Proceedings of the International Symposium on Forests-Water-Livelihood Nexus in the Lesser Himalaya

Ge Sun
US Forest Service

L. Adrian Bruijnzeel
King's College London

Jun Zhang
TNO

Krishna Tiwari
Tribhuvan University

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Welcome from Symposium Co-Chairs

Dear Colleagues,

Welcome to the International Symposium on "the Forests-Water-Livelihood Nexus in the Lesser Himalaya", hosted by the Institute of Forestry, Tribhuvan University, Pokhara, Nepal.

The chief objective of the symposium is to provide an opportunity to bring international experts working on forest hydrology and watershed resource management together with forest ecologists and social scientists to share research and exchange experiences and innovative ideas, and to develop a synthesis of the state of knowledge on the forest-water-livelihood nexus in the Lesser Himalaya region. Through enhanced communications among scientists, land managers, and policy makers in the Lesser Himalayan region and beyond, the symposium further aims to identify outstanding knowledge gaps on Community Forestry-Water-Livelihood interactions and define pathways and collaborations towards closing these gaps.

The Himalaya region is known as one of the world's biodiversity and climate change 'hot spots ' where community-based forest management is applied increasingly to help balance a range of ecosystem services including stable water supplies and sustainable harvest of forest products. The region is experiencing tremendous environmental changes and socioeconomic and demographic transformations. Climate change, land use/cover changes, and forest management have been identified as some of the major drivers of changes in forest ecosystems, water resources, and people's livelihood in the region. A sound understanding of the interactions between forest management, hydrologic functioning, and livelihoods is critical for developing Nature-based Solutions to many emerging environmental and resource management challenges in Nepal and throughout the region.

This symposium is made possible by the collective efforts of our organization committee and the organizations they represent. We thank them heartily for their contributions and welcome you all to Nepal. Major financial support was provided by China Natural Science Foundation-UNEP, US National Science Foundation, and Tribhuvan University.

With our best regards,

Prof. Dr. Krishna Raj Tiwari, Co-Chair
Institute of Forestry, Tribhuvan University,
Kirtipur, Nepal

Prof Dr. Lu Hao, Co-chair
Nanjing University of Information Science
and Technology (NUIST), Nanjing, China

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Run Tang, Nanjing University of Information Science and Technology, China
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Devendra Amatya, Southern Research Station, USDA Forest Service, USA
L.A. (Sampurno) Bruijnzeel, King's College London, UK
Jun Zhang, EMSA-TNO, The Netherlands
Chandra Ghimire, SCION, Christchurch, New Zealand
Conghe Song, University of North Carolina (UNC) - Chapel Hill, USA

Accommodations and Contacts

Hotel The Kantipur, Lakeside Rd 22, Pokhara 33700, Nepal, Tel +977 985-6031655

For Emergency Local Contact during symposium:
Mr Rajan Subedi, Institute of Forestry, Pokhara Campus, Tribhuvan University, Nepal.
Mobile: +977-9846084390
Email: rsubedi@iofpc.edu.np
Ms Run Tang, Nanjing University of Information Science and Technology (NUIST), China.
Email: Run_Tang0727@163.com

Oral Presentation Schedule

(September 29, 2023)

<u>8:30-8:50 Welcome session</u>

Moderator Prof. Dr. Krishna Raj Tiwari, Tribhuvan University

Professor Bir Bahadur Khanal Chhetri, Dean of Institute of Forestry, Tribhuvan University

Dr. Linxiu Zhang, Co-Principal Investigator of the National Natural Science Foundation of China-UNEP (NSFC-UNEP) Project , Director of United Nations Environmental Programme – International Ecosystem Management Partnership (UNEP-IEMP)

Dr. Lu Hao, Co-Principal Investigator of the National Natural Science Foundation of China -UNEP (NSFC-UNEP) Project, Professor of Ecohydrology, Nanjing University of Information Science and Technology (NUIST), China

Dr. Conghe Song, Principal Investigator of the U.S. National Science Foundation (NSF) Project, and Professor and Chair of the Department of Geography and Environment, University of North Carolina-Chapel Hill, USA

<u>Introductory presentations</u>

Moderator: Prof Dr. Krishna Raj Tiwari

8:50-9:20 Community forestry and people in Nepal: progress and future. *Prof Ridish Pokharel and Prof Dr. Krishna Raj Tiwari (Institute of Forestry, Tribhuvan University, Nepal)*

9:20-9:50 Nature-based Solutions (NbS) Addressing the ‘Forestry-Water-Livelihoods ’Nexus in Nepal. *Prof Dr. Lu Hao (Nanjing University of Information Science and Technology, Nanjing, China)*

9:50-10:20 Coupled Nature and Human Systems (CHANS): Case studies in Nepal*. Prof. Dr. Conghe Song (University of North Carolina - Chapel Hill, USA)*

<u>10:20-10:40 Tea Break and Group Photo</u>

Keynote presentations

Moderator: Prof Dr. Lu Hao

10:40-11:25 Forest hydrological processes in the Lesser Himalaya and management impacts: What do we know? *Prof. Emeritus Dr. L.A. (Sampurno) Bruijnzeel (King's College London, UK)*

11:25-12:10 Prospects and progress: watershed and springshed management research and education in Nepal through IOF Initiatives. *Assistant Prof Mr. Rajan Subedi and Professor Dr. Krishna Raj Tiwari (Institute of Forestry, Tribhuvan University)*

12:10-13:10 Lunch Break

Moderator: Dr. Conghe Song (UNC Chapel Hill, USA)

13:10-13:30 An overview of the eddy covariance technique to quantify carbon and water exchanges from Pine and Oak ecosystems of the Lesser Himalaya, India. *Dr. Sandipan Mukherjee, Eng. Kireet Kumar (GB Pant National Institute of Himalayan Environment and Sustainable Development, Almora, India)*

13:30-13:50 Comparative understanding of forest hydrological processes in oak and pine forests in Northwest India. *Mr. Denzil Daniel, Prof. Sumit Sen (Indian Institute of Technology, Roorkee, India).*

13:50-14:10 Changes in runoff response to rainfall along forest degradation gradients in the Lesser Himalaya of Northwest India. *Dr. Nuzhat Qazi, former research scientist (National Institute of Hydrology, India) (Online).*

14:10-14:30 Climate change and hydrometeorology in Nepal. *Mr. Ram Prasad Awasthi (Department of Hydrology and Meteorology, Government of Nepal, Kathmandu)*

14:30-14:50 Challenges in hydrological monitoring assessment in Nepal. *Dr. Kapil Gnawali, operational hydrologist (Department of Hydrology and Meteorology, Government of Nepal, Kathmandu)*

14:50-15:10 Migration due to scarce water in use: a nationwide survey for spring/natural pond dryness and its relation to the migration *Mr. Ram Pantha, Ecosystem Based Adaptation (EbA) practitioner, Former Senior Watershed Management Officer (Government of Nepal, Kathmandu)*

15:10-15:30 Tea Break

Moderator: Dr. Devendra Amatya (USDA Forest Service)

15:30-15:50 Climate change impacts on hydrology in the Langtang River Basin, Nepal. *Prof Dr. Dhiraj Pradhananga (Tribhuvan University, Kathmandu, Nepal).*

15:50-16:10 Ecohydrological nexus with vegetation dynamics in a changing climate in Nepal. *Prof Dr. Binod Baniya (Chinese Academy of Sciences, Tribhuvan University, Kathmandu, Nepal)*

16:10-16:30 Climate change and response of forest trees in Nepal Himalaya. *Prof Dr. Achyut Tiwari (Tribhuvan University, Kathmandu, Nepal)*

16:30-16:50 Uncertainty of remotely sensed vegetation growth dynamics in Nepal. *Prof Dr. Decheng Zhou (Nanjing University of Information Science and Technology, Nanjing, China)*

16:50-17:10 Effects of conservation measures on crop diversity and their implications for climate-resilient livelihoods: the case of Rupa Lake Watershed in Nepal. *Dr. Yunli Bai (Chinese Academy of Sciences, Beijing, China)*

17:10-17:30 Cryo-bio-social cycle: Understanding the cycling interactions between ecosystem, water, climate, and livelihoods in the Hindu Kush Himalaya. *Dr. Sunita Chaudhary (International Centre for Integrated Mountain Development (ICIMOD), Pathan, Nepal)*

17:30-17:50 Modeling forest-water interactions at multiple scales in Nepal. *Dr. Ge Sun (U.S. Forest Service, Durham, USA)*

17:50-18:10 Highlights of international forest hydrology research. *Dr. Devendra Amatya (U.S. Forest Service, Cordesville, USA)*

18:30 Group Dinner

Symposium Reflection and Moving Forward

(September 30, 2023)

Moderators: Prof. Dr. Krishna Raj Tiwari and Prof. Dr. Lu Hao

8:30-9:00 Symposium Summary: What have we learned? *Dr. Ge Sun (USDA Forest Service) and Dr. Jun Zhang (EMSA-TNO, The Netherlands)*

9:00-11:45 Open discussion (All Participants)

- Reflection: science advances and challenges
- Looking forward: suggestions for future research from scientists, land managers and policy makers

Questions for consideration:

(1) What are the main hydrological impacts of current community forestry management practices (notably grazing and litter harvesting) in terms of

- net groundwater recharge (and therefore baseflows) and
- surface runoff and erosion - particularly for Sal Forest (as the chestnut and pine zones are largely covered by past work in Nepal and ongoing work in India)?

(2) To what extent are the declining discharges of springs in the Lesser Himalaya the result of poor land management (see 1) or climate change (higher temperatures and potential evapotranspiration, lower winter or pre-monsoon rainfall)? Or both?

(3) What is the water use of regenerating vegetation on abandoned rain-fed agricultural terraces following out-migration of villagers in the Hills to the cities and abroad?

(4) On the socio-economic front:

- What are the amounts of products taken from (different types of) forests and how do these relate to natural rates of wood increment and leaf litter production?

- Is outmigration in the hills and agricultural abandonment reducing the pressure on the forests (e.g., litter harvesting) and if so, to what extent?
- Forest management and mitigating extreme climate change impacts (floods, landslides, drought)

(5) Opportunities for national and international collaborative proposals, funding, and publications

(6) Opportunities for academic exchange and education on forest-water-livelihood issues

11:45-12:00 Closing remarks (*Dr. Linxiu Zhang, UNEP*)

12:00 Lunch and farewell

Abstracts of presentations

(sorted by presentation sequence)

Community Forestry and People in Nepal: Progress and Future

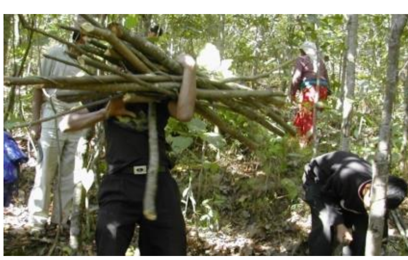
Ridish K. Pokharel and Krishna R. Tiwari

Institute of Forestry, Tribhuvan University, Nepal

Emails: ridishp@gmail.com; krishna.iof@gmail.com

ABSTRACT Nepal is a pioneer country in community forestry in the region. Based on the experience of practicing it, the country has moved forward setting the objectives of community forestry from fulfilling basic forestry needs of communities to contributing to local communities 'well-being. The country officially initiated the community forestry 45 years ago in the name of Panchayat Forests and Panchayat Protected Forests by enacting Panchayat Forest Rules and Panchayat Protected Forest Rules in 1978. Forest protection and management responsibilities, which were initially given to Panchayat, a political administrative unit, have been gradually shifted to community forest user groups (CFUGs), groups of people who use forests for any purposes irrespective of political boundary. The concept of CFUGs had emerged while preparing 25 Year Master Plan for Forestry Sector in 1988 and backed by the Forest Act 1993. The act defines CFUG as an autonomous body with authority to make decisions independently regarding the protection and management of local forest resources. This paper illustrates Nepal's community forestry focusing on policy related to socio-economic development and its status, challenges, and way forward.

Generating income through selling forest products is one of the activities of CFUG. On average, a CFUG is making a total income of NRs290,000 per year (GoN, 2013). Of the generated income, they are required to invest 25 percent in forest development, and 50 percent each in socio-economic development, and welfare of the communities, respectively from the remaining 75 percent. The forest policy also ensures the participation of women and the poor in forest management. The country has converted 39 percent (2.4 million ha) of national forests into community forests and handed over to 22,682 CFUGs involving 3 million households and benefiting about 40 percent of the total population of the country.



Evidence shows that community forestry has contributed to improving forest conditions, increasing availability of forest products and ecosystem services, promoting biodiversity conservation, improving rural livelihoods, and strengthening local democracy. Moreover, it has contributed to improving water quality and water availability to local communities through forest restoration (Pokharel and Suvedi, 2007; Birch et al., 2014; Thapa et al., 2018). Recently, CFUGs has been facing challenges to hold regular executive meetings and carrying out forest development activities due to changes in the environment in which they operate. One major change is labor migration to overseas from villages and towns resulting in the emergence of remittance economy (Paudel et al., 2021). Such an economy has contributed to making rural people less dependent on forests by replacing fuel wood and building materials with natural gas and aluminum, respectively which are easily available in local markets.

There are indications of changing social value of forests. Changes in water use patterns such as commercial vegetable and livestock farming and modern housing with multiple bathrooms have developed people's interests in managing forests for water (Paudel et al., 2018). This paper suggests that accommodating changing preferences is essential to keep interest of local people in forest management. Building capacity of CFUG to perform beyond regular forest protection works focusing on commercialization of value-added forest products and ecosystem services is necessary. Moreover, the policy should focus on promoting management approaches that are sustainable, less conservative, and more market oriented.

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Nature-based Solutions (NbS) Addressing the 'Forestry-Water-Livelihoods 'Nexus in Nepal

Lu Hao[1*], Linxiu Zhang[2], and Krishna R. Tiwari[3]

[1]Collaborative Innovation Center on Forecast and Evaluation of Meteorological Disasters (CIC-FEMD), Nanjing University of Information Science and Technology, Nanjing, China.
[2]International Ecosystem Management Partnership, United Nations Environment Programme, Beijing, China
[3]Institute of Forestry, Tribhuvan University, Pokhara Campus, Pokhara, Nepal
*Email: haolu@nuist.edu.cn

ABSTRACT An international collaborative research project has been funded in 2020 by the United Nations Environment Programme (UNEP) and National Natural Science Foundation of China to address 'Forest-Water-Livelihood 'nexus in Nepal. The overarching goal of this effort is to understand the interactions of forest management, water resource, and human wellbeing under a changing climate. 'Community Forestry 'in Nepal is recognized as an effective way to improve people's livelihood toward sustainable development aligned with the principles of a Nature-based Solutions (NbS) approach. However, scientific data on the effectives of NbS are lacking globally. Implementations of NbS may have unintended and unwanted consequences when the tradeoffs of ecosystem services are not addressed. There is still a large knowledge gap on how land management policies and climate change impact on forests, water, and ecosystems services, and people's livelihood in Nepal.

This study will focus on: (i) how Nepal's climate and vegetation (including native forests and community forests) has changed over the past decades? (ii) has the climate and vegetation significantly changed ecohydrology characteristics during the past three decades in Nepal? and (iii) what is the contribution of vegetation and climate change to hydrological response and its effects on local water availability? The variability, extremes, and trends of precipitation, temperature, and watershed hydrology are examined. A water balance model (WaSSI) will be revised and parameterized at the national scale to model evapotranspiration (ET), streamflow, ecosystem productivity across Nepal. Climate change, land cover change (e.g. forest management) and associated changes in leaf area index (LAI) ('greening up' phenomena) will be investigated using MODIS remote sensing products and historic climate records and future climatic projections. The results from this study will contribute to understanding human-nature interactions that are essential in guiding local forest and watershed management practices in Asians 'Water Tower 'region.

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Coupled Human and Natural Systems in the Community Forestry Landscape:

Case Studies in Nepal

Conghe Song[1*], Erin Sills[2], Rajesh Bista[3], Sophia Graybill[1], Prabin Bhsul[2], Anukram Adhikary[2], Rajan Parajuli[2], Richard Bilsborrow[1], Lawrence E. Band[4], Qi Zhang[1], Ge Sun5, Binod P. Heyojoo[6], Bir B. K. Chhetri[6], and Naya Paudel[7]

[1]Department of Geography, University of North Carolina at Chapel Hill, NC, USA.
[2]Department of Forestry and Environmental Resources, North Carolina State University
[3]WinRock International, Washington DC, USA
[4]Department of Environmental Science, Charlottesville, VA, USA
[5]Southern Research Station, USDA Forest Service, RTP, NC, USA
[6]Institute of Forestry, Trubhuvan University
[7]Forest Action, Kathmandu, Nepal
* Email: csong@email.unc.edu.

ABSTRACT This study explores the dynamics of Coupled Human and Natural Systems (CHANS) in the Community Forestry (CF) landscape in Nepal. CF is a participatory forest management regime that engages local people by devolving a degree of authority and responsibility to achieve the dual goals of forest conservation and livelihood support. It has become a major forest governance strategy in Nepal and many other developing countries. At present, more than one-sixth of the world's forests are under community management, supporting the livelihoods of over 700 million people as well as providing vital ecosystem services. Therefore, the success of CF has major consequences for not only the local communities but also for the world as a whole, such as conservation of biodiversity and carbon sequestration. However, CF are not always successful, and in some cases the socioeconomic outcomes are negative. CF programs do not exist in isolation but shape and are shaped by the dynamics of the CHANS of which they are a vital part. **Fig. 1** provides a conceptual framework for the processes that shape the dynamics of the CHANS.

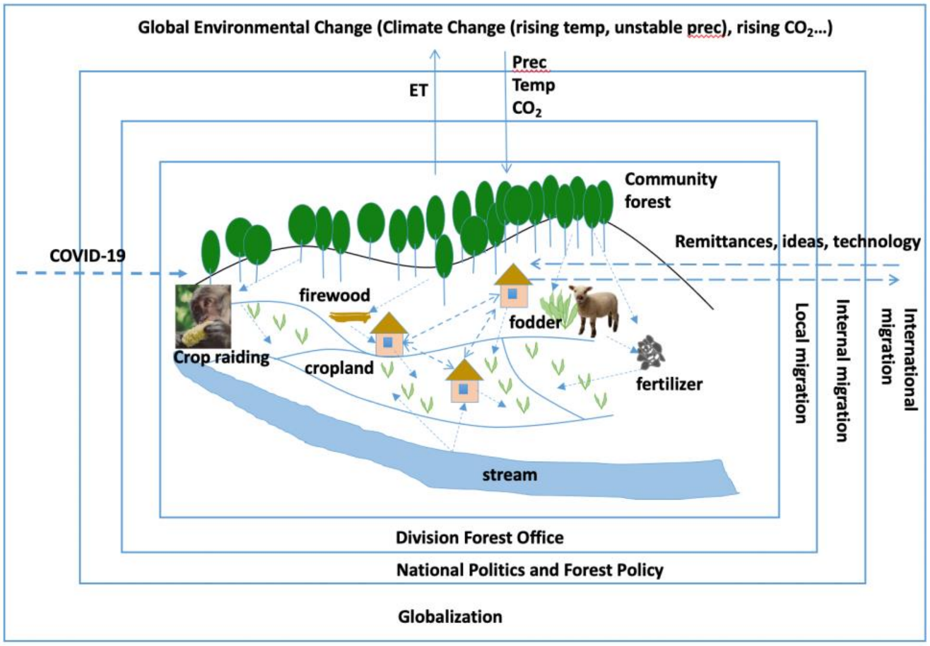

Figure 1. Theoretical conceptualization of mechanisms through which community forests shapes and be shaped by the dynamics of the CHANS in Nepal. ET indicates evapotranspiration, and the dashed arrows to the right indicate out-/return-migration.

Community forestry engages the local people to participate the management and decision-making. With guidance from a local district forest office, Community Forest User Groups (CFUGs) develop rules to govern community forests, including distribution of vital livelihood goods (e.g., timber, fuelwood, fodder etc.) and management measures. These activities could enhance the social capital of the community in some cases, while marginalize the poor and low caste households in the power dynamics of social interactions of forest management and decision-making in other cases. Since the implementation of CF in Nepal in the late 1970s, the world has gone through tremendous transformation, particularly globalization that integrated the developing countries and developed countries into a globalized community, leading to unprecedented population shift in the form of local, internal and international migration. Moreover, improvement in forest conditions as a result of community management have feedback effects on local people's livelihood options, which may be positive (e.g., improved forest conditions allow more fuelwood and fodder to be harvested) or negative. Such dynamics often determine the success of the community forestry program for a given community.

Based on surveys over more than 1,400 households, we found the majority of households suffer from crop raiding, and such negative feedback from is getting stronger. The crops that suffered the most damage are corn, wheat and rice, primarily by monkeys, porcupines, deer and wild boar. About 50% of the cropland parcels experienced crop-raiding, and approximately 30% of the households lost livestock to wild-animals in the study area. Livestock unit, distance to forests, household elevation, and number of neighboring households were identified as the significant factors associated with livestock depredation, while crop-raiding was strongly related to distance from parcels to forest edges, walking distance from home to parcels, elevation, crop type and the number of crop rotation.

Our study found approximately 70% of the households have at least one migrant member. No significant relationship between the number of international migrants in the household and the level of participation in forest management and decision making. The majority of the households do not participate in community forest management and decision-making, only ~20% and ~30% of the households were actively participating in forest management and decision making, respectively. The household size and the number of internal migrants, together with multiple resource characteristics and institutional attributes, were major factors affecting users 'participation in CF decision-making and forest management.

The association of water resource availability and community forestry is complex because there are multiple factors influence the water resources, including both natural (e.g., climate change) and anthropogenic (irrigation facilities). Only a small fraction of the households surveyed had some ideas why their water resource availability is change with time. More research is needed to better understand how the water resource availability is changing with time and its driving factors.

We found that the impacts of COVID-19 were severe on the households with larger family size, those belonging to the marginalized caste groups, having lower number of livestock, low wellbeing index, those who rely on daily wage-based occupation, with low level of education, and the households with return migrants. A significant number of migrants were found to return to their village of origin. As a result, there was a decrease in abandoned land and an increase in the livestock number and forest product use.

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Forest Hydrological Processes in the Lesser Himalaya and Management Impacts: What Do We Really Know?

L. A. (Sampurno) Bruijnzeel

Visiting Professor, Department of Geography, King's College London, London WC2B 4BG, UK
E-mail: sampurno.bruijnzeel@kcl.ac.uk

ABSTRACT Arguably, the need for quantitative information on the hydrological functioning of different Himalayan forest types for water resources management is greater than ever: the climate is warming, seasonal precipitation patterns and intensities are shifting, and demands water by growing urban populations and lowland agriculture are increasing. Moreover, ongoing changes in land use and land cover can have significant hydrological effects. Examples include abandonment of rain-fed agriculture after outmigration from the 'hills', with crops being replaced by regenerating vegetation; increased fire incidence and other disturbances of the oak forests in the drier Western Himalaya causing increased encroachment by *chir* pine; as well as intensified use of forests around urban centres. Several of the above changes in climate and land cover (along with road building and pine reforestation) are often mentioned as possible factors contributing to the widely observed decline in spring discharges on which so much of the rural population depends for their domestic needs. To disentangle the effects of concurrent changes in climate and land cover/use requires application of appropriately parameterized hydrological models – preferably process-based. For this, quantitative knowledge is required, in turn, of such key hydrological processes as evapotranspiration (ET) and its components (rainfall interception, E_i; transpiration, E_t; and to a lesser extent soil evaporation, E_s), the partitioning of precipitation at the surface into infiltration and runoff (overland flow, OF), and the main pathways along which infiltrated water moves on its way to the groundwater table and the nearest stream / springhead. Different forest types tend to have different ET and will thus produce different amounts of water (for the same rainfall), whereas ET and especially rainfall partitioning at the surface, are influenced by forest management and use intensity as well.

This presentation seeks to give an overview of the current state of field-based knowledge of the above key processes for the chief forest types of the Lesser Himalaya, and of the impacts that such widely practiced activities as lopping trees for firewood and fodder, tree felling for timber, grazing by roaming cattle, and harvesting of leaf litter for animal bedding or composting have on forest hydrological functioning. Here, the Lesser Himalaya is taken to include the Terai lowlands and adjacent Siwalik Foothills (*Chure* in Nepal) in the South, the Middle Mountains and adjacent Middle Hills in the centre, as well as the lower slopes of the High Mountains up to ~2,500 m further North (*Figure 1*). The chief forest types considered here include the *Sal* (*Shorea robusta*) forests of the Terai, Siwaliks and Middle Hills (below 1,000–1,200 m), the *Schima-Castanopsis* and *Pinus roxburghii* forests found mostly between ~1,000 and ~2,000 m, and the evergreen oak forests between ~2,000 and ~2,500 m elevation. Ecohydrological information for the temperate and sub-alpine mixed deciduous, *Rhododendron* and coniferous forests at higher elevations is still too scant to justify separate discussion.

Figure 2 shows the prime locations of ecohydrological process research along the Himalayan range to lie in the Indian NW Himalaya and Central Nepal, and to a lesser extent in Sikkim and Meghalaya in the East. *Table 1* provides a tentative summary of the ecohydrological knowledge status for the respective sub-regions[1] which may serve as a basis for discussions as to where additional field-based measurements might be targeted best to support / ground-truth remotely sensed data.

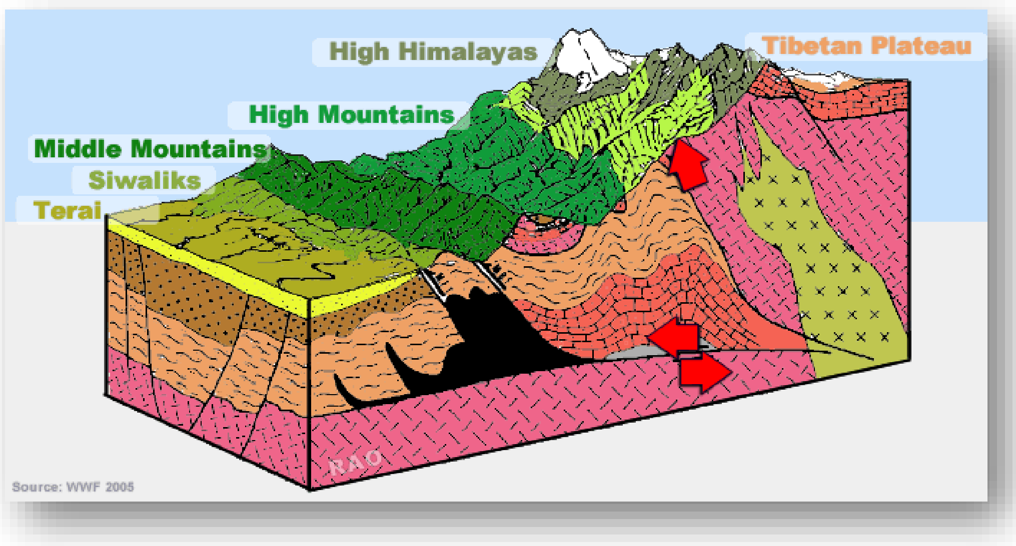

Figure 1. Main physiographic units of the Lesser Himalaya as used in this presentation.

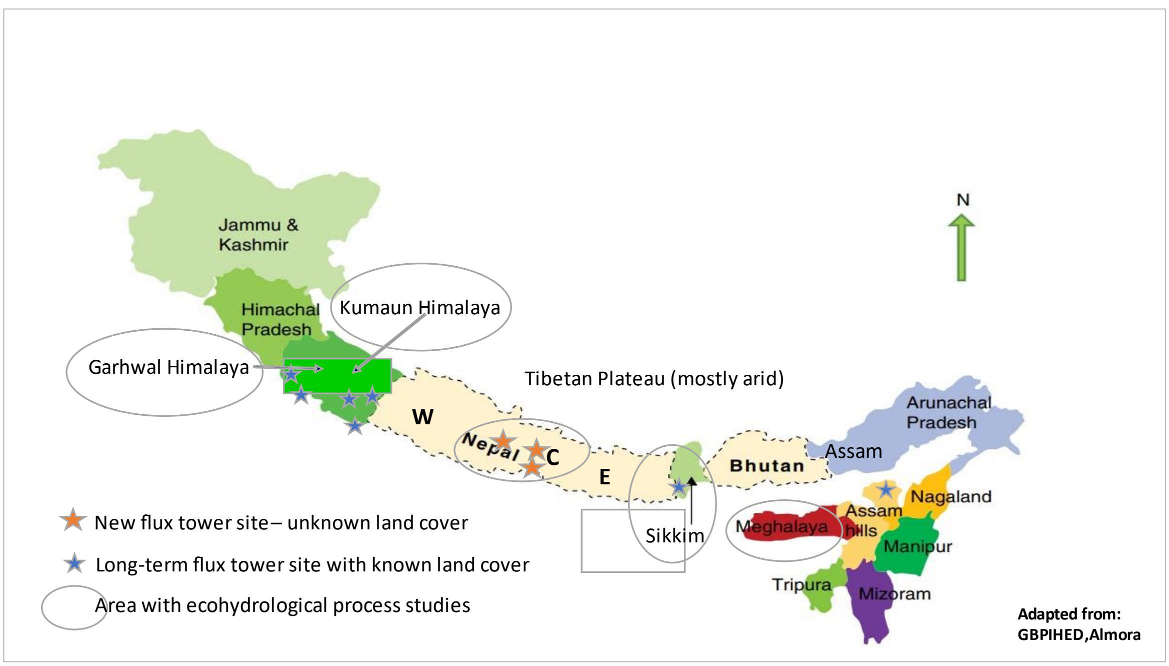

Figure 2. Forest hydrological research 'hot spots' in the Lesser Himalaya

Table 1: Preliminary summary of ecohydrological process knowledge for the respective Himalayan sub-regions distinguished in Figures 1 and 2.

MMZ: Ecohydrological *terra incognita*?

Process or variable	Knowledge status	Where?
Rainfall interception	Fair	HP, Kumaun, Siwaliks, **C Nepal**, Sikkim
Transpiration	Poor to fair (flux tower sites)	Terai, Siwaliks, **Kumaun**, **C Nepal (sap)**, Sikkim (short-term sap), Assam
Infiltration	Fair	Siwaliks, **Garhwal**, Kumaun, **C Nepal**, Meghalaya
Surface runoff generation	Fair to good	Siwaliks, **Garhwal**, **Kumaun**, **C Nepal**
Soil water dynamics	Poor (on-site)	Garhwal, Kumaun, **C Nepal**
Subsurface stormflow	Poor	Inferred (Garhwal, Kumaun, C Nepal)
Soil variable	**Knowledge status**	**Where?**
Unsaturated zone thickness, roots	Poor to very poor	**Garhwal**, **Kumaun**, Sikkim?
Hydraulic conductivity profiles	Poor	Siwaliks, Garhwal, Kumaun, **C Nepal**
Moisture retention	Fair	Siwaliks, **Garhwal**, Nepal
Hydrogeology irt springs	Fair to good	**Garhwal**, **Kumaun**, **Sikkim**, **Nepal**

Information on evaporative losses from the <u>*Sal* forests of the lowlands and Siwaliks</u> consists mostly of rainfall interception studies in NW India, several of which may have overestimated E_i because of non-random sampling of crown drip[1]. Likewise, corresponding estimates of forest floor evaporation (E_s) may well be exaggerated as samples were exposed to full sun and rain in forest clearings[1]. Annual ET based on eddy covariance measurements above *Sal* near Dehradun was reported as ~695 mm out of 1,115 mm of rainfall; this may represent an underestimate as an open-path sensor was used and gaps in the wet season record were numerous and the degree of energy budget closure low (73%)[2]. User pressure on *Sal* forest is high (including grazing) and surface runoff and erosion rates can be massive, particularly in the Siwaliks with their poorly consolidated rocks and shallow soils[3,4]. Reported OF in *Sal* forests in the Middle Mountains ranges from negligible in undisturbed forest to substantial in grazed forests[1]. *Studies of catchment-scale ET and water yield from hill Sal forest seem to be lacking entirely*[1].

The subtropical to warm-temperate <u>*Schima-Castanopsis* and *Chir* pine belt</u> is arguably the best studied Himalayan forest zone, with information on E_i, OF, infiltration, and to a lesser extent transpiration and ET available for several sites in East Central Nepal and the Indian NW[1,5-7]. That said, reported estimates of annual ET for <u>planted and natural pine forests</u> vary greatly (575–1,150 mm yr^{-1})[1,5,7], with lower estimates based on a summation of E_i, E_s and sapflow-derived transpiration[7] or the eddy covariance technique[5]. High annual ET totals were obtained using the catchment water budget (deep leakage losses?)[1] and for a young, vigorous plantation using a micro-meteorological approach (advected heat?)[8]. Further comparative site analysis for differences in radiation loads (aspect), elevation (temperature), rainfall distribution and growth stage is desirable. Corresponding information for the <u>evergreen broad-leaved *Schima-Castanopsis*</u>

forest is limited to a single site in East Central Nepal[7] and short-term observations of E_t in supra-wet Sikkim[1,9]. *Dedicated catchment-scale work for this type of forest seems to be lacking*[1]. Again, OF in *Chir* and *Schima* forests varies with degree of soil disturbance (litter harvesting, grazing)[1,7,10], but hillslope runoff response is also increased in the case of shallow soils[6].

The hydrology of the mixed evergreen oak forests of the lower temperate zone is comparatively well-studied in the drier Garhwal and Kumaun Himalayas of NW India[1,6,11] but comparable work in the wetter eastern Himalaya appears to be lacking. Rainfall interception losses are lower than for *Schima forest* and OF production minimal, unless the soil is disturbed or so shallow that it saturates completely during prolonged monsoonal rains and starts to generate 'saturation-excess overland flow[6,11]. *Chir* pine tends to invade oak forests after fire or opening up and a number of small-catchment studies have compared flows from pine-covered areas (usually south-facing) with oak forests (northerly aspects) suffering various degrees of structural degradation including shrub-dominated land[1,6,11]. Differences in catchment leakage and rainfall between sites preclude derivation of meaningful annual ET or water yield (560–1,345 mm yr^{-1} for dense oak forest; 640–1,060 mm yr^{-1} for open oak/shrub) or baseflows[1], but stormflows from non-grazed oak forest or shrub land are low, regardless of canopy density, even under high rainfall as long as soils are not degraded and sufficiently deep[1,11]. Again, much more pronounced runoff responses occur in the case of shallow soils that become saturated during the monsoon[6,11]. Oak forests become 'mossier' with elevation due to exposure to fog and low cloud. Although the combination of 'occult' inputs of fog water and reduced ET is expected to produce a zone with seasonally enhanced water yield between 2,500 and 3,000 m, no dedicated studies have been conducted anywhere along the mountain chain[1].

In brief, stepped up field research to better document the water budgets and catchment water yields for hill *Sal* forest, mossy oak forests, and regenerating vegetation on abandoned rain-fed fields would be desirable. There is also a dearth of information on hydrologically active soil depths associated with different rock types (governing water storage capacity and runoff response to rainfall)[6,11] and changes in soil hydraulic conductivity (governing partitioning of infiltrated water between vertical and lateral percolation)[4,6,7,11] to improve hydrological modelling.

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Prospects and Progress: Watershed and Springshed Management Research and Education in Nepal through Institute of Forestry Initiatives

Rajan Subedi* and Krishna Raj Tiwari
Institute of Forestry, Tribhuvan University, Pokhara, Nepal
* Email: rsubedi@iofpc.edu.np

ABSTRACT This paper offers an insight into the evolving landscape of watershed and springshed management research and education in Nepal, driven by the dedicated initiatives of the Institute of Forestry, Tribhuvan University (IOF-TU). More than five decades of experience, IOF-TU stands as a pioneering academic institution committed to the higher education in natural resource management and research. A major focus is to train human resources in the area of integrated watershed and landscape management, aimed at addressing the multifaceted challenges posed by various hazards in Nepal's diverse and fragile terrain. This approach has played a pivotal role in promoting sustainable practices and bolstering community resilience across the country. IOF-TU has made substantial contributions to academia through a range of educational programs spanning undergraduate to postgraduate levels, all centered around forest management, wildlife and biodiversity conservation and watershed management, emphasizing practical, field-based learning and research.

Nepal's watersheds provide numerous ecosystem services to society (Paudyal et al., 2018), but they face mounting pressures from factors such as rural-to-urban migration, haphazard development practices and climate change (Anees et al., 2022). To achieve sustainable development requires integrating watershed principles into land use and development planning and balancing the interplay of water, energy, food, and ecosystems (Upreti, 2023). Analyzing synergy and tradeoff among nexus comments accounting the role ecosystem management is crucial for the sustainability. IOF-TU has conducted various studies highlighting the importance of experimental catchments to generate scientific data and demonstrate the consequences of ongoing processes on landscape ecosystems. Furthermore, a critical issue in Nepal's mountain regions is the drying spring sources due to climate change, earthquakes, unplanned land use, and road construction (Adhikari et al., 2020; Chettri et al., 2020; Poudel & Duex, 2017) . IOF-TU has involved to conduct research as a case study to address this challenge by mapping spring water sources, conducting sensitivity analyses for conservation prioritization, stable isotope analysis, and local hydrogeological mapping for recharge area identification. It is recognized that conventional watershed management practices may not sufficient for spring revival, as recharge often occurs beyond topographical watershed boundaries (Matheswaran et al., 2019; Shrestha et al., 2018). Additionally, while nature-based solutions involving forests have been used for springshed and watershed management. There is a limited, ecohydrological knowledge and technology, accounting for individual trees and various forest management and land use practices, remains a challenge (Badu et al., 2019; van Meerveld et al., 2021). IOF-TU emphasizes the need for integrated studies to promote sustainable landscape planning and development in Nepal. Due to significant heterogeneity in ecosystems and usage patterns, information

generated from global, regional, and basin-scale models may not fully capture the scenario, necessitating case-based, plot-level, or micro-catchment-level studies to comprehend ecohydrological processes and their implications under diverse biophysical and socio-economic settings.

To facilitate practical interventions and long-term monitoring, IOF-TU is establishing research and demonstration sites focused on springsheds and watersheds management. These sites encompass studies and experiments at plot, springshed, and catchment levels across various ecosystem management scenarios, offering valuable insights for integrated watershed management in Nepal. Simultaneously, these efforts enhance field-based teaching and learning opportunities at IOF-TU. The institution is actively initiating springshed management research and demonstrations, including the establishment of a climate-forest-water-livelihood learning catchment in Pokhara, while also welcoming opportunities for research collaboration and collaborative project development to address ecosystem management and usage questions in light of significant migration, unplanned urbanization, and rising climate-related risks.

This paper presented the watershed and springshed management research insights derived from authors research activities in Pokhara Valley, focusing on water spring source assessment and land use land cover transition analysis, and their consequential impacts on ecosystem services within the Phewa Watershed. The spring study meticulously investigated 765 perennial spring sources within the Ramsar site of Pokhara Valley. It prioritized these springs using a conservation sensitivity analysis based on factors like land use, topography, and usage demands. Additionally, stable isotope and hydrogeological mapping were employed to delineate potential recharge areas for the identified critical springs. Concurrently, for the watershed study, the study utilized the InVEST model to simulate various ecosystem services under different land use land cover change scenarios. This modeling approach facilitated the interpretation of sediment flow observations and water quality analysis within the lake. Notably, the study observed an increase in forest cover in the upper regions of the lake watershed, while built-up areas expanded in the lower parts, predominantly at the expense of agricultural land. This expansion of forest cover led to an augmentation in the catchment area's sedimentation retention capacity and carbon stock, albeit with the challenge of increased nutrient loading particularly phosphorous due to poor management of sewage from urbanized areas.

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An Overview of the Eddy Covariance Technique to Quantify Carbon and Water Exchanges from Pine and Oak Ecosystems of the Lesser Himalaya, India

Priyanka Lohani[1], Leena Khadke[2], Puja Mehta[3], Sandipan Mukherjee[4], KC Sekar[3], Pramit Kumar Deb Burman[5,6], Subimal Ghosh[2], Kireet Kumar[1]

[1]Centre for Land and Water Resource Management, GB Pant National Institute of Himalayan Environment, Kosi-Katarmal, Almora, 263643, India

[2]Department of Civil Engineering, Indian Institute of Technology (IIT), Bombay, Maharashtra, India

[3]Garhwal Regional Centre, GB Pant National Institute of Himalayan Environment, Srinagar, 263643, India

[4]Ladakh Regional Centre, GB Pant National Institute of Himalayan Environment, Leh, 194101, India

[5]Centre for Climate Change Research, Indian Institute of Tropical Meteorology (IITM), Pune, 411008, India

[6]Department of Atmospheric and Space Sciences, Savitribai Phule Pune University, Pune, 411007, India

ABSTRACT The Pine (*Pinus* Spp.) and Oak (*Quercus* Spp.) systems in the central Himalaya are known to provide substantial ecosystem services to the people of hill and nearby plains. However, sub-daily to annual scale interactions of Pine and Oak ecosystems with microclimatic and environmental parameters remain not investigated in detail. Since the quantification of ecosystem responses to micro-climatic fluctuations is expected to be beneficial for sustainable management of plant biodiversity, a detailed ecosystem-level assessment of plant, water, and microclimatic interactions are carried out. The eddy covariance observations of carbon and water fluxes were made over the Kosi (Pine-dominated) and Hat-Kalika (Oak-dominated) watershed areas in Uttarakhand, India. In terms of the ecosystem carbon exchange, both Pine (*P. roxburghii*) and Oak (*Q. leucotrichophora*) dominated ecosystems were found to be a sink of carbon (600-1000 gC m^{-2} for Pine and 500-800 gC m^{-2} for Oak). Higher carbon sequestration in the Pine-dominated vegetation resulted from lesser ecosystem respiration in monsoon. Moreover, a comparative assessment of ecosystem carbon and water exchanges between the Pine site at Kosi and a mixed broadleaf deciduous forest at the Kaziranga National Park in the Himalayan foothills in Assam, India indicated the Pine site to have significantly higher annual carbon sequestration rate than the Kaziranga National Park (approx. 29 gC m^{-2}). Similarly, the potential evapotranspiration varied between 150-420 $Wm^{-2}$and 100-250 Wm^{-2}over the braodleaf and Pine sites, respectively. We have also identified the rainfall amount thresholds for Pine and Oak-dominated ecosystems (10±0.7 and 17±1.2 mm, respectively) that resulted in the highest ecosystem carbon assimilation in monsoon. The diurnal patterns of sap flux density of *P. roxburghii, Q. leucotrichophora,* and *Q. glauca* trees are calculated along with an emphasis on their seasonal patterns. The initial results indicated *P. roxburghii* had almost 1.5-2.0 times the sap flux densities than the other two *Quercus* species indicating higher water extraction by the *P. roxburghii* stands. We used the information network theory to identify the micrometeorological controls affecting the ecosystem carbon assimilation and found the *P. roxburghii* dominated ecosystem is heat dominating whereas the *Q.*

leucotrichophora dominated ecosystem is moisture dominating at sub-daily scale. The overall inference of this study indicates that the *P. roxburghii* dominated ecosystems are better sink of carbon at the cost of higher loss of surface and ground water, consequently, *Q. leucotrichophora* dominated ecosystems are better for soil and water conservation as envisaged by the traditional knowledge.

Comparative hydrological processes in Oak and Pine forests in NW India

Denzil Daniel[1] and Sumit Sen[2]

[1]Research Scholar, Department of Hydrology, Indian Institute of Technology Roorkee, India
[2]Associate Professor of Hydrology and Head of the Centre of Excellence in Disaster Mitigation & Management, Indian Institute of Technology Roorkee, India
Emails: denzil_d@hy.iitr.ac.in; sumit.sen@hy.iitr.ac.in

ABSTRACT The background to the research presented here is the traditional perception in the Western Himalayas that Oak forests provide the most effective water conservation. Pine forests are likewise perceived as colonizers, replacing Oak forests in large areas while consuming excessive water and affecting downstream ecosystems. We conducted plot-scale experiments representative of two small (<100 hectares) forest watersheds, pine-dominated and oak-dominated, respectively, to understand the controls on runoff generation in these forests. The field-saturated hydraulic conductivity measured using a mini-disk infiltrometer showed significant surface infiltration differences between the forest floors (8 mm/hour for Pine Forest and 2 mm/hour for Oak Forest). However, this significant difference is reasonable considering that the soil samples in the Pine Forest were characterized as sandy loam with negligible clay fraction. In contrast, the Oak soils were silty loam with a large silt fraction.

The hydraulic properties of the soils further reveal that the Pine soils have a larger drainable pore space of 93mm compared to 56mm for the Oak soils in the top 30 cm of soil. The Pine soils were shallow, with a relatively impermeable stratum of mica schist at a depth of 30cm. In contrast, the Oak soils were deep, with no perceptible barrier up to 70cm. Over 30 rainfall events were identified during 2022 to characterize soil moisture response and runoff generation under Pine and Oak forests, respectively. The maximum 30-min rainfall spell across storms was, on average, slightly higher over the Oak forests than the Pine forests (19.5 mm/hour and 16.6 mm/hour, respectively). A few storms (six Pine, four Oak) generated noticeable runoff with a maximum rainfall-runoff conversion of 20% from the Pine runoff plot (event c58) and 35% from the Oak runoff plot (event o34). The saturated hydraulic conductivity on the Pine Forest floor is very high (57mm/hr), which precludes any possibility of infiltration excess overland flow (IOF) as the average over maximum intensity 30-min duration rainfall spell across runoff events was 31.9 ± 16.7 mm/hour in the Pine Forest.

Further, the observations of soil moisture response during rainfall events under Pine forests indicate lateral flows and preferential flow pathways. In contrast, the Oak forests' soil moisture response evidenced saturation excess overland flow (SOF) and threshold behaviour. Previous research in the Western Himalayas has looked at a comparison between a grassed hillslope and an agro-forested hillslope (Nanda et al. 2019), and in their plot scale runoff experiments have observed that IOF was the dominant runoff

mechanism on both hillslopes (Nanda et al. 2018). In another study at the watershed scale, Qazi et al. (2017) discuss possible runoff generation mechanisms from a dense forested (Oak dominated) and a degraded forested watershed, suggesting only lateral subsurface stormflow from the dense forest and IOF as an important mechanism from the degraded forest watershed. The emerging observations from the current study can better constrain regional hydrological models in the Western Himalayas, where additional information on the distribution of Pine- and Oak-dominated watersheds is available, thus guiding policy directives on the plantation or selective loping of Pine and Oak trees of the Himalayas.

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Changes in Runoff Response to Rainfall along Forest Degradation Gradients in the Lesser Himalaya of NW India

Nuzhat Qazi[1*] and L. Adrian Bruijnzeel[2]

[1]Research Hydrologist, Formerly with National Institute of Hydrology, Roorkee, Uttarakhand, India
[2]Visiting Professor, Department of Geography, King's College London, London WC2B 4BG, UK
E-mail for correspondence: qazinuzhat82@gmail.com

ABSTRACT The status of forest cover plays an important role in the partitioning of rainfall at the soil surface into infiltration and surface runoff (overland flow, OF), and thus in the generation of storm runoff at the catchment scale. In undisturbed forests with a well-developed understory and litter layer on sufficiently deep soils, all rainfall will infiltrate and percolate vertically until it is deflected laterally upon meeting a dense layer or bedrock. Under such conditions, stormflow (*i.e.*, the increased streamflow during and shortly after rain) is typically dominated by rapid subsurface flow (SSF) from the hillslopes. However, where soils are shallow (*i.e*., have limited water-storing capacity) and rainfall inputs highly seasonal, 'saturation-excess overland flow' (SOF) after full saturation of the soil profile can become an important hillside runoff generating mechanism as well. Further, following forest soil disturbance (*e.g*. by litter harvesting, cattle grazing), soil infiltration capacity (I_c) tends to be reduced and 'infiltration-excess overland flow' (IOF) occurrence increased. Little is known about the relative importance of SSF and SOF in undisturbed Himalayan forests, although high values of IOF have been reported for intensively used Himalayan forests[1,2]. OF-dominated stormflows tend to have higher peak discharges than SSF-dominated stormflows.

Here, we present comparative data on the runoff responses of two neighbouring catchments near Mussoorie (MAP ~2,000 mm) in the Garhwal Himalaya of NW India: Arnigad (286 ha, dense evergreen oak forest) and Bansigad (190 ha, largely degraded oak forest; 28% 'barren' land). This is followed by a comparison of OF occurrence at the micro-plot scale (1 m^2) in relation to rainfall and soil moisture status under variously degraded oak forests in the drier Jijli catchment (MAP ~1,200 mm), located some 30 km further North. Rainfall in all three catchments was highly seasonal, with up to 78% (Jijli) and 80–92% (Mussoorie) of the annual total delivered during the monsoon season (June–September). Streamflow at Arnigad was perennial with a mean annual runoff coefficient (RC) of 54% (range over 3 years: 44–61%) against 62% at Bansigad (range: 53–69%). Despite the higher streamflow total at degraded Bansigad (by ~250 mm $year^{-1}$), the stream ceased to flow early in the pre-monsoon season (March). Stormflows at Arnigad made up only 8–11% of total streamflow and occurred mostly during the monsoon (78–98%), whereas stormflows at Bansigad constituted nearly half of all flow (49%) and occurred also in the post-monsoon season. As a result, baseflows at Arnigad were far more stable (90% of total flow) than at Bansigad (51%)[3]. Seasonal patterns of soil moisture (measured bi-weekly) mirrored the contrasts in baseflow between the catchments[4]. Continuous soil moisture measurement at Arnigad showed that the permeable sandy loam soils never reached full saturation; hence, hillside SOF was absent, and stormflow effectively represented SSF[5]. Continuous soil water observations were not available for Bansigad but the

nearly five-fold stormflow totals and much higher stream sediment loads[6] suggested major OF contributions, likely from the most degraded part of the catchment (the 28% of barren land). Indeed, application of the concept of minimum contributing area (MCA) – where the MCA equals the fractional area within a catchment that would return all rainfall it received again as stormflow – supports this contention: average MCA-values associated with stormflows during the monsoon seasons at Bansigad varied from 23–30%[3]. It is less clear, however, whether the surface runoff generated on this degraded land consists of IOF or SOF. I_c measured by double-ring infiltrometer during the dry season beneath shrub and degraded forest exceeded recorded rainfall intensities[3], suggesting SOF rather than IOF to be dominant. On the other hand, IOF cannot be ruled out entirely because actual rates of infiltration during the wet season (as derived from subtracting surface runoff from rainfall at the plot scale) elsewhere in the Himalaya have been shown to be lower than infiltrometer-based I_c by a factor of two to four[7]. Further work at the plot scale is necessary to confirm the dominant process of storm runoff generation at Bansigad. However, the stark contrast in hydrological response with the adjacent forested catchment underscores the importance of avoiding excessive loss of topsoil and organic matter if soil moisture retention, groundwater recharge, and dry-season flows are to be maintained under the prevailing seasonal conditions and steep topography[3].

The effect of forest degradation on the generation of OF was examined in further detail in the Jijli catchment through measurements of rainfall, OF on small runoff plots (1–3 m^2), I_c, and changes in soil hydraulic conductivity (K_{sat}) and soil moisture with depth at seven experimental sites representing different levels of forest cover (dense, open and shrub following manual logging and burning)[8]. Large rainfall events (50–110 mm) made up ~10% of all events, with maximum daily totals reaching ~170 mm at several sites. Sand (>23%) and stone/gravel contents (>21%) of the mostly shallow (~50 cm) soils were high and clay content low (<5%), with the most degraded sites not only showing the highest stone/gravel fractions (44–68%) but also numerous mega-pores (>2 cm diameter) associated with rodent- and snake infestation. As a result, values of surface I_c at all sites were very high (210–1055 mm h^{-1}) and well in excess of rainfall intensities. Likewise, values of K_{sat} down to 50 cm depth were generally high (mostly >145 mm h^{-1}), except where silt content was high (Sites 1 and 3) or horizontally orientated stones and/or buried boulders interfered with the flow (Sites 4 and 5). Accordingly, percolation of infiltrated rain would be expected to be mostly vertical down to ~50 cm depth and runoff to consist primarily of shallow lateral SSF between 35 and 50 cm depth. However, although soil moisture levels were indeed higher around 35 cm depth, OF was observed frequently during the monsoon on the 1-m^2 runoff plots at all study sites. Examination of soil moisture levels (measured every 4 h) showed that prolonged continuous rains were able to fully saturate the soil profile and thus generate SOF. However, whilst discontinuous rainfall events also increased soil moisture, these did not always seem to exceed the saturation threshold, although OF was observed. Further threshold analysis considering the *sum* of antecedent soil water content (ASW_{50}) and rainfall input for these storm events[9] will have to establish whether the associated OF is of the infiltration-excess type or not.

The work at Jijli thus confirms that rain falling on steep slopes underlain by permeable but shallow soils can indeed produce SOF during the monsoon[8]; in contrast, runoff generation on slopes with deeper soils – such as those at nearby Arnigad – is dominated by SSF[5].

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Hydrometeorology and Climate Change in Nepal

Ram Prasad Awasthi

Department of Hydrology and Meteorology, Ministry of Energy, Water Resources and Irrigation, Government of Nepal

Email: awasthiramprasad@gmail.com

ABSTRACT Nepal started hydrological and meteorological observation, monitoring and related public services before the 1965 and thereby managing in organized way by 1988 through Department of Hydrology and Meteorology (DHM). In early stages DHM operating manual stations for rainfall, climate, synoptic and hydrological observations in different parts of the country but the density is very sparsely distributed due to the physiographical complexity and difficulties in accessibility. As the rapid advancement in science and technology and gradual sectorial development, numbers of Hydro-meteorological observation network have been enhanced in last decades. The demands for hydrometeorological service have been increasing day by day in Nepal and DHM endeavors to strengthen its service for public and the different sectors. In Nepal, climate extremes are increasingly becoming more common and devastating. Hydro-meteorological disasters account for more than half of the total economic and human losses due to natural disasters every year. Climate change and its spatial variability can be related to the intensity and frequency of extreme events. The average temperature is significantly increasing throughout the country showing intensification of warming with altitude. However, extreme precipitation indices also have an increasing trend. The reliable weather, climate and hydrological data are important to understand climate change and useful for planning and management of disasters, protect nature, ecosystem, biodiversity and building climate resilience in Nepal.

Challenges in Hydrological Monitoring Assessment in Nepal

Kapil Gnawali
Senior Divisional Hydrologist, Water and Energy Commission Secretariat, Government of Nepal.
Email: kapilgnawali6@yahoo.com

ABSTRACT Nepal started hydrometeorological observation in an organized way since 1968. Nepal is home to 8 of the 10 highest mountain peaks in the world, including Mount Everest (8,848 masl) with small north south variation of 200 KM. Despite the smallest altitudinal variation, Nepal experiences almost all types of climates found globally. All the major rivers of Nepal are snow and glacier-fed and accommodate significant volumes of water flow throughout the year. Hydrometeorological monitoring is a challenging task due to varied climatic conditions within the short range of distance and geographical complexity. Department of Hydrology and Meteorology (DHM) has established around 800 hydrometeorological stations (308 precipitation, 158 climatic, 28 agrometeorological, 9 synoptic, and 8 Aero-synoptic stations and 300 hydrometric stations), despite some of them are not in operation. Similarly, around 300 hydrometeorological stations has been providing real time data in every 10-minutes interval. Those stations have great importance to save lives and properties by providing forecast and issuing early warning. But the existing hydrometeorological monitoring network is not sufficient to observe the regular high mountain weather, snow and glacier conditions. Additional monitoring stations in High Mountains and Himalayas are necessary to adequately address the flash flood, debris flow, and glacial lake outburst flood risk. The information from the monitoring stations acts as basis for the early warning system and is crucial tool for the weather and flood forecasting to reduce and manage disaster. There is lack of technical capability for the hydrometeorological assessment to meet the needs of different sectors and to contribute for the socio-economic prosperity of the nation. Therefore, it is needed to develop capacity in technical, policy and institutional aspects including the human resources to provide better hydrometeorological services through public-private partnership and formal dissemination of hydrometeorological information by the federal, provincial and local government.

Migration due to Scarce Water in Use:
a Nationwide Survey for Spring/natural pond Dryness and its Relation to the Migration

Ram Hari Pantha
Advisor in the Center of Rural Infrastructure and Environment Development (CRIED), Nepal
former Senior Soil Cons & WS Mgt. Officer, Under Secretary Govt. of Nepal.
Email: erhpantha@hotmail.com

ABSTRACT Climate Change is scientifically proven, and its impacts are universal. The most visible impact is on the status of the water and the temperature. The temperature variability affects the water status. Climate change is the change of water status, and it is a fact.

Water is the main constituent in the life of the human beings and the biological creatures. Change in the water affects the life and livelihoods. Climate change is the fact that change in the water availability, amount, pattern, and variability in the earth. The life pattern changes with a change in the water status. It affects human behavior, society, culture, food habits, etc. Throughout history, civilization has been regenerated along the river sides, lake, and the nearby water source. When the status of water changed, mismanaged, and shorted; civilization was severely hampered, and society migrated to relatively easier places. The migration may be planned or unplanned, and as a result, the existing civilization in place as Harrappa, Maya, Indus, the Mississippians etc.

In practice, many factors affect migration as employment, income status, physical infrastructures, and market as the expected life strategy changes. The main factor of the internal migration is the availability of water in the agrarian community in Nepal. The availability may vary based on the aspect of the mountains, and natural disasters such as landslides, erosion, and deforestation. A substantial number of the villages have already shifted from one place to accessible other places in the mountains of the country i.e. Dhey to Chambeleh[2] in Mustang Nepal. Very few villages have migrated as earlier planned areas whereas the majority are haphazard as the whole society shifted in one place or at random ie. Rajapani[3] village in Khotang district. Migration even the planned one is not satisfactory. The mind and the feelings are not comfortable compared to the available privilege.

The proposed survey is based in the water sources-based migration. The survey will be conducted nationwide in all seven provinces, 18 districts, and many villages as guided by the District Co-ordination Committee- a government body formed for the coordination mechanism with the local governments and in between local government and the provincial government, as a representation. Although, it may change based on the severity of the issue and the resource availability.

The survey does not follow hardcore statistical research. Instead, it explores the causes, places, and status of water use-based migration and support as an eye opener for the policy-level discussion.

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Climate Change Impacts on Hydrology in the Langtang River Basin, Nepal

Dhiraj Pradhananga[1,2] *, Susa Manandhar[2,1], Bharat Dhungel[2,1], Manavi Chaulagain[2,1], Sujan Bhattarai[3,2]

[1]Tribhuvan University, Department of Meteorology, Tri-Chandra Multiple Campus, Kathmandu, Nepal,
[2]The Small Earth Nepal, Kathmandu, Nepal,
[3]University of California Santa Barbara, Bren School of Environmental Science and Management, Santa Barbara, United States
* Email: dhiraj@smallearth.org.np

ABSTRACT The Himalayas are home to some of the world's most important glaciers and snow-covered areas, which play a crucial role in mountain biodiversity and in regulating downstream flow, providing water to millions of people. These mountain snow and glaciers are changing in response to climate change. Glaciers and snow-covered areas are retreating and changes in rainfall fraction as snow precipitation, in turn, impacts water availability downstream. Mountain basins in the Nepal Himalayas have complex hydrological processes and are remote for regular observation and monitoring. The study of trends in the precipitation phase and understanding of hydrological processes using physically based models in the Nepal Himalayas are limited. The study investigates the changes in streamflow, peak flow, and precipitation phase in the Langtang River Basin, Nepal (Figure 1), in response to climate change using a physical-based glacio-hydrological model.

The study uses the Cold Regions Hydrological Modelling platform (CRHM; Pomeroy et al. 2007, 2022), a physical-based distributed hydrological modelling system based on a modular design, which links the energy and mass balances (Figure 2). It is a useful research tool for diagnosing and predicting hydrological process functions over a river basin in cold regions (Pradhananga and Pomeroy 2021). CRHM-glacier (Aubry-Wake et al. 2022; Pradhananga and Pomeroy 2022) is an advancement in modelling glacierized basins in high mountains.

Meteorological observations are limited in the mountains; therefore, we used a bias-corrected reanalysis product, Water and Global Change (WATCH) Forcing Data methodology applied to ERA-Interim data (WFDEI, Weedon et al. 2011), to drive the model. We simulated model falsifications under various scenarios of climate and glacier configurations.

The results of the study show that climate change is leading to a reduction in streamflow, an advancement in peak flow, and a change in the precipitation phase, with an increasing trend in rainfall fraction in the headwater hydrology, particularly evident during the post-monsoon months. These findings have important implications for water resource management in the Nepal Himalayas. The reduction in streamflow could lead to water shortages during the dry season. The advancement in peak flow could increase the risk of flooding. The change in the precipitation phase could also affect the timing and distribution of water resources.

This study provides valuable insights into the complex hydrological processes within the headwaters of the Nepal Himalayas and the impacts of climate change on these processes. The findings can provide valuable insights for decision-making in water resource management and foster sustainable development in the region amidst ongoing climate challenges.

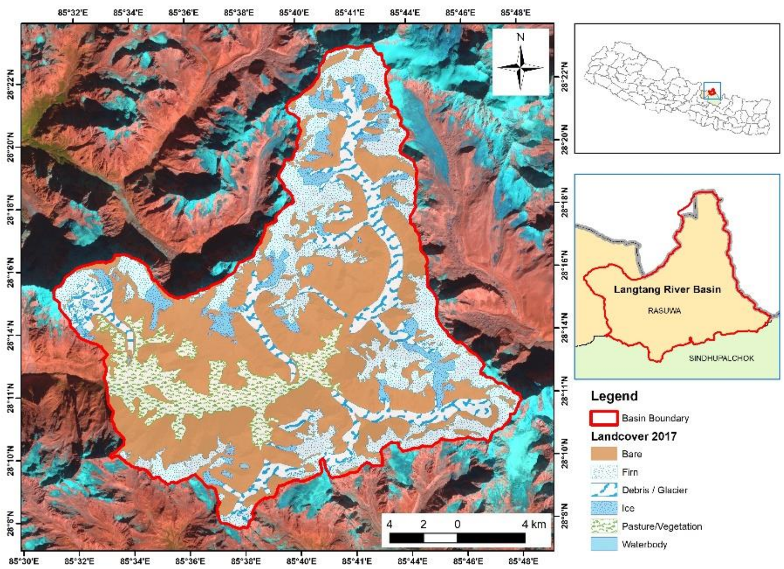

Figure 1: Langtang River Basin (Pradhananga n.d.).

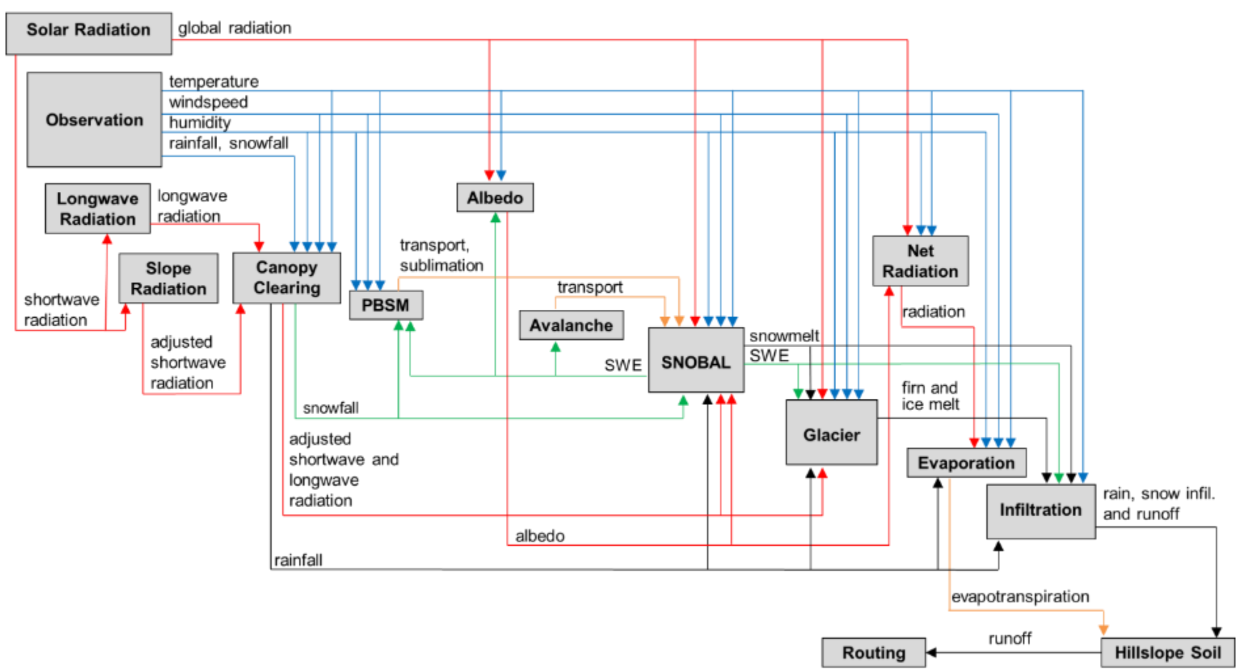

Figure 2. Modular structure of CRHM-glacier (Pradhananga and Pomeroy 2022). Red linking arrows are radiation terms; blue lines are climate observations; orange lines are mass transport; green and black lines are model outputs or processed variables of water equivalents, in solid and liquid forms respectively.

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Ecohydrological Nexus with Vegetation Dynamics in Changing Climate in Nepal

Binod Baniya[1,2]*, Qiuhong Tang[1], Gang Zhao[1]

[1]Land Surface Processes and Global Change Research Group, Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China.
[2]Department of Environmental Science, Patan Multiple Campus, Institute of Science and Technology, Tribhuvan University, Nepal

* Email: binod.baniya@pmc.tu.edu.np (Tel: +977-9841832743)

ABSTARCT Global ecological systems are widely regulated by water represents ecohydrology, which directly impacts vegetation growth, water balance, and regional climate (Rodriguez-Iturbe, 2000; William K. Nuttle, 2002). Among all the environmental complex, water is one of the principles determinants of forest growth (Billing WD, 1952; Peter S. Eagleson 2002). The vegetation has strongly influenced by climate change (Nemani et al. 2003; Xu et al. 2013; Zhou et al. 2001) and also driven by elevated atmospheric CO_2 and ecohydrological system (Rodríguez-Iturbe, I., & Porporato, A. 2005). China and India are leading to the greening world mainly due to forest growth in China and agricultural practices in India (Chen et al, 2018). In this context, this study examined vegetation dynamics in response to climate change using satellite derived NDVI and their environmental covariates in Nepal. The NDVI data were collected from NOAA, AVHRR, NDVI3g.V1 (8 ×8 km, 15 days) during 1981-2015 (Tucker et al. 2005) and MODIS NDVI, MOD13Q1 (250m, 15days) during 2000-2017 (Didan 2015). The monthly data was processed using maximum value composite (MVC) method (Holben 1986). In-situ observed temperature and precipitation data during same time periods were used that obtained from the Department of Hydrology and Meteorology. The forest biomass carbon density model (R2 of 0.64, p<0.001) was used to identify forest biomass using NDVI in Nepal (Piao et al. 2005) and compared with the national forest inventory report of Nepal (DFRS 2015). Furthermore, Ecosystem Service Values and VCI based drought conditions were also assessed. The main finding from this study are highlighted as follows

- The NDVI has significantly increased with a 57.35% areal percentage showing greening and 16.10% showing browning during 1982-2015
- Positive intensity of growing season (April to October, excluding evergreen forest) vegetation changes was found with a higher NDVI below 3000 m altitude.
- Temperature is the main driver of vegetation dynamics in which 34.97% of areas showed significant positive correlation. Meanwhile, precipitation shows a hysteretic relationship with vegetation in many cases.
- Nepal's forest total carbon stock was estimated as 685.45×106 t (i.e. 115.392 t C/ha) with an annual carbon sequestration rate of 0.10 t C/ha during 1982-2015.

- The total ESV in Nepal was found to be 21.88 billion USD in 2017 in which the Koshi Province has found the highest ESV and the Madesh Province has the lowest ESV in Nepal.
- The VCI based ecological drought showed that the years 1982, 1984, 1985 and 2000 experienced severe drought in Nepal.

The annual greening and browning NDVI trends in national and provincial scales are highlighted in 7 major provinces in Nepal as shown in Figure 1, where P1=Koshi, P2=Madesh, P3= Bagmati, P4=Gandaki, P5=Lumbini, P6-Karnali and P7=Sudurpachim Provinces. The red color indicates decreasing vegetation trend and other color indicates increasing vegetation trend in Nepal (**Figure 1**)

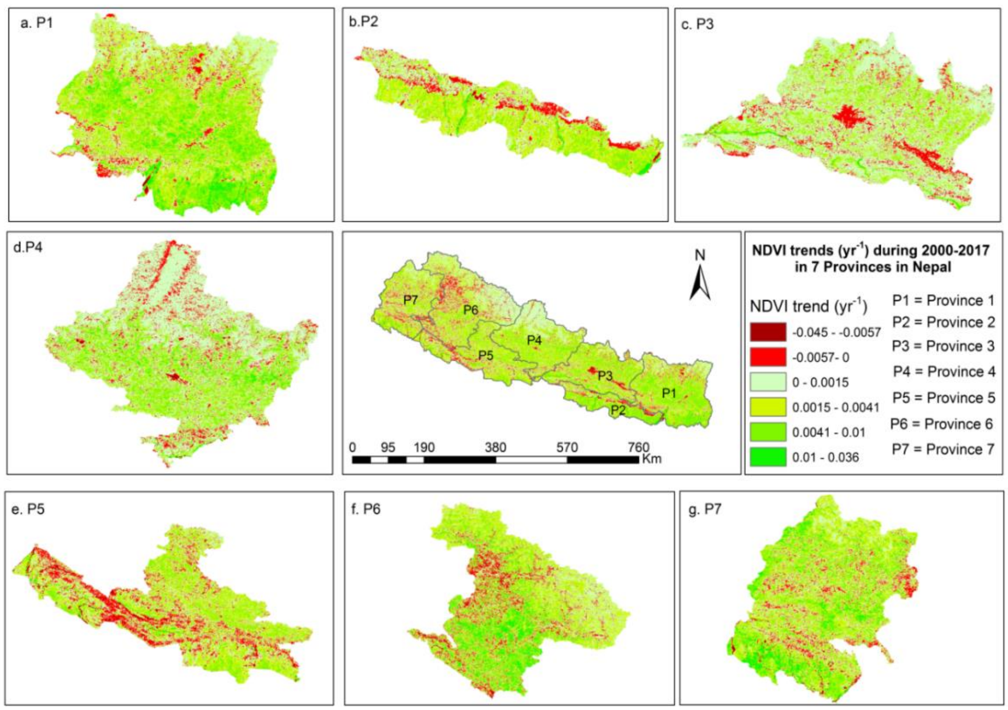

Figure 1: Linear trends of annual NDVI at national and provincial scales based on MODIS NDVI data during 2000-2017

This study further suggests that vegetation dynamics are likely to be co-regulated by solar radiation in Nepal. Additionally, the nexus between vegetation and water (consumption, recharge and circulation) as a part of ecohydrological system is crucial for scientific investigation in the forest of Nepal.

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Climate Change and Response of Forest Trees in Nepal Himalaya

Achyut Tiwari

Central Department of Botany, Tribhuvan University, Kathmandu, Nepal.
Email: achyutone@gmail.com

ABSTRACT Climatic changes are more intense in Himalayan region, and they have already altered the hydroclimatic balance, tree growth trend and plant distribution patterns in the region. The greater topographic variation including altitudinal gradients shapes the regional climate patterns, offering us the great opportunities to explore and understand the impact of changing climate to forest composition changes, tree growth patterns and changes in distribution patterns of Himalayan forest trees. Dendrochronological studies include tree ring records as high resolution proxies for investigating response of climatic changes in tree growth and forest health. Tree rings from Himalyan region are highly important which is associated with diverse climate variation modulated by anthropogenic disturbances. My studies in more than seven different plant species including conifers and broadleaved trees broadly indicated that the radial growth is mainly conrolled by temperature related moisture in early growth season (March-May) in Himalaya, however there is site and species specific growth sensitivity. More particularly, the trees in altitudinal treelines are more sensitive to temperature, while those of timberline and at low elevation (sub-tropical, temperature) show higher sensitivity to availability of moisture. Warming temperatures, mainly day temperature (Tmax) is increasing more rapidly in entire Himalayan region (exceeding global average) than the mimimum temperature warming (Tmin) and this has elevated evapotranspiration trend causing moisture limitation for tree radial growth for majority tree species in Nepal Himalaya. Hence it can be cocluded that the future trajectories of tree growth pattern is highly dependent on intensity of warming temperature and monsoon seasonality associated with overall precipitation trend. Further, tree radial growth at temperate and sub-tropical region in Himalaya is also influenced by forest level disturbance factors including human interference in forest management, and including deforestation, forest fragmentaion, grazing, forest fire etc. More specified investigations on tree ring isotope analysis, wood anatomy and multi species response to climate variation are yet to be carried out for Himalayan region in order to improve our understanding about the nexus of climate, forest and hydrological changes in Himalayan region.

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Uncertainty of Remotely Sensed Vegetation Growth Dynamics in Nepal

Decheng Zhou[1]*, Lu Hao[1], and Ge Sun[2]

[1]Nanjing University of Information Science and Technology, Nanjing 210044, China.
[2]Southern Research Station, USDA Forest Service, Research Triangle Park, NC 27709, USA
* Email: zhoudc@nuist.edu.cn

ABSTRACT Mountain ecosystems provide multiple ecosystem services and are "natural laboratories" to understand ecosystem responses to global change. Because of the inaccessibility and the high cost of field surveys, remote sensing indices are the major and sometimes the only measures to monitor the vegetation growth dynamics in mountains. However, there are large discrepancies in those indices that should be quantified in mountainous regions. This case study in Nepal, a highly mountainous region, explores the consistency and inconsistency of six widely used remote sensing indices in monitoring vegetation growth from 2000 to 2020. The study considers three greenness indices of normalized difference vegetation indices (NDVI), enhanced vegetation index (EVI), and near-infrared reflectance of vegetation (NIRv), one cover index of leaf area index (LAI), and two productivity indices of gross primary productivity (GPP) and solar-induced chlorophyll fluorescence (SIF). We find high spatial consistency in the multiyear means (r = 0.79~1, N = 4300, P < 0.01), especially in the highlands and between EVI and NIRv, and a logarithmic relationship between greenness indices or GOSIF and LAI or GPP. In contrast, the long-term trends differ substantially by the index and space. Only 7% of the lands show synchronized significant increase on a per-pixel basis though all the indices show a widespread increasing tendency (77-87% of the lands). The prevalent non-significant changes of all the indices primarily contribute to the trend uncertainties, especially in the highlands. The inconsistencies between greenness and productivity indices and in them further exaggerate the uncertainties. Our results emphasize the large discrepancies of remote sensing indices in quantifying mountain vegetation growth dynamics. Larger inconsistency is expected if consider disparities among the quality-control schemes, study seasons, remote sensing models, satellite platforms, and sensors. Reinforced remote sensing data, model improvements and/or new indices are needed for an accurate quantification of the vegetation growth dynamics in mountain ecosystems.

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Effects of Conservation Measures on Crop Diversity and their Implications for Climate-Resilient livelihoods: the Case of Rupa Lake Watershed in Nepal

Yunli Bai[1], Chao Fu[1]*, Thapa Balaram[2], Rana Ram Bahadur[2], Linxiu Zhang[3]

[1]Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences

[2]United Nations Environment Programme

[3]Local Initiatives for Biodiversity, Research and Development (LI-BIRD)

* Email: chao.fu@unep-iemp.org

ABSTRACT Agrobiodiversity refers to the diversity of plants, animals, and microorganisms that underpin agricultural systems (Wood & Lenné, 1999). It is importance in terms of supplying genetic resources that provide a wide range of critical benefits to achieve SDGs, such as income opportunities and nutritious diets (Kahane et al., 2013; Sibhatu & Matin, 2018), the provision of ecosystem services such as soil health and water conservation (Hajjar et al., 2008), and adaptations to climate change in agricultural systems (Kozicka et al., 2020). Agrobiodiversity is even more important for smallholders in mountainous areas, which are more vulnerable in both ecological and socioeconomic aspects (Kruijssen et al., 2009) and agriculture is always the most important sector for employment and income sources for local populations (Panagos et al., 2018). Recent evidence implies that crop diversification practices can contribute to climate-smart agriculture (Makate et al. 2016). However, few recommendations exist on how to diversify cropping systems in ways that best fit the agroecological and socioeconomic challenges farmers face (van Zonneveld et al. 2020). This study aims to estimate the effects of raising conservation awareness (RCA), building diversity blocks (BDB), and their combination on crop diversity among 240 randomly selected households surrounding the Rupa Lake Watershed in Nepal. Based on descriptive analysis and multiple regression models, the results indicate that the two single measures had no significant effect on the numbers of crop species and varieties grown by households in 2018. However, the combination of RCA and BDB had a significantly positive effect on the number of crop varieties, especially for grain and vegetable crops. Diversity crop varieties is negatively and significantly correlated with the farmer's perception of climate disaster. Considering that these crops are essential in the daily lives of local people, the results indicate that a strategy that combines both awareness raising and on-farm conservation measures can generate higher crop diversity and better serve the climate-resilient livelihoods of people in mountainous areas.

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Cryo-Bio-Social Cycle: Understanding the Cycling Interactions between Ecosystem, Water, Climate, and Livelihoods in The Hindu Kush Himalaya

Sunita Chaudhary*, Finu Shrestha, and Yathartha Dhungel

International Centre for Integrated Mountain Development (ICIMOD)
* Email: sunita.chaudhary@icimod.org

ABSTRACT The Hindu Kush Himalayan (HKH) region encompasses the highest mountain ranges in the world and contains the largest volume of ice on Earth outside of the polar regions, as well as large expanses of snow. Drawing from the earth system science understanding of the "Earth" as an integrated, symbiotic, and self-regulating complex system, this paper explores the complex interactions and feedback between cryosphere, hydrosphere, biosphere, and society. While exploring, the study identifies the process, changes, associated impacts and response of each of the systems, and map out the cyclic interactions between them. In doing so, the paper discusses the existing and possible adaptation strategies for enhancing the socio-ecological resilience in the highlands, which is important for policy makers and practitioners.

Modeling Forest-Water Interactions at Multiple Scales in Nepal

Ge Sun[1]*, Ning Liu[2], Run Cao[3], Kailun Jin[3], Lu Hao[3], and Conghe Song[4]

[1]Supervisory Research Hydrologist and Center Director, Eastern Forest Environmental Threat Assessment Center, Southern Research Station, USDA Forest Service, Research Triangle Park, NC, USA.
[2]Research Scientist, CSIRO Environment, Canberra, ACT, Australia
[3]Respectively, Graduate Student, Graduate Student, and Professor, Collaborative Innovation Center on Forecast and Evaluation of Meteorological Disasters (CIC-FEMD)/ Key Laboratory of Ecosystem Carbon Source and Sink, China Meteorological Administration (ECSS-CMA), Nanjing University of Information Science and Technology, Nanjing, China
[4]Professor and Department Chair, Department of Geography and Environment, University of North Carolina at Chapel Hill Chapel Hill, NC, USA
* Email: Ge.Sun@usda.gov

ABSTRACT Hydrological models have been widely used as an effective tool for investigating the effects of forest management and climate change and variability on watershed hydrology and water resources. Modeling is essential for data synthesis, data gap filling, extrapolation, projection, and deriving hydrological variables that are too expensive to directly measure or estimate. Models also play a significant role in training and education in fully understanding the entire hydrologic cycles in a systematic manner. However, models are developed using our existing knowledge about how the nature works. Thus, modeling results 'can be no more reliable than a prior agreement between the assumptions of the model and the known facts about the real phenomenon'. Models, empirical or physically based, require field data to verify to be creditable to be used to answer real management questions or predicting hydrological change under novel conditions. Nepal is known to have complex landscapes, climate, and vegetation dynamics, and there are tremendous heterogeneities and complexity in hydrological processes from hillslope to the national scales. This paper reports preliminary results from a study that aims at modeling the water balances at watershed and national scale to understand how climate and land use/cover change affect water supplies with limited data. A process-based, distributed hydrological model (Zhang et al., 2008; Lu et al., 2009), MIKE SHE, was parameterized using plot and watershed data in the middle hill region to simulate spatial distribution of soil moisture and shallow groundwater table depth on hillslopes. Simulated results were compared to site level measurements of total evapotranspiration of natural and plantation forest stands (Ghimire et al., 2014), and were used to detect groundwater table dynamics. The Water Supply Stress Index (WaSSI) model (Sun et al., 2011) and InVest model (Bastola et al., 2019) were applied in Nepal to map water balances at a monthly and annual time scales. Our study suggests that there are large uncertainty of evapotranspiration estimates and both local climate and soil information is essential to match modeled and measured streamflow, even at the monthly scale. Forest lands are

important water sources in Nepal among other land uses. Future studies should focus on model validation at multiple scales using multiple data sources.

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Highlights of International Forest Hydrologic Research

Devendra M Amatya, PhD, PE

USDA Forest Service, Cordesville, South Carolina, USA
Email: devendra.m.amatya@usda.gov

ABSTRCAT Long-term research at small, gauged, experimental forested watersheds within the USDA Forest Service as well as other parts of the world has contributed substantially to our current understanding of forest water balance, soil moisture, runoff generation, and flow paths and relationships between forests and streamflow, helping forest landowners/managers identify hydrologically sensitive areas that contribute to overland runoff, soil/gully erosion, sediment and pollutant discharge, while improving ecohydrology model predictions. Most studies have used a paired watershed approach to evaluate the effects of forest management (e.g. harvesting, thinning, afforestation, deforestation, prescribed fire, road/drainage etc.) on hydrological responses including stormflows, peak flows, water yield, ground water table, water quality, and other ecosystem services in the context of changing climate (extreme precipitation, flooding, droughts, etc.), providing a basis to develop nature based solutions for managing/restoring resilient forest ecosystems.

This presentation will highlight the forest water budget components, examples of paired watershed approach with extensive field monitoring, backed up by hydrologic modeling in some cases, implemented in North and South Americas for evaluating hydrologic impacts of various forest management practices. Multi-modeling approaches to fill data gaps and assess management strategy-based ecohydrologic predictions and their uncertainties on forested lands will be highlighted. Importance of assessing rainfall intensities and high (flood) and low flow frequencies using statistical/empirical models with available hydro-meteorological datasets to aid in nature-based solutions for design/restoration of resilient cross-drainage structures (high flow) and spring water sources (low flows), that are increasingly being vulnerable to climate change in community forestry systems, will also be touched upon. The presentation will end highlighting recent literature on related regional studies in Nepal for potential information/data sharing and emphasizing a need of a long-term pilot experimental forest catchment to understand the basic ecohydrologic processes and human interactions in the study region and to provide as an educational field laboratory for both the students and faculty at Institute of Forestry, Tribhuvan University and beyond other institutions with an interest in this field.

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List of participants

ID	Last Name	First Name	Affiliation	Country	E-mail	Expertise
1	Hao	Lu	Nanjing University of Information Science and Technology (NUIST)	China	hl_haolu@163.com	Ecohydrology
2	Jin	Kailun	NUIST	China	jkl_nuist@163.com	Forest hydrology
3	Tang	Run	NUIST	China	Run_Tang0727@163.com	Forest hydrology
4	Zhou	Guoyi	NUIST	China	gyzhou@nuist.edu.cn	Ecosystem ecology
5	Zhou	Decheng	NUIST	China	zhoudc@nuist.edu.cn	Remote sensing
6	Yu	Zhen	NUIST	China	zyu@nuist.edu.cn	Ecosystem ecology
7	Liu	Lei	NUIST	China	liulei@nuist.edu.cn	Ecosystem ecology
8	Chi	Jinshu	Hong Kong University of Science and Technology (Guangzhou)	China	jinshuchi@ust.hk	Ecohydrology
9	Bai	Yunli	Chinese Academy of Sciences	China	baiyl.11b@igsnrr.ac.cn	Agricultural economic management
10	Wang	Guoqin	Chinese Academy of Sciences	China	wanggq@igsnrr.ac.cn	Ecosystem ecology
11	Daniel	Denzil	Department of Hydrology, Indian Institute of Technology Roorkee	India	denzil_d@hy.iitr.ac.in	Hydrology
12	Mukherjee	Sandipan	GB Pant National Institute of Himalayan Environment and Sustainable Development	India	sandipan@gbpihed.nic.in	Hydrology
13	Qazi	Nuzhat	Formerly with National Institute of Hydrology	India	qazinuzhat82@gmail.com	Forest Hydrology

ID	Last Name	First Name	Affiliation	Country	E-mail	Expertise
14	Tiwari	Krishna Raj	Institute of Forestry, Tribhuvan University	Nepal	krishna.iof@gmail.com; krtiwari@iofpc.edu.np	Watershed Management
15	Subedi	Rajan	Institute of Forestry, Tribhuvan University	Nepal	rsubedi@iofpc.edu.np	Watershed Hydrology
16	Pokharel	Ridish	Institute of Forestry, Tribhuvan University	Nepal	ridishp@gmail.com	Community forestry
17	Gnawali	Kapil	Nepal's Hydrology and Meteorology Department	Nepal	kapilgnawali6@yahoo.com	Hydrology
18	Pantha	Ram	EbA practitioner and Former Senior Watershed Mgt Officer in Govt	Nepal	erhpantha@hotmail.com	Agriculture and Forestry
19	Baniya	Binod	Environmental Science, PMC-TU	Nepal	bbaniya@cdes.edu.np	Ecohydrology
20	Awasthi	Ram Prasad	Department of Hydrology and Meteorology, Government of Nepal	Nepal	ram.awasthi@nepal.gov.np; awasthiramprasad@gmail.com	Hydrometeorology
21	Chaudhary	Sunita	International Centre for Integrated Mountain Development	Nepal	sunita.chaudhary@icimod.org	Ecosystem Services
22	Pradhananga	Dhiraj	Tribhuvan University, Department of Meteorology and Hydrology	Nepal	dhirajmet@hotmail.com	Mountain Hydrology
23	Mukherjee	Sandipan	GB Pant National Institute of Himalayan Environment and Sustainable Development	India	sandipan@gbpihed.nic.in	Hydrology
24	Tiwari	Achyut	Central Department of Botany, Tribhuvan University	Nepal	a.tiwari@cdbtu.edu.np	Forest Ecology
25	Khanal Chhetri	Bir Bahadur	Institute of Forestry, Tribhuvan University	Nepal	dean@iof.tu.edu.np	Community Forestry

ID	Last Name	First Name	Affiliation	Country	E-mail	Expertise
26	Heyojoo	Binod	Pokhara Campus Institute of Forestry, TU, Pokhara	Nepal	binod.heyojoo@pc.tu.edu.np	Forest Engineering
27	Devkota	Bishnu	Pokhara Campus Institute of Forestry, TU, Pokhara	Nepal	bishnu.devkota@pc.tu.edu.np	Biometrics
28	Devkota	Krishna	Provincial Policy and Planning Commission Gandaki Province,	Nepal	kesandevkota@gmail.com	Policy and Planning
29	Ghimire	Bisal	Ministry of Industry, Tourism, Forest and Environment Gandaki Province	Nepal	bishalghimire.mofe@gmail.com	Forest Management
30	Shrestha	Ramkaji	Forest Directorate, Gandaki Province, Pokhara	Nepal	ramkajishrestha1966@gmail.com	Forest Management
31	Malla	Rajesh	Forest Research and Training Centre, Gandaki Province, Pokhara	Nepal	raj_malla@yahoo.com	Forest Management
32	Maharjan	Sujan	Basin Management Centre, Gandaki basin, Pokhara	Nepal	sujanmaharjan1980@gmail.com	Watershed Management
34	Pokhrel	Santosh	The republic, Media network (Nagarik News), Pokhara	Nepal	gulmelisantosh@gmail.com	Media
35	Pariyar	Deepak	Kantipur News, Pokhara	Nepal	4dipshikha@gmail.com	Media
36	Baral	Krishna Mani	Annapurna Post, Pokhara	Nepal	baralkrish@gmail.com	Media
37	Sharma	Jamuna Barsha	Federation of Nepali Journalist, Kaski /National News Agency (RSS), Pokhara	Nepal	Jamuna.barsha@gmail.com	Media
38	Jojiju	Bikesh	Institute of Forestry, Pokhara	Nepal	jojijubikesh8@gmail.com	Watershed Management
39	Bruijnzeel	L.A. (Sampurno)	Visiting Professor with King's College London	UK	sampurno.bruijnzeel@kcl.ac.uk	Ecohydrology
40	Zhang	Jun	TNO Applied Science	Netherlands	jzg290@outlook.com	Ecohydrology
41	Zhang	Linxiu	United Nations Environment Programme (UNEP)	UN	linxiu.zhang@un.org	Agricultural Economics

ID	Last Name	First Name	Affiliation	Country	E-mail	Expertise
42	Qu	Qinghe	UNEP	UN	qhqu.ccap@igsnrr.ac.cn	Socioeconomic
43	Amatya	Devendra	USDA Forest Service	USA	Devendra.m.amatya@usda.gov	Forest hydrology
44	Sun	Ge	USDA Forest Service	USA	Ge.Sun@usda.gov	Forest hydrology
45	Song	Conghe	UNC Chapel Hill	USA	csong@email.unc.edu	Nature-Human Coupling