Research Article **Open Access**

Rajiv Pandey*, Dhanraj Meena, Roberta Aretano, Sachidananda Satapathy, Teodoro Semeraro, Ajay Kumar Gupta, Sushma Rawat, Giovanni Zurlini

Socio-ecological Vulnerability of Smallholders due to Climate Change in Mountains: Agroforestry as an Adaptation Measure

DOI 10.1515/cass-2015-0003
received March 7, 2015; accepted September 23, 2015

Abstract: The present study aims to assess the socio-ecological vulnerability of smallholders through an index of Tehri Garhwal Himalaya. The index provides a realistic approach to recognize the contributions of social and ecological factors for household welfare vulnerability to climate change. The approach puts forward various indices for each component of vulnerability to climate change - exposure, sensitivity, and adaptive capacity including two more indices: one for overall impact under the exposure of climate change and another for overall vulnerability. The five indices were proposed to assess the vulnerability status of with and without agroforestry practicing households in Himalayan region. These indices are based on 35 indicators (8 for exposure; 12 for sensitivity, 15 for adaptive capacity), selected through inductive approaches. A questionnaire for households was designed for the above aim and was administered to 121 heads of households through face-to-face interviews with 77 households practicing agroforestry and 44 without agroforestry. The questionnaire dealt the general household information, and indicators of the vulnerability including the issues related to agroforestry. The results highlight slightly higher adaptive capacity of agroforestry practicing households due to specific contribution of agroforestry. The low contribution of agroforestry among smallholders was due to small land holding. The study also results that remoteness, specific issues of smallholders' such as poverty, education and employment are responsible for the present condition. In particular this study clearly shows that poverty is the key driver for vulnerability. All of these issues can be addressed if future programs and policies, include and implement regulations to remedy attributive factors. This paper may be applicable to other mountainous regions providing insights for effective adaptation strategies to climate change.

Keywords: Adaptive Capacity, Exposure, Global Change, Resilience, Sensitivity, Tree Plantation

***Corresponding author, ???**
Rajiv Pandey, Ajay Kumar Gupta, ICFRE, Dehradun
Dhanraj Meena, Sushma Rawat, HNB Garhwal University, Srinagar Garhwal, India
Roberta Aretano, Teodoro Semeraro, Giovanni Zurlini, University of Salento, Italy
S. Satpathy, MoEF, New Delhi, India

1 Introduction

Climate change is equivocal with profound impacts on natural and human systems across the continents and lead to reduction of food production thereby resulting into food insecurity in several regions of world [1]. The decrease in agricultural productivity may be to the tune of 10-20 percent over the next 40 years [2] with serious implications for the rural dwellers in developing and transition countries [3,4]. Strategies are being developed to reduce the anticipated impacts and vulnerability of the poor to the climate change [5].

India, a country with agriculture as a primary livelihood for 70 percent households, faces great risks for agriculture productivity due to change in climate [6,7]. Land degradation and biodiversity loss further exacerbate the criticality [8] and hence enhance the overall vulnerability of the poor households. Indian Himalaya nurtures various ecosystems and farmlands and provides array of vital ecosystem services to the communities [9,10]. The ecosystem and farmlands are vulnerable to the change [11] thereby, putting threat to the local communities.

The impossibility to predict the real expression of climate change in terms of extreme events forces rural communities to adjust and adopt changes without losing their fundamental identity. Adjustments by local communities target at increasing the adaptive capacities of their social-ecological systems and their resilience [12]. The high functional capacity of agricultural ecosystem facilitates the adaptation [13] as well as lead to climate change buffering and suppression of associated feedbacks [14]. Diversification of food and livestock production is a key strategy used by climate-vulnerable households to increase food security. Agroforestry, the intentional use of trees in the cropping system to increase farm productivity, is another potential strategy for reduction of climate change vulnerability [15,16,17,18,19] by reducing household's dependence on a single staple crop [20,21,22] and through improving household well-being and environmental health [23].

Agroforestry is less sensitive to intra- and interannual climate variability due to their deep root system [24] and provides several potential benefits: (i) sequester carbon and contribute to mitigate climate change, (ii) enhance resilience to climate variability [25], (iii) improve food security and livelihoods [26], (iv) trees on farms also facilitate for stabilizing the soil against landslides and to raise the infiltration rates [27] besides preventing landscape degradation, (v) diminish the effects of weather extremes such as droughts or heavy rain [26]. Agroforestry may provide a financial viable way of protecting crops in areas where microclimatic factors regularly exceed the optimal range [e.g. 13].

Given the level of uncertainty in tree-crop interaction and competition in mountainous region, it is not possible to precisely capture the actual trade-off between the crop cultivation and agroforestry, in spite of the expected benefits for the post. Limited research has been conducted to assess the specific role of agroforestry in reducing household's vulnerability to climate change in mountainous region. Such information is required to communicate the role of agroforestry to policy makers and to encourage the tree plantation at farm level for promoting resilient systems. The presented study attempts to fill this gap by evaluating the role of agroforestry in reducing household's vulnerability and enhancing adaptation by comparing the households that have or not have carried out agroforestry practices in the Himalaya. Vulnerability assessment is being made with the premises that vulnerability is not only capturing the susceptibility and coping capacity, but also adaptive capacity, exposure [28] and also facilitate the assessment of the past, current and future vulnerability [29]. In this study vulnerability indices have been developed and applied to two groups of households with and without agroforestry in the districts of Tehri-Garhwal, Uttarakhand in Indian Himalayas with the aim to assess the capability of agroforestry.

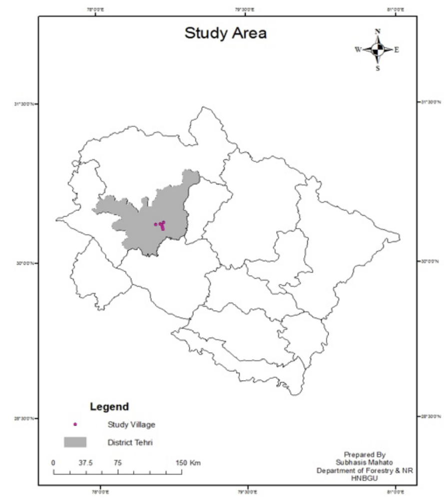
2 Methods

2.1 Study Area

The model region is Tehri Garhwal, a district of Uttarakhand state of India, that lies at the Shiwalik range (the outer ranges of the mid Himalayas) and is situated between the parallels of 30° 3' to 30° 53' N Latitude and 77° 56' to 79° 04' E Longitude (Figure 1). The district spreads in 4,421 km^2 geographical area. Topographically, the study area is characterized by undulating hills and rugged mountains. The cross profiles of the fluvial valleys show convex form with steep valley sides. Slopes are mostly steep to precipitous. Soils of the region are red to dark, black clay and brown forest and are very fertile. With the total land of 0.48 million ha of the district, the share under forest area is 66 percent; cultivable waste is 16 percent with negligible area under tree crops and groves [30]. Major forest tree species are chir pine, deodar, kharsu oak, moru oak, bamboo, banj, sal, kail, spruce, silver fir, kharik, and toon [31]. The climate of the region is sub-temperate to temperate on higher elevations with well marked seasons. The winter season is from mid-November to February and temperature even falls up to 0˚C with snowfall characterization during last December to early February. The temperature during the summer ranges between 18˚C and 30˚C. The area receives heavy rains (1500 mm^3) in July due to summer monsoon. During rainy season, the climate is very cool and full of greeneries.

The clustering of villages is confined mainly on the gentle slopes of the ridges on the fluvial terraces. According to the 2011 census, population of the district is 0.62 million (87 percent rural) and 1078 male per thousands female with 1.93 percent growth rate and 169 population density; and 75 percent literacy rate [32]. All the villages are remote and lack basic infrastructure in terms of road connectivity, transportation, bank and hospital facilities. Agriculture is the primary profession in spite of poor irrigation status with only 14 percent land under irrigation, and wage labour accounts as the secondary profession of the population. The share of marginal and small farmers is 91 percent among the total 81,079 farmers. Farmers under these categories have nearly 70 percent of agricultural land out of total 70 thousands ha. Villagers rear cattle for milk supply for self consumption and for dung for manure. The distribution of livestock is skewed with proportional share of 34 percent cows, 32 percent buffaloes, 4 percent sheep, 28 percent goat and only 2 percent other animals out of the total 362,131 units of animals [30,33]. The villagers are dependent on forest resources for fuelwood, fodder and

India



Uttarakahnd

Figure 1: Map of study area

manure besides other resources such as fruits and meat.

Farming, mostly rainfed (86 percent), is mainly terrace based with major crops as mandua, rice (*Oriza sativa*), wheat (*Triticum spp*.), jhangora (*Echinochloa crus-galli*), maize (*Zea mays*), barley (*Hordeum vulgare*). The major pulses are arhar (*Cajanus cajan*), greengram (*Vigna radiate*), and blackgram (*Vigna mungo*). Cucumber (*Cucumis sativa*), pumpkins (*Cucurbita maxima*), tomato (Lycopersicon esculentum), brinjal (*Solanum melongena*), potatoes (*Solanum tuberosum*), green leafy vegetables such as palak (*Spinacea oleracea*), rai (*Brassica juncea*), radish (*Raphanus sativus*), and chaulai (*Amaratus viridis*) are grown for self consumption mostly. The major fruits grown are malta (Citrus spp.), peach (*Prunus persica*), anar (*Punica granatum*), mango (*Mangifera indica*), apple (*Malus pumila*), apricot (*Prunus armeniaca*) and plum (*Prunus domestica*). Organic fertilizers (a mix of dung with tree leaves) are generally used for increasing farm production. The total cropped area in the district is 0.10 million ha [31]. Major tree species for agroforestry in the region are banj oak (*Quercus leucotricophora*), chamkharik (*Celtis australis*), chir (*Pinus roxburghii*), padam (*Prunus cerasoides*), kweral (*Bauhinia varigata*), kakhad (*Pistacia integerrima*), toon (*Toona ciliata*), timla (*Ficus roxburghii*) and bhimal (*Grewia optiva*).

2.2 Conceptual Framework

Vulnerability, a non-measurable [34] and theoretical concept [35], is context specific. The Third Assessment Report (AR) of the Intergovernmental Panel on Climate change (IPCC) defines vulnerability as: *"…the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate change and the variation to which a* [social-ecological] *system is exposed, its sensitivity and its adaptive capacity"* [36].

Vulnerability is driven by the dimensions of exposure, sensitivity, and adaptive capacity which can either be quantitatively measured or qualitatively characterized. Exposure is a measure of the magnitude and extent (spatial and temporal) of exposure to climate change impacts by capturing important weather events and patterns that affect the system. Sensitivity reflects the responsiveness of a system to climate-induced stress and the degree to which changes in climate might affect it in its current form. The adaptive capacity is a measure of the potential or ability of a system to decrease exposure or sensitivity to climate-induced stress and to change in a way that makes it better equipped to deal with external influences through the implementation of adaptation policies and measures [37,38,39]. Exposure and sensitivity together describe the potential impact that climate change can have on a system. It may be noted that even though a system may be considered as being highly exposed or sensitive to a stress or to climate change, that does not necessarily mean that it is vulnerable [40]. Only exposure and sensitivity are not accounting the vulnerability; rather vulnerability is the net impact of climate change that remains after accounting the adaptation (Figure 1). Thus, the adaptive capacity of a system affects its vulnerability to climate change by modulating exposure and sensitivity [41,42].

Households are rational decision makers and consider the availability of various capitals at their disposal before entering into the decision-making processes. The household welfare depends on own internal resources as well as the extent of availability of external resources. Any change in the existing livelihood is a result of their interest of change or regulation of available resources to maximize the output with the notion to counter the effect of regulation agent. Under the prevailing complexities of the mountainous households, especially fragility and remoteness, it can be assumed that the household with agroforestry in mountains is generally governed under a similar set of rules as the households without agroforestry. Households facing external influences or stress such as climate change in the present case, attempt to counter the impact, by modifying the existing welfare mechanism or ratifying the changes through adjustment. Households try to adjust the impact of external stress based on their own mix of resources including the internal and external adjustment within the farms. More precisely, against the exposure to climate change, the responses would be adjusted according to the sensitivity of biological system at farm coupled with available external resources. Against any exposure regime, the system gets perturbed and responds, accordingly. The responses are aggregation of all actions, counteractions and interactions within and between various sub-systems of the system, generated in consequence to the perturbation (Figure 2).

The assessment of vulnerability, in general, is complex due to the reliance of vulnerability on several factors and their interactions. Numerous indices have been developed to account for the vulnerability with different sets of parameters such as climate vulnerability index [43,44,45], livelihood vulnerability index[46]; livelihood effect index [47]. In the present case, indices for each component of vulnerability to climate change - exposure, sensitivity, and adaptive capacity were estimated to evaluate vulnerability. Two more indices: overall impact index and vulnerability index were also estimated [48,44]. In total, five indices were proposed to assess the vulnerability status of with and without agroforestry households. The overall impact is the difference of sensitivity with adaptive capacity and vulnerability is directly (positively) influenced by overall impacts under exposure (Figure 3).

Indicators and indices help to represent complex phenomena and problems and facilitate the

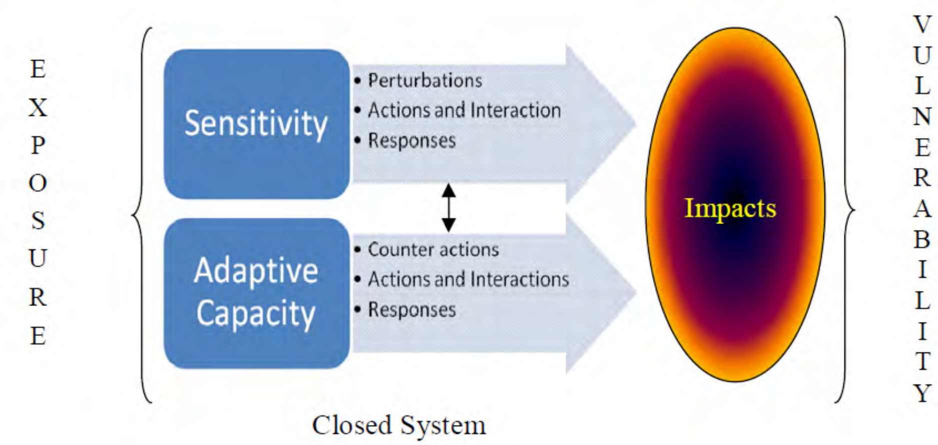


Figure 2: The conceptual vulnerability assessment framework for the agroforestry practicing households [37,48]

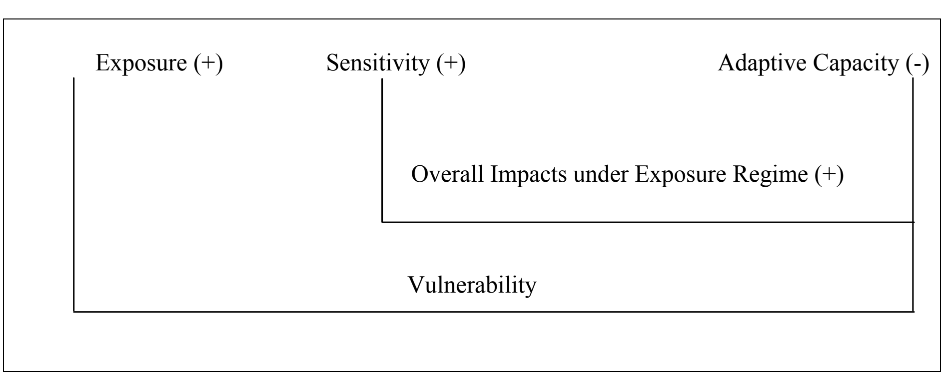


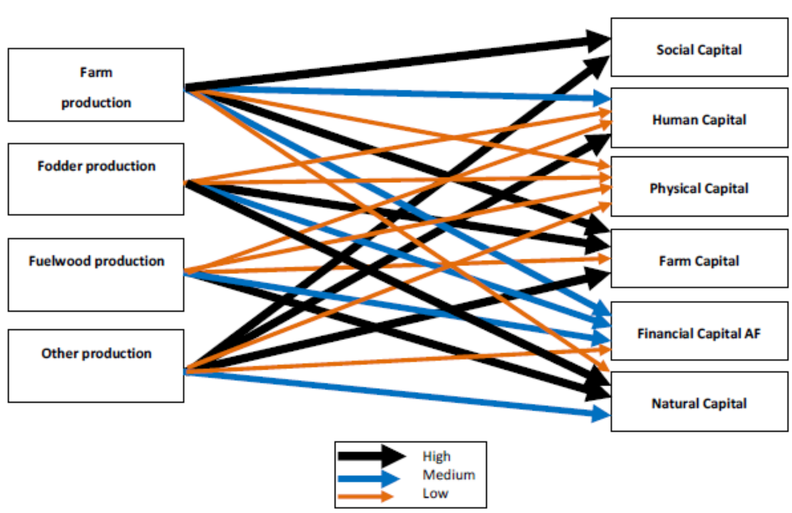
Figure 3: Directional relationship between the different dimensions of vulnerability, impacts with vulnerability [48]

communication of the problem to stakeholders [29]. The contextualization about the role of agroforestry for socio-ecological system assisted to identify indicators for assessing the climate change vulnerability. The major requirement of subsistence livelihood revolves around the provision of food for the household, fodder for the livestock, energy, and other household requirements such as shelter, water. These requirements are being met and regulated as per the accessibility and availability of households' capitals for a sustainable livelihood.

These capitals are [49]: social capital - namely the social networks and associations participation by individuals that may facilitate different livelihood strategies; human capital - refers to knowledge and skills, labor force; physical capital - made up of infrastructure and production tools used during the process of economic production; financial capital from farm or agroforestry production; natural capital consisting of the natural resources and ecosystem services used for survival and for generating products. These capitals contribute directly or indirectly to bounce back or mitigate the stress through conscious decisions about the ability of a household to make adaptive adjustments to farm practices. The adaptive capacity is estimated considering the social capital index (food sufficiency), the human capital index (education of household head), the physical capital index (number of trees at farm, change in harvesting time, fertilizer and manure application), the financial capital index based on fuelwood, fodder and leaf manure production from farm and agroforestry and the natural capital index (fuelwood, fodder, and leaf manure from forest). In present context, for better clarity, financial capital has been classified into farm capital and agroforestry capital (tree products) to segregate their tree products. These capitals are determined by various household production processes. Such as for the present study on agroforestyry, the various productions were classified as farm production, fodder production, fuelwood production and other production. It can be postulates that in the present case, farm production shapes household social and farm capital due to high significance at household well being, however also influences human and financial capital from agroforestry (due to existence of alternative) at secondary level; and physical and natural capital at low level (Figure 4).

2.3 Vulnerability Assessment

In the present case, each of the three vulnerability components (exposure, sensitivity and adaptive capacity) is accounted with several indicators. In totality, 35 indicators were selected (8 for exposure; 12 for sensitivity, 15 for adaptive capacity). The indicators for each component were selected based on the published records [26,44,19] and familiarity of the first two authors with the study region. Table 1 provides an overview on the indicators. In particular, exposure indicators reflect the nature and degree to which a system is exposed to significant climatic variations; the indicators of sensitivity reflect the responsiveness of a system to climatic influences shaped by both socio-economic and environmental conditions; and indicators of adaptive capacity take into account the ability of farms to minimize potential damages, to reorganize and cope with the consequences



Note: Financial Capital AF – Financial capital from Agroforestry; Farm capital – Financial Capital from farm other than agroforestry products

Figure 4: Linkages between household requirement and various capitals of an ideal household

from climate change impacts. The exposure is assessed based on the perception of the head of household for the trend of climatic parameters with consideration that the perception differs at local level and is governed by the traditional knowledge and experience about various climatic factors noted by the head of household.

Exposure is adjudged through variability in temperature, precipitation, hot weeks, cold waves and humidity. Exposure results into the change in the volume of the production of the crop and trees. Interpretations of sensitivity are more diverse due to the lack of precise information about the nature of response transfer functions against the climate impacts. In the presented case, the agroforestry and farm productivity are being triggered by diverse factors including climate and these factors decide upon the interactions and relevance of other associated components, for example nutrient uptake is highly influenced by change in temperature. Sensitivity was determined considering the indicators related to farm outputs (e.g. crops, fruit production), crop residues, grass and tree products (e.g. fodder, fuelwood, grasses and crop residues), and other feedback (e.g. water, soil fertility, crops failure, and loss of land). Adaptive capacity was measured through access to and availability of capital (natural, financial, social, human and physical). The financial capital (farm and agroforestry) and natural capital was assessed taking into account the tree products, specifically the fuelwood, fodder and leaf manure. The actual extraction of fuelwood, fodder and leaf manure was also assessed for comparative purposes.

Initially, the selected indicators for each component were aggregated to assess the exposure, sensitivity and

Table 1: Indicators for the various components of vulnerability with their hypothetical relation to vulnerability ("+": the higher the indicator the higher the level of vulnerability; "-" the higher the indicator the lower the level of vulnerability)

Component of vulnerability	Major component	Indicator	Measurement Scale	Relation with vulnerability
Exposure (8)	Temperature variation (4)	Temperature	Ordinal	+ ve
		Hot weeks	Ordinal	+ ve
		Humidity	Ordinal	+ ve
		Humid month	Ordinal	+ ve
	Precipitation variation (4)	Rainfall	Ordinal	+ ve
		Rainfall pattern	Ordinal	+ ve
		Cold wave	Ordinal	+ ve
		Hailstorm	Ordinal	+ ve
Sensitivity (12)	Farm output (4)	Cereals	Ordinal	- ve
		Vegetable	Ordinal	- ve
		Spices	Ordinal	- ve
		Pulses	Ordinal	- ve
	Crop residue, Grass and Tree product (4)	Tree fodder	Ordinal	- ve
		Grass fodder	Ordinal	- ve
		Crop residues	Ordinal	- ve
		Fuelwood	Ordinal	- ve
	Other feedback (4)	Water availability	Ordinal	- ve
		Land fertility	Ordinal	- ve
		Crop production	Ordinal	+ ve
		Loss of land	Ordinal	+ ve
Adaptive capacity (15)	Social capital (1)	Food insufficiency	Number (in months)	+ ve
	Human capital (1)	Literacy	Index	- ve
	Physical capital (4)	Tree planted per unit land	Number	- ve
		Change in harvesting time	Number (in days)	- ve
		Fertilizer application	Ordinal	- ve
		Manure application	Ordinal	- ve
	Financial capital from Farm other than agroforestry produce (3)	Fuel wood	Percent	+ ve
		Fodder	Percent	+ ve
		Leaf manure	Percent	+ ve
	Financial capital from Agroforestry (3)	Fuel wood	Percent	+ ve
		Fodder	Percent	+ ve
		Leaf manure	Percent	+ ve
	Natural capital (3)	Fuel wood	Percent	+ ve
		Fodder	Percent	+ ve
		Leaf manure	Percent	+ ve

Note: Indicators for financial capital from farm and agroforestry are same due to the similar settings of the households of the region as well as identify the specific contributions of agroforestry.

adaptive capacity, and finally all components were combined to calculate the composite index for assessing the household's vulnerability to climate change with special reference to agroforestry. For simplicity in estimating the aggregate index, indicators were equally weighted. Before processing the indicators to develop the index, each indicator was subjected to normalization through the minimum-maximum (min-max) and maximum-minimum (max-min) approach depending on the indicators relations with the vulnerability [46,45].

Normalization facilitates converting immeasurable indicators to measurable indicators [50] based on their functional relationship. The positive relationship determines an increase in vulnerability with increase in the value of indicator (Equation-I – *min- max approach*) and vulnerability decreases with increase in value of indicator i.e. negative relationship (Equation-II – *max-min approach*).

Equation – I: $$\text{Index}_{sv} = \frac{S_v - S_{min}}{S_{max} - S_{min}}$$

Equation – II: $$\text{Index}_{sv} = \frac{S_{max} - S_v}{S_{max} - S_{min}}$$

where,

Sv is the actual value of indicator in the series.

S_{min} and S_{max} are the minimum and maximum values of indicator in the series.

After the normalization of indicators, each major component of exposure, sensitivity and adaptive capacity was estimated as follow:

$$M_C = \frac{\sum_{i=1}^{n} n_i * \text{Index}_i}{n}$$

Where,

MC is the Major component present in the table 1 *ni* is the number of indicators in the i^{th} sub-components of the C^{th} components of the vulnerability.

n is the total number of indices.

The *Climate Vulnerability Index for Agroforestry* was determined as inverse relationship of exposure keeping in view of analyzing the per unit absolute capability of the system against the exposure to adjudge the responses of the climate threats.

$$\text{CVI for Agroforestry} = \frac{\textit{Sensitivity – Adaptive Capacity}}{\textit{Exposure}}$$

Its values range from –1 to 1, where values from -1 to zero indicates the system's ability to absorb the stress and values greater than zero indicate the system is under impact.

2.4 Data Collection

Three villages for each two groups were selected at random. These two groups were considered based on the intensity of tree plantation at farm and termed as agroforestry (Group – I) and non-agroforestry (Group – II). Village with tree plantation at minimal (less than 5 percent) was considered as non-agroforestry village, otherwise as agroforestry village. This results into three villages namely Rishkoti, Khalpali, and Shyalkhund under Group – I and villages Koti, Magro and Paukhal, under Group – II (Table 2). Vegetation, crops, fruits, spices, topography, soil condition, and environmental condition are more or less homogeneous in all the selected villages (Figure 5).

During the pilot survey, it was observed that some of the indicators were redundant such as social networking (help provided and received by others), therefore these indicators were discarded from the questionnaire. Pre-tested semi-structured questionnaire were administered to randomly selected households in both groups. The respondents were generally the head of households, otherwise, mostly senior members, if the head was not available. In totality 121 households were interviewed for data collection by personally approaching them during the months of May – July 2014. A total of 77 households were surveyed under Group – I (with agroforestry)

Table 2: Locational description of the villages selected for the study

Tehsil	Village	Location		Altitude (m asl)
		Latitude	Longitude	
Agroforestry practicing villages				
Devprayag	Rishkoti	30°20'32.44"N	78°37' 59°70'E	1,297
Ghansali	Khalpali	30°20'58.02"N	78°37'50.05"E	1,460
Ghansali	Shyalkhund	30°21'32.03"N	78°37'15.08"E	1,365
Non-agroforestry practicing villages				
Ghansali	Koti	30°21'28.0"N	78°37'53.09"E	1,600
Ghansali	Magro	30°21'00.8"N	78°37'40.09"E	1,420
Ghansali	Paukhal	30°21'34.61"N	78°36'23.43"E	1,223

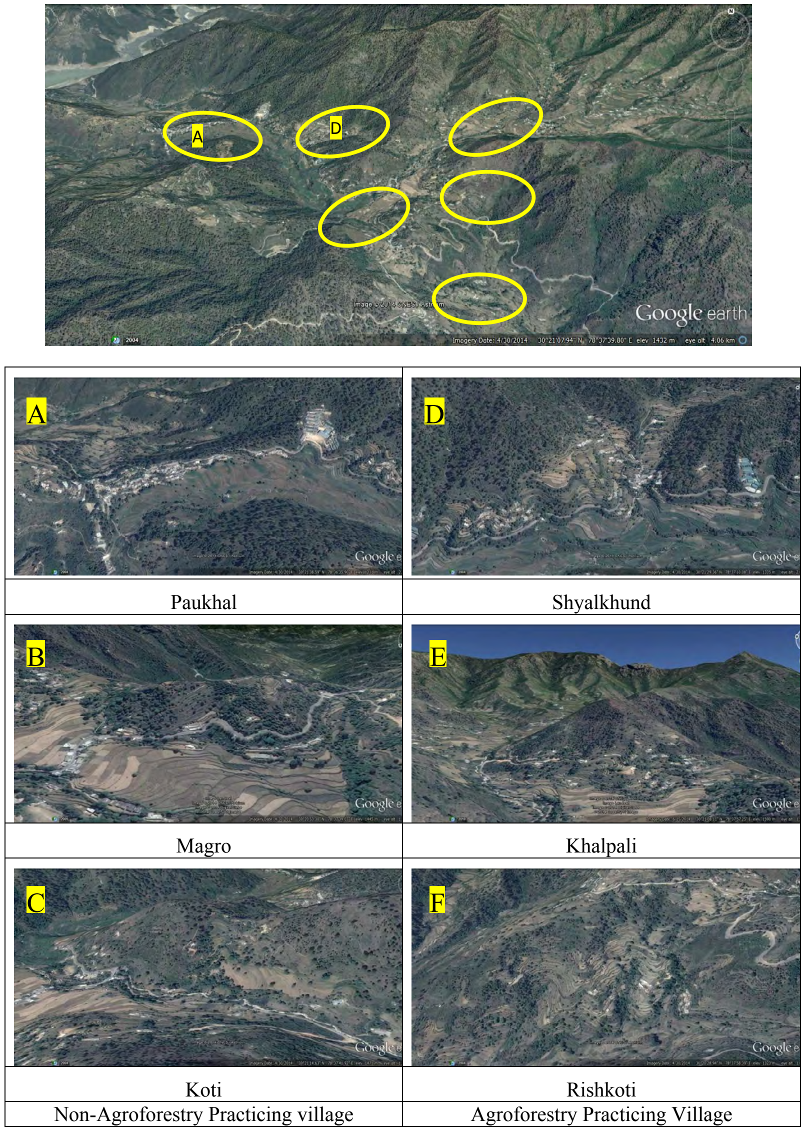


Figure 5: Map of non-Agroforestry (A-B-C) and Agroforestry (D-E-F) study villages

and 44 for Group – II (without agroforestry). The high number of samples for Group-I was due to high variability in the number of trees at farm level. Questions focused on observed changes in climate, farming practices, farm production, and agroforestry and forest contribution, besides their coping strategies. Precisely, the questionnaire consists of four sections. Section – I dealt the general household information including demographic parameters. Sections II to IV were dedicated to investigate the three components of the vulnerability. In particular, the section II was focused to evaluate the perception of the climatic parameters. The section III was focused to sensitivity dealing information related to agroforestry based livelihood strategy. It focuses on the perception on farm and other production inputs with the mixed farming inputs (fodder and fuelwood). The section IV of questionnaire dealt with the adaptive capacity. Various indicators pertaining to the social, human, natural, financial and physical capitals were part of this section including the social networking indicators. The respondents were asked 'whether they have experienced, observed or witnessed' for the given parameters of climate change; biodiversity and agriculture. Three response options were provided including 'decreasing trend', 'no change', and 'increasing trend' for close ended questions.

Several studies have examined perception based evaluation of climate issues on Himalaya [51,52,53,54]. Indigenous knowledge of the local communities about climate change is a potential information for climate science and policy [55,56]. Therefore, perception based on indigenous knowledge can be used for testing specific hypotheses for designing adaption strategies for climate change [56].

Additionally, focus group discussions (FGDs) were conducted in four villages different from the surveyed villages with a mix of households of both groups. The purpose of the FGDs was to test the validity of household responses by assessing the concordance of results obtained from the two sets. The in-depth focus group discussions were conducted in Hindi language and local dialect with the help of a local educated person. The comparison of mean extraction of total of fuelwood, fodder and leaf from various sources for the two groups i.e. with and without agroforestry households, was assessed based on independent t-test using SPSS software version 16. It was hypothesized that the household requirements for fuelwood, fodder and crop residue are same for both group i.e. agroforestry practicing and non-practicing groups.

3 3. Results and discussions

3.1 General Characteristics of the Households

The survey results show that due to patriarchy system and associated culture prevailing in the area, approximately 95 percent and 93 percent head of households were male in Group-I and Group-II villages, respectively. It was also observed that the female headed households were not by choice rather due to absence of male member in the family. The maximum and minimum age of household head was 73 and 27 years in Group-I and 75 and 30 years in Group-II with the average age of household head of 51 years in both groups. The education status was poor among the heads of household. Thirty six percent and twenty seven percent heads were illiterate in Group-I and Group-II, respectively. Only a small number of household heads was educated up to bachelor and above in both groups. Family size has high significance in mountainous region due to family labour force. In the region, maximum and minimum family size was 6 and 2 in agroforestry, and 10 and 4 in non agroforestry practicing households, respectively. However, the family size of 4-6 was most common among the households in the region.

The economic status measured by types of houses showed prevalence of three types of houses i.e. kaccha, semi-pakka, and pakka in the region. In Group-I, the proportions of kaccha, pakka and semi-pakka houses were 39, 34 and 27 percent, respectively, while in Group-II, they were 21, 51 and 29 percent, respectively. The cause of apparent high proportion of pakka houses under Group-II could not be ascertained. Generally, households, depend on more than one profession for their subsistence. The primary profession (40 percent) was agriculture followed by wage labour (27 percent) and skilled jobs (23 percent) in Group-I. Almost 60 percent of the households adopt agriculture as secondary profession in the group. The scenario was different for Group-II, with wage labour (39 percent) constituting the larger share of primary profession. The agriculture profession accounts for 30 percent and 20 percent share was of skilled jobs, however, almost 70 percent of the households were practicing agriculture as secondary profession. The male and female, both participated in cultivation of crops on terraced land with high contribution of female labour in both groups. In general, the young male member of the family has migrated to nearby town for either higher education or for income generation. Generally, households of Group-I prefer plantation of the local tree species suitable for fodder and fuelwood production for household consumption with an average number of trees of 110 with a maximum of 1100 and a minimum of 15 trees under agri-silviculture system (79 percent).

Most of the immovable property of the family is either in possession of the head or taken care by him. The households of Group-I were having approximately double land than the Group-II. The numbers of adult cattle units

Table 3: Household assets and adjustment for climate change in the region

Characteristics	Agroforestry	Non Agroforestry
	Mean ± SE	**Mean ± SE**
Total Land (in ha)	0.72 ± 0.04	0.39 ± 0.84
Irrigated Land (in ha)	0.12 ± 0.02	0.20 ± 0.04
Unirrigated Land (in ha)	0.60 ± 0.04	0.19 ± 0.04
Adult cattle units (ACU)	2.86 ± 0.24	2.53 ± 0.26
Number of trees/household	110.74 ± 21.75	-
Food storage time in month	2.63 ± 0.25	3.30 ± 0.31
Change in crop harvesting time (in days)	16.30 ± 0.89	15.43 ± 1.32

were more or less the same in both the groups, confirming the integral part of livelihood of these households. Primarily, livestock is reared for manure and milk. The number of trees per ha was quite low, probably, due to low land assets and availability of tree produce from nearby forests. These peasant households of both groups had excess food for three months. The households of Group-II had an edge over the Group-I households for food security. In both groups, households adapted to climate change by adjusting harvesting time nearly by a fortnight (Table 3).

The location of farms was nearer for Group-I than Group-II households with better irrigation facilities for Group-II. The Group-I villages are surrounded by chir forests, which have low inputs for fuelwood and fodder, while for Group-II, the adjoining oak forests are more productive. Group-I villages are on steep slopes, thus agroforestry is also practiced to reduce soil erosion. In the surveys, the villagers pointed out that agroforestry improve microclimate and thus assist to germination of agricultural crops by reducing the intensity of direct sunlight and conserving the soil moisture, as also suggested by [13]. Non-agroforestry households presume that trees provide shelter to birds and monkeys and they consume the seeds and soft seedlings instead destroying the crops. Another mention was that crop productivity decreases, if trees are in the farm and also favor the growth of insects and pests, which can cause serious implications on the productivity of the crops.

The contribution of forests for fuelwood was almost 100 percent for Group-II, and 50 percent for Group-I. The farmland contributions for fuelwood mainly in the form of maize bio-sticks were negligible for both groups of households, however, nearly 42 percent of households of Group-I collect fuelwood from their agroforestry resources. Fodder was collected from forests by both groups. The crop fodder (7 percent) contribution was mainly from the rice and wheat straw for Group-II households. The scenario was different in the groups of households for leaf manure (including crop residue), though still higher extractions prevail from forests. The lopping residue of agroforestry was also being used for leaf manure by the Group-I households (Table 4).

The demand of fodder and fuelwood resources was measured quantitatively for the three sources i.e. forest, agroforestry and farm to analyse the contrasting situation between the two groups. The t-test results into homogeneous demand of tree, grass and crop fodder irrespective of extraction sources by both groups. This confirms that regardless of agroforestry practices, the needs of household were similar for livestock fodder (Table 5). Though the demand of fuelwood was not varied much between the two groups of households, a significant difference was observed with high demand by the Group-II households (Table 5).

3.2 Exposure, Sensitivity and Adaptive Capacity

Based on the questionnaire response, the exposure index was estimated by developing temperature variability index and precipitation variability index of the two groups, separately. Results show that the temperature variability index was 0.78 for Group-I and 0.66 for Group-II, and rainfall variability index was 0.96 for Group-I and 0.86 for Group-II. The empirical analysis showed that on the perceptional basis, households with agroforestry were more exposed to temperature and rainfall variability than

Table 4: Proportional share of contribution of forests, agroforestry and farmland for fuelwood, fodder and manure to the households

Parameter	Agroforestry	Non-agroforestry
	Mean ± SE	Mean ± SE
Forest		
Fuel wood	54.87 ± 2.84	98.18 ± 0.87
Fodder	61.95 ± 10.35	92.50 ± 5.62
Leaf manure	20.19 ± 2.89	66.48 ± 4.05
Farm Land		
Fuel wood from some biosticks	2.47 ± 0.83	1.82 ± 0.87
Fodder from crop residue	0.32 ± 0.32	7.05 ± 0.69
Leaf manure from farm residue	20.19 ± 2.40	33.52 ± 4.05
Agroforestry		
Fuel wood	42.27 ± 2.23	0
Fodder	36.10 ± 7.33	0
Leaf manure	55.71 ± 6.21	0

Table 5: Mean and standard deviation (SD) of fuelwood and fodder resources extracted from the two groups of households and results of t-test

Parameter	Category	Mean (kg/day)	Standard error (SE)	F-test (p-value)	t-test (p-value)
Tree fodder	Agroforestry	32.01	2.63	0.91	0.16
	Non-agroforestry	32.66	3.04	(0.34)	(0.87)
Grass fodder	Agroforestry	26.55	2.25	0.01	0.67
	Non-agroforestry	28.98	2.87	(0.92)	(0.51)
Crop residue	Agroforestry	5.91	0.46	3.09	0.31
	Non-agroforestry	6.18	0.74	(0.08)	(0.76)
Fuelwood	Agroforestry	22.74	0.72	1.64	2.76
	Non-agroforestry	25.82	0.65	(0.20)	(0.01)

households without agroforestry. The value of exposure index for agroforestry and without agroforestry was 0.87 and 0.76, respectively (Table 6). The changes in perception were attributed to the realization of the households based on their overall productivity of farm and tree wherever available as well as their experiences with tree cultivation. The high perception of the variability of climatic factors for agroforestry households was probably the result of the overall impacts of climate changes in crop and tree production and considering that even small changes may disturb the overall farm and tree productivity. The scientific reason may revolve around the increased competition for water and nutrients between the crop and the tree besides the ameliorative influence of the shade of trees on the microclimate of the undergrowth due to climate variability [27]. Shade of trees may lead to increasing growth and productivity [57] and the microclimatic variation influenced crop performance in a wide range of species [58].

Results show that the indicators of farm output, crop residue, grass and tree products and other feedback were respectively 0.83, 0.50 and 0.60 for agroforestry practicing households and 0.64, 0.59 and 0.71 for non agroforestry households. The overall sensitivity index for agroforestry was 0.64 while for non agroforestry household was 0.66 (Table 6). The differences may be attributed to human action that, if necessary, they act to ensure agricultural productivity and their survival. So, in the case of non-agroforestry household, people act mostly to keep production steady, perhaps through a greater use of resources. However, agroforestry households are more sustainable due to the production of various products such as fooder, fuelwood, shade, ecological services, [59]. Various factors such as water and nutrient input govern the agriculture productivity, however, competition interplay between tree and crop leading to change in the physiology of both the crop and tree such as competition for nutrient, water, light. Deficiency of light and shade may result into dwarf crop, weak stem and decrease in the quantity of grain, thus reducing the overall productivity [58]. The crop productivity may also be influenced by the allelopathic effect of agroforestry trees due to possible release of toxic chemical that check the crop growth [19]. The trees on farm act as habitat for small birds and wild animals (monkeys) may further lead to affect the crop productivity, as they consume and destroy the whole seed. Precisely, agroforestry systems have higher productivity compared to monoculture systems due to complementarities in resource-capture i.e. trees acquire resources that the crops alone would not [60].

Results of adaptive capacity show that the indices for various capitals as social, human, physical, farm, agroforestry and natural were respectively 0.18, 0.64, 0.22, 0.40, and 0.49 for agroforestry, and 0.38, 0.64, 0.60, 0.50, 0.00 and 0.74 for non Agroforestry. The overall adaptive index for agroforesty was 0.46 while for non agroforestry was 0.48 (Table 6). Most probably this result can be explained by the fact that agroforestry households do not use chemical fertilizer and insecticide as they have better option in terms of leaf litter and farmyard manure. The diversification of multi-sectoral products besides improving farm productivity, and planting drought resistance crops [14] has been advocated by various researchers such as [61,60] for improving the resilience.

The analysis clearly depict that the agroforestry households were less prone to climate change with high perception of climate variability than non-agroforestry households. The high sensitivity of the non-agroforestry farms was also due to high variability and diversity of crop production, probably due to a lack of desired cropping and tree density, restricting the congenial microclimate for crop growth. The similar adaptive capacity of both groups of households was mainly due to the similar level of overall household capitals. The inequality of the capital was being adjusted by making more extractions from common lands by non-agroforestry farmers.

3.3 Overall Impact and Vulnerability

The overall impact index was negative for both groups. The absolute difference was very low, however, this shows that there was a tendency to tackle the stress caused by climate change by households of both groups, and they were struggling to confront the stress caused by climate change (Table 6). The climate vulnerability index (CVI) was 0.21 and 0.24, for Group-I and Group-II, respectively. Result shows that the CVI value of agroforestry households was lower than non Agroforestry households (Table 6). The similar vulnerability level of the two groups was probably due to similar livelihood practices depending on mixed terrace farming and similar settings of these households. The low level of household assets, including small land holding, restricts these households to optimize the tree density for maximizing the response. The low productivity restricts agroforestry farmers for adjusting the household affair to get the maximum benefits of agroforestry as highlighted in various studies [17,62]. This study clearly shows that poverty is the key driver for vulnerability.

Present finding shows that the agroforestry practicing households understood the importance of diversification as well as agroforestry, however, they are not be able to maximize the contribution of agroforestry, probably because of the small landholding, infrastructure and lack of optimization of the resources. The lack of the optimum size of agroforestry may reduce the level of amelioration of microclimatic conditions of the undergrowth due to the shade of trees. The importance of microclimate in determining crop performance is well documented [58], still, the knowledge is incomplete with respect to the impact of trees on the microclimate and resultant physiological response and yield of the understorey crop [63]. Agroforestry may be a potential strategy for reducing vulnerability to climate change for subsistence households through increasing farm productivity, diversify income sources and improve environmental services [64,65]. Moreover, it was argued that enhanced tree based system and marketing facility for value added tree products have a potential to reduce farmers vulnerability to climate variability [66].

4 Conclusions

The defined methodological based empirical result for the peasant households of Himalaya elaborate the existing livelihood practices with a broad overview of vulnerability against the climate stress. The indices may serve as a useful starting point for portraying the vulnerability of small holders in similar regions. The results also provide useful indicators of different farm adjustment besides poverty as key elements for vulnerability under the existing fabrics of household and, by considering the adjustment of these, might safeguard the households against vulnerability.

Generally, humans influence resilience by managing their socio-ecological systems [67]. Thus, humans should attempts to manage social-ecological interactions in a manner that maintains the system state. The result apparently highlights the potential benefits of agroforestry compared to the traditional cultivation. A significant adaptation through agroforestry may be achieved by making provisions for improving the economic capacity of households besides upgrading technical support for tree and crop cultivation. Planting density as well as the growth of trees at farm may be manipulated to maximise output by making the provisions of congenial microclimatic environment. Pruning reduces the productive biomass and consequently typical services of the trees besides reducing the shadow effects on the understorey vegetation with positive effects for crop productivity. These contradictory effects require more research on how to establish optimal tree and crop densities and appropriate management practices.

Notably, the agroforestry and agriculture policies and funding strategies should focus on introducing appropriate technological and management solutions [68] besides addressing the poverty. Although the study indicates that policy, support and interventions should be targeted to the households, however, any implementation will require considerable care in the management of structural reform for overall households to relish the intended benefits of agroforestry. This will also provide impetus to the National Agroforestry Policy of 2014, which flagged the carbon sequestration role of the agroforestry and also recommend for incentives in terms of money on various inputs of the tree growing [69]. This will facilitate further incorporation of tree at farm and mechanism for the payment of incentives to the households under REDD+ program [70]. The payment for the tree planting will facilitate these peasant households to overcome low capital limits and thus help to reduce the vulnerability.

Table 6: Mean and Standard deviation (SD) of various major components of vulnerability, and values of impact and vulnerability for agroforestry and non-Agroforestry households

Vulnerability components	Major component	Agroforestry household				Non-agroforestry household			
		Mean ± SE	Mean ± SE	Impact	Vulnerability	Mean ± SE	Mean ± SE	Impact	Vulnerability
Exposure (8)	Temperature variation (4)	0.78 ± 0.03	0.87 ± 0.02	0.028 (Cross the Resilient Limit)	0.21	0.66 ± 0.06	0.76 ± 0.04	0.026 (Cross the Resilient Limit)	0.24
	Rainfall variability (4)	0.96 ±0.01				0.86 ± 0.04			
Sensitivity (12)	Farm output (4)	0.83 ± 0.02	0.64 ± 0.01			0.64 ± 0.03	0.66 ± 0.02		
	Crop residue, Grass and Tree product (4)	0.50 ± 0.03				0.59 ± 0.03			
	Other feedback (4)	0.60 ± 0.03				0.76 ± 0.03			
Adaptive capacity (15)	Social capital (1)	0.18 ± 0.02	0.46 ± 0.01			0.38 ± 0.04	0.48 ± 0.01		
	Human capital (1)	0.64 ± 0.04				0.64 ± 0.04			
	Physical capital (4)	0.68 ± 0.02				0.60 ± 0.03			
	Farm capital (3)	0.22 ± 0.02				0.50 ± 0.04			
	Agroforestry capital (3)	0.40 ± 0.01				0.00			
	Natural capital (3)	0.49 ± 0.02				0.77 ± 0.03			

Values within parenthesis are number of indicators.

References

[1] IPCC., Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Ed.: Field C.B., Barros V.R., Dokken D.J., Mach K.J., Mastrandrea M.D., Bilir T.E., et al., 2014, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1-32.

[2] Nelson G.C., Rosegrant M.W., Koo J., Robertson R., Sulser T., Zhu T., et al., Climate change: impact on agriculture and costs of adaptation, 2009, IFPRI, Washington.

[3] Thompson J., Millstone E., Scoones I., Ely A., Marshall F., Agri-food system dynamics: pathways to sustainability in an era of uncertainty, 2007, Working Paper 4, STEPS Centre, Brighton.

[4] Lissner T.K., Reusser D.E., Lakes T., Kropp J.P., A systematic approach to assess human wellbeing demonstrated for impacts of climate change, 2014, Change and Adaptation in Socio-Ecological Systems, Vol 1, 98-110.

[5] Morton J., The impact of climate change on smallholder and subsistence agriculture, 2007, Proceedings of the National Academy of Sciences of the United States of America, 104(50): 19680.

[6] Gadgil S., Kumar K.R., The Asian monsoon, Agriculture and economic. In: Wang, B. (ed), The Asian Monsoon, 2006, Springer, Paris, 651-83.

[7] Jayaraman T., Murari K., Climate Change and Agriculture: Current and Future Trends, and Implications for India, 2014, Review of Agrarian Studies, 4(1), (http://www.ras.org.in/climate_change_and_agriculture_83).

[8] Salvatore Y., Gunnar K., Ringler C., Estimating the impact of climate change on agriculture in low income countries: Household level evidence from the Nile basin Ethiopia, 2011, J Environ Res Econ, 28:32–43.

[9] Korner C., Mountain biodiversity, its causes and function, 2004, Ambio Supplement, 13:11–17.

[10] Viviroli D.,Weingartner R., Hydrological significance of mountains: from regional to global scale, 2004, Hydrological Earth Systems Science, 8(6):1016–1029.

[11] Vitousek P. M., Mooney H. A., Lubchenco J., Melillo J. M., Human domination of Earth's ecosystems,1997, Science, 277:494-499.

[12] Cassidy L., Barnes G. D., Understanding household connectivity and resilience in marginal rural communities through social network analysis in the village of Habu, Botswana, 2002, Ecology and Society, 17(4), 11. http://dx.doi.org/10.5751/ES-04963-170411.

[13] Lin B.B., Agroforestry management as an adaptive strategy against potential microclimate extremes in coffee agriculture, 2007, Agric. For. Met, 144: 85–94.

[14] Lin B., Resilience in Agriculture through Crop Diversification: Adaptive Management for Environmental Change, 2011. Bioscience, 61:183-193.

[15] Challinor A., Wheeler T., Garforth C., Craufurd P., Kassam A., Assessing the vulnerability of food crop systems in Africa to climate change, 2007, Climate Change, 83(3), 381-99.

[16] Lin B., Perfecto I., Vandermeer J., Synergies between Agricultural Intensification and Climate Change Could Create Surprising Vulnerabilities for Crops, 2008, Bioscience, 58: 847-854.

[17] Verchot L.V., Van Noordwijk M., Kandji S., Tomich T., Ong C., Albrecht A., et al., Climate change: linking adaptation and mitigation through agroforestry, 2007, J Mitig Adapt Strat Glob Change, 12:901–918.

[18] World Bank., World development report: Agriculture and development, 2008, World Bank, Washington.

[19] Neufeldt H., Dawson I.K., Luedeling E., Ajayi O.C., Beedy T., Gebrekirstos A., et al., Climate change vulnerability of agroforestry, 2012, ICRAF Working Paper No 143, World Agroforestry Center, Nairobi.

[20] Neupane R.P., Thapa G.B., Impact of Agroforestry Intervention on Soil Fertility and Farm Income under the Subsistence Farming System of the Middle hills, Nepal, 2001, Agriculture, Ecosystems and Environment, 84: 157–167.

[21] Mithoefer D., Waibel H., Income and labour productivity of collection and use of indigenous fruit tree products in Zimbabwe, 2003, Agroforestry Systems, 59: 295–305.

[22] Garrity D., Okono A., Grayson M., Parrott S., World agroforestry into the future, 2006, World Agroforestry Centre, Nairobi.

[23] Scherr S.J., Franzel S., Introduction. In Franzel S., Scherr S.J., (Eds.) Trees on the Farm: Assessing the Adoption Potential of Agroforestry Practices in Africa, 2002, CABI Publishing, New York.

[24] World Bank., Agriculture investments sourcebook: Module 5 - Agroforestry systems, 2005, World Bank, Washington.

[25] Dupraz C., Burgess P.J., Gavaland A., Graves A.R., Herzog F., Incoll L.D., et al., SAFE (Silvoarable Agroforestry for Europe) Synthesis report, 2005, SAFE project (August 2001–January 2005), http://www.ensam.inra.fr/safe/english/results/finalreport/SAFEpercent20Fourthpercent20Yearpercen-t20Annualpercent20Reportpercent20Volumepercent201.pdf,Accessed 23 July 2014.

[26] Neufeldt H., Wilkes A., Zomer R.J., Xu J., Nangole E., Munster C., et al Trees on farms: Tackling the triple challenges of mitigation, adaptation and food security, 2009, World Agroforestry Centre Policy Brief 07, World Agroforestry Centre, Nairobi.

[27] Ma X., Xu J.C., Luo Y., Aggrawal S.P., Li J.T., Response of hydrological processes to land-cover and climate changes in Kejie watershed, south-west China, 2009, Hydrological Processes, 23: 1179-1191.

[28] Turner B. L., Kasperson R.E., Matson P.A., McCarthy J.J., Corell R.W., Christensen L., et al., A framework for vulnerability analysis in sustainability science, 2013, PNAS, 100(14): 8074–8079

[29] Birkmann J., Risk and vulnerability indicators at different scales: Applicability, usefulness and policy implications, 2007, Environmental Hazards, 7, 20-31.

[30] WMD., Uttarakhand state perspective and strategic plan: 2009-2027, 2008, Report, Watershed Management Directorate (WMD), Dehradun. dolr.nic.in/dolr/downloads/spsp/SPSP_Uttarakhand.pdf. (Assesd on 20th August, 2014).

[31] MSME., Brief Industrial Profile of District: Tehri Garhwal. Micro, Small & Medium Enterprises-Development Institute, 2012, Nainital, Uttrakhand (http://dcmsme.gov.in/dips/

DIPSRpercent20-percent20 TEHRI.pdf Assesd on 20th August, 2014)
[32] Census of India., 2011, http\www.censusindia.gov.in
[33] Sharma C.M., Gairola S., Ghildiyal S. K., Suyal, S., Forest Resource Use Patterns in Relation to Socioeconomic Status. Mountain Research and Development, 2009, 29(4):308-319.
[34] Patt A.G., Schroter D., de la Vega-Leinert A.C., Klein R.J.T., Vulnerability research and assessment to support adaptation and mitigation: Common themes from the diversity of approaches. In: Patt A.G., Schroter D., de la Vega-Leinert A.C., Klein R.J.T., (Eds.), 2008, Environmental Vulnerability Assessment. Earthscan, London.
[35] Hinkel J., Indicators of vulnerability and adaptive capacity: towards a clarification of the science-policy interface, 2011, Global Environmental Change, 21(1): 198-208.
[36] McCarthy J. J., Canziani O. F., Leary N. A., Dokken D. J.,White K. S., Climate Change: Impacts, Adaptation and Vulnerability, 2001, Cambridge University Press, Cambridge.
[37] Fussel H., Klein R.J.T., Climate change vulnerability assessments: An evolution of conceptual thinking, 2006, Climatic Change, 75: 301–329.
[38] Metzger M.J., Leemans R., Schroter D., A multidisciplinary multi-scale framework for assessing vulnerabilities to global change, 2005, International Journal of Applied Earth Observation and Geoinformation, 7: 253-267.
[39] Glick P., Stein B.A., Edelson N.A. (Ed)., Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. National Wildlife Federation, 2011, Washington.
[40] Aretano R., Teodoro S., Petrosillo I., De Marco A., Pasimeni M. R., Zurlini G., Mapping ecological vulnerability to fire for effective conservation management of natural protected areas, 2015, Ecological Modelling, (295)163–175.
[41] Gallopín G.C., Linkages between vulnerability, resilience, and adaptive capacity, 2006, Global Environmental Change 16 (3), 293–303. http://dx.doi.org/10.1016/j.gloenvcha.2006.02.004.
[42] Callo-Concha D., Ewert F., Using the Concepts of Resilience, Vulnerability and Adaptability for the Assessment and Analysis of Agricultural Systems, 2014, Change and Adaptation in Socio-Ecological Systems, Vol.1, 1-11.
[43] Smit B., Pilifosova O., Adaptation to climate change in the context of sustainable development and equity. In: McCarthy J., Canziani O F., Leary N F., Dokken D J., White K S., (Eds) Climate Change Impacts, adaptation and vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, 2001, Cambridge University Press, Cambridge. pp 876–912.
[44] Pandey R., and Jha S.K., Climate vulnerability index - measure of climate change vulnerability to communities: a case of rural Lower Himalaya, India, 2012, Mitigation and Adaptation Strategies for Global Change, 17(6): 487-506.
[46] Hahn M.B., Riederer A.M., Foster S.O., The livelihood vulnerability index: a pragmatic approach to assessing risks from climate variability and change - a case study in Mozambique, 2009, Global Environmental Chang, 19(1):74–88.
[45] Pandey R., Kala S., Pandey V. P., Assessing climate change vulnerability of water at household level, 2014, Mitig Adapt Strategy Glob Change; DOI 10.1007/s11027-014-9556-5.
[47] Urothody A. A., Larsen H.O., Measuring climate change vulnerability: a comparison of two indexes, 2010, Banko Jankari, 20(1):9–16.
[48] Tripathi A., Farmers' Vulnerability to Climate Change in Uttar Pradesh, India: Measurement and Correlates, 2014, IEG, New Delhi.
[49] Li C., Li S., Feldman M.W., Daily G.C., Li J., Does out-migration reshape rural households' livelihood capitals in the source communities? Recent evidence from western China, 2012, Asian and Pacific Migration Journal, 21(1), 1-30.
[50] Davies R.A.G., Midgley S.J.E., Risk and Vulnerability Mapping in Southern Africa: A Hotspots Analysis, 2010, One World Sustainable Investments Ltd., Cape Town.
[51] Duerden F., Translating climate change impact at community level, 2004, Arctic, 57: 2004-212.
[52] Vedwan N., Rhoades R. E., Climate change in western Himalayas of India: a study of local perception and response, 2001, Climate Research, 19:109-117.
[53] Salick J., Ross N., Traditional people and climate change, 2009, Global Environmental Change, 19:137-139.
[54] Sharma E., Chettri N., Tse-ring K., Shrestha A.B., Jing F., Mool P., Climate change impact and vulnerability in the eastern Himalayas, 2009, ICIMOD, Kathmandu.
[55] Reidlinger D., Berkes F.,. Contribution of traditional knowledge to understanding climate change in the Canadian Arctic, 2001, Polar records, 37: 315. (doi :10.1017/ S003224740017058)
[56] Chaudhary P., Bawa K.S., Local perceptions of climate change validated by scientific evidence in the Himalayas, 2011, Biology Letters, 7:767-770.
[57] Gregory P.J., Ingram J.S.I., Global change and food and forest production: future scientific challenges, 2000, Agric. Ecosyst. Environ, 82: 3–14.
[58] Slingo J.M., Challinor A.J., Hoskins B.J., Wheeler T.R., Introduction: Food crop in a changing climate 2005, Philos. Trans. R. Soc. B, 360: 1983–1989.
[59] Singh S.V., Pandey D.N., Multifunctional Agroforestry Systems in India: Science-Based Policy options. Climate change and CDM Cell Rajasthan State Pollution Controll Board, p.35, 2011.
[60] Charles, R.L., Munishi, P.K.T., Nzunda, E.F., Agroforestry as Adaptation Strategy under Climate Change in Mwanga District, Kilimanjaro, Tanzania, 2013, International Journal of Environmental Protection, 3(11):29-38.
[61] Thorlakson T., Reducing subsistence farmers` vulnerability to climate change: the potential contributions of agroforestry in western Kenya, Occasional Paper Nairobi: World Agroforestry Centre, 16. p. 76, 2011.
[62] Ajayi O.G., Akinnifesi F.F., Sileshi G., Chakeredza S., Mn'gomba S., Nyoka I., *et al.*, Local solution to global problems: the potential of Agroforestry for climate change adaptation and mitigation in South Africa. Lilongwe, Malawi, 2008.
[63] Ong C.K., Anyango S., Muthuri C.W., Black, C.R., Water use and water productivity of agroforestry systems in the semi-arid tropics, 2007, Ann. Arid Zone, 46: 255–284.
[64] Smit B., Wandel J., Adaptation, Adaptive capacity and vulnerability, 2006, Global Environmental Change, 16: 282-292.
[65] de Souza H.N., de Graaf J., Pulleman M.M., Strategies and economics of farming systems with coffee in the Atlantic Rainforest Biome, 2011, Agroforestry systems., 84 (11): 227-242.

[66] Garrity D.P., Agroforestry and the achievement of the Millennium Development Goals, 2004, Agroforestry systems, 61:5-19.
[67] Walker B., Holling C.S., Carpenter S.R., Kinzig A.P., Resilience, adaptability and transformability in social – ecological systems, 2004, Ecol. Soc. 9 (2), 5. http:// www.ecologyand-society.org/vol9/iss2/art5/.
[68] Lott J.E., Ong C.K., Black C.R., Understorey microclimate and crop performance in a Grevillea robusta-based agroforestry system in semi-arid Kenya, 2009, Agricultural and Forest Meteorology, 149: 1140–1151.
[69] National Agroforestry Policy., 2014, http\\www.agricoop.nic.in
[70] Van Noordwijk M., Hoang M.H., Neufeldt H., Oborn I., Yatich T., (Eds.) . How trees and people can co-adapt to climate change: reducing vulnerability through multifunctional agroforestry landscapes. World Agroforestry Centre, 2011, Nairobi.