Hydrological impacts of community forests in the mid-hills catchments of Kavre district, Nepal

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Acronyms

ADB	Asian Development Bank
CBS	Central Bureau of Statistics
CFUG	Community Forest User Group
CRED	Centre for Research on the Epidemiology of Disasters
DDC	District Development Committee
DFO	District Forest Office
DFRS	Department of Forest Research and Survey
DHM	Department of Hydrology and Meteorology
DoF	Department of Forests
FAO	Food and Agriculture Organisation of the United Nations
GIS	Geographic Information System
GoN	Government of Nepal
IUCN	International Union for Conservation of Nature
MFALD	Ministry of Federal Affairs and Local Development
MFSC	Ministry of Forests and Soil Conservation
MLESS	Ministry of Labour, Employment and Social Security
MoFE	Ministry of Forests and Environment
NPC	National Planning Commission
NLC	Nepal Law Commission
NPR	Nepali Rupee
NRC	National Research Council
RECOFTC	Regional Community Forestry Training Center for Asia and the Pacific
REDD+	Reducing Emissions from Deforestation and Forest Degradation
SFM	Scientific Forest Management
USD	United States Dollars

Abstract

The widely held perceptions that forest development improves catchment streamflow regulation have led to the implementation of many forestation programs worldwide. This is despite several studies showing forestation to generally reduce catchment water yield. Importantly, however, these studies poorly represent the tropical and subtropical regions, because they do not incorporate the effects of local forest use as found in Nepal's mid-hills catchments.

Forests of the mid-hills catchments are extensively used by the local community forest user groups (CFUGs), mainly to collect firewood, fodder and litter. During the 1970s, degradation of these forests allegedly caused widespread eco-hydrological problems, which subsequently led to the implementation of large-scale reforestation programs, largely to the species of pine. At present, CFUG-managed broadleaf and pine forests dominate the mid-hills' catchments that are increasingly important for downstream water use. However, hydrological effects of this forest development or CFUG practices are essentially uncertain. This study aimed to examine these effects, particularly in view of the expanding community forest areas of the mid-hills catchments and Nepal's recent focus to scientific forest management.

This study employed a mixed method of scientific research. It combined local perceptions of forest-water relationships with experimental results measuring hydrological components of various community forests; a natural broadleaf (BF), planted pine-dominated (PF) and mixed broadleaf-pine forest (MF) in Roshi Khola catchment of Kavre district that pioneered community forestry. The BF and MF were used extensively by the CFUGs, while the PF only occasionally because it had limited supply of the traditional forest products. The survey showed a perception gap about forest-water relationships among sections of the Nepalese community, including the CFUGs' disproval for pine forests as they supposedly reduced water quantity. Furthermore, soil properties of the research sites, particularly soil organic carbon (SOC), bulk density (BD) and saturated hydraulic conductivity (K_s) at various depths were compared with a minimally used religious forest (RF). SOC values of the RF were significantly higher *($P < 0.05$)* and BD significantly lower than the PF and MF, mainly at 0-50 cm depth. The median K_s values (16-98 mm hr^{-1}) were generally higher for the less used PF and RF. Subsequent comparison of the K_s values with the prevailing rainfall intensities showed PF to favour vertical percolation with possible greater contributions to subsurface storage. The overland flow production (OF) during June 2015 - December 2016 for the BF, MF and PF was 8.4%, 7.3% and 3.7% of incident rainfall, respectively. While the lower OF in the PF is likely explained by the site's higher K_s values, overall results highlight the critical role of forest use related disturbance on water retention and runoff amounts of the mid-hills catchments with implications for downstream water use.

Thesis declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no materials previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint award of this degree.

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Publications arising from this study

1. Badu, M, Nuberg, I, Cedamon, E, Sharma, S 2019, 'Management of the forested catchments of Nepal's Mid-hills amid mismatched perceptions of forest– water relationships: challenges and opportunities', *Mountain Research and Development*, 39, 4, R27-R36, https://doi.org/10.1659/mrd-journal-d-18-00023.1.

2. Badu, M, Nuberg, I, Ghimire, CP, Bajracharya, RM, Meyer, WS 2019, 'Negative trade-offs between community forest use and hydrological benefits in the forested catchments of Nepal's Mid-hills, *Mountain Research and Development*, 39, 3, R22-R32, https://doi.org/10.1659/mrd-journal-d-18-00066.1.

3. Badu, M, Ghimire, CP, Nuberg, I, Bruijnzeel, LA, Meyer, WS 2020, 'Rainfall partitioning in three major types of forests in the Mid-hills of Nepal, EGU General Assembly 2020, online, 4–8 May 2020, EGU2020-22314, https://doi.org/10.5194/egusphere-egu2020-22314.

Chapter 1

1. Thesis introduction

1.1 Forest development and water in perspective

In many tropical and sub-tropical areas, afforestation or reforestation is often carried out to improve catchment hydrology (FAO/RECOFTC 2016) including run-off and low flow regulation (Schreier et al. 2006). It is anticipated that incorporation of organic matter after forestation improves rainfall absorption and groundwater storages through, what is sometimes referred to as the 'sponge effect' (Myers 1983; Ogden et al. 2013; Spears 1982). Furthermore, while there are claims that forests contribute to rainfall stimulation and climate regulation (Ellison et al. 2012; Ellison et al. 2017; Makarieva et al. 2014; Sheil 2014; Sheil & Murdiyarso 2009), forested catchments are more valued for downstream water use (Creed & van Noordwijk 2018; NRC 2008).

At the same time, the socioeconomic benefits of the forests are increasingly linked to the realisation of the United Nations Sustainable Development Goals (Bastos Lima et al. 2015; The United Nations 2015; Swamy et al. 2018). This is because forests are often the direct source of food, income and cultural depiction for many traditional communities (FAO 2006), particularly in the tropical and sub-tropical regions (FAO 2018). Accordingly, several governments and non-governmental development organisations regularly incorporate forestation into their development agenda. This, combined with the influence of market economies (Gilmour 2015), has resulted in increased forest areas in some countries (FAO 2016)- Nepal being a case **(Figure 1.1)**.

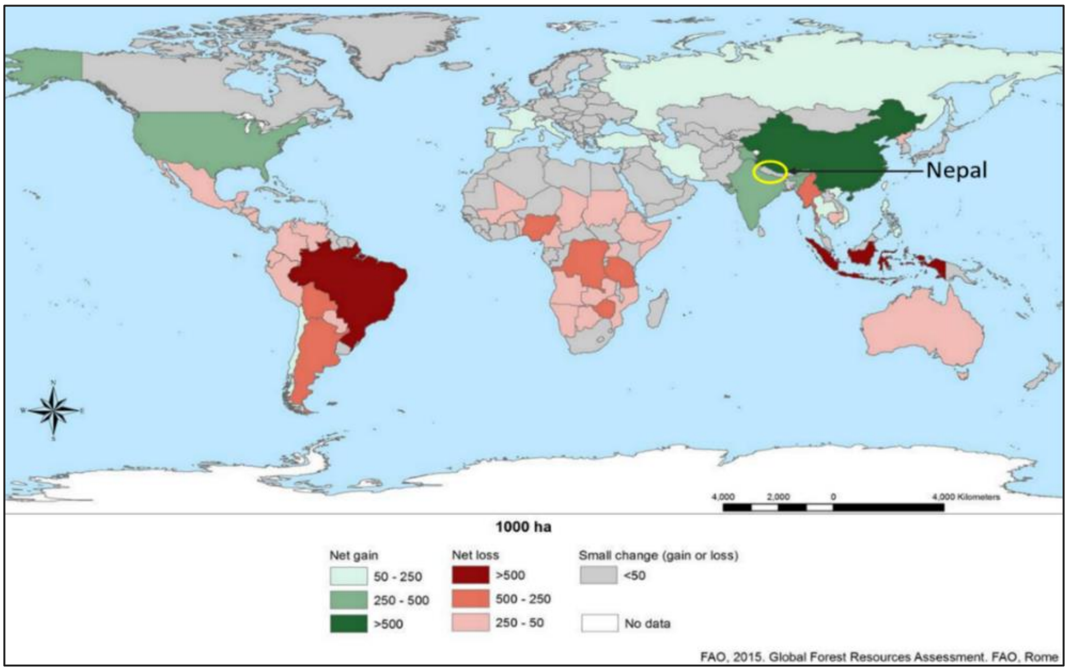

Figure 1.1: Change in forest areas of Nepal and the world during 1990-2015 (FAO 2015b)

According to Nepal's Forest Resource Assessment 2015 (GoN 2016a), forests and woodlands jointly occupy an approximate area of 6.6 million ha (ca. 45% of the total area) which is nearly a 6% increase since the preceding survey of 2011 **(Table 1.1)**. The increase is particularly evident in the country's mid-hills where forests occupy more than half of the region's 4.3 million ha. This is notable because, during the 1970s, high rates of deforestation in the mid-hills were linked to widespread incidences of large-scale floods and landslides (Eckholm 1976) as well as drying up of springs and reduced water availability (National Planning Commission n.d.; The World Bank Report 1979).

Table 1.1: Change in Nepal's forest area during 1965-2015 (ADB 2014)

Assessment year	Total forest Area	
	(000 ha)	% of total land
1965	6,467	43.8
1978	6,307	42.8
1985	6,224	42.2
1994	5,828	39.5
2011	5,734	38.9
2015	6,610	44.7

In fact, claims of linkages between deforestation and eco-hydrological problems were made for the broader Himalayan region including China (Sun & Li 2005) and India (Bartarya 1991; Bartarya & Valdiya 1989). The widespread publicity of these claims led to the implementation of large-scale reforestation programs in many parts of the Himalayas, including Nepal's mid-hills (Gilmour & Fisher 1991). The mid-hills reforestation largely involved the use of pine species, particularly *Pinus roxburghii* and *Pinus patula* (Dangal & Das 2018; Paudyal 2018), mainly because the species were better suited to the nutrient poor soils of the mid-hills (Gilmour et al. 1990; Mohns et al. 1988).

In addition to providing remedial measures to the contended eco-hydrological problems, reforestation of the mid-hills enriched the critical supply of forest products including timber, firewood, compostable litter and livestock fodder to the local communities (Mahat et al. 1987; Springate-Baginski & Blaikie 2007). For instance, more than 85% of the mid-hills population relies on the composted forest litter for soil fertility enrichment (Balla et al. 2014) **(Figure 1.2)** while approximately 75% of the country's population uses firewood for cooking (NPC 2017). This forest-people relationship is legislated through Nepal's community forestry policy, which is currently the main guide for forest management in the mid-hills (DFRS 2015b).

Figure 1.2: A basic diagram showing forest litter use in the mid-hills (All pictures from present study area)

The mid-hills forests are composed of planted pine, naturally regenerated broadleaf and mixed species and cover an approximate area of 2.3 million ha (DFRS 2015a). A large majority of this forest area (65% of the total (Sharma 2017)) is managed by the locally organised Community Forest User Groups (hereafter CFUGs). This model of forest management has inspired numerous researchers, practitioners and academics worldwide due to its reported contribution to improving the local environmental and socioeconomic conditions; Thwaites et al. (2018) referred to Nepal's community forestry areas as the "living laboratory" for studying the theories and practices of natural resources management.

1.2 The contextual basis of forest-water research in Nepal's mid-hills

In parts of Asia including China and India, the combined effect of the governments' forest development programs and socioeconomic change has led to a condition of 'forest transition' characterised by recovery of the lost forest cover (Mather 2007). While the increase in Nepal's forested area, particularly the mid-hills region, is likely an indication of this trend, this landuse change is mainly the result of the nearly 40-year old community forestry practices of the mid-hills (DFRS 2015a; Nagendra 2010; Paudyal, Putzel, et al. 2017), even though outmigration and land abandonment have also contributed in recent years (Jaquet et al. 2015; Paudel et al. 2014; Paudyal, Putzel, et al. 2017; Poudel, Kafle, et al. 2018). In fact, community based forestry is practiced globally as an effective forest management strategy that contributes to the development of social and financial capitals of the communities involved (Baynes et al. 2015; Gilmour et al. 2004; Pagdee et al. 2006; Roberts & Gautam 2003). Accordingly, the forest areas that are either managed or owned by local communities have globally increased. For instance, an analysis of the forest tenure rights in 52 countries during 2002-2013 showed a 92% increase (from 50 to 96 million ha) in areas of such forests, which was approximately 74% for Nepal (from 1.02 to 1.77 million ha) (Rights and Resources Initiative 2014). Yet, as highlighted by Gilmour (2016), research gaps remain about the contributions of community managed forests toward providing ecosystem services.

The community forests in Nepal's mid-hills are increasingly recognised for the environmental services, including water provisions (Bhandari et al. 2016; Chaudhary & McGregor 2018; Paudel 2017; Paudyal et al. 2015; Paudyal, Baral, et al. 2017; Van Oort et al. 2015) as the downstream water needs intensify mainly due to the socioeconomic development and effects of climate change (Pandey et al. 2012; Shrestha & Aryal 2011; Udmale et al. 2016). Crucially, there are growing reports of declining dry season flows across the mid-hills catchments (Maharjan et al. 2018; Poudel & Duex 2017; Sharma 2014; Sharma et al. 2016) with concerns about the role of pine plantations in causing the decline (Bhatta et al. 2015; Dhakal 2010; Menon 2011; Shrestha 2016). While pine forests cause greater reductions in overall catchment water yield than broadleaf forests in other parts of the world due to, for instance, higher transpiration rates (Komatsu et al. 2008; Komatsu et al. 2007; Sahin & Hall 1996; Swank & Douglass 1974), there is little scientific evidence in Nepal mid-hills catchments (Baral 2012; Ghimire, Lubczynski, et al. 2014). In fact, hydrological implications of increased forest cover in the human-dominated tropical and semi-tropical landscapes are generally poorly understood (Malmer et al. 2010). This is despite the widely known effects of forest use on the structure and composition of species (Lewis et al. 2015; Rijal & Meilby 2012; Wright 2010) as well as resultant hydrology (Bredemeier et al. 2010; Creed & van Noordwijk 2018; Giambelluca 2002a; Holscher et al. 2005; Julich et al. 2015). For instance, the disturbance related to sustained forest use is known to affect soil hydraulic conductivity in India (Bonell et al. 2010), Madagascar (Zwartendijk et al. 2017) and parts of Nepal mid-hills (Gilmour et al. 1987) with likely implications for the dry season flows (Ghimire, Bruijnzeel, Bonell, et al. 2014). However, these findings provide only a partial understanding of the forest-water relationships for the mid-hills due to the complex landscape, climate, vegetation as well as the landuse practices of this region (Lilleso et al. 2005). Crucially, the studies overlook the likely effects of successional change in forest ecosystems, in particular the ability of pine plantations to incorporate broadleaf species naturally or through anthropogenic factors (Gilmour et al. 1990; Mohns et al. 1988; Paudyal & Sapkota 2018). This transition of species composition is increasingly reported in the mid-hills forests (Gautam & Webb 2001; Gautam et al. 2002; DFO Kavre 2014b) as is commonly found in the tropical environments including the Philippines (Wills et al. 2016), Indonesia (Kuusipalo et al. 1995) and Panama (Feeley et al. 2011). In some cases, the CFUGs have proposed plans to replace the pines with broadleaf species (DFO Kavre 2014a) as these are more desirable for the production of much needed livestock fodder and compostable litter (KC et al. 2015; Shrestha & Brown 1995). Likewise, mixed species forests dominate parts of the mid-hills. For instance, in the Kavre district **(Figure 1.3)**, these forests cover approximately 12,000 ha or 51% of the total community forest areas as compared with approximately 2,600 ha of the plantations which are mostly pine (DFO Kavre 2014b). However, the likely hydrological implications of this forest transition are uncertain.

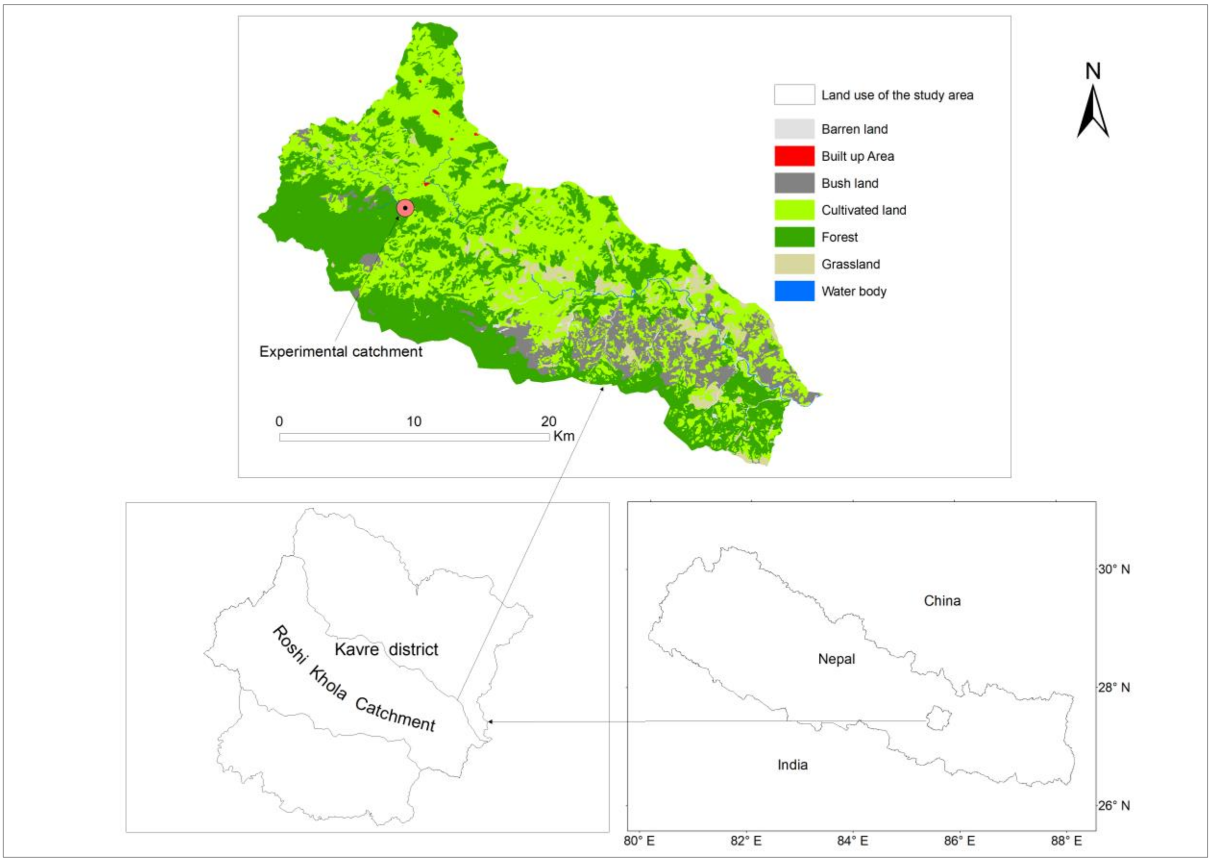

Figure 1.3: Location of the experimental catchment in Kavre district, Nepal (*Note.* See attachment 7 of the annex section for newly published political and administrative map of Nepal)

Thus, while there is an essential need to quantify the hydrological effects of the various forest types in Nepal's mid-hills, there are opportunities to align the scientific research with the public perceptions on forest-water relationships. This is because the perceptions that the forests increase water production (or decreases due to forest loss) are common in many societies (Calder 2005; Calder et al. 2007; Gilmour 2014) including Nepal. In a recent survey of over 5,000 households countrywide, over one fourth of the respondents (26%) said that the decreased water quantities and drying up of water sources in various parts of the country were results of forest loss (CBS 2017). This is despite the scientific evidence showing that the forests generally use more water than the lower vegetation (Chapter 2, section 2.5), including the central mid-hills of Nepal where the planted pine forests used more water due to their higher evapotranspiration rates (577 mm/year) than the pasture land (225 mm/year) (Ghimire, Bruijnzeel, Lubczynski, et al. 2014). While the expanding community forestry practices of the region (DFRS 2015a) confound the forest-water relationships, the overall shortage of scientific evidence also gives rise to the persistence of simplistic assumptions about these relationships (Calder 2005), such as the alleged linkages between deforestation in the mid-hills and the incidences of floods and landslides in parts of India and Bangladesh (Ives 1987, 2004; Surendra & Rajesh 2015; Thompson & Warburton 1985). In fact, evidence-based policy making in Nepal's forestry sector is still at infancy (Acharya 2005a; Gerrard 2007). In recent years however, there is growing institutional focus to incorporate the principles of scientific forestry. This is evidenced by the development of Scientific Forest Management guidelines (MFSC 2014c) and the key forestry legislations including the Forests Act 2019 (NLC 2019) and the Forest Sector Strategy 2016-2025 (GoN 2016b). Moreover, the increased emphasis to community forestry (e.g. increasing the community forests areas from 39 to 42 % of the total forests by 2030 (NPC 2017)) in these documents means that any organised forestry research in Nepal needs to be undertaken in the context of community forestry.

1.3 Research aims and objectives

In view of the growing uncertainty about expanding community forest areas and water availability in Nepal's mid-hills catchments, this research aims to examine the hydrological effects of various types of community forests in a representative mid-hills catchment. It employs a mixed approach to scientific research as it broadens the knowledge base and increases acceptability of results, particularly when there is a strong social component to natural resources management (Hattam et al. 2015), such as in this case. This research integrates local perceptions of forest-water relationships with experimental measurements of key hydrological components of community forest sites; a naturally regenerated broadleaf forest, a predominantly planted pine forest and a mixed pine-broadleaf species forest. These sites are located in Roshi Khola catchment of Kavre district that typically represents the lifestyle and landscape of Nepal's mid-hills **(Figure 1.3)**. The overall research aim is addressed in the following objectives;

1. Document existing knowledge of forest-water relationships in the broader mid-hills region of Nepal (Chapters 2 and 3);

2. Survey perceptions of the local CFUGs on forest-water relationships in the study area (Chapter 3);

3. Measure key hydrological components of the experimental forested sites, particularly soil infiltration, rainfall interception, and overland flow generation (Chapters 4 and 5) to develop an understanding of the effects of various CFUG-managed forests on catchment streamflows of the mid-hills,

4. Contextualise the research findings and recommend appropriate steps for managing the forested catchments of Nepal's mid-hills as envisaged by Nepal's key forestry documents, including the Forest Act (2019) and Forest policy (2019) (Chapters 6 and 7).

1.4 Thesis structure

This thesis is logically structured into the following 7 chapters;

Chapter 2 sets the basis for succeeding chapters. It provides a broad discussion on the forest-water science, particularly in the context of scientific forestry discourse emerging in Nepal, and presents an overview of Nepal's forestry sector including the history and evolution of community forestry.

Chapter 3 discusses the status of knowledge on forest-water relationships in the study area and the broader Nepalese society. This is because the local perceptions of forest-water relationships influence sustainable management of forested catchments, either directly by way of how people use the forest, or indirectly by way of how they influence overarching forest policy. Thus, this chapter presents the results of a perception survey conducted among the CFUG members of the study area along with an assessment of Nepal's key forestry legislations and the widespread grey literature to illustrate the socio-cultural interpretations of forest-water relationships.

Chapter 4 presents analysis of selected soil physical properties including texture, soil organic carbon, bulk density and saturated hydraulic conductivities (K_s) of the experimental forests to show the effects of persistent community forestry practices in those forests. The K_s measurements are subsequently compared against the rainfall intensities measured at the experimental catchment to infer potential hydrological pathways of a rainfall event.

Chapter 5 presents measurements of daily rainfall and its partitioning into throughfall, stemflow and derived interception in various forest sites based on experiments carried out during June 2015-December 2016. In addition, measurements of overland flow production are provided. These results combined, show the effects of various forest types as affected by the CFUG activities and have implications for the management of the forested catchments for local and downstream water use.

Chapter 6 discusses the overall findings of the above sub-projects and contextualises these to the local circumstances. This is important because, in the absence of context-specific studies, forestry decisions in Nepal are often generalised from external experience (Ojha et al. 2007), including the current discourse in ecosystem services of the forests (Chaudhary & McGregor 2018).

Chapter 7 concludes the thesis and proposes future research recommendations that are expected to contribute toward informed decision-making of Nepal's mid-hills catchments as well as community-managed forested landscapes in similar environments.

Chapter 2

2. Forest management regimes and forest-water research in Nepal

2.1 Introduction

Since the mid-20th century, much literature has suggested that the local forest users are important determinants of loss and gain of Nepal's forest area. While these associations have formed an essential theme of social forestry research in the past decades, the biophysical aspects of forest development are far less studied. Ironically, however, regulatory measures including the forest policies often focus on technical and centralised approach to forest management, even though the efficacy of these measures to improve forest condition or the wellbeing of the forest users has been questionable. For instance, despite stronger bureaucratic control of the country's forests through the endorsement of the Private Forest Nationalisation Act (1957) and the Forest Act (1961), the deforestation rates remained high (Gautam et al. 2004b). The implementation of these measures was based on the perception that community use of the local forests caused widespread deforestation allegedly resulting in loss of soil fertility and increased incidences of floods and landslides (Eckholm 1975). These underlying misconceptions about the causes and effects of forest degradation also provided opportunities for the application of "populist" policies (Hobley & Malla 1996) and reduced appreciation for empirical evidence (See Ives 2004 for further details). Recently, there is growing advocacy to practice scientific forest management, including silviculture in community forests, mainly to improve forest biomass and in turn, socioeconomic wellbeing (Baral, Vacik, et al. 2017; Basnyat et al. 2017; Joshi et al. 2018). However, its effective implementation remains uncertain. This is mainly because of the inherent mistrust among stakeholders, particularly the government officials and local forest users (Poudyal et al. 2020). The current chapter provides an account of Nepal's historical and contemporary forest management regime including brief discussions on the major events that have either shaped or are likely to shape Nepal's forest management. This understanding is important to develop an appreciation of the local forestry sector as well as appraise the prospects of successfully implementing the results of current research.

2.2 Historical perspectives of forest management in Nepal

Despite increasing influence of the market economy, Nepalese society is predominantly agrarian. This is because the agriculture, forestry and fisheries sector jointly provide employment to over 6 million people or 64% of the economically active population (Regmi & Gautam 2014). Historically, the forests were used as a means to consolidate power and influence by rulers of Nepal that often overlooked national interests and welfare of the forest dependent communities (Malla 2001; Springate-Baginski &

Blaikie 2007). For instance, during the 17th and 18th centuries, parcels of forests were gifted to those loyal to the state while state-sponsored forest-farm conversion occurred in large parts of the mid-hills because the agricultural land there comprised the major revenue base (Mahat et al. 1986).

In the *Terai* region **(Figure 2.1)**, the state's systematic deforestation persisted until the mid-twentieth century. In addition to the push for increased revenue through agricultural land expansion by the Ranas, the rulers at the time, deforestation intensified due to high demand for railway construction in India and land clearing by the migrant populations (Soussan et al. 1995). While this occurred, the traditional use of forest resources including extraction of timber, firewood, livestock fodder, compostable litter and medicinal herbs by the local communities continued, and indeed, persists today (Thwaites et al. 2018).

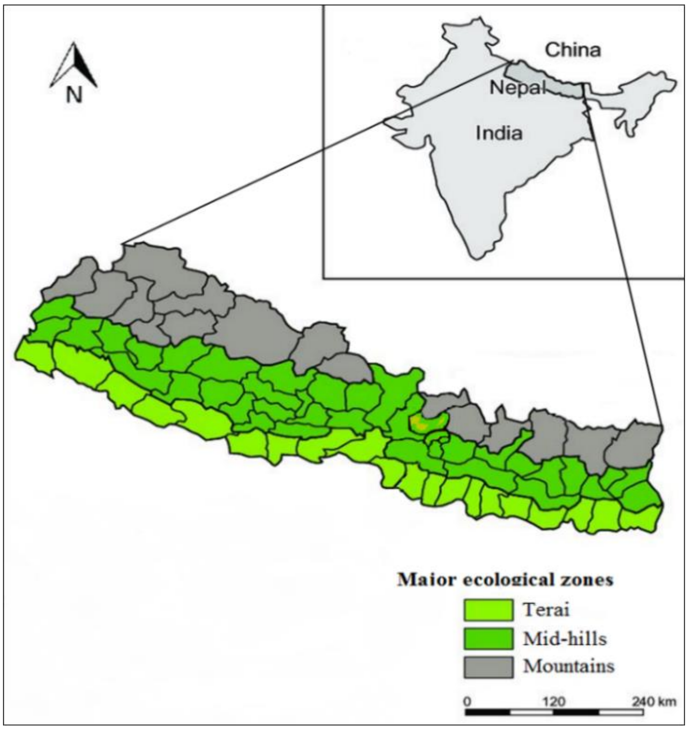

Figure 2.1: Nepal's main ecological zones (Source: Schwab et al. (2015))

The traditional forestry regimes have often portrayed the local use of forests as problematic to forest management (Ojha 2006). This viewpoint was institutionalised through the enactment of the Private Forest Nationalisation Act in 1957 that brought the ownership and management of all forests under government control. Subsequent efforts to expand bureaucratic efficiency continued through various changes to the regulatory framework including the Forest Protection Act 1967, Forest Products Rules 1970 and the National Forestry Plan 1976. However, because these changes overlooked the inherent role of local communities in forest protection and the Forest Department lacked adequate means to implement or monitor its activities, the rate of forest loss escalated (Gautam et al. 2004b; Gilmour & Fisher 1991; Mahat et al. 1986; Soussan et al. 1995). For instance, there was an approximate 6%

reduction in the area of forest (6.5 to 6.1 million ha) during 1964-1979 (Wallace 1988). Subsequently, as a result of the evolving national and international political environment, there was growing recognition for the role of community engagement in the forestry sector, particularly in view of the degrading mid-hills catchments (Hobley & Malla 1996). Accordingly, amendments to the Forest Act in 1977 and the development of Panchayat Forest Rules (1978) enabled local councils (called Panchayats) to manage the forests that were classified into four categories viz. Panchayat forest, Panchayat protected forest, Leased forest and Religious forests. However, the countrywide deforestation rates remained high due to the inadequate co-ordination between the local and central governments as well as the control of the rural forests by the local elites (Bajracharya 1983). To address these issues, the Master Plan for the Forestry Sector (1990) was developed that outlined the institutional and benefit sharing mechanisms for community participation in forest management in Nepal (MFSC 1988). Subsequently, the regulatory framework identified by the Master Plan was legitimised through the enactment of the Forest Act (1993), which led to the development of Nepal's contemporary guidelines, procedures and ad hoc decisions on forest management (Carter et al. 2011).

2.3 Reforestation following the "theory of Himalayan environmental degradation"

While the current extent of Nepal's forest area (6.6 million ha or approximately 45% of the land area (GoN 2016a)) is comparable to that reported in the mid-1960s (6.5 million ha in 1964 (Wallace 1988)), it fluctuated widely during the years in-between **(Figure 2.2)**.

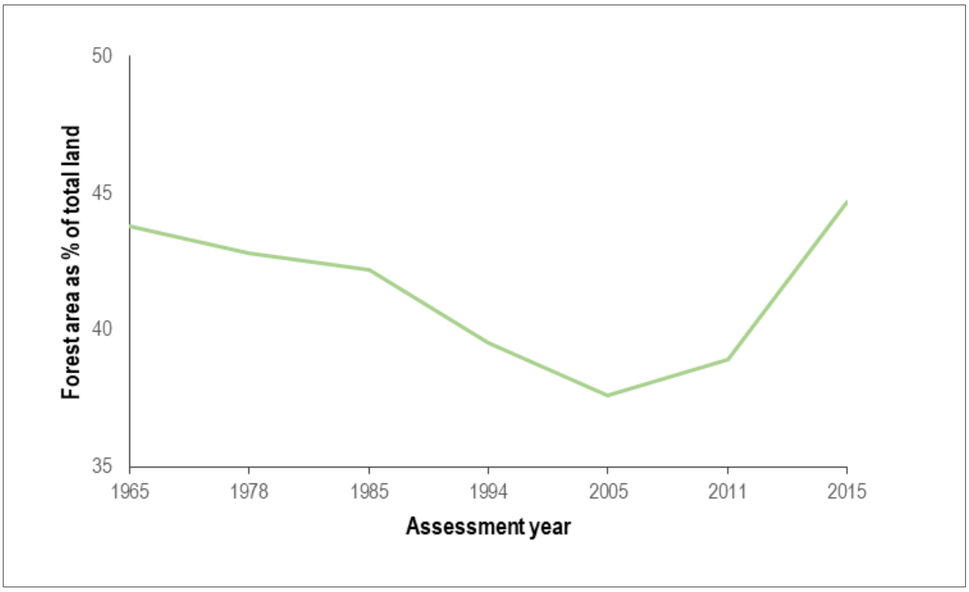

Figure 2.2: Nepal's forest cover change during 1965-2015 (Source ADB (2014); FAO (2005))

The debatable causes of deforestation in Nepal include population growth, intensive use of forest resources, ineffective government policies, tourism (Chaudhary et al. 2016) and to some extent, the methodological variations applied to measuring the forest cover (Soussan et al. 1995). In fact, deforestation rates have historically been high in most of the broader Himalayan region including India and China (Haigh et al. 1990; Nautiyal & Babor 1985; Nigel 1986; Tucker 1987). However, the rates were claimed to be particularly high in Nepal, mostly in the mid-hills so much so that the hills were predicted to lose nearly all forests by 1990 (The World Bank Report 1979). The consequent eco-hydrological problems allegedly included increased incidences of floods, landslides and removal of large volumes of fertile soil from the hills to the plains across the national boundaries (Haigh et al. 1990; Myers 1986; Rieger 1981). These consequences of deforestation in Nepal mid-hills were depicted as an 'ecological disaster' by Eckholm (1976) and critically denoted by some as the ''theory of Himalayan environmental degradation" (see Ives (2004)). However, the simplistic nature of these linkages between the reported forest loss and the large-scale hydrological processes have been widely refuted (Gardner & Gerrard 2003; Gilmour 1988; Hofer & Messerli 2006; Ives 1989). This is because the claims did not account for the role of young geology, steep terrain or the concentrated rainfall patterns of the region, even though the hydrological effects of these factors are widely acknowledged (Bruijnzeel & Bremmer 1989; Hamilton 1987; Ives 1987; Metz 1991). Regardless of these, the alleged 'ecological crisis' not only secured global attention, forming the basis of foreign aid and development plans to Nepal (Soussan et al. 1995), it also influenced the subsequent national forest policies focussing largely on reforestation programs (Guthman 1997; Hobley & Malla 1996).

In addition to solving the perceived eco-hydrological issues, reforestation was needed to supply the traditional forest product needs of the local communities. For instance, during 1978/79, it was estimated that an additional 2.1 million ha were needed to adequately meet the fodder demands based on 1 ha of farmland requiring an equivalent of 2.8 ha of forest land (Wallace 1988). Accordingly, the newly formed Master Plan for the Forestry Sector aimed to develop forests in 1.25 million ha area (MFSC 1988) while the World Bank recommended planting at annual rates of 50,000 ha until 1990 and 10,000 ha until 2000 (Sattaur 1987). These proceedings were accompanied by the government's expanding reforestation targets **(Figure 2.3)** along with the donor-funded forestry programs such as the Nepal-Australia Forestry project which supported the establishment of approximately 20,000 ha new plantations in two central mid-hills districts during the 1980s/90s (Cribb 2006; Gilmour 2003). Expectedly, subsequent studies reported increased forest areas in the mid-hills, particularly with planted pines (Gautam et al. 2003; Schreier et al. 1994). In a chronological illustration of Nepal's forestry history, Kanel and Acharya (2008) termed the period (1987-2003) as the "expansion stage". According to Dangal and Das (2018), an estimated area of 0.4 million ha have been reforested since the early 1980s mostly with pine species for increased biomass production and landscape restoration in the mid-hills due to the species' high suitability to the region.

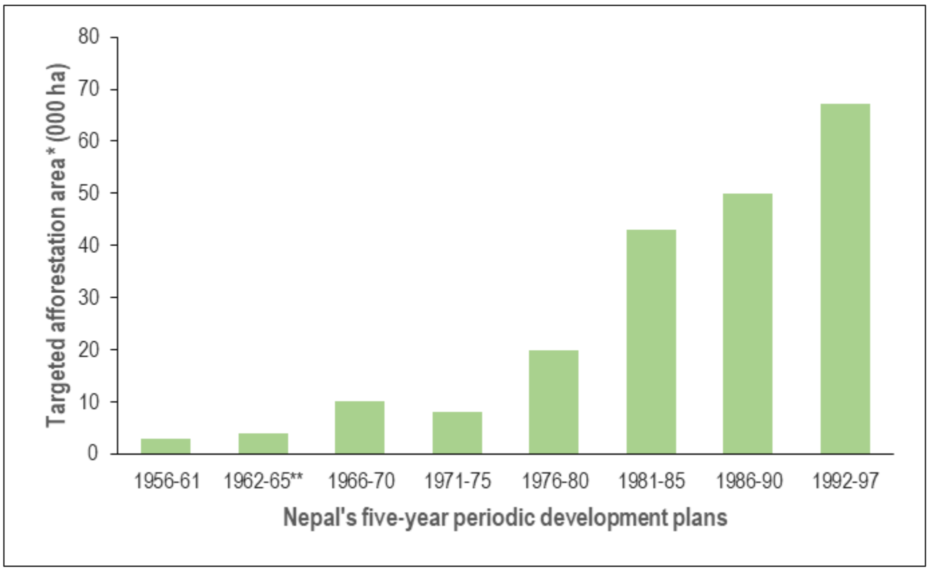

Figure 2.3: Afforestation targets in various development plans (Source: NPC (2016a))
* Figures do not include the areas afforested by the community or non-government organisations
** Figures also include areas of nursery establishment in this 3-year development plan.

Following on from the years of forest expansion, there is a strong focus to protecting the forests. In addition to reduced incidences of floods and landslides (Mathema 2016), forest-protection is increasingly linked to climate change mitigation, particularly through the schemes such as Reducing Emissions from Deforestation and Forest Degradation (REDD$^+$) of the United Nations (Paudel 2018; Poudel, Rana, et al. 2018).

2.4 Community forestry as the mainstay of forest management

It is often claimed that, under appropriate circumstances, local management of forest resources is more effective than centralised control in achieving the objectives of Sustainable Forest Management (SFM) (FAO 2019). This recognition has also led to the adoption of community-based forest management practices, particularly in regions of high forest dependence (Gilmour 2016; Thwaites et al. 2018). Although started as a progressive movement to respond to the community needs and ecological concerns (RECOFTC 2013), community-based forestry now entails "initiatives, sciences, policies, institutions and processes" directed toward increased local control of forest management responsibilities (Gilmour 2016). In Nepal, while this mode of forest management represents the long-standing system of collective resource use, it was formalised only in the late 1970s, largely as a policy instrument to reduce high deforestation rates under centralised governance as stated before. The introduction of the policy was further encouraged by growing global concerns about the environmental effects of deforestation in developing countries and the calls for decentralised governance. Thus, there was a subsequent emergence of internationally funded community forestry projects including the Australian, Swiss, the UK and USA governments in Nepal (Fisher et al. 2018). According to Soussan et al. (1995), more than half of the various 68 agencies undertaking forestry projects by the late 1980s included elements of community forestry.

The community forestry policy as it is now implemented, recognises the CFUGs as the autonomous local organisations to implement various forest management activities as per the government-approved Operational Plan (DoF 2009). Thus organised practices have continued to expand in terms of both geographic area as well as the number of households involvement as seen in Kavre district **(Figure 2.4);** this is a pioneering district to implement community forestry practices in Nepal (DFO Kavre 2014b). Countrywide, a total of 2.2 million ha or 41% of the national forest area is currently managed by nearly 2.9 million households as per the policy (DoF 2018b).

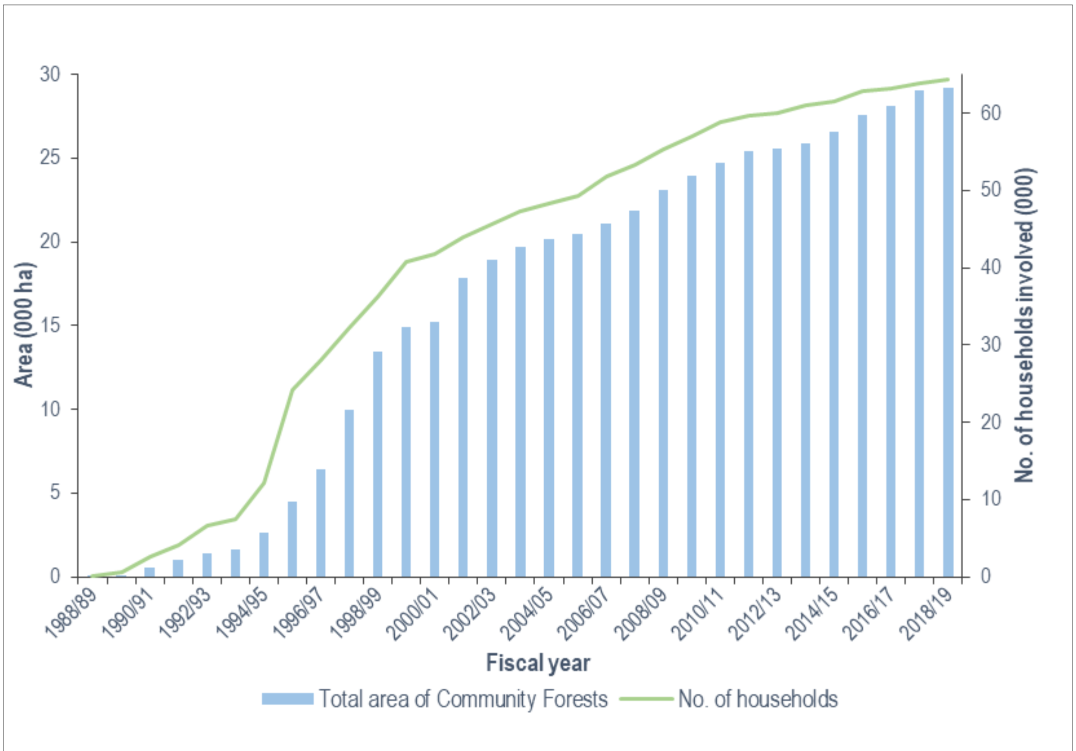

Figure 2.4: Trends of community forestry in Kavre district (Source: DFO Kavre (unpublished data)

It is estimated that the sale or use of forest products including timber, firewood, fodder and medicinal herbs from the community forests of the mid-hills generates approximately USD 5 million (NPR 604.1 million) annually (Kanel & Niraula 2004). These funds constitute an important source of local development because the program guidelines (DoF 2009) require at least 35% of this budget to be directed toward community development activities including the construction of roads, schools and local employment. Likewise, the Forest Act 1993 (GoN 1993) mandates a CFUG to direct a minimum of 25% of its income toward forest restoration and conservation. As such, a number of studies have highlighted the socioeconomic contribution of the community forests (e.g. Adhikari et al. 2007; Bhattarai 2011; Dev & Adhikari 2007; Dev et al. 2003; Devkota, Thwaites, et al. 2018; Ojha et al. 2009; Oli et al. 2016) despite challenges to the CFUGs tenure rights (Bhandari & Uibrig 2008; Ojha 2006) and benefit sharing among forest users (Adhikari & Lovett 2006; Agarwal 2001; Dhakal & Masuda 2009; Gilmour 2003; Lama & Buchy 2002; Thoms 2008). Interestingly, there is a greater recognition that community forests contribute to improved forest conditions and environmental quality **(Table 2.1)** including carbon sequestration and climate change mitigation (Karky & Skutsch 2010; Khanal et al. 2010; Maraseni et al. 2014; Paudel 2018; Sharma et al. 2015).

Table 2.1: Examples of studies on contributions of community forestry in Nepal

Contributions to improved forest conditions (area, density, biodiversity)	(Acharya 2004; Bajracharya et al. 2006; Chand et al. 2015; Edmonds 2002; Fleming & Fleming 2009; Fox 1993; Gautam 2007; Gautam & Shivakoti 2005; Gautam et al. 2002; Gautam et al. 2004a; Gilmour & Fisher 1991; Gilmour & Nurse 1991; Jackson et al. 1998; Luintel, Bluffstone, et al. 2018; Nagendra et al. 2008; Niraula et al. 2013; Pandit & Bevilacqua 2011; Paudyal, Putzel, et al. 2017; Poudel et al. 2015; Shyamsundar & Ghate 2011; Virgo & Subba 1994; Webb & Gautam 2001; Yadav et al. 2003)
Contributions to ecosystem services including water supply	(Bhandari et al. 2016; Bhatta et al. 2014; Bhatta et al. 2015; Birch et al. 2014; Paudel 2017; Paudyal et al. 2015; Paudyal et al. 2018; Paudyal, Baral, et al. 2017; Van Oort et al. 2015)

While the application of community forestry policy in Nepal demonstrates the theoretical success of locally organised resources management strategies (Ostrom 1990; Varughese & Ostrom 2001), there is an increasing need to quantify the effects of increased forest cover due to community forestry practices, particularly considering the growing importance of the mid-hills catchments for downstream water supply.

2.5 Forest-water research in the context of emerging scientific forestry debate

The notion that forests increase downstream flow has been refuted by many experimental studies (e.g. Bosch & Hewlett 1982; Brown et al. 2005; Calder et al. 2003; Farley et al. 2005; Filoso et al. 2017; Hornbeck et al. 1993; Jackson et al. 2005; Jayasuriya et al. 1993; Robinson et al. 2003; Sahin & Hall 1996; Sun & Li 2005; Zhang et al. 2001; Zhang et al. 2017) as streamflows generally reduce following reforestation **(Figure 2.5a).** This is largely due to the higher water use of forests as compared with the vegetation that are usually replaced **(Figure 2.5b).** Thus, a pasture vegetation would yield more runoff than would be expected from a forested area receiving the same amount of rainfall. Yet, uncertainties remain about the extent and nature of the hydrological effects (Calder 2005) particularly in relation to the type, location, age and use of afforestation (Venkatesh et al. 2014). Moreover, because the studies reporting the streamflow reductions due to forestation are unrepresentative of the tropical environments

(Farley et al. 2005; Filoso et al. 2017; Jackson et al. 2005), Malmer et al. (2010) cautioned against generalising the results. In particular, these studies fail to take into account the effects of forest use related disturbance arising from the complex forest-people relationships in the region that affects several aspects of hydrological functioning of the forested landscapes (Bonell & Bruijnzeel 2005; Bonell et al. 2010; Bruijnzeel 1989, 2004; Ghimire 2014a; Gilmour et al. 1987; Scott et al. 2005; Sun et al. 2006; Zhang 2018; Zhou et al. 2002; Ziegler et al. 2006; Zimmermann et al. 2006; Zwartendijk et al. 2017).

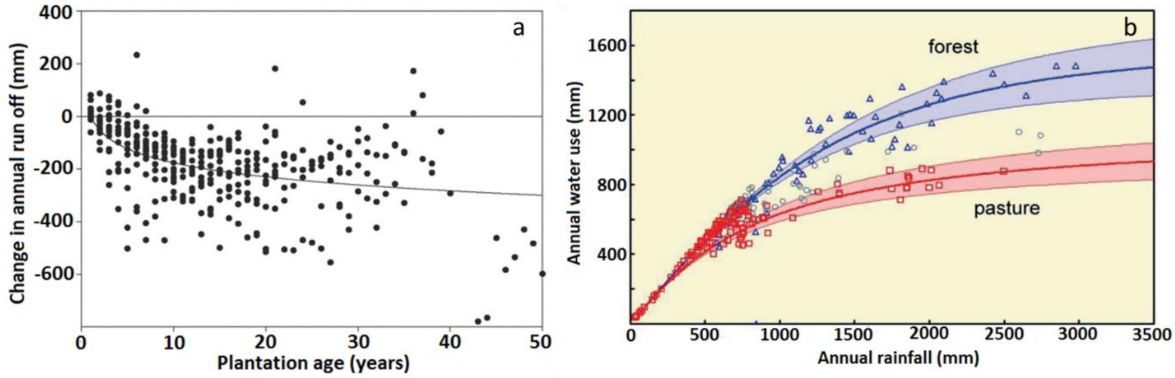

Figure 2.5: Change in run off due to forest plantations (a) (Jackson et al. 2005), and comparative water use by forest and pasture (b) (Zhang 2018).

While tropical forests are the primary source of livelihood opportunities to large populations (Byron & Arnold 1999; Lamb 2011; Reed et al. 2017), the interpretations of forest-water relationships are often based on anecdotal evidence that contradict the mainstream scientific literature (Andréassian 2004; Gilmour 2014; Kaimowitz 2005). In Nepal, for instance, claims about increased water availability due to forestation (Lamsal 2014; MFSC 2014b) and conversely, reduced dry season flows due to deforestation (Shrestha 1994, 1999) are frequently documented. Similarly, the benefits of upland reforestation on flood mitigation are also overestimated, which subsequently creates room for intensive exploitation of catchment resources (Calder & Aylward 2006). In light of these differing opinions, Calder (2002) emphasised the need to reconcile science with the public perceptions on forest-water relationships for managing forested landscapes.

It is perhaps the legacy of the "theory of Himalayan environmental degradation" that the focus of the contemporary forestry policies in Nepal has been largely on afforestation/reforestation and conservation. For illustration, the government of Nepal planned to reforest 200,000 ha of land during the "forest decade" period of 2014 to 2024 (MFSC 2015a). Similarly, as part of the country's sustainable development goals, specifically goal 15 (National Planning NPC 2017), there are plans to afforest 5,000 ha private and public lands annually while also increasing the per hectare tree density from 430 to 645 during 2015-2030. Moreover, the plans emphasise carrying out bioengineering for river conservation that involves, among others, revegetating the river banks (Dhital et al. 2013). While these are the customary catchment conservation strategies in Nepal, considerations are required toward the ensuing hydrological effects of revegetating degraded lands.

In recent years, there is a growing realisation that Nepal's approach to forest management is largely conservation-centric and that the forests contribute sub-optimally to the national economy (Jayasawal & Biswokarma 2016; Yadav et al. 2009). This has called for the wider application of silvicultural practices for increased yield of timber and non-timber forest products (Cedamon et al. 2017). It is estimated that scientific management of the major planted and natural forests of Nepal can add NPR 100 billion (approximately 8.2 million USD) to the national economy (MFSC 2014c). Scientific forestry practices are still at primitive stage in Nepal as the areas managed in this way are limited only to 81,500 ha (Kafle 2018) while questions also remain about the viability and acceptance of the practices (Basnyat et al. 2018; Joshi et al. 2018; Rutt et al. 2015)). Nevertheless, there are early reports showing improved forest cover (Pokharel et al. 2018) and higher seedling and sapling regeneration rates (Khanal & Adhikari 2018) due to the application of silviculture in parts of Nepal. Again, the specific hydrological effects of these changes in forest structure and composition are unclear, even though increased crown cover and stem density as reported in these instances, are important factors affecting rainfall partitioning and components of hydrological cycle. For instance, partitioning of rainfall as well as transpiration, overland flow and infiltration were variously affected by different forest types in parts of the central mid-hills (Baral 2012; Ghimire 2014a) while higher tree density was associated with increased transpiration in the tropical India (Kallarackal & Somen 1997). Similarly, species composition affected the amount of intercepted rainfall, throughfall and stemflow in the sub-tropics (Gupta & Usharani 2009; Loshali & Singh 1992; Pathak et al. 1985) as well as overland flow and infiltration in the central Himalayan region of India (Negi et al. 1998). Thus, these variations call for the development and application of region-specific guidelines for scientific forest management, specifically considering the overall shortage of field-based data in the region (Thompson & Warburton 1985).

2.6 Conclusion

The state of Nepal's forestry sector is perhaps most aptly described by Westoby (1987) in saying that it is about people rather than forests. Thus, while community forestry practices represent the long-standing traditions to managing common property resources, it is unclear how these increasingly structured activities (e.g. through the application of silviculture) affect the hydrological functioning of forested landscapes. This is particularly true in the community forestry-dominated areas of the mid-hills that are characterised by the complex geography, climate and overall shortage of credible empirical evidence on the forest-water relationships. Importantly, the established perceptions about those relationships strongly influence the evidence-based policy-making processes to manage the forested catchments of Nepal mid-hills as illustrated by the succeeding chapter.

Chapter 3

3. Management of the forested catchments of Nepal's mid-hills amid mismatched perceptions of forest-water relationships: Challenges and opportunities

3.1 Statement of Authorship

Title of Paper	Management of the forested catchments of Nepal's mid-hills amid mismatched perceptions of forest-water relationships: Challenges and opportunities		
Publication Status	☑ Published ☐ Submitted for Publication	☐ Accepted for Publication ☐ Unpublished and Unsubmitted work written in manuscript style	
Publication Details	Badu, M., Nuberg, I., Cedamon, E., Sharma, S., 2019. Management of the forested catchments of Nepal's mid-hills amid mismatched perceptions of forest-water relationships: Challenges and opportunities. Mountain Research and Development, 39 (4), R27-R36		

Principal Author

Name of Principal Author (Candidate)	Manoj Badu		
Contribution to the Paper	Theoretical conceptualisation, data collection and analysis, manuscript writing, corresponding author		
Overall percentage (%)	85		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidatuɪe and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	05/11/2020

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate in include the publication in the thesis; and
iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	Ian Nuberg		
Contribution to the Paper	Supervision of the study, assistance in theoretical conceptualisation, manuscript evaluation and editing		
Signature		Date	05/11/2020

Name of Co-Author	Edwin Cedamon		
Contribution to the Paper	Assistance in data analysis using SPSS, manuscript evaluation and editing		
Signature		Date	05/11/2020

Name of Co-Author	Subodh Sharma		
Contribution to the Paper	Assistance in research area identification, manuscript evaluation and editing		
Signature		Date	05/11/2020

3.2 Abstract

The expanding community forestry practices since the late 1970s and, recently, outmigration have led forest cover to increase in Nepal's mid-hills catchments (>52% of the 4.3 million ha). The catchments traditionally provide food and income for local communities, and they are increasingly important for ecological functions, particularly downstream water use. While the hydrological effects of increasing forest cover are generally unclear in the mid-hills region, mismatched perceptions of forest-water relationships between sections of Nepalese society and scientists challenge the management of the catchments in meeting traditional community needs and growing water demand sustainably. This paper shows the prevalence of the culturally formed notion of "more forest-more water" within broader Nepalese society and the conservation-centric attitude of forest policymakers, who focus on reforestation and afforestation. These perceptions contradict general scientific evidence that shows forest development reduces catchment water yield. Conversely, the results of semi-structured interviews (n=150) conducted among members of community forest user groups (CFUGs) in the Roshi Khola catchment of the mid-hills district Kavre showed that 44% of respondents consider that forests contribute to increased water quantity, and 37% think forests decrease it. Furthermore, the respondents that viewed forests as reducing water quantity disliked pine forests because these allegedly caused the reduction. Interestingly, there was a positive correlation between the duration of membership in the CFUG and the perception that forests increase water. Thus, while there is a high research need to understand the forest-water relationships in the mid-hills, extensive communication of research results and deliberation about them are crucial to developing widely acceptable plans for managing the catchments. This is particularly important in the context of expanding community forestry practices and the current debate on scientific forestry presented by Nepal's key forestry documents, including the Forestry Sector Strategy 2016-2025 and Forest Policy 2019.

Key words: Forest; water; community perceptions; Nepal mid-hills; community forestry

3.3. Introduction

Current scientific literature largely acknowledges that increased forest cover in catchments reduces water availability due to, for instance, increased evapotranspiration (Bosch & Hewlett 1982; Zhang et al. 2001), reduced streamflow or run-off generation (Farley et al. 2005; Johnson 1998). These relationships between forest area and catchment water yield have been reported for diverse vegetation and climatic conditions including in Europe (Nelson 2013), Australia (Cornish & Vertessy 2001; van Dijk & Keenan 2007), and the tropics (Bruijnzeel 2004; Scott et al. 2005), among others; many authors have found similar results from global catchment studies (Andréassian 2004; Brown et al. 2005; Sahin & Hall 1996; Zhang et al. 2017). Yet, beliefs that forests improve water availability persist and affect forest policymaking processes (Calder 2002, 2006, 2007; Gilmour 2014).

The belief that forests improve hydrological outcomes is commonly reiterated by the media, forestry practitioners, and development agencies globally. This association between forests and hydrological benefits has often led to increased focus on afforesting or reforesting degraded landscapes (Calder 2005). Thus, increased forest cover is strongly linked to realizing the United Nations' Sustainable Development Goals (Bastos Lima et al. 2015; Gratzer & Keeton 2017; Gregersen et al. 2017) and climate change mitigation (Ellison et al. 2017), and forested landscapes are increasingly recognized for their ecological value, as well as spiritual and cultural values. Accordingly, the forest area managed explicitly for soil and water protection has risen to over a billion hectares (>25% of the global forest area), while growing number of countries (42 in 1990 to 51 in 2015) have recognised the cultural values of forests (Miura et al. 2015). This is matched by the declining global deforestation rates overall, although high rates persist in many low-income countries (Keenan et al. 2015; Sloan & Sayer 2015). Recently, however, some countries in this category, such as Nepal, have reported increases in forest area.

Based on its 2015 Forest Resources Assessment (DFRS 2015b), the total forest area in Nepal reached approximately 6 million ha, while it was 5.6 million ha in 1978/1979 and 4.3 million ha in 1994. By contrast, the forest areas allocated for soil and water protection grew by nearly 14 % to 650,000 ha from 1990 to 2015 (FAO 2015a). Moreover, the forested area composed of naturally grown or planted varieties of broadleaved and pine species constituted over 52% of the 4.3 million ha of the country's mid-hills catchments, mostly as a result of prevalent community forestry practices since the late 1970s and, increasingly, outmigration (Jaquet et al. 2015; Kc et al. 2017; Pandey et al. 2016; Paudyal, Putzel, et al. 2017; Tiwari & Bhattarai 2011). This increase is notable because the region's allegedly high deforestation rates during the mid-1970s caused severe hydrological effects of transnational significance (Eckholm 1976) prompting large-scale revegetation programs (Gilmour 2003) while concurrently raising concerns about the programs' inability to incorporate local community needs and principles of scientific forestry (Bajracharya 1983).

Recently, forestry documents, including the Forest Policy 2075 (NLC 2019) and Forestry Sector Strategy 2016-2025 (GoN 2016b) have underlined the importance of scientific forestry, mainly due to the realization that the forests contribute suboptimally to the national economy. At the same time, the Scientific Forest Management guidelines 2014 estimated an annual gain of NPR 15 billion (about US$126 million) through scientific management of nearly 247,000 ha southern *Terai* forests (MFSC 2014c). More recently, the first National Silviculture Workshop (19-21 February 2017) emphasised the incorporation of silvicultural principles for improved forest production and income generation (DoF 2017). Despite the progress, consideration of the hydrological effects of forest growth or management is mostly missing at the practical or policy level in Nepal, and it is poorly understood overall for increases in forest cover through afforestation or reforestation (Venkatesh et al. 2014). This is particularly valid for the broader mid-hills region where nearly 0.4 million ha plantations of mainly the pine species *(Pinus roxburghii* and *Pinus patula*) have been generated since the 1980s (Dangal & Das 2018). These plantations were implemented jointly by the local communities, the Nepal government, and international development agencies, particularly the Nepal-Australia Forestry Project (Gilmour 2003; Nuberg et al. 2019). They are now predominantly managed by local communities, who are organised into community forest user groups (CFUGs), as part of the community forestry program that began in the late 1970s (Gilmour & Fisher 1991; Thwaites et al. 2018).

This article aims to support sustainable management of the forested catchments of Nepal's mid-hills, which encompass a variety of broadleaf and pine species, provide livelihood to over 11 million local inhabitants (Pathak & Lamichhane 2014), and supply water for drinking, irrigation and hydropower generation to a much larger downstream population (GoN 2011). Importantly, the mid-hills constitute a hydrologically important mountainous region characterised by a complex society-water interface (Nüsser 2017). They experience a highly variable seasonal discharge owing to the prevailing climate, where nearly 85 % of the annual rainfall is concentrated during June-September (Merz et al. 2003). This regularly causes socioeconomic hardships to local and downstream communities (Adhikari 2013; CRED 2018). The catchments' water sources face mounting pressure in supplying the growing urban population (Gyawali & Dixit 2010; Udmale et al. 2016) amid shifting hydrological regimes due to climate change (Sharma & Shakya 2006; Shrestha et al. 2016). At the same time, there is growing recognition of the catchments' ecological services, including providing water (Bhandari et al. 2016; Bhatta et al. 2015; Birch et al. 2014; Paudyal, Baral, et al. 2017; Rai et al. 2015; Van Oort et al. 2015), while concerns about the forests' role in the declining water sources grow, particularly in areas of the mid-hills that were reforested to pine (CBS 2017; Poudel & Duex 2017; Sharma et al. 2016; Shrestha 2016).

3.4. Balancing forest–water relationships for effective catchment management planning

There is a clear need for improved scientific understanding of forest-water relationships that take into account the site or species-specific hydrological effects of forest development in Nepal's mid-hills catchments. This understanding is crucial for developing evidence-based management plans for the forested catchments, as found in certain countries such as South Africa (Edwards & Roberts 2006), the United States (Gartner et al. 2013; Jones et al. 2009), and Australia (Keenan et al. 2003; Stirzaker 2002; Vertessy 2000). Importantly, effective implementation of such plans requires extensive deliberation and communication among various sectors of the community (Creed & van Noordwijk 2018). It provides opportunities to develop a consistent knowledge base and minimize risks associated with the biophysical and socioeconomic complexities of resource use that are characteristic of the mid-hills (Ives 2004), as well as the broader mountainous region (Breu et al. 2017; Kotru et al. 2015).

Conversely, however, this article shows the prevalence of the divergent views about forest-water relationships among sections of the Nepalese community that pose a restrictive policy environment on developing and implementing such plans. This is mostly due to the culturally-formed general notion of 'more forest-more water' held by the broader Nepalese society, and the conservation-centric attitude of the forest policymakers, who largely focus on reforestation or afforestation activities (Ojha 2017). On the other hand, the perceptions of the CFUGs, as the direct users and managers of the majority of the mid-hills forests (Sharma et al. 2017; Thwaites et al. 2018), presented here are consistent, to a greater extent, with the limited scientific evidence on forest-water relationships in the region. The broad consistency between available scientific evidence and CFUG perceptions, representing the deeper experiential understanding of forest management, presents opportunities for developing evidence-based catchment management plans that are locally applicable, particularly for integration into the widespread CFUG programs in the mid-hills (DFSC 2019). This is prudent because the traditional policymaking practices in Nepal's forestry sector inadequately integrate the expertise or interests of the local communities despite the well-founded knowledge systems of forest management (Nightingale 2005). This attitude of the forest policymakers further impedes policy innovation and effective implementation in Nepal (Ahlborg & Nightingale 2012; Ojha 2013; Ojha et al. 2016; Sunam et al. 2013). Incorporation of divergent views on forest-water relationships increases the acceptability of the ensuing catchment management plans (Calder 1996; Calder & Aylward 2006; Pant et al. 2005) and improves contextual appreciation of resource use. This is because both the forest and water resources are used, managed and symbolized uniquely across societies (Baviskar 2007).

3.4.1 Sociocultural interpretations of forest-water relationships in Nepal

Religious faiths strongly inspire forest management globally (Bhagwat & Rutte 2006; Hamilton 2002; Nelson 2013), including in Nepal (Ingles 1994). Nepalese society maintains a firm cultural base constructed predominantly on Hindu-Buddhist philosophies (81 % Hindus and 9 % Buddhists) (Dahal 2014)) that explicitly recognize the role of forests (Baltutis 2016; Clark 2011) and their ability to influence other ecosystem components, particularly water (Allison 2015; Bhagwat et al. 2014). Accordingly, numerous tree species evoke a tradition of worship (Majupuria & Majupuria 1978; Niroula & Singh 2015), and, thus, Nepal's overarching forestry document, the Forest Act 2076 (NLC 2019), incorporates provisions for managing parts of the national forest as religious forest to signify the sacred values assigned by the local communities; this area constituted over 2,000 ha in 2014 (MFSC 2014a). This is perhaps why Nepal is known to have embraced an "enlightened" approach to conservation (Heinen & Yonzon 1994; Ormerod & Juttner 1999) which constitutes an inherent aspect of Hinduism (Adhikari 2016).

The interpretations of forest-water relationships are embedded in various forms of sociocultural faiths and rituals (Calder 1999; Sitthisuntikul & Horwitz 2015). In Nepal, planting or protecting trees, particularly around religious sites and water sources, is customary (Basnet 1992). For example, Jana and Paudel (2010) identified a number of religious and cultural sites across the country that integrate forests and water bodies, particularly ponds and lakes that are conserved and protected by local community groups. While these practices are manifestations of the dominant religious faiths in Nepal, the local belief systems intermixed with these consider water availability or scarcity as an 'Act of God' as are other natural events such as floods, landslides (Sherry & Curtis 2017) and the onset of rain (Khatry 1996).

Nevertheless, while tree-planting is practiced as a strategy to tackle water scarcity at community level (Yang et al. 2014), the perceptions that forests improve hydrological outcomes, such as water availability, are prevalent in the broader Nepalese society, including the mid-hills, as is seen in **Table 3.1**. The selected excerpts from media coverage in **Table 3.1** highlight the important role of the media in influencing public debate on broader environmental issues in Nepal (Khatri et al. 2016). These suggest the prevalence of the 'more forest-more water' beliefs in Nepalese society that are also common globally (Calder 2005; Gilmour 2014).

Table 3.1: Broader societal perceptions of forest-water relationships from selected Nepal media.

Excerpts of the reported propositions	Source
Water sources restored because of the community forests	Shahi (2011)
Water sources restored because of the community forests	Silwal (2013)
Ban on tree cutting within 100 m of water sources for improved water availability	Ghimire (2014)
Water sources drying up fast in eastern Nepal due to deforestation, locals saving forests to avert the situation	Khadka et al (2016)
In addition to the other traditional community benefits, recent increase in the forest cover contributes to water sources availability	Basnet (2016)
Deforestation contributing to rampant water scarcity, need to plant broadleaf tree species that induce rain and retain moisture, not pines	Anonymous (2018)
Forest loss around the lakes contributed to their drying up	Kantipur (2019)

3.4.2 Traditional forest policies focus largely on reforestation/afforestation activities

The hydrologic importance of trees and forests, including for improved water availability, has been historically documented in Nepal. For example, in 2000 BC, cultural customs about communal use of natural resources became authoritative decrees to protect forest resources, including specific trees, such as *Shorea robusta*, a broadleaf deciduous tree endemic to the South and Southeast Asia (Orwa et al. 2009), to sustain ground water (Oli 1996). Likewise, R*ule fourteen* of King Ram Shah during the early AD 1600s ordered the protection of trees around springs for continuous water supply and applied a NPR 5 fine (similar to fines applied for social offences eg illicitly accusing someone of witchcraft) to those cutting down trees near water sources (NLC n.d.).

Until the mid-20th century, successive regimes systematically exploited the forests to consolidate political and financial power (Bajracharya 1983; Gautam et al. 2004bb; Gautam 2006; Springate-Baginski & Blaikie 2007), giving rise to protection-centric legislation, which was further supported by the growth of nature-centred tourism and concerns for nature conservation globally (Heinen & Shrestha 2006). However, emphasis on increased forest cover to improve hydrological outcomes grew after the widely-publicized but contested (see Ives (2004) for details) environmental crisis (Eckholm 1976), as many national and international agencies linked this deforestation to reduced water availability. For example, the World Bank Report (1979) predicted that all accessible hill forests would disappear by 1990 and linked forest loss to the drying up of the springs, along with the advice to reforest at annual rates of 50,000 and 10,000 ha until 1990 and 2000, respectively (Sattaur 1987).

Subsequent emphasis on afforestation and reforestation activities is evident in the government's development plans, mainly the 5 year periodic plans of the National Planning Commission (NPC 2016b). For example, the sixth such plan (1980-85) aimed to afforest and improve forest in over 125,000 ha, while the seventh plan (1985-90) aimed for 175,000 ha, stating "no single forest patch to remain in the following two decades", if the prevailing forest-loss continued (NPC 2016b:54). The seventh plan also reported increased difficulty in obtaining water in the mid-hills due to forest loss, and the eighth plan reiterated drying up of springs and submitted proposals to plant trees along the riverbanks and catchment zones of the larger irrigation and hydropower projects for increased water accretion and hydrological stability (NPC 2016b). Aptly, therefore, increased water availability due to forest development is commonly reported in many parts of the mid-hills that generally host broadleaf species (e.g.Adhikari et al. 2015; Gurung et al. 2013; Lamsal 2014; Thapa et al. 2018).

As seen globally (Adams & Hutton 2007; Neumann 2014; Robbins 2000), forest protection or expansion is often a political rather than a scientific issue. This is also true in Nepal, as suggested by the ways forestry policy and decisions are made (Amatya et al. 2017). For instance, in 1999, the Ministry of Forests and Soil Conservation banned all types of green felling. Then, in 2002, they developed a biodiversity strategy that pushed a limited and non-scientific approach to forest management that did not consider the forest-dependent communities (Ojha et al. 2007). In 2003, the ministry stipulated planting 25 saplings for each tree lost due to a development activity (Uprety 2003, 2013). Then, in 2014, the government declared the 10-year period from 2014 to 2024 to be a "forest decade" with the tag "one household one tree, one village one forest, one city many parks" (MFSC 2015b). These directives, while seeming to reinforce pro-conservation policies, systematically overlook the principles of scientific forestry, particularly silviculture, for improved socioeconomic returns and thus they impede sustainable forest management (Ojha 2017). In a thorough account of Nepal's forestry sector, Hobley and Malla (1996) called this approach "populist", prioritizing forest protection over local community needs with concurrent emphasis on reforestation or afforestation.

The reasons for this attitude of the forest policymakers in Nepal include an inadequate appreciation of forest ecosystems (Gautam 2006), historic predominance of state interests in forest management (Ojha et al. 2010), and the influence of Western environmental protectionist philosophies in the forestry sector (Nightingale 2003) that are conveyed financially and technically by the international development community (Malla 2001). In recent decades, much protection-centric forestry has centred around environmental schemes such as Reducing Emissions from Deforestation and Forest Degradation (REDD+) (Ojha et al. 2013), which have been extended to catchment management, focussing largely on afforestation and reforestation and implemented extensively through foreign aid. For example, in 2015, there were 12 major forestry projects of this nature countrywide, while nearly a quarter (23.5%) of the annual forestry budget (year 2015/16) was composed of foreign aid (MFSC 2015b).

3.5 Survey of CFUG perceptions of forest-water relationships

3.5.1 Study area

Roshi khola catchment (85^{0}23'-85^{0}49'E; 27^{0}23'–27^{0}41'N) has an approximate area of 564 km^2 in the mid-hills district of Kavre, Nepal **(Figure 3.1)**. Typical of the mid-hills, agriculture and forest are the major land-use types in the catchment with expanding community forestry practices since the late 1970s that affect the land-use patterns of the catchment considerably. For instance, forest fragmentation has been reduced by pine plantations and regeneration (Gautam et al. 2003), with an overall increase in forest during 1976-2000 (Gautam et al. 2004a) while high forest areas increased at the cost of shrub and cultivated land during 1978-1992 (Gautam et al. 2002).

The climate varies from sub-tropical below 1000 m above sea level (masl) to cool-temperate above 2000 masl. Rainfall is between 1300-2000 mm annually, with nearly 80 % occurring during June-September. These variations in turn influence the vegetation distribution, such that *Shorea robusta* grow below 1000 masl, *Quercus* occurs in the cooler temperate areas above 1700 masl, and natural and planted species of *Castanopsis, S. wallichii* and *P. roxburghii* dominate elevations in between (DFO Kavre 2014b).

Large sections of the catchment drain either directly into the Roshi river or into its tributaries, including streams and ponds. Roshi discharge is used for drinking water, irrigation and hydropower generation (DDC 2014), with increasing demand to supply the growing urban population. For example, the ongoing Kavre Valley Integrated Water Supply Project aims to supply drinking water to the urban populations of Dhulikhel, Panauti, and Banepa municipalities in Kavre district (GoN 2014), which have jointly undergone over a 100 % population rise since 2011 to 134,385 in 2017 (MFALD 2017; Subedi 2014).

3.5.2 Data collection to understand community perceptions and analysis

Topographic maps obtained from the Survey Department of Nepal were used to delineate catchment boundaries and determine the local administrative units, called Village Development Committees (VDCs) that constituted the catchment (Note: These local units have been rearranged since the elections in 2017 as per the new constitution passed in September 2015). The records available until July 2013 at the District Forest Office, Kavre showed that a total of 288 community forests were handed over to the CFUGs in the VDCs comprising the Roshi Khola catchment in part or whole, from which 30 (ie >10 % of total) were randomly chosen to represent the catchment. This region is pioneering community forestry practices representing the typical lifestyle of the mid-hills (Gautam et al. 2002; Gautam et al. 2004a; Kavre 2014b). Further, 5 randomly selected members of the chosen CFUGs were interviewed, bringing the total number of respondents to 150. Interviews were conducted during January-March 2015, using a semi-structured questionnaire (Badola et al. 2012) through household visits. This method provided the opportunity to collect perceptions that were most reflective of the respondents' usual life and experience (Vihervaara et al. 2012).

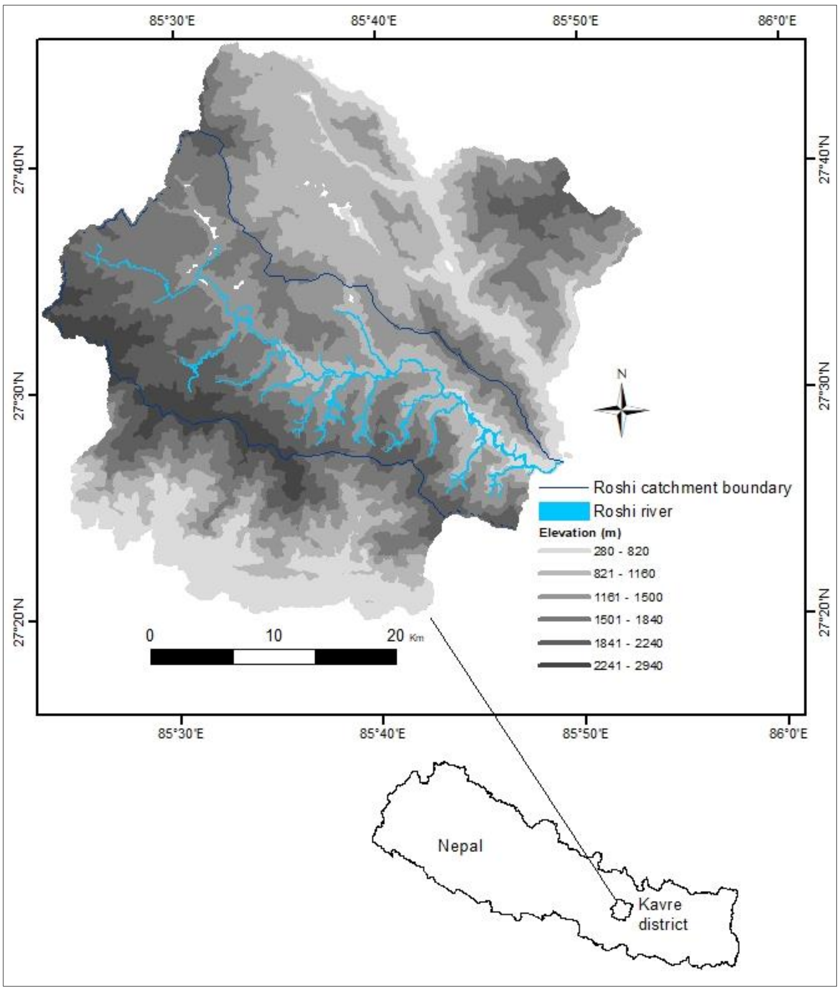

Figure 3.1: The study area: Roshi Khola catchment in Kavre district, Nepal

The interviews were conducted in the *Nepali* language by the first author of this paper and 2 local field assistants. In addition to the name, gender and primary occupation of the respondents, the interviews gathered information that highlighted the respondent's role within the CFUG (ie whether an active CFUG member or also a member of the executive committee), and the duration of membership in the CFUG. Similarly, the respondents were asked to report their understanding of changes to the water quantity (whether more or less water) and quality (whether more or less visibly turbid or polluted water) that had occurred over a period of time. The respondents were also asked to state whether any specific attributes of the forests (eg forest type, condition, management activities, etc) also affected the forest-water relationships.

3.6 Results

3.6.1 Respondent attributes and perceptions of the relationship between forest and water quantity and quality

Responses were analysed for descriptive statistics, including Pearson's X^2 test to calculate the independence between perceptions and respondents' characteristics, including gender, role within the

CFUG, and duration of the CFUG roles (0-10, 11-20, 21-30, and >30 years). The probability value of 0.05 was used to determine significance.

Of the total respondents interviewed (n=150), 76% were male, and 24 % were female. The majority (71%) identified agriculture as their primary occupation, a typical lifestyle of the mid-hills. At the time of interviewing, about 83% of the respondents were active CFUG members, while the remaining (17%) served on the CFUG executive committee. About half (49%) of the respondents had been CFUG members for 11-20 years and nearly a third (32%) had been CFUG members for 21-30 years.

Regarding water use, 83% of the respondents used river or stream water, 9% used wells or ponds, while 8% had multiple source of water for agricultural and domestic use. A very large proportion (94 %) said that the quantity of water had decreased, with over 82 and 18% indicating that the decrease had occurred in the past 10 and 20 or more years, respectively. Interestingly, earlier studies around this time reported increased forest cover in the study area, particularly due to the success of pine plantations and CFUG activities ((Gautam et al. 2002; Gautam et al. 2004a). Additionally, only 20 % of the respondents said that the water quality had diminished, with 80 % and 17 % of those considering this to have occurred in the past 10 and 20 or more years, respectively. A large majority (69 %) said that water quality had remained unchanged.

As evident from **Table 3.2**, the results showed that 44 % of the respondents perceived the forests to contribute to increased water quantity, and 37 % perceived the forests to contribute to decreased quantity. Moreover, of those who thought that forests decreased water quantity, a vast proportion (96 %) said that it was the effect of pine plantations in the area.

Table 3.2: Community forest users' group perceptions of the forests' effects on water quantity and quality

Perceived effect of forests on water quantity (%) *n* = 150	**Perceived effect of forests on water quality (%)**				**Total**
	Water quality diminishes	**No effect**	**Not sure**	**Water quality improves**	
Water quantity decreases	5	23	6	3	37
No effect	0	7	1	2	10
Not sure	0	1	7	1	9
Water quantity increases	0	20	9	15	44
Total	5	51	23	21	100

When cross-tabulations were conducted between respondents' views and their characteristics, there were no significant relationships among gender, occupation, and roles within the CFUG. However, perceptions of forest effects on water were influenced by the duration of membership in a CFUG, such that the respondents with longer CFUG experience were significantly more likely to perceive forests as contributing to increased water quantity ($X^2 = 17.56$, $df = 9$, $p = 0.041$).

3.7 Discussion

3.7.1 Changing CFUG perceptions on forest-water relationships as an opportunity for evidence-based policymaking

The public perception is that forests improve environmental quality (Maraseni & Cadman 2015), including water availability (Calder et al. 2007; Kaimowitz 2005). This is also evident from the results of this survey, as the largest proportion of the respondents (44 %) considered that forests increase water quantity, which is the dominant viewpoint within broader Nepalese society and forest policymakers as discussed earlier. The belief that forests improve water availability has also been documented in other parts of the mid-hills of Nepal (Adhikari et al. 2015; Gurung 1989).

The tendency of experienced CFUG members to consider forests as contributing to increased water quantity is notable. While this is consistent with the views of the broader Nepalese society, the situation is an example, as pointed out by Calder (2005: 29-62), wherein the deep-rooted collective intellect denies acceptance of an alternative notion that contradicts the historically acquired wisdom about forest-water relationships. However, it is expected that reforesting degraded landscapes revives disturbed hydrological conditions due to improved rainfall absorption by the soil (Bonnesoeur et al. 2019; Ilstedt et al. 2007; Scott et al. 2005), which can occur following years of forest development under low disturbance (Bonell et al. 2010; Ghimire, Bruijnzeel, Bonell, et al. 2014). Thus, it is reasonable that the afforestation and reforestation activities continue to form part of the strategies to mitigate flood and landslides, or conserve soil and water, in line with the Soil and Watershed Conservation Act 1982, despite evidence against the ability of the forests to reliably deliver those results (Calder 2005). This inherent trust of the authorities in traditional methods to catchment management, including tree-planting, has also contributed to the failure of more sustainable systems catering to local needs and interests (eg the end of decades-old ropeway in the mid-hills; (Gyawali & Dixit 2010)). This is because the traditional methods to catchment management, entailing excessive mechanization of the catchment landscape, provided suitable conditions for the government's forestry officials to exercise power and influence.

In some cases, people with deep experiential knowledge of forest use and management in Nepal assign an "emotional affection" to the trees on account of the perceived benefits of forest development (Karn et al. 2017) that apparently impedes scientific forest management. Again, while this attitude of the "experienced" forest users and managers in Nepal broadly aligns with the perceptions of the CFUGs with sustained forestry experience in this study, the views also suggest a need to apply caution in interpreting forest-water relationships, particularly in relation to the role of pine species in catchment water availability. This is because catchment water yield is affected by a host of biologically mediated and anthropogenic factors related to forest use and management, as shown by a number of studies in the broader mid-hills region (Bonell et al. 2010; Ghimire et al. 2013; Gilmour et al. 1990) and elsewhere in the tropics (eg Zwartendijk et al. 2017). Importantly, the hydrological effects in the forested catchments are further uncertain, with successional change leading to alterations in forest structure and composition; for example, broadleaf species integrating with pine plantations in parts of the mid-hills, including the study area (Gautam & Webb 2001; Gilmour et al. 1990; Paudyal & Sapkota 2018)

Nevertheless, over a third of the respondents (37 %) perceived the forests to decrease water quantity, while a much smaller fraction (15%) perceived forests to improve both water quantity and quality. A vast proportion of the respondents believed pine trees reduced water quantity, which is supported by limited scientific evidence in the mid-hills. For example, the planted pine forests contribute to reduced dry season flows due to their higher evapotranspiration (Baral 2012; Ghimire, Lubczynski, et al. 2014b) and lower soil hydraulic conductivity (Ghimire et al. 2013) as compared to the natural broadleaf species. Similar effects on water yield due to pine and broadleaf species have also been reported in other parts of the world, including north America (Swank & Douglass 1974; Swank & Miner 1968) and Japan (Komatsu et al. 2008). The study in Japan further suggested converting coniferous forests into broadleaf forest to increase water yield, as reportedly done by some local governments. However, the results are not uniform, as species respond in different ways to site conditions. For example, a mixed beech-spruce stand used up more water than a spruce only stand in Norway (Schume et al. 2004), whereas the water use by *Eucalyptus* varied with soil type in India's dry zones and used no more water than the deciduous natives (Calder et al. 1993). Likewise, evaporation by the broadleaf and pine forests was similar in Japan (Komatsu et al. 2007), while the age of *Eucalyptus regnans* was significant in affecting water use in Australia (Vertessy et al. 2001). Importantly, local perceptions of pines are not consistent, as one participant with over 25 years of CFUG experience in *Balthali* village opined, "the pines have made our dry barren hills *(sukkha rukho danda haru)* look greener- much better than before". This also suggests that more studies on pines' effects on local water availability are needed.

Yet, it is unclear whether forest-water relationships or perceptions of them will remain the same or change as the rural economies of the mid-hills transition to market-based systems, due to, for example, outmigration (Jaquet et al. 2016; Ojha et al. 2017; Sunam & McCarthy 2016) and reduced agricultural productivity (Paudel et al. 2014). Similar circumstances elsewhere are predicted to cause further increases in forest cover, for example, in India (DeFries & Pandey 2010).

3.8 Conclusion

This study shows a perception gap of forest-water relationships in Nepal, particularly among the members of the CFUGs, forest policymakers and broader Nepalese society. The broader societal perceptions that forests increase water availability, and the perceptions of the forest policymakers that focus essentially on tree planting reflect cultural beliefs and traditional practices. Conversely, CFUG perceptions, which are largely founded on lived experience in forest use and management, are more discerning: Only 44% of respondents considered forests to increase water quantity, while 37 % considered that forests reduced it. The respondents also disliked pine forests due to the alleged role of the species in causing the reduction.

We consider that the mismatched perceptions of forest-water relationships described here pose challenges to the management of Nepal's mid-hills catchments in 2 major ways: (1) They impede collective action (ie the development of widely acceptable catchment management plans); (2) the cultural interpretation of these relationships obstructs, or at least delays, the integration of scientific evidence into forest policymaking processes. This is despite CFUG perceptions that align more closely with the scientific evidence showing that forest development in the catchments reduces water yield overall.

Thus, while the overall shortage of knowledge on forest-water relationships in the broader mountainous region underscores the need for increased scientific research, the divergent views on these relationships offer opportunities for adopting more inclusive research methods to concurrently integrate science with the perceptions held by the various sections of the Nepalese society. This is particularly important in view of expanding community forestry practices and the ongoing debate on scientific forest management.

Chapter 4

4. Negative trade-offs between community forest use and hydrological benefits in the forested catchments of Nepal's mid-hills

4.1 Statement of Authorship

Title of Paper	Negative trade-offs between community forest use and hydrological benefits in the forested catchments of Nepal's mid-hills
Publication Status	☑ Published ☐ Accepted for Publication ☐ Submitted for Publication ☐ Unpublished and Unsubmitted work written in manuscript style
Publication Details	Badu, M., Nuberg, I., Ghimire, C.P., Bajracharya, R.M., Meyer, W.S., 2019. Negative trade-offs between community forest use and hydrological benefits in the forested catchments of Nepal's mid-hills. Mountain Research and Development, 39 (3), R22-R32

Principal Author

Name of Principal Author (Candidate)	Manoj Badu		
Contribution to the Paper	Sampling, experimentation and data analysis, manuscript writing, corresponding author		
Overall percentage (%)	80		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	05/11/2020

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate in include the publication in the thesis; and
iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	Ian Nuberg		
Contribution to the Paper	Supervision of the work, manuscript evaluation and editing		
Signature		Date	05/11/2020

Name of Co-Author	Chandra Prasad Ghimire		
Contribution to the Paper	Assistance in rainfall data and hydrological pathways analysis, manuscript evaluation and editing		
Signature		Date	12/11/2020

Name of Co-Author	Roshan Man Bajracharya		
Contribution to the Paper	Assistance in soil profile analysis, experimental set up, manuscript editing		
Signature		Date	12/11/2020

Name of Co-Author	Wayne S. Meyer		
Contribution to the Paper	Co-supervision, manuscript evaluation and editing		
Signature		Date	18/11/2020

4.2 Abstract:

Widespread community forestry practices in Nepal's mid-hills catchments involve removal of forest products - including firewood, litter, fodder, and medicinal herbs- by the local communities. Uncertainty is growing about how sustainable the management of these catchments is and whether it can meet traditional needs and maintain ecosystem services, particularly water. As part of a broader study on the hydrological effects of community forestry practices, we measured selected soil properties including saturated hydraulic conductivity (K_s), bulk density (BD), and soil organic carbon (SOC) across four depths (0-10, 10-20, 20-50 and 50-100 cm) in three types of community forest sites - broadleaf, pine-dominated, and mixed - in the *Roshi Khola* catchment of Kavre district. The same measurements were made at a minimally disturbed religious forest site in the catchment that had higher K_s values than the mixed and broadleaf sites, signifying a lower degree of forest use related disturbance. Likewise, SOC values for the religious forest were significantly higher ($p < 0.05$) and BD values significantly lower than the pine-dominated and mixed forest sites, particularly at shallower depths (0-50 cm). Importantly, comparison of the median K_s values (16–98 mm h^{-1}) with the rainfall intensities measured at the catchment showed the less intensively used pine-dominated site to be conducive to vertical percolation with possible greater contributions to subsurface storage even during high-intensity rainfall events. These results highlight the critical role of forest use practices in landscape hydrology and have implications for the management of the forested catchments in the broader Himalayan region, particularly in relation to the negative local perceptions of the role of pine plantations on declining water resources.

Key words: Community forest use; water; saturated hydraulic conductivity; forested catchments.

4.3 Introduction

During the early half of the 20th century, forest to farmland conversion and high local demand for forest products, including timber, firewood, livestock fodder and compostable litter caused significant loss of forest cover in Nepal's mid-hills and gave rise to the widely publicised but contested 'theory of Himalayan environmental degradation' (Gilmour 1988; Hofer & Messerli 2006; Ives 2004). The alleged effects, mainly episodes of large-scale flooding and landslides (Eckholm 1976), prompted local and international initiatives to reforest the area as a remedial measure that concurrently fulfilled traditional forest needs. For example, a Nepal-Australia forestry project supported the planting of 20,000 ha of the central mid-hills during the early 1990s (Collett et al. 1996), while the World Bank proposed planting at annual rates of 50,000 and 10,000 ha until 1990 and 2000, respectively (Sattaur 1987). The reforestation programs largely used fast-growing species of pine such as *Pinus roxburghii*, due to the species' high adaptability to the nutrient-poor soils of the mid-hills (Gilmour et al. 1990). Importantly, forest development activities increased focus on community involvement, as the customary forest policies systematically alienated local forest users (Acharya 2005b; Springate-Baginski & Blaikie 2007) leading also to the inception of Nepal's community forestry policy in the late 1970s (Cribb 2006). At present, more than half (over 2.2 million ha) of the mid-hills catchments contain naturally grown or planted species of broadleaf and pine, more than two-thirds of which are managed by nearly 7 million local users organised as members of the Community Forest User Groups (hereafter CFUGs) (DFRS 2015b).

Forestation is commonly associated with improved landscape stability and hydrological conditions through, for instance, improved soil infiltration (Archer et al. 2013; Bonnesoeur et al. 2019; Buytaert et al. 2007; Neary et al. 2009). While the time taken for results to be apparent varies from years (Van Noordwijk et al. 2003) to decades (Bonell et al. 2010), the varied nature of the forest management practices confounds the processes, including the ensuing hydrological regime (Bonell & Bruijnzeel 2005; Farley et al. 2004; Julich et al. 2015; Marín et al. 2018; Ochoa-Tocachi et al. 2016; Wohl et al. 2012). In the lesser Himalayas, where communities rely heavily on local forests for food, fuel and income (Breu et al. 2017; Chakraborty et al. 2018), forestry activities are known to affect many aspects of forest functioning. These activities commonly involve regular planting and harvesting of forest products by local communities. For instance, the persistent harvesting of forest litter and understorey in southern China negatively affects the soil's structural complexity and supply of organic matter (Brown et al. 1995), while cattle grazing diminished soil nutrient availability and soil hydraulic conductivity in forests in southern India (Mehta et al. 2008). In the mid-hills of central Nepal, soil hydraulic conductivity was negatively affected by sustained forest use (Ghimire, Bruijnzeel, Bonell, et al. 2014; Gilmour et al.

1987), consisting of collection of litter, firewood, fodder and medicinal herbs that typically constitute CFUG activities in the region.

However, the likely hydrological effects of forest use are nonuniform across forested catchments because the intensity or regularity of CFUG activities is determined by varied community needs, as well as forest type and condition. For instance, pine forests are frequented less by CFUG members (oral communication, 2016, Rajendra KC), because pine needles are not as suitable for composting or livestock fodder as broadleaf (Gautam & Webb 2001; KC et al. 2015). Further, the evolving nature of forest ecosystems through successional change, for example broadleaf species integrating into pine plantations (Gilmour et al. 1990) as reported from parts of the mid-hills (Gautam et al. 2002; Kavre 2014b) obscures the poorly understood forest-water relationships in the region. Clearer understanding of these relationships is critical given growing concerns about increased water shortages during the dry season in the mid-hills (Poudel & Duex 2017) that are frequently attributed to pine plantations (Bhatta et al. 2015; Sharma et al. 2016). Additionally, the forested areas of the mid-hills catchments, managed mostly by local CFUGs (DFRS 2015a), are vital for the local and regional water supply (Rasul 2016), which is significantly affected by the region's highly seasonal climate (~ 85% of the annual rainfall occurs during June-September (Merz et al. 2003)).

As part of a larger study to examine the hydrological effects of the community forestry practices in Nepal's mid-hills, this paper compares selected soil properties from three types of unequally used community forest (CF) sites – a broadleaf, a pine dominated, and a mixed pine and broadleaf forest – with a minimally used religious mixed species forest in the central hill district of Kavre. The specific soil properties are texture, bulk density (BD), soil organic content (SOC), and saturated hydraulic conductivity (K_s). Further, the paper compares the K_s results with rainfall intensities measured at the research site to infer the possible hydrological pathways. Finally, the broad implications of the present findings for likely effects on dry season flows are discussed.

4.4. Methods

4.4.1 Study area

The study area was the northwestern part of Roshi Khola catchment of Kavre district, Nepal (**Figure 4.1**). The climate varies from sub-tropical to warm-temperate with annual mean temperature of 17 ± 0.21 ^{0}C and rainfall 1330 ±84 mm as shown by the 15-year (2001-2015) records of the Department of Hydrology and Meteorology (DHM) of Nepal. The rainfall patterns are highly seasonal, with 60-90 % of the annual rainfall occurring during the monsoon period of June to September (Hannah et al. 2005; Merz et al. 2006). The elevation and aspect influence the microclimate such that the north-facing slopes are moister and cooler than the south-facing slopes (Gautam et al. 2003). Typical of Nepal's mid-hills, the soils in the study area are weakly developed and relatively shallow (<100 cm). They are moderate to poorly drained with silt or silt-loam texture and are acidic (pH 4.0-4.3). Forests in the area encompass naturally grown or planted species of broadleaf and pine (mainly *Pinus roxburghii*), managed primarily by the CFUGs (DFRS 2015a). The area under pine forest increased as a result of reforestation programs conducted primarily during the 1980s (Karki & Chalise 1995).

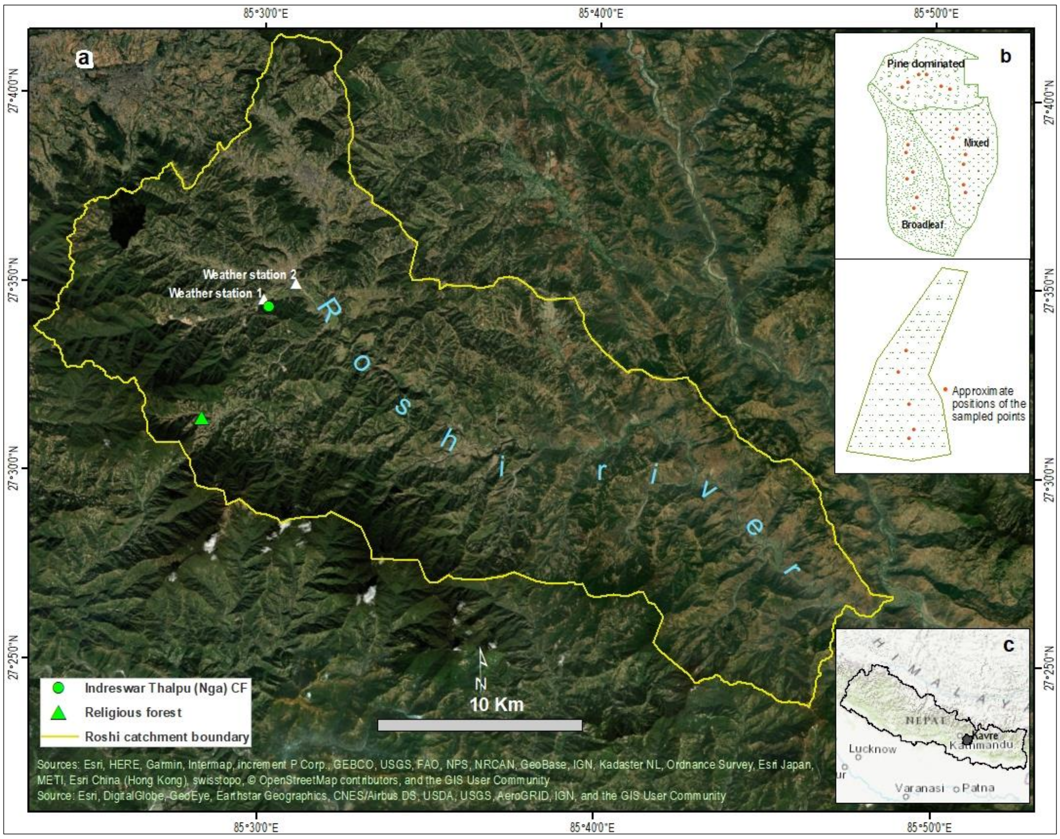

Figure 4.1: Location of the study sites in Roshi Khola catchment of Kavre district, Nepal

Current study sites were a forested catchment of Indreswar Thalpu (Nga) Community Forest (hereafter referred to as the experimental CF) located 27°34'10" N, 85°30'15" E at an elevation of 1710 masl that encompassed stretches of planted pine, natural broadleaf, and mixed forests. After pervasive forest loss, the sites were revegetated naturally and through plantation during the late 1970s and early 1980s, mostly through the auspices of the Nepal-Australia forestry project. In the early 90s, the forest management responsibilities were officially handed over to the local CFUG (*Indreswar Thalpu, Nga*) (DFO Kavre 2014a). Thus, organised CFUG activities in those sites have persisted for nearly 30 years (see **Table 4.1**).

The current Operational Plan (OP) document of the CFUG (2014/15 to 2024/25), shows that 174 households (total population 790) rely considerably on local forest products. In particular, there is a high annual demand for livestock fodder (> 3200 tonnes) and compostable litter (> 1600 tonnes) mainly from broadleaf species. However, the annual production levels of the forest are insufficient to meet these demands. This is mainly because of the predominantly agriculture-based lifestyle of the community as well as the significant presence of the pine species in the forest that have low use value for fodder and litter production. Nevertheless, the forest provides a surplus supply of firewood and timber that is occasionally sold in the local markets to earn additional income for the CFUG. This income contributes to funding community development activities, including the construction and maintenance of the local infrastructure, as well as employment (e.g. wages for the forest watcher).

Table 4.1: Forest management activities of the Indreswar Thalpu (Nga) CFUG, Kavre, Nepal (Based on the CFUG Operational Plan document, 2014/2015-2024/2025)

CFUG activities	Frequency	Time of year	No. of users involved
Fodder and grass collection	2 times/day	Oct–May	1 user/household
Litter collection	1 time/day	Oct–May	1 user/household
Firewood collection	1 time/month	Nov–May	As arranged
Weeding	Every 3 years	As arranged	10–15 people
Thinning	Every 6 years	Nov–Feb	As arranged
Pruning	Every 3 years	Nov–Feb	As arranged
Plantation	Every 3 years	Nov–Feb	As arranged

A religious forest **(Figure 4.1)** with a similar forestry history and soil type was used as a control site that currently undergoes minimal community use because there is a much lower need to obtain forest products for religious purposes.

The individual sites are described in the next section based on the current OP documents, local community insights and our field assessments, including a forest inventory conducted mostly during January to September 2015. An analysis of the soil profile for each of the forested sites showed the soils to be the fine to fine-loamy derivatives of weathered sandstone, schist or phyllite of the order Inceptisol (Soil Survey Staff 1994) that transitioned to the parent material at a depth of about 50 to 60 cm. Further details about the location and topography of the sites are provided in **Table 4.2**.

Table 4.2: Location of study sites

Site	Aspect	Area (ha)	Coordinates	Altitude (masl)	Mean slope
Broadleaf	North	1.2	27°34'18"N 85°30'17"E	1615	22°
Pine dominated	South	0.8	27°34'27"N 85°30'13"E	1550	18°
Mixed	South to southwest	0.9	27°34'21"N 85°30'17"E	1585	19°
Religious	West to northwest	1.5	27°31'03"N 85°28'42"E	1955	21°

4.4.2 Description of sites

Broadleaf forest site: This site was regenerated naturally through community initiatives that primarily involved fencing off the area to restrict traditional forest use. The dominant vegetation consists of *Schima wallichii*, *Castanopsis tribuloides* and *Myrsine capitellata* along with shrub species such as *Cleyera japonica, Eurya acuminate*, *Lyonia ovalifolia* as well as *Rhododendron arboreum* in the higher elevations **(Figure 4.2a)**. This site undergoes high disturbance due to persistent community use, as the abundance of relatively low-lying (mean height ~ 9 m) broadleaf vegetation is collected for firewood, fodder and litter **(Figure 4.2e)**. There is minimal presence of ground cover on the site except in the less accessible, steeper sections that occasionally have a thin distribution of common grass species.

Pine-dominated forest site: This site is dominated by *P. roxburghii*, which was planted mostly during the late 1970s to early 1980s. However, due to the proximity to the broadleaf site, the broadleaf species appear randomly along with the occasional patches of *Nephrolepis* fern as ground cover **(Figure 4.2b)**. The low species diversity and dominance of pine species on the site has lower value for local users because the pine needles are less suitable as livestock fodder or compostable litter than broadleaf vegetation. Occasional signs of trampling are seen as some local residents visit the site for leisure, seasonally, to collect wild berries and mushroom. This level of forest-use intensity entails low to moderate disturbance on the site.

Mixed forest site: This site borders both the broadleaf and the pine-dominated site **(Figure 4.2c).** The broadleaf species, including *S. wallichii* and *C. tribuloides,* are mixed with *P. roxburghii,* although broadleaf species dominate the lower elevations closer to the broadleaf site. While the local CFUG members use the site consistently, it also experiences disturbance due to occasional visits for leisure by commuters along the road on its northern boundary **(Figure 4.2f)**. The road is unsealed and supports vehicles, mostly during the dry season (October-May). Minor signs of erosion are seen on the site.

Religious forest: The dominant vegetation in this site is a mix of planted and naturally propagated *Pinus wallichiana*, *Quercus semicarpifolia, P. roxburghii*, and *Alnus nepalensis* **(Figure 4.2d)**. There is some regeneration and shrub species, including *Taxus wallichiana, E. acuminate* and *R. arboreum* along with the ground cover of common grass species in steeper sections. Based on the current OP document (2014-2024), the age of the vegetation varies from 5 to 30 years. Although this site is part of the historically degraded national forest, the local community has used the forest for religious purpose since the mid-1980s, until the government formally handed over the management duties to the

Mukteswar Mahadev religious committee in 2014. Current forest management activities include tree planting, restricted access, and occasional removal of forest products for religious events.

Figure 4.2: (a) Broadleaf forest; (b) pine dominated forest; (c) mixed forest; (d) religious forest; (e) litter from the broadleaf forest site piled up at the catchment for composting; (f) unsealed road on the northern boundary of the mixed forest site.

4.4.3 Soil sampling and analysis

Multiple field visits and meetings with the local forest users were held to obtain an in-depth understanding of the forested sites. Samples were collected during March to mid- April 2015 from six (five for the religious forest) representative points located approximately 20-30 m apart in each site along an approximate S-shape **(Figure 4.1b).** As applied in other parts of the mid-hills, the sampling strategy ensured that the sampling sites were not clustered and were distributed evenly (Shrestha et al. 2007). The sampling equipment (*EijkelKamp* Agrisearch Equipment, the Netherlands) comprised chromium-plated stainless steel rings (100 cm^3), fitted to an Edelman auger. This was used to draw minimally disturbed core samples from 4 depths (0-10, 10-20, 20-50 and 50-100 cm) at each of the representative points, resulting in a total of 92 samples. Similar soil-depth categories have been used by other studies in the mid-hills (Ghimire, Bruijnzeel, Bonell, et al. 2014; Ghimire et al. 2013; Gilmour et al. 1987), and core samples from similar numbers of representative locations have been used to describe the soil hydrological properties globally, including in Brazil (Lozano-Baez et al. 2018), the UK (Archer et al. 2016), and Switzerland (Amrein et al. 2005). Importantly, obtaining representative measures of K_s is difficult because it is naturally highly variable (Zimmermann et al. 2006) and is affected by methods of measurement (Hangen & Vieten 2018; Paige & Hillel 1993; Reynolds et al.

2000; Zhang et al. 2019). As such, our sample size may not be sufficiently large to account for such variations, so the K_s data presented here need careful interpretation.

The samples were drawn from the midrange of each depth, except for the deepest layer (50-100 cm), where the depth to the parent material affected the sampling decision. The samples were analysed at the laboratory facilities of the Kathmandu University, located approximately 5 km from the experimental CF**.** Texture was determined by the soil hydrometer method (Gee & Bauder 1986), BD by the core method (Blake & Hartge 1986), SOC by the dry combustion method (Nelson & Sommers 1982) and pH using the glass calomel electrode probe in a soil water ratio of 1:1 (McLean 1982).

Saturated hydraulic conductivity (K_s) was determined using the constant head method based on the Darcy equation given as;

$$K_s = VL/[At(H_2-H_1)];$$

Where;

V= volume of water flowing through the soil sample

L= sample length

A= cross sectional area of the sample

t= time taken

H_2-H_1 = hydraulic head difference

The K_s measurements and apparatus design are based on procedures described by Klute and Dirksen (1986 pp. 694-696). The apparatus comprised a rack to hold 4 core samples that incorporated a constant head maintained by a common water supply. Water was siphoned individually to the soil cores, and the percolated volume was recorded every 10 minutes until 3 constant measurements were obtained. The core method used here is relatively simple, cost-effective and reliable, particularly in complex landscapes (Ilek & Kucza 2014) such as these.

4.4.4 Rainfall intensity

The rainfall data used to infer the dominant hillslope hydrological pathways were recorded at a nearby location (about 270 m from the experimental CF; Figure 4A, Weather station 1) during the respective monsoon periods of 2015 and 2016. Rainfall was recorded using a tipping-bucket rain gauge (Onset Computer Corporation, USA) at 30 min intervals.

A rainfall event was categorised as an event that measured a minimum of 5 mm in total and occurred after a dry period of at least 3 hours from the preceding event (Negishi et al. 2006). For each event, the maximum 30-minute (I_{30max}) and 60-minute (I_{60max}) rainfall intensities (expressed as equivalent hourly rainfall intensities) were determined by computing the maximum rainfall over the corresponding periods (Ghimire et al. 2013).

4.4.5 Data analysis

A nonparametric Kruskal-Wallis test (Kruskal & Wallis 1952) applicable for nonnormal data was used in R (Version 3.4.0) to statistically compare the results of the selected soil properties (BD, SOC and K_s) of the various forest types. Dunn's multiple comparison test (Dunn 1964) with Bonferroni correction was further used to compare the results across 4 depths. Difference was considered significant when $p<0.05$.

The K_s values obtained were used to infer the likely hydrological pathways with respect to rainfall intensities based on the daily rainfall data collected as described. In doing so, median surface and subsurface K_s values for each forest type were compared with the selected percentiles of maximum rainfall intensities (eg over 30 min, I_{30max}) to estimate the rainfall at the soil surface (Bonell et al. 2010; Ghimire et al. 2013; Gilmour et al. 1987). This is important because the K_s distribution and rainfall intensities strongly influence the hydrological pathways in areas with concentrated rainfall such as these (Germer et al. 2010; Zimmermann et al. 2006).

4.5. Results and discussion

4.5.1 BD and SOC measurements as influenced by the intensity of forest use

The BD measurements, as expected, generally increased with depth for all sites **(Figure 4.3d)**. In particular, median values for the mixed forest site were significantly higher than those of the religious forest at the 3 upper depths ($p< 0.007$, 0.01 and 0.003 at 0-10, 10-20 and 20-50 cm, respectively). While site attributes could account for this difference, the higher values for the mixed forest suggests increased foot traffic-related compaction that occurs due to the site's proximity to the road **(Figure 4.2f)**. Although the contribution of increased foot-traffic is difficult to categorise here, BD as a measure of compaction increases with increased frequency and intensity of forest management activities (Osman 2013), including thinning (Tarpey et al. 2008) and harvesting (Whitford & Mellican 2011). Thus, the generally higher median values for the broadleaf site compared with the religious forest could reflect the degree of community use.

In regards to SOC, the median values **(Figure 4.3c)** ranged from approximately 2 to 8 %. The maximum, (11%) was obtained from the religious forest and minimum, (1%) for the pine-dominated site. As expected, SOC decreased with depth. The values for the religious forest were significantly higher than those for the pine-dominated site at all corresponding depths, suggesting the reduced contribution of pine needles to SOC compared with that of accumulated litter in the religious forest. The SOC levels for the pine-dominated site are consistent with those in other parts of the mid-hills (Aryal et al. 2013; Shrestha & Singh 2008) including China (Yang et al. 2010) and India (Sharma et al. 2011).

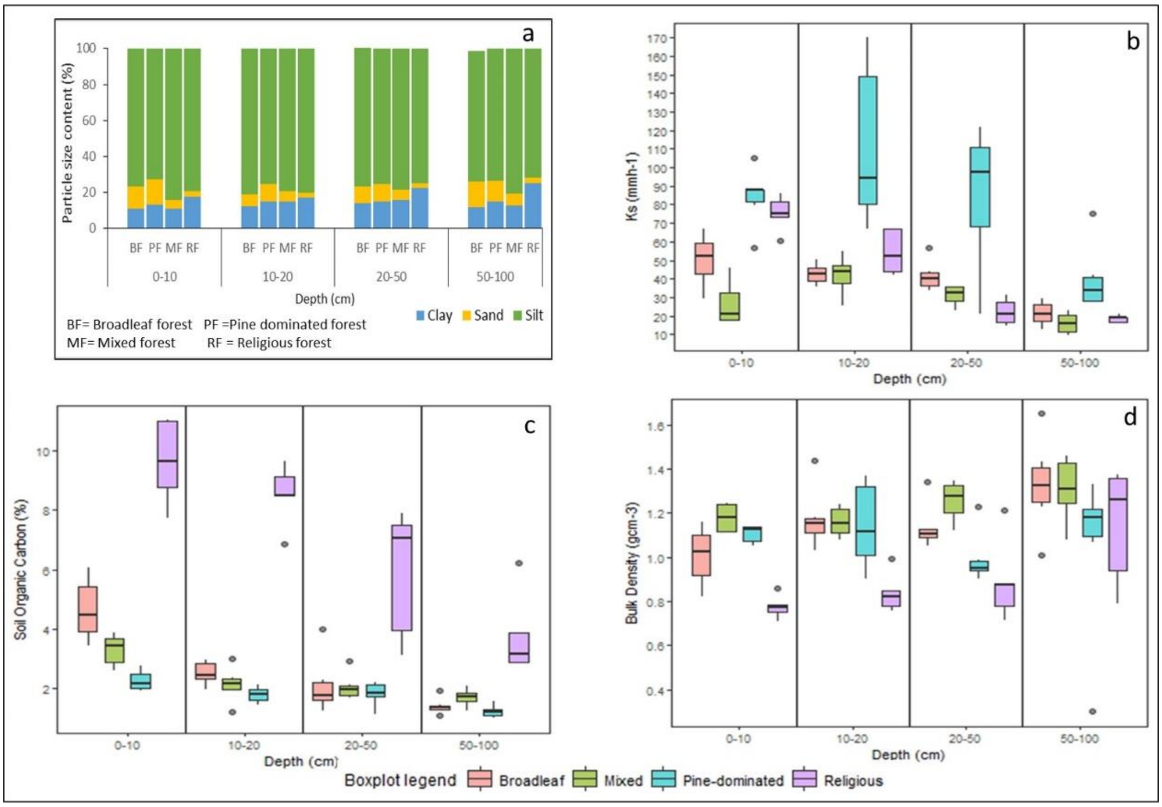

Figure 4.3: (a) Particle size distribution; (b) K_s; (c) SOC; and (d) BD at various depths at each of the study sites.

In Nepal's mid-hills, inherent factors affecting the SOC levels include forest type, climate and topography (Bajracharya & Sherchan 2009). These are further affected by community forestry practices, including removal of biomass. The higher SOC levels for the religious forest compared with other sites indicate reduced removal of litter, fodder, or firewood, allowing higher biomass accumulation and decomposition. Similar effects, such as increased SOC levels and associated nutrient availability due to prolonged length of litter retention, have been reported in other parts of the mid-hills (Schmidt et al. 1993) and globally, including parts of South and North America. In these cases, the persistent removal of aboveground organic matter reduced soil carbon (Hofstede et al. 2002; Powers et al. 2005). Conversely, the retention of harvesting residue conserved organic matter and improved site quality and productivity in south Australia (Hopmans & Elms 2009) and Spain (Merino et al. 2004).

4.5.2 K_s measurements and inferred hillslope hydrological pathways

The median K_s values generally remained higher for the pine-dominated and religious forest (in the shallower depths), likely indicating the lower degree of anthropogenic disturbance related to forest use in these sites (Ziegler et al. 2004; Zimmermann et al. 2006). The median values ranged approximately from 16-98 mm h^{-1} with maximum for the pine-dominated and minimum for the mixed forest sites **(Figure 4.3b)**. While the values were generally lower for more intensively used sites, that is, broadleaf and mixed forests, the consistently higher median values for the pine-dominated site were significant at three depths ($p < 0.001$, 0.004 and 0.003 at 0-10, 10-20, and 50-100 cm, respectively) compared with the mixed forest site. Similar results showing an inverse relationship between K_s and disturbance have been reported in other tropical landscapes (Zwartendijk et al. 2017) and in parts of the mid-hills, using in-situ methods comprising a constant head well permeameter combined with ring infiltrometers (Gilmour et al. 1987) and disc permeameter (Ghimire, Bruijnzeel, Bonell, et al. 2014). The mid-hills studies showed that forestation improved soil infiltration, particularly in the less-disturbed natural forests. This is believed to improve hydrological outcomes in tropical landscapes (Ilstedt et al. 2007) through reduced compaction and increased macroporosity due, for instance, to increased SOC levels (Lal 1988; Neary et al. 2009). Notably, however, the mixed and broadleaf forest sites of the present study had lower K_s values, despite the higher SOC levels, compared with the pine-dominated site (**Table 4.3).** This underlines the critical role of anthropogenic disturbance on soil hydraulic conductivity, as has been found in other parts of the lesser Himalayas (Bonell et al. 2010).

Table 4.3: Descriptive statistics of the soil parameters for the study sites: broadleaf forest (BF), pine-dominated forest (PF), mixed forest (MF), and religious forest (RF)

		K_s (mm h^{-1})				**SOC (%)**				**BD (g cm^{-3})**			
		BF	**PF**	**MF**	**RF**	**BF**	**PF**	**MF**	**RF**	**BF**	**PF**	**MF**	**RF**
0–10 cm	**Mean**	50	84	26	76	4.7	2.3	3.3	9.6	1.01	1.11	1.18	0.78
	Median	52	88	21	76	4.5	2.2	3.5	9.7	1.03	1.13	1.18	0.77
	Std. deviation	14	16	12	10	1.0	0.3	0.5	1.4	0.13	0.04	0.07	0.06
	Minimum	29	57	17	61	3.5	1.9	2.6	7.7	0.82	1.05	1.11	0.71
	Maximum	67	105	46	86	6.1	2.8	3.9	11.0	1.16	1.14	1.25	0.86
10–20 cm	**Mean**	43	112	42	55	2.5	1.8	2.1	8.5	1.18	1.14	1.16	0.84
	Median	43	94	44	52	2.4	1.8	2.2	8.5	1.16	1.12	1.15	0.82
	Std. deviation	5	45	10	12	0.4	0.3	0.6	1.0	0.14	0.2	0.07	0.09
	Minimum	36	67	25	42	2.0	1.5	1.2	6.9	1.03	0.9	1.08	0.76
	Maximum	50	170	55	67	3.0	2.1	3.0	9.6	1.44	1.37	1.24	0.99
20–50 cm	**Mean**	42	85	31	22	2.1	1.8	2.1	5.9	1.14	0.99	1.26	0.89
	Median	40	98	33	21	1.8	1.8	2.0	7.1	1.11	0.95	1.28	0.88
	Std. deviation	8	38	5	7	1.0	0.4	0.4	2.2	0.1	0.12	0.09	0.19
	Minimum	34	21	23	15	1.3	1.2	1.7	3.1	1.05	0.9	1.12	0.72
	Maximum	57	122	36	31	4.0	2.2	2.9	7.9	1.34	1.23	1.35	1.21
50–100 cm	**Mean**	21	40	16	18	1.4	1.2	1.7	3.8	1.33	1.05	1.31	1.14
	Median	21	34	16	19	1.4	1.2	1.7	3.2	1.33	1.18	1.31	1.26
	Std. deviation	6	18	6	2	0.3	0.2	0.3	1.4	0.21	0.38	0.15	0.26
	Minimum	13	27	9	17	1.1	1.0	1.3	2.9	1.01	0.3	1.08	0.79
	Maximum	29	76	23	21	1.9	1.6	2.1	6.2	1.65	1.33	1.46	1.37

As **Figure 4.3b** shows, the median K_s values did not vary significantly among sites at the deepest layer (50-100 cm) but varied widely at the shallower depths (0-50 cm). This is probably a function of the vegetation cover and forest use rather than the inherent site qualities such as soil type. Interestingly, a comprehensive analysis of the global database on these relationships (Jarvis et al. 2013) reported that

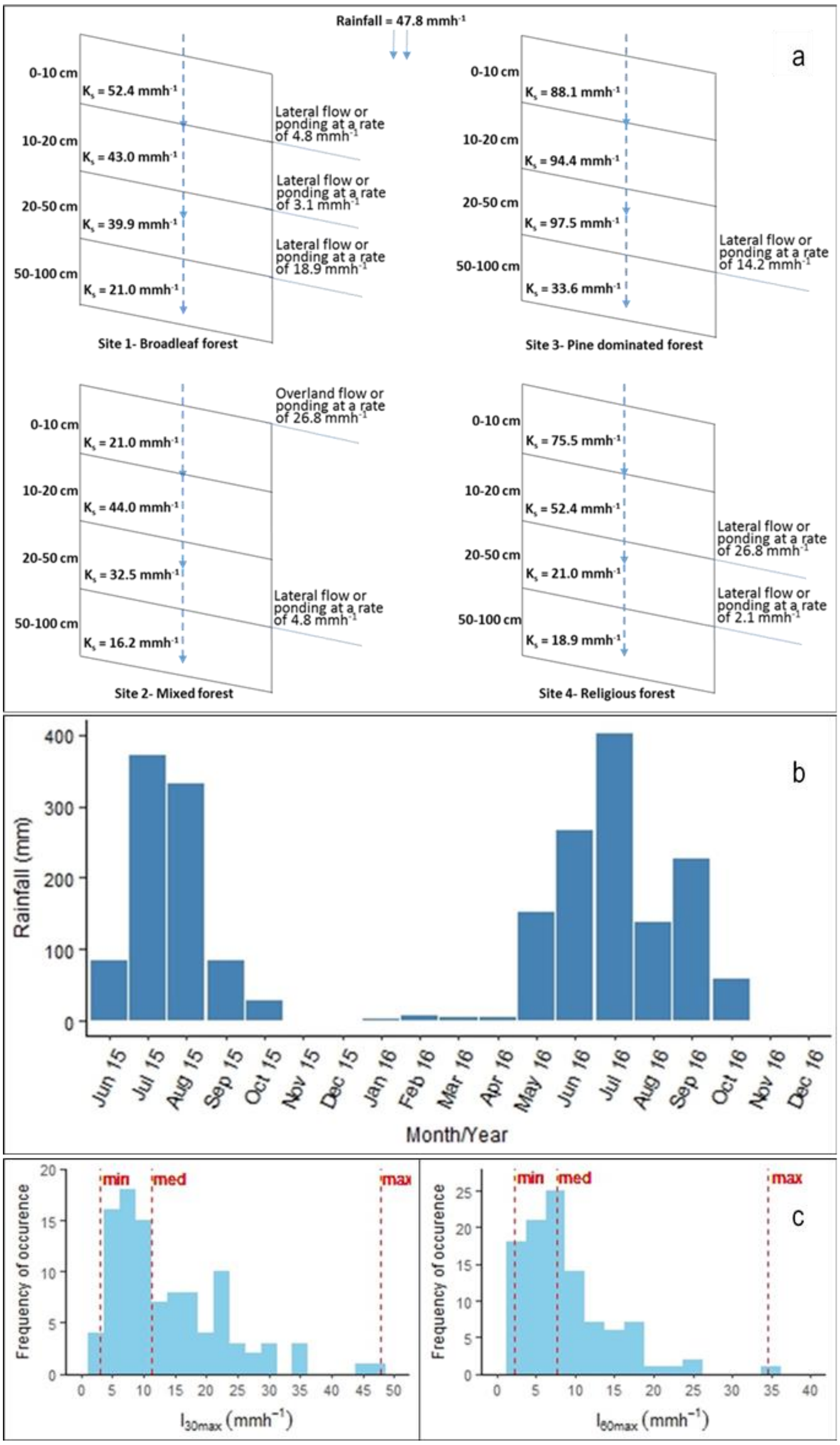

Figure 4.4: (a) Potential hydrological pathways for the various study sites after a 30-miute rainfall intensity of 47.8 mm h^{-1}; (b) monthly rainfall distribution during the study period; (c) frequency distribution of maximum 30-minutes (left) and 60-minute (right) rainfall intensities recorded at the study sites in the Roshi Khola catchment of Kavre Nepal

soil texture has only a weak effect on soil hydraulic conductivity, particularly at shallower depths (<30 cm) compared with SOC, BD and land use. Thus, due to those variations, as well as the presence of an impending layer, the shallower depths largely govern hydrological pathways causing water to pond or flow laterally, depending on the rainfall intensity **(Figure 4.4a).** For instance, overland flow or ponding is probable in the mixed forest site with maximum 30-minute (I_{30max}) or 60-minute (I_{60max}) rainfall intensities of 47.8 mmh^{-1} and 34.6 mm h^{-1}, respectively. The intensities were derived from a total of 103 rainfall events recorded during the monsoon periods of 2015 and 2016 that highlight the significant contribution of monsoonal rainfall to the annual totals **(Figure 4.4b).** Specifically, the monsoonal totals were 874 mm (97 % of the June-December rainfall) in 2015 and 1031 mm (82 % of the annual rainfall) in 2016. These values are comparable to the long-term measurements of 944 mm (76 % of the annual totals) recorded close to the present study area (Weather station 2, Figure 4.1a). The frequency and distribution of the maximum 30-min (I_{30max}) and 60-min (I_{60max}) rainfall intensities for the study area are presented in **Figure 4.4c.**

However, the observed patterns at the mixed forest site are unlikely to be the dominant flow path because the median values of I_{30max} (11.2 mm h^{-1}) and I_{60max} (7.6 mm h^{-1}) suggest vertical percolation with overland flow or ponding probable only beyond the 80 % percentile (21.8 mm h^{-1}) of I_{30max}. In fact, percolation to varying depths occurs at all other sites, even under the maximum of I_{30max}, until ponding or lateral flow occurs **(Figure 4.4a)**, with the pine-dominated site allowing percolation to the deepest layer (20-50 cm).

Even though higher rainfall intensities for shorter intervals, for example a maximum hourly equivalent of 88.8 mm h^{-1} to 130 mm h^{-1} for 5-min intervals, have been used to infer the hydrological pathways in other parts of the mid-hills (Ghimire, Bruijnzeel, Bonell, et al. 2014; Ghimire et al. 2013; Gilmour et al. 1987), studies have recognised such rainfall patterns to be less dominant in the region.

4.5.3 Hydrological implications of the sustained community forestry practices

Forest-use practices strongly influence the hydrological outcomes of many tropical and sub-tropical landscapes (Ilstedt et al. 2007), which often support the traditional lifestyle of many local communities. In Nepal's mid-hills, the forest fodder and litter are mixed with animal dung, which constitutes the primary source of soil enrichment (Giri & Katzensteiner 2013; Pilbeam et al. 2005), including improvement of N, P and K levels (Balla et al. 2014). While all forest types of the mid-hills (national, private or community forests) supply these products, community forests alone contribute more than 50 % of the litter supplied (Adhikari et al. 2007).

Yet, the hydrological effects of the sustained removal of these forest products are uncertain, even though the resulting reductions in soil microbial activity (Ding Ming et al. 1992) and SOC levels are known to reduce rainfall infiltration (Franzluebbers 2002). Further, the corresponding increase in compaction, resulting from higher foot traffic and trampling, exacerbates the situation because it impedes soil hydraulic conductivity (Startsev & McNabb 2000). The lower K_s values of the broadleaf forest site are indicative of this effect as it undergoes higher foot traffic due to the greater use value of the forest products, while the mixed forest site has higher foot traffic due to its proximity to the road and has correspondingly low K_s values. This could hamper the replenishment of soil and groundwater reserves, contributing to reduced dry-season flows in the area, even though water use by vegetation is an important consideration in evaluating these effects (Ghimire, Bruijnzeel, Lubczynski, et al. 2014; Ghimire, Lubczynski, et al. 2014). Indeed, removal of litter and woody debris has been found to cause increased soil loss and runoff (Hartanto et al. 2003), while the compaction related to forest use accelerates erosion, shallow landslides (Sidle et al. 2006) and floods (Alaoui et al. 2018). Moreover, a recent study (Upadhayay et al. 2018) showed that community forestry practices induce higher sediment loss, than that lost from agricultural land in Nepal's mid-hills catchments. Such a situation confounds reported land use-related social and environmental consequences in the region (Gardner & Gerrard 2003; Jaquet et al. 2016) and is ironic because much of the forest in the mid-hills was established to curb sediment loss.

4.6 Conclusion

Increased forestation is widely believed to improve hydrological conditions, particularly in tropical and sub-tropical environments. However, land use history and prevalent management regimes, such as community forestry practices, might have a greater effect on forest-water relationships, as shown by the results of this study. Specifically, the broadleaf and mixed forest sites showed higher compaction (BD) and lower hydraulic conductivities (Ks) than the minimally used religious forest, which is likely the result of the higher foot traffic and increased trampling associated with greater use of the sites by CFUG members. The Ks values of the broadleaf and mixed forest sites were lower, despite their higher SOC values, than the pine-dominated site, even though higher levels of SOC improve soil infiltration of forested sites. With growing debate about the role of pine plantations on reduced dry season flows in parts of the mid-hills of Nepal, this preliminary study suggests that a more nuanced understanding of the impact of community forestry on catchment hydrology is needed. It also highlights the need for increased research, particularly in view of the prevailing community forestry practices in the broader mid-hills region.

Chapter 5

5. Rainfall interception and overland flow production in various types of community forests of Nepal's mid-hills

5.1 Statement of Authorship

Title of Paper	Rainfall interception and overland flow production in various types of community forests of Nepal's mid-hills
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Principal Author

Name of Principal Author (Candidate)	Manoj Badu		
Contribution to the Paper	Field experimentation, data collection and analysis, manuscript writing, corresponding author		
Overall percentage (%)	85		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	13/11/2020

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution

Name of Co-Author	Chandra Prasad Ghimire		
Contribution to the Paper	Assistance in hydrological data presentation and analysis, manuscript evaluation and editing		
Signature		Date	19/11/2020

Name of Co-Author	Ian Nuberg		
Contribution to the Paper	Supervision of the work, manuscript evaluation and editing		
Signature		Date	13/11/2020

Name of Co-Author	Wayne S. Meyer		
Contribution to the Paper	Co-supervision, manuscript evaluation and editing		
Signature		Date	18/11/2020

5.2 Abstract:

Community forestry is the main mode of forest management in Nepal's mid-hills catchments. It involves implementing traditional silvicultural practices including seedling planting, thinning and pruning of forest trees by the local community forest user groups (CFUGs). The nature and frequency of implementing these activities is determined by the local forest conditions as well as the need to obtain the much needed forest products, mainly timber, firewood, livestock fodder and compostable litter. Despite wide documentation of the social and environmental benefits of these practices, hydrological effects are largely unknown, particularly in view of the changing structure and species composition of the community forests. This article presents measurements of gross rainfall (P), throughfall (Tf), stemflow (Sf) and overland flow (OF) during June 2015-December 2016 from three types of community forests experiencing varying levels of forest disturbance arising from the implementation of traditional CFUG activities. These forests are; a naturally grown broadleaf forest (BF), mostly-planted pine forest (PF) and a mixed pine-broadleaf forest (MF) in Roshi Khola catchment of Kavre district, Nepal. The BF and MF are used regularly by the CFUGs to harvest traditional forest products, whereas the PF is used only occasionally due to low availability of these products and hence, experiences low disturbance, offering conditions for natural succession. For the period of study, the Tf measurements were 72.0%, 73.7% and 77.5% of P for the BF, MF and PF, respectively while the corresponding Sf values were 1.6%, 1.3% and 0.6% for the respective sites suggesting Sf to be only a minor component of P in these forests. This resulted in rainfall interception (I) of 26.4%, 25.1% and 21.9% for the BF, MF and PF, respectively. The OF measurements were 8.4%, 7.3% and 3.7% of incident P for the BF, MF and PF, respectively and as expected, were strongly concentrated during monsoon (June-September). The results highlight the important role of community forestry practices in influencing the structure and composition of forest species with implications for resultant hydrology of the forested catchments of Nepal's mid-hills.

Key words: Community forestry; rainfall interception; overland flow; Nepal mid-hills; forest succession;

5.3 Introduction

Forests of naturally regenerated broadleaf and planted pine species are the dominant landuse of Nepal's mid-hills catchments (DFRS 2015a). While the traditional supplies from these forests mainly include timber, firewood, livestock fodder and compostable litter to the local communities (Karki et al. 2018), the catchments are increasingly important for hydrological functioning, particularly water supply (GoN 2011; IUCN 2013; Nepal et al. 2014; Udmale et al. 2016). However, challenges remain about managing the forested catchments for balanced supply of traditional forest products and downstream water use. This is exacerbated due to high susceptibility of the catchments to land degradation and eco-hydrological problems arising from complex topography, concentrated rainfall and rapidly draining soils (Hannah et al. 2005; Merz et al. 2010; Schreier et al. 2006). In some cases, high amounts of forest product extraction by the local communities has also been linked to increased incidences of floods and landslides (eg Eckholm 1976; Myers 1986), even though the linkages were subsequently disproved (Gardner & Gerrard 2003; Gilmour 1988; Ives 1987; Ives & Messerli 1989; Metz 1991; Thompson & Warburton 1985). Nevertheless, publicity of these linkages, combined with the need to ensure the local supply of traditional forest products have led to the implementation of large-scale reforestation programs in the mid-hills (Gilmour 2003). In fact, reforesting the degraded landscapes for improved hydrological outcomes, including streamflow regulation and water yield is a common strategy in the tropical and sub-tropical environments (CIFOR 2012), even though catchment water yield generally decreases following reforestation (Calder 2006; Filoso et al. 2017).

Approximately 370,000 ha of the mid-hills catchments are now reforested primarily to the fast-growing species of *Pinus roxburghii* and *Pinus patula* (Dangal & Das 2018), mostly because of the species' suitability to nutrient poor soils (Gilmour et al. 1990). These plantations constitute the nearly 1.6 million ha of the mid-hills community forests that are managed by local Community Forest User Groups (hereafter CFUGs) as per Nepal's community forestry policy (DoF 2018a). Several benefits of the CFUG-managed forestry in the mid-hills are documented. These include improved local environment (Acharya 2004; Chand et al. 2015; Gurung et al. 2013; Pandit & Bevilacqua 2011), socioeconomic standards (Bhattarai 2011; Dhakal & Masuda 2009; Oldekop et al. 2019; Oli et al. 2016; Paudyal et al. 2018) and ecological conditions including water availability (Birch et al. 2014; Chaudhary & McGregor 2018; Paudyal, Baral, et al. 2017; Thapa et al. 2018; Van Oort et al. 2015). Conversely, there are growing concerns about the role of pine plantations in diminishing dry season streamflows across the mid-hills, that are often ascribed as the effect of pine plantations (CBS 2017; Maharjan et al. 2018; Poudel & Duex 2017; Sharma et al. 2016). However, empirical evidence on the forest-water relationships in these CFUG-managed catchments is limited (eg Gardner & Gerrard 2002; Ghimire, Bruijnzeel, Bonell, et al. 2014; Ghimire et al. 2013; Gilmour et al. 1987). Moreover, the experimental results to evaluate the hydrological outcomes of forest development and management in the broader mid-hills region are greatly varied. For example, a community-managed broadleaf forest in the central mid-hills produced higher overland flow compared to an open-access government forest (Tiwari et al. 2009). Conversely, overland flow was found to be higher for a community used planted pine forest than a natural broadleaf forest located further East of the previous sites (Ghimire et al. 2013). Such variations in overland flows have also been reported from similar sites in the HKH region of India (Pande 1991; Pathak et al. 1985) that also highlighted the role of forest use related disturbance in overland flow production. However, this understanding is limited in the case of Nepal's mid-hills forests (eg Ghimire et al. 2012; Ghimire et al. 2013) particularly in view of the changing forest structure and composition; such as, the integration of broadleaf species into pine plantations. In the mid-hills, this occurs through natural succession and anthropogenic disturbance, in particular the CFUG activities (Gautam et al. 2002; Gilmour et al. 1990; DFO Kavre 2014b; Paudyal & Sapkota 2018). While this understanding is crucial for the overall management of Nepal's mid-hills catchments, it is contextual in view of the government's recent forest policy (2019) to implement scientific forest management and focus on reforestation (NLC 2019).

As part of a larger study to examine the hydrological impacts of community forestry in Nepal's mid-hills catchments, this paper quantifies the partitioning of gross rainfall in three major types of forests of the region. The forests are, predominantly planted pine (PF), naturally regenerated broadleaf (BF) and a mixed species pine-broadleaf forest (MF) that are used and managed by the local CFUG in varying intensity because of the varying nature and quantities of products these provide. The results for the various forest types are discussed, along with broad implications for the local hydrological outcomes.

5.4 Methods

5.4.1 Study area

Current study sites lie within the Roshi Khola catchment (RKC) of Kavre district, Nepal **(Figure 5.1)**. The RKC has a sub-tropical climate with annual mean temperature 17 ^{0}C and annual rainfall 1329 (±316) mm as shown by the 16-year records (2001-2016) measured at 1552 masl in the district headquarters of Kavre (DHM 2016, unpublished data). Microclimate of the RKC varies due to geographic complexity and altitudinal variation (280-2940 masl); for instance, the south-facing slopes are generally hotter and drier than those facing North (Gautam et al. 2002). The soils in the study area are derivatives of schist phyllite, and quartzite that are weakly developed (DFRS 2015a). Sections of the RKC drain either directly into the Roshi river **(Figure 5.1)** or into its tributaries that show wide fluctuations in seasonal flow. The river provides water for drinking, irrigation and hydropower generation to local and fast-growing urban populations downstream (Devkota, Khatri, et al. 2018; Devkota & Neupane 2018).

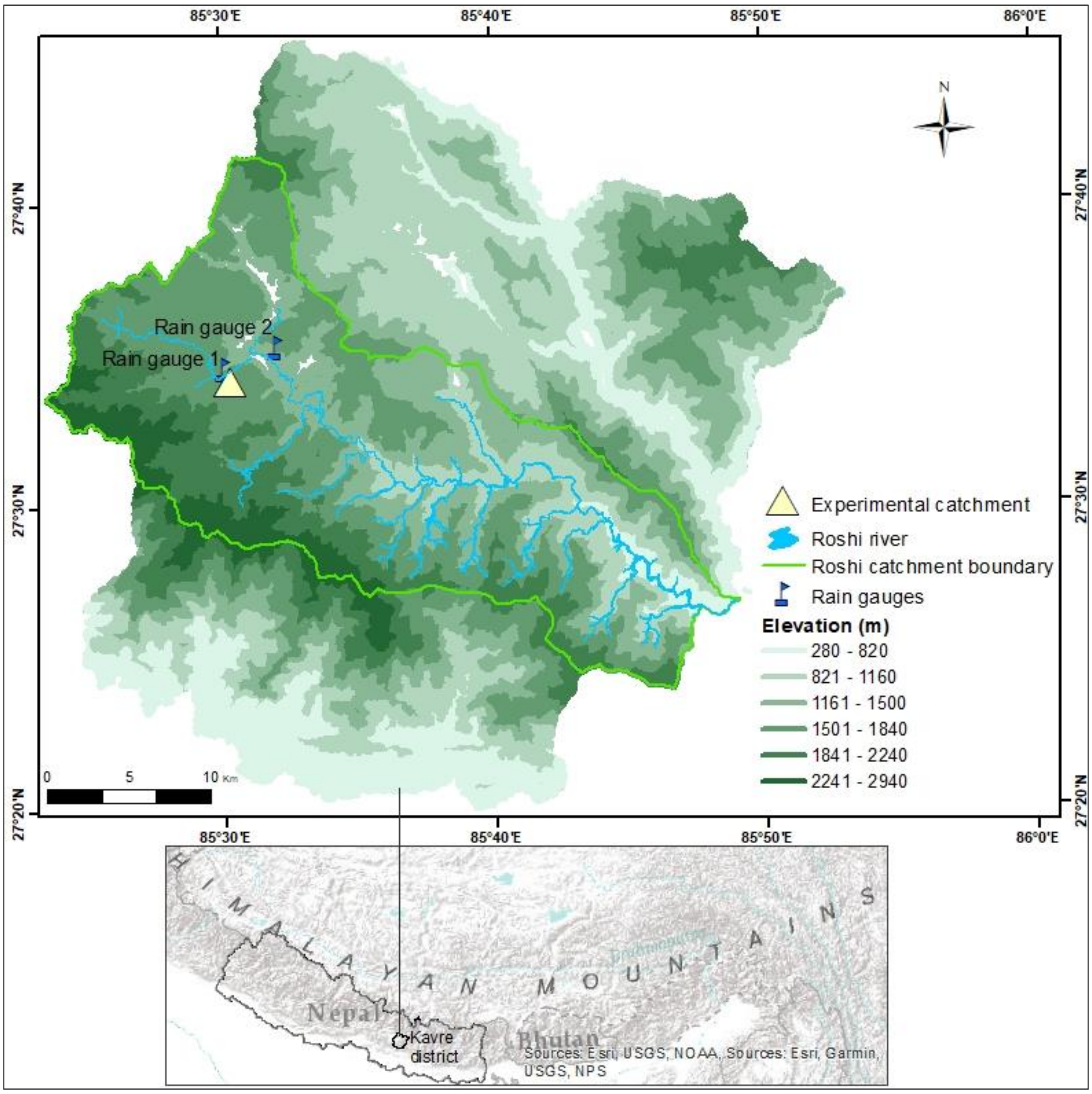

Figure 5.1: Location of the experimental catchment in Kavre district, Nepal

The forests of the study area are managed mainly by the local CFUGs that carry out activities including planting, thinning, pruning and harvesting of the forest products as per an approved operational plan (Thwaites et al. 2018). The present study sites are managed by *Indrewar Thalpu* CFUG *(Nga)* since the early 1990s (DFO Kavre 2014a). These are presented in **Table 5.1** and described below.

Naturally regenerated broadleaf forest (BF)

Traditionally, this site formed part of a locally used forest that was rapidly deforested after the nationalisation of Nepal's forests in 1957. The local CFUG implemented forest restoration measures including tree planting and user restrictions during the mid-1990s (DFO, 2014). At the time of inventory (September 2015), the dominant tree species were *Schima wallichii, Castanopsis tribuloides* and

Lyonia ovalifolia comprising approximately 70% of the overall species composition. The stem density with DBH (diameter at breast height, measured at 1.3 m above ground) ≥ 5 cm was 2,415 trees/ha with a corresponding basal area of 20.6 m^2/ha. Although the stem density of this site is higher than the average for mid-hills forests of similar type (eg 1685/ha; DFRS 2015a), it varies widely e.g. 1,167 – 2,831 trees/ha (Sapkota et al. 2009) and reduces with increased levels of forest use. The mean DBH and height were 9.5 (± 4.4) cm and 9.4 (± 3.6) m, respectively. This site is used extensively by the local CFUGs as the abundant broadleaf species provide suitable livestock fodder, compostable litter and firewood. Consequently, the understory vegetation is poorly developed and non-uniform representing the gradient of disturbance. The mean Plant Area Index (PAI) values derived from processed canopy images (CAN-EYE software, version V6.313 (Weiss & Baret 2014)) in May 2015, September 2015 and May 2016 were 4.02 (±0.73), 4.05 (±0.86) and 3.41 (±0.93), respectively.

Predominantly planted pine forest (PF)

Planted *Pinus roxburghii* comprises the dominant vegetation of this site that was established mostly during the 1980s as part of the revegetation program of the Nepal-Australia forestry project (Gilmour et al. 1990). However, the broadleaf species including *S. wallichii* and *C. tribuloides* were randomly dispersed as the understory while *Nephrolepis* fern appeared irregularly as the ground cover. This integration of broadleaf species in pine plantations occurs through, both natural succession as well as the CFUG activities, including seedling planting (Gautam & Webb 2001). The forest had a stem density (DBH≥ 5 cm) of 1385 stems/ha and basal area of 27.7 m^2/ha. The mean DBH and height were 14.5 (± 6.7) cm and 13.7 (± 4.2) m, respectively. The PAI measurements of the forest in May 2015, September 2015 and May 2016 were 1.18 (± 0.39), 1.7 (± 0.56) and 1.3 (± 0.41), respectively. The lower values of PAI in this case are consistent with the lower Leaf Area Indices (LAI) of pine plantations than the brodleaf forests of the mid-hills (Ghimire et al. 2012). This site has low use value to the CFUG because the pine needles are not ideal as livestock fodder or compostable litter. Some locals occasionally collect litter and seasonal mushroom from the site while others visit for leisure.

Mixed broadleaf-pine species forest (MF)

The vegetation of the site consists of planted *P. roxburghii* randomly mixed with the broadleaf species including *S. wallichii, C. tribuloides* and *Myrsine capitellata.* These species are more frequent in the Eastern and Southern boundaries of the site because of the proximity to the BF, suggesting natural succession. The forest had a basal area of 25.1 m^2/ha with a stem density of 2090 trees/ha. The mean DBH and height were 11.1 (± 5.5) cm and 11.5 (± 4.2) m, respectively. The forest had a mean PAI of 2.97 (±0.77), 2.98 (±0.83) and 2.98 (±0.76) in May 2015, September 2015 and May 2016 respectively. The Northern boundary of the site meets an unpaved road which is a regular thoroughfare for the local commuters although vehicles use it mainly during dry season. In addition to being widely used by the local CFUGs, the site also experiences disturbance from the local commuters.

Table 5.1: Description of the experimental sites

Parameters	BF	PF	MF
Area (m^2)	12,000	8,200	9,100
Latitude/longitude	27°34'18"N/85°30'17"E	27°34'27"N/85°30'13"E	27°34'21"N/85°30'17"E
Elevation (masl)	1,615	1,550	1,585
Aspect	North	South	South to southwest
Slope (degrees)	22	18	19
Stem count (ha^{-1})	2415	1385	2090
Mean DBH (±SD) cm	9.5 (±4.4)	14.5 (±6.7)	11.1 (± 5.5)
Basal area (m^2)	20.6	27.7	25.1
Mean height (±SD) m	9.4 (± 3.6)	13.7 (± 4.2)	11.5 (± 4.2)
Mean PAI (range)	3.8 (1.5 - 5.73)	1.44 (0.51 - 3.74)	2.98 (1.64 - 5.41)
Levels of community use	High	Low	High

5.4.2 Data collection

5.4.2.1 Rainfall

Daily rainfall was recorded between 1 June 2015 and 31 December 2016 using a tipping bucket rain gauge (Onset computer corporation, USA; 0.254 mm per tip) installed approximately 270 m from the experimental catchment at 1495 masl in the RKC (Rain gauge 1, **Figure 5.1**). The rainfall data were recorded at 30 min intervals. Additionally, two manual funnel type rain gauges (Orifice area 182.4 cm^2) were installed as backup and read daily at around 8:45 AM local time to coincide with the regular recording times of the Department of Hydrology and Meteorology (DHM), Nepal. Long-range rainfall data of the DHM recorded approximately 2 km from the experimental catchment at 1515 masl (Rain gauge 2, **Figure 5.1**) were referred to for a comparison.

5.4.2.2 Throughfall

Throughfall plots of 75 m x 25 m in BF and 55 m x 30 m in PF and MF were outlined taking into account the topography and vegetation characteristics of the sites. A total of 12 manual funnel type rain gauges comprising a 4 L collector and a funnel (Orifice area 182.4 cm^2) were installed in each forested site. The gauges were randomly repositioned approximately every 4 weeks within the throughfall plots during the rainy season. The gauges were set up to ensure that the orifices remained sufficiently high above the ground (approx. 40 cm) to restrict splash back from the forest floor. Throughfall volume was read daily at around 8:45 am. Corresponding throughfall values (in mm) were obtained by dividing the average throughfall volume by the orifice area of the manual gauge.

5.4.2.3 Stemflow

Stemflow was measured from June 30 to October 12, 2016 on 3 dominant trees from 20 m x15 m representative plots in each forested site. In the BF, the trees were *S. wallichii, C. tribuloides,* and *L.*

ovalifolia. In the MF, these were *P. roxburghii, C. tribuloides and M. capitellata* while all three were *P. roxburghii* in the PF. Stemflow collection system consisted of a rubber tubing spirally wrapped and sealed around the trunk of the monitored trees at 1.3m above the ground. The stemflow volume was collected in 5 L plastic containers and was measured daily at around the same time as throughfall. Stemflow (in mm) was calculated using the formula of Killingbeck and Wali (1978) and projected to the plot level by multiplying the average stemflow per species with the corresponding stem density (after slope correction). These values were used to obtain the stemflow for the entire period of study, which was only a minor component of the incident rainfall.

5.4.2.4 Overland flow

A total of three run-off plots (6 m x 3 m) were set-up in each of the study sites for the collection of overland flow **(Figure 5.2a).** The collection system consisted of a gutter (3 m x 0.13 m) that collected and directed the runoff volume into two successive 200 L metal drums **(Figure 5.2b)**. The drums were arranged such that the first drum delivered only 1/5th of the spill over into the second because of the 5-slot splitter system fitted to it. The water level in the drums was read manually every day at 8:45 that was converted to volume in litres using a calibrated relationship between water level and volume. The drums were emptied and cleaned after the measurement. After correcting for direct throughfall inputs into the drums and the gutter, the resulting overland flow volume was divided by the corresponding area of the plot (corrected for slope) to obtain overland flow in mm per day.

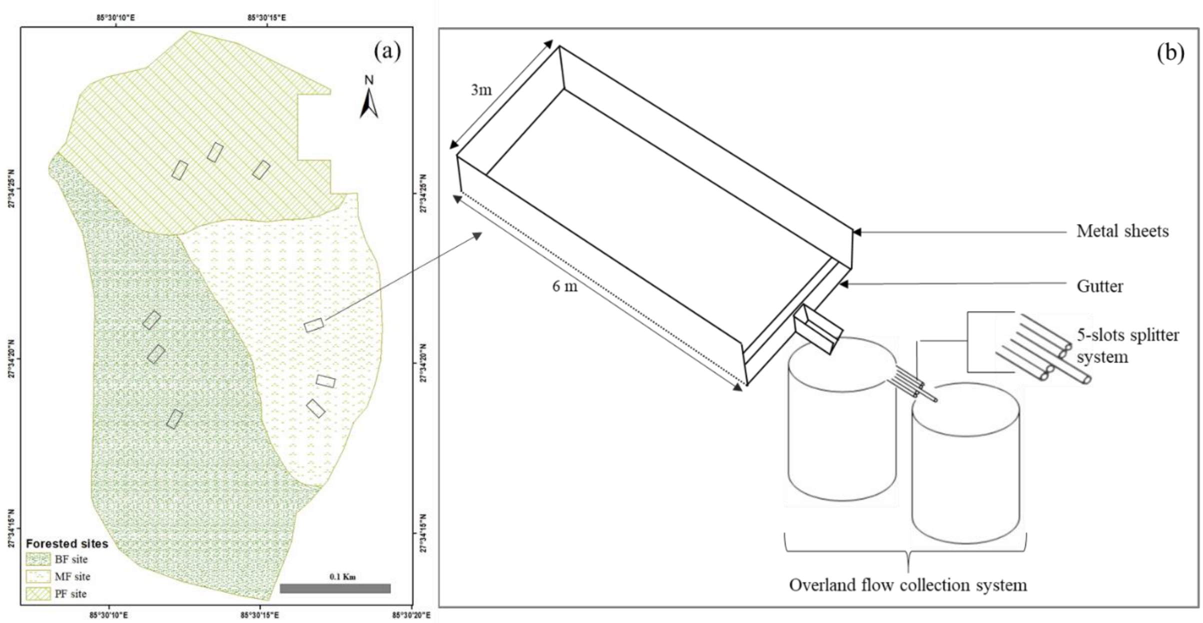

Figure 5.2: Approximate arrangement of the runoff plots at the study sites (a), and an illustration of the overland flow collection system used in the study (b) (Adapted from Atreya et al. (2006))

5.5 Results and discussion

5.5.1 Rainfall characteristics of the experimental catchment

A total of 2,166 mm of rainfall was recorded during the study period (June 2015-December 2016). This amount is similar to the measurements of DHM (Rain gauge 2, **Figure 5.1)** for the corresponding period (2071 mm). While a direct comparison is unattainable for 2015 due to partial data coverage (the data cover June-December only), the annual totals in 2016 (1,264 mm) were comparable to the long-range averages (2001-2016) of DHM (1,250 mm) and showed similar annual distribution **(Figure 5.3).**

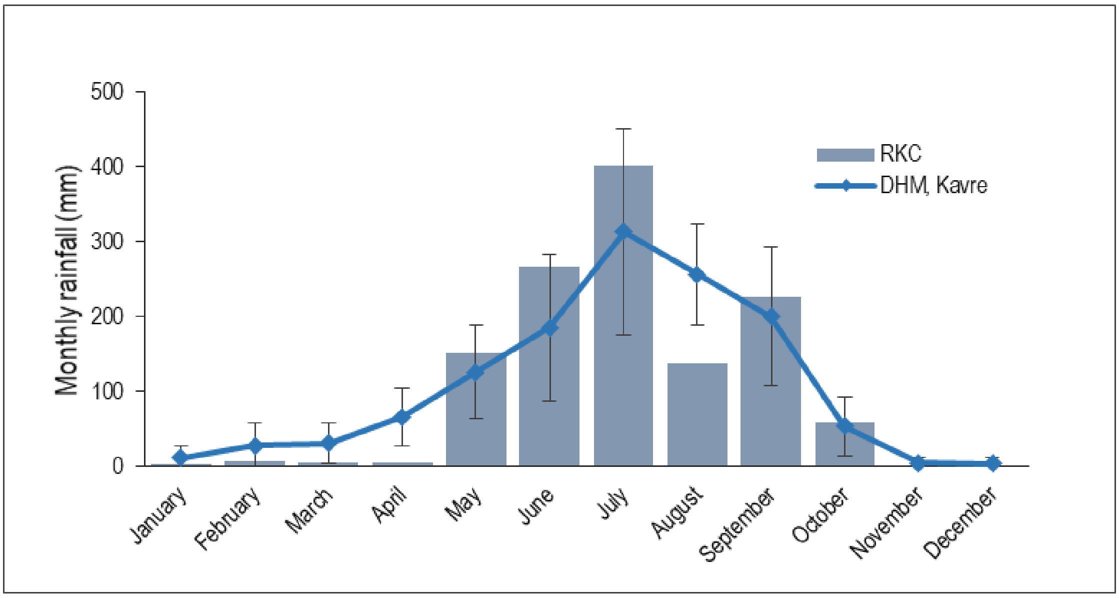

Figure 5.3: Monthly rainfall for 2016 at the experimental catchment and long-range (2001-2016) monthly averages recorded by the DHM station (Rain gauge 2, Figure 5.1) in Kavre

The frequency distributions of event size, duration and intensity of rainfall are provided in **Figure 5.4.** Typical of the mid-hills, the rainfall was highly monsoon-centric with relatively higher monsoonal totals for 2016 as compared to 2015, i.e. 1,031 mm vs. 874 mm **(Figure 5.4a).** There were 269 rainfall events distributed over 215 rainy days (classified to have ≥ 0.5 mm of rainfall) during the study period. The event-based median values of rainfall amount (mm), duration (hr) and intensity (mm h^{-1}) were 3.8, 2.5 and 1.5, respectively **(Table 5.2).**

Table 5.2: Descriptive statistics of rainfall events (n=269) during the study period

Parameters	Rainfall amount (mm)	Duration (h)	Intensity (mmh^{-1})
Mean	8.0	3.5	2.7
Median	3.8	2.5	1.5
Minimum	0.5	0.5	0.2
Maximum	50.3	18	21.5

In general, rainfall was of low-magnitude as events ≤ 5 mm occurred approximately 55 % of the time **(Figure 5.4b).** Most events had intensities ≤ 2.5 mmh^{-1} **(Figure 5.4c)** and lasted between 2-5 hours

(Figure 5.4d). These measurements are comparable to those reported from other parts of the mid-hills (Ghimire et al. 2012; Merz et al. 2006) as well as the monsoon-dominated regions of central Himalayas (Qazi et al. 2017).

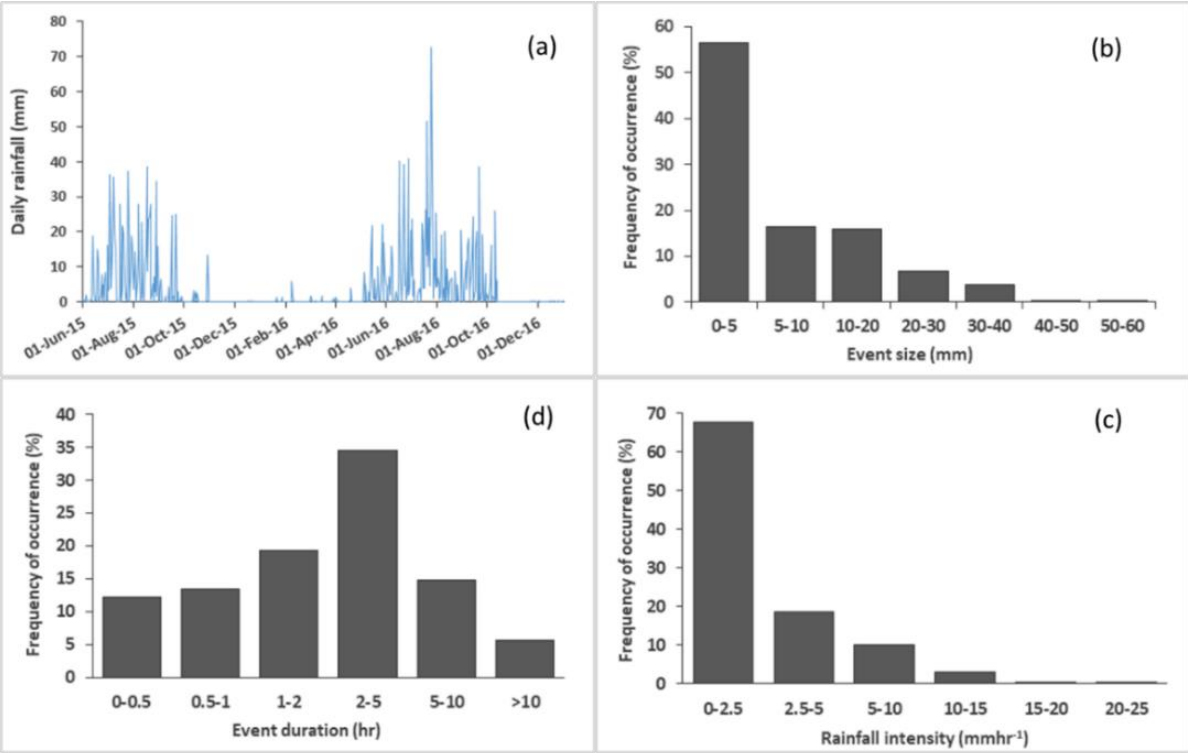

Figure 5.4: Daily rainfall (a), and frequency distributions of the amount (b), duration (c) and intensity of rainfall events (d) at the experimental catchment during the study period

5.5.2 Throughfall, stemflow and derived interception

Results of throughfall and stemflow measurements and derived interception during the study period are shown in **Table 5.3.** The throughfall totals of 1678 mm or 77.5 % of the incident rainfall for PF are higher than the comparable totals of 1,560 mm and 1,595 mm i.e. 72 % and 73.7 % of the incident rainfall for the BF and MF, respectively. A comparative exploration of these results is unattainable due to the lack of documented information on rainfall partitioning in the community forests of Nepal's mid-hills, particularly in the context of transitioning forest composition. Nevertheless, similar amounts of throughfall were found in *P. roxburghii* plantations (83% of incident rainfall) and natural broadleaf forests (76.2% of incident rainfall) in other parts of the mid-hills (Ghimire et al. 2012). These measurements are also comparable to the findings from the central Himalayan forests of India, i.e. approximately 76 % and 81% of incident rainfall for the *P. roxburghii* and the mixed *Pine-Quercus* species forests, respectively (Loshali & Singh 1992). Notably, the observed differences in throughfall in the present study are consistent with the Plant Area Indices (PAI) of the corresponding sites.

Table 5.3: Measurements of throughfall, stemflow and derived interception at various experimental sites during the study period

Sites		Gross rainfall (P)	Throughfall	Stemflow	Interception
BF	mm	2166	1560	34	572
	% of P		72.0	1.6	26.4
PF	mm	2166	1678	13	475
	% of P		77.5	0.6	21.9
MF	Mm	2166	1595	28	543
	% of P		73.7	1.3	25.1

Stemflow measurements were generally low for all forested sites, i.e. 0.6%, 1.3% and 1.6% of the incident rainfall for the PF, MF and BF, respectively. While similar measurements of stemflow were found in other parts of the mid-hills (Ghimire et al. 2012), these have been as small as 0.12% of incident rainfall in mixed *Quercus* species forest in India (Loshali & Singh 1992). Rainfall amount and intensity as well as individual tree morphology are important determinants of stemflow generation. Given that the experimental sites were subjected to similar rainfall conditions, the observed stemflow measurements are largely a factor of tree morphology. For instance, thick, absorptive bark and reduced branching of *P. roxburghii* (Brown et al. 2011) negatively affect stemflow generation (Crockford & Richardson 2000) and partly explain the lower stemflow values of the PF site.

Based on the wet-canopy water balance equation (P= I + Tf + Sf), derived interception for the BF, PF and MF represented 26.4%, 21.9% and 25.1% of the incident rainfall **(Table 5.3).** Expectedly, these measurements reflected the prevailing monsoonal patterns of the mid-hills **(Figure 5.5)** as the monsoonal rainfall of 1905 mm constituted approximately 88% of the study period totals (2166 mm). The dry period rainfall was only 261 mm or 12% of the study period totals **(Table 5.4).**

Table 5.4: Seasonal rainfall (P), throughfall, stemflow and derived interception at various sites during the study period

		Monsoon (June-September)				Dry period (October-May)			
Sites		Rainfall	Throughfall	Stemflow	Interception	Rainfall	Throughfall	Stemflow	Interception
BF	mm	1905	1398	30	476	261	162	3	96
	% of P		73.4	1.6	25.0		61.9	1.3	36.8
PF	mm	1905	1504	11	389	261	174	1	86
	% of P		79.0	0.6	20.4		66.5	0.5	33.1
MF	mm	1905	1431	25	448	261	164	3	95
	% of P		75.2	1.3	23.5		62.8	1.0	36.2

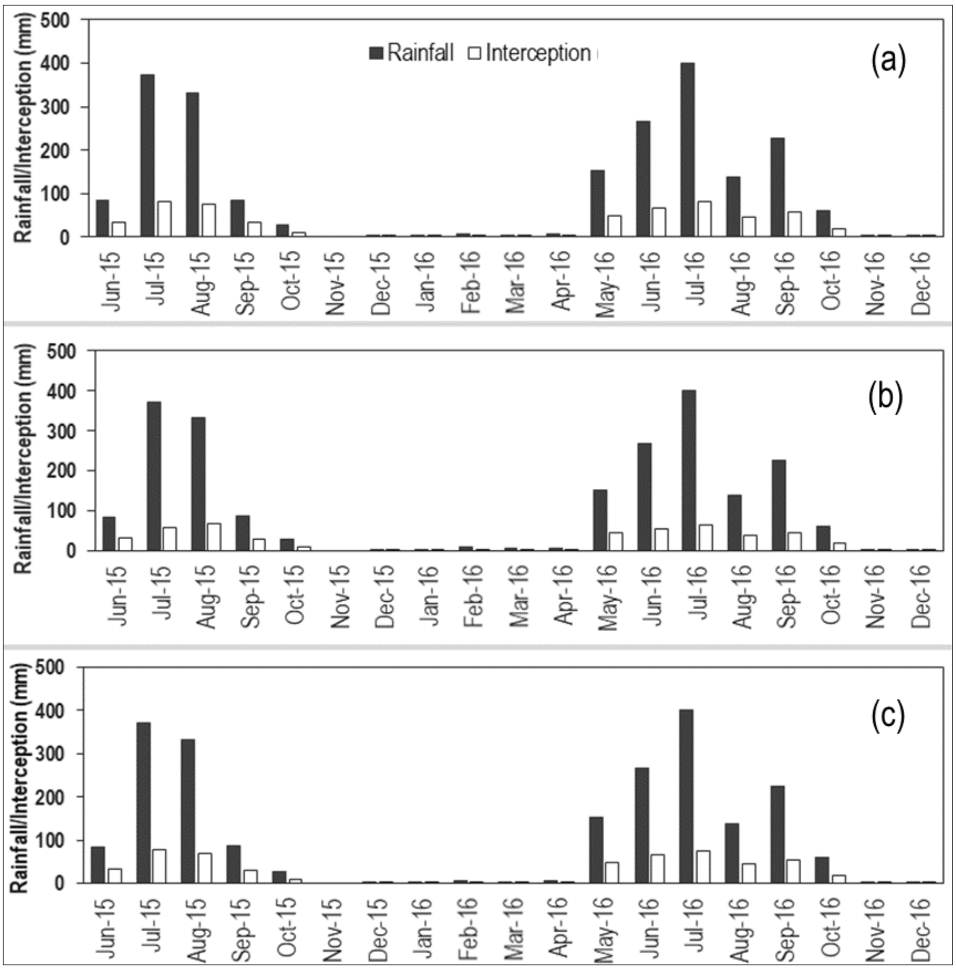

Figure 5.5: Monthly rainfall and derived interception for BF (a), PF (b) and MF (c) during the study period.

5.5.3 Overland flow

The overland flow measurements and their relative apportionment to rainfall are presented in **Table 5.5.** The study period totals of overland flow were 11.4% 9.8% and 4.7 % of net rainfall for the BF, MF and PF site, respectively. These values are equivalent to 8.4%, 7.3% and 3.7% of the incident rainfall for the corresponding sites suggesting that overland flow occurs only in moderation in those sites. Moreover, the differences in overland flows found here, generally reflect the gradient of disturbance associated with the varying intensities of forest use, particularly the removal of forest biomass. For instance, the community forest comprising the present study sites produces an estimated 420 tonnes of livestock fodder and 550 tonnes of compostable litter annually that mainly come from the broadleaf species (Kavre 2014a). Although these amounts are grossly insufficient to meet the local needs, the CFUGs harvest these products regularly during a year affecting soil hydraulic properties of the forested sites negatively, particularly reduced rainfall infiltration (Badu, Nuberg, et al. 2020). This is also reflected by higher amounts of overland flow in more intensively used BF and MF than the occasionally used PF **(Figure 5.6a).** In addition, overland flow rarely occurred below 4 mm of rainfall, particularly at the PF site**.** These observations are in line with the mid-hills studies showing overland flow to increase with advanced levels of site degradation. For instance, runoff coefficients (run off as % of rainfall) were 1-2% for a grassland and a mixed broadleaf forest but 33% for a highly degraded forest, increasing up to 64% for barren sites (Gardner & Gerrard 2002). Similarly, as a proportion of incident rainfall, monsoonal overland flow totals were much higher in a degraded pasture (21.3%) than a planted pine (15.5%) or a natural broadleaf forest (2.5%) (Ghimire et al. 2013). This high dominance of monsoonal rainfall, and therefore overland flows during this season **(Figure 5.6b)** is a critical consideration for forest-water research as well as management of the mid-hills catchments.

Table 5.5: Gross and net rainfall, and overland flow at various sites during the study period

Sites	Gross P (mm)	Net P (Throughfall + Stemflow, mm)	Overland flow (mm)	Overland flow as % of net P
BF	2166	1594	181.9	11.4
PF	2166	1691	79.1	4.7
MF	2166	1623	158.4	9.8

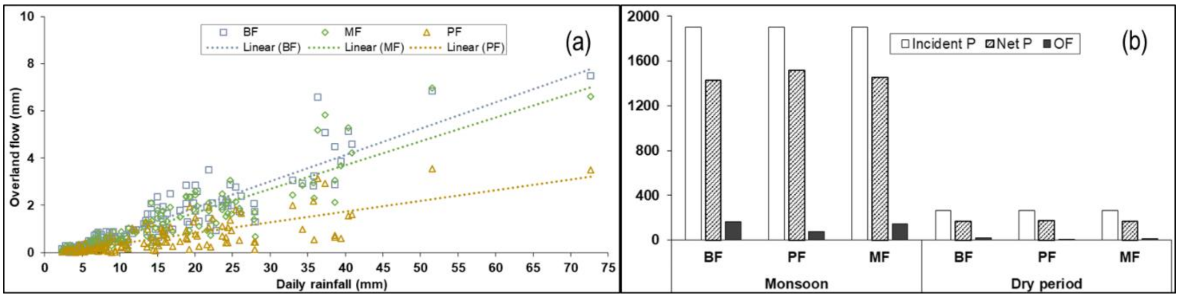

Figure 5.6: Daily overland flow (a), and its seasonal distributions in various forested sites during the study period (b)

5.5.4 Hydrological implications of the widespread CFUG activities and transitioning forest structure and composition in the mid-hills catchments

A number of experiments in diverse climatic conditions have shown reductions in catchment water yield after forest plantation (Jackson et al. 2005; Scott et al. 2005; Scott & Prinsloo 2008b). However, in Nepal's mid-hills catchments, the quantitative information in this regard is limited. For instance, a planted *P. roxburghii* forest, used regularly for product harvesting and livestock grazing, contributed to declining dry season streamflow because the species had higher water use than a less disturbed natural broadleaf forest (Ghimire, Lubczynski, et al. 2014). Furthermore, the plantation had significantly lower soil hydraulic conductivity (K_s) and produced higher amounts of overland flow (Ghimire et al. 2013) than the broadleaf forest, owing to the highly disturbed state of the plantation site from intensive local use. Conversely, an undisturbed *P. roxburghii* forest under similar climatic conditions to the current study sites in North-West India, produced negligible overland flow (Pandey et al. 1983; Pathak et al. 1984) leading to the deductions that the studied catchments were sub-surface flow systems and were highly vulnerable to the effects of deforestation. The studies further highlight the importance of site disturbance on resultant landscape hydrology, in addition to the species type. Importantly, however, incorporation of the species water use data is necessary for a fuller understanding of the hydrological effects of community forestry in the forested catchments of Nepal mid-hills.

As previously described, the present study sites undergo varying levels of site disturbance. This is because both BF and MF are subjected to repeated biomass removal combined with persistent trampling of the forest floor from the ongoing CFUG traffic, which is minimal on the PF site. These activities reduce surface roughness of the forest floor causing further reductions in rainfall infiltration (Langford 1975). The resultant effects are reflected by higher overland flow generation in the more intensively used BF and MF sites **(Figure 5.6a)**. Moreover, potential for infiltration access overland flow (IOF) characteristically increases as reduced soil hydraulic conductivities are combined with the concentrated rainfall patterns of the broader mid-hills (Bonell et al. 2010; Bruijnzeel & Bremmer 1989; Ghimire et al. 2013; Gilmour et al. 1987), which exacerbates the “too little or too much” water situation in the area (Schreier et al. 2006). Improvement in soil infiltration capacity due to increased organic carbon, microbial activity and macropore formation following years of undisturbed forest development (Singh et al. 2014) is seriously impeded (Bonell et al. 2010; Gilmour et al. 1987). Admittedly however, this mode of forestry, i.e. forest development separated from local use is a distant thought in Nepal’s mid-hills, specifically because of the high community reliance on local forest products and concurrent government policies to promote community forestry (Karki et al. 2018; Nuberg et al. 2019). For illustration, an estimated 14 million people are organised as CFUGs to manage approximately 2.2 million ha of Nepal’s forests, a vast majority of which are in the mid-hills (GoN 2018).

Community forests of the mid-hills are increasingly valued for water related services, with reports of increased water yield after forest restoration (Thapa et al. 2018). However, as shown in this study, increases in water yield from forest restoration are not universal. While such reporting adds to the ongoing global debate about forest-water relationships (Andréassian 2004; Ellison et al. 2017; Gilmour 2014; Ponette-González et al. 2015), reforestation and forest protection programs continue to form an essential part of catchment management plans in Nepal (Pokharel 2019). For instance, reforestation programs of the 1980s in the mid-hills catchments caused a marked increase in the areas of *P. roxburghii* forest (Schreier et al. 1994), which currently is the third most common species in the area (DFRS 2015a). Although it was initially planted to mainly reduce soil loss and rehabilitate degraded mid-hills, it is increasingly valued for conservation-centric schemes such as the REDD+ (Reducing Emissions from Deforestation and Forest Degradation) of the United Nations (Luintel, Scheller, et al. 2018; Pariyar et al. 2019). Thus, due to the combined effects of strongly conservation-centric management, natural succession and CFUG activities, increased areas of the mid-hills pine plantations will likely undergo transitions in structure and composition as seen in the presently studied PF site (and observed in other parts of the mid-hills (DFO Kavre 2014b). Therefore, even though partitioning of rainfall in such forests will predictably be similar to the PF site, the overall hydrological effects will need to be evaluated against the microclimatic conditions of the catchments and intensity of forest use.

5.6 Conclusion

This project showed the partitioning of rainfall in three types of community forests, viz. a natural broadleaf (BF), planted pine-dominated (PF) and mixed species broadleaf-pine forest (MF) that are used for collecting firewood, litter and livestock fodder in varying intensities by the local CFUGs in a mid-hills catchment of central Nepal. In addition, it presented measurements of overland flow production in these forests for the study period of June 2015 to December 2016. Measured throughfall, stemflow and derived interception for the BF were 72.0%, 1.6% and 26.4% of the incident rainfall, respectively. These values corresponded to 73.7%, 1.3% and 25.1% for the MF, and 77.5%, 0.6% and 21.9% for the PF. The overland flow production were 8.4%, 7.3% and 3.7% of incident rainfall for the BF, MF and PF, respectively. As expected, the derived interception values corresponded with the stem densities and Plant Area Indices (PAI) of the experimental forests. However, the overland flow measurements reflected the amount of disturbance, with the more intensively used BF and MF producing higher amounts than the occasionally used PF. These results highlight the important role of forest use related disturbance on forest vegetation as well as the forest floor that have implications for long-term management of the mid-hills catchments, particularly in relation to widespread community forestry practices and downstream water supply.

Chapter 6

6. Thesis discussion to contextualise the present findings

The preceding chapters show that the forests of Nepal's mid-hills catchments primarily serve two concurrent objectives; i.e. supply immediate forest products to the local communities, and provide ecosystem services, including regulation of hydrological flows. The synergetic nature of forest-people relationships in these catchments is widely acknowledged by natural scientists, theorists and community development organisations (Thwaites et al. 2018). However, the hydrological effects of sustained forest use activities of the local people are barely understood. This is despite the widespread implementation of community forestry practices since the late 1970s that are the main methods of changes to forest structure and composition, particularly in the mid-hills catchments (DFRS 2015a). This research contributes to understanding the forest-water-people dynamics of the mid-hills catchments as the conventional studies of forest-water relationships that purely evaluate the two, i.e. forests and water in a catchment, offer too narrow a perspective of the mid-hills and other community-used forested landscapes of the tropical and sub-tropical regions of the world. The sub-headings below discuss the current findings in light of what is known and unknown about forest-water relationships, mainly in relation to sustained community use of the forests of the mid-hills catchments. This is important to develop the social and institutional context of managing those catchments as well as the forested landscapes in similar environmental conditions worldwide.

6.1 Community forestry practices are important considerations of forest-water relationships

In addition to the evident product value, the trees and forests have deep religious and spiritual significance to the predominantly Hindu-Buddhist population of Nepal (Niroula & Singh 2015). This significance, along with the culturally-formed institutions of resources management (Ostrom 1990) strongly shape contemporary forest management systems of Nepal including community forestry (Gilmour & Fisher 1991; Ingles 1995). At present, there are an estimated 14 million people organised nationally as CFUGs to manage over 2 million ha of community forests (~ 37% of the total forests), that are found largely in the mid-hills catchments (GoN 2018). Although inherently protection-centric, the focus of Nepal's community forestry policy progressively changed with the ever-changing local and global context (Nuberg et al. 2019; Ojha et al. 2009). In recent years, the well-established community forests of the mid-hills catchments are increasingly viewed as suppliers of ecosystem services, particularly water (Paudyal et al. 2015) with some studies reporting improved water yield with increased forest (Thapa et al. 2018). Furthermore, the popular beliefs that forests increase water (Calder 2005; Gilmour 2014) are frequently found in Nepal's public domain (e.g. Ghimire 2014b; Lamsal 2014; Shahi

2011; Silwal 2013). This is despite a number of paired catchment experiments showing forests to generally reduce water yield (Farley et al. 2005; Jackson et al. 2005; Smith & Scott 1992). In Nepal, the essential shortage of context-specific evidence on forest-water relationships, and the culturally framed forest-people relationships **(Chapter 3),** likely lead to the persistence of the notion that forests are necessarily good, including improved water yield.

Amidst the ongoing debate on forest-water relationships (Andréassian 2004; Chappell 2005; Ellison et al. 2017; Ponette-González et al. 2015), reforestation programs are an important part of catchment management (van Dijk & Keenan 2007), especially when water quality is paramount. This is because forests reduce surface runoff, soil erosion and shallow landslides (Bruijnzeel 2004; Sidle et al. 2006) with increased surface roughness due to the combined effects of forest litter, understorey layer and tree roots (Waterloo et al. 2007). To a greater extent, this understanding constituted the stimulus to reforesting the mid-hills catchments (Soussan et al. 1995) particularly after the publicity of the perceived linkages of increased flood incidences and soil erosion with high rates of deforestation (Eckholm 1975; Myers 1986). However, these linkages have been contested for both Nepal mid-hills (see Ives (2004)) and globally, mainly on grounds that reforestation driven catchment management plans disproportionately highlight the negative effects of deforestation in flood generation and soil erosion as compared with other land uses including urbanisation and road construction (Kaimowitz 2005). In some cases, particularly in developing countries, reforestation programs to control soil erosion are described as politically driven (Barr & Sayer 2012; Blaikie 1985). Notwithstanding the political side of the discussion, Zimmermann et al. (2012) showed that the role of forests in flood reduction and soil erosion is, indeed overstated because the experimental studies inadequately accounted for the prevailing site characteristics of forested catchments. Likewise, forest use related disturbance is a critical factor affecting catchment hydrology in the tropical and sub-tropical regions (Flores et al. 2019; McNulty et al. 2018) and warrants particular caution against generalisation of global results. This is because much of the understanding of forest-water relationships comes from studies carried out in non-tropical environments (Bruijnzeel 2004; Malmer et al. 2010). Accordingly, hydrological effects of forestation including improved soil infiltration capacity that are realised generally after years of undisturbed forest growth (Giambelluca 2002b; Scott et al. 2005) are largely unrealistic in the case of mid-hills catchments because of the widely-practiced community forestry activities. These activities have significant effects on soil properties including organic carbon, bulk density and saturated hydraulic conductivities with implications for rainfall infiltration **(Chapter 4)** (Badu, Nuberg, et al. 2020). Similar results, i.e. reductions in soil hydraulic conductivities due to the imposition of forest use related disturbance have also been reported from other parts of the mid-hills (Ghimire, Bruijnzeel, Bonell, et al. 2014; Gilmour et al. 1987).

Disturbance related to organised or sporadic removal of forest products particularly firewood, forest litter, fodder and cattle grazing is common across the forests of the lower Himalayas (Brown et al. 1995; Ives 2004; Mehta et al. 2008). In Nepal's mid-hills, such disturbance is more pronounced in the government-managed forests than the private or community forests (DFRS 2015a). This is because the poorly-resourced management framework of the government bodies as well as the cultural and political intricacies of forestry bureaucracy render these forests to high levels of exploitation and degradation **(Chapter 2)**. This reality also guided the inception of community forestry policy in the late 1970s (Gilmour 1988; Gilmour & Fisher 1991). As a logical response to high rates of forest exploitation and land degradation, large parts of the mid-hills catchments (including the current study area) were reforested during the 1980s and 1990s. The reforestation programs were carried out as joint projects of the local communities, national and international government agencies, mainly Nepal-Australia Forestry Project (ACIAR 2020). However, recent improvements to the degraded state of the mid-hills forests are largely attributed to the wider application of community forestry practices (DFRS 2015a; Paudyal, Putzel, et al. 2017). Thus, the local forest users, particularly the CFUGs are both the drivers as well as beneficiaries of forest development in the mid-hills catchments, and therefore, important stakeholders of the forest-water relationships.

6.2 On the pine forests-dry season streamflow dilemma of the mid-hills catchments

The traditional reforestation programs of the mid-hills largely used the fast-growing species of pine, particularly *Pinus roxburghii*. The species is native to the broader Himalayan region. It is widely found between the elevations of 400-2,300 masl, in monsoon-dominated regions of India, China, Pakistan and Bhutan (Farjon 2013) and generally in between 1,000-2,000 masl in Nepal (Jackson 1987). In the central mid-hills, the plantations occur mostly in the drier, well-drained, south-facing slopes that were initially planted at an approximate density of 1,700 stems/ha (Applegate et al. 1988). It has superior growth qualities over the common broadleaf species, particularly suited to the degraded and nutrient poor soils of the mid-hills region (Dangal & Das 2018; Gilmour et al. 1990; Hunt et al. 2001; Jackson 1987; Speer et al. 2017). At present, *P. roxburghii* is the third most common species of the mid-hills forests and the plantations cover an estimated catchment area of 0.2 million ha (i.e. ~9 %) (DFRS 2015a). Despite the growth advantages, the plantations offer limited use value to the local communities. This is because the firewood and litter they provide are of inferior quality, while livestock fodder which is often in high demand (Jackson 1987; KC et al. 2015), is practically absent, Some studies in the mid-hills catchments have also found the use of pine litter as composting material to affect soil fertility negatively because it increased soil acidity (Fleury 2000; KC et al. 2013; Schreier et al. 1995).

There are growing public concerns about the plantations reducing dry season stream flows in the mid-hills catchments (Menon 2011; Shrestha 2016). Although extensive research is still lacking, a central mid-hills study showed higher water use of the pine plantations than the natural broadleaf forest (Ghimire, Lubczynski, et al. 2014). This is perhaps the only published study in the central mid-hills catchment to integrate the measurements of soil hydraulic conductivities (Ghimire, Bruijnzeel, Bonell, et al. 2014), overland flow production (Ghimire et al. 2013) and evapotranspiration (Ghimire, Lubczynski, et al. 2014) of contrasting forest types and report on the hillslope hydrological functioning. A separate study in the catchment also suggested pine plantations to have contributed to declining dry season streamflows due to their higher transpiration rates than the natural broadleaf forests (Baral 2012). Notably, however, because the pine plantations of the mid-hills were established on sites with little or no vegetation (Hunt et al. 2001), a holistic study to analyse vegetation effects on catchment streamflows should be inclusive of this landuse, i.e. little or no vegetation.

A number of global studies have found fast-growing coniferous plantations to use more water and cause greater reductions in streamflows than slow-growing broadleaf species (Sahin & Hall 1996; Swank & Douglass 1974). However, water use usually declines as plantations mature (Calder 2007) as has also been found in, for example, South Africa (Scott & Prinsloo 2008a) and Japan (Komatsu et al. 2008). By inference, this suggests that water use of pine plantations of central mid-hills catchments is only going to decline as the plantation further mature. However, water use of species is inconsistent across sites. For instance, this was a factor of prevailing climate and soil water availability for *Eucalyptus urophylla* that were planted in varying density and soil types of China (Morris et al. 2004). Likewise, water use of exotic fast-growing species *Eucalyptus camaldulensis* was similar to that of the native deciduous broadleaf species *Tectona grandis* in low rainfall zone (800 mm yr^{-1}) of India. The study further suggested that it was a factor of water availability and soil depth (Calder et al. 1993). Clearly, as synthesized by Aranda et al. (2012) and Komatsu et al. (2011), water use of forest species is a complex interplay of site characteristics, species traits and prevailing climate as these together affect runoff generation, rainfall infiltration and evapotranspiration of forested catchments. Thus, it is possible (more likely) that water use of *P. roxburghii* would be dissimilar in the western mid-hills of Nepal where rainfall is lower than the central mid-hills (Karki et al. 2016) and the species occur both in the north and south-facing slopes (Jackson 1987).

Another particularly important consideration for the mid-hills catchments is the nature and intensity of forest use as forests are subjected to a varying degree of disturbance based on the type of products these supply. Among the presently studied sites, broadleaf forest (BF) supplied the highly useful livestock fodder and composting litter to the agriculture-based community (DFO Kavre 2014a). Accordingly, this site was intensively used by the local CFUGs in comparison to the pine-dominated forest (PF) or the mixed species forest (MF) that did not supply those products as adequately. These differences on forest use intensity correspondingly affected the soil parameters as discussed in **chapter 4** (Badu, Nuberg, et al. 2020). In particular, the PF site, experiencing minimal disturbance due to low use value, had higher saturated hydraulic conductivity (K_s) than the more intensively used sites, BF and MF. Similar trends of lower K_s values for more intensively used sites are also found in other parts of the central mid-hills (Ghimire, Bruijnzeel, Bonell, et al. 2014).

Similarly, the PF site produced lower overland flows as compared with the BF or MF sites during the study period (June 2015-December 2016), broadly reflecting the variations in forest use intensity as discussed in **chapter 5** (Badu, Ghimire, et al. 2020). The results are in line with previous findings of the central mid-hills that showed more degraded sites (resulting from high levels of disturbance) to produce higher overland flows. For instance, a degraded forest produced much higher runoff than a grassland or a mixed broadleaf forest i.e. 33% vs 1-2% of the incident rainfall (Gardner & Gerrard 2002). Likewise, an intensively used pine forest also had higher amounts of overland flows (15.5 % of the incident rainfall) than a mostly protected natural broadleaf forest (2.5% of the incident rainfall) (Ghimire et al. 2013). In this case, the overland flow production also corresponded to the soil hydraulic conductivities of the sites reflecting the level of site disturbance. Thus, higher overland flows or low saturated hydraulic conductivities of more intensively used sites irrespective of the vegetation type, highlight the importance of land use and management practices in evaluating streamflows of the mid-hills catchment.

The deductions that *P. roxburghii* plantations reduced dry season streamflows of the mid-hills catchments need additional considerations and indeed, further research. Forest plantations are inherently dynamic systems. The pine plantations of the mid-hills are increasingly mixed with broadleaf species including *Schima wallichii, Castanopsis indica and Lyonia ovalifolia*, as seen in the pine-dominated site of the present study. This change of species composition occurs due to a variety of reasons in the mid-hills including natural succession (DFO Kavre 2014b; Webb & Gautam 2001), deliberative manipulation of the species composition by the CFUGs (Baniya et al. 2019), and recently, the introduction of alternative silvicultural operations in those plantations (Cedamon et al. 2018).

6.3 Socioeconomic transition affecting forest-people-water relationships of the mid-hills

As acknowledged earlier, government interventions and local forestry practices are the direct agencies of change to the composition and structure of the mid-hills forests. In recent years, these changes also occur indirectly through socioeconomic modifications of the Nepalese society that Ojha et al. (2017) described as "socio-environmental pathways". In particular, the high rates of outmigration from rural mid-hills to urban areas (internal and overseas) cause significant labour shortages to sustain the traditional agriculture-based lifestyle. For illustration, the number of migrant workers to the countries of the Gulf Cooperation Council alone increased to nearly 230,000 in 2018/19 from approximately 7,000 in 1997/98. This level of migration and resulting loss of labour causes abandonment of farming lands altogether leading to the successional development of forests in the abandoned lands (Jaquet et al. 2019; Paudel et al. 2014). Furthermore, the subsequent increase in household remittance and access to alternative commodities also reduces direct community reliance on traditional forest products including firewood for energy or fodder and litter as agricultural supplements contributing to further forest development in the mid-hills catchments (Oldekop et al. 2018; Shrestha & Fisher 2018). Similar pathways to forest transitions are common in many countries where remittance drives socioeconomic change (Hecht et al. 2015). In Nepal, incoming remittance (nearly 9 billion USD in 2018/19) contributes to as much as a quarter of the annual Gross Domestic Production and is a major driver of rural to urban lifestyle change (MLESS 2020). Among many challenges associated with this change, the cultural shift of resources use, particularly water, has important implications for its long-term management and supply. In traditional Nepalese society, water is obtained from communal sources such as a community tap, spring or a spout. However, with the increasing influence of a market-based economy in recent years, individualistic modes of resource use are pursued, such as piped water supply per household (Molden et al. 2016; Tripathi et al. 2018). Water demand is further affected due to increased awareness about personal hygiene, sanitation and lifestyle choices including use of modern full-flushed toilets, increased washing or cleaning habits in both rural and urban areas (Gurung et al. 2019; Udmale et al. 2016). Therefore, a fuller evaluation of the dry season flows in the mid-hills catchments needs to be extended beyond the forest-water debate, such that it also incorporates changed demand for water.

6.4 Policy implications of the present findings

Implementation of research-based policy-making in Nepal's forestry sector involves technical and institutional challenges (Amatya et al. 2017). Technical challenges arise mostly due to complete lack of or poor access to context-specific experimental data of forest management. Accordingly, forestry policies and practices are often based on foreign experience which exposes them to administrative manipulation, local dissent and dismissal (Laudari et al. 2020; Ojha et al. 2016); the use of government led operational plans of the CFUGs to manage the local community forests is an example (Baral, Meilby, et al. 2017; Basnyat et al. 2018). On the other hand, the institutional challenges arise due to the highly involved bureaucratic and political interests in Nepal's forestry sector **(Chapter 2)** (Ojha 2013; Ojha et al. 2007), which according to Gautam (2006), further impedes research-based forestry practices in Nepal. Unfortunately, the politicisation of water use and supply is equally, if not more complex in Nepal as the stakeholder involvement extends beyond geographic boundaries (Blaikie & Muldavin 2004; Gyawali 2013). In fact, this is common across the wider Himalayan region, which diverts the attention from scientific research to sustainably manage these resources, often compromising the wellbeing of the people dependent on them (Ives 2004).

In addition to the nature and level of politicisation, the methods of water resources management in Nepal are similar to those for forests. This is because there is high involvement of organised local community groups in catchment water management programs including irrigation and drinking water supply (Rautanen et al. 2014). Despite these similarities and the documented recognition for an integrated approach to catchment management, practical strategies to integrate forest and water are still missing (Biggs et al. 2013) and the two resources are dealt with separately. This is mainly because of the knowledge gap about the relationships between the two resources as well as the disintegrated responsibilities of the authorities involved in catchment management (Pant et al. 2005).

Hydrological effects of forest development are not prioritised, if at all considered in Nepal's forestry sector, unlike in many other countries including Japan (Komatsu et al. 2011), South Africa (Edwards & Roberts 2006), Australia (Stirzaker 2002) and the USA (Bredemeier et al. 2010; McLaughlin et al. 2013). It is perhaps the legacy of the 'theory of Himalayan Environmental Degradation' (Eckholm 1975; Ives 1987) that the traditional forest policies are primarily conservation-centric. Accordingly, the reforestation and afforestation programs of the Ministry of Forests and Environment (previously Ministry of Forests and Soil Conservation) are often aimed at 'fixing' the land degradation issues **(Chapter 3)**, or improving environmental quality, such as carbon storage (Pokharel 2019). Expectedly, Nepal's community forests are prominent participants of the global conservation programs, in particular Reducing Emissions from Deforestation and Forest Degradation (REDD+) of the United Nations (Luintel, Scheller, et al. 2018; Maraseni et al. 2014; Pariyar et al. 2019). On the other hand, there are growing deliberations about the prospects of these forests to contribute to local economy through systematic harvest and sale of forest products, particularly timber giving rise to divergent, and at times conflicting, views about the management of these forests (Banjade 2012; Ojha et al. 2019). Amid the debate, the government has recently implemented Scientific Forest Management (SFM). In principle, this involves the application of modern, rather than traditional silvicultural systems of forest management allowing for timely harvest and regeneration opportunities (MFSC 2014c).

It is claimed that implementing SFM in community forests of the mid-hills provides concurrent economic and ecological benefits (Jayasawal & Biswokarma 2016). However, while uncertainties remain about their realisation due to underlying conflicts between the local communities and technical foresters (Poudyal et al. 2020), the SFM guidelines fail to address the resultant hydrological effects of changes to forest structure and composition arising from the application of modern silvicultural systems. Among others, these systems directly affect species density, diversity and crown cover that are important factors affecting the microclimate of forested sites including partitioning of rainfall **(Chapter 5).** Furthermore, reduced species density following a thinning operation generally increases run-off (Hawthorne et al. 2013; Ruprecht et al. 1991) with maximum yield obtained from clear felling (Bruijnzeel 2004; Hubbart et al. 2007). Although these systems are considerations for optimising catchment water yield in some cases (Dung et al. 2012; Goeking & Tarboton 2020), they are undesirable for the mid-hills catchments. This is because the yield improvements from the thinning operations are short-term (NRC 2008), while increased run-off generation adds to the water management challenges already faced due to the concentrated rainfall patterns and steeper topography of the mid-hills. Furthermore, large scale thinning operations to improve catchment water yield are likely to face dissent from the pro-conservation interest groups, as has been the case with the implementation of SFM in Nepal (Joshi et al. 2018). Alternatively therefore, activities directed at improving rainfall infiltration (and groundwater storage) have greater relevance for sustained water yield from these catchments (Upadhya 2012). Unfortunately, the consistent removal of biomass reduces opportunities for a protective layer to develop on the forest floor which promotes higher rainfall infiltration and percolation in undisturbed or less disturbed conditions, as found in the PF site of this study. But again, biomass removal is crucial to supporting the traditional agriculture of the mid-hills (Balla et al. 2014). Balancing this trade-off situation requires high levels of understanding of the local landscape and community needs that can be met from increased focus to research. In particular, recharging groundwater storage from monsoonal rainfall is critical to sustaining the dry season (September-May) streamflows and water supply. In recent years, there are local level efforts to harvest monsoon runoff in artificial ponds with expectations to recharge groundwater storage and revive declining water sources of the mid-hills catchments (Sharma et al. 2016). However, there is inadequate experimental data to know the long-term hydrological effects of such methods. A practical evaluation needs considerations for downstream water use, particularly the rain-fed crop production systems of Nepal such as rice, maize and wheat (Shrestha et al. 2013).

There are global trends to use a monetary value for quantifying the upstream-downstream services of forested catchments, particularly water supply (Brauman et al. 2007). While such a value of the forested catchments of the mid-hills is still unknown, some early applications of “Payments for ecosystem services” are found in Nepal. In this scheme, the downstream users of water from a forested catchment pay a certain sum of money to the upstream ‘producers’ or ‘suppliers’ (Wunder et al. 2008). These practices are likely to be valuable for the mid-hills catchments, particularly with the increasing influence of market economy in Nepalese society as described by the “theory of ecological modernisation” (Mol & Sonnenfeld 2007). This is highlighted by the reported shifts in the importance of community forests from being the providers of traditional forest products to suppliers of ecosystem services, particularly water.

Chapter 7

7. Conclusion and future research recommendations

Reforestation or afforestation of degraded lands is often a recommended strategy for catchment streamflow regulation. This is based on the expectation that forests improve rainfall infiltration and groundwater storage (CIFOR 2012). However, these improvements from forestation can be realised when forest development occurs in undisturbed conditions, unlike most parts of Nepal's mid-hills catchments where community forestry practices are widespread. Nevertheless, perceptions that forests are necessarily good for hydrological flow regulation of a catchment, including improved water quantity and quality persist across sections of Nepalese society as discussed in chapter 3. Importantly however, the perceptions of the local CFUGs about forest-water relationships are more objective. This is shown by the interview results in the chapter as nearly 37% of the respondents *(n=150)* believed forests to reduce water quantity, while 44% believed the forests to increase it. There was also disapproval of pine species as they supposedly contributed to reduced water quantity.

The perceptions that pine plantations reduce dry season streamflows of the mid-hills catchments have some scientific support because planted pine forests were found to use more water than the pasture vegetation and natural broadleaf forests (Ghimire, Lubczynski, et al. 2014). However, results of this study highlight the important role of forest use intensity in affecting forest-water relationships of a forested catchment. This is because the less intensively used planted pine-dominated site (PF) had higher rates of saturated hydraulic conductivity (K_s) than the intensively used broadleaf (BF) or mixed forest site (MF). The PF site also produced lower overland flows i.e. 4.7% of net precipitation during the study period of June 2015-December 2016, as compared to 9.8% and 11.4% for the MF and BF sites, respectively. In particular, the significantly higher K_s values at shallower depths (0-50 cm) of the PF site allowed higher rainfall infiltration implying greater groundwater storage potentials of the site (Chapter 4). These results warrant caution against generalisation of the interpretations that pine plantations reduce dry season streamflows and draw attention to the importance of forest management practices, ie. the CFUG activities, in evaluating hydrological effects of forest development in the mid-hills catchments. Moreover, the findings of the study reiterate the important, yet often overlooked, role of forest use related disturbance in catchment hydrology, particularly the dry season flows. This disturbance reduces rainfall infiltration opportunities and enhances peak flows associated with soil degradation of many forested landscapes in the tropical and sub-tropical environments (Bruijnzeel 2004). Importantly, these findings highlight the opportunities for reconciling science with community perceptions of forest-water relationships (Calder 2002), particularly in the context of the policy debate about scientific management of the forested catchments of Nepal's mid-hills.

This study employed a novel approach to forestry research in that it combined process-based experimental data with the local perceptions of forest-water relationships in a typical mid-hills catchment of Nepal. The aptness of this approach is particularly valid to develop wider acceptability of catchment management plans because it integrates the prevailing biophysical and institutional factors as well as diverse knowledge systems of forest management found in many tropical and sub-tropical parts of the world (Bonell & Bruijnzeel 2005). Additional research identified below will further contribute to evidence-based management of the mid-hills catchments to concurrently realise the local forest product needs and downstream water use;

i) detailed hydrologic characterisation of forest development on catchment hydrology including effects of species type, age and areas covered in varying climatic conditions of the extended mid-hills catchments e.g. the wetter east vs drier west (Karki et al. 2016). This is additionally important in the face of predicted climate change effects on rainfall, temperature and forest regeneration (Bhatta et al. 2015) including the commonly planted species of *P. roxburghii* (Aryal et al. 2018),

ii) hydrological effects of Scientific Forest Management in various forest types, particularly in relation to the application of modern silvicultural operations that significantly affect forest structure and composition. For instance, a recent forest harvesting trials

iii) use of hydrological models to analyse the spatial and temporal effects of landuse change on catchment water-balance. This provides opportunities for upscaling the current plot level findings to landscape level particularly because forest areas of the mid-hills catchments as well as community forestry practices are likely to expand further as per the government policy (NLC 2019). Crucially, because the success of hydrological models depends greatly on quality on-ground data, identification of catchment characteristics is critical for implementing the modelling exercises.

iv) an analysis of water demand vs supply capacities of the forested catchments that also take into account the changes in seasonal stream flows,

v) effects of land use and forest cover change due to development projects including road, hydropower plants as well as regenerated forests in abandoned farmlands.

Appendices

Attachment 1: Letter of ethics clearance

THE UNIVERSITY of ADELAIDE

RESEARCH BRANCH
OFFICE OF RESEARCH ETHICS, COMPLIANCE AND INTEGRITY

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13 November 2014

Dr I Nuberg
School of Agriculture, Food and Wine

Dear Dr Nuberg

PROJECT NO: H-2014-241
Hydrological impact of community forests in the mid-hills catchment of Kavre district, Nepal

I write to advise you that on behalf of the Human Research Ethics Committee I have approved the above project. Please refer to the enclosed endorsement sheet for further details and conditions that may be applicable to this approval. Ethics approval is granted for a period of three years subject to satisfactory annual progress reporting. Ethics approval may be extended subject to submission of a satisfactory ethics renewal report prior to expiry.

The ethics expiry date for this project is: 30 November 2017

Where possible, participants taking part in the study should be given a copy of the Information Sheet and the signed Consent Form to retain.

Please note that any changes to the project which might affect its continued ethical acceptability will invalidate the project's approval. In such cases an amended protocol must be submitted to the Committee for further approval. It is a condition of approval that you immediately report anything which might warrant review of ethical approval including (a) serious or unexpected adverse effects on participants (b) proposed changes in the protocol; and (c) unforeseen events that might affect continued ethical acceptability of the project. It is also a condition of approval that you inform the Committee, giving reasons, if the project is discontinued before the expected date of completion.

A reporting form for the annual progress report, project completion and ethics renewal report is available from the website at http://www.adelaide.edu.au/ethics/human/guidelines/reporting/

Yours sincerely

Dr John Semmler
Convenor
Human Research Ethics Committee

THE UNIVERSITY of ADELAIDE

RESEARCH BRANCH
OFFICE OF RESEARCH ETHICS, COMPLIANCE AND INTEGRITY

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Applicant: Dr I Nuberg

School: School of Agriculture, Food and Wine

Project Title: ***Hydrological impact of community forests in the mid-hills catchment of Kavre district, Nepal***

THE UNIVERSITY OF ADELAIDE HUMAN RESEARCH ETHICS COMMITTEE

Project No: **H-2014-241** RM No: 0000019524

APPROVED for the period until: **30 November 2017**

Thank you for the response dated 3.11.14 to the matters raised. It is noted that this project will be conducted by Mr Manoj Badu, PhD student.

Refer also to the accompanying letter setting out requirements applying to approval.

Dr John Semmler
Convenor
Human Research Ethics Committee

Date: 13 November 2014

Attachment 2: Extension letter of ethics clearance

THE UNIVERSITY *of* ADELAIDE

RESEARCH SERVICES
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13 November 2017

Dr Ian Nuberg
School of Agriculture, Food & Wine-RW

Dear Dr Nuberg

ETHICS APPROVAL No:	H-2014-241
PROJECT TITLE:	Hydrological impact of community forests in the mid-hills catchment of Kavre district, Nepal

Thank you for the Annual Report on Project Status provided by Manoj Badu on 10 November 2017. Our office has approved an extension to cover the writing up stage of Manoj's thesis.

The ethics amendment for the above project has been reviewed by the Secretariat, Human Research Ethics Committee and is deemed to meet the requirements of the *National Statement on Ethical Conduct in Human Research (2007)* involving no more than low risk for research participants.

You are authorised to commence your research on: 13/11/2014
The ethics expiry date for this project is: 30/11/2020

NAMED INVESTIGATORS:

Chief Investigator:	Dr Ian Nuberg
Student - Postgraduate Doctorate by Research (PhD):	Mr Manoj Badu
Associate Investigator:	Professor Wayne Meyer

Ethics approval is granted for three years and is subject to satisfactory annual reporting. The form titled Annual Report on Project Status is to be used when reporting annual progress and project completion and can be downloaded at http://www.adelaide.edu.au/research-services/oreci/human/reporting/. Prior to expiry, ethics approval may be extended for a further period.

Participants in the study are to be given a copy of the information sheet and the signed consent form to retain. It is also a condition of approval that you immediately report anything which might warrant review of ethical approval including:

- serious or unexpected adverse effects on participants,
- previously unforeseen events which might affect continued ethical acceptability of the project,
- proposed changes to the protocol or project investigators; and
- the project is discontinued before the expected date of completion.

Yours sincerely,

Ms Sabine Schreiber
Secretary

The University of Adelaide

Attachment 3: Participant consent form

Human Research Ethics Committee (HREC)

CONSENT FORM

1. I have read the attached Information Sheet and agree to take part in the following research project:

Title:	**Hydrological impact of Community Forests in the mid-hills catchment of Kavre district, Nepal**
Ethics Approval Number:	**H-2014-241**

2. I have had the project, so far as it affects me, fully explained to my satisfaction by the research worker. My consent is given freely.

3. I have been given the opportunity to have a member of my family or a friend present while the project was explained to me.

4. Although I understand the purpose of the research project it has also been explained that involvement may not be of any benefit to me.

5. I have been informed that, while information gained during the study may be published, I will not be identified and my personal results will not be divulged.

6. I understand that I am free to withdraw from the project at any time.

7. I am aware that I should keep a copy of this Consent Form, when completed, and the attached Information Sheet.

Participant to complete:

Name: ____________________________Signature: _______________________________

Date: ______________________________

Researcher/Witness to complete:

I have described the nature of the research to

____

(print name of participant)

and in my opinion she/he understood the explanation.

Signature: _________________________Position:_________________________________

Date: ______________________________

Attachment 4: Participant information sheet

PARTICIPANT INFORMATION SHEET

PROJECT TITLE: Hydrological impact of community forests in the mid-hills catchment of Kavre district, Nepal
PRINCIPAL INVESTIGATOR: Dr. Ian Nuberg
STUDENT RESEARCHER: Manoj Badu
STUDENT'S DEGREE: PhD

Dear Participant,
You are invited to participate in the research project described below.

What is the project about?
Overall aim of this research project is to investigate the impact of different types of community forests (broadleaf, pine and mixed) on the quantity and quality of water in the Roshi Khola catchment of Kavre district, Nepal.
Field-experiments will be conducted in the study plots to be set up in the various types of community forests within the study area. Information to be obtained from the field experiments will include; weather conditions, the amount of water received and released by the forest floor. The results obtained from these experiments will be used to predict the distribution and movement of water in the catchment. With an objective to understand the prevailing state of knowledge about the community forests-water relationship, a brief survey will be conducted through structured interviews. Participants of the interview will be the members of the Community Forest User Groups (CFUGs) of the community forests in the study area.

Who is undertaking the project?
This project is being conducted by Manoj Badu. The research will form the basis for the degree of PhD at the University of Adelaide, under the supervision of Dr. Ian Nuberg and Prof. Wayne Meyer.

Why am I being invited to participate?
You are being invited to participate in the survey because of your role as a CFUG member of the selected community forest in the study area. .

What will I be asked to do?
You will be asked to provide answers to the structured questions during an interview with the researcher.

How much time will the project take?
As part of the brief survey, the one-off interview with each participant will take approximately 15 minutes. Other activities (field experiments, lab analysis, presentation of the results etc) of the project will continue until mid-2017.

Are there any risks associated with participating in this project?
The possible risks are negligible. You will be asked to contribute approximately 15 minutes of your time towards an interview with the researcher. Prior to conducting the interview, the researcher will confirm your willingness to participate, convenient time and location to conduct the interview.

What are the benefits of the research project?
The findings of this research are expected to fill-in the obvious knowledge gap that exists about the role of community forests in influencing the quantity and quality of water. This is likely to assist in the

adoption of more sustainable forest, water and land management strategies in Nepal and worldwide. It is anticipated that the enhanced understanding of the participants and community members about the forests-water relationship will allow them to consider choosing forest species and management strategies from a hydrological point of view.

Can I withdraw from the project?

Participation in this project is completely voluntary. If you agree to participate, you can withdraw from the study at any time.

What will happen to my information?

Your personal identity will be kept private and confidential unless we have your consent to being identified. The information generated from the interview will be used for publication in the scientific journals, media and presentation in the seminars and conferences to make it available to the interested researchers, policy-makers and general public worldwide. Information) will be stored for at least 5 years at the University of Adelaide's secure facilities, which cannot be entered without prior approval. .

Who do I contact if I have questions about the project?

For any questions about the project, please contact the persons below:
Primary contact: Dr. Ian Nuberg, 0061-8-8313 0527 (email: ian.nuberg@adelaide.edu.au)
Researcher in the field: Manoj Badu, 0061-0429781284 Mobile in Australia; 977-9841232231 mobile in Nepal (email: manoj.badu@adelaide.edu.au)
Co-supervisor of the research: Prof. Wayne Meyer, 0061-8-8313 8110 (wayne.meyer@adelaide.edu.au)

What if I have a complaint or any concerns?

The study has been approved by the Human Research Ethics Committee at the University of Adelaide (approval number H-2014-241). If you have questions or problems associated with the practical aspects of your participation in the project, or wish to raise a concern or complaint about the project, then you should consult the Principal Investigator. Contact the Human Research Ethics Committee's Secretariat on phone 0061-(08) 8313 6028 or by email to hrec@adelaide.edu.au, if you wish to speak with an independent person regarding concerns or a complaint, the University's policy on research involving human participants, or your rights as a participant. Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

The independent contact in Nepal who can also be consulted in case of complaints and concerns about the project is Professor Subodh Sharma- Head of the department of Environmental Science and Engineering at Kathmandu University on 00977-11-661 399 or email at subodh.sharma@ku.edu.np.

If I want to participate, what do I do?

Please contact the member of the research team (contact details above) to discuss your interests or possibilities of participation.

Yours sincerely,
Manoj Badu,
Student researcher

Attachment 5: Nepali questionnaire to study the CFUG perceptions of forest-water relationships

म सामुदायिक वन र पानीको सम्बन्धबारे ‘द युनिभर्सिटी अफ एडीलेड’मा अनुसन्धानरत बिद्यावारिधीको बिद्यार्थी हुँ। तपाई मेरो अनुसन्धानक्षेत्र, नेपालमा काभ्रे जिल्लाको रोशीखोला जलाधार क्षेत्र भित्र चुनिएका सामुदायिक वनको उपभोक्ता हुनुभएकोले तपाईको विचार र अनुभव निम्नानुसारको प्रश्नावली मार्फत संकलन गर्दैछु। तपाईको महत्वपुर्ण जवाफ मेरो अनुसन्धानकोलागी मात्र उपयोग हुनेछ र ब्यग्तिगत विवरण पूर्ण रुपले गोप्य रहनेछ। यस अनुसन्धानबारे थप जानकारी, सुझाव वा गुनासो भए उल्लेखित “सहभागीहरुको निम्ती जानकारीपाना” हेर्नहुन अनुरोध छ। सहयोगको लागी धन्यवाद।

सहभागीको विबरण

नाम (महिला/पूरुष), ठेगाना:
मुख्य पेशा: कृषि/सरकारी वा गैर सरकारी रोजगार/ब्यापार/अन्य
सम्बन्धित सामुदायिक वनको नाम/स्वीकृत भएको साल..................
उक्त सा.व. मा तपाईको भूमिका र आबद्ध हुनु भएको अवधी: उपभोक्ता/व्यवस्थापन समिति सदस्य र ...... बर्ष

प्रश्नावली

१. तपाईको कृषी, घरेलु वा अन्य प्रयोजनको लागी पानीको मुख्य श्रोत के हो?
२. तपाईको खेत, बारी, घर वा संलग्न हुनु भएको सामुदायिक वन नजिकै पानीका कुनै श्रोतहरु जस्तै नदीनाला, झरना, खोलाखोल्सी, तलाउ आदि छन्? (छन्/छैनन्)
यदि छन् भने; कुन किसिम? नदी/खोलाखोल्सी/झरना/तलाउ/अन्य
३. उपयोगिताको हिसाबले उक्त श्रोत तपाईको निम्ति कत्तिको महत्वपूर्ण छन्? (अत्यन्त/केहि/खासै छैनन्)
४. अ. उक्त पानीका श्रोतहरुमा हुने पानीको सतह/मात्रामा कुनै परिवर्तन देख्नु वा भोग्नु भएको छ?
क. बढेको छ ख. घटेको छ ग. कुनै फरक छैन घ. थाहा छैन
आ. उक्त परिवर्तन बिगत कति समयदेखि भएको ठान्नु हुन्छ?
क. करिब १० बर्ष ख. करीब २० बर्ष ग. करीब ३० वर्ष घ. ३० वर्ष भन्दा बढी
इ. कुन समयमा उक्त परिवर्तन बढी हुन्छ?
क. बर्ष भरी नै ख. कुनै बिशेष समय जस्तै वर्षा वा सुक्खा याममा ग. भन्न सकिदैन
५. अ. उक्त पानीका श्रोतहरुमा हुने पानीको गुणस्तरमा कुनै परिवर्तन देख्नु वा भोग्नु भएको छ?
क. बढेको छ ख. घटेको छ ग. कुनै फरक छैन घ. थाहा छैन
आ. उक्त परिवर्तन बिगत कति समयदेखि भएको ठान्नु हुन्छ?
क. करिब १० बर्ष ख. करीब २० बर्ष ग. करीब ३० वर्ष घ. ३० वर्ष भन्दा बढी
इ. कुन समयमा उक्त परिवर्तन बढी हुन्छ?
क. बर्ष भरी नै ख. कुनै बिशेष समय जस्तै वर्षा वा सुक्खा याममा ग. भन्न सकिदैन

वन र पानी सम्बन्धी तपाईको बिचार र अनुभव

६. अ. सामुदायिक वनहरुले पानीका स्रोतहरूको सतह/मात्रामा कस्तो भूमिका खेल्छन?
क. सकारात्मक/बढछ ख. नकारात्मक/घटछ ग. कुनै फरक पार्दैन घ. थाहा छैन
आ. उक्त भूमिका निभाउन सामुदायिक वनका कुन गुणहरु सबैभन्दा बढी प्रभावशाली हुन्छन?
क. वनको क्षेत्रफल ख. वनको किसिम (प्रजाति) ग. वनको अवस्था (घनत्व, उमेर, बिबिधता) घ. उपभोग सम्बन्धि गतिबिधि ङ. अन्य च. थाहा छैन
अन्य सुझाव ....

७. अ. सामुदायिक वनहरुले पानीका स्रोतहरूको गुणस्तरमा कस्तो भूमिका खेल्छन?
 क. सकारात्मक ख. नकारात्मक ग. कुनै फरक पार्दैन घ. थाहा छैन
आ. उक्त भूमिका भूमिका निभाउन सामुदायिक वनका कुन गुणहरु सबैभन्दा बढी प्रभावशाली हुन्छन?
 क. वनको क्षेत्रफल ख. वनको किसिम (प्रजाति) ग. वनको अवस्था (घनत्व, उमेर, बिबिधता) घ. उपभोग सम्बन्धि गतिबिधि ङ. अन्य च. थाहा छैन
अन्य सुझाव ....

English translation of Nepali questionnaire

I am a PhD student at the University of Adelaide studying hydrology of community forests (CFs) in the Roshi Khola catchment of Kavre district, Nepal. Because of your role as a user/manager of a randomly selected CF in my research area, I am collecting your opinion using the following questionnaire. Your valuable response will be used solely for my research and your personal details will be kept strictly confidential. For additional information, suggestions and complaints about the project, please refer to the "Participant information sheet' that I've described to you. Thank you for your help.

Participants' details
Name (Male/female), Address:
Primary occupation: Agriculture/Govt or Non-government service/self-employed/others
Relevant CFUG and the year handed over:
CFUG roles & duration in the role: CFUG member/CFUG executive committee member & ……. yrs

Questionnaire
1. What is/are your primary source of water for agricultural, household or other purposes?

2. Are there any water sources eg. river, stream, waterfall, pond etc near your house, farm or CF? Yes/No

3. How important are these water sources to you (Very important, somewhat important, not so important)

4. i. Any change observed in the level/quantity of water in these sources?
 a. It has increased b. It has decreased c. No change d. Not sure
ii. Tentative duration of such change.
 a. About 10 yrs b. About 20 yrs c. About 30 yrs d. More than 30 yrs
iii. Or particular times the change occurs.
 a. All year-round b. Specific time of a year e.g. during dry or wet season c. Can't say

5. i. Any change observed in the quality of water (e.g. more/less turbid, polluted etc)
 a. Improved/it is cleaner b. Diminished c. No change d. Not sure
ii. Tentative duration of such change?
 a. About 10 yrs b. About 20 yrs c. About 30 yrs d. More than 30 yrs
iii. Or particular times the change occurs.
 a. All year-round b. Specific time of a year e.g. during dry or wet seasons c. Can't say

Perceptions about forest-water relationships
6. i. What roles do the forests have in influencing water quantity?
 a. Positive/increase water b. Negative/decrease water c. None d. Not sure

ii. Any particular forest attributes that are influential in causing this effect.

a. Area b. Forest type (Species) c. Forest condition (Density, age, diversity)

d. Use and management activities e. Others f. Not sure

Additional comments ……………………………………………………………………………………………

7. i. What roles do the forests have in influencing water quality?

a. Positive/improve quality b. Negative/diminish quality c. None d. Not sure

ii. Any particular forest attributes that are influential in causing this effect.

a. Area b. Forest type (Species) c. Forest condition (Density, age, diversity)

d. Use and management activities e. Others f. Not sure

Additional comments ……………………………………………………………………………………………….

Attachment 6: Selected photographs showing various field-work activities of the study

Plate 1: Collection of local perceptions of forest-water relationships

Plate 2: Forest inventory planning at the experimental catchment

Plate 3: Forest inventory works at the MF site

Plate 4: Slope determination at the PF site

Plate 5: Raingauge set up at the experimental catchment

Plate 6: Canopy photo acquisition to determine Plant Area Indices (PAI) at the PF site

Plate 7: Groundworks for overland flow system at the PF site

Plate 8: Overland flow collection system at the BF site

Plate 9: Soil sampling at the MF site

Plate 10: Soil profile pit at the MF site

Plate 11: Manual raingauge placement at the MF site

Plate 12: Stemflow system preparation at the PF site

Attachment 7: Newly published political and adminstrative map of Nepal

Plate 13: Political and adminstrative map of Nepal published in 2020 (Source: Survey Department of Nepal, 2021)

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