confirming tap water as unsafe for drinking. The samples taken from the safe drinking water filters showed no coliform bacteria and safe for consumption. The quality of tap water has to be improved to minimize the health risk among the residents, staffs and also tourists. Out of 12 water samples from the pre-monsoon, 9 (75%) were found to be contaminated with total coliform and 2 (16.66%) were found to be contaminated with fecal coliform. Likewise, out of 16 water samples from monsoon, 15 (93.75%) were found to be contaminated with total coliform and 13 (81.25%) were found to be contaminated with fecal coliform. High presence of coliform bacteria during rainy season maybe due to contamination ofthe source by runoff.

The results of the different physico-chemical analyses of the drinking water samples are presented in Table 6.

Table 6 *Mean values of physico-chemical parameters showing seasonal variation*

Parameters	**Unit**	**Pre-monsoon**	**Monsoon**
pH	--	8.04	7.73
Temperature	°C	14.42	19.80
Cl^-	mg/L	33.84	27.07
Total Hardness	mg/L	106.73	136
Ca Hardness	mg/L	51.82	84.55
Mg Hardenss	mg/L	54.91	51.45
NO_3^-	mg/L	1.42	0.66
PO_4-^{3}	mg/L	BDL	5.84
SO_4^{-2}	mg/L	5.36	5.01

Independent t-test showed pH, temperature, total hardness, calcium hardness, Nitrate and phosphate of the water samples at the point of use have significant seasonal variation ($p<0.05$). The concentrations of the ions were within the permissible limit of the WHO guidelines.

Conclusion

The overall sustainability of any ecotourism destination is dependent on all three pillars of sustainability- social, economic and environment. There has to be a balance in all the three aspects and improvement in only one is not sufficient for achieving sustainability. The study revealed improved awareness of community towards the benefits of ecotourism such as employment for local people. However, concerns were seen regarding some effects tourism such as; increase in price of local goods, minimum participation of women in tourism related activities, limited or no trainings for skill development to the staffs by the venture and lack of community involvement in the decision making structures. It is very important to highlight and resolve the issues of community concern because this may be the reason of conflict in future. Satisfaction level of tourists with ecotourism in the study area is high though many of them are of the opinion that improvements on different aspects of tourism should be achieved. Bacteriological contamination is a serious environmental issue with health implications.

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Policies and Practices Addressing Pastoral Communities in High Mountain Regions of Nepal

Krishna R Tiwari[1]*, Bishal K Sitaula[2], Roshan M Bajracharya[3], NaniRaut[3]

[1]Institute of Forestry, Tribhuvan University, Nepal
[2]Departments of International Environment and Development Studies, Norwegian University of Life Sciences (NMBU), Norway
[3] Department of Environmental Science and Engineering, Kathmandu University, Nepal

*****Correspondence author: krishna.iof@gmail.com

Abstract

Mountain pastoralism is the one of the important traditional farming systems for livelihood of the local communities in the Hindu Kush Himalayan regions. This system is continuously deteriorating in recent decades due to socio-political and environmental changes. Therefore the study was conducted to analyze existing socio-political changes particularly focusing on policy and practices for managing sustainable rangeland management and livelihood of the pastoral communities of Nepal through review of the existing Acts, rules, regulations, policies, traditional practices and field survey. Field study was conducted in five selected National Parks and Conservation Areas of the country from high mountain regions from east to west of Nepal in 2017 and 2018. Assessment of different acts, policies and guidelines showed that there is a gap in rangeland management and policy as well as program implementation mechanism. Present policies and programs have ignored the traditional pastoralist practices in rangeland management. Additionally, newly implemented federal system in Nepal has changed different roles, responsibilities and implementation mechanisms at central, provincial, local government levels. Local Government Act states that the local government has main responsibilities to implement the sustainable rangeland management program and improve the livelihood of the pastoral communities in respective municipalities. However, the Rangeland Policy, National Park and Conservation Area policies and guidelines poorly address the local government responsibility and focus mainly the user committee or user groups. Field study found livestock farming is the main occupation in the high mountain region and contribute about 46 percent of the household income. However, the newly formed local government and their institutions do not have any priorities, programs and activities to implement rangeland management. Buffer Zone and Conservation Area Management programs and activities address the pastoral community needs and livelihood support programs through user committee in a participatory way and revenue sharing mechanisms. The study suggests that all the rangeland related policies and guidelines should be revised and should be compatible in the newly implemented Local Government Act and regulations for implementing sustainable rangeland management in a participatory approach. Additionally, local institutions including user groups committee under the municipalities should be empowered and strengthened through programs, budget and human resources for sustainable rangeland management in the region.

Keywords: Local government acts, Regulations, Traditional practices, User committee, Livestock farming, Institutions.

Introduction

Pastoralism in the mountain region is one of the oldest and well-established common practices of farming system globally (Montero et al., 2009). It is reported that globally more than 120 million pastoralists rely on more than 5 billion hectares of rangelands for their livelihoods (Korner & Ohsawa, 2005). Rangeland covers more than 60% (or about 2 million Km^2) of the Hindu Kush–Himalayan (HKH) region (Miller, 1996; Wilkes, 2008; Wu et al., 2013) and consists of natural grassland, shrub/scrub land, tundra, marshland, and sparsely vegetated drylands, open woodland that can be used for livestock grazing. Rangelands comprise an area of 3.326 million hectares and constitute 22.60% of the total land area in Nepal. Most of the rangelands (about 80 %) in Nepal are located in the high mountains and alpine zones of the country.

Livestock farming with different practices (agro pastoralism, transhumant, stall feeding and seasonal grazing) and agriculture with livestock farming, as well as off-farm activities are the main livelihood strategy of the mountain region of the HKH region. According to the data from Central Bureau of Statistics (CBS) 2017, livestock covers approximately about 27 % of agricultural Gross Domestic Product (GDP) and about 11 % of the total country's GDP. In Nepal mountain households, livestock alone contributes 47.3 % and 35.7 % of the total agricultural income in the mountains and hills respectively (Parajuli et al., 2013).

Importance of the Rangeland in the Hindu Kush Himalaya

It is estimated that a vast area - 59.41% - of the Hindu Kush Himalaya (HKH) region consists of rangelands (Table 1) where 30 million people depend on livestock for their livelihoods. In parts of Afghanistan, Bhutan, China, India, Nepal, and Pakistan, livestock production particularly for meat, milk and wool, plays a major role in food security and income generation. Rangelands in the HKH not only support many communities in the high mountains that earn their livelihood from pastoral production, but also provide many ecological (such as water cycling and filtration, nutrient cycling, and soil formation) as well as economic services (such as fodder supply) and retain clean air and open spaces for recreational purposes (Kreutzmann, 2012; Dong et al., 2016).

Moreover**,** rangeland ecosystem has been increasingly recognized as a priority eco-region for conserving biodiversity because of its highly distinctive faunal and floral species, ecological processes and evolutionary phenomena (Spehn et al., 2010; Wester et al., 2019). About 12 % of area is under rangeland in Nepal (Table 1), which represents about 2 % of rangeland in the HKH region. Despite the vast area of rangeland in the HKH region (Table 1) and its importance for their livelihood, pastoral communities in those areas in general are poor, marginalized and rangeland is neglected or under-recognized resource in terms of research, legislation, government policy and programs for sustainable utilization (Kreutzmann, 2012).

Table 1. *Range land area covered in the HKH country*

S.N.	Country	Area of the Rangeland (%)
1	Afghanistan	7.57
2	Bhutan	0.45
3	China	40.09
4	India	4.36
5	Nepal	2.02
6	Pakistan	4.88
	Total	59.41

Many scholars have expressed that pastoralism in the mountain regions is affected by socio-political and ecological dynamics. These dynamics are co-evolved interactions and feedbacks between socio-political and ecological systems (Fernandez-Gimenez & Swift, 2003; Fernandez-Gimenez et al., 2012; Li & Li, 2012; Huntsinger & Oviedo, 2014; Dong et al., 2016). Therefore, rangelands should be managed in an integrated way to address political, social, economic, ecological as well as institutional issues. In this context, Nepal with its new federal structure has also implemented new rules and regulations, institutions and resource management mechanisms in natural resource management (Local Government Acts (2073) (2016 AD). The importance of the rangeland and its dependent pastoral communities has encouraged to analyze its policies, practices and gaps in changing context of new Constitution, 2015, in the federal structure of Nepal for sustainable rangeland management and livelihood of the pastoral communities in the mountain regions. Therefore, this study has analyzed how existing policies, programs, practices and institutions address to manage rangeland and pastoral communities' livelihood in the high mountain community of the HKH region particularly Nepal in changing socioeconomic and institutional context through review of acts, policy, guidelines and research papers, as well as field study with pastoral communities.

Materials and Methods

Study area

The study was conducted in the high mountain regions of Nepal representing different areas from east to west. Five selected National Parks and Conservation Areas namely Makalu Barun Conservation Area in Sankhuwasabha district (east); Manaslu Conservation Area in Gorkha district (west), Annapurna Conservation Area in Lamjung and Mustang districts (west) and Dhorpatan Hunting Reserve Baglung district (west) were studied (Figure 1). The altitude ranged from 1000 m to up to alpine zone where trans human agro pastoralism is practiced with livestock grazing n different altitudes in different seasons.

Figure 1. *Study area and Rangeland in the high mountain National Park and Conservation Area of Nepal (study area marked as stars)*

Data collection

This study has employed a qualitative research approach, which included analyzing policy documents in terms of sustainable rangeland management practices (Grazing management, rangeland improvement activities, rules and regulations for grazing (*de jura* and *de facto* practices). Additionally, institutional arrangement in the rangeland management (User Groups, Committee, Government institutions and implementing process) were also reviewed and analyzed. Furthermore, field interactions were conducted in the selected sites of the rangeland area communities and herders in Nepal. Similarly, rangeland area in Nepal having mostly located in the National Parks and Conservation Areas, their rules, regulations, guidelines were also reviewed to regulate grazing practices and rangeland improvement inside park and Buffer Zone of the National Park and Conservation Areas.

Results and Discussion

Rangeland improvement and livelihood support through national park and conservation area program

National Park and Conservation Area, Buffer Zone User Committee also have the right to prescribe grazing allowed area, kind, number of animal and grazing fees in the park with consultation of the park authorities. Study found that grazing inside the park is limited and discouraged, but park management activities such as trail improvement, water source protection and construction, removal of invasive species and regulatting the rotational grazing may enhance rangeland improvement and availability of the quality forage for the livestock. Moreover, in the Buffer Zone Management Regulation (1996), there is a provision to allocate 30 to 50 % income from the park revenue which should be utilized in the Buffer Zone area for resource conservation, development and livelihood improvement of the Buffer Zone communities (Buffer Zone Guidelines, 1999/Local Self Governance Act, 2055 (1999 A.D)). Study found that income generating activities; livestock development program (veterinary training and service, fodder and forage production in the Buffer Zone area and private land) improved vegetable farming, and ecotourism promotions were practised in the high mountain region of Buffer Zone areas. Similarly, different types of capacity enhancing training provided by Buffer Zone communities and park staff to the user groups particularly poor, marginalized people enhanced their livelihood through self-employment; and off-season income generating activities resulted in resource management in the Buffer Zone area. Additionally, provision of the compensation mechanisms (MoFE, 2017) to the livestock depredation from the wild animals also has positive impact on the pastoral communities. These activities help to improve livelihood of the pastoral communities as well as improve rangeland management. Many studies also supported the Buffer Zone program enhanced the livelihood of the Buffer Zone communities through income diversification, capacity enhancement, resource conservation, ecotourism, increase farm production and minimize the conflict between park and communities through revenue distribution (Budhathoki, 2004; Silwal et al., 2013; Lamichhane et al., 2019).

The study revealed that Conservation Area Management Committee (CAMC) is the main institution at the Municipality level (formerly Village Development Committee (VDC) level) for overall planning, implementing the resource conservation, development and livelihood improvement activities. Study found that the CAMC and sub-committee were involved in management and conservation of the natural resources and including range land management and livelihood improvement program of the pastoral communities. It is reported that livelihood improvement activities such as distribution of solar 'tukies' (lights) to the mobile herders along with tent sets and sleeping bags was undertaken. Such activities have been significant in supporting large numbers of the community to deal with the crisis of livestock depredation and have had a significant role in increasing wildlife population in those areas over the past decade. Additionally, tree saplings were distributed from nurseries and planted in those areas to minimize the pressure of fodder and fuelwood demand simultaneously greening large areas. Similarly, *Pennisetum purpureum* (Napier grass), *Thysanolaena maxima* (grass) were also distributed to the local farmers for increasing fodder availability in some parts of the area. Farmer´s group were encouraged for cash crop farming focused on planting cardamom, tea and coffee; Non-Timber Forest Products (NTFPs) such as *Swertia chirayita* (locally known as 'chiraito') cultivation. Besides diversifying community's scope for income, these initiatives have simultaneously resulted in increased productivity of barren lands, discouraged out-village migration to cities, and introduced modern farming techniques, while also helping in the greening of the environment. Furthermore, it is found that in Gorkha district, trail improvement for livestock grazing, reconstruction of damaged sheds (that was damaged in 2015 earthquake of 7.8 on Richter scale) was supported through USAID- Hariyo Ban Program.

Gap in National Park rules and regulations for rangeland management

The protected area legislations not only ignored the customary laws and institutions but also imposed restrictions on using rangeland resources (Aryal et al., 2016; Acharya & Baral, 2017). Such situations created tensions and conflicts between protected area authorities and local herding communities in the high mountain areas. As a result, some herders are still struggling to survive, while others are engaged in alternative economic livelihood options such as tourism, trekking and hotels, ultimately resulting in the decline of transhumance grazing practices. Such decline in pastoralism is also enhanced by other factors such as globalization, socioeconomic change, youth migration and less motivation among new generations (Montero et al., 2009). However, interestingly, the roles played by the indigenous system of transhumance pastoralists and their various customary laws and institutions in managing the high mountain forests and pasture resources are still in existence even ignoring and neglected the present rules and policies.

Strengths and weaknesses of rangeland policy for rangeland management and livelihood improvement

Natural resource management in the region has been traditionally managed by the locals from generation to generation through locally evolved norms, indigenous practices, and institutions (Achary & Baral, 2017; Ojha et al., 2019). With country entering into the federal structure, government intervention and involvement have increased with the introduction of rules, regulations, acts as well as declaration of the communally managed land in Protected and Conservation Areas (Stevens, 2013; Ojha et al., 2019) ignoring traditional norms and practices. Table 3 shows different rules and regulations to manage the natural resource management including range land management in the last 70 years. Forest

Nationalization Act (1956) and Pasture Land Nationalization Act (2031) (1974 AD) abolished the community and private ownership of the forest and pasture land and brought in government system. Multiple acts, rules and regulations as well as policy have provision on rangeland which resulted in the complexity of the range land management for the pastoral communities. For instance, Acts, regulations such as Forest Act (2049) (1993 AD), Local Self Governance Act (2055) (1999 A.D) and Pastureland Nationalization Act (2031) (1974 AD) added complexity by making several organizational structures with overlapping jurisdictions. These acts and regulations abolished the traditional management and the right of use, which gradually decreased the pastoral management by the local communities. Furthermore, National Park and Conservation Area acts and regulations further restrict grazing in rangeland area within the Park. Additionally, Forest Policy Act (1993) had provision to hand over the forest management to the local communities (Community Forest Management) that ignore user right of the transhumant pastoralists to graze their livestock in the community forest routes and discourage transhumant pastoralists in the mountain areas (Aryal et al., 2016; Gentle & Thwaites, 2016; Acharya & Baral, 2017). In contrast, the National Rangeland Development Policy (2012) has recognized the concerned VDCs as the authority of issuing grazing rights and managing rangelands in their territories.

Nepal has now adopted federal structure with three tiers of government system i.e. Central Government, Provincial Government and Local Government (Municipality). Present constitution (2015) provides the roles and responsibility to the Provincial and Local Government with regard to the natural resource management, livestock development Furthermore, recently implemented Local Self Governance Act (2073) (2016 A.D) expressed the local resources including livestock management, community forest and rangeland management be managed by local government. Similarly, Pasture Land Nationalization Act (1974) also expressed that all pasture land should be under the jurisdiction of Village Development Committee for conservation and utilization. In this context Municipalities have a key role and responsibilities to manage the rangeland development through planning, budgeting and implementing activities.

Assessment of Rangeland Policy (2012) and its Guidelines (2015) do not clearly mention the role of the local government (Municipalities which were formerly VDCs) to manage the rangeland and livelihood improvement to the pastoral communities. It has mentioned that pasture land user committee will formed at the VDC level by the representation of the different pasture user groups. Similarly, policy and guidelines have given emphasis to the District Livestock Office as key implementing unit for technical as well as financial support and committee formation. However, the newly implemented constitution of 2015 and Local Government Act (2016) have not mentioned any role of the district offices, such as District Livestock Development Office and District Development Office. It means policy provision implementing office will not be exist in the district level. In the changing political context of Nepal, the Rangeland Policy and its Guidelines should be reformulated and along with strengthening of the local government (Municipality) to manage the rangeland by forming the management committee, user committee and user groups under the Local Self Governance Act (2073) (2016 A.D). In this context, the Local Self Governance Act (2016) has the mandate to manage rangeland at local level. However, consultation with the Rural Municipalities in the study areas showed that there are no any plans; activities and human resources existed for rangeland management and livestock improvement. In such scenario, implementation of the rangeland policy and program will be ineffective without any responsible institutions in the area.

In 2073 BS (2015 AD), Government of Nepal formulated the Rangeland improvement program implementation guidelines that allow the grazing in the pasture land even in National Parks and Conservation Areas. It has the provision to form user groups at the settlement level; users committee at the Village Development Committee and council at the District level, which already exists in the National Park and Conservation Areas as Buffer Zone Community Forest User Groups (BZCFUGs). Similarly, National park and Conservation Area management activities including pasture land management in the park and BZ areas are the some of the strengths of the rangeland improvement in the Nepalese context.

All National Parks and Conservation Areas are under the jurisdiction of the Central Government. Therefore, rangeland management in these areas has to be implemented by the central government staff and Buffer Zone user groups. However, Rangeland Policy (2012) and its Guidelines (2015) have not mentioned the rangeland management options for the National Parks and Conservation Areas. Similarly, Local Self Governance Act (2073) (2016 A. D) also has the mandate to manage local resources but Buffer Zone area management comes under the activities of the Central Government. Furthermore, these rangeland areas are under the jurisdiction of the Divisional Forest Office of the Provincial Government; and improvement of rangelands is under the jurisdiction of Livestock Development Office. Such complexity in the administrative part of different institutions may result in inefficiency in rangeland management in the region. Thus, conflicts may arise with respect to resource management, program implementation and resource sharing among different institutions and the local government.

Table 3. *Rangeland Policies in Nepal*

S.N.	Year(AD)	Policy and Legal framework	Key features	Remarks
1	Before Act	Traditional law implemented before nationalization of the forest	Local 'Mukhaya', 'Jimbhual', 'Kipat' system managed the rangeland resources	*De facto* practice exists in some parts of the country.
2	1956	Nationalization of the forest	Abolished the 'Kipat', 'Mukhya' and 'Jimindari' system	Land tenure according to Government system
	1974	Pastureland Nationalization Act 1974	Abolished the 'Kipat', 'Mukhya' and 'Jimindari' system	Provision to Village 'Panchayat' for management
3	1973	National Parks and Wildlife Conservation Act	Restriction of the grazing and resource collection in the park. Limited grazing and resource management in Himalayan park and conservation area	Authority to the Park warden to regulate the rangeland inside the park
4	1996 and 1998	Conservation area management and Buffer Zone Management rules and Guidelines	Participatory approach for conservation and development in BZ area and conservation area to minimize conflict between park and people	Conservation Area Management. Committee and BZ community involve in resource management and livelihood improvement
5	1998 and 2016	Local Government Act	VDC and Municipalities have main responsibility to implement local resource management and utilization	No any priority regarding conservation and management in local government
6	1991, 2018	Forest Policy and community forest	Restriction for transhumant pastoral system and forest management to the local user groups	User groups formed for forest management but ignore the traditional grazing right.
7	2010, 2015	Landuse Policy	Categorization of different types of land use for sustainable land management	No any institutions to implement the land use program
8	2012, 2015	Rangeland Policy Rangeland Guidelines	Highlights the importance of rangeland and its management through formation of the legal institutions	Different rules and regulations from different institutions has changed role in newly formed federal system
9	2015	Constitution of Nepal	Local government has mandate	Need to revise Rangeland Policy and its Guidelines

Source: HMG/ Nepal, 1956, 1974; MOFSC/ HMG-Nepal, 1973, 1976, 1998; Constitutions of Nepal 2015, Local Self Governance Act, 2016

Formal Institutional arrangement for rangeland management in present context

Ministry of Forest and Environment is the lead ministry, and Ministry of Agriculture and Livestock is the working ministry responsible for rangeland improvement and livestock development. Department of Livestock Service is responsible for managing rangeland or pastureland. However, these land areas are under the jurisdiction of the Department of the Forest and Soil Conservation and of the Provincial Forest Ministry at present federal structure. Similarly, in the high mountain region more than 80 % of the rangeland areas belong to Protected Areas under the Department of National Park and Wildlife Conservation- a Central Government institution responsible for the conservation and management of these Protected Areas and the rangeland within those areas.

The Rangeland Policy mentions that central level institutions such as Ministry of Agriculture and Livestock; Department of Livestock Development; and National Agriculture Research Council are responsible for development and research on livestock and rangeland land improvement. The policy also states the implementing mechanisms from central to local level. Therefore, there is a provision to form high level coordinating committee chaired by the member of Planning Commission, Government of Nepal with representations from all the relevant government institutions and stakeholders. This committee has the responsibility to coordinate with all the line agencies, and Ministry for the development of rangeland and fund generation. Additionally, there is also a provision of department level management committee chaired by Director General of Livestock Service with representation from the relevant government institutions and stakeholders. The management committee's main responsibility is to prepare working modality and guidelines for managing rangeland all over the country. Similarly, the committee has the mandate to prepare annual plan, budget and human resource management for implementing the Rangeland Policy and programs at district level. However, newly formed federal structure and the Local Government Act (2016) ignore some of the institutions while new institutions have been established. Rangeland Policy (2012) has given high priority to plan, implement and development of rangeland and livelihood improvement of the pastoral communities at the district level. However, district level development offices like Livestock Development Office has no any existence at the present government structure, as it will be merging with the Municipality.

Forest land conservation and management comes under the jurisdiction of the Ministry of Forest, Industry, and Tourism under Provincial Government but rangeland management in the National Park and Conservation area is the mandate of the Department of National Park and Wildlife Conservation under the central government.

The Rangeland Policy and its Guidelines have given more emphasis on implementing sustainable rangeland management through pasture user committee at the municipality or village level; and user groups at the village level by forming executive committee. At present context, all the community-managed land including rangeland management is decided by the related Municipality (Local Government Act, 2016). However, the Rangeland Policy and its Guidelines do not mention the role and responsibilities of the Municipality personnel. According to the Local Government Act (2016), all committee should be registered at the Municipality and district level activities can be done through Municipality. Therefore, in order to manage the rangeland as mentioned in the objectives of the Rangeland Policy (2012), the Municipality should be responsible for preparation of annual plans and activities; budget allocation and technical human resources.

Weaknesses of the Sustainable Rangeland Management in the present context

Overall, Rangeland Policy (2012) and its Guidelines (2015) and Local Government Act (2016) as well as present federal structure and the institutional role and responsibility show that sustainable rangeland management should be implemented as a multidisciplinary approach. It should cover both socio- political and ecological perspectives Dong et al (2016). Study found that traditional rules, norms and practices are continually being lost in the rangeland management. Rangeland management and livelihood improvement of the pastoral communities have not been prioritized in the country. At present, local elected government (Rural Municipality) has the right to manage all resources at local level. However, these institutions are not aware of the importance of rangeland. Nepal has entered into federal structure with three governance systems-central, provincial and local level. The practice to implement the program and activities through these systems are also new and some rules, regulations and policies are still being formulated. This results in conflict in the rules and regulations among the different institutions in terms of power sharing, resource distribution and management. There is a conflict between traditional rights and local elected authority to regulate grazing land management, tax and levy collections as well as resource sharing. Similarly, there are problems of coordination because rangeland is under ministry of Forest and Environment and grazing land improvement and livestock farming is under the Ministry of Agriculture and Livestock development at the central level. Similarly it will happen at the Province level government for rangeland management. Additionally, National Park and Conservation Area rule and regulation hinder to implement the rangeland improvement program such as improved grass cultivation in the pasture land, and limits the traditional right also. Weak coordination among the government institutions and limited capacity of the local elected body have resulted in hindering the rangeland improvement program at present in Nepal.

Conclusion

Study showed that different acts, regulations, policies have ignored the traditional pastoral system. It is found that most of the rangeland and pastoral communities are in the high mountain regions and these areas are mostly under the control of the National Park or Conservation Areas. Park authorities have provided only limited access for resource use and livestock grazing. Similarly, forest law and policy including community forest management activities also discourage transhumant practices in the region. It is suggested that present Rangeland Policy and its Guidelines should be revised and prepared in the line with present Local Government Act to implement the sustainable rangeland management in the region. Rangeland management and pastoral community livelihood support program were implemented in the Buffer Zone and Conservation Area. However, there are still gaps to manage local resources including rangeland management from the Local Government Act, National Park and Conservation Area regulations, and forest policy in coordination, resource sharing, program implementation under the newly implemented federal system in Nepal. It is suggested that the policy and program related to the rangeland management and livestock farming to be institutionalized in the local government systems so that local government should keep in their priorities to implement activities by providing budget and technical human resource regularly for sustainable rangeland management and livelihood of the pastoral communities.

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Disaster Management in India: A Study on Andhra Pradesh

Anil Kumar Kukkakmalla[1*]

[1]Department of Arts, Koneru Lakshmaiah Education Foundation, (KL Deemed to University, Vaddeswaram, Guntur District, A.P. India

*Corresponding author: dranilkumarau@gmail.com

Abstract

Natural disasters are not uncommon phenomena in country like India. The country gets, an average of an annual precipitation of 88 cm on its land mass but there are large differences in the quantity of precipitation from area to area, varying from less than 400 mm annual precipitation to well over 2000 mm in some of the areas. The impact of natural disasters such as floods, droughts, scarcity conditions following the failure of rains, earthquakes, cyclones, etc., is felt in several ways by those who become victims of these unexpected natural phenomena. To meet the challenges of disasters there is a need to develop some 'Universal' and some 'Specific' tools which may effectively tackle the impacts of situations of disaster. Consequently, disaster governance is going to be a vital discipline of study in the next century. According to the State Disaster Management Department of Andhra Pradesh, India, about 44 per cent of the state is vulnerable to tropical storms and related disasters. Vulnerability to storm surges is not uniform along the coast of Andhra Pradesh. The present study based on secondary data, is to analyze impact of cyclones and activities carried out by the Government of Andhra Pradesh in the affected coastal Andhra districts.

Keywords: Natural disaster, Cyclone, Andhra Pradesh, RTGS

Introduction

Since the dawn of civilization, human society, the natural environment, and disasters have been closely interlinked. Both natural disasters and the increasing environmental degradation worldwide are serious threats to development. Natural disasters threaten all three dimensions of development: economic, social and environmental. Disasters injure and kill people; they cause emotional stress and trauma, destroy homes and business, cause economic hardships; and spell financial ruin. In the past twenty years, earthquakes, volcanic eruptions, landslides, floods, tropical storms, droughts and other natural calamities have killed more than three million people, inflicted injury, disease, homelessness, and misery on one billion other, and has caused billions of dollars of material damage. In order to comprehend the magnitude of the potential of disaster, particularly in developing countries, it is first necessary to understand the nature of the disaster and the place where it occurs.

The Indian subcontinent is highly vulnerable to droughts, floods, cyclones and earthquakes, though landslides, avalanches and bush fires too frequently occur in the Himalayan region of northern India. Cyclone is one of the major disasters as the country has a very long coastline of about 5700 km thereby making it vulnerable to tropical cyclone arising in the Bay of Bengal and the Arabian Sea. The Indian Ocean is one of the six major cyclone prone regions of the world. In India, cyclones occur usually between April and May, and also between October and December. The eastern coastline is more prone to cyclones as it is hit by about 80 percent of total cyclones generated in the region (Suma & Balaram, 2014). An analysis of the frequencies of cyclone on the East and West coasts of India during 1891-1900 shows that nearly 262 cyclones occurred (92 severe) during the period in a 50 km wide strip on the East Coast; 33 events of severe cyclonic activity occurred in the same period in the West Coast. Cyclones on the east coast originate in the Bay of Bengal in the Andaman Sea and usually reach the coastline of Tamil Nadu, Andhra Pradesh, Odisha and West Bengal, which are most vulnerable to this type of hazards (Suma & Balaram, 2014). About eighty tropical cyclones occur (with wind speeds equal to or greater than 35 knots) from the world’s waters every year. Of these about 6.5% develop in the Bay of Bengal and the Arabian Sea. Since the frequency of cyclones in the Bay of Bengal is about 5 to 6 times the frequency of those in the Arabian Sea, the Bay of Bengal’s share comes out to be about 5.5%. The Bay of Bengal is one of the major centers of the world for breeding of tropical storms. Cyclones over the Bay of Bengal usually move westward or northward and cross the east coast of India or Bangladesh. When this happens, it brings strong winds and high rainfall to the coastal region, causing damage to property and loss of life (Suma & Balaram, 2014). The cyclone disasters are one of the major challenges the impacts of which is to be effectively addressed and efficiently managed for sustainable development and poverty alleviation particularly in developing countries like India.

Andhra Pradesh is one of the Indian states in the peninsular India battered by every kind of natural disasters such as to cyclones, storm surges, floods and droughts. The state has about 974 km of coastline which runs through nine districts *viz.* Srikakulam, Vizianagaram, Visakhapatnam, East Godavari, West Godavari, Krishna, Guntur, Prakasam, and Nellore (Figure 1).

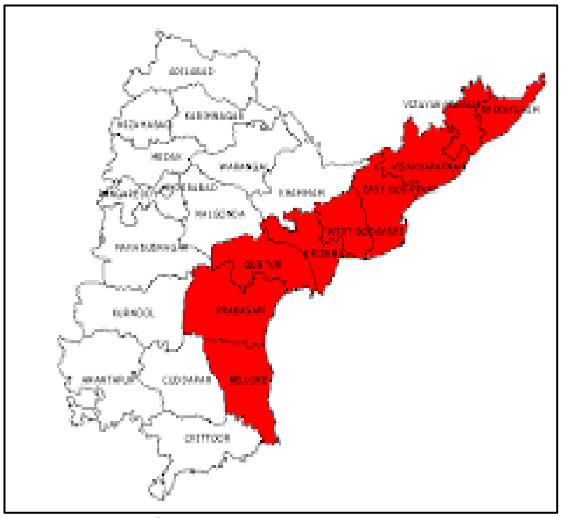

Figure 1 *Map of Andhra Pradesh showing the coastal districts*

The coastal Andhra Pradesh is highly vulnerable to repeated cyclones with varying intensities. (Ramuje & Rao, 2014). A moderate 60 severe intensity cyclone can be expected to make landfall in the state every two to three years. More than 103 cyclones have affected Andhra Pradesh this century (Sahni et al., 2001). About 44% of the state is vulnerable to tropical storms and related hazards. The regular occurrence of natural disasters in coastal Andhra Pradesh in India has had a series of repercussions on the state country's economy, its development policies and political equilibrium and daily life of millions of Indians. For instance, the 1977 cyclone and tidal wave which resulted in great loss of life; and property damage in the Krishna delta region, attracted attention of the central and state Governments of India and the international donor communities, as did those of 1979, 1990 and 1996. The 3 to 4 m storm surges occurred respectively in the 1990 and 1996 killed thousands of people and millions of livestock, besides damaging property in Godavari delta region (Andhra Pradesh Regional Geography, 2019). In this backdrop, this paper is focuses on the major and recent cyclones; the scale of their devastation in Andhra Pradesh and the latter's efforts and actions in tackling the impacts of the aftermath of these natural disasters.

Table 1 shows the major cyclones and the scale of devastation in Andhra Pradesh

Table 1. *Some of the Major Cyclones to hit Andhra Pradesh*

Year	Nature of cyclone	Scale of devastation
November 1977	Severe cyclonic storm considered the most devastation in the past 40 years	Eight coastal districts affected; around 10,000 casualty; loss of around 250,000 cattle heads; 1 million houses damaged; crops on 1.35 million hectares of land damaged. Estimated monetary loss: INRs.172 Crores
May 1979	Cyclonic storm with core of hurricane winds; Heavy rains and floods	748,000 lakh houses damaged Estimated monetary loss: INRs. 242 Crores
October-November 1987 (3 cyclones in total	Severe storm	October storm : No casualty in the first storm November storm: 10 districts affected; 119 casualty; More than 100,000 houses damaged; crop damage in 960,000 hectares Estimated monetary loss: INRs. 126.48 Crores
July 1989	Cyclone followed by heavy rains and floods.	22 districts affected; death toll 232; crops on about 600,000 hectares lost. Estimated monetary loss: INRs. 913.5 Crores
May1990	Severe cyclonic storm with core of hurricane winds	14 districts affected; Death toll 817; 1.4 million houses damaged; crop loss on more than 500,000 hectares Estimated monetary loss: INRs. 2137.27 Crores
August 1990	Heavy rainfall	50 casualty Estimated monetary loss: INRs 179 Crores
November 1996	Severe cyclonic storm with core of hurricane winds	Four districts affected; 1077 casualty; 600,000 houses damaged; crop loss on 500,000 hectares. Estimated monetary loss: INRs. 6, 129.25 Crores
December 1996	Severe cyclone	27 casualty
May 2010	Cyclone Laila -cyclone	14 districts affected; 22 casualty; 14,298 houses damaged; crop loss on 260,000 hectares of land. Estimated monetary loss: INRs. 1,603 Crores
November 2012	Cyclone Nilam- severe cyclone	30 casualty; crop loss on over 700,000 hectares of land. Estimated monetary loss: INRs. 1,710 Crores

The more recent cyclones and associated scale of devastation are described below.

Hudhud Cyclone

The Hudhud was the strongest tropical cyclone in year 2014. Hudhud originated from a low pressure system that formed under the influence of an upper-air cyclonic circulation in the Andaman Sea on 6th October. Hudhud intensified into a cyclonic storm on 8th October and as Severe Cyclonic Storm on

9th October. Hudhud underwent rapid deepening in the following days and was classified as Very Severe Cyclonic Storm by the Indian Metrological Department (IMD). Shortly, before landfall near Visakhapatnam, Andhra Pradesh, on 12th October, 2014, Hudhud reached its peak strength with three minute wind speeds of 175 Km/hour and a minimum central pressure of 960 mbar (millibar Pressure Unit). The system then drifted northwards towards Uttar Pradesh and Nepal, causing widespread rains in both areas and heavy snowfall in the latter. Hudhud caused extensive damage to the city of Visakhapatnam and the neighbouring districts of Vizianagarm and Srikakulam of Andhra Pradesh. The cyclone made landfall in the Port City around noon witnessed the following: Sources of communication towers were also uprooted by strong winds, disrupting telephone and mobile network. Scores of electricity poles were knocked down and thousands of trees were uprooted as strong gales accompanied by heavy rainfall lashed the city. Paddy fields and fruit orchards spread over thousands of acres, and long stretches of roads in the north coastal Andhra and East Godavari district were damaged in the heavy rain and winds brought by Cyclone Hudhud. Almost every household in the four affected districts suffered damage at least to some extent. With heavy destruction of basic infrastructure in the region, industrial production and business transactions were badly hit. And with electricity unlikely to be restored in the state government is yet to estimate the total loss, it is expected to be at least Rs. 10,000 crore. Reports of damage to hundreds of fishing boats have come in from Srikakulam, Vizianagarm, and Visakhapatnam and East Godavari districts. 436 villages across 64 ‘mandals’ in the five districts have been identified as exposed to the threat of cyclone. The government of AP identified 370 relief camps for the evacuated people in these districts. 35,000 people in Srikakulam district; 6000 in Vizainagarm; 15,000 in Visakhapatnam; 50,000 in East Godavari; and 5,000 in the West Godavari districts were evacuated.

Because of Hudhud:

- Over 2 million families were affected
- More than 135 thousand residents were evacuated.
- 4484 villages in 4 districts were hit
- More than 41,000 houses were partially or fully damaged
- Crop areas in more than 237,000 hectares of land were destroyed
- 7300 transformers and 1526 distribution systems were damaged.

Titli Cyclone

The India Meteorological Department (IMD) announced the formation of the two very severe cyclones—Titli and Luban—on two sides of the Indian mainland as ‘rarest of rare’ occurrences in 2018. The IMD also said the movement of both these storms was unique. While Titli changed its direction and moved towards the northeast after making a landfall, Luban too kept going in different directions over the nine days that it travelled through the south-eastern Arabian Sea towards Yemen and Oman on the Gulf coast and then made landfall on October 13.

Andhra Pradesh also faced considerable losses because of the cyclone. Nine people (two in Vizianagaram and seven in Srikakulam) (8 Males and 1 Female) had died in the state till October 15, while one was injured, and one fisherman was missing. The devastation was restricted to the two districts of Srikakulam and Vizianagaram in the state. 18 'Mandals' in Srikakulam were affected. The total affected population was almost 12.5 lakhs spread across 872 villages. Estimated monetary loss was worth more than Rs 400 Crores. In Srikakulam district, people are still facing problems in the affected areas as electricity in more than 57 per cent of the villages is yet to be restored. Crops in 4 lakh hectares of land have been destroyed in Srikakulam district, 97 per cent of which is paddy. Around 2,500 acres were also destroyed in Vizianagaram. Farmers are staring at trying times ahead as the loss due to crop damages is pegged at a massive Rs 800 crore. The horticultural sector has also met with significant losses to the tune of Rs 1,000 crore due to this cyclone. Cashew and coconut plantations, which were considered long-term sources of livelihood for the farmers, have seen the most severe damage in Srikakulam district. Cashew trees in 44,500 acres and coconut trees in 34,600 acres have been destroyed by the cyclone (Down to Earth, 2018).

Some more statistics of devastation caused by Titli are:

- **Infrastructure Damage**
    - Buildings and about 360 Km of road was damaged in Srikakulam district were damaged; 19 Km stretch of road damage In Vizianagaram district.
    - House damaged: Total of 30,061 houses damaged
    - Fully Damaged 'Pucca' House – 3,921
    - Fully Damaged 'Kutcha' Houses – 14,066
    - Severely Damaged 'Pucca' House – 1,942
    - Severely Damaged 'Kutcha' Houses – 2,454
    - Partially Damaged Houses – 7,629
    - Huts – 49
- **Crop Damage**
- Total Agriculture Damage in Srikakulam – 1,39,844 Hectares with approximate estimated cost of INRs. 676.38 Crores
    - Sugarcane – 142 Hectares

  - Paddy – 1,36,531 Hectares
  - Cotton – 2,021 Hectares
  - Maize – 1,150 Hectares
- Total Agricultural Damage in Vizianagaram – 308.1 Hectares with approximate estimated cost of INRs. 4.25 Crores
  - Paddy – 432.5 Hectares
  - Sugarcane – 143.2 Hectares
  - Cotton – 122.6 Hectares
  - Maize – 97 Hectares

Fani Cyclone

Cyclone Fani in May 2019 has been classified as an extremely severe cyclone (ESC) is the 10th such cyclone to hit India in the past 52 years. Data from the India Meteorological Department (IMD) show that the last time an extremely severe cyclone hit India in May was in 2004. The other years when such cyclones were witnessed in May are: 1968, 1976, 1979, 1982, 1997, 1999 and 2001.Generally, extremely severe cyclones hit India's east coast in the post-monsoon season (October-December).

RTGS-AWARE: An early warning alert mechanism

The Government of Andhra Pradesh has taken initiatives to minimize the severity of the cyclone damages. Recently the AP government has taken steps in using of technology to assess cyclone severity and alert the people to minimize the damages through RTGS-AWARE (AP Weather Forecasting and Early Disaster Warning) (RTGS, 2019). RTGS-AWARE uses advanced ensemble modelling for weather forecasting. The AP Government through RTGS has entered into collaboration with Indian Space Research Organization (ISRO) to provide in house meteorological services to Government of Andhra Pradesh such as weather forecasting, nowcasting, agro-advisories, sea-state forecasting, extreme weather events like thunderbolts, lightning, cyclones monitoring etc.

What does RTGS-AWARE do?

- All extreme weather events that may occur in the state are forecast and the advisories and communication are immediately sent by RTGS to respective clientele viz., district, ‘mandals’ and village level administrations, citizens, farmers, fishermen, etc.

- Agro-advisories are sent bi-weekly to all the agricultural functionaries

- RTGS uses the People Hub databases in taking contact details of fishermen and IVRS call alerts are sent advising them not to venture into the sea. Rough Sea Alerts are sent to fisherman 48 -72 hours prior to their occurrence to the to the fisheries department, district administration and individual fishermen.

- For Thunderbolts/Lightning, an advanced weather modelling application is put in use for prediction of lightning and thundershowers wherein the system is be able to detect occurrence of a lightning event 40 minutes prior to the fall. During such events, RTGS through the ‘Parishkara Vedika’ platform blasts IVRS calls to the local citizens, farmers, agricultural labourers, and important village functionaries like Panchayat secretary, VRO, ‘Sarpanch’ of the village, ‘mandal’ where lightning is about to happen alerting them to stay inside safe and secure buildings.

- For cyclones/depressions: Events like Cyclones and Depressions are also forecast and their track monitored by RTGS AWARE and appropriate dissemination, alerts are sent to local administration.

RTGS was largely responsible for successfully alerting the district administrations of Srikakulam and East Godavari during the Cyclones Titli and Phethai respectively

Conclusion

Despite increasing frequency and severity of natural catastrophes, destruction from natural hazards can be minimized by the presence of a well-functioning warring system, combined with preparedness on part of the vulnerable community and the commitment from the government. Warning systems and preparedness measures reduce and modify the scale of impact of disasters. A community that is prepared to face disasters receives and understands warnings of impending hazards and take precautionary and mitigating measures will be able to cope better and can resume normal life sooner. The laudable initiation of the RTGS by Government of Andhra Pradesh was largely responsible for successfully alerting the district administrations of Srikakulam and East Godavari during the Cyclones Titli and Phethai respectively

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ISBN 978-9937-0-7329-5