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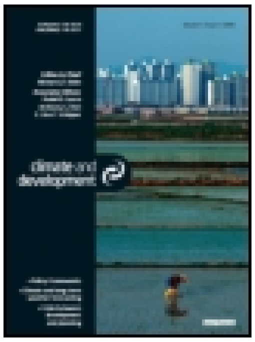

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RESEARCH ARTICLE

Responses of the Tharu to climate change-related hazards in the water sector: Indigenous perceptions, vulnerability and adaptations in the western Tarai of Nepal

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ABSTRACT
Climate change perceptions of Indigenous peoples (IP) are important because of their close connection with nature and the environment. This study assesses climate change insights of the Tharu in Bardiya district of Nepal in relation to climate variability and water sector-related hazards, focussing on Indigenous knowledge (IK) for adaptation and mitigation in agriculture. Tharu are the first settlers in Tarai, Nepal and largely depend on farming. Our sequential mixed-method approach first quantifies perceptions and then analyses qualitative information from participatory methods. We found the Tharu have perceived a temperature increase but a rainfall decrease; the former is validated with weather data, but not the rainfall trend due to high annual variation. The high ranking of flooding in both villages and drought in Bikri indicates the importance of the water sector and related hazards. Tharu have used Indigenous as well as scientific knowledge for weather predictions, coping and adaptation to water-related hazards in agriculture-based livelihoods. As the application of IK-based traditional agricultural practices has decreased due to their lower yield than modern agricultural practices, there is need for documentation, research and policy actions to integrate IK and science to reduce climatic vulnerability and increase productivity of resilient agricultural practices.

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Water; flooding; droughts; vulnerability; traditional knowledge; Nepal

1. Introduction

Climate change is a serious global threat impacting multiple sectors and thus human livelihoods. Agriculture is one sector that is heavily impacted by climate change, challenging global food systems and the livelihoods of dependents. There is an established relationship between climate change and natural disasters (IPCC, 2012; IPCC, 2014a). Climate change alters natural cycles, thereby accelerating natural hazards and extreme events (Anderson & Bausch, 2006; IPCC, 2012). Changes in temperature and precipitation patterns lead to extreme events, such as flooding, droughts and heat/cold waves, which have a severe impact on farming and livelihoods (IPCC, 2012). Global temperatures have increased by 0.78°C since the pre-industrial era (pre-1850) and are predicted to increase by at least 2°C by the end of the twenty-first century (IPCC, 2014b). At the regional level, the temperature increment is substantial in South Asia and particularly in higher altitudes, expected to exceed 2°C in the late twenty-first century (IPCC, 2014c; Lal, 2011) which will further impact ecosystems, biodiversity, agriculture, livelihood and wellbeing, particularly of natural resource-dependent populations, including Indigenous peoples (IP).

In Nepal, many have reported a rapid increase in temperature and unpredictable precipitation patterns (DHM, 2015, 2017; Practical Action, 2009; Shrestha et al., 1999). The growing frequency of climate extreme events, including floods and droughts, has increased the vulnerability of local peoples, as well as uncertainty in farming (IPCC, 2012; Lal, 2003; MoHA & DPNet-Nepal, 2015; Practical Action, 2017). Nepal is regarded as one of the multi-hazard prone countries in the world, ranking fourth in regard to climate change and twentieth with regard to multiple hazards, such as floods and landslides (MoHA, 2018). Globally, Nepal has been ranked thirtieth in flooding risk (Practical Action, 2017). Nationally, flooding is the greatest hazard, particularly in the Tarai (lowland plains area) and hill regions; it has caused 1235 deaths, 663 missing and 693 injured in the period 2011–2016 (MoHA, n.d.; MoHA & DPNet-Nepal, 2015). Similarly, drought, fire, cold and heat waves are other hazards related to climate change in Nepal, all of which can impact agrarian livelihoods and wellbeing (DesInventar, 2018).

The Tharu are an Indigenous Nationality (*Aadibasi Janjati*) of Nepal (NFDIN, 2002). They mostly live in the Tarai region from Jhapa in the east to Kanchanpur in the west. The Tharu are the second-largest Indigenous nationality after the Magar, with their 2 million people amounting to 6.2% of the national population (CBS, 2011). Tharu have lived in the Tarai for centuries, with the earliest evidence of occupation from the fifth to seventh century (Krauskopff, 2000); therefore, they are the frontier people of the Tarai, who converted marshy, malarial, forestland into Nepal's most prosperous region (Chaudhary, 2003; Chaudhary, 2008). Due to continuously living in this malarial region, the Tharu have adapted, with a seven-fold lower incidence of malaria, resulting in a ten-fold reduction

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in morbidity from malaria (Modiano et al., 1991). Historically, few Tharu were subject to state intermediaries (e.g. the *Jimidari* system to collect land tax) before the unification of Nepal in 1768, but majority of the Tharu gradually lost land ownership and were systematically marginalized during different Nepalese political regimes in the name of nation building, social integration and mass resettlement in the Tarai of other groups from the hills and mountains of Nepal (Guneratne, 1998, 2002, 2007, 2010; Krauskopff, 2000; Panjiyar, 2000; Rajaure, 1981; Regmi, 1977).

The Tharu have been subject to a combination of increasing social and climatic vulnerability. Vulnerability is commonly understood as the susceptibility of a system/community arising from its inability to cope with the adverse effects/impacts of various types of change (IPCC, 2001, 2014a). Social vulnerability is socially constructed and determined by types of livelihood capital (physical, natural, financial, social/cultural, and human) in combination with climatic vulnerability, which has become severe due to climate-sensitive livelihoods and limited adaptive capacity (Adger, 1999; Adger & Kelly, 1999; Deressa et al., 2008). It is vital to increase adaptive capacity to reduce vulnerability, to mitigate climate risk and improve the resilience of people and the ecosystems they inhabit. Adaptive capacity for such groups relates primarily to agriculture, which has been the predominant livelihood and cultural focus of the Tharu of this region. Until twenty-first century reforms, the Tharu in western Nepal worked as agricultural tenants and *bataiya* (sharecroppers), having no land of their own – trapped in the *kamaiya* bondage labour system (Chaudhary, 2008; Chaudhary & Maharjan, 2011).

Local perceptions of climate change are important, since the Tharu have coped with environmental changes in water, agriculture, forest and biodiversity in the Tarai for centuries. Climate perception is a process by which individuals sense and realise changes in climate-related stimuli, where stimuli include changes in climate variables and extremes (IPCC, 2014a). Climate extremes and measurable shocks help build such perceptions (Wachinger et al., 2010). The perceptions and responses of the Tharu can contribute to science and the development of adaptation and mitigation strategies for the Tarai region and beyond. Local perceptions, adaptation initiatives and associated knowledge and practices among the Tharu are poorly documented (Devkota et al., 2011; Maharjan et al., 2011). However, Indigenous knowledge (IK) is increasingly appreciated because scientific knowledge alone is recognized as inadequate to deal with the complex global climate crisis (Casimir, 2008; Finucane, 2009); hence the documentation of IK and practices is emphasized globally (Galloway McLean, 2009; Nakashima et al., 2012; Sterrett, 2011), as IK plays a crucial role in forming such human perceptions and strategizing adaptation (Chaudhary et al., 2011; Chaudhary & Bawa, 2011). However, previous studies of Tharu IK have largely focussed on their knowledge of wild foods and medicinal plants (Dangol, 2008; Ghimire et al., 2000; Manandhar, 1985; Müller-Böker, 1993; Uprety et al., 2010), though studies by Dahit (2008) listed several IK domains (e.g. farming, fishing and hunting among western Tharu). Khadka (2016) has analysed the Tharu *barghar-mukhiya* Indigenous institution, while Sarbahari (2016) has focussed on the Tharu *guruwa* (shaman and spiritual), while Locke (2011) has written on wild animal capturing and elephant training. However, there is limited information on Tharu knowledge regarding how specific climatic hazards related to water impact their livelihoods and wellbeing despite the significance of water issues to improve adaptive capacity for resilient and productive agriculture. Therefore, in this study, we address two questions. First, what are the perceptions of the Tharu related to climate change? And, second, what are their water-induced vulnerabilities and adaptation strategies for agrarian livelihoods? This research provides novel insights from the ground concerning how Indigenous knowledge and practices have been reducing climatic vulnerability, as well as concerning how such knowledge and practices can complement the contributions of agricultural science in a context where the Tharu are increasingly adopting modern agricultural methods for their primary grain crops, but not for supplementary crops such as legumes.

2. Research methodology

2.1. The fieldwork area

The study was conducted in two rural villages, Thapuwa and Bikri, in Gulariya municipality, Bardiya district, Nepal as shown in Figure 1. The villages are situated between the latitude of 28° 14′ N and longitude of 81° 18′ E at an altitude of approximately 215 m above the mean sea level. Bardiya district has a tropical climate in the plains and sub-tropical climate in the mid-hills (*Churiya*); summer is hot and humid. The temperature climbs to a mean of 39.8°C in May–June, and during the winter goes down to 9.6°C in December–January. The average annual rainfall is 1118 mm, dominated by the summer monsoon (DDC Bardiya, 2013). The district shares a southern border with India. The Bardiya district was selected due to the high percentage of the Tharu in the district (53%, ∼226089) (CBS, 2014), highly agriculture-based livelihood (DADO Bardiya, 2015; DDC Bardiya, 2013), liability to flood disasters (MoHA & DPNet-Nepal, 2015; Practical Action, 2017) and being one of the least developed districts in the *naya muluk* (new territory – Bardiya, Banke, Kailali and Kanchanpur) in terms of the human development index (HDI, 0.466) (Government of Nepal & UNDP, 2014). Within the Bardiya district, Thapuwa and Bikri villages were chosen based on predominance of Tharu ethnicity and flooding and drought vulnerabilities, respectively (DDC Bardiya, 2013; RKJS/Practical Action, 2013). The Babai River passes both villages, but Thapuwa is closer to the river. Thapuwa village is long-settled, whereas Bikri village was settled in 1967 by immigrants from Dang-Deokhuri, which is more than 100 km east.

2.2. Research methods and data analysis

The research utilized a sequential mixed-methods approach, with collection of quantitatively analysed data followed by qualitative data elicited through in-depth interviews, focus group discussions (FGDs) and participant observation, conducted across six months in two phases in 2018. A summary of the research methods used is given in Table 1.

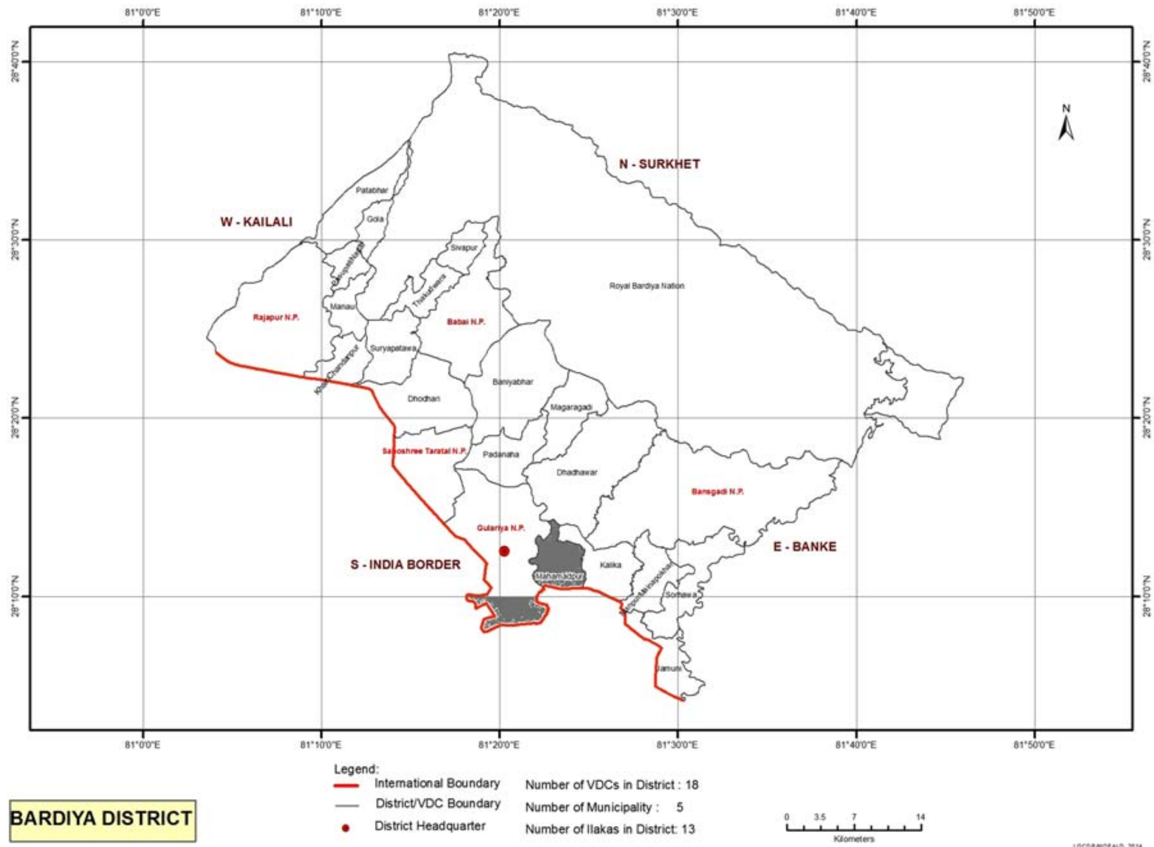

Figure 1. Bardiya district map showing the two fieldwork villages, Thapuwa and Bikri. Source: DoFRS (2019).

Table 1. Interviews, focus group discussions (FGD) and household surveys during fieldwork in 2018.

Village	No. of interviews	No. of female interviewees	No. events observed[a]	No. of FGD	No. of participants in FGD	No. of female participants in FGD	No. of households surveyed	No. female respondents in the survey	Female-headed households
Thapuwa	17	3 (18%)	4	4	38	20 (53%)	143	45 (32%)	1 (1%)
Bikri	12	6 (50%)	3	3	30	14 (47%)	86	32 (37%)	8 (9%)
Totals	29	9 (31%)	7	7	68	34 (50%)	229	77 (34%)	9 (4%)

Note: Figures in parentheses represent the percentage of females in the respective category.
[a]In Thapuwa, the field researcher observed the feast of house construction, a public hearing of the women's group, bore installation to lift underground water, and rice seedling and transplantation. In Bikri, he observed two meetings of the Bhawani community forest user group and one meeting of a women's group for saving and credit.

The research utilized a mixed-methods approach because the study deals with knowledge and agricultural practices of the Tharu that require data validation and triangulation. The knowledge, interpretation, and experience of people are guided by their cultural beliefs; therefore, ethnoscience, with its emic focus on local classifications and knowledge, defined one study framework. Etic analysis of climatic data and agricultural production required quantitative analysis. Mixed methods increase the reliability and validity of research from both approaches (Creswell & Plano Clark, 2011; Neuman, 2004). A mixed-methods approach includes the use of qualitative methods (participant observation, in-depth interviews, FGDs and participatory tools) to elicit locally grounded data to complement quantitative results and also facilitates triangulation of data (Creswell & Plano Clark, 2011). In the study, qualitative and quantitative analyses were performed separately, and the findings were mixed for discussion/ interpretation.

2.2.1. Quantitative methods

A census was conducted of 229 households (143 in Thapuwa and 86 in Bikri), comprising all village households in the populations under study, using a semi-structured survey questionnaire after one month of familiarization and rapport-building with the people to ensure reliable information. There was only one non-Tharu household in Bikri (that of the blacksmith) and seven non-Tharu households in Thapuwa. The survey questionnaire was designed in three sections: agriculture, climate change and livelihoods. The survey was conducted with a household head or member engaged in farming, both wife and husband, if possible. Particular consideration in the choice of interviewees was given to people over 30 years old so that they could recall 10–20-year-long scenarios of climate and farming.

Individual perceptions of climate change were recorded in regard to change in the temperature and rainfall during the winter season (December–February) and the monsoon season

(June–September). Following Chaudhary and Bawa (2011) and Chaudhary et al. (2011), participant perceptions of climate change were classified based on their observation and experience: 'yes' if they have experienced a change; 'no' if they have not experienced change; and 'don't know' if they were unsure about sets of climate change indicators. Vulnerability and the impact of climate change were measured in terms of hazards and extreme events in agriculture and livelihood over 10-year and 20-year periods from the household survey and FGDs.

We validated community perceptions of temperature and rainfall with data from the Department of Hydrology and Meteorology (DHM), Kathmandu from the meteorological stations, Chisapani (Karnali) and Rani Jaruwa Nursery of Bardiya district for temperature analysis. The annual mean temperature (maximum, minimum and average) data of 38 years (1979–2016) were compared between two equal periods (pre- and post-1997) by independent t-test. For precipitation, we considered the rainfall data from 1973–2016 (data from 2011 and 2012 are unavailable) at Gulariya meteorological station, Bardiya. We analysed the total annual rainfall as well as inter-seasonal variation (monsoon and winter).

The frequency of climate change perception was counted and computed as respondent percentages. Chi-square (X^2) was used to determine the consistency of responses of household perceptions on climate change. IBM SPSS version 20 was used to calculate means, standard deviations and t-tests for the temperature and rainfall analyses.

2.2.2. Qualitative methods

During the first month, several transect walks, bike-rides and many informal conversations were undertaken with the villagers. Building rapport was facilitated by the field researcher (i.e. the first author) also being Tharu and having been brought up in the region. The *barghar* (traditional village head), *guruwa* (shaman), school teachers and social leaders were approached as key informants and to obtain their support for the study. Various participatory rural appraisal (PRA) tools, such as hazard mapping, vulnerability matrix ranking, hazard timeline, hazard calendar and stakeholder mapping were deployed during the FGDs to assess the overall views of villagers related to climate change in terms of vulnerability and its impact, as well as local practices for adaptation. Details of PRA tools, main purposes and methods/processes used are summarized in Table 2.

For each of the 6 FGDs conducted, 8–10 people representing different ages, genders, educational levels and landholding sizes were selected. Focus group discussions were conducted with three types of participants – farmers, animal herders, and heads of the households and *barghar*. An additional FGD at Thapuwa was carried out mixing village key informants and commercial farmers to supplement the hazards impact and adaptation initiatives in agriculture (mostly based on scientific agriculture). The FGDs including the farmer group's representative identified and assessed the impact of climate change in agriculture. Similarly, animal herders reported their observations, experience and perceptions of changes in agriculture, forest food and agrobiodiversity. The FGDs with the household heads and village key informants, such as *barghar* and *chaukidar* (village watchman), included preparing a hazard map, hazard timeline, hazard matrix and stakeholder analysis to support them. The FGDs were conducted during pre-monsoon seasons (April–May) to reflect water-related hazards and preparation for coping with extremes. The FGDs took place in the community hall used by the entire village, and each lasted for a maximum of four hours. The questionnaire checklist and framework for each FGD were translated into Tharu to facilitate the researchers leading the discussion with support of a local facilitator.

The qualitative data were manually categorized into themes, and tabulated. NVivo 12 Plus (Qualitative Research Software (QSR) International) was used to analyse qualitative information. Interviews were manually transcribed. The qualitative data files were uploaded into the NVivo 12, categorized into different groups such as FGDs, interviews and observations. The uploaded files were coded to form the nodes and sub-nodes in the software, where node and sub-node identify a theme and sub-theme. Different facilities of NVivo, such as node comparison, hierarchical chart and cluster analysis, were used as a foundation for analysis in terms of important words and thematic areas (nodes). The final analysis was conducted by reading and re-reading transcriptions, digesting the information and reflecting upon the interpretation of interviews to reach conclusions regarding knowledge and practices regarding climate and agriculture of the Tharu.

3. Results

3.1. Perceptions of climate change by the Tharu

The responses of participants regarding the perception of climate change were rated against seven indicators, as shown in Figure 2. Chi-square tests showed some highly significant

Table 2. Participatory tool, purpose of use and methodology used in the study.

Tools	Purpose of use	Methodology
Hazard map	To identify and assess livelihood resources and potential impact of hazards.	The community prepared social resource maps on paper indicating resources and hazards in their village.
Vulnerability matrix	To rank the hazards based on the severity of impact upon livelihood capital.	Facilitator oriented participants to the five livelihood capitals and requested the participants to rate hazard from 1–4 (higher the value, higher the impact on livelihood). The hazard that received the highest score is the most disastrous.
Historical timeline	To know past hazards and extreme climatic events, their impacts, and coping and adaption strategies.	The major hazards of the past 30–35 years were assessed in terms of the impact and coping and post-disaster adaptation strategy.
Hazard calendar	To analyse the trend of hazards occurrence and its consequences in the agriculture crop calendar.	Upon identification of disastrous hazards, the participants compared hazard occurrence times over 10 and 20 years.
Stakeholder mapping	To identify the organization working in the community for livelihood improvement and climate adaptation.	Discussed with *barghar*, *chaukidar* (village watchman), group representatives; listed the government agencies and NGOs working in the village. The impacts of programme and relationship with the community were assessed.

Note: Adapted from (CARE International, 2009; Pasteur, 2011).

(p<.001) positive responses of respondents to the indicators when combining responses from the two villages (Thapuwa and Bikri), but differences between villages in response to climate change indicators were non-significant, which indicates the consistency of perception over communities. All indicators except one (increased winter temperature) were consistent with the perceptions since three-quarters of the respondents have observed changes.

We analysed temperature and rainfall data to assess Tharu perceptions. An analysis of pre- and post-1997 annual mean temperature clearly showed a significant increase in maximum and mean annual temperatures. During this period, maximum and mean temperatures increased almost by 1°C and 0.6°C, respectively (Table 3).

There was no clear trend in rainfall. The analysis of total annual rainfall, and seasons showed decreasing trends, but the year-to-year variation for all rainfall variables (total annual, monsoon season and winter season) was very high (Figure 3(a, b)). As a result, we could not tell if the apparent reducing trend for rainfall was real or just due to chance/random fluctuation in rainfall. To illustrate the erratic nature of rainfall, for example, it decreased drastically in 2002 and increased in 2007, but again decreased in 2013 (Figure 3(a,b)).

The perceptions of temperature change positively correlated with measures of climate trends in the region. Most participants indicated increased monsoon temperatures, which is in line with temperature data trends. There is less agreement in the perception of the winter temperature trend. Some respondents perceived warmer winters than in the past 10–20 years; however, there were more people (55%) who perceived either colder winters or no increase in winter temperature.

We could not validate local Tharu perceptions of decreasing rainfall with climate data. The data were so variable from year-to-year that the statistical analysis was inconclusive about the trend. Respondents perceived that rainfall was delayed in the monsoon season, unpredictable and decreased in the total number of rainy days in both monsoon and winter. However, people felt the increase in the intensity of rainfall, particularly in the post-monsoon period (October–November) caused flooding. A delay in onset of the monsoon and unpredictable rainfall exert an impact particularly upon rice cultivation and irrigation planning in agriculture.

Table 3. Comparison of mean annual temperatures from 1979–2016 in Bardiya.

Time frame	Maximum temperature	Minimum temperature	Mean temperature	Standard deviation of mean temperature
Pre-1997	29.9**	18.8	24.3**	0.30
Post-1997	30.7**	19.1	24.9**	0.72

**Significant at 5% significance level.

3.2. Ranking of climate-induced hazards

The matrix ranking PRA tool was used to prioritize hazards in the study villages, as shown in Table 4. Participants marked each hazard against the livelihood capital in a scoring range of 1–4, with 1 for no or least impact and 4 for the highest impact. The hazard having the highest total scores was the most important in terms of vulnerability to villagers. The Tharu ranked flooding as the number one hazard in both villages, followed by drought in Bikri and storms in Thapuwa.

3.3. Historical timeline of hazards

The historical timeline is an important PRA tool to analyse trends, impacts and adaptation strategies of the community. Table 5 gives a timeline of hazards identified through the FGD in Thapuwa and Bikri village. The Tharu community has experienced frequent flooding, droughts and intense cold waves over the past 20 years. The other hazards, such as storms and hailstones, were considered natural phenomena like those experienced in the past.

Major flooding was periodic in nature, occurring almost at 10-year intervals in the past (1985, 1995, 2005), but in the last decade, the frequency has increased with flooding in 2014 and then again in 2017 (Table 5). According to informants, the

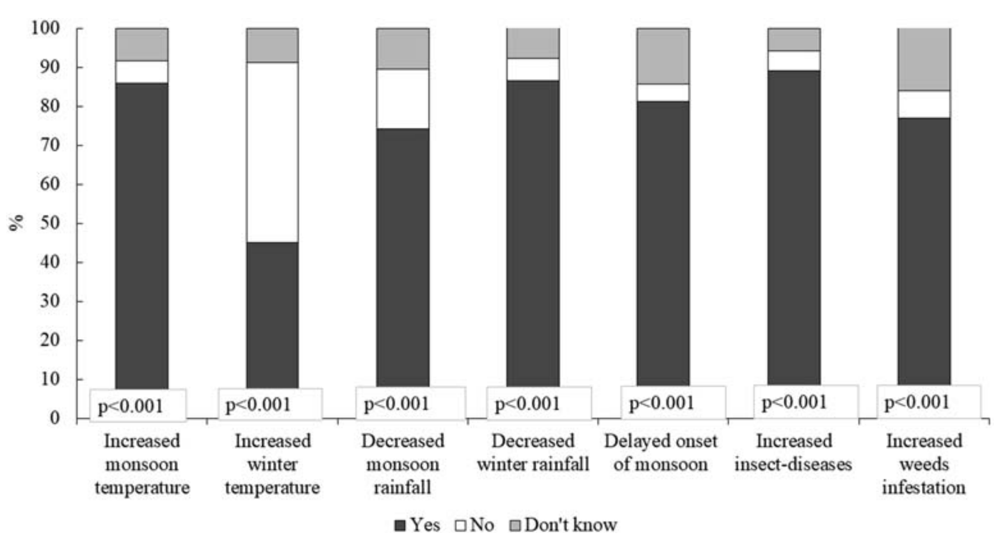

Figure 2. Perception of climate change indicators (black, yes; white, no; shaded, don't know) (n = 229); p-values are shown in boxes.

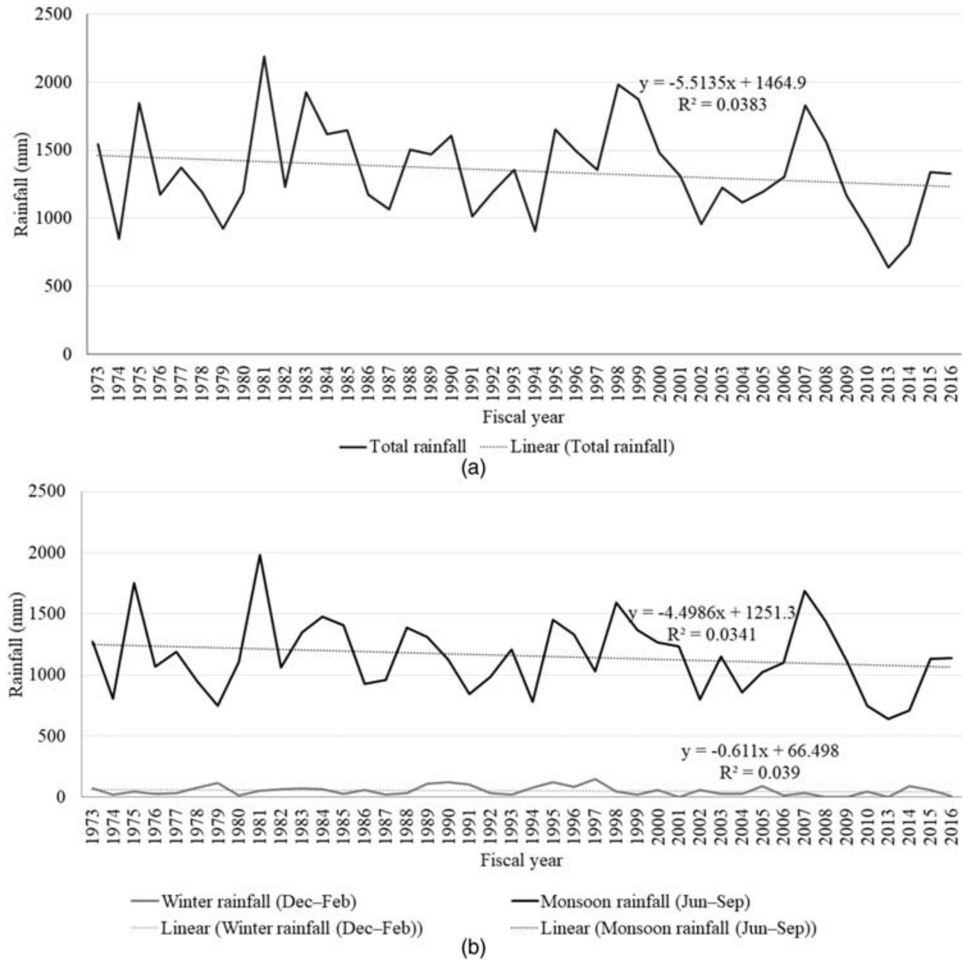

Figure 3. (a) Total annual rainfall in Gulariya, Bardiya of last 42 years (1973–2016), excludes years 2011 and 2012. (b) Seasonal variation in rainfall in Gulariya, Bardiya of last 42 years (1973–2016), excludes years 2011 and 2012.

Table 4. Hazard ranking at Thapuwa and Bikri villages.

	Flood		Drought[a]		Hailstone		Cold waves		Storm		Insect/Dis	
Livelihood capital	Thap	Bik	Thap	Bik	Thap	Bik	Thap	Bik	Thap	Bik	Thap	Bik
Physical	4	4	1	1	2	2	1	1	3	1	1	1
Natural	4	3	2	3	4	3	3	2	4	2	4	3
Financial	3	1	3	2	3	1	4	2	4	1	1	1
Social	4	2	2	2	2	1	4	2	4	1	2	1
Human	4	3	3	3	1	1	3	3	3	1	3	1
Total score and rank	19 **(I)**	13 **(I)**	11 (V)	11 **(II)**	12 (IV)	8 (IV)	15 (III)	10 (III)	18 **(II)**	6 (VI)	11 (VI)	7 (V)

Acronyms: Thap = Thapuwa village, Bik = Bikri village.
Score ranking: 1 = no impact, 2 = low impact, 3 = medium impact and 4 = high impact. The participants had given a score to each hazard based on the impact on livelihood capital. Various indicators were considered for scoring livelihood capital, such as physical (house, road), natural (land, water), financial (credit, loan), social (education, health) and human (skill, services). The score is summed up and the hazards having the highest score were considered most hazardous impacting on overall livelihood capital for each village.
[a]The lower ranking of drought than storm and cold wave in Thapuwa was because of the availability of irrigation technology to pump underground water.

biggest flooding events were experienced in 1995 and 2017. The communities have experienced delays in the onset of floods by almost one month compared to the past 20 years.

Drought was a serious problem in the past (until the 1980s) before the availability of irrigation technology and modern agriculture – mainly improved varieties and inputs. The introduction of short-duration rice varieties and heat-tolerant maize has helped reduce drought vulnerability. Electrification in Thapuwa enabled farmers to pump underground water for irrigation. However, Bikri village still experienced problematic drought, as it is not well connected into the Babai irrigation scheme, as well as being an irrigation end-user. Drought causes varying levels of yield reduction to complete crop failure; hence, farmers have recognized the impact of drought upon a considerable yield loss.

3.4. Vulnerability to hazards and local adaptation strategies

Vulnerability was found to be in an inverse relationship with size of land holdings, education and availability of extension services; having higher levels of land ownership and

Table 5. Hazard timeline at Thapuwa and Bikri villages.

Year	Hazard	Impact on livelihood	Local coping and adaptation
1979 (2036)	Drought	Rice completely dried up in the field, hunger situation in the village.	Boiled rice loan from *Mahajan* (money lender), consumption of *Maar* (Rice soup with pulses).
1985 (2042)	Flooding	Riverbank erosion approx. 1 ha in Bikri and approx. 8 ha in Thapuwa. Maize crop buried.	Plantation of bamboo and *Bersama* (*Ipomoea sp.*) in the riverbank; Sandbag piled up for the river wall.
1988 (2045)	Drought	No production from rice and maize.	Pouring of water from pond and canal; Water lifting from the Babai River
1995 (2052)	Flooding	Buried 20 ha maize, nine houses submerged in Bikri; Several cattle, pig, goat swept away in flood; Stored grains damaged.	Transferred household stuff and livestock in a safe place; Flood control river wall and spur constructed in few places.
2005 (2062)	Flooding	Approx. 10 ha riverbank erosion with standing field crops in Thapuwa	Grain and food support from relatives; Flood control river wall and spur construction; Cleaning of water drainage canal in the village.
2007 (2064)	Hailstones	It can happen from throughout the winter to spring season (November–May); Damaged wheat and lentil.	No measures; People believe it as a natural phenomenon.
2014 (2071)	Flooding, Insect-disease	Riverbank erosion about 8 ha and damaged 33 ha standing rice in Thapuwa and 12 ha in Bikri.	Earthen embankment and stone filled in gabion wires spur constructed.
2017 (2073)	Drought	Reduced rice yield reported in varying levels (15–25%).	Irrigation, local landrace, short growth period rice variety and early rice transplantation.
2017 (2074)	Flooding, Insect-disease	Land erosion with field crops about 8 ha, partially damaged 47 ha of rice in Thapuwa; In Bikri, 30 ha of rice were buried and the rice field was deposited with sand; Rice panicle-cutting insects (armyworm) problem in the flooding year. Damaged 12 ha of rice.	Direct seeding of local rice landrace (*Karangi*) was done; Earthen embankment constructed, many houses shifted to a safe area, house foundation constructed at flooding height; Irrigation of rice if it is still in early maturity state, early harvesting of rice to protect from armyworm.
2017 (2074)	Storm	Strong wind during summer before monsoon starts is a regular phenomenon every year, though, the frequency and intensity vary; Damaged house, trees and destroys summer maize	House design north-south facing, house roofing materials fastened tightly.
2017 (2074)	Cold waves	Hard to work in the field, children and elderly people suffer from cold and, pneumonia, and some crops such as potato suffered from late blight disease.	Wearing of warm dress, woollen cap and muffler; Firewood and rice husk are burning to warm up human and livestock; Spraying of ash and fungicide in crops

*Figures in Parentheses are *Bikram Sambat* – Nepali vernacular calendar, which is almost 57 years earlier than the Gregorian calendar.

accessibility to extension services lowers the vulnerability. The educational level of household determines the adaptation through facilitating accessing information, as well as training and services from government, non-government and private sector agencies.

Tharu adaptation options to the two major climatic hazards, flooding and droughts, can be divided into three groups – adaptations in agriculture, income diversification and migration. The adoption of improved varieties and practices has been increasing in the villages, particularly for major grains, while locally adapted traditional practices have also continued with regard to landraces. We found that about 90% of households have shifted maize cultivation from the monsoon season to the winter season, and they now cultivate rice during the monsoon season in maize fields. Similarly, most farmers used improved and hybrid varieties of rice, wheat and maize (93%) and inorganic fertilizer, pesticides and herbicides (95%). Farmers still have not replaced all landraces; they have allocated a certain percentage for the local varieties in major cereals (rice, wheat and maize), but a significant portion for minor crops (lentil, pea, mustard) and vegetables. Inorganic fertilizer was found used in combination with farmyard manure, and herbicide use has recently started in rice and wheat – particularly in Thapuwa. Considering off-farm based adaptations, 41% of households diversified income through various skilled and un-skilled employment in the village and local market. Youth have been attracted to carpentry, masonry and iron-work. In recent decades, youth labour migration (31%) (domestic and overseas) has started. Small, poor and marginalized families mainly migrated to domestic and Indian labour markets, whereas members of households of medium-sized landowners (0.5–2 ha) largely entered into foreign labour markets, such as in Malaysia, Qatar and Saudi Arabia.

The perceptions and experienced impact of climate change also differed by gender. The lower adaptive capacity of women due to socioeconomic and cultural constraints render Tharu women more vulnerable than the men. Women are culturally restricted from performing certain agricultural activities, such as ploughing and driving bullock carts. The wives of migrant workers and widows suffer from such restrictions, which results in poor production. As one participant indicated,

> My husband went to India without informing me at a critical stage of having a daughter; even the navel cord had not fallen off. He became out of contact for many months because of no communication means in a village like this [showing her mobile phone]. I cannot live separately from the joint family in the absence of my husband for ploughing land and bund preparation in the rice field. He came home after five years and started a small retail shop in the village, but the shop was destroyed and the house was cracked by flooding so, he went to Qatar two years ago. I cannot continue farming in my husband's absence.

3.4.1. Flooding and adaptation

Flooding was rated as the most disastrous hazard in the study villages. Flooding destroyed houses and roads, swept away stored grain, affected livestock, inundated standing crops, and sometimes caused irreversible damage to agricultural land by converting it into sandy riverbed (about 181 ha, calculated from Table 5). There have been no human casualties in the study villages, but considerable cattle, small livestock and poultry have been swept away by flooding. The impact has been greater in Thapuwa than in Bikri in terms of house damage and loss of land, livestock and crops. The flooding has multiple implications for social, cultural, and overall poverty among the Tharu. The market value of land in the flood-prone area has reduced, and banks selectively take land as collateral for loans. Flooding of the Babai River and the Kanjarwa stream reduces mobility and poses risks for travel to school, work and marketing agricultural produce, mainly from Bikri. There was no all-season road, and no bridge over the Kanjarwa, to connect to Bikri. People in flood-prone areas are stigmatised by others as 'unsettled' and may need to move their houses. Parents hesitate to marry their daughters into flood-prone areas due to community vulnerability. It has changed the Tharu traditional pattern of inhabiting one-storey houses into living in two-storey houses (*thanthi/tauwa*).

As the Tharu have not had access to any specific flooding prediction technologies, they have relied on their IK, as well as scientific weather forecasts. Tharu IK uses a combination of physical and biological indicators to predict extreme climate phenomena, such as excessive rainfall and droughts. Physical indicators include wind speed and its direction according to the local season, such as the locally identified *Rawaniya* wind that blows from the southeast to the northwest during the monsoon season. Similarly, insect, bird and animal behaviours were considered as biological indicators for flooding and droughts, such as hens spreading their feathers under the *chharin* (balcony) of a house. Furthermore, they also performed rituals called '*gaiya berhna*' and '*magha lotna*' to induce rain. As adherents of Hinduism, the Tharu believe that the god of rain, Indra, listens to the voice of people in the performance of *gaiya berhna* and to children's rain requests in the form of producing the sound of a frog in *magha lotna*, as the Tharu believe that rain comes upon the crying of the frog.

Protecting houses and agriculture from flooding is an important adaptation strategy for the Tharu. A recent integration of an early warning system for flooding into the Tharu *barghar* village leadership institution and helping each other to cope with flooding have reduced vulnerability. In agriculture, farmers cultivated traditional rice varieties (e.g. *Karangi* and *Sauthyari*) when flooding destroyed transplanted rice and there was either unavailability of rice seedlings or it was too late in the season to cultivate other varieties. *Karangi* and *Sauthyari* are drought tolerant and short-growth-period rice varieties that can be directly seeded in a dry as well as into a wet bed. Tharu use *dehari* (large earthen grain storage vessels) as an Indigenous crop storage technology that is at least partially oriented toward safety from flooding. *Dehari* has been modified in the flood-prone village by raising the leg height with water-insoluble materials, such as wood and bricks instead of mud.

Multiple stakeholders have intervened to support local coping responses and strengthen adaptive capacity of the Tharu. The Red Cross Society and NGOs have supported the short-term immediate coping responses during flooding and the post-flooding period, whereas government agencies have focused on long-term adaptation. The *barghar* and *chaukidar* facilitate effective dissemination of information and responses during flooding disasters. The villagers have received disaster preparedness training from NGOs, including safety houses built in both villages. Post-flooding adaptation measures, such as tree planting along riverbanks and a temporary river wall erected by piling sacks filled with sand, have proven not to be effective as long-term solutions. Now, as a long-term planned adaptation strategy, earthen embankments and wire fencing filled with stone are being constructed by the government to control flooding in both villages.

3.4.2. Droughts and adaptation

Drought was the second most important hazard in Bikri, but not in Thapuwa. The most severe droughts remembered were in 1979 and 1988. Participants indicated that the production of rice and maize was severely affected. The drying up of the rice in the field caused food scarcity, so many farmers had to borrow rice from *mahajan* (money lenders). Man Bahadur, aged 45 years, from Bikri recalled:

> In the past, drought was more frequent and severe, the growing period of rice was long, and irrigation machinery was lacking. Almost every year we used to suffer from drought, though there was not a complete failure of crops. In 1979 and 1988, rice even dried up in the field, so we cut it and fed it to cattle. Rice planted in the *jabda* (lowlands rice field) did not develop grain as well. We had a terrible food scarcity in the village, so we borrowed partially boiled rice and money from *mahajan* (money lenders) in Nepalgunj. It took us a long time to repay because of the high interest rate.

Drought was still a common threat despite the use of an irrigation canal in Bikri and the pumping of underground water at Thapuwa. During the interviews, six farmers (five from Bikri and one from Thapuwa) commented upon reductions of rice yield at varying levels from 10% to 20% in 2016/2017. Furthermore, farmers perceived a reduced duration of drought, particularly in the post-monsoon period because by that time most of the short-growth-duration rice is ready for harvest. Farmers also experienced a greater problem with weeds during drought than in a year with flooding.

In response to drought, Tharu have resorted to traditional as well as modern agricultural practices, irrigation technology and income diversification. Formerly, farmers used to cultivate drought-tolerant traditional crop varieties, as is still practiced with direct seeding of *Karangi* and *Sauthyari* rice varieties. Moreover, Tharu people have a long tradition of relay sowing of winter crops, mostly lentil, linseed and grass pea, before harvesting the rice to utilize soil moisture and crop residues. Conservation agricultural techniques, such as covering soil with plant residues and crop rotation, are also practiced. Most of the rice fields are rotated with legumes, but in recent decades, it has been replaced with winter season maize. Similarly, mixed cropping, mostly in the winter, has reduced the risk of complete crop failure, as well as providing food diversity to smallholders. In regard to irrigation technology, the pumping of underground water is now massively used in Thapuwa for early rice transplanting and maize irrigation during the spring season (6–8 times per fortnight). Nowadays, the Tharu farmers have used non-farm based adaptation strategies, such as pursuing wage labour to diversify income, to deal with climatic shocks and stresses, including droughts.

4. Discussion

This paper draws insight from the ethnoscience perspective, which focuses on the worldview of local communities. It conceptualizes and values Indigenous views, understanding and beliefs and responses to the subject matter – in this case, climate change and agriculture (Fowler, 1977). The Tharu in the western Tarai have perceived climate change, as well as experiencing its impact on agriculture and livelihoods. Indigenous knowledge has helped them to perceive changes in weather, decreased vulnerability to extremes and also provided strategies for adaptation and mitigation.

The perception of the Tharu regarding changes in temperature triangulates with the meteorological data during both monsoon (June–September) and winter seasons (December–February). Increasing temperatures, particularly maximum and minimum temperature during the monsoon seasons, have been reported for Nepal (DHM, 2017; Practical Action, 2009; Shrestha et al., 1999). Inconsistent perceptions of winter temperature have also been reported in Nepal (Budhathoki & Zander, 2020). The inconsistencies among perceptions of winter temperature in the area might be due to cold waves and fog in the Tarai. An increasing intensity of cold waves, foggy days with extended hours, and sudden drops in night temperatures have all been reported in the Tarai (Manandhar et al., 2011; Shrestha et al., 2018). The implication of increased temperature adversely affects the yield of major crops, including rice, wheat and maize (Howden et al., 2007; Lobell et al., 2012; Lobell et al., 2013). Further increases in temperatures are expected to reduce the yield of rice, wheat and maize in Tarai, Nepal because the temperature has reached maximum threshold levels of rice and wheat (Karna, 2014; Poudel & Kotani, 2013).

Perception of decreased rainfall by the Tharu was not validated with rainfall data because of very high year-to-year variation in rainfall. Unpredictable (low and sometimes high rainfall) and erratic rainfall patterns have been reported in Nepal (DHM, 2015, 2017; MoE/NAPA, 2010; Practical Action, 2009). Unpredictable and erratic rainfall has increased uncertainty with regard to the onset of the monsoon, which affects agriculture, mainly rice cultivation, irrigation management and sometimes off-season rainfall damage to winter crops (e.g. lentil) in the field. Drought conditions with increased temperature accelerate evapotranspiration, thereby reducing biomass, yield and quality of grain, such as in winter wheat (Asseng et al., 2004; Gooding et al., 2003; Lal, 2011). Therefore, a long-term time-series data of precipitation is required for the trend analysis and predicting future impact in different sectors, including agriculture, which is lacking in Nepal (DHM, 2017; MoE/NAPA, 2010).

Climatic extremes, especially water-related hazards – flooding and droughts – and their increasing frequency have impacted livelihoods and thus the wellbeing of the Tharu. Flooding was the most serious hazard, since flooding not only destroys physical property, but it also has impacted social and cultural aspects of people's lives. Flooding has changed the village landscape, house architecture, stigmatized those vulnerable to it as unsettled people, and induced reluctance to marry daughters into the flood-affected villages. The Tarai region of Nepal is particularly vulnerable to flooding and riverbank erosion from hydrological phenomena (Dewan, 2015; MoE/NAPA, 2010). Sharma (2016) found higher risks of flooding and landslides in the Tarai and hills of Nepal than the mountain region due to high (>400 mm) and intense rainfall exceeding 550 mm in 24 h. The government of Nepal also considers the Tarai vulnerable to flood, drought and fire (MoHA & DPNet-Nepal, 2015). Indigenous knowledge and practices to predict rainfall, flooding and climatic extremes are insufficient to cope with and reduce the impact; so, a flooding early warning system is now being provided to the villages. Yet, villagers are still waiting for a long-term solution to flooding. Similarly, drought was a regular phenomenon impacting rainfed agriculture in the study area. Farmers are more concerned about the start of monsoon rainfall rather than dry spells during crop growth. Recently, there has been no complete crop failure due to the availability of irrigation, especially canal irrigation, and agricultural technologies; hence, farmers expressed less vulnerability to droughts than formerly.

Variations in perception and adaptation are determined in part by differing amounts of livelihood capital of individuals and communities. The ownership and use of pumping equipment are determined by the amount of land ownership and household income. Small landholders owned less pumping equipment, as well as fewer tractors and other farm machinery, than large landholders, which affected their capacity for conducting timely irrigation and performing other agricultural operations. Similarly, canal irrigation in Bikri from the Babai Irrigation Project has supported seasonal irrigation. Timely provision and adequate quantities of water have been a major issue, as farmers in Bikri are tail-users of the canal, a situation which often leads to insufficient timely water. Farmers at Bikri repeatedly commented on the unavailability of water during rice transplantation, but excess water during unwanted times, such as rice harvesting and the growing season of winter pulse crops. Crop damage due to the excess discharge of water in irrigation canals when unwanted was also an issue in Bikri. Pulse crops, particularly lentil and pea, are sensitive to water-logging, and anaerobic conditions kill plants in different crop growth stages (Erskine et al., 1994; Malik et al., 2015; Wiraguna et al., 2017; Zaman et al., 2018). Shivakoti and Ostrom (2002) have described how the tail-enders are less satisfied than the head-enders in the farmer-managed irrigation system (FMIS) in Nepal, and the success of the FMIS depends on the satisfaction and relationships between head- and tail-enders. Furthermore, Pradhan et al. (1997) have analysed how the existing water users consider they have an exclusive right over the water and resist sharing it with new users, creating conflicts around water resource. The learning and application of the Tharu Indigenous irrigation management system, '*kulapani chaudhari*', can continue to contribute to water sharing and distribution between top- and end-users (Howarth & Lal, 2002).

Adaptation to perceived climate extremes (hot/cold, droughts and flooding) is influenced by the adaptive capacity of households, and adaptive capacity is largely determined by the sociocultural context, including such factors as age, gender, education, income, occupation, access to information and services (Adger et al., 2013; Deressa et al., 2011; Piya et al., 2012; Sugden et al., 2014). The influence of land ownership and size of land holdings, the role of education, access to information and services have been discussed by others in line with the findings of this research (Sugden et al., 2014; Tiwari et al., 2014). However, poor and marginalized people and communities are most vulnerable irrespective of place and accessibility (Gentle & Maraseni, 2012; Piya et al., 2016).

Given the importance of sociocultural context for adaptive capacity, Indigenous knowledge and practices of the Tharu are important for perceptions and planning for adaptation and mitigation in water, irrigation and agriculture. The general importance of IK for prediction of climatic extremes, coping and adaptation has been widely analysed; climate science alone cannot deal with the complexity of climate-related problems in their local contexts because the perceptions and responses are largely related to social-cultural and behavioural aspects of people and communities (Casimir, 2008; Ellen, 2007; Sillitoe, 2007, 2017). Tharu perform various rituals to induce rain and green, healthy and productive agriculture. Although there may not be scientific evidence for the efficacy of such ritual events, they do bring people together in harsh conditions for cooperation, allowing the creation of tacit knowledge, and its transformation and transmission (Nonaka & Takeuchi, 1995). Local perceptions and institutions are important to take action to reduce deleterious impacts and adjust to changed situations (Deressa et al., 2011). As an Indigenous institution in every Tharu village in western Nepal, the *barghar* local leadership system governs village social, cultural, quasi-judicial and agriculture-related communal work through such institutions as *begari* (free labour contributions). Linked with the *barghar*, the *guruwa* system of shamanic practice also functions to protect and promote the wellbeing of villagers and their agriculture.

Indigenous knowledge and practices help Tharu respond to changing climate for adaptation and mitigation. Although Indigenous knowledge-based agricultural practices are mostly climate-resilient, some of them have a comparatively lower yield than modern scientific practices with use of chemical inputs; therefore, most of the Indigenous or traditional agricultural practices have been decreasing in Tharu villages. Small landholders face dual responsibility for household food security and family economic needs. Improved crop varieties, agricultural inputs and production technology have been adopted in major cereal crops (rice, wheat and maize), whereas many landraces and traditional production practices or technology are still used for minor crops, such as lentil, pea, mustard and garlic. Traditional agricultural practices, such as relay sowing of lentil before rice harvest and mixed cropping of lentil/pea with mustard, are still intensively practiced in Tharu villages. This system incorporates legume crops in the rice field, thereby improving soil and human health. Relay sowing and no/zero-tillage also reduce emissions, energy use and help to mitigate the effects of emissions. Fewer greenhouse gases emissions, low use of direct energy, increased yield in the long-term (>5 years), increased water productivity and reduced production costs are described for such conservation agriculture, as well as for no/zero-tillage system as compared to the conventional full-tillage system (Jat et al., 2014; Pokhrel & Soni, 2018; Sapkota et al., 2015). Our study has shown the contribution of traditional agricultural practices for adaptation and mitigation, but has neither calculated nor projected the quantitative contribution to mitigation, which might be useful to conduct at the district and national levels in Nepal. Furthermore, this research has provided limited quantitative data to back up the contribution of traditional agricultural practices and associated knowledge to reduce climate vulnerability and improving wellbeing of the Tharu.

The research has nevertheless demonstrated many insights from the perspective of Indigenous people in terms of climate perceptions, its impact, vulnerability and local responses that contribute to the theoretical discourse of integration of Indigenous and scientific knowledge in hybrid knowledge systems for resilient agriculture and conservation of agro-biodiversity. In terms of policy implications, the research has documented and explored some Tharu Indigenous knowledge and practices that can be further studied by agricultural research for use in response to the needs and vulnerability of Tarai farmers to improve livelihood and adaptive capacity of farmers. For the Tharu community, the research helps identify climatic extremes and vulnerability, particularly to water-related hazards, that will assist their planning for adaptation and reduced vulnerability with support from local authorities.

5. Conclusions

Water is a critically important natural resource whose use is subject to cultural criteria of perception and social regimens of control. Water-related extremes, such as flooding or droughts, are directly induced by changes in climate, such as increased variability. The Tharu in the western Tarai of Nepal have perceived a consistent increase in temperatures, and this perception has been validated with meteorological data. Flooding and droughts are the two water-related hazards with the greatest impact upon Tharu agriculture and livelihoods. With the availability of irrigation, droughts are now considered less hazardous to cropping.

We conclude that neither Indigenous knowledge nor scientific knowledge alone is sufficient to improve the resilience of Tharu farming communities. The Tharu have embraced ‘hybrid knowledge’ – a combination of Indigenous and scientific knowledge, technology and practice to increase yield and maximize profit as well as decrease vulnerability to extreme weather events. This hybridity is evident in the complementarity of the employment of modern varieties and scientific agricultural practices for the major grains and the continuing use of landraces for minor crops such as lentils, peas and mustard. Indigenous knowledge-based agriculture encourages the use of local resources, low-energy intensive practices and the conservation of crop biodiversity, which can provide options of the diversity of knowledge for decisions making and policy options in national and global levels.

Our findings regarding the main drivers of adaptive capacity indicate that three interventions could further reduce the vulnerability of the Tharu against climatic extremes and both flooding and drought: first, providing skill enhancement and vocational training, particularly for youth, to diversify the income of smallholders through off-farm related activities; second, continuing infrastructure provision for improved safety and accessibility; and, third, strengthening agricultural extension services to provide techniques to reduce the risk of flooding and droughts. While water is a pre-requisite for life and livelihoods, climate changes, such as increased climatic variability, increase the potential for hazards such as floods and droughts. Local adaptations based on hybrid knowledge can help mitigate these trends by contributing to the improved management of water and its associated hazards.

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