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Article

Potential Impact of Climate Change on Ecosystem Services in *Panchase* Mountain Ecological Region, Nepal

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Abstract: Ecosystem services (ES) are increasingly recognized as a means to adapt to the ongoing impact of climate change and associated impacts. However, these ES itself are facing adverse impact of climate change especially in developing countries where most of the people are dependent on these services for their livelihood. Very little is known about the relationship between the climate change and ES. Here we assess the impact of climate change on ecosystem services in ES rich landscape of *Panchase* Mountain Ecological Region of western Nepal. The study area was divided into three ecoregions from lowland through midland to the upland region. Focus group discussion, and key informant interview were used to elicit the required data for the study, which was further supported by transect walk, field observation and secondary source of information. Major impacts of climate change were observed are, reduced availability of water, reduced food production, forest ecosystem, shifting species composition in forest ecosystem, farmland abandonment, and their associated ecosystem services. We recommend to initiate the management actions to help ES adapt to climate change, and which in return could support the ecosystem itself and people dependent on the ES in adaptation to climate change by providing various goods and services.

Keywords: Climate Change; Ecosystem Services; Impact; adaptation; Nepal

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1. Introduction

Ecosystem provides different goods and services such as food, fiber, timber, flood protection, clean water, and clean air for human beings. The benefits people obtain from ecosystems are known as ecosystem services (ES) [1]. Many forest ecosystems are rich in biodiversity and provide multiple services to human wellbeing [2-3]. People in developing countries, such as Nepal are largely dependent on these services for their subsistence livelihood system [4-5].

Though forest and agro-ecosystem deliver a wide range of goods and services to human beings [6], climate change could reduce an ecosystem's ability to deliver such services [7]. Ecosystem services are influenced directly by climate change [8-10] but also indirectly through associated changes in the ecological and social environment [11-13]. Climate change will likely impact on the biophysical process that underpin ecosystems dynamics, which ultimately may affect benefits from these ecosystems [14-16]. On the other hand, ecosystem services may also enable adaptation to the impacts of climate change; for instance, they may buffer ecological response and/or provide novel livelihood opportunities [17].

Climate change negatively impacts forests, water resources, and agriculture diversity [18]. Rural people are typically dependent on forests and agriculture and associated ES for their livelihoods [19-

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20]. The strong connection between ES and livelihoods suggests that rural communities in Nepal are highly vulnerable to the impacts of climate change [21].

Nepal, a landlocked mountainous country, is expected to have experienced prominent impact of climate change on different ecosystem and ES including forest and agroecosystem. However, there is very little study on the impact of climate change on status of ES in mountain terrain due to lack of appropriate data, tools and policy [22]. Therefore, impact of climate change on various ecosystem and relative importance of ecosystem services on climate adaptation is poorly understood. There is an urgent need to assess ES for an improved understanding their role in livelihoods but also on the impact of recent climate change on their provisioning and relative benefit they provide in climate adaptation [23-24]. With advent of geospatial tools and techniques it has become easier to collect the data and understand the trends of ecosystem change, even for remotely located areas with inaccessible terrain. Remote sensing datasets work as an 'eye in the sky' and provide throughout the year information about various important functions of the forest ecosystems.

A knowledge gap also exists in the potential for climate adaptation initiatives at grass root level as the linkages between these services and local management practices have not been defined. The study will explore these knowledge gaps and assess recent climate change impacts on ES in *Panchase* Mountain Ecological Regions (PMER) of western Nepal.

2. Materials and Methods

2.1 Study Area

The study was carried out in approximately 132 km^2 Harpankhola catchment of the *Panchase* Mountain Ecological Region (PMER) (altitude 815 to 2517 m asl, latitude: 28° 8' 36'' N to 28° 18' 17'' N, longitude: 83° 43' 69'' E to 83° 59' 5'' E; Figure. 1). It was selected to represent the wider region because it provides range of ES such as food, water, and forest products, upon which people from both downstream and upstream areas in the regions are dependent for their livelihoods. The region is also regarded as a repository of biodiversity (agro and forest biodiversity), water resources and different cultural values [25], with the potential of providing a variety of ES to the people.

The Panchase region is disproportionately rich in forest and biodiversity resources and provides several ES to the local communities to sustain their livelihood [26]. More than 14,807 households in the area are dependent on ecosystem services for their livelihood. A diversity of goods and services available from the region's forests may be due to the diversity in forest and tree species that occur across an ecocline of 815 to 2517 masl [18]. While the area has been identified as rich in ES, it is also affected by environmental drivers, especially climate change, so people have started to adapt with the changes. Due to altitudinal and climatic variation from lowland to the upland region, land use and ES vary; therefore, the study area was divided into three ecoregions: lowland, midland and upland. Lowland represents the area around *Thulakhet* from 815 to 1300 m asl, midland regions represent the area from 1400 to 1900 m asl, and the upland regions represent areas occurring at > 2000 m asl (Figure 1). In some instances, it is broadly classified as upland and lowland regions indicating both middle and upland regions as an upland region as a whole.

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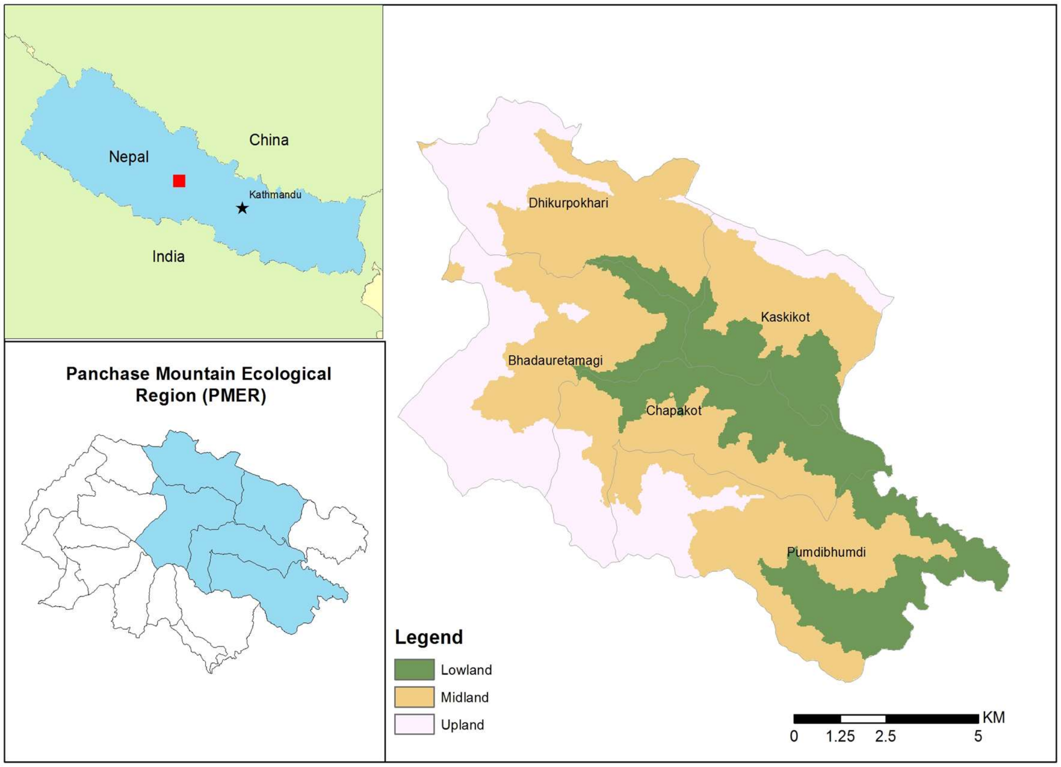

Figure 1: Map of study area in the Panchase Mountain Ecological Region of Nepal

The lowland area is primarily a production landscape comprising agriculture crops and food such as *Orizya* spp, *Zea* Spp, and *Triticum* spp. Forests occur adjacent to agricultural areas. Similarly, the midland region contains both forest and agricultural land. The forest in the regions is mainly managed by local users as a community forest, which is regarded as the fringe area of the Panchase protected forest (PPF). In contrast, the upland region is characterized as a core region of PPF, managed mainly for the conservation of biodiversity and ecosystem services especially medicinal and aromatic plants [27], provision of water, cultural, landscape and aesthetic beauty. Most land (61%) throughout the regions is covered by forest ecosystems, followed by agriculture (34%), grassland (3%) and wetland (1.3%) [18]. The overall objectives for land management in the region is to conserve a representative examples of Nepal mountain ecosystems while providing connectivity between lowland areas and the Himalayas [28] whilst providing a range of ES.

The lower region has higher average temperatures and lower precipitation than midland and upland regions [25, 29]. Climatic differences contribute to changes in vegetation and biodiversity from sub-tropical and temperate mixed evergreen forest. For instance, low land is dominated by subtropical *Shorea robusta, Schima castanopsis* forest, whereas, the midland region is covered by *Alnus species* and *Castanopsis indica* while the upland region is characterized as temperate mixed evergreen forest dominated by *Quercus species*. The pattern of food production also varies from the low land to upland regions: rice cultivation in the lowland and maize and millet in upland regions.

Besides agriculture and forests, the study area also has significant cultural, aesthetic, and ecotourism values. Sacred landscapes, with cultural and religious importance for the indigenous *Gurung* culture exist within the region. The Panchase area is also the source of drinking and irrigation water for both upstream and downstream communities; the *Harpan* river originates from the peak of the Panchase, and fulfills irrigation needs for agriculture in the mid and lowland regions of the watershed. It also serves as the main feeder stream for *Phewa* lake, a major tourist attraction in the Pokhara valley.

2.2 Primary Data Collection

2.2.1 Interviewee Selection

As a first step, interviewee was selected for structured and semi-structured interview. For this, contact was made with the Panchase protected forest program (PPFP) and District forest office Kaski to collect basic information regarding different ES from these landscapes, perceived climate change pattern and their impact on these services in the changing scenarios. Similarly, different NGOs working in the field were also consulted in the second stage in this process. Then field visits from low land to upland part was carried out to gain an overall picture of the study landscape and identify the issues and potential respondents for the data collection. This field observation and preliminary consultations with different stakeholders helped to tentatively identify sample groups and potential respondents for the interview following the snowball sampling techniques [30]. As a result, a set of questionnaire was prepared for the individual interview and focus group discussion.

2.2.2 Interviews

Non-proportional quota (purposeful) sampling was used to interview different people who play active managerial and decision-making roles in managing the ecosystem. Similarly, they are the one who are experiencing the changes in climatic pattern and its impact on ES and their livelihood, as most of them are reliant on the landscapes' ES for their livelihoods. We conducted 37 in-depth semi-structured interviews of forest managers, policy makers, forest users, relevant NGO representatives, elderly people, people from indigenous and marginalized communities, social mobilisers, school teachers, other community groups such as a farmers group, women's group and disaster risk reduction (DRR) group. Our aim with this sampling method was to solicit and engage a wide spectrum of values and stakeholders to gain insight into the topic of discussion instead of having high sample size for proportional quota sampling [31-32]. Similar to the experience of Klain et al. [31], once we completed 30-35 in-depth interviews, new information diminished. The interviews were mainly focused on the perception on the availability of major ES in the region, changes in climatic pattern and their impact on the available ES and livelihood of people dependent on these services. The interviews lasted from 1-1.5 hours. Each interview was audio-recorded and then the recording was transcribed into the note copy. Punch (2013) [33] has emphasized the significant role of open-ended semi-structured questions for understanding the complex behaviors and perceptions that does not impose any a priori categorization, which might limit the field of inquiry. Responses from each respondent where also crosschecked with those of other respondents as part of triangulation.

2.2.3 Focus Group Discussion

After a series of individual interviews, we also employed interactive focus group discussions (FGD), one in each region, along with one FGD among forest managers and experts in the field of forest management and ES. Generally, FGD involve 5 to 10 participants moderated by the trained facilitator with particular focus on a specific set of issues to gain a broad range of views on the research topic [34-35]. Each FGD had 5 participants. Participants in the FGD in the field were mainly executive members of CFUGs, school teachers, members from women groups, disaster risk reduction (DRR) group, farmer groups, indigenous ethnic groups and elderly people. FGD with the managers and experts were carried out in the district headquarters among forest officers, rangers, managers of PPF, and the chairperson of the PPF council. In each FGD, a facilitator had moderated the discussion among the participants instead of asking questions repeatedly. Public spaces and CF buildings were used for holding the discussions. The FGD was also audio- recorded and key points during the discussion were noted down.

2.3 Secondary Data Collection

Major sources of secondary data used in the study included:(i) climatic data from nearby meteorological stations; (ii) published and unpublished reports of relevant government and NGOs

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(iii) a topo-map of the study area; (iv) operational plan of PPFP and various community forest user groups; and, (v) community forest based community adaptation plan of action.

There were some limitations within the study as well. For instances, representative sample was taken from low land to high hill of Panchase in terms of field visit and interview with people. It might not represent overall Panchase region while generalizing the research findings. Similarly, major field data collection was carried out in peak farming period and people were much more engaged in their agriculture farm during that period. On the other hand, as the meteorological data was collected a bit far from the field site and it may not represent the exact climatic field situation.

We assessed the sensitivity of forest ecosystems to climate change and other anthropogenic factors using geospatial tools and techniques. This mainly includes analysis of forest fire risk in the study area. We used forest occurrence data from 2001 to 2018 MODIS satellite sensor to understand the trend of forest fire in the study area and also to analyze the risk of forest fire occurrence. Forest fire risk was calculated using following variables based on Matin et al., (2017): land cover, Average summer land surface temperature, Distance from settlement, Distance from road, Elevation, and Slope. We also analyzed the disaster risk of the villages in the study area based on the disaster occurrence data from 2000 to 2014 acquired from Ministry of Home Affairs (MoHA).

2.4 Data Analysis

2.4.1. Qualitative and Quantitative Data Analysis

Though most of the data were in qualitative in nature, we used mix of both qualitative and quantitative data for the study. Qualitative data were analyzed with the help of Nvivo **[36-37]** and Microsoft Excel program. In which first we gathered all the interviews in the excel sheet and then Nvivo was used for manipulating data records, browsing, coding and interpreting them. Similarly, Microsoft Excel and Minitab was used for analyzing quantitative information and producing graphs and charts.

3. Results and Discussions

3.1 Changes in Climatic Pattern

Almost all respondents (98%) perceive that climate change is occurring in the region (Figure 2). Most of them perceive that temperatures in the summer have increased and while 39% of respondents feel that the winter season has become colder. Temperature data from the last 30 years from both lowland and upland regions also confirm changes in temperature patterns during this period (Figure 3). For example, the upland region, near to *Lumle* meteorological station (Figure 3), has experienced increase an average annual temperatures of about 1°C over 30 years, whereas the summer maximum temperature increased by almost 2°C during that period.

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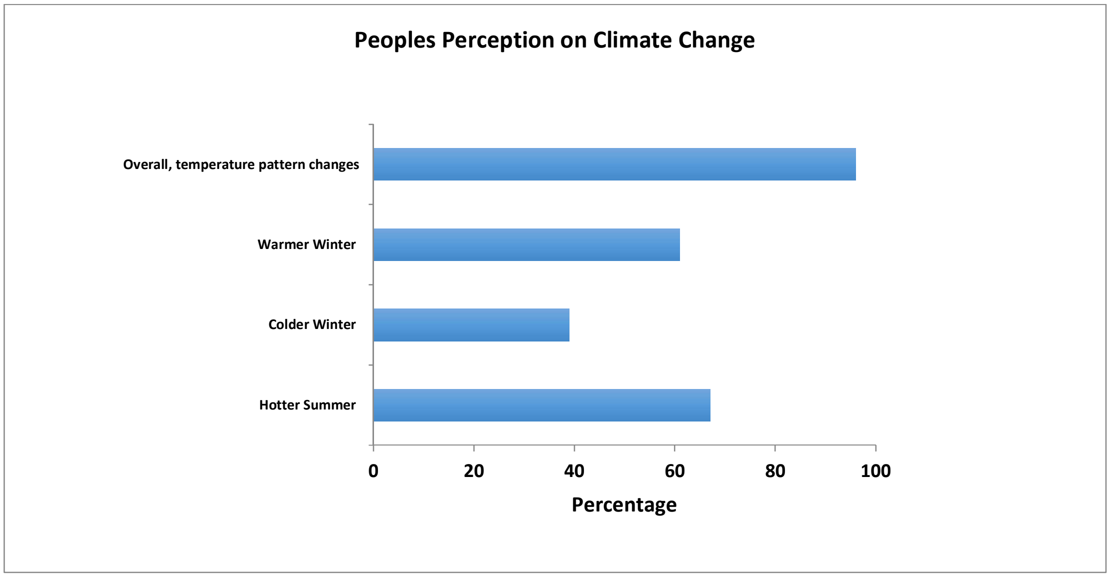
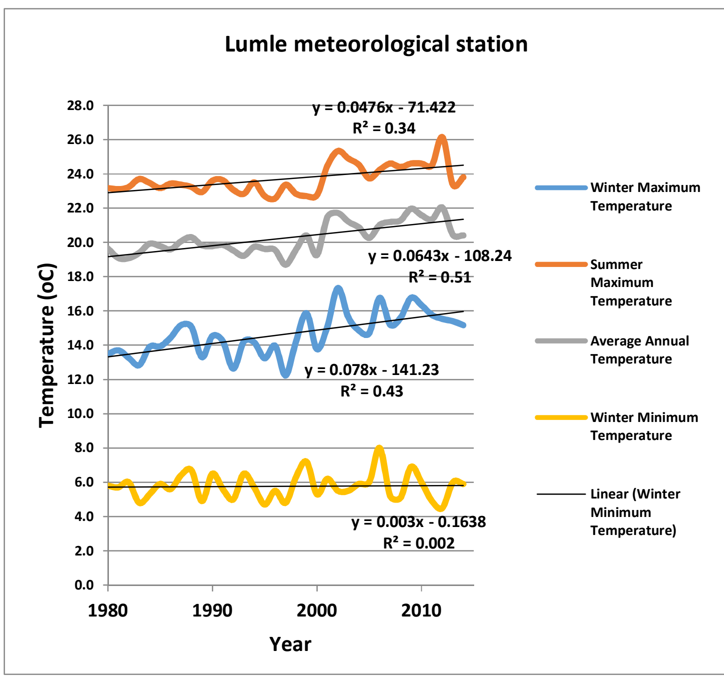


Figure 2: Perception of respondents on climate change in Panchase Mountain ecological region



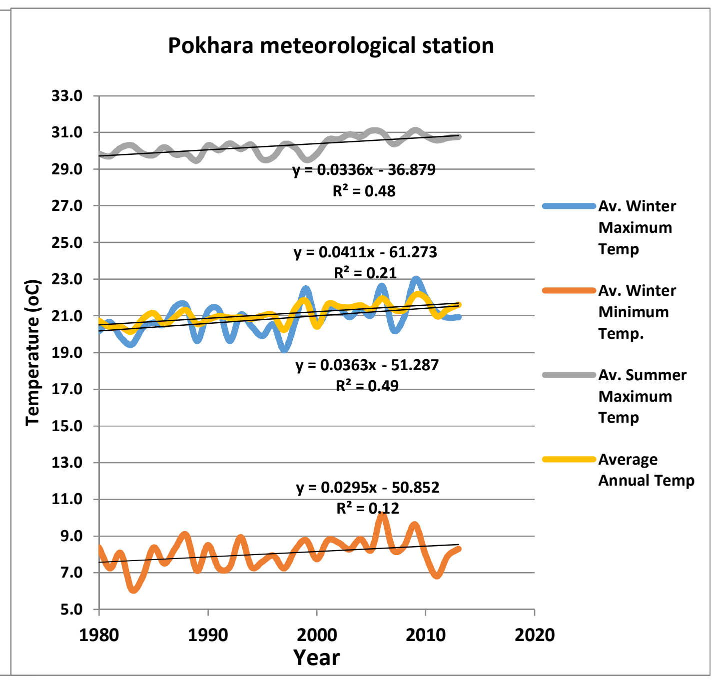


Figure 3 : Annual and seasonal temperature at the Lumle meteorological station, representing upland region of the study landscape

Figure 4: Annual and seasonal temperature at the Pokhara meteorological station, representing lowland region of the study landscape

GIS map of observed and predicted climate change in temp and pptn

Similar results have been observed in low land areas, near Pokhara meteorological station (Fig 3).

3.2 Impact of Climate Changes on ES

The impacts of recent climate change are perceived by locals to be having an impact on several ES and the people dependent on them. Major impacts identified were on the provision of water, occurrence of invasive species, agricultural land abandonment, shifting species composition, flashfloods, and on the availability of food and forest products (Figure 4).

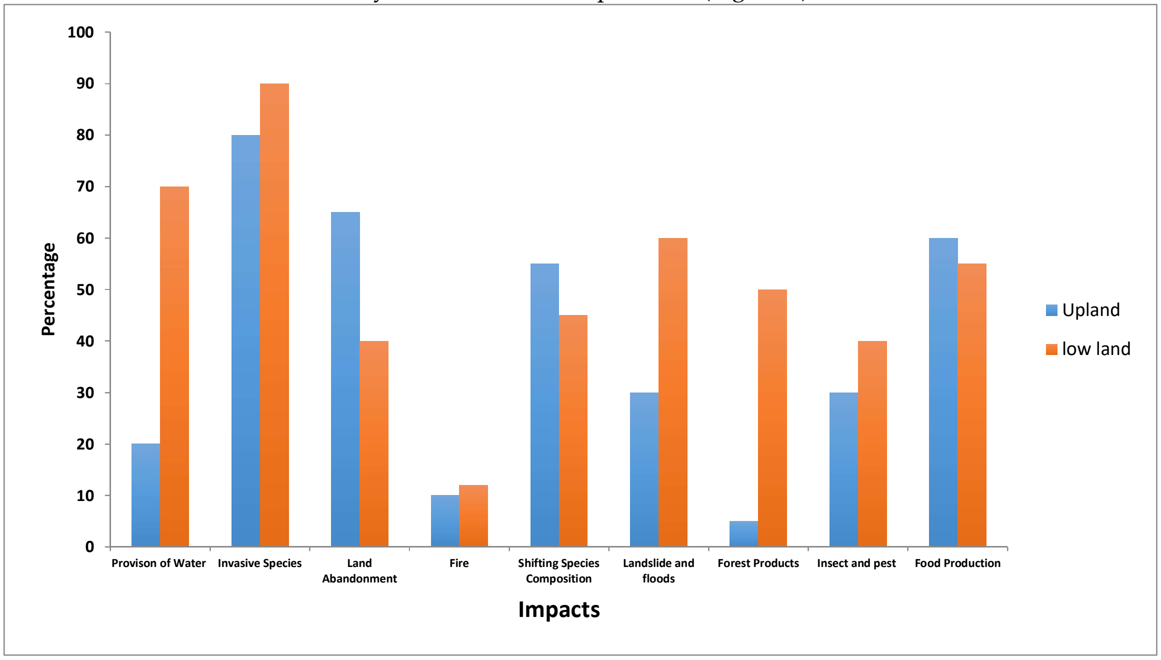


Figure 4: Perceived impact of climate changes by the respondents in both upland and lowland region in the study landscape.

3.2.1 Impact on Provision of Water

The provision of water was identified as one of the major impacts of climate change; 70% of the respondents in the lower region have observed a decline in water availability during the last few decades compared to 20% in the upland region. The scarcity of water has influenced domestic water use for people and livestock, and irrigation for production of food crops. Respondents reported that traditional water sources (springs) have virtually dried and irrigation systems were not working well. Our finding on decreased water availability with the changing climatic pattern seems consistent with the finding from similar studies from Nepal [38-40] and globally [41-43]. Poudel and Duex [39] have reported severe decline of precipitation and the drying up of springs in *Thulokhola* watershed of Nuwakot district of Nepal and recommended suits of adaptation options to cope with the problem, which is in agreement with our finding.

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Figure 6: Drying of water sources in the study landscape. A respondent showing his traditional water pond, that is completely dried now and invaded by invasive species *Ageratum conyzoides.*

The major impact observed on availability of water resources varying from place to place might be explained by differences in geography in the study area. Upland communities are nearer to the water sources providing sufficient access to water resources whereas people in the mid land and low land areas have experienced more problems associated with water availability. Some of the expert respondents in the interviews perceived that the availability of water in the upstream area has also decreased; however, people may not have observed this decline mainly for two reasons. First, there is low population pressure in the upland due to outmigration, and remaining families have access to sufficient water as in the previous years. Second, and most importantly, there is no baseline data quantify the actual changes of water resources to compare the changes in the provision of water in the region although the elderly experts were confident about the declining trend. The increasing forest cover in the study area supports this as trees and woody vegetation usually uses a large proportion of rainfall compared to other land uses such as agriculture and pasture and can reduce the supply of this resource in streams and rivers [44-45].

3.2.3 Invasive Species

The invasion of alien species was reported by 80% of respondents in the upland region and 90% in the lowland regions. Both farmland and forest area were reported as being invaded by invasive species. *Ageratina adenophora,* and *Ageratum conyzoides* have invaded the farmland, especially abandoned agricultural land and adjoining public spaces, whereas the understory of forests were reported as being heavily invaded by *Ageratina adenophora*, and local species such as *Lyonia ovalifolia (Angeri), hadeunyeu, katre kanda,* and *Bilaune*. Invasive grasses were also observed across the study area in both in farm and forestlands. Similar to our findings, effect of invasive species intensified by ongoing climate change on ecosystem services are widely discussed from around the world [46-49]. For example, our finding on increase in invasive species with changing climatic condition and their subsequent impact on various ecosystem services are in agreement with those obtained by Bhatta et al. [20] who reported new invasive species colonizing the forest, while preventing the regeneration of locally preferable species and their services to the local community. Thus, these kind of proliferation of invasive species in both forest and farmland might have reduced the biodiversity and associated ecosystem services, and also might have worked as a driver of habitat destruction and extinction of native species leading to changes in ecosystem structure and their services to the human wellbeing [50, 51].

Figure 7: Invasive species encroaching the farmland in the midland farm land (a), and thorny bushy species covering the understory of forests in the upland region (b).

3.2.4 Farm Land Abandonment

The results of our study provide further evidence of growing trend of farmland abandonment and decreasing of ES especially in rural mountainous areas of Nepal. We found that farmland abandonment in the upland region was a major change observed during the last decade with more than 60% of respondents in the upland region and 40% in the lower region reporting this land use change. Furthermore, recent changes in the climatic pattern have also created uncertainty about the ecosystem services such as the production of food and forest products that support livelihoods, forcing people to search for new opportunities. For example, due to a lack of irrigation water, farmers could not grow enough crops. Moreover, most of the farmland is rain-fed, and irregular rain will have direct consequences. Similarly, by nature forest and farm-based livelihoods are difficult, especially in hilly terrain where there are resource constraints and people choose to find easier options as far as possible. The lowland region has a comparatively low land abandonment problem, but the problem was also observed in unirrigated farmland (*barland*) nearby forest area in the lowland as well, which has further implication on the ecosystem services from the agro-ecosystem of their farmland.

Contrary to the possibility of the expansion of cropland to satisfy the growing demand of land-based products such as food and other ecosystem services for growing population, it is interesting to note the pattern of farmland abandonment both in Nepal [52-53] and in other countries [54-56]. Jaquet et al. [52] had identified the high level of men outmigration for the employment opportunities have an effect on land management and ultimately the land abandonment in our study landscape. As consistent with the finding from other studies [54-56], these abandoned lands have gradually been converted into shrub and forest, and consequently, forest area has increased in the landscape. With proper adaptation measures to tackles with the impact of climate change and other associated factors of farmland abandonment in place, these abandoned farmland could be recultivated in a suitable productive area to increase the food and other ES from the farmland and cater the ever increasing demand of food and other ES [57-58].

3.2.5 Shifting Species Composition

About half of the respondents, from both upland and lower regions, identified changes in species composition. Changes were reported as either shifting of species to higher locations, extinction of species, increase in some species in some locations, and changes in overall composition of species in

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the region. For example, respondents observed *Schima wallichi* (Chilaune) and *Castanopsis indica* (Katus) have shifted their distributions to higher altitudes in recent years. *Castanopsis indica*, *Michelia species* (Champ), *Diospyros lanceifolia* (Teju), and *Toona ciliate* (Tooni) however were reported to be gradually decreasing in abundance. Importantly, traditionally valuable timber species such as "kalo Jangali Champ" *(Michelia Kisopa*), locally referred to as *Champo*, has become very rare, and a new species of Champ locally known as "*Thulo Pante Champ*" has been introduced to provide timber for construction.. People also observed decreases in fruit trees in the forest such as *Myrica esculenta* (Kaphal*), Choerospondis axillaris* (Lapsi*), and Castanopsis indica* (Katus*)*. Two species that were reported to have increased in abundance are *Daphniphyllum himalense* (Rakchan) in the upland region and *Alnus nepalensis* (Uttis*)* in landslide-affected sites. The increase *A. nepalensis* on landslide affected areas is preventing further erosion and landslides in the regions.

Similarly, some fodder species such as *Quesrcus species (phalat)*, *Ficus roxburghii*, and species used for non-timber forest products such as *Paris polyphylla* (Satuwa), *Asparagus racemosus* (Kurio), *Zanthoxylum pepper* (Siltimur), *Taxus wallichiana* (Lauthsalla) and *Swertia chirayita* (Chiraito) were also reported to be in decline. Some fodder species, notably *Litsea monopetala (*Kutmero), *Ficus subincisa*(Bedulo), and *Ficus semicordata* (Khanyeu) were reported to have colonised upland regions.

Respondents identified that invasive grasses and shrubs such as *Ageratina adenophora (*Banmara), and other thorny species, have largely replaced palatable grasses, such as *Banso or khar*. The increase in cover of invasive species is believed to be affecting the regeneration of locally important tree species such as *Castanopsis* species and *Schima wallichi* in both the lower to midland regions.

Changes in species composition in the study area such as an extinction of some of the valuable species for instances *Michelia kisopa, Taxus baccata*, might be due to over exploitation of these species for timber and other purpose, or due to loss of their favorable environment as a result of changes in local environment. Similarly, shifting in the ranges of species availability might also be explained by the expansion of favorable environment for a particular species in new localities [59]. Rapid expansion of *Daphniphyllum himalayense* in upland area and *Alnus nepalensis* in moist and landslide-affected area from lowland to upland region might be due to more favourable environment for these species with the changing environment.

Overall, though forest area and vegetation covers seems to have increased, most of the respondents were in agreement that it's just an increment in quantity but not in quality, thereby affecting the different ES such as biodiversity, forest products, water resources from the landscape. The result from our study on shifting in species composition in forest ecosystem seems comparable with the other similar studies [60-63]. Implementation of various management action to support adaptation to the impact of climate change and conservation of threatened species in the face of changing climatic pattern could be the effective means of managing forests ecosystem to adapt to the climate change [64-65].

3.2.6 Availability of Forest Products

Major forest products people depend upon for their livelihoods are timber, firewood, fodder, forest food and fruits. Almost all respondents from the upland region did not feel problems of managing these products from the forest, while 50% of respondents in lowland experienced comparatively less production compared to the products they used to get from the forests. Major sources of these forest products were community-managed forest in the mid land and lowland regions, along with private forest and farmland as an agroforestry. Demand for the forest products was determined by the economic status and major occupation of the household, number of livestock and overall dependence on these products and sources of livelihood.

On the other hand, single storey forest having only the upper strata of tress and understory of bushy and invasive species is another major changes observed in the region, which ideally have to have multi-strata forest such as upper, middle and lower strata to ensure ecological balance and various goods and services from the forest to the human well-being. As a result, people have already started to face the problem of managing forest products especially in the case of heavily populated low land area. This finding is in consistent with Jaquet et al. [52]. Therefore, there needs to be further

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studies on how to manage forest while ensuring multi-strata in the forest for the benefit of both the ecosystems and the people.

3.2.7 Forest Fire

In contrast to the general trend that the climate change phenomenon is increasingly recognized as one of the major causes of forest fire [66-69], fire was not found to have a major impact in the study landscape despite increases in temperature well above the global average in the region. Only about 10% of the respondents identified fire as a major issue in their landscape; however, there was the general understanding that fire was a major issue in earlier decades but decline in fire incidents only in recent years. Yet, there are still some incidences of small fires especially in the summer season both in farm and forest land.

The decline in fire incidents in recent years might be due to following major reasons. First, increased awareness through different governmental and non-governmental organizations, school education, local radios and so on. Second, community intervention in forest management in the form of community forest and protected forest, and thereby local rules, governance and institutions responsible for managing forest fire. Third, shifting cultivation practice, open grazing and using fire as a means of hunting wildlife is no longer in practice, which in earlier days used to play a crucial role. Fourth, and most importantly, the forests are facing towards the northern aspect which is less prone to the forest fire. However, some respondent have reported fire as a major problem in the southern aspect of the Panchase landscape in Parbat district, and less fire in our study landscape might be due to northern facing forest and comparatively less drier than that of the southern facing slopes. Therefore, as a consequence of less fire, the forest area throughout the region seems to have been conserved as an intact dense forest, providing different provisional and regulating services to support human well-being [69].

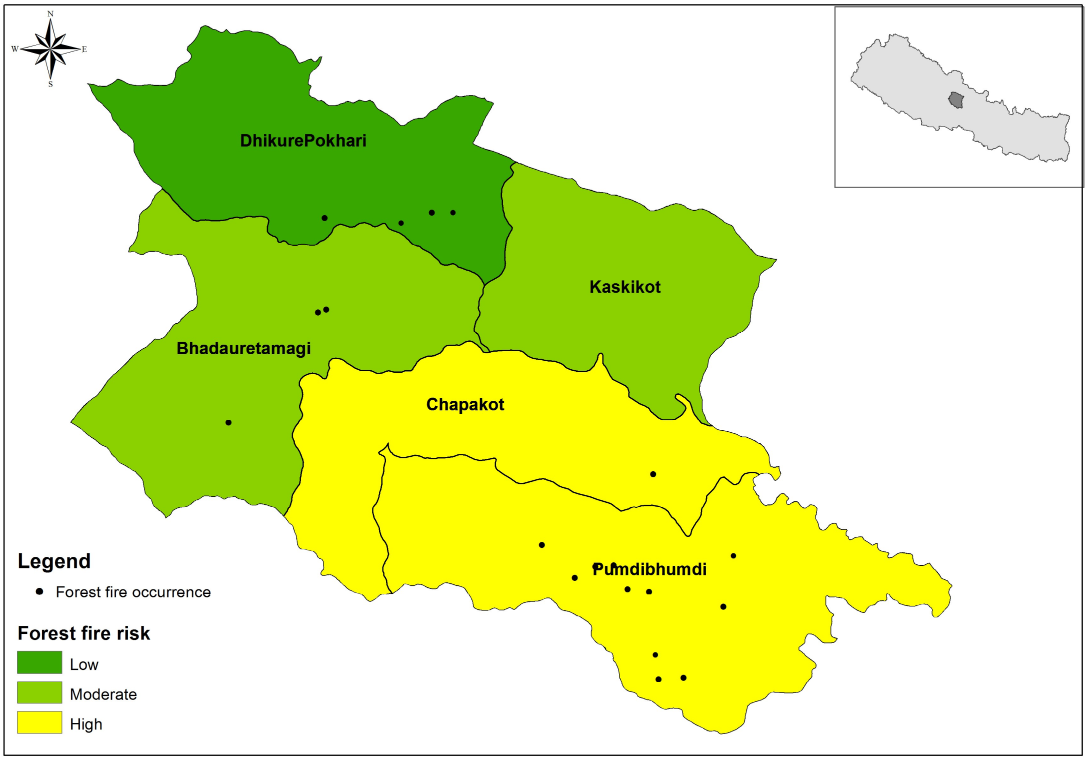

Figure 8: Forest fire risk map of the study area

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Yet, we identified the potential fire risk area with the use of geospatial tools. Forest fire risk ranged from low to high in the study area with most of the high forest fire risk areas falling in lowland and midland areas. We observed that highest forest fire risk in Pumdibhumdi, & Chapakot, while moderate risk in Kaskikot and Bhadauretamagi, and lastly low risk in Dhikure Pokhari, which is situated in highland area. The reason behind high forest fire risk in lowland areas could be easy access to forests resulting in high level of anthropogenic interference and disturbance making the forest ecosystems in these areas vulnerable to human-induced forest fire.

3.2.8 Food Production

Respondents identified that a shift in cultivation practices has occurred in the region. Farmers used to grow millet, maize and potatoes in the upland region, but these crops do not grow well anymore. Similarly, traditional varieties of rice such as *Resaly Ghaiya* have almost become extinct, and new crop varieties such as *Bagale Ghaiya* and *Chhumlungle Ghaiya* have been introduced. Lack of irrigation was one of the major issues hampering agriculture production, as much of the farming practices are rain-fed. In upland regions, some respondents identified that rice cultivation is now possible in areas with suitable irrigation due to warmer temperatures.

Due to recent changes in climate, cropping patterns and productivity are changing. The traditional pattern of wheat/mustard-maize-paddy cropping cycle is gradually changing with farmers shifting cropping species and patterns in innovative ways. For example, off-season vegetable farming has been initiated in the region.

Farmers have also observed early ripening of agricultural crops relative to previous years. Now they are also using introduced varieties that have the potential to suit the locality and increase production to the new environment.

3.2.9 Forest Insects and Diseases

Some respondents reported insect and pest problems in both forest and farmland in the study area. Dieback of *Shorea robusta* in the lower region was reported. According to the respondents from interview and focus group discussion, two years ago, removal of leaves from Shorea trees resulting in a dying back problem was a major issue in the winter season, but the problem was resolved on its own. Similarly, caterpillars infecting *Alnus nepalensis* and *Castanopsis* species was also reported. Our finding on increase in insect and pest infestation are in line with those obtained by Alamgir et al [70] who reported increased pest infestation in *Schima wallichii*, and *Castanopsis indica* due to higher summer temperature, and delayed rainfall in a nearby forest adjacent to our study area. Pests were also reported by respondents to having affected agriculture crops. For example, blights in potatoes, was reported.

3.2.10 Flashfloods and Landslide

Though natural hazards such as flashfloods and landslides are not a major problem in the upland region (5 %, of respondents) but are in lowland regions (50% of respondents). Recently, flashfloods in the lower regions of the *Thulakhet* area claimed the lives of 15 people and destroyed surrounding cultivated land in April 2015 [53]. Due to these hazardous incidents, floodplain areas in the valley bottom have increased, so the area covered by gravel and sand was found to be greater than that of 1995 (Figure 9(b).

Fewer incidence of landslide in the upper regions might be due to the fact that it was fully covered by vegetation, whereas downstream regions were found susceptible to the impacts of floods and erosion due to comparatively less vegetation cover, higher population pressure, and increased agriculture and grazing practices [52]. Furthermore, riverbank erosion along the *Harpan* river is also equally problematic, and expansion of the riverbed has destroyed agriculture land, with implications for food production and support to the sustained well-being of the increased population in the region. However, in the upland region, small incidents of landslide and erosion were also reported, mainly because of recent practice of rural road construction. But earlier landslides in those regions in the forests have already been reclaimed by tree vegetation [70] mainly due to *Alnus nepalensis.*

Figure 9: Landslide in the upland region (a), and flashflood affected area in lowland, which claimed the life of 15 inhabitants in April 2015, (b).

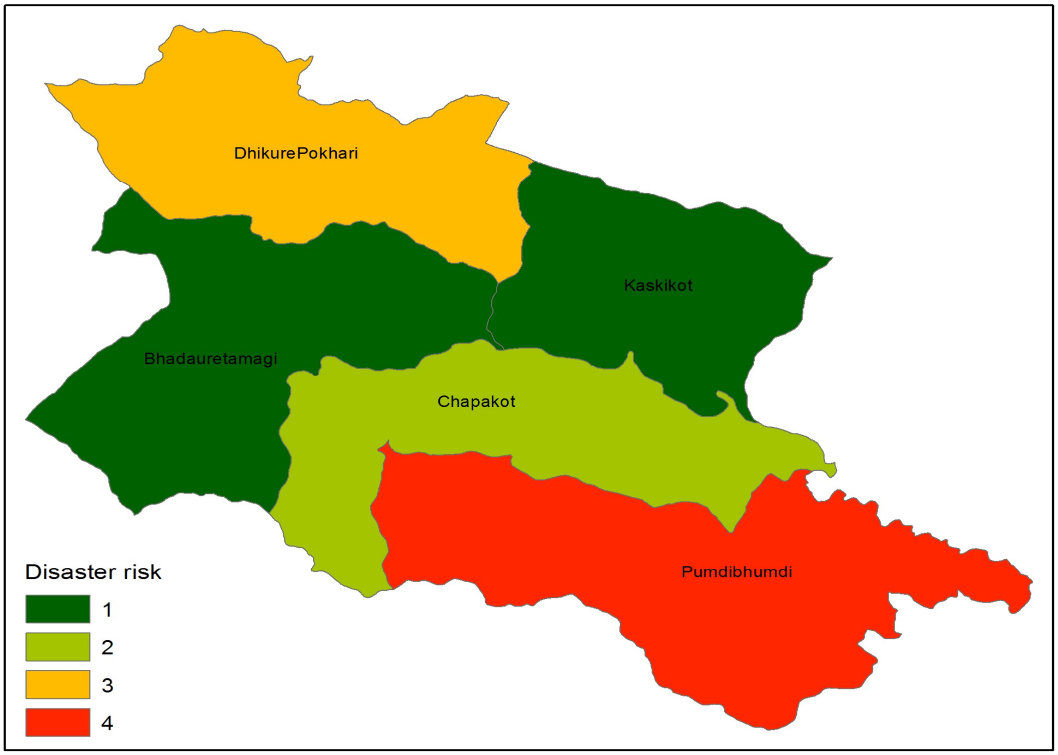

Figure 10: Disaster risk map of the study area depicting different levels of risk

The disaster risk ranged from low to very high in the study area, however the variation in the risk did not coincide with the altitudinal gradient. Very high disaster risk was observed in Pumdibhumdi, followed by high risk in Dhikure Pokhari, moderate risk in Chapakot, and low risk in Kaskikot and Bhadauretamagi.

4. Conclusions

Our study shows that the local communities have perceived the impact of climate change, *inter alia,* on different ecosystem services and, as a result, in their livelihood. Major perceived impacts were in the forest ecosystem, agro-ecosystem, water resources, and associated ES. An increase in forest coverage was reported but a decrease in quality and productivity of the forests and forest products. The increase in forest area is mainly due to out-migration and abandonment of traditional farmland in the upland region, which has resulted in abandoned farmlands gradually converting into the shrub and forest areas. An increase in invasive species was reported on both farmland (abandoned and cultivated) and in forested areas. Based on our analysis, we conclude that some of the villages in the study area have high risk of disasters and forest fire, which needs to be considered while prioritizing the adaptation activities. Efficient planning is required to reduce the disaster risk of these areas. A separate study is required to assess the role of forest ecosystem services in disaster risk reduction e.g. flood control etc. in these areas.

At the same time, availability of water and associated ES was found decreased during the period of last two decades. Other impact observed in this study includes shifting species composition, extinction of some of the species, and some incidence of water induced problems such as flash floods, landslide and so on. Though these were the major impacts observed in the field, detailed systematic study on the impacts of climate change in each/major ecosystem services would be helpful to elicit impacts in details and design adaptation measures.

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