Impact of Climate Change in Eastern Madhya Pradesh, India

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Research Article

Impact of Climate Change in Eastern Madhya Pradesh, India

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Abstract
This paper reports case studies in eastern Madhya Pradesh – a central Indian province – on community adaptation strategies for sustainable livelihood options. With about 90% of the region being rain-fed, erratic rainfalls in the last fifteen years have caused up to a 60% decrease in crop yields, directly impacting the food security of the region. The System of Rice Intensification (SRI) and horticultural expansion are adaptation measures for tackling climate change. The expansion of kitchen gardens from subsistence-level to commercial-level is another significant development in the region. Meanwhile, increased pressure on common lands has caused fuelwood scarcity for households and decreased livestock fodder. While output of most non-timber forest products (NTFPs) has reduced drastically due to unsustainable extraction, production of mahua (*Madhuca indica*) has not suffered as much, thanks to a community-managed user regime. Community-based institutions have the potential to support the ecosystem-based livelihoods of forest-dependent communities.

Key Words: Climate change, livelihoods, adaptation, forest-dependent communities

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Introduction

India's economy grew by over 9 percent annually during 2003-04 to 2007-08, and by 8.6 percent during 2010-11 [1]. However, based on per capita total consumer expenditure, 28.3% of India's rural population remains below the poverty line [2]. This impoverished demographic is concentrated in the states of Bihar, Orissa, Uttar Pradesh, Jharkhand and Chhattisgarh [3]. These states are characterized by low literacy levels and strong dependence upon natural resources. Poverty is widely prevalent in tribal-dominated areas and among scheduled castes and scheduled tribes. These communities are often highly dependent on local natural resources such as forests, hence are far more vulnerable to the impacts of climate change than urbanised parts of the country [4, 5]. With carbon dioxide concentration doubling from pre-Industrial Revolution levels, India's climate could become warmer by 2.33 to 4.78°C during the twenty-first century [6]. A warmer climate would be accompanied by greater precipitation for India overall, but there would be considerable geographic variation in the magnitude of change for both temperature and rainfall [7].

While temperatures across all of India are expected to increase, some places may become wetter while others become drier [7]. India's climate change projection scenarios predict little change in monsoon rainfall until the 2050s [8], followed by a 15-40% increase in rainfall by the end of 21st century [9]. An increase in monsoon rainfall intensity was also suggested by recent research studies [10, 11]. However, contradictory results [12, 13] suggest substantial uncertainty in predictions of future annual precipitation in India.

Climate change can affect forests by causing shifts in vegetation types and altering the frequency, intensity, duration, and timing of fire, drought, insect and pathogen outbreaks [7, 14]. Changes in the climate and atmospheric carbon dioxide concentration also affect forest structure [15, 16] and species composition [17-19], as these conditions determine the ecological niches within which different organisms can thrive and the amount of primary productivity that can be sustained [20, 21] by the ecosystem. Climate change may alter the productivity of forests, causing a shift in resource management, adaptation, and ultimately forest production at both national and regional levels [22, 23]. Forests also play an important role in global hydrological cycles, affecting rainfall patterns and temperature regimes [24]. Hence, the alteration of forest function by climate change may have reinforcing feedback effects.

About 100 million people living in and around forests in India derive their livelihood from the collection and marketing of non-timber forest products (NTFPs) [25]. Changes in forestry could have profound implications for biodiversity, traditional livelihoods, industry, soil and water resources, and hence, agricultural productivity [26, 27]. Moreover, climate change-induced effects will aggravate existing stresses attributable to non-climate factors, such as land-use changes and unsustainable exploitation of natural resources [28].

Highly climate sensitive, Indian agriculture, 65 per cent of which is in rainfed areas, contributes nearly 25 per cent of Gross Domestic Product (GDP), employs 65 per cent of the total workforce, and accounts for 13.3 per cent of total exports together with allied activities (allied activities include tea, coffee, cereals, unmanufactured tobacco, spices, cashew nuts, oil meals, fruits & vegetables, marine products, and raw cotton) [29]. Indian agriculture is considered especially vulnerable to warming temperatures in the coming decades, though not necessarily uniformly across the country [30, 31]. Indian agronomic studies suggest that extensive warming could cause significant reductions in yields in the absence of adaptation and carbon fertilization [32]. If temperatures rise by 4^0C in India, grain yields (i.e., rice, wheat, coarse grains, and protein feed) could collectively fall by 25-40 percent [33], with rice yields declining by 15-25 percent, and wheat yields by 30-35 percent [34].

Studies suggest five ways to reduce the impact of climate change on agriculture: altering sowing period; switching to crops which are less sensitive to climate change; switching to new drought/heat resistant varieties; conversion from rain-fed to irrigated cultivation; and increasing the intensity of irrigation [35-38]. This paper focuses on (a) micro-level steps taken by tribal communities to tackle climate change; (b) small but significant success realized by tribals and the lessons learned thereby; and (c) the role of institutions in tackling the challenge of climate change.

The objective of this paper is to document the linkages between tribal livelihoods and climate-induced changes within the central Indian state of Madhya Pradesh. First, I briefly review recent rainfall data for central India, and then present an overview of the study area and tools employed for data collection. Major findings on agriculture, livestock, NTFPs, and alternate livelihoods are presented in the subsequent Results section. In the final section, I discuss the lessons drawn from these micro-level studies.

Observed Rainfall in Central India

The rainfall variability during the summer monsoon (June to September) in central India (74.5°E–86.5°E; 16.5°N–26.5°N) has changed significantly between 1950 and 2000 (Appendix Figure 1). The frequency of days with heavy rainfall (i.e., at least 100 mm/day) increased from 45 to 65 days per year, while the frequency of extreme rainfall events (at least 150 mm rainfall/day) has doubled from 9 to 18 days per year during this period. In contrast, the frequency of days with moderate rainfall (i.e., between 5 and 100 mm/day) has decreased. Thus, the spread of rainfall over the years during this time frame has increased.

Interannual variation in the monsoon cycle is determined by the relative contribution of multiple external and internal air-sea interactions and oscillations, with heavy or less rainfall traditionally resulting in floods or droughts, respectively [39 - 41]. However, an increased frequency of extreme events and erratic rainfall along with a decline in number of rainy days provide evidence that climate change is occurring [42].

Methods

Study Area

A large population of tribal communities resides in the central Indian state of Madhya Pradesh, which is endowed with rich natural resources such as seven river basins, the second highest production of mineral resources in India, and forest areas which cover 30.7% of the state, with a forest area per capita of 0.16 Ha (compared to a national average of 0.07 Ha) [43, 44]. However, abject poverty, primitive farming methods, Naxalism, and other challenges have caused this tribal belt to lag behind other Indian states in a number of social indicators. The Human Development Index of Madhya Pradesh has consistently ranked the state among the four worst in India over the past few years [45]. Appendix Table 2 reports the major education and health indicators of seven districts of Eastern Madhya Pradesh as an illustration of socioeconomic conditions in this part of country, along with percent forest cover in each district. This part of Madhya Pradesh is characterized by high forest cover, a tribal-dominated population, and large-scale poverty. This study focuses on Mandla, one of these seven districts.

The district of Mandla is located in the eastern part of the central Indian state of Madhya Pradesh (Fig. 1). The district has 49% forest cover (tropical moist deciduous forest), 26% of which is classified as “very dense forest”, 43% “moderately dense forest”, and 31% “open forest” [44]. The forest area is dominated by teak *(Tectona grandis)* and sal *(Shorea robusta)*, mixed with other species like haldu *(Adina cardifolla)* and aonla *(Emblica officilanis).* Some of the important NTFPs are *tendu* leaves *(Diospiros melonoxylon)*, *mahua* flowers *(Madhuca indica)* and *harra (Terminalia chebula).*

The district, one of the most underdeveloped in Madhya Pradesh, suffers from widespread, chronic poverty. Per government estimates, 57% of the total population of the district consists of scheduled tribes [49] while the state average is 20% [50]. Most of the tribals in India are victims of acute poverty and are living in the worst living conditions [51]. A number of studies highlight chronic poverty and living standards in different tribal groups of India [52-55].

The district is home to the Primitive Tribal Groups (PTGs) *Gond* and *Baiga* communities. A PTG is defined as a group of tribals who have the following three characteristics: pre-agricultural level of technology, extremely low level of literacy, and near stagnant or diminishing populations [56]. Seventy-five such tribes in India are categorized as PTGs and are accorded special government programs for their development.

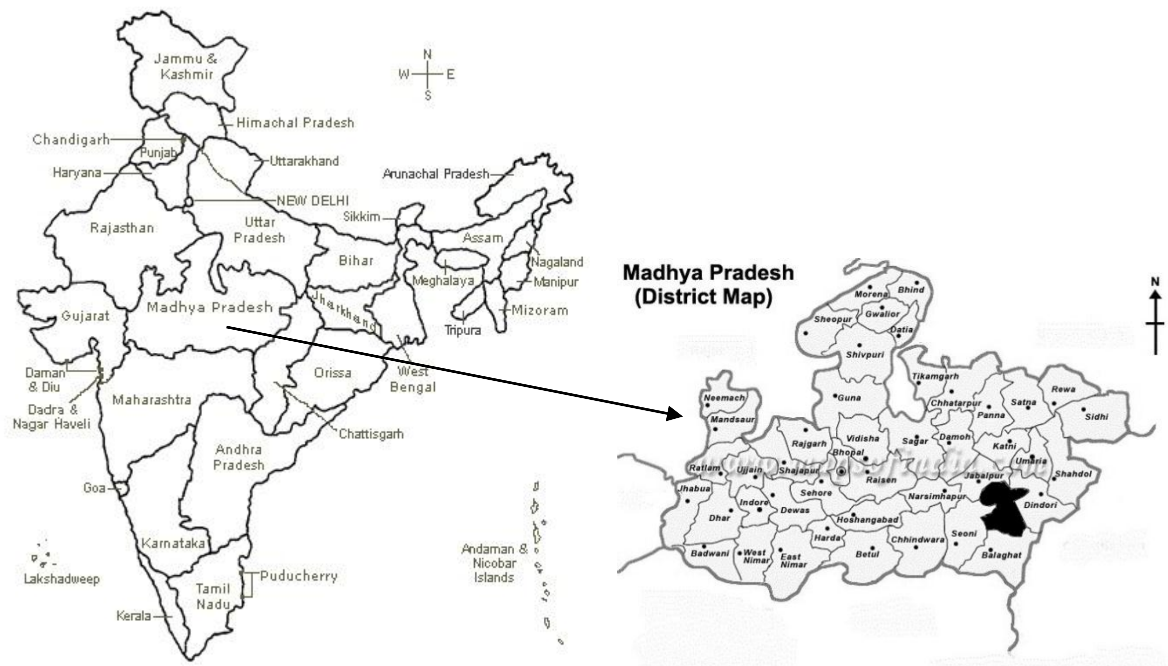


Fig. 1. Map showing study area (Mandla district in dark) [46]. Adapted from [47].

Tools

This study comprises a part of a larger research project that attempts to reconcile biodiversity conservation with local livelihoods in Mandla district. This study is based on various case studies documented through regular visits and meetings with a cross-section of local communities, participatory rural appraisal (PRA) exercises, and personal observation. Primary empirical data were collected using household questionnaires.

Participatory Rural Appraisals: In 1973, the government of India selected the Kanha Tiger Reserve (KTR) as one of the first nine protected areas (PAs) under "Project Tiger". KTR, located in Mandla and Balaghat districts, is a renowned PA harboring many endangered faunal species including the tiger *(Panthera tigris)*, Indian Gaur *(Bos gaurous)*, Indian Wild Dog *(Cuen alpinues)*, and vultures *(Gyps bengalensis, Gyps tenuirostris)*. KTR also has the distinction of harboring the last surviving population of hardground Barasingha *(Cervus duvauceli branderi)*. KTR is comprised of three areas, the National Park core zone (940 km^2), a buffer zone (1,009 km^2), and the satellite Phen Wildlife Sanctuary (110 km^2). One hundred sixty one villages are located in the buffer zone of the Tiger Reserve [57]. In June 2009, I conducted PRAs in seven of these villages: Indragram, Batwar, Sarhi, Taktua, Mocha, Chappri, and Khatiya. These villages, selected for convenience of sampling, are also located within four to five miles of each other.

This study employs a PRA technique known as "time trend," in which respondents provide an account of their past and discuss how matters close to them have changed over a period of time [58]. First, a list of NTFPs available in nearby forest areas was prepared by villagers. Next, to determine the change in availability of NTFPs over last 15 years, the participants were given 20 coins (the same denomination) representing the amount of NTFP available 15 years earlier. Then, the participants were asked to represent the amount of NTFP available 5 years ago and present availability by withdrawing or adding new coins. For example, if 20, five and two coins represented the amount of a particular NTFP available 15 years ago, five years ago and today, it was inferred that the availability of NTFP decreased from 100% to 25% and then to 10% during said period. This exercise was conducted with villagers more than 40 years of age, and engaged in NTFP collection for at least 30 days (with at least three hours of collection per day) per year. A typical group consisted of 10-12 participants. A total of 25 such exercises were conducted in all 25 hamlets of seven villages. The role of the author was limited to facilitating the discussion among group participants and documenting the results.

Focus group discussions (FGDs) also were conducted with villagers to determine recent impacts of heavy and low rainfall on agriculture, livestock and overall livelihoods in the region. FGDs were conducted in different groups based on gender, social background, and primary occupation.

A typical village has two to four hamlets, with about 25 to 50 households each. The author conducted PRAs in all hamlets of a village. One representative from every household of a hamlet that fulfilled abovementioned criteria (age, time devoted for NTFP collection) was invited to participate in PRA exercises. The exercises were conducted at a public space within the village. A typical FGD comprised 10 to 12 members and took about 45 minutes. In total, 25 FGDs were conducted in seven villages.

Semi-structured Interviews: A five-year demonstration vermicomposting program was launched in 2007 by a non-governmental organization (NGO), the Foundation for Ecological Security (FES), with 35 farmers in ten villages of Mandla district. I conducted a mid-term review of this program in 2009 to assess its impacts. The review was conducted with the farmers through a semi-structured interview addressing four themes: change in agricultural productivity, perceived change in soil quality, procedural problems faced while using vermicompost/ vermiculture, and financial loss or benefit through vermicomposting.

Household questionnaires: Household questionnaires were administered in 14 villages covering a total of 580 households to gather socio-economic data on family size, agriculture, livestock, sources of income and expenditures, and migration patterns[1]. Detailed questions on some of these issues were asked. For example, for agriculture, I assessed community perceptions towards indigenous versus modern agricultural practices, using a five-point Likert scale covering four areas: long-term financial benefits, water retention capacity of soil, production stability, and pest attacks. Data on change in perception level of soil fertility and fertilizer usage over ten years were collected only from farmers more than 40 years of age and actively engaged in agricultural activities for the past 15 years. Only selected and relevant household-level data, listed in Table 1, are presented in this paper.

Finally, during the course of this research, the author came across a unique case of vegetable cultivation in Gadia, a village situated on the banks of Matiyari Dam in Mandla. Gadia was not included among the villages surveyed because it falls off-cluster, i.e., is isolated from the others. Information about Gadia was collected through informal discussions with eight farmers only.

Results and discussion

In Mandla, agriculture is the primary economic activity undertaken by the community on a large scale. The major crops grown are rice, wheat, maize, mustard, minor millets, linseed, rapeseed, lentil, chick pea, red gram, and black gram. The net sown area in Mandla is 23%, less than half of the state average of 48% (Appendix Table 3). Average land holding per household in 2000-01 in Mandla was 1.8 ha [48]. Per capita gross cropped area in the district is 0.31 ha. Irrigation coverage in the district is poor, and a vast majority of the agricultural area is rain-fed, as only 8% of the net sown area is irrigated. Average fertilizer consumption per ha of gross cropped area is 16 kg/ha, far less than the state average of 55 kg/ha and the country average of 90 kg/ha. Per capita food grain production in the district is 172 kg, less than the state's average of 219 kg per capita.

Table 1. Data generated in this case study, method of collection and sample size (n).

Data	**Method**	**n**
Agricultural productivity of rice	Household questionnaires	150
Migration pattern	Household questionnaires	140
Attitudes of communities towards indigenous agriculture	Household questionnaires	440
Change in availability of NTFPs	Participatory rural appraisals (time trend)	25
Change in perceptions of soil fertility and fertilizer usage	Household questionnaires	95
Income from vermicomposting	Semi-structured interviews	35

[1] This study draws from several separate surveys, using only those surveys which are relevant to the discussion here. Though a total of 580 households were surveyed, not all households participated in all surveys. Sample sizes for specific surveys are listed in Table 1.

Even though critical factors like net sown area and irrigation facilities are far less than the state average, per capita production of the district is not much less than the state average. This is primarily due to a regional disparity in productivity within the district. The southwestern part of the district, *Haveli* and *Hirdenagar*, covering about one-fifth of total geographical area of district, practices agriculture on commercial scales. This region is endowed with favorable geophysical conditions (e.g., flat topography and black soil [59]) and sufficient water availability. Commercial agriculture uses modern irrigation facilities (e.g., canals) and high fertilizer dosage to enhance production levels. Meanwhile, most of the district lacks such opportunities, primarily due to chronic poverty, and practices traditional rain-fed agriculture. In the latter case, gross cropped area is high, but yield per hectare is far less than the former case. Note that the field data used in this study does not come from the resource-rich area.

The productivity of major crops of the district, primarily rice and wheat, is below the state average production per hectare (Appendix Table 4). At the district level, agricultural production is sufficient to meet subsistence needs, and a meager part of the produce, primarily rice, is sold in local markets. Data collected from 150 households suggest that only 16% of households surveyed actually sold any agricultural produce in the market (Table 2). In a study covering 113 households, Debnath [60] found an average annual income in three villages of Mandla of 138 USD, which comes mainly from agricultural output (52%) and wage work (27%).

Table 2. Agricultural Productivity of Rice (2004-05). Primary agricultural productivity data were collected from 150 households across seven villages of Mandla district. Among all seven villages, sixteen percent of farmers sell some portion of their rice yield.

Village	Average productivity (kg/ha)
Bhardwara Maal	760
Kusmi	585
Mawai Rayat	550
Mawai Maal	835
Mohgaon	410
Padarpani	785
Rousar	610
Mandla (district average)	680
Madhya Pradesh (state average)	818

Due to the lack of industrial development, especially at the small and medium scales, wage-labor opportunities are scarce in the region. Consequently, during the non-agricultural season (i.e., mid-January to April), males migrate to regional industrial hubs located 100-200 miles away from the home village to earn cash income for the family (Table 3). Females generally stay in the village to care for children and family elders, and work under government and non-government sponsored labor schemes to earn cash income. Males prefer not to work under these labor schemes primarily because these opportunities are not available throughout the year, the supply of labor exceeds demand, and the remuneration offered is less than one-third of the wages paid in industrial hubs.

Table 3. Key migration statistics in 2007. Primary data on short-term labor migration were collected from 140 households total, 20 households from each of seven villages of Mandla district (Indra gram, Batwar, Sarhi, Taktua, Mocha, Chappri, and Khatiya.)

Statistic	Value	Unit
People migrating for less than one month	2.3	number/household/year
People migrating for one to three months	1.6	number/household/year
People migrating for more than three months	0.8	number/household/year
Ratio of destination wage rate to home village wage rate	3.2	
Average distance of migration	150	miles

Agriculture and Rainfall

Climate change is likely to intensify the variability of weather patterns, leading to a rise in extreme seasonal aberrations, such as increased precipitation and devastating floods in some parts of India and reduced rainfall and prolonged droughts in other areas. The Climate Vulnerability Index (CVI), calculated from social, economic, agriculture, water resource, forest and climate indices, suggests that Mandla is among those districts most vulnerable to climate change [61].

Agricultural production in Mandla is strongly dependent upon the amount and distribution of rainfall in a year. The bulk of the rainfall (97%) over a year occurs from June to September, during the south-west monsoon (Appendix Table 5). Thus the intensity and distribution of rains during this period play a pivotal role in determining the success of water-intensive crops like rice.

Rainfall intensity and distribution have also varied substantially over the period under study. For example, in June 2007, the district received just 97 mm of rainfall while in the next year it received 602 mm rainfall during the same month (Appendix Table 5). June is a critical period for Indian agriculture, because the sowing of rice occurs during this time and the availability of water has direct implications on success or failure of agricultural crops. Even if a particular monsoon season receives average rainfall and may be considered a normal monsoon overall, the distribution of rainfall from June to September is nonetheless important to agricultural output.

Since 2005, the farming community within the Mandla region has been gradually adopting organic farming under the System of Rice Intensification (SRI) method for rice cultivation. SRI, developed in the 1980s and 1990s in Madagascar, enhances the yields of rice (*Oryza sativa* L.) through synergy among several agronomic management practices [62]. The main components of SRI include transplanting of young seedlings at wide spacing (about 10 inches), water management that keeps the soil moist but not continuously flooded, weeding before canopy closure, and reliance on organic compost. SRI advocates suggest that synergies among these unconventional management practices unlock the physiological potential of rice [63]. These modifications to seed preparation and sowing decrease input costs and increase production.

SRI can be considered a tool for local adaptation to climate change. Both the seed required for sowing and water required for irrigation are reduced by 80-90%, while production increases about two-fold. Stronger root systems help the plants to withstand drought and winds. Additionally, since SRI uses home-made organic manure, water retention capacity of the soil increases significantly [64-67]. Professional Assistance for Development Action (PRADAN), a national-level NGO working on livelihoods programs in the region (Balaghat, Dindori and Mandla districts), promotes SRI among farmers through demonstrations and training. In 2009, it reported a two-fold increase in rice productivity from 1.7 tonnes/ ha to 3.8 tonnes/ ha while working with 111 farmers in Mandla [68].

SRI addresses food-security needs of the region through higher productivity and more efficient utilization of water resources, which can be put to use in other agricultural and livestock systems. At the district level, the area under SRI cultivation in the region increased from 35 ha to 791 ha between 2005 and 2009 [69]. The results of the socio-economic survey described below (Table 4) show that farmers prefer indigenous over modern agricultural methods. SRI involves locally available inputs like seeds and organic manure and little enhancement to indigenous methods of farming, such as seed treatment and agricultural field preparation. Hence, SRI is more accessible to poor farmers than input-dependent technologies that require greater capital and logistical support [70]. Despite all these positive results, outreach of SRI is limited primarily by lack of awareness (e.g., from low literacy levels) and deep-rooted faith in traditional agricultural practices.

No investigation of the GHG emissions from SRI has been done. However, because rice plots are not flooded under SRI, this method of rice cultivation is expected to reduce methane emissions from flooded rice fields [71-74]. Other studies have reported that manure has approximately one-fifth as much impact on climate change as synthetic nitrogen fertilizers [75]. Since SRI uses organic fertilizers, the decreased input of nitrogen fertilizers potentially reduces nitrous oxide emissions, though further investigation is necessary [76].

Table 4. Perception of communities in Mandla towards indigenous agriculture. Composite score of "community attitude towards indigenous agriculture versus modernized agriculture" calculated from four items (long-term financial benefits, water retention capacity of soil, production stability, and pest attacks), with a maximum possible score of 20. A higher score suggests greater favorability towards indigenous agriculture.

Village	Number of households interviewed	Composite score
Katang Seoni	171	16
Padarpani	67	15
Bhardwara Rayat	32	17
Mawai Maal	66	16
Bhardwara Maal	27	17
Mawai Rayat	77	18

Livestock dependency

Livestock are an important component of agricultural output across most of rural India. Livestock provide high-value, protein-rich animal products, provide draught power and manure, and act as an investment that can be sold for cash when needed. The impact of climate change on livestock is a matter of serious concern, as the majority of livestock in India is in the hands of resource-poor households [77]. An increase in temperature would negatively impact growth, reproduction and production of livestock, impacting the livelihoods of those who depend upon it [78].

Oxen, cows, buffalos, pigs, goats and hens are the major types of livestock reared in the region. Most of the livestock in Mandla are indigenous varieties. Hybrid or cross-bred varieties are generally not preferred, primarily due to greater water and fodder requirements. Currently, feed and fodder shortages are amongst the main problems faced by the communities in Mandla. A significant part of feed is obtained through the husk derived from rice grown in agricultural fields. The remaining fodder requirement is met through open grazing, generally on forest lands. Over the years, this has resulted in extensive pressure on an already depleted forest resource base, limiting animals' access to both quantity and quality of fodder species.

Since 2005, communities have taken steps towards the development of common lands by growing species to augment fodder and fuelwood supplies, which were becoming increasingly scarce in village common lands, including forests. This was possible through technical help from the Madhya Pradesh Forest Department and community mobilization through NGOs like Action for Social Advancement, Foundation for Ecological Security, and World Wide Fund for Nature - India. In one case, in the village of Luhari, locals revegetated a small hillock of 12 ha to meet fuelwood and livestock fodder requirements expected for coming years. Recognizing the problem of fuelwood and fodder scarcity, villagers themselves formulated rules and put into place an institutional mechanism to protect the revegated hillock from overgrazing. Such issues, when discussed at the appropriate village-level forums, resulted in the formulation of rules regulating the use of common property resources (CPRs). The community has recognized the importance of CPRs to their livelihoods, as well as the changes observed over time in availability of CPRs like tree species and water.

NTFP Dependence

NTFPs form a significant part of the annual income of a typical tribal household of central India. On average, NTFPs contribute about 30% of the total cash income per year of a household [79]. *Mahua (Madhuca indica)* is an important NTFP, the flowers of which are either distilled and consumed as liquor, or dried and eaten, sometimes with corn-flour, in periods of extreme drought. Other important NTFPs in Mandla include *Anogeissus latifolia* (used for construction material and animal fodder)*, Terminalia bellirica* (fruit used in curing bronchitis and asthma, and used along with *Phyllanthus emblica* and *Terminalia chebula* to prepare a herbal combination), *Emblica officinalis* (Indian gooseberry, rich source of Vitamin C, oil used as hair-restorer). Results from the PRA with villagers suggest that, over the past few years, unsustainable harvesting of these and other commercially valuable NTFPs has resulted in a sharp decline in their availability (Table 5).

Table 5. Non-timber forest products (NTFPs), uses, and observed change in availability over 15 years. Data were obtained from participatory rural appraisals (time trend) conducted in seven villages of Mandla district (Indra gram, Batwar, Sarhi, Taktua, Mocha, Chappri, Khatiya) in 2010. Availability is presented in terms of percentage of the baseline availability in 1995.

			Availability (%)		
Scientific name (family)	**Local name**	**Uses**	**1995**	**2005**	**2010**
Anogeissus latifolia (Combretaceae)#	dhawara	construction, gum extract, medicine (skin diseases) , animal fodder	100	50	10
Buchanania lanzan (Anacardiaceae)#	chironji	food	100	80	50
Chlorophytum tuberosum (Liliaceae)*	safed musli	medicine	100	50	10
Cassia tora (Cesalpinaceae)	chakora, charonta	medicine (snake bite), food	100	70	40
Celastrus paniculatus (Celastraceae)*	malkangni	medicine (headache)	100	50	10
Curculigo orchioides (Amaryllidaceae)*	kali musli	medicine (jaundice, asthma)	100	80	75
Diospyros melanoxylon (Ebenaceae)	tendu	local cigarette, medicine (snake bite), edible fruit	100	80	70
Emblica officinalis (Euphorbiaceae)	aonia	edible fruit	100	40	10
Madhuca indica (Sapotaceae)	mahua	liquor, oil, food	100	90	75
Schleichera oleosa (Sapindaceae)	kusum	medicine (arthritis), edible fruit, oil	100	75	50
Terminalia bellerica (Combretaceae)	bahera	medicine (bronchitis, asthma), food	100	50	25
Terminalia chebula (Combretaceae)	harra	medicine (cough)	100	50	25

* Similar results were found in Mishra [80] in Mandla and in # Kala [81], Central India.

A complex combination of economic and other factors affect the rate of NTFP extraction. Studies elsewhere in India [82-83] and other countries [84] suggest that the rate of extraction of NTFPs is linked to the degree of agricultural stress. For example, when low agricultural productivity occurs in a drought year, tribals in Mandla tend to extract and sell more NTFPs to meet the food security needs of their households. Since NTFPs have a ready and accessible local market, income from NTFPs helps compensate for lean harvests. Moreover, the typical flowering season of many of the major NTFPs coincides with the agricultural post-harvest period in March. Consequently, not only do tribals have sufficient time to go to forest areas to extract NTFPs, but they can also determine the level of extraction based on the results of the agricultural harvest.

According to the PRAs conducted within the seven villages of Mandla, since 2005 the tribal communities have observed a significant change in the phenology of local *mahua*: a gradual shift in fruiting and flowering period from mid-March to mid-February. The shift in the flowering season of *mahua* reflects a discernible change in the local forest ecology. During mid-February, the agricultural season is about to end and farmers are preoccupied with harvesting their produce. Early onset of *mahua* flowering during the harvest period leaves less time for the community to collect this NTFP. Such situations have a direct implication for the food security of the region. As the availability of major NTFPs diminishes (Table 5), the number of livelihood alternatives for meeting subsistence needs decreases.

At the same time, note that the harvest of *mahua* has fallen less than that of other NTFPs over the years (Table 5). This is due to the user regime of *mahua,* which has been in place for many generations. Traditionally, the rights to harvest the fruit and flowers of each *mahua* tree have been assigned to households in the village. This tenure mechanism has resulted in sustainable collection from this species, though the shifting of its flowering season has seriously impacted the livelihoods of tribals. The 25% decrease in availability shown in Table 5 is due primarily to the shift in flowering season rather than to unsustainable harvesting practices. In contrast, villagers revealed in their time trends that other NTFPs were harvested at a large scale to fulfill demands of contractors and earn "easy cash." Thus, except *mahua*, all other NTFPs listed in Table 5 were likely harvested through unsustainable practices, resulting in decreased availability over the years.

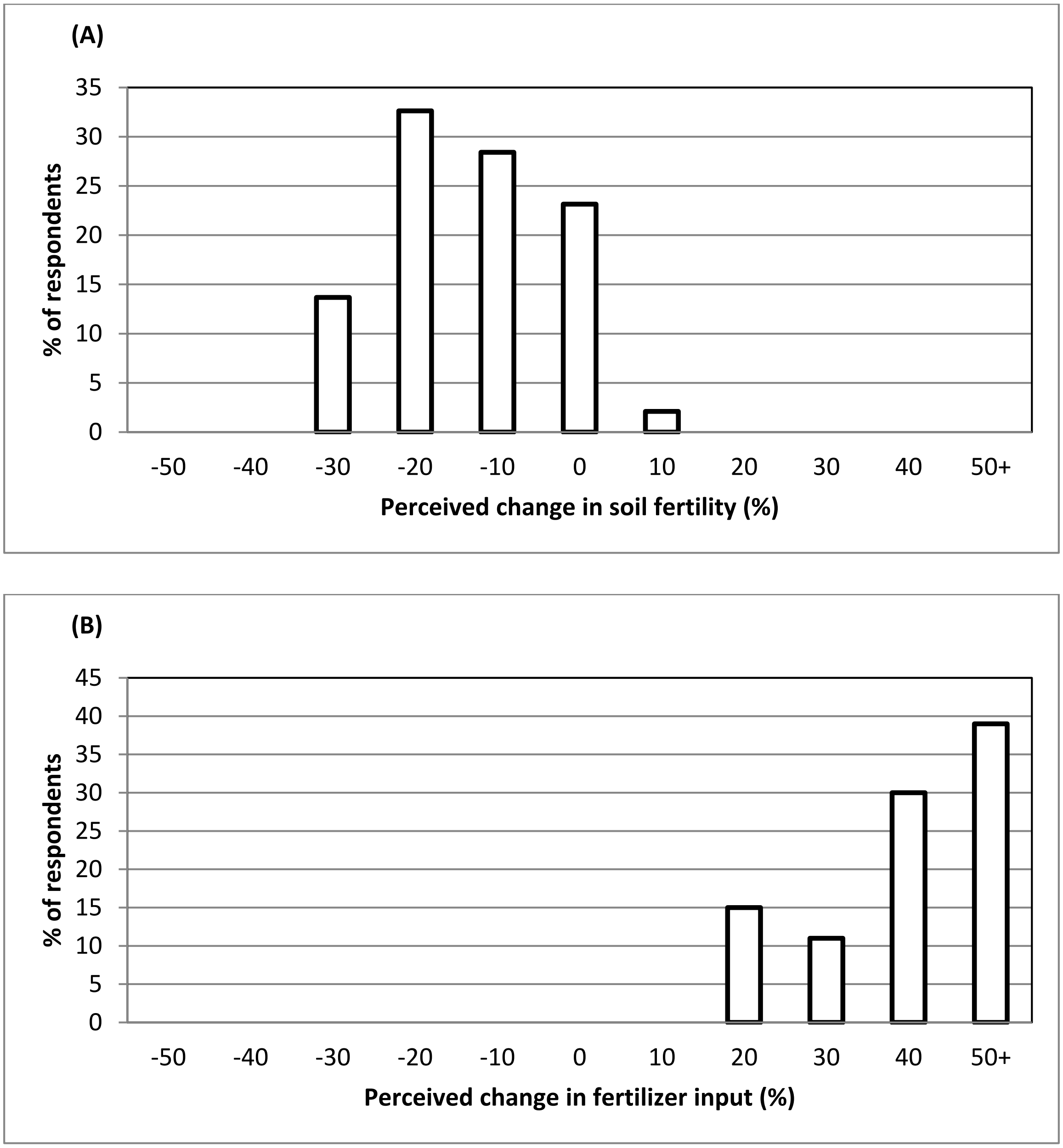
Alternate livelihood options

Due to decreasing agricultural productivity, a tribal family needs additional sources of income to ensure the food security of the household. The tribal communities in the study area have developed alternate livelihood options to cope with changing climatic conditions.

The household surveys reveal that three-fourths of farmers perceived that soil fertility, based on their agriculture experiences, had degraded over the last ten years (Figure 2). Presently, one cannot conclude whether climate change has directly affected the soil fertility of the region or not, as the effects of warming on soil composition have been poorly studied [85]. Correspondingly, fertilizer consumption over the past ten years has increased by more than 50% for more than 40% respondents surveyed (Figure 2).

Due to the combination of decreased soil fertility, the consequent increase in expensive fertilizer use, erratic rainfall patterns, and the lack of irrigation facilities, the farming communities needed new low-cost land productivity enhancement techniques. One of the options exercised in the region is organic farming through vermicomposting. The communities are gradually adopting organic farming to enhance land productivity, improve edaphic quality, and earn cash income through the sale of vermiculture and vermicompost. Local purchasers of vermiculture and vermicompost often anticipate adopting this form of farming and want to see results from vermicompost before setting up their own composting operations.

Fig. 2. Distribution of perceived changes in (A) soil fertility and (B) artificial fertilizer input compared to ten years prior. Primary data collected from 95 households from five villages (Katang Seoni, Padarpani, Bhardwara Maal, Bhardwara Rayat and Mawai Maal) of Mandla district. Results in B) exclude organic farmers.



Results from the midterm review of the vermicomposting program in 2009 revealed that out of 35 farmers, the majority of farmers were practicing vermicomposting for self-consumption (Table 6). However, fourteen farmers were actively selling vermicompost and vermiculture to fellow farmers living within the same or neighboring villages. One of these farmers, practicing vermicomposting at a large scale due to resource availability (e.g., land, water and initial investment), realized an income of 275 USD in a six month cycle. Since such initiatives are only two years old, the change in edaphic quality has not yet been measured empirically. However, the farmers claim that the moisture retention capacity of the soil has increased moderately since adoption of vermicompost.

Table 6: Distribution of income from vermicomposting. Primary data were collected from semi-structured interviews with 35 farmers in Mandla district.

Income realized in last six months (USD)	No. of farmers
No Income	21
20	8
40	3
50	2
275	1

Horticulture is another option for tribal communities to adapt to changing climatic conditions and tackle to increased climate-induced risk to traditional income-generating activities. Horticulture development is a long-term investment, as well as an expansion and diversification of the “livelihoods basket” of a tribal family to cope with fluctuating agricultural and livestock productivity. Tribals have traditionally grown fruit-bearing trees in the backyards of their households to meet household-level needs. However, due to central government schemes (e.g., National Horticulture Mission, *Nandan Phalodyan*) and community receptiveness towards block plantations of horticulture tree species, the region has witnessed a gradual shift towards commercial production in the past five years. Note that if practiced on too small a commercial scale, horticulture requires significant effort and can be a risky proposition due to its significant vulnerability to water scarcity.

During the summer season, when the water available to households is most scarce, devoting water towards horticulture is far more difficult and critical. To cope, farmers have used innovative methods to ensure water availability for horticulture. For example, discarded hospital saline bottles were modified to act as drip irrigation to increase the efficiency of water usage and ensure an uninterrupted supply with minimal loss during the first three years of plantation. After three years, the root systems of the plants develop sufficiently to reduce significantly their mortality rate. Another low-cost method to ensure moisture availability for horticultural trees, especially during the initial three years of plantation, has been the placement of small-sized rocks near the plant, within a half-meter radius. The rocks assist in moisture retention by reducing evaporation from porous soils, even during the water-scarce summer, which helps the young plant to survive.

Along with horticulture, commercial vegetable cultivation has been increasingly used to ensure an adequate food supply for the household. Traditionally grown in home gardens, vegetables have an established market, and yield more income with lower inputs in a relatively shorter time frame compared to grain crops like rice and wheat. Such benefits, along with financial subsidies from the state agriculture department and technical support from NGOs mentioned earlier, have motivated the farming community to take up vegetable production, starting by initially cultivating less than half a hectare per farmer. However, water remains a critical factor in vegetable cultivation because of their relatively high sensitivity to water stress compared to rice and wheat. Thus, a limited set of farmers who have access to sources of irrigation such as canals and tube wells, or have informal arrangements with owners of private wells, have been able to cultivate vegetables. For this reason, scalability of the area under vegetable cultivation beyond half a hectare per farmer has not been possible despite strong interest among farmers in the region[2].

The case study of Gadia village further illustrates the challenges of establishing alternative sources of livelihood. All 47 families of this village were relocated here in the late 1980s due to the submergence of their traditional land by the state government for dam construction. All families belong to the *Baiga* primitive tribal group. In 2008, a group of eight villagers began vegetable cultivation on a patch of submerged land of Matiyari dam's reservoir, 0.75 miles away from the village boundary. During the summer season, the reservoir water level decreases significantly, allowing vegetable cultivation on a patch with soil quality far superior to the agricultural fields of the village. Water availability for irrigation was not an issue given the close proximity to the reservoir. The farmers pledged to use only organic manure as usage of fertilizers could potentially harm the fish in the reservoir, another important livelihood option for fishermen belonging to this and neighboring villages. Vegetable cultivation was timed for April harvest, the peak time for vegetable prices, in order to maximize profits. Thus, an alternate livelihood option was added to the portfolio of this tribal group by utilizing an unused piece of land.

In their interviews, the eight-member group reported earning USD 320 by selling the produce in the local market and consumed vegetables worth USD 160 over a period of six months. These villagers were so enthusiastic about the returns from vegetable cultivation that they decided to undertake it again the next year. In 2009, the group prepared the same area for vegetable cultivation. However, soon after the seeds were sown, unexpected autumn rains destroyed the crop. This heavy rainfall was entirely unexpected based on recent historical experience: note that 118 mm of precipitation fell in November 2009, whereas nearly no rainfall had occurred during this time of year since at least 2004 (Appendix Table 5). This case clearly highlights that some adaptation strategies in a predominantly rain-fed agricultural region are acutely vulnerable to unpredictable climatic fluctuations. Though adapting to climate change will require diversification of local livelihood portfolios, selecting alternative livelihood options less vulnerable to changing climatic conditions would enhance their probability of success and long-term sustainability.

[2] Spacing between horticultural trees is between 3-5 meters, whereas with vegetables it is as little as 0.22 meters. Moreover, a plot of horticultural trees may have 25-40 trees, while vegetable plants number in hundreds within a small plot of land. Thus, the tight spacing and sheer number of plants preclude the replication of water-saving methods from horticulture to vegetable cultivation.

Conclusions and implications for conservation

The cases described above highlight climate-induced changes experienced by agricultural tribal communities in Central India. With only 8% of cultivation areas irrigated in Mandla, rainfall and temperature variations have a significant effect on agricultural productivity. Where agriculture is practiced using traditional (i.e., non-mechanized) methods to meet subsistence needs, the role of rainfall patterns becomes more critical. Due to poverty and heavy traditional dependence on cultivation and harvest of natural resources, tribal communities often find it difficult to adopt non-farm activities. Indigenous and locally available agricultural resources and practices have a higher probability of acceptance by tribals. Livestock provides crucial agriculture support, although sustaining livestock has gradually become a challenge due to limited water and fodder availability.

Due to the great proportion of total geographical area under forests, the role of forests in tribal livelihoods cannot be ignored. However, the yield of major NTFPs has decreased substantially during the past two decades, primarily due to increased rates of extraction linked to increased agricultural stress. To cope with these changes in traditional livelihood systems, tribals have explored alternate livelihood options like horticulture and vegetable cultivation. These alternate livelihood options were practiced on a small-scale experimental basis with mixed results. These findings suggest that: (a) critical inter-linkages exist between forest, agriculture and water resources; (b) short, medium and long term planning are necessary; and (c) strategies for adapting to climate change must incorporate complex inter-relationships among different natural resource components.

In India, community-based natural resource management (CBNRM) has historically resulted in mixed outcomes for all the stakeholders involved. There are numerous examples documenting both the success and failure of institutional attempts at CBNRM [86-94]. However, we cannot ignore the need for stronger democratic institutions for supporting community resilience to the livelihood impacts of climate change. I do not propose that village-based institutions are the sole solution for tackling climate change in tribal dominated areas or elsewhere. Nevertheless, institutions, such as village meetings, offer an open and democratic platform for discussing common issues arising out of climate change.

This paper raises serious questions about the future management of natural resources, especially water and forests, in central India. Although the tribal community of the region has taken a few steps to cope with changing climatic conditions, most of these steps have been at the local level and have primarily focused on diversifying livelihoods. Moreover, in spite of these small improvements, all major components of tribal livelihoods (agriculture, livestock, NTFPs) will continue to be directly dependent upon water and forest resources for the foreseeable future. Thus, biodiversity conservation, to the extent that it impacts forest health and water availability, is of prime importance for local resilience to climate change. Like the adaptation strategies described above, government agencies and local NGOs, acting with local community participation, can play a strategic role in initiating conservation measures.

It is beyond the scope of this paper to document the loss of floral and faunal species in the region over the past few decades. However, a study of species' habitat loss could provide an improved understanding of complex inter-relationships among different natural resource components.

Presently, the future of tribal communities is difficult to predict - whether traditional livelihood systems will succeed or the role of alternate livelihood options will gain more importance; whether farm-based alternate livelihood options will gradually mature and contribute significantly in tribals' "livelihood basket", or non-farm based livelihood options will emerge. Regardless, climate change surely will critically impact food security, forest structure and function, and human welfare for these subsistence communities.

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References
[1] Government of India. 2010. *Annual Economic Survey 2010-10.* Government of India, New Delhi.

[2] Planning Commission of India. 2009. *Report of the expert group to review the methodology for estimation of poverty.* Planning Commission, New Delhi.

[3] United Nations Development Programme. 2008. *Human Development Report, Meghalaya.* Oxford University Press, New Delhi.

[4] Bhattacharya, P. and Prasad, R. 2009. Initial Observation on Impact of Changing Climate on NTFP Resources and Livelihood Opportunities in Sheopur District of Madhya Pradesh (Central India). A Paper presented at XIII World Forestry Congress, Buenos Aires. Argentina, October 18 – 23.

[5] Thomas, D. S. G. and Twyman, C. 2005. Equity and justice in climate change adaptation amongst natural-resource-dependent societies. *Global Environmental Change* 15:115-124.

[6] Lonergan, S. 1998. Climate Warming and India. In: *Measuring the Impact of Climate Change on Indian Agriculture*. Dinar, A., Mendelsohn, R., Evenson, R., Parikh, J., Sanghi, A., Kumar, K. Mckinsey, J., Lonergan, S. (Eds), pp.33-68. World Bank, Washington, DC.

[7] Ravindranath, N. H., Joshi, N. V., Sukumar, R. and Saxena, A. 2006. Impact of Climate Change on Forest in India. *Current Science* 90:354-361.

[8] NATCOM. 2008. *India's Second National Communication to the United Nations Framework Convention on Climate Change.* Ministry of Environment and Forests, Government of India, New Delhi.

[9] NATCOM. 2004. *India's initial national communication to the United Nations Framework Convention on Climate Change.* Ministry of Environment and Forests, Government of India, New Delhi.

[10] Rajendran, K. and Kitoh, A. 2008. Indian summer monsoon in future climate projection by a super high-resolution global model. *Current Science* 95:1560–1569.

[11] Sabade, S. S., Kulkarni, A., Kripalani, R. H. 2011. Projected changes in South Asian summer monsoon by multi-model global warming experiments. *Theoretical and Applied Climatology* 103:543–565.

[12] Moors, E. J., Groot, A., Biemans, H., van Scheltinga, C. T., Siderius, C., Stoffel, M., Huggel, C., Wiltshire, A., Mathison, C., Ridley, J., Jacob, D., Kumar, P., Bhadwal, S., Gosain, A. and Collins, D. N. 2011. Adaptation to changing water resources in the Ganges basin, northern India. *Environmental Science and Policy* 14:758–769.

[13] Pal, I., Al-Tabbaa, A., 2011. Assessing seasonal precipitation trends in India using parametric and non-parametric statistical techniques. *Theoretical and Applied Climatology* 103:1–11.

[14] Dale, V. H., Joyce, L. A., McNulty, S., Neilson, R. P., Ayres, M. P., Flannigan, M. D., Hanson, P. J., Irland, L. C., Lugo, A. E., Peterson, C. J., Simberloff, D., Swanson, F. J. Stocks, B. J. and Wotton, B. M. 2001. Climate Change and Forest Disturbances. *BioScience* 51:723–734.

[15] Dunbar, J., Eichorst, S. A., Gallegos-Graves, L. V., Silva, S., Xie, G., Hengartner, N. W., Evans, R. D., Hungate, B. A., Jackson, R. B., Megonigal, J. P., Schadt, C. W., Vilgalys, R., Zak, D. R. and Kuske, C. R. 2012. Common bacterial responses in six ecosystems exposed to 10 years of elevated atmospheric carbon dioxide. *Environmental Microbiology* 14:1145-1158.
[16] Jones, T. H., Thompson, L. J., Lawton, J. H., Bezemer, T. M., Bardgett, R. D., Blackburn, T. M., Bruce, K. D., Cannon, P. F., Hall, G. S., Hartley, S. E., Howson, G., Jones, C. G., Kampichler, C., Kandeler, E. and Ritchie, D. A. 1998. Impacts of Rising Atmospheric Carbon Dioxide on Model Terrestrial Ecosystems. *Science* 280:441-443.
[17] Berendse, F., Breemen, N. V., Rydin, H., Buttler, A., Heijmans, M., Hoosbeek, M. R., Lee, J. A., Mitchell, E., Saarinen, T., Vasander, H. and Wallén, B. 2001. Raised atmospheric CO_2 levels and increased N deposition cause shifts in plant species composition and production in Sphagnum bogs. *Global Change Biology* 7:591–598.
[18] Coviella, C. E. and Trumble, J. T. 1999. Effects of Elevated Atmospheric Carbon Dioxide on Insect-Plant Interactions. *Conservation Biology* 13:700–712.
[19] Manning, W. J. and Tiedemann, A. v. 1995. Climate change: Potential effects of increased atmospheric Carbon dioxide (CO_2), ozone (O_3), and ultraviolet-B (UV-B) radiation on plant diseases. *Environmental Pollution* 88:219–245.
[20] Dukes, J. S., Pontius, J., Orwig, D., Garnas, J. R., Rodgers, V. L., Brazee, N., Cooke, B., Theoharides, K. A., Stange, E. E., Harrington, R., Ehrenfeld, J., Gurevitch, J., Lerdau, K., Stinson, J., Wick, R. and Ayres, M. 2009. Response of insect pests, pathogens, and invasive plant species to climate change in the forests of northeastern North America: What can we predict? *Canadian Journal of Forest Research* 39:231-248.
[21] O'Connor, M. I. 2009. Warming strengthens an herbivore–plant interaction. *Ecology* 90:388–398.
[22] Mendelsohn, R., Dinar, A. and Williams, L. 2006. The distributional impact of climate change on rich and poor countries. *Environment and Development Economics* 11:159–178.
[23] Sohngen, B., Mendelsohn, R. and Sedjo, R. A. 2001. A Global Model of Climate Change Impacts on Timber Markets. *Journal of Agricultural and Resource Economics* 26:326-343.
[24] O'Brien, K. L. 1998. Tropical Deforestation and Climate Change: What Does the Record Reveal? *The Professional Geographer* 50:140-153.
[25] Saxena, N. C. 2003. *Livelihood Diversification and Non-Timber Forest Products in Orissa: Wider Lessons on the Scope for Policy Change?* ODI Working Paper No. 223, Overseas Development Institute, London, UK.
[26] Center for Excellence in Environmental Economics. n.d. *Impact of Climate Change on Economy.* http://coe.mse.ac.in/onerview/11.pdf.
[27] Semwal, R. L., Nautiyal, S., Sen, K. K, Rana, U., Maikhuri, R. K., Rao, K. S. and Saxena, K. G. 2004. Patterns and ecological implications of agricultural land-use changes: a case study from central Himalaya, India. *Agriculture, Ecosystems & Environment* 102:81–92.
[28] Gupta, V. 2005. Climate Change and Domestic Mitigation Efforts. *Economic and Political Weekly* 40:981-987.
[29] Government of India. 2002. *Economic Survey 2001-02.* Government of India, New Delhi.
[30] Mall, R. K., Singh, R., Gupta, A., Srinivasan, G. and Rathore, L. S. 2006. Impact of Climate Change on Indian Agriculture: A Review. *Climatic Change* 78:445–478.
[31] World Bank. 2009. *South Asia: Climate change strategy*. The World Bank, Washington, DC.
[32] FAO. 2003. *Measuring the effect of climate change on developing country agriculture.* http://www.fao.org/docrep/003/x8044e/x8044e04.htm.

[33] Rosenzweig, C. and Parry, M. 1994. Potential Impact of Climate Change on World Food Supply. *Nature* 367:133-138.

[34] Kumar, K. and Parikh, J. 1998. Climate Change Impacts on Indian Agriculture: The Ricardian Approach. In: *Measuring the impact of climate change on Indian agriculture: World Bank Technical Paper 402.* Dinar, A., Mendelsohn, R., Evenson, R., Parikh, J., Sanghi, A., Kumar, K. Mckinsey, J., Lonergan, S. (Eds.), pp.33-68. Washington, DC.

[35] Bryan, E., Deressa, T. T., Gbetibouo, G. A. and Ringler, C. 2009. Adaptation to climate change in Ethiopia and South Africa: options and constraints. *Environmental Science and Policy* 12:413–426.

[36] Luo, Q., Bellotti, W., Williams, M. and Wang, E. 2009. Adaptation to climate change of wheat growing in South Australia: Analysis of management and breeding strategies. *Agriculture Ecosystems & Environment* 129:261-267.

[37] Mendelsohn, R. and Dinar, A. 1999. Climate Change, Agriculture, and Developing Countries: Does Adaptation Matter? *The World Bank Research Observer* 14:277-293.

[38] Mythili, G. 2010. Are there Regional Variations in the Farmers' Adaptation to Climate Change in Developing Economies. Paper presented at ISEE 2010 Conference, 22-25 August, Oldenburg & Bremen, Germany.

[39] Goswami, B. N., Wu, G. and Yasunari, T. 2006. The Annual Cycle, Intraseasonal Oscillations, and Roadblock to Seasonal Predictability of the Asian Summer Monsoon. *Journal of Climate* 19:5078–5099.

[40] Ratna, S. B., Sikka, D. R., Dalvi, M. and Ratnam, J. V. 2011. Dynamical simulation of Indian summer monsoon circulation, rainfall and its interannual variability using a high resolution atmospheric general circulation model. *International Journal of Climatology* 31:1927–1942.

[41] Neena, J. M., Suhas, E. and Goswami, B. N. 2011. Leading role of internal dynamics in the 2009 Indian summer monsoon drought. *Journal of Geophysical Research* 116:D13103, doi:10.1029/2010JD015328.

[42] Chattopadhyay, N. 2008. Climate Change and Food security in India. International symposium on climate change and food security in South Asia. August 25-30. Dhaka, Bangladesh.

[43] Madhya Pradesh Council of Science and Technology. 2007. *Resource Atlas – Madhya Pradesh.* Madhya Pradesh Council of Science and Technology, Bhopal, India.

[44] Forest Survey of India. 2011. *India State of Forest Report 2011.* Dehradun, Uttarakhand, India.

[45] Planning Commission of India. 2011. *India Human Development Report 2011: Towards Social Inclusion.* Oxford University Press, New Delhi.

[46] Indus Excursion. 2012. *Maps of Indian Tourist Places.* http://www.indusexcursion.com/maps-of-india/india-tourist-maps.html.

[47] National Centre for Medium range Weather Forecasting. *Districts of Madhya Pradesh.* http://www.ncmrwf.gov.in/t382-model/t382-district/dist_madhyapradesh.htm.

[48] United Nations Development Programme. 2007. *Human Development Report, Madhya Pradesh.* Oxford University Press, New Delhi.

[49] Mandla district website. 2012. *District Statistical Profile.* http://mandla.nic.in/District.htm

[50] Census of India 2001. 2001. *Madhya Pradesh Data Highlights: The Scheduled Tribes.* http://censusindia.gov.in/Tables_Published/SCST/dh_st_madhya_pradesh.pdf.

[51] Sharma, A. N. and Dwivedi, P. 2007. An Assessment of Poverty and Living Standard of the Baigas of Samnapur Block of Dindori District, Madhya Pradesh. *Study Tribes Tribals* 5:143–147.

[52] Mahapatra, L. K. 1994. *Concept of Health among the Tribal Population Groups of India and its SocioEconomic and Socio-cultural cornelates in Tribal Health in India*. Manak Publications, New Delhi.

[53] Saxon, G. 1957. *Socio-economic status, illness and the use of Medical Services.* The Milbank Memorial Fund, New York.

[54] Sharma, A. N. and Jain, M. 2004. *The Denotified (Ex- Criminal) Kuchbandiyas of Shahgarh.* Sarup and Sons, New Delhi.

[55] Yadav, A., Sharma, A. N. and Jain, A. 2001. Socio Demographic Characteristics of Semi Nomadic Lohar Gadiyas of Malthon Town of Sagar District, Madhya Pradesh. *The Anthropologist* 3:135-137.

[56] Nanjunda, D. C. 2008. *Thoughts on Redesigning Tribal Education: The why and What?* Kalpaz Publications, Delhi.

[57] Gopal, R., Shukla, R. 2001. *Management Plan for Kanha Tiger Reserve for the Period 2001–2002 to 2010–2011.* Office of the Conservator and Field Director, Mandla, India.

[58] Goodarzi, A., Tavassoli, M., Ardeshiri, G. and Ahmadi, S. 2011. Using Participatory Rural Appraisal (PRA) in rural research. *Advances in Environmental Biology* 5:2981-2985.

[59] Unni, K. S. 1996. *Ecology of River Narmada*. APH Publishing, New Delhi.

[60] Debnath, D. 2005. Role of Non-Timber Forest Products in Traditional Economic System and Cultural practices of a Primitive Tribal Group - The Baiga Caste of Mandla District in Madhya Pradesh. In: *Primitive Tribes in Contemporary India: concept, ethnography and demography: Volume 2.* Chaudhari, S. K. and Chaudhari, S. C. (Eds.), pp.85-100. Mittal Publications, New Delhi.

[61] Housing and Environment Department, Government of Madhya Pradesh. 2012. *Draft Madhya Pradesh State Action Plan on Climate Change.* Bhopal: India.

[62] Thakur, A. K., Rath, S., Roychowdhury, S. and Uphoff, N. 2010. Comparative Performance of Rice with System of Rice Intensification (SRI) and Conventional Management using Different Plant Spacings. *Journal of Agronomy and Crop Science* 196:146-159.

[63] Stoop, W. A., Uphoff, N. and Kassam, A. 2002. A review of agricultural research issues raised by the system of rice intensification (SRI) from Madagascar: opportunities for improving farming systems for resource poor farmers. *Agricultural Systems* 71:249–274.

[64] Bhagat, R. M. and Verma, T. S. 1991. Impact of rice straw management on soil physical properties and wheat yield. *Soil Science* 152:108–115.

[65] Edwards, C. A. and Lofty, J. R. 1982. Nitrogenous fertilizers and earthworms populations in agricultural soils. *Soil Biology and Biochemistry* 14:515–521.

[66] Motavalli, P. P., Singh, R. P. and Anders, M. M. 1994. Perception and Management of Farmyard Manure in the Semi-Arid Tropics of India. *Agricultural Systems* 46:189-204.

[67] Rawlsa, W. J., Pachepskyb, Y. A., Ritchiea, J. C., Sobeckic, T. M. and Bloodworth, H. 2003. Effect of soil organic carbon on soil water retention. *Geoderma* 116:61–76.

[68] PRADAN. 2010. *Annual Report* 2009-10, PRADAN, New Delhi, India.

[69] Mandla Agriculture Department. 2010. *District Agricultural Statistics*. Mandla, Madhya Pradesh, India.

[70] Uphoff, N. 2004. System of rice intensification responds to 21st century needs. *Rice Today* 3:42.

[71] Bellarby, J., Foereid, B., Hastings, A. and Smith, P. 2008. *Cool Farming: Climate Impacts of Agriculture and Mitigation Potential.* Greenpeace International, Netherlands.

[72] Dobermann, A. 2004. A critical assessment of the system of rice intensification (SRI). *Agricultural Systems* 79:261–281.

[73] Stoop, W. A. and Kassam, A. H. 2005. The SRI controversy: a response. *Field Crop Research* 91:357–360.

[74] Uphoff, N. 2002. Changes and evolution in SRI methods. In: *Assessment of the System for Rice Intensification.* Uphoff, N., Fernandes, E. C. M., Yuan, L. P., Peng, J. M., Rafaralahy, S. and Rabenandrasana, J. (Eds), pp.8–14. Cornell International Institute for Food, Agriculture and Development, Ithaca, NY, USA.

[75] Moreno-Caselles, J., Moral, R., Perez-Murcia, M., Perez-Espinosa, A. and Rufete, B. 2002. Nutrient value of animal manures in front of environmental hazards. *Communications in Soil Science and Plant Analysis* 33:3023–3032.

[76] Scialabba, N. E. H. and Muller-Lindenlauf, M. 2010. Organic agriculture and climate change. *Renewable Agriculture and Food Systems* 25:158–169.

[77] Blummel, M., Wright, I. A. and Hegde, N. G. 2010. Climate Change Impacts on Livestock Production and Adaptation Strategies: A Global Scenario. National Symposium on Climate Change and Rainfed Agriculture, February 18-20, CRIDA, Hyderabad, India.

[78] Gaughan, J., Lacetera, N., Valtorta, S. E., Khalifa, H. H., Hahn, L. and Mader, T. 2009. Response of Domestic Animals to Climate Challenges. In: *Biometeorology for adaptation to climate variability and change: Biometeorology 1.* Ebi, K. L., Burton, I. and McGregor, G. R. (Eds.), pp.131-170. Springer Science, Heidelberg, Germany.

[79] Sharma, M. C., Masih, S. K. and Sharma, C. B. 1997. Tribal's dependence on non-timber forest produce in district Mandla. *Vaniki Sandesh* 21:14-24.

[80] Mishra, M. 2011. Wild Harvesting and Management of Some Medicinal Plants in the Natural Forest of Central India. *Indian Journal of Fundamental and Applied Life Sciences* 1:90-97.

[81] Kala, C. P. 2009. Aboriginal uses and management of ethnobotanical species in deciduous forests of Chhattisgarh state in India. *Journal of Ethnobiology and Ethnomedicine* 5:1-12.

[82] Thomas, M., Sahu, P., Shrivastava, A. and Hussain, Z. 2011. Biodiversity and Livelihood Options of people in Chambal Ravine of Morena District, Madhya Pradesh, India. *Journal of Tropical Forestry* 27:40-56.

[83] Delacote, P. 2007. Agricultural expansion, forest products as safety nets, and deforestation. *Environment and Development Economics* 12:235-249.

[84] Illukpitiya, P. and Yanagida, J. F. 2010. Farming vs forests: Trade-off between agriculture and the extraction of non-timber forest products. *Ecological Economics* 69:1952–1963.

[85] Frazer, L. 2009. Will Warmer Soil Be as Fertile? *Environmental Health Perspectives* 117:59.

[86] Agrawal, A. and Gibson, C. 1999. Enchantment and Disenchantment: The Role of Community in Natural Resource Conservation. *World Development* 27:629-649.

[87] Banerjee, A. K. 2004. Tracing social initiatives towards JFM. In: *Root to Canopy: Regenerating Forests through Community–State Partnerships*. Bahuguna, V. K., Mitra, K., Capistrano, D. and Saigal, S. (Eds.), pp.45-56. Winrock International India and Commonwealth Forestry Association, New Delhi.

[88] Berkes, F. Ed. 1989. *Common Property Resources - Ecology and Community Based Sustainable Development*. London: Belhaven Press.

[89] Chopra, K. C., Kadekodi and Murthy, M. 1989. People's Participation and Common Property Resources. *Economic and Political Weekly* 24:A.189-A.195.

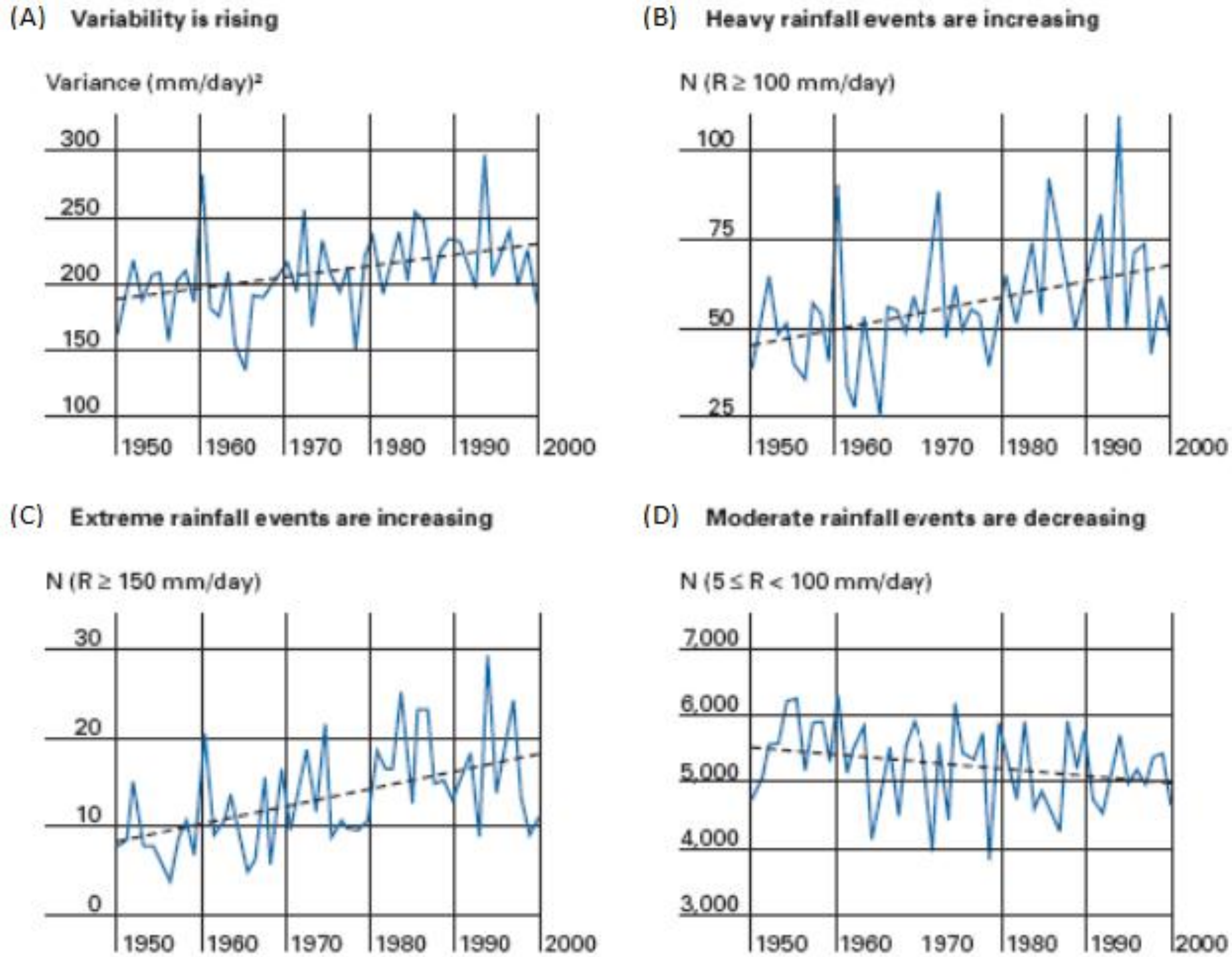
[90] Dove, M. R. 1993. A Revisionist View of Tropical Deforestation and Development. *Environment Conservation* 20:17-24.

[91] Rasul, G., Thapa, G. B. and Karki, M. B. 2011. Comparative Analysis of Evolution of Participatory Forest Management Institutions in South Asia. *Society & Natural Resources: An International Journal* 24:1322-1334.

[92] Ribot, J. C. 2004. *Waiting for democracy: the politics of choice in natural resource decentralization.* World Resources Institute, Washington, DC.

[93] Singh, G. S. and Ram, S. C. 1997. Prospects of Sustainable Development of Kullu Valley in North-Western Himalaya. *Journal of Rural Development* 16:359-368.
[94] Sood, K. K. and Gupta, H. K. 2007. Implications of Indian Foresters' Perspectives of Joint Forest Management. *Small-Scale Forestry* 6:291-308.
[95] Goswami, B. N., Venugopal, V., Sengupta, D., Madhusoodanan, M. S. and Xavier, P. K. 2006. Increasing trend of extreme rain events over India in a warming environment. *Science* 314:1442-1445.
[96] Indiaagristat. 2011. www.indiaagristat.com.
[97] India Meteorological Department. n.d. Hydromet Division. www.imd.gov.in.

Appendix Figure 1. Rainfall (R) patterns in Central India, 1950-2000. (A) Time series of the variance of daily anomalies during summer monsoon seasons (June 1 to September 30). (B) Time series of heavy (R≥100mm/day) daily rainfall events. (C) Time series of extreme (R≥150mm/day) daily rainfall events. (D) Time series of moderate (5≤R<100mm/day) daily rainfall events. Linear trends are represented by dashed lines. From [95]. Reprinted with permission from AAAS.



Appendix Table 2. Major education, health and forest data of seven districts of Eastern Madhya Pradesh, India. Source: [48]**.** Literacy and health status reflect the overall development of a region. Indian states that score high on these two indicators tend to score high on the Human Development Index. Although 30.7% of Madhya Pradesh officially categorized as forest, some of this area may not actually have any trees, having been cleared for agriculture, housing and other uses. According to a quantitative assessment via remote sensing, conducted biennially by the Forest Survey of India, 25% of Madhya Pradesh actually has forest cover, including areas not officially classified as forest by the government.

	District							
Indicator	Balaghat	Dindori	Katni	Mandla	Seoni	Shahdol	Umaria	State average
Literacy of total population in 2001 (%)	69	54	64	60	66	59	59	64
Literacy of scheduled tribes in 2001 (%)	54	49	41	51	53	45	45	41
Population per health care center in 2006 (#)	5,695	3,333	5,566	2,720	7,308	3,351	2,662	6,645
% area under forest	54	37	26	49	35	27	50	25

Appendix Table 3. Key agricultural statistics in Mandla, Madhya Pradesh, and India. Source: [43].

Indicator	Mandla	Madhya Pradesh	India
Net sown area (%)	23	48	43
Per capita gross cropped area (hectare)	0.31	0.33	0.18
Net irrigated area (%)	8	40	33
Fertilizer consumption per hectare gross crop area (kg/ha)	16	55	90
Per capita food grain production (kg)	172	219	199

Appendix Table 4. Yields of ice, maize, and wheat in Madhya Pradesh (MP) and Mandla district in kg/ha. Source: [96].

Year	Rice		Maize		Wheat	
	MP	Mandla	MP	Mandla	MP	Mandla
1996-97	819	853	1,091	1,515	1,818	N.A.
1997-98	742	613	1,334	1,485	1,655	367
1998-99	892	701	1,457	1,526	1,883	995
1999-00	1,059	838	1,586	1,388	1,938	780
2000-01	605	364	1,459	1,681	1,535	406
2001-02	1,005	793	1,984	1,994	1,620	897
2002-03	646	560	1,751	1,617	1,520	806
2003-04	1,074	790	2,068	1,819	1,867	880
2004-05	818	680	1,400	1,367	1,821	944
2005-06	1,045	N.A.	1,455	1,349	1,710	N.A.

Note:- N.A. = Data not available

Appendix Table 5. Monthly rainfall in Mandla district, Madhya Pradesh (2004-2010). R = monthly rainfall in mm. % dep. = departure of rainfall from the long term (1951-2000) monthly averages for the district. Parentheses indicate deviations below the long-term average, whereas values without parentheses indicate deviations above the long-term average. Source: [97].

Month		2004	2005	2006	2007	2008	2009	2010	Average R
January	R	15	78	0	0	0	12	0	19
	%dep.	(50)	169	(100)	(100)	(100)	(58)	(100)	
February	R	0	16	0	1	3	0	14	4
	%dep.	(100)	(38)	(100)	(95)	(88)	(100)	(46)	
March	R	0	11	3	10	35	0	0	11
	%dep.	(100)	(52)	(88)	(56)	59	(100)	(100)	
April	R	2	0	0	2	4	0	3	2
	%dep.	(76)	(100)	(100)	(85)	(61)	(100)	(66)	
May	R	0	16	13	3	0	0	7	6
	%dep.	(100)	111	75	(63)	(95)	(100)	(8)	
June	R	277	197	12	97	602	19	114	237
	%dep.	61	14	(93)	(44)	249	(89)	(34)	
July	R	260	505	599	370	338	393	539	414
	%dep.	(42)	12	33	(18)	(25)	(13)	20	
August	R	484	367	415	289	351	247	361	381
	%dep.	7	(19)	(8)	(36)	(22)	(45)	(20)	
September	R	101	266	96	395	152	141	426	202
	%dep.	(53)	24	(55)	84	(29)	(34)	98	
October	R	23	22	2	8	11	24	23	13
	%dep.	(41)	(44)	(96)	(79)	(72)	(38)	(41)	
November	R	1	0	0	0	6	118	2	1
	%dep.	(89)	(100)	(100)	(100)	(42)	1033	(80)	
December	R	0	0	0	0	0	5	0	0
	%dep.	(100)	(100)	(100)	(100)	(100)	(62)	(100)	
Total R		1,163	1,478	1,140	1,175	1,502	959	1,489	1,272