emerald PUBLISHING

ISSN 1756-8692
Volume **12** Number **1 2020**

International Journal of

Climate Change Strategies and Management

Published in association with

International Climate Change Information Programme
ICCIP
Internationales Klimawandel-Informationsprogramm

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ISSN 1756-8692

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Journal Citation Reports/Social Sciences Edition
QUALIS
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Effects of a changing climate on livelihoods of forest dependent communities

Evidence from Buyangu community proximal to Kakamega tropical rain forest in Kenya

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Received 7 January 2018
Revised 16 May 2018
17 January 2019
7 May 2019
Accepted 22 August 2019

Abstract

Purpose – Climate change and variability present different challenges to the livelihoods of forest-dependent communities. This paper aims to determine climate variability/change and its effects on the livelihoods of the Buyangu community, which depends on Kakamega tropical rain forest in Kenya.

Design/methodology/approach – Rainfall and temperature trends were analysed using Mann–Kendall tests and Sen's slope estimator. The effects of climate variability on the community were determined using household survey questionnaires, focus group discussions and in-depth interviews with key stakeholders.

Findings – Temperature trend analyses represent statistically significant trends for the period of 1980-2015. Results reveal a warming trend for both mean annual maximum temperatures and mean annual minimum temperatures by 0.04°C/year and 0.02°C/year, respectively. Moreover, analysis of annual precipitation (1923-2015) indicated an increase of 0.068 mm/year; however, the mean monthly rainfall showed a decreasing trend. As a result, crop production and livestock rearing are negatively affected. Although there is a high level of awareness of climate variability and its related effects on livelihoods, a majority of the Buyangu community still do not understand the influence of climate change on forests and the provision of forest products. Lack of knowledge on this subject will consequently limit adaptation responses.

Originality/value – This research fulfills the need to study climate variability and its effects on the livelihoods of forest-dependent communities. The study calls for all-round stakeholder participation of local and national players in formulating coherent adaptation strategies that will enhance the resilience of forest-dependent communities to a changing climate.

Keywords Climate variability/change, Livelihoods, Effects, Buyangu community, Kakamega forest

Paper type Research paper

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Data for this study was collected by the lead author for her Masters studies. The fieldwork activities and publication of this paper was made possible by research funding received from African Forest Forum (AFF). Special thanks goes to the reviewers for their insightful comments from which this paper emanates.

International Journal of Climate Change Strategies and Management
Vol. 12 No. 1, 2020
pp. 1-21
Emerald Publishing Limited
1756-8692
DOI 10.1108/IJCCSM-01-2018-0002

1. Introduction

Africa is one of the continents most vulnerable to the effects of climate change and variability, owing to its high exposure and low adaptive capacity. This is aggravated by multiple stress factors that are non-climatic, such as high poverty levels, population pressures and overexploitation (Intergovernmental Panel on Climate Change (IPCC), 2014). It is been widely projected that as global warming persists, climatic conditions will become more unpredictable.

In sub-Saharan Africa (SSA), climate change projections manifest a warming trend with changes in precipitation patterns (Serdeczny *et al.*, 2015). The severity of climatic events is increasingly becoming a challenge not only to humanity but also to the existing natural systems (Intergovernmental Panel on Climate Change (IPCC), 2012). The main sectors in this region – agriculture, forestry, health and transport – forming the backbone of the national economy are the hardest hit. Currently, millions of people across SSA depend on forest products and services for their daily income and well-being. However, not all incomes of forest-based communities are obtained from forest products alone. Often, part of the income is also gathered from agricultural activities and other livelihood options (Adhikari *et al.*, 2004).

In recent years, Kenya's forests have been depleted at an alarming rate with the current forest cover estimated at 7.4 per cent of total land area, which is below the recommended global minimum of 10 per cent (FAO, 2010). The low forest cover in the country is largely attributed to deforestation, induced by excessive human activities, such as illegal logging, unsustainable charcoal production and clearing of forests for farming and settlement (Lambrechts *et al.*, 2005; Ongong'a and Sweta, 2014), resulting in forest fragmentation. Kakamega Forest, the only tropical rainforest in Kenya, is no exception as nearly half of it has been lost in the past 38 years due to human activity, leaving only about 230 km^2 of it standing [Kakamega Forest Ecosystem Management Plan (KFEMP), 2012]. While the Government of Kenya (GOK) has made enormous efforts to protect this forest from human interference, it is difficult to save it from the impact of climate change.

Of particular concern are the livelihoods of the Buyangu community, who live in close proximity to Kakamega Forest and who draw on forest resources to support their livelihoods. Added to the low adaptive capacities of rural populations, climate change impacts on forests will exacerbate the vulnerability of any forest-dependent community (Davidson *et al.*, 2004; Okali, 2011). Past studies conducted in Kakamega County have identified and emphasised the impacts of climate change on smallholding farmers (Barasa *et al.*, 2015; Ochenje *et al.*, 2016; Mulinya, 2017). However, little is known and documented on climate variability and related impacts on the communities that depend on Kakamega Forest.

Sadly, most climate change studies have either ignored or devalued climate variability, probably due to uncertainties with regard to expected future changes in rainfall and temperature variability (Ramirez-Villegas *et al.*, 2013; Thornton *et al.*, 2014). For this reason, the effects of climate variability on forest-dependent communities are still poorly understood (Williamson *et al.*, 2005; Turpie and Visser, 2013). Understanding climate variability trends is critical in mitigating adverse effects on the livelihoods of forest-dependent communities.

Against this backdrop, this study sought to determine the impacts of a changing climate on the Buyangu community's sources of livelihoods and its dependence on Kakamega tropical rain forest. The findings will not only enrich our understanding of climate variability and its related impacts on such communities but also will provide insights to

researchers and policymakers on practical initiatives needed to enhance resilience at the local scale.

2. Literature review

The interaction between climate change and forest-dependent communities cannot be underestimated. Climate change will interfere with entire livelihoods of the rural poor, producing both negative and positive effects: negative externalities often being more pronounced (Somorin, 2010). Past studies have demonstrated how forested areas and their surroundings have experienced general reductions in precipitation and increases in temperature over time (Stern, 2007; Boon and Ahenkan, 2011). These changes profoundly affect the overall health of the ecosystem, reducing the supply of forest materials such as foods, fuelwood, medicinal herbs and other non-timber forest products (NTFPs). In due course, this will impose additional stress on the livelihoods of mostly poor, forest-dependent people.

Perhaps, the most severe is the impacts of weather extremes on NTFPs, which are becoming scarcer by the day (Easterling *et al.*, 2007). Changing climate patterns cause biodiversity loss, as forest plant species become extinct, leading to further ecological destabilisation and an alteration of community livelihoods in the affected areas (Dube *et al.*, 2016). However, Seppälä *et al.* (2009) notes that climate change effects on NTFPs are still not clear, as there is still uncertainty regarding the ecological effects. Needless to say, NTFPs thrive on the delicate balance of natural factors.

On the same perspective, weather extremes are well-known to have grave impacts on agricultural farming. As rural livelihoods become more precarious, rain-fed agricultural and livestock systems will bear the brunt of climate extremes, adding to the vulnerability of forest-dependent communities who form a significant portion of poor rural farmers (Ofoegbu *et al.*, 2016). Specifically, reduced crop yields compromise food security, affecting the health conditions of vulnerable groups including the elderly, women and children (Altieri and Nicholls, 2017). Moreover, while grazing animals inside forests is a widespread practice among forest-adjacent communities, biodiversity loss means inadequate pastures and this adds more psychological pressures on livestock farmers, who will be forced to look for alternative animal feeds.

Also, as climate changes, populations living within fragmented forests stand a higher risk of contracting zoonotic infectious diseases such as yellow fever, dengue, malaria and sleeping sickness, arising out of increased contact with vectors at the forest edges (Graczyk, 2002). Furthermore, when temperatures rise to a critical level, forest fires are expected to occur more frequently, causing various respiratory diseases associated with smoke inhalation, such as asthma and bronchitis (Molyneux, 2003).

Last but not least, communities closely entwined with forests tend to regard them with much spirituality and respect, believing that powerful spirits are resident within (Laird, 2004). Indeed, most African forests have been used as gathering points where community leaders meet with their people to discuss crucial issues or conduct important ceremonies, such as circumcision. A lot of the ceremonies are conducted under sacred trees such as *Maesopsis eminii* (Mutere) and *Brachystegia spiciformis* (Musasa) in Western Kenya. The cultural and spiritual values associated with forests and trees underline the importance of considering the social dimension of climate change on the livelihoods of forest communities. It must, therefore, be emphasised that climate change will induce fundamental changes to the cultural values of forest-dependent communities (Seppälä *et al.*, 2009).

3. Research methodology

This section presents the methodology of the study, describing the characteristics of the study area, sampling procedure, the main techniques used for data collection and data analysis.

3.1 Description of the study area

The study was carried out in Buyangu village, near Kakamega tropical rain forest in Kakamega County (Figure 1). The forest is located in Western Province in Kenya at 0.29°N 34.86°E. The choice of the study site was informed by its high human population with higher demands on forest products (Muller and Mburu, 2009) but whose accessibility is prohibited by Kenya Wildlife Service (KWS), a state corporation whose mandate is to enhance conservation of wildlife and its resources, including protecting forests from human interference. The study targeted households living within 6 km from the forest margin, as they are the largest consumers of the forest's resources, despite the visibility of KWS officers (Mbuvi *et al.*, 2009). The area receives bimodal rains of about 2,000 mm annually and temperatures range from 18°C to 29°C. January-March are the hottest months while April-July receive the most rainfall (GOK, 2013). Forest resources, rain-fed agriculture and livestock are key to the livelihoods of the majority of Buyangu dwellers.

3.2 Research design

The study undertook a transdisciplinary approach, which emphasises the collaboration and engagement of all stakeholders, including the local communities, in addressing complex societal challenges such as climate change and its effects (Balsiger, 2004; Ramadier, 2004). A

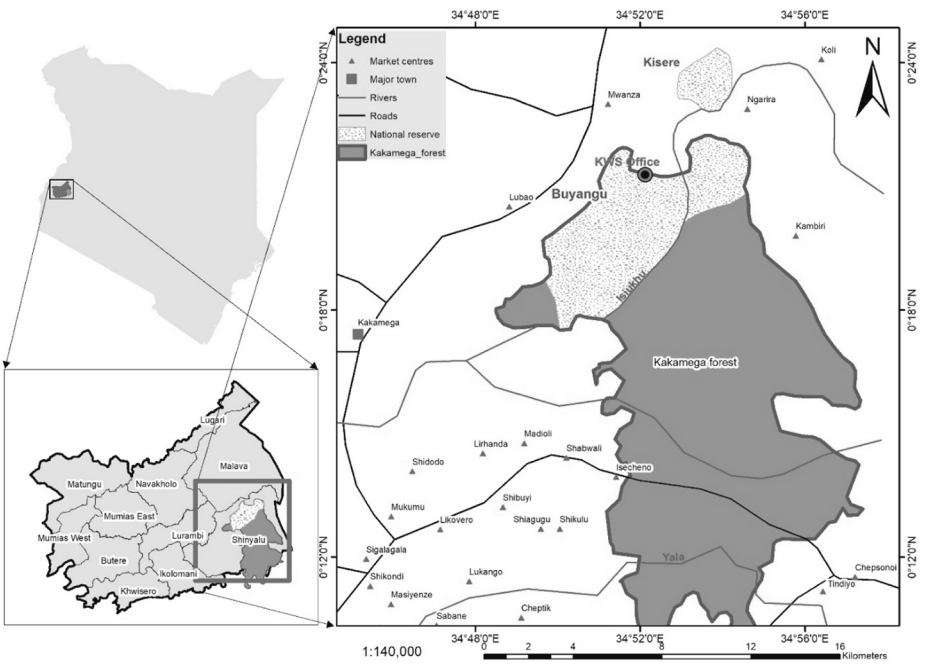

Figure 1.
Location map of Buyangu in Kakamega County

mixed research method was used, using both qualitative and quantitative techniques to understand the research problem.

3.2.1 Sampling technique and sample size. Simple stratified random sampling was used to categorise households in Buyangu. This technique was considered supreme as the target population is heterogeneous and not widely spread out geographically. Past studies have used simple random sampling in selecting households living adjacent to forests (Balama *et al.*, 2016), which in most cases results into underrepresentation or overrepresentation of some elements within the groups. According to Alvi (2016), simple random sampling works better in a homogenous population where an exhaustive list of elements is available. Relative to simple random sampling, selection of units using a stratified procedure improves representation of particular strata (groups) within the population. Thus, households were divided into three strata according to their distance from the forest edge: 0-2 km, 2-4 km and 4-6 km. Efforts were made to map out both male- and female-headed households in each stratum during the reconnaissance survey. All female-headed households identified in the three strata were purposively sampled to ensure adequacy in female gender sample representation. However, male-headed households were selected for a household survey through simple random sampling. A considerable sample of 203 was arrived at through Yamane (1967) formula.

3.2.2 Data collection process. A variety of data collection methods were incorporated to collect both quantitative and qualitative data from both primary and secondary sources. Primary data was gathered through household survey questionnaires, focus group discussions (FGDs), key informant interviews (KII), desk research and observations. Generally, the questionnaire administered to household heads captured the socio-economic activities in Buyangu, knowledge of climate variability and its effects on the main sources of livelihoods. Two separate FGDs were organised (men and women), with an average of eight participants in each. Both the FGDs created a forum for interaction and discussions on climate variability and how it impacts the community's livelihoods. More insights were gathered from key informants: forest officers (KWS), agricultural officers, the area chief and village elders in Buyangu.

Past meteorological data on rainfall and temperature parameters was sourced from Kenya Meteorological Department (Sichirai station) located at 0.28°N 34.75°. Data included average monthly rainfall for the years between 1923 and 2015, as well as minimum and maximum temperatures covering 1980-2015 to support analysis. Similarly, average crop yields data for common crops in Buyangu for the period 1985 to 2015 were compiled from different annual reports provided by the Ministry of Agriculture, Livestock and Fisheries in Kakamega County.

3.2.3 Data analysis. Analysis combined both qualitative and quantitative approaches. The Mann–Kendall (MK) test, a non-parametric test, was considered the most ideal to determine rainfall and temperatures trends over time. This test was applied at 95 per cent confidence levels and used as described by Sneyers (1990). Positive (+ve) values from the results indicated an increase over time while negative (−ve) values point to a decreasing trend. MK detects non-linear trends but is limited in showing the magnitudes of significant trends (Babar and Ramesh, 2013). Thus, Sen's slope estimator, also a non-parametric test, was used to detect magnitudes of climatic trends for both rainfall and temperatures.

Predictions of yield changes in response to changes in climate variables were assessed through multiple regression, which is considered relatively accurate (Lobell and Field, 2007; Boubacar, 2010). Further, an analysis was carried out on common crops cultivated in the

region (dependent variables) and climate variables (annual mean temperature and annual mean rainfall), which were considered explanatory variables. Additional quantitative analyses were derived through SPSS 16 and Microsoft Excel. Qualitative data obtained from FGDs and KII were analysed thematically.

4. Results and discussion

4.1 Analysis of rainfall and temperature variability in Kakamega

4.1.1 Mean monthly rainfall variability. Observations of the behaviour of mean monthly rainfall for the period 1923-2015 indicate a rainy season in the months of April (255 mm) and May (257 mm) (Figure 2). The precipitation then slightly subsides in June before picking up again in July with August registering higher amounts (222 mm). December, January and February recorded the least amount of rainfall at 91 , 68 and 92 mm, respectively. Generally, the March-April-May (MAM) peaks were stronger than the October-November-December (OND) peaks. According to Nicholson (2017), MAM constitutes the long rainy season, while OND covers the short rain season in most parts of equatorial Eastern Africa. This coincides with crossing the inter tropical convergence zone along the equator in south-north, before taking the north-south migration (Camberlin and Philippon, 2002).

MK tests for mean monthly rainfall (1923-2015) indicate positive trends in January, March, April, September, October, November and December (Table I).

However, increase of rainfall both in October and November were declared significant at $\alpha = 0.01$. The remaining calendar months displayed trends that were not significant, with the exception of July, which was significant at 95 per cent level. Sen's slope ranged between -0.543 and 0.761 for the same climatological period. Results on the magnitude of change are largely negative, with the month of May indicating a decline in rainfall by 0.543 mm/year. On the same note, the magnitude of change was highly positive in November implying an increased precipitation by 0.0761 mm/year.

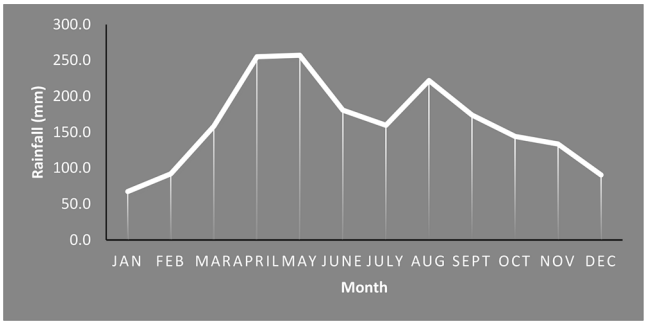

Figure 2.
Mean monthly rainfall in Kakamega (1923-2015)

Test methods	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
MK test (Z)	1	−1.77+	1.88+	0.3	−1.78+	−1.23	−2.2*	−0.77	0.93	2.79**	3.04**	1.15	0.97
Sen's slope (Q)	0.181	−0.38	0.596	0.104	−0.543	−0.265	−0.518	−0.234	0.262	0.619	0.761	0.237	0.068

Notes: **Trend at $\alpha = 0.01$; *trend at $\alpha = 0.05$; $^{+}$trend at $\alpha = 0.1$

Table I.
Rainfall MK test

4.1.2 Mean annual rainfall variability. Figure 3 below shows appreciable variations of mean annual rainfall for the period 1923-2015. Notable peaks of rainfalls were experienced between 1963 and 1983, whereas significant dips were emerged in 1988 and 2012. While coefficient of rainfall variation (R^2 linear = 0.193) was low and probably insignificant, the cumulative effects of rainfall variability are expected to advance in future with less predictability.

The MK test for annual precipitation for the same period was found to increase by 0.068 mm/year (Table I), probably due to increased frequency of hailstorms in the region during previous years. Lau and Wu (2007) asserted that satellite-based studies conducted in the tropics during 1979-2003 reported an increase in the occurrence of heavy rain-related events.

4.1.3 Mean monthly temperature variability. Maximum and minimum temperatures in Kakamega County both escalate from January to April while they are at their lowest from July to September (Figure 4). It is important to note that onset of the long rainy season is always expected towards the end of March and into the month of April. Given that April comes immediately after a dry spell (January-March), temperatures in the region would still be expected to be higher as displayed in the graph (Figure 4). February was the hottest (31°C) month during the climatological period while September was the coolest at 13.6°C. The three-month period July, August and September recorded the lowest minimum temperatures, while April had the highest minimum temperature of 15.2°C. These findings concur with observations made by Barasa *et al.* (2015) on temperature variations in the region. Generally, it can be deduced that temperature trends on both scales (maximum and minimum) increase/decrease almost at the same time range.

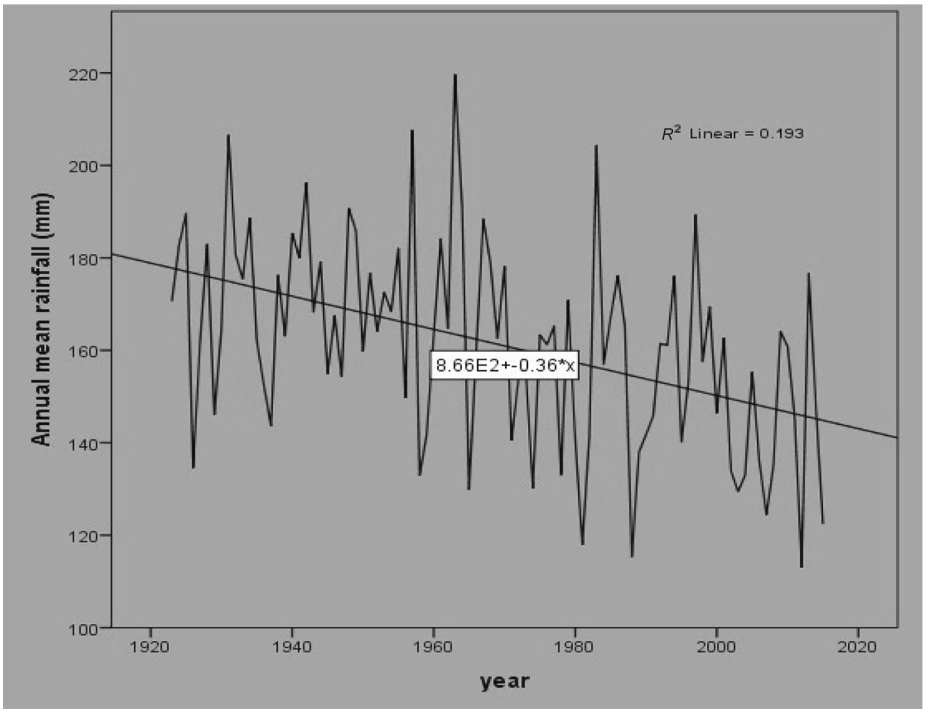

Figure 3.
Mean annual rainfall in Kakamega (1923-2015)

4.1.4 Mean annual temperature variability. Figure 5 below represents the mean annual temperature trends for the period 1980-2015. There was variability in both annual mean maximum and minimum temperatures, with the highest values recorded in 2009 and 2014. The lowest mean maximum temperatures of 19.9°C, 20.4°C and 22.6°C were recorded in 1999, 1991 and 1994, respectively. Similarly, mean minimum temperatures were lowest (10.4°C) in 1999. This coincides with the lowest maximum temperatures recorded for the same year, marking 1999 as the coolest year for the entire period under examination. However, the highest minimum temperatures (15°C) occurred in 2010.

The MK test for maximum and minimum temperatures indicates positive trends, suggesting that temperatures have been on the rise for the climatological period 1980-2015 (Table II).

With regard to maximum temperatures, the rise was found to be significant at $\alpha = 0.05$ for January, February, September, November and December. The magnitude of the temperature increase as represented by Sen's slope was 0.019°C/year for minimum temperatures and 0.037°C/year for maximum temperatures. The findings indicate that global warming is being felt in the region, echoing Mulinya *et al.* (2016), who observed similar characteristics in temperature trends. The knowledge of the significance of temperature variations is pertinent in the understanding of climate change.

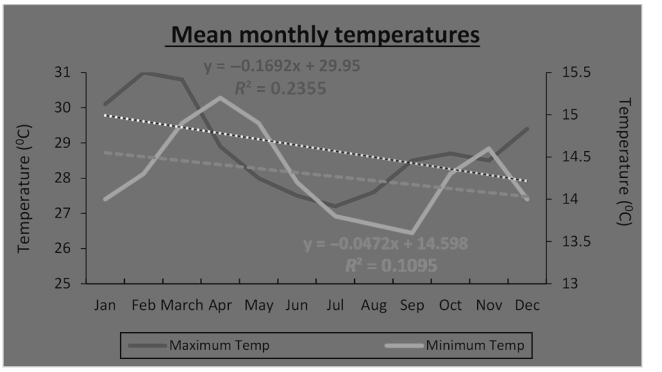

Figure 4.
Mean monthly maximum and minimum temperatures (1980-2015)

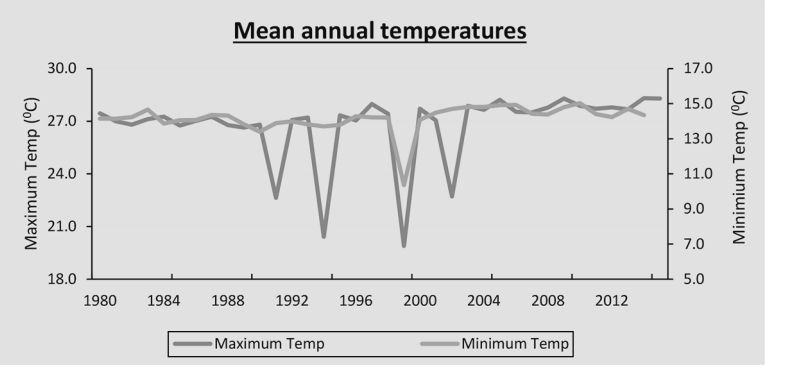

Figure 5.
Mean annual temperatures in Kakamega (1980-2015)

Variable	Z test		Sen's slope	
	Max temp	Min temp	Max temp	Min temp
January	2.32*	1.38	0.054	0.016
February	2.11*	0.79	0.058	0.009
March	1.91^{+}	0.93	0.047	0.005
April	3.39***	0.35	0.066	0.003
May	4.92***	0.78	0.049	0.007
June	4.02***	2.22	0.039	0.016
July	4.43***	3.56	0.059	0.024
August	3.26**	2.87	0.033	0.024
September	1.99*	2.93	0.018	0.029
October	1.17	2.85**	0.014	0.025
November	2.19*	1.81+	0.027	0.019
December	1.96*	1.59	0.032	0.015
Annual	4.78***	3.06**	0.037	0.019

Notes: ***Trend at $\alpha = 0.001$; **trend at $\alpha = 0.01$; *trend at $\alpha = 0.05$; $^{+}$trend at $\alpha = 0$

Table II. Mann–Kendall test and sen's slope for max and min temperatures

4.2 Perceptions of climate variability

The views collected from study participants as regards to climate variability were vital for comparison with meteorological data. In general, the majority of respondents were aware of climate variability and would explain their experiences using observable features, such as delayed rainfall, rising temperatures and prolonged drought spells over the past 20 years and more (Table III).

Many respondents felt that rainfall patterns were uncertain, probably due to large interannual fluctuations in rainfall quantities over the years. These perceptions reinforce our findings on the meteorological data analysis on temperatures and rainfall patterns. Simply, it can be deduced that farmers are cognizant of climate variability and its effects on livelihoods, especially on a short-term basis. Concerns about rural people's ability to perceive climate change and variability is equally important as many farmers may take

Perceptions of respondents	Frequency	(%)
Weather changes experienced		
Delayed rainfall	91	44.7
Long dry spells	74	36.5
Heavy rainfall (hailstorms)	9	4.7
Rising temperatures	29	14.1
Total	203	100
Rainfall trends		
Increasing	17	8.2
Decreasing	153	75.3
Unpredictable	33	16.5
Total	203	100
Temperature trends		
Increasing	193	95.3
Decreasing total	10	4.7
	203	100

Table III. Perceptions of climate variability in the past 10-20 years

longer to understand the unusual weather patterns, which actually represent a permanent shift in climate (Maddison, 2007). In the same vein, Simelton *et al.* (2013) suggested that locals' perspectives of climate variability play a significant role in addressing climate change, as farmers are likely to adapt.

4.3 Effects of climate variability on livelihood options of Buyangu community

Climate variability has affected the main sources of livelihood of Buyangu residents in several ways. The key ones are crop farming and livestock rearing.

4.3.1 Effects of climate variability on crop production. Based on the perspectives of farmers in Buyangu, Table IV displays a myriad of negative effects on crop production caused by climate variation. Feedback provided shows that there has been a high decline in common crop productivity over the past years with maize, sugarcane and vegetables being hardest hit.

These findings are in agreement with previous studies conducted in the region, when farmers experienced a decline in crop yields during years past (Barasa *et al.*, 2015; Mulinya *et al.*, 2016). Buyangu is predominantly home to an *Abaluhya* community that relies heavily on maize for preparation of an Ugali meal. And whenever there is an increase in climate extremes, the disruption falls on maize production. For instance, one farmer told us:

> We are now harvesting nearly half the yield we used to harvest some years ago from the same piece of land. While most of us are poor, we cannot afford to buy fertilizers to multiply our harvests.

Another farmer added:

> We used to plant and harvest maize twice a year because even short rains were sufficient and reliable, but nowadays we plant once a year as the short rains are no longer predictable.

Maize has been observed to be highly sensitive not only to water deficiencies but also temperature variability (Slingo *et al.*, 2005; Lobell *et al.*, 2011). Multiple reasons can be assigned to declining crop yields, and lack of farming accessories (e.g. fertiliser) for smallholding farmers cannot be underestimated. The authors argue that because Buyangu

Table IV.
Effects of climate variability on crop production

Effects on crops	(%)
Impacts of climate variability on crop production	
Reduced yields of common crops	52
Floods on farms	32
Increased pests and disease attacks	16
Total	100
The degree of impact of climate variability on crop yields	
High	58
Moderate	33
Insignificant	9
Total	100
Most affected crops	
Maize	62
Sugarcane	34
Vegetables	4
Total	100

is a community accustomed to high levels of poverty, the fall in crop yields may be a result of other combined factors of which climate variability cannot be overruled.

4.3.2 Trend of common crop yields. Multiple regression analysis was undertaken to establish relationships between productivity of common crops (Kgs per hectare) and climate variables as shown in Table V.

Yield trends of common crops based on regression coefficient over time shows that the effect of rainfall variability was statistically significant on sugarcane and cabbages ($p < 0.05$) resulting into 93.2 and 77 per cent decline in yields, respectively. However, trends of yields for other crops, including maize, displayed no significant changes as regards variations in temperature and rainfall over time. Authors explain that drops in maize harvests as attested by almost 62 per cent of the respondents (Table IV) are probably due to delays in the onset of rains, but farmers strive to improve yields thereafter by using top dressing fertilisers and compost manure.

4.3.3 Nature of livestock production in Buyangu. Livestock keeping is a mainstay of most rural households in Kenya and contributes significantly to their livelihoods. In Buyangu, many households rear livestock, such as cattle, pigs, goats and chickens (or some combination of these), mainly to generate income and for subsistence. According to the Kakamega County Integrated Plan (2018-2022), chicken rearing is predominant with 63 per cent of the households keeping them while 24 per cent are engaged in cattle rearing. Another 6, 5 and 2 per cent of the population rear sheep, goats and pigs, respectively (Figure 6).

This is also a replica of the Buyangu community, where chicken farming is commonest followed by cattle keeping. While 66 per cent of cattle farmers in Buyangu kept 1-3 animals, a significant 27 per cent of farmers did not rear cattle (Table VI).

	Intercept		Mean annual temp		Mean annual rainfall			
Crops	Coefficient	*p*-value	Coefficient	*p*-value	Coefficient	*p*-value	R^2	Sig *F*
Maize	−9,018.2	0.739	520.6	0.715	−1.9	0.928	0.318	0.682
Beans	−5,490.4	0.651	304.9	0.632	−3.2	0.740	0.199	0.801
Indigenous Veg.	−283,582.6	0.410	15,804.5	0.386	−207.2	0.450	0.394	0.606
Cabbage	−89,714.3	0.465	5,661.8	0.393	−147.0	0.212	0.770	0.230
Kales	106,527.0	0.869	−5,815.1	0.863	171.9	0.745	0.149	0.851
Tomato	53,525.3	0.821	−3,094.3	0.803	121.3	0.547	0.483	0.517
S. potato	−166,644.7	0.656	8,393.3	0.667	−16.7	0.955	0.457	0.543
Cassava	−9,020.1	0.969	619.3	0.959	44.5	0.815	0.311	0.689
Sugarcane	−897,268.7	0.123	53,605.9	0.098	−1439.1	0.036	0.932	0.034

Table V.
Effect of climate variables on yield of major crops in Buyangu

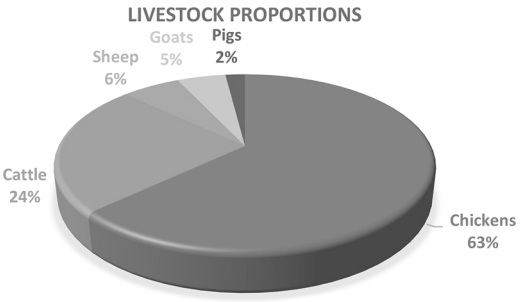

Figure 6.
Livestock proportions in Kakamega County

This outcome resonates with Peters *et al.* (2012), who established that 76 per cent of small scale farmers in Kakamega County could not sustain large herds due to high poverty rates and small land acreage. As depicted in Table VII, this community is land-constrained with an average land size of 1-3 acres per household.

However, more analysis indicated that indigenous cattle breeds were preferred by farmers (Figure 7), mainly because of their ability to withstand harsh weather conditions, require less feed and resist disease. However, a section of farmers (39 per cent) still opt for cross-breeds for higher milk and meat production.

Table VI.
Herd size

No. of cows	Frequency	(%)
0	54	26.5
1	60	29.4
2	50	24.7
3	24	11.8
4	10	4.7
5	2	1.2
6	2	1.2
7	1	0.5
Total	203	100

Table VII.
Land sizes

Land size	Frequency	(%)
< 1 acre	72	35.3
1-3 acres	111	54.7
4-5 acres	13	6.5
6-10 acres	5	2.4
>10 acres	2	1.2
Total	203	100

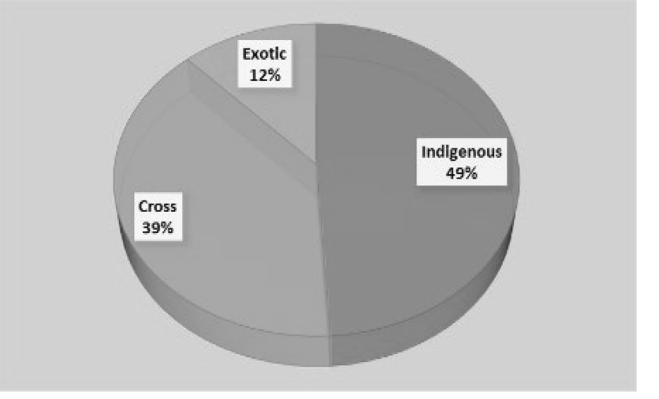

Figure 7.
Cattle breeds reared in Buyangu

4.3.4 Adverse effects of climate variability on livestock production.

4.3.4.1 Herd size. The study revealed that a majority of the respondents (87 per cent) had reduced their herd size by selling part of their livestock, due to the unavailability of pasture on their farms arising out of prolonged drought spells (Figure 8). It is important to note that seasonal variations in weather patterns affect pasture growth, resulting in decreased forage production.

Prolonged dry spells force farmers to better manage their livestock to minimise losses. In Buyangu, a large group of farmers are reducing their herd size to a manageable size of one or two cows (Table VI) as a way of reducing vulnerability to climate change. Lesnoff *et al.* (2012) emphasise that livestock farmers with a cattle-dominated herd structure will have difficulties in coping with shortages of animal feed during dry episodes. Most households in this region have to make do with low incomes that cannot sustain purchasing sufficient cattle feed. It is worthwhile mentioning that despite the Buyangu community being a farming group, cattle rearing is slowly being abandoned, while chicken rearing, which demands less feed, is being preferred. This demonstrates livelihood transitions, which predispose the community to future uncertainties, especially with the advent of climate change, bearing in mind that cattle rearing has been one of the major contributors to rural households' income.

4.3.4.2 Milk production. The majority (37 per cent) of the respondents who reared dairy cattle had their animals produce an average of 1-3 L of milk per day, while 28 per cent had their dairy animals producing no milk at all (Table VIII).

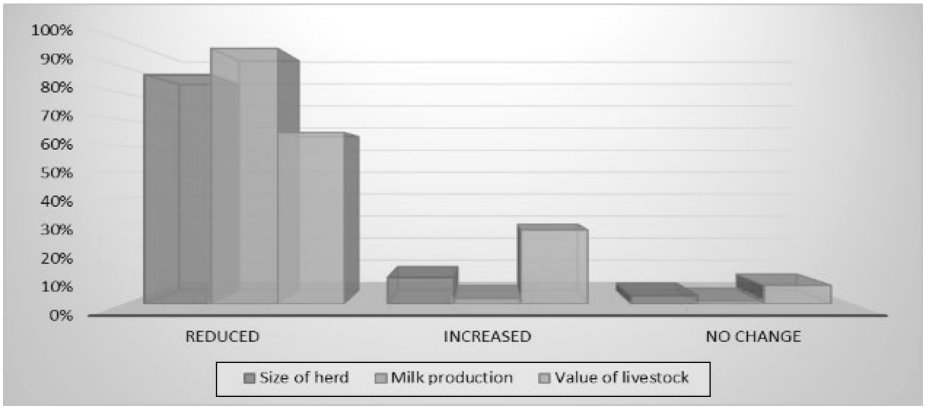

Figure 8.
Effects of climate variability on livestock

Litres of milk/per day	Frequency	(%)
0	57	28.1
1-3	76	37.4
4-6	45	22.2
7-10	18	8.9
>10	7	3.4
Total	203	100

Table VIII.
Milk production

The low or zero milk output in dairy cattle is mostly attributed to insufficient animal forage, due to prolonged dry spells. Wanjala and Njehia (2014) also reported that milk production for one animal per day is relatively low in Western Kenya. As much as the respondents in the study considered milk production from their cattle sufficient for their own domestic consumption, optimum milk production is yet to be realised. Kenya's dairy sector experiences milk shortages during times of drought, thereby inflating prices of dairy products in the market, especially in the urban areas. Njarui *et al.* (2011) maintains that pasture and water are the largest inputs for dairy farming and their inadequacy impacts negatively on milk supply.

Consequentially, scarcity of green pasture in Buyangu arising from climate variability has forced farmers to feed livestock with crop residues, mostly gathered from sugarcane leaves (bagasse) and maize stalks. This resonates with Mutibvu *et al.* (2012) who made similar revelations of livestock being fed crop residues, especially during dry seasons. Participants in the FGDs attested to the fact that feeding animals with crop residues is not as productive as it results in low milk output. Where farmers have been forced to either purchase or seek alternative animal feed, many have chosen to abandon animal husbandry altogether.

4.3.4.3 Livestock market value. A majority of the farmers (65 per cent) deduced that climatic variation directly impacts on pasture, greatly influences livestock body weight and ultimately determines the market prices for livestock (Figure 8). High temperatures and long dry spells deplete pastures, resulting in reduced fodder availability, reduced livestock productivity, and lower market returns due to animals' poor health (Lagat and Nyagena, 2016). Moreover, an increase in vector-borne diseases, such as pneumonia and foot and mouth, were mostly attributed to excessive rainfall. This sentiment was echoed during FGDs, where participants explained their inability to manage climate-related diseases affecting livestock. According to Devendra *et al.* (2000), livestock diseases are a major setback to livestock production and marketing in the Tropics. Düvel and Stephanus (2000) assert that animal health issues are a barrier to livestock trading, due to reduced animal productivity and increased morbidity.

In summation, climate variability impacts on livestock have interfered with households' incomes, as many people who relied on the net returns from domestic herds find that they cannot meet their household needs. Cattle are more sensitive to climate variability and their vulnerability increases as the climate gets drier and warmer (Lunde and Lindtjørn, 2013).

4.3.5 Forest accessibility and resource use across gender groups. To gauge forest accessibility based on the households' proximity to forest, the respondents estimated their household distances from the forest edge. The study revealed that almost 63 per cent of the households were located within 3 km from the forest's edge (Table IX).

These households were frequent consumers of the forest resources, exerting pressures on the natural base. A similar observation was made by Kisaka and Sitati (2014), who found that households' proximity to the forest is a major contributor to the depletion of forest materials, especially along the forest edges. Mujawamariya and Karimov (2014) also

Table IX.
Access to forest

Distance from forest	Frequency	(%)
<1 km	55	27.0
1-3 km	72	35.6
4-6 km	76	37.4
Total	203	100

observed that people living closer to a forest had a higher dependency on forest resources than those located farther away.

4.3.5.1 Women and forest resource use. In exploring gender differences in the use of forest resources, the study established that the majority of women (70 per cent) obtain firewood from the forest (Figure 9).The main factor behind the large percentage of women harvesting firewood from the forest is their societal gender role of ensuring a constant supply of cooking fuel for their families.

Although women seem to commercialise forest products less often than men, FGDs revealed that selling firewood is a thriving business in Buyangu. The reduction in crop yields affected by changing weather patterns has now forced women to diversify their sources of income by selling firewood gathered from the forest and the cash remittances used to purchase maize from the markets. This further increases women's dependence on forests to meet food security needs as many lack alternative options for generating income. Additionally, the task of collecting firewood for women in Buyangu is a nightmare as many are not brave enough to access the forest amid the presence of KWS officers. This situation is further aggravated by the compelling evidence of climate change affecting forest ecosystems and influencing availability of resources through periodic variations of temperatures and precipitation. FGDs held with men and women further revealed that there is actual disappearance of tree species best known for fuel wood and medicinal purposes. Difficulties in accessing fuel sources and other forest materials are indirect impacts of climate change posing considerable challenges to the livelihoods of women in rural set-ups (Brown *et al.*, 2014).

4.3.5.2 Men and forest resource use. Generally, men are reported to collect forest products for commercial purposes (Cavendish, 2000; Shackelton and Shackelton, 2000). This was in contrast to men in Buyangu as we observed that they gather forest products – animal fodder – mainly for domestic purposes (Figure 10).

Customarily in the Abaluhya community, searching for animal pastures is a male dominated activity that starts from an early age. Male household heads will always ensure Napier grass and other animal feeds are planted on farms. This only works with households owning larger pieces of land, which can support both cultivation of crop foods and animal feed. However, the intrusion of men into the forest in search of animal fodder supports

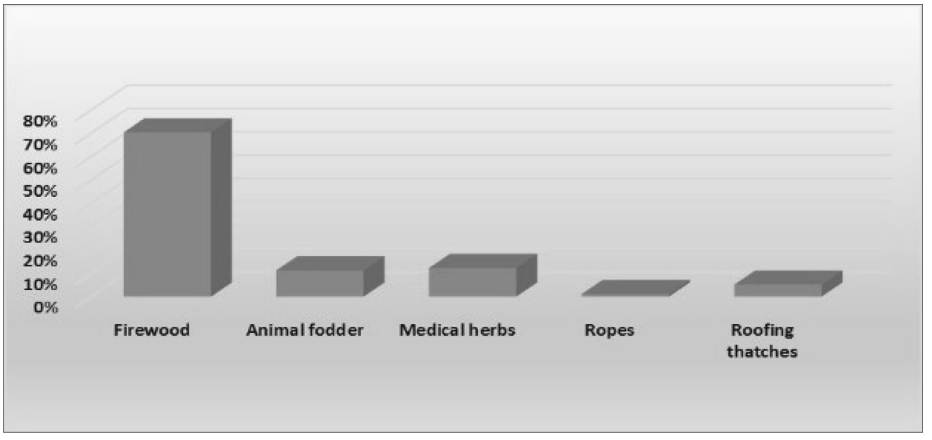

Figure 9.
Forest resources collected by women

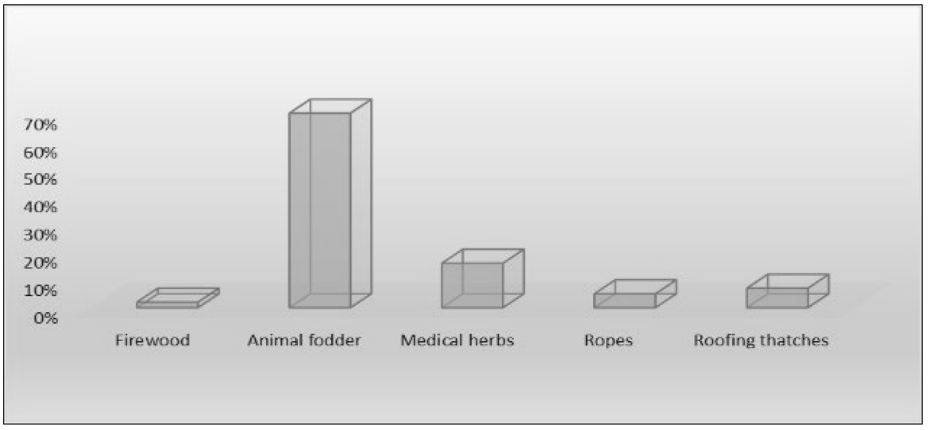

Figure 10.
Forest resources collected by men

current observations by the community on the decline of on-farm pastures because of climate change and variability.

4.3.6 Understanding factors that influence supply of forest resources. The study sought to establish opinions of the Buyangu community as regards to supply of forest resources over the past years. Figure 11 illustrates that most of the respondents observed a decline in forest resources, except for 39 per cent of the respondents who reported the contrary.

The reduction in forest resources was largely attributed to overharvesting, while the increase was linked to the presence of KWS officers protecting the forest heritage. This corresponds with Hermans-Neumann *et al.* (2016), whose study also associates the increase of forest resources with forest management. However, with respect to a decrease in supply of forest resources, all respondents unanimously named overharvesting as a presumable cause, while the influence of climate variability on forest resources was not underscored. These revelations demonstrate high levels of ignorance amongst forest-based communities

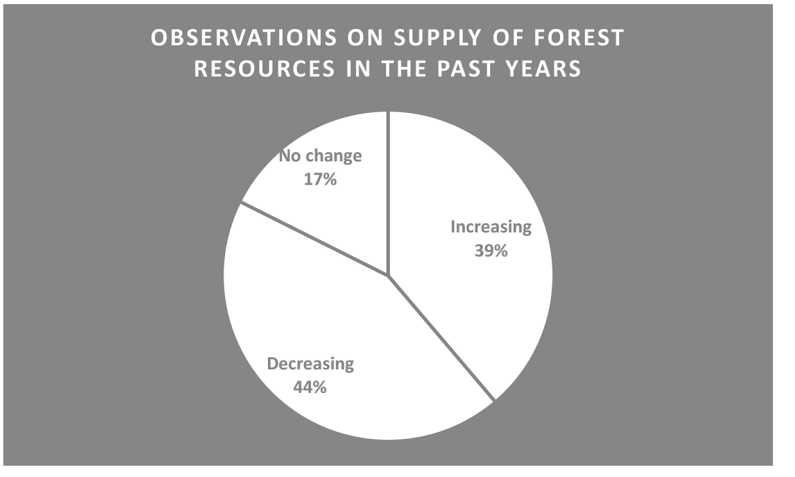

Figure 11.
Observations on supply of forest resources in past years

who do not regard extreme climatic events to be a significant threat to the forest ecosystems, thereby affecting their livelihoods.

Productivity and distribution of forests could be affected by both changes in climatic (temperature and precipitation) and non-climatic factors (population pressure, overharvesting, etc.). Both these factors are expected to alter forest ecosystems and the supply of forest resources will no longer be business as usual (Fisher *et al.*, 2010). As much as past studies have shown that future distribution of forest biomass in tropical forests will be determined by climate variables, mostly temperature and rainfall (Lin *et al.*, 2010; Song and Zeng, 2017); the impact of human-induced climate change on forests cannot be underestimated. Unless forest-dependent communities realise that there have been changes in forest ecosystems arising out of anthropogenic activities, they cannot be expected to take up appropriate measures to adapt.

5. Conclusions

This paper has demonstrated climate variability and its considerable effects on the livelihoods of the Buyangu forest-dependent community, both directly and indirectly. The community explained how locals have been experiencing delayed onset of rains, long dry spells and increasing temperatures over the past few years, which have resulted in reduced common crops yields from recurrent seasons. Yields of sugarcane, maize and vegetables are adversely affected by the current climate trend in Buyangu. Similarly, reduction in rainfall and increasing temperatures have suppressed animal pastures, compromising milk output, herd sizes and livestock market values.

The study findings on the effects of climate variability and the supply of forest resources provide valuable insights into the community's lack of knowledge on the subject. A majority of the respondents suggested that the decline in forest resources was more influenced by the socioeconomic pressures of overharvesting rather than the manifestation of climate change and variability. The community's ignorance of climate change directly impacting on forest resources demonstrates the likelihood of higher vulnerabilities and the need to prioritise adaptation strategies. Understanding the factors that underscore the vulnerability of forest-dependent communities to climate change and variability is essential in developing initiatives that will foster resilience.

This study, thus, concludes that there is need for integration of the various stakeholders at both local and national levels in addressing the impacts of climate change and variability on forest-dependent communities. Specifically, local governments need to identify adaptive measures for such communities and estimate costs of implementing them. For instance, agroforestry has the capacity to improve agricultural yields while mitigating environmental damage. It is necessary for the government to support such initiatives and encourage community participation through provision of agroforestry species and other farm inputs. The authors further recommend that government programmes working towards maximisation of crop yields should first consider food-crops such as maize and vegetables, which are an important staple food for many communities in Kenya. It would be important for the government agencies to ensure farmers gain access to good quality maize seeds varieties that are affordable and resistant to harsh climatic conditions.

Because forest-dependent communities are smallholder farmers, non-governmental organisations and the private sector should also collaborate in empowering such communities by providing support in climate-smart agriculture initiatives that will increase agricultural productivity and household incomes. Smallholding farmers need to be encouraged to practice conservation agriculture, crop rotation, integrated crop-livestock management, the use of improved pasture, use of energy-saving cooking stoves and

cultivation of short-term drought tolerant crops. Local communities must not be left behind in the decision making processes to formulate more successful adaptation strategies that address their actual concerns.

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Received 23 April 2019
Revised 11 October 2019
Accepted 17 October 2019

Sunshine, temperature and wind

Community risk assessment of climate change, indigenous knowledge and climate change adaptation planning in Ghana

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Abstract

Purpose – This paper aims to draw on community risk assessment (CRA) for assessing vulnerability to climate change in north-western Ghana, focusing on sunshine, temperature and wind, elements of climate which are seldom explored in vulnerability assessments to climate change.

Design/methodology/approach – The paper draws on data collected from a qualitative research design that used participatory rural appraisal methods, particularly, in-depth interviews, focus group discussions and seasonal calendar analysis in three selected rural communities of the Sissala East District. Furthermore, an inter-generational framework was adopted for comparative assessment of vulnerability and changes in vulnerability to climate change.

Findings – The results show that the current generation of smallholder farmers is more vulnerable to climate change than the past generation, the era of grandparents. Thus, farmers are exposed to higher-intensity sunshine, temperature and wind in contemporary times than was the case in the past. Consequently, their livelihoods are affected the most by the damaging effects of these climatic hazards. The CRA process revealed the relevance of indigenous knowledge systems for vulnerability assessments and at the same time, underpins the need for adaptation of such knowledge if it is to sustain smallholder farmer efforts at climate change adaptation at community levels.

Practical implications – The paper recommends an endogenous development approach to climate change adaptation planning (CCAP), one that will build on indigenous knowledge systems for effective community education, mobilization and participatory response to climate change. Policy interventions should aim at enhancing climate change adaptation through innovations in soil and water conservation, access to water for irrigation and domestic use, climate smart-housing architecture and agro-forestry within the framework of decentralization and district development planning.

Originality/value – This paper will contribute to climate change research in two ways: first, by drawing attention to the usefulness of CRA in vulnerability assessment; and second, by focusing on climate elements which are critical for CCAP but rarely given sufficient attention in vulnerability assessments.

Keywords Climate change, Vulnerability, Indigenous knowledge,
Climate change adaptation planning, Community risk assessment

Paper type Research paper

International Journal of Climate Change Strategies and Management
Vol. 12 No. 1, 2020
pp. 22-38
Emerald Publishing Limited
1756-8692
DOI 10.1108/IJCCSM-04-2019-0023

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This research was supported by the Endogenous Development Service (EDS), Ghana.

1. Introduction

The paper draws on indigenous people's knowledge for conducting community risk assessment (CRA) of climate change and climate variability, focusing in particular, on sunshine, temperature and winds in Ghana. Most climate change research focuses on rainfall changes because of its direct effect on farming to the neglect of other equally important factors that affect livelihoods. It is evident that scientific knowledge systems need to be complemented with indigenous knowledge systems for enhancing effective community resilience to climate change.

Climate change, precipitation variability and recurrent droughts have adversely affected the economy of Ghanain urban and rural settlements annually (World Bank, 2010). Rainfall variability, increasing intensity of temperature, sunshine and wind intensities are getting worse and compromising agriculture and food security in Ghana. Temperatures in northern Ghana are the highest in the country and projected to increase by about 2.1-2.4°C by the year 2050 (World Bank, 2010). The forecast is that climate change will have a profound adverse effect on agriculture, leading to a decline in crop and livestock production and consumption in northern Ghana (World Bank, 2010; Gyampoh and Asante, 2011). Thus, CRA is critical for informing climate change adaptation planning (CCAP).

2. Vulnerability to climate change in West Africa

Climate change is distinct from climate variability mainly in relation to time or period of change. Climate change often refers to changes in the mean and/or the variability of its properties for a long period, typically decades or longer. Climate change may be caused by natural internal processes or by external factors as in anthropogenic forces (IPCC, 2012). Climate variability is variations in climate, including the normal highs and lows, wet and dry periods, hot and cool periods and extreme values. It can range from day-to-day variability and to year-to-year variability. It can even refer to decadal scale variability except that such variability over a multi-decadal scale is climate change (USAID, 2014).

Evidence of climate change in West Africa abounds in the literature. In respect of precipitation, the pattern in West Africa demonstrates a high level of year-to-year variability with alternating wet and dry years occurring in series over decades (Hulme *et al.*, 2001). The periods 1950-1970 and 1971-2000 in the climate history of Africa and Sub-Saharan Africa were long, wet and dry periods, respectively. The forecast is that West Africa will witness significant decrease in total rainfall by 2100 because of anthropogenically driven global warming (Lemoalle, 2007; IPCC, 2007). Forecast for Ghana suggests a cyclical pattern for all regions and decrease and increase precipitations toward the northern and southern parts of the country, respectively. Temperatures in Sub-Saharan Africa are projected to increase with mean annual temperatures in the Sahel part of the Volta basin rising by 2°C and further by more than 3°C in April (Kunstmann and Jung, 2005). Forecast for temperature and precipitation trends over a 40-year period (2010-2050) show warming across Ghana with higher temperature projections for northern Ghana (World Bank, 2011). Such increase in temperatures in the basin will have a negative impact on agriculture, food security and health of the inhabitants. For instance, increased temperatures will likely increase the levels of water related diseases such as cholera in tropical waters and reduce agricultural yields (Lemoalle, 2007).

In Sub-Saharan Africa, high levels of poverty, low education, low technology, inequality, limited access to information and low financial status make countries and their populations the most vulnerable to the impacts of climate change (Care International, 2011). These factors coupled with rapid population growth drive extensive exploitation of natural resources and environmental degradation leading to scarcity of water and water resources in the Volta basin (Welling *et al.*, 2012). The incidence of annual floods, droughts and other

hydro-meteorological hazards in the Volta basin already breeds tensions between and among the six riparian countries that share the basin (Brown and Crawford, 2008; Oyebande and Odunugu, 2007).

The agriculture sector is climate sensitive and very vulnerable to climate change. Agriculture is the primary occupation for majority of the active youth in West Africa and accounts for about 40 per cent of economic output in the Volta basin. The effects of increasing variations in precipitation and temperatures are negatively threatening agriculture and food security, water and water resources in Sub-Sahara Africa. Changes in precipitation manifest in shorter duration of the rainy season with severe consequences on rain fed agriculture and food security (Lemoalle, 2007; Kunstmann and Jung, 2005; McCartney *et al.*, 2012). A dramatic precipitation decrease of up to 70 per cent over the entire Volta basin is predicted for the beginning of the planting season (Kunstmann and Jung, 2005). This will adversely affect food crop, poultry and livestock production in Sub-Saharan Africa including regions within the Volta basin. Furthermore, increased temperatures will have adverse effects on evapotranspiration, vegetation, animal distribution and productivity. The concentration of carbon dioxide across West Africa reveals an adverse shift in the length of the growing season, with a decrease of about 20 days in the central part of the Volta basin (Lemoalle, 2007). In Benin, it is anticipated that climate change will cause a decrease of about 10-20 per cent in agricultural production by the year 2050. Food crop and livestock production in Togo are also anticipated to be adversely affected by climate change because of decreases in rainfall and increases in temperatures (Lemoalle, 2007). According to Brown and Crawford (2008), a decrease in annual rainfall by 3.4 and 7.3 per cent by 2025 and 2050, respectively, will seriously affect the production of cotton, maize and yam in Burkina Faso. This combined with a rise in temperatures by 1.7°C will reduce water availability for livestock in many Sub-Saharan African countries including Ghana.

In Ghana, as in many Sub-Saharan African countries, rain-fed agriculture is the primary source of livelihood (Antwi-Agyei *et al.*, 2011; McCartney *et al.*, 2012; Republic of Ghana, 2013). This implies that food crop farming and livestock production are vulnerable to climate change and climate variability and thus, undermine efforts at attaining food security, particularly in northern Ghana. Extreme climate conditions result in poor crop yields, crop failures, loss of livestock and loss of agricultural lands in northern Ghana. Overall, climate change evidenced in precipitation and temperature changes and the consequences of droughts and floods adversely affect agriculture production and translate into low agricultural production in Ghana and northern Ghana in particular (File, 2015). Farmers' inability to predict the onset of the rainy season amid decreasing rainfall and increasing duration of dry periods further increases their exposure to climatic risk and hazards such as droughts, floods and extreme temperatures that result in crop failure and loss of livestock (Laube *et al.*, 2008, p. 2; Andreini *et al.*, 2000). The floods that occurred in 2007 in Ghana affected about 332,600 people and caused the death of 56 persons in the Upper East, Upper West and Northern Regions and parts of Western Region (Kankam-Yeboah *et al.*, 2010; Republic of Ghana, 2013). These trends may undermine the socio-economic well-being of the country, particularly, northern Ghana given that the local economy is dominated by agriculture and other climate-sensitive sectors (Kuuzegh, 2007; World Bank, 2011; Republic of Ghana, 2013).

3. Community risk assessment and indigenous knowledge: conceptual framework for assessing climatic risks

In this paper, CRA is adapted as a conceptual framework for drawing on indigenous knowledge of the Sissala people for assessing climate variability. CRA involves the use of

participatory approaches for assessment of vulnerabilities (hazards and capacities for disaster risk reduction) at community level (Aalsta *et al.*, 2008, p. 165). The CRA uses participatory approaches that combine local knowledge with scientific information to enable clear understanding of the implications of climate change for the lives and livelihoods of the people. This process builds local people's understanding about climate risks and adaptation strategies. It therefore provides a framework for dialogue within and between communities and other stakeholders for analyzing vulnerability and capacity to adapt to climate change at the community level (Care International., 2011). The recognition of indigenous knowledge in CRA makes it unique.

The CRA process can be complex and detailed depending on the availability of local resources. Rural communities are mostly confronted with inadequate access to weather and climate forecast information, low technology, poor infrastructure and low education among other challenges. In any case, the use of practical participatory tools create room for the use of local knowledge and available local resources in gathering, organizing and analyzing information on the vulnerability and adaptive capacity of communities, households and individuals. This makes CRA a simple process for community members and other users. The participatory process of CRA also provides learning and clear understanding of climate change impacts and adaptation initiatives and as well recognizes the role of indigenous knowledge in in CCAP. Therefore, the extent to which communities conduct risk assessment processes may usually depend much on the capabilities of communities and the resources available to them (Stouffer, 2015).

CRA serves as a guide for taking practical steps in preparedness and mitigation actions on climatic events that reduce both the chance of emergencies and the consequences when they cannot be avoided. It thus facilitates a clear understanding of community vulnerability and exposure to hazards to inform the process of preparing community contingency, emergency response and recovery action plans for addressing climatic events. It provides risk information that informs community residents, business owners and institution managers of the hazards to expect and how to best prepare for them (SRC, 2007). CRA can contribute to vulnerability and risk assessments by helping users to collect, synthesize and organize information about the development context, the climate context, climate impacts and risks and the design of adaptation responses (IISD, 2012).

The International Institute for Sustainable Development (IISD, 2012) outlines three phases and practical steps for conducting CRA in the project context. Phase 1 deals with the context of livelihoods and climate system of communities. The process specifies the impacts of and responses to identified climate hazards in the community. The outcome is a list of livelihood resources for men and women that are most affected by climate hazards and most important for responding to the impacts of these hazards. Phase 2 evaluates the implications for the project and builds on the information collected in Phase 2 to analyze how project activities affect livelihood resources that are either vulnerable to climate hazards or important for responding to the impacts of these hazards. The evaluation process enables actors to revise process activities of CRA toward reducing the level of exposure of livelihood options to climatic risks and hazards and designing new activities to reducing climatic risks. The outcomes include a list of project adjustments and prioritized new activities that support climate adaptation and a list of key opportunities and barriers to successful implementation of activities. Phase 3 is concerned with monitoring and evaluation (M&E) of climate adaptation. It helps identify some key elements that can be integrated into existing or newly developed M&E framework. It assesses the implementation of adaptation activities and the factors that influence or could influence their outcomes. This phase therefore,

produces a list of desired adaptation outcomes and important influencing factors to be monitored.

Phase 1 and its steps, processes and outputs are relevant for this paper (Table I). Phase 1 concerns itself with understanding the livelihood and climate context and in particular, providing an opportunity for the local populations to participate in mapping the climate related risks that affect their livelihood systems and totality of life.

Thus, community consultations are very crucial for a successful CRA process. Consultations help identify the real key climatic issues affecting communities and livelihoods and also engage community members to participate fully in the process. This process allows for effective identification of critical issues for effective community risks assessment that informs strong adaptation planning. Community engagements and consultations can be held with key actors, community members, partners and experts throughout the entire CRA process. Consultations are important especially during the initial stages of the CRA process where information is gathered on climate and livelihoods to explore local-level perceptions on climate hazards and their impacts. It also explores the current and potential responses to both present and future climatic risks in communities (IISD, 2012). Community engagements also ensure proper planning, adjustments and management of activities according to local needs, priorities and conditions. The approaches in engagements, however, need to be flexible to ensure maximum participation and accuracy of information.

Indigenous knowledge is critical and crucial for conducting CRA. Indigenous knowledge is the body of knowledge, or bodies of knowledge, of the indigenous people of particular geographical areas that they have survived on for a very long time (Mapara, 2009; Shoko, 2012). Thus, participatory methods of gathering information such as site visits, focus group discussions (FGDs), informal meetings and/or organized workshops using participatory rural appraisal tools such as resource mapping, vulnerability matrix and seasonal calendars are usually used for enabling genuine participation of the local populations in the CRA process and for tapping into their indigenous knowledge. These allow for full participation of all groups/stakeholders and opinion leaders and in particular, drawing on the indigenous and or local knowledge of the local populations participating in the process.

4. The study area and context

The study was conducted in the Sissala East District, located in the north-eastern part of the Upper West Region of Ghana. The district has a total land size of 4,744 sq. km representing

Table I.
CRA framework: understanding the livelihoods and climate context

Steps and processes		
Step 1: Understanding the livelihood and climate context	Step 2: Analyses of climatic risks	Outputs
Describe livelihood activities, key actors, gender and diversity aspects, and the ecological context	Document observed and projected climate changes in the area	List of livelihood resources for men and women that are most affected by climate hazards and most important for responding to climate impacts
Assess the implications for analysis	Identify current and potential future climate hazards	
Identify resources that are important to local livelihoods and who has access and control over them	Document the impacts of these hazards	
	Document community responses to climate impacts	

Source: Adapted from IISD (2012, p. 12)

26 per cent of the total landmass of the region (Figure 1). The estimated population of the district is 56,528. Of this number, 48.7 per cent are males and 52.3 per cent females (Ghana Statistical Service, 2012). The district capital, Tumu, has 19.03 per cent of the district population and it is the only settlement with the status of a town population and infrastructure. The settlement pattern is highly dispersed and rural by nature.

The district falls within the Guinea Savannah vegetation belt. The vegetation consists of grasses with scattered fire resistant trees such as the shea nut, the baobab and dawadawa trees. Acacia is also a common tree of this vegetation belt. The heterogeneous collection of these trees meets domestic requirements for firewood and charcoal, construction of houses, cattle kraals and fencing of gardens. The shorter shrubs and grasses provide fodder for livestock. The shea tree is one of the great economic assets of the district.

The climate is tropical continental as experienced in the northern regions of Ghana. Throughout the year, temperatures are high with a minimum of 23°C at night and a maximum of 42°C during the day. The mean monthly temperature ranges between 21°C and 32°C. The highest monthly maximum temperature rises up to 40°C before the rainy season in May with lowest minimum temperature of 12°C in December during the *harmattan* season.

The district has a single rainy season usually from May to September/October during which farmers cultivate crops. This is the main production season as irrigation is very limited. In 2009, the first quarter of the year recorded 6.9 mm rainfall and the second quarter, 447.2 mm. At the beginning of the third quarter, drought occurred threatening food production. Subsequently, rains set in and the quarter registered 937.4 mm of rain. The rains intensified and resulted in floods which adversely affected crops yields, especially, maize and groundnuts. Some fields were totally submerged under water and others were washed away. This affected the entire district but the eastern block was the worst affected. There is an indication that rainfall intensity is decreasing in the district. The total number of days of rain ranged from 70 to 80 days in 1999 compared to 51 days of rain in 2009. The mean annual rainfall in 1999 was 121 mm compared to 104 in 2009 (SEDA, 2013). This has implications for food security in the district.

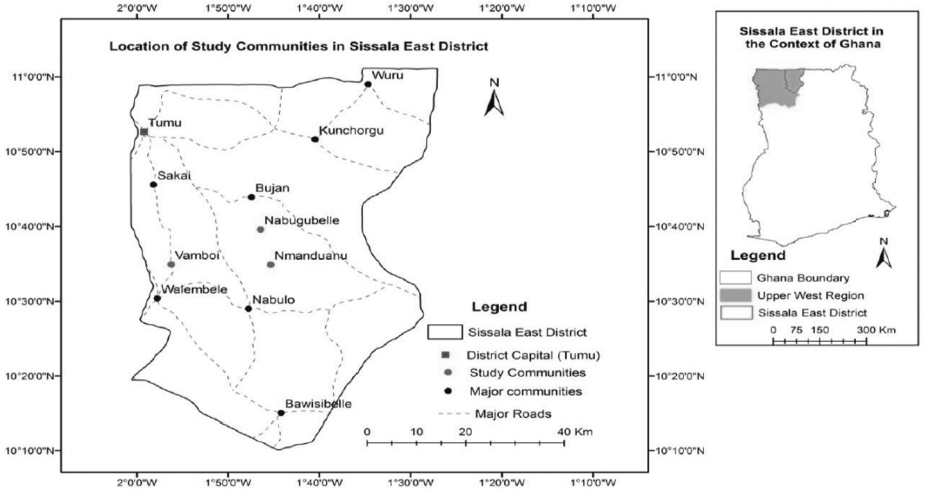

Figure 1.
Map showing Sissala East District in national and regional context

5. Methods of data collection

The paper draws on a qualitative research design, using in-depth interviews, FGDs, seasonal calendar and inter-generational analysis for assessing changes in the selected climatic elements. Three communities namely, *Vamboi*, *Nabugubelle* and *Nmanduanu* in the Sissala East District were randomly sampled from a list of six purposively selected communities prominent in rain-fed crop farming in the district (Figure 1).

In-depth interviews were conducted among 27 purposively sampled key informants, 9 in each community. The distribution was as follows: *Jantina* (earth priest) (3), chiefs (3), traditional chief farmers (3), traditional queens (3), *Magazia* (women leaders) (3) and household heads (12). These interviews enabled an in-depth probe of the issues drawing on the wealth of knowledge and experience of the target respondents.

Data was also collected through 15 FGDs. Five FGDs were conducted in each five community among different groups of discussants, including, elders (usually male), male farmers, female farmers, male youth and female youth. The discussants per session ranged from 8 to 12 and sessions were facilitated with the aid of an FGD guide. Gender segregation was necessary to allow for free expression. Women do not actively participate in discussions in the middle of men because of cultural factors. Seasonal calendar analysis was applied as part of FGDs for understanding indigenous knowledge systems of seasons, activities and changes in seasons. This enabled participatory analysis of changes in climatic elements such as sunshine, temperature and winds.

An inter-generational framework was adopted for data collection and analysis. We analyzed changes between two generations, the era of grandfathers (past generation) and the era of grandsons (present generation). The present generation in this framework refers to the present generation of household heads who were interviewed and the era of their fathers, the transition phase for understanding the changes between the past and present.

6. Results

The results are analyzed around three themes. These include sunshine, temperature and winds and how these have changed over time and between generations.

6.1 Sunshine and changes in sunshine

The indigenous knowledge of the *Sissala* people reveals five local seasons of sunshine that phase into each other in an annual and continuous cycle of occurrence associated with the farming calendar. These include *Wulungyia*, *Kpabilayia*, *Yibiinyia*, *Gbanchanyia* and *Tafaayia*, which were distinct forms of sunshine seasons with varying degrees of intensity in the traditional farming calendar (Table II).

In the traditional farming calendar, *Wulungyia*, meaning the warm or heat season was experienced from February to April in the grandfathers' era. This sunshine was characterized by extreme high intensity, heat and high temperatures both during the day and night. From the analysis, this high intensity sunshine is now experienced over a longer period, from January to May in the present generation. This period is the yam planting season and the extreme conditions cause newly planted tubers to rot and/or wilt especially when tubers are planted after 8.00 a.m. in the morning. Thus, this sunshine is known to cause poor germination in yam farming. It also affects other tubers and root crops such as potatoes.

Kpabilayia is the next season and it was known to occur between June and July and associated with dry spells in the farming season in the grandfathers' era. Sunshine intensity was moderate, with a few intermittent sunny days in the week. It neither affected crops nor farming activities. The season coincided with the second weeding in the farming calendar

Type	Past characteristics – era of grandfathers	Present characteristics – era of grandsons
Wulungyia	Starts from February-April	Starts from January-May
	Intense/scorching sunshine	Very intense/scorching
	Certain and predictable	Difficult to distinguish from others
	Distinguishable	Uncertain and unpredictable
		Long duration
Kpabilayia	Occurs from June-July	Absent/difficult to distinguish or established period of occurrence
	Alternating sunshine intensity (low and high)	Uncertain and predictable
	Alternating sunny days	High sunshine intensity
	Distinguishable	
	Certain and predictable	
	Duration was short (2-3 weeks)	
Yibiinyia	Starts from July-September	August-September
	Certain and predictable	Difficult to distinguish
	Distinguishable	Uncertain and unpredictable
	Limited sunny days per week	Many sunny days
	Low sun intensity	High sun intensity
	Limited visibility of sun cloudy conditions	Visible sun throughout the week – limited cloudy days
Gbanchanyia	Starts from late September-October	Starts from late August-October
	Certain and predictable	Difficult to distinguish
	Distinguishable	Almost absent
	Sunshine with little rains	Uncertain and unpredictable
	Intense sunshine that warm surface/stagnant waters	
Tafaayia (harmattan sunshine)	Late October-January	Starts from November-December
	Occurs during harmattan	High sunshine intensity because of absence of smoke-like substance to reduce sun rays
	Low sunshine intensity	Uncertain and unpredictable
	Presence of smoke-like substance that traps sun rays	Difficult to distinguish
	Certain and predictable	Short duration
	Distinguishable	Starts from November-December

Table II.
Sunshine types and characteristics

and this helped weeds to dry up after clearing. Farmers report that this season appears to have disappeared in the grandsons' era. The entire raining season is characterized by the alternating occurrence of high sunshine intensity and rains. During dry spells, such high-intensity sunshine has proven harmful to crops and led to crops wilting and or stunning in growth

The next season, *Yibiinyia*, coincided with the peak of the rainy season, from July to September. The intensity of sunshine was low and farmers did not feel the impact in the past. Sunny days were rare. The skies were cloudy and the sun virtually invisible. Heat from the sun rays was not felt. Sunshine was very limited as narrated by a farmer in *Vamboi*:

> In the past we smoked Kuomifian early maturing yellow corn harvested during the peak of the rainy season as a method of drying on our farms. This is because you could not see the sun for many weeks. One could wake up from bed and would not see the sun for the whole day; the sky was always covered with heavy clouds. There was no sunshine for us to dry our yellow corn.

> Smoking corn was virtually done the way meat is smoked to prevent germination due to high moisture and/or to prevent infestation of insects. Have you seen or heard that farmers are smoking maize these days? He asked, rhetorically.

Sunshine intensity is high and the number of sunny days has increased significantly during the peak of the raining season in present times. In fact, sunshine days and rainy days alternate. There is experiencing of sunshine during the entire period because of the absence of heavy cloud cover. Dry spells are common and associated with high-intensity sunshine that destroy crops and or disrupt tussling of cereal crops such as maize, guinea corn and sorghum.

Gbanchanyia is the sunshine experienced at the end of the peak of the rainy season, from September to October. The season was characterized by simultaneous combination of high-intensive sunshine and intermittent drops of rain. Rains did not last more than 5 min and rainfall intensity was low. There were many sunny days than cloudy or rainy days in a week. This sunshine affected late maturing crops. Millet and yams shed leaves within a week. In present times, *Gbanchanyia* has become difficult to distinguish from other seasons, particularly, *Yibiinyia* and *Tafaayia* . These three types of sunshine appear to have similar characteristics, especially, in intensity and frequency of sunny days. In the past, this sunshine helped farmers to dry their harvest for storage. At present, it is still useful in that respect but when dry spells occur, it dries the land and hampers the harvesting of groundnuts and potatoes which require manual uprooting or digging.

Tafaayia coincided with the harmattan season, from October to January, when the sky was covered with a smoke-like substance and dust particles. There was low intensity of sunshine and farmers did not feel the heat of the sun rays while working on their farms because of the sky cover. The local name *Tafaayia* literally means "a hidden sun" depicting the phenomenon in which the sun was mostly covered by a smoke-like substance, thus, moderating the penetration of sun rays and causing low intensity. In present times, the smoke-like substance is absent in the sky and thus, sunshine intensity is very high and unbearable to many farmers. Such high intensity sunshine was reported to destroy crops such as cotton, beans and vegetable crops.

The analysis revealed indigenous classification of sunshine types. These include *Wulumgyia*, *Kpabilayia*, *Yibiinyia*, *Gbanchanyia* and *Tafaayia*. The results show that these indigenous classifications of sunshine seasons have become difficult to distinguish by their known and peculiar characteristics in the past. *Wulumgyia*, the warm season appear to be the dominant sunshine type extending its influence over the entire year and overriding other known indigenous seasons of sunshine. The results generally reveal an increasing intensity of sunshine and thus, the dominant influence of *Wulungyia*.

6.2 Temperature and changes in temperature

In the indigenous knowledge of the people, there are two temperature seasons, namely, *Wulumung* and *Tafiala* (Table III).

Wulumung is classified as the warm season. The season was known to occur from February to April, after the *Harmattan*. Thus, it coincided with *Wulungyia*, a high-intensity sunshine season (Table II). Sunshine was very intensive and temperatures were very high, both during day and night. This situation resulted in people sleeping in the open courtyards during nights. Narratives of the people reveal that temperatures have more than doubled during the season in recent times. According to an FGD discussant, sunshine and temperature is "more intense than when we were young" (over 40 years ago) and that **"**the warm season was no longer distinguishable from other seasons." The *Paari-Nyimma*, chief farmer (CF) of *Nabugbelle* noted during an in-depth interview:

Type of temperature	Characteristics in the past	Present characteristics
Wulumung (warm season)	Starts from February-April	Starts from January-May
	High daily temperatures	Very high daily temperatures
	High night temperatures	Very high night temperatures
	Certain and predictable	Uncertain and unpredictable
	Distinguishable	Difficult to distinguish
	Short duration	Long duration
Tafiala/waaring (cold/ harmattan season)	Starts from October-January	Starts from November-December
	Low daily temperatures	High daily temperatures
	Low night temperatures	Mild night temperatures
	Severe cold conditions at mornings and nights	Mild temperatures at mornings and nights
	Presence of smoke-like substance that traps sun rays during the day	Absence of severe cold conditions
	Distinguishable	Absence of smoke-like substance
	Certain and predictable	Short duration
	Long duration	Difficult to distinguish
		Uncertain and unpredictable

Table III.
Temperature seasons and characteristics

> Wulumung has become more intensified these days than in the past. These days, one still feels abnormal high temperature even if you are sleeping in the courtyard. In the past people packed back into their rooms after 3:00 am because it was extremely cold at that time. Today, temperatures remain warm from night to dawn and so people sleep in the open courtyards till day break. In the future, the world may perish due to extreme high temperatures.

According to the CF, these temperatures do not favor farming. He intimates that farmers would have to adopt a combination of scientific and modern strategies or techniques to secure farm livelihoods. According to him, the changes are becoming more extreme and local strategies adopted by local farmers are becoming overwhelmed. Amid this, available modern scientific solutions do not suit the situation of local farmers; they are by design more suited only to "*Karichising*" meaning, literate/ educated people, and thus, may not yield the needed results for the majority of rural farmers who are illiterates.

Tafiala Waaring is the cold season, also known as the *harmattan* season. In the past, temperatures were low with severe cold and dry conditions, especially during nights and early mornings. Because of the severity of *Waaring* (cold), most people, especially children and the aged preferred to be indoors from 7.00 p.m. to 9.00 a.m. the following morning. Men gathered in groups around fires set outside homes to keep warm, during which there was sharing and transmission of information and values among themselves and to the younger generation. The local people assert that one could not take a bath with river water in the morning nor drink it because it was usually as cold as ice block. A discussant corroborates this assertion during an FGD in *Nmanduanu*:

> As children, we used to carry logs from farms to the house for our mothers and the aged to set fires in their rooms. We were usually found in the rooms of our grandparents sitting by the fire every morning till sunrise. These days nobody carries logs to the house for same purpose. The intensity of cold has drastically reduced. One rarely sees old people setting fires in their rooms. The cold season has become warm too.

Overall, farmers observe that the severity of cold and duration of the cold season have reduced significantly in present times. In the past, *Tafiala* started in October and reached its peak in November through to mid-January before it starts to decrease as *Wulumung* sets in. In present times, the season still starts in November but has become difficult for local people to tell when it reaches its peak. Accordingly, there are no significant differences in cold conditions before and during the *harmattan* season. A female discussant noted that:

> The world is really coming to an end [. . .] because we are unable to distinguish the seasons in terms of temperatures. These days we feel heat even during the rainy season and the Tafiala/Waaring (cold/harmattan) season.

Further to this, an old man asked a rhetoric question during an in-depth interview:

> Do you see men gather around fires during Waaring as it happened in the past? He asserts that "the severity of the cold (waaring) had significantly diminished so that nobody feels the severity of the cold that was experienced in the past during the season in present times. He asked again, 'Who baths warm water these days? Even old men like me bath cold water because the warm season has extended and temperatures have increased almost throughout the year.

The analysis reveals significant changes in the characteristics of *Wulumung* (warm season) and *Tafiala/Waaring* (*harmattan* season) between the past (grandfather's generation) and the present (grandson's generation). *Wulumung* (warm season) has become longer in duration, shifting from approximately three months duration to five months duration. Similarly, temperatures are significantly higher and more intense in the present era than the past.

6.3 Wind and changes in wind

In the indigenous knowledge of the people, there are three types of winds, namely, *Duonpeling, Tafaapeling* and *Kukulpapeling* (Table IV). Wind plays an important role in the traditional farming calendar of farmers. In the past, observed wind patterns, direction, speed and intensity informed planning of farming activities. These include planting, staking of yams and harvesting of food crops.

Duonpeling are the rain storms. These winds are usually associated with early rains (rains marking the beginning of rainy season) and late rains (rains marking the end of the

Table IV.
Wind types and characteristics

Type of wind	Past characteristics	Present characteristics
Duonpeling (rainstorms)	Came with rains (prevalent at beginning and end of the rainy season)	Mostly come without or with little rains
	Intensive with limited destruction	Very intensive and more destructive
	Mostly came from east-west	Uncertainties in terms of directions
		More predominant only at the beginning of the rainy season
Tafaapeling (harmattan winds)	Starts from October-January	Stars from November-December
	Cold winds both day and night	Mild cold winds at mornings
	Normal/low intensity and no destruction	Becoming absent
	Blow during day time	Normal intensity
	Very cold winds in mornings	Short duration
Kukulpapeling (sweeping winds)	Starts from February-April	Starts from February-April
	Characterized with regular and intensive whirling winds	Absence/irregular whirling winds
	Not destructive	Ineffective winds

rainy season). In the past, they blew from the east to the west and were associated with heavy rainfall. The direction of the rainstorms determined the direction of rainfall. Rainstorms were highly intensive winds. They caused a lot of damage to houses and food crops. Many houses and other built infrastructure were ripped-off and trees uprooted. They also damaged farms by breaking the stems of cereal crops such as maize, sorghum, guinea corn and millet. They pushed down staked yam plants and sometimes uprooted yam plants from the mounds, especially when they blew from a different direction other than the east to west direction. The locals assert that these winds have been disastrous in nature both in the past and present. However, in recent times, the direction of these winds is not certain. They blow from any direction and commonly associated with low rainfall or no rain at all in the beginning of the rainy season. The results show that these rainstorms are more destructive to property in present times than in the past.

Tafaapeling, are the *harmattan* winds occurring from October to January. These winds are normal winds that indicate the end of the rainy season and are usually felt during the day. They were cold winds and brought severe cold conditions during the *Harmattan* season in the past. They were dry and caused cracked heels, lips and dry skins among people. People frequently applied body cream to their bodies to maintain body moisture. These winds caused general dry weather conditions during and after harvest of crops. The results revealed that the severity of coldness is lower in present times than in the past.

Kukulpapeling, sweeping and or whirl winds, occur from February to April and coincide with *Wulumung*. They swept away rubbish and the top soil in open or bare lands. They were characterized by whirl winds locally known as *vinviling* and causing a dusty environment. This was the period farmers planted yam and did mulching for yams. The results reveal that this wind is still prevalent except that the prevalence and intensities have significantly reduced in recent times if compared with the past.

The results show indigenous classification of three types of winds, namely, *Duonpeling*, *Tafaapeling* and *Kukulpapeling*. All three types of winds have changed in nature over the past few decades. In the case of *Duonpeling*, there is growing uncertainty about the direction of flow and it has become more intensive and destructive in recent times than in the past. *Tafaapeling* are the harmattan winds and are associated with dry and less cold conditions in present times than the past. *Kukulpapeling* are whirl winds and coincide with the warm/heat season. They are less prevalent and intensive but they pollute the environment with dust because of their sweeping nature.

7. Discussion

Comparative analysis of results reveals significant changes in sunshine, temperature and winds with profound implications for development planning in Ghana. The results reveal that increased and prolonged high sunshine intensity in recent times has made it difficult to distinguish between indigenous classifications of sunshine seasons and hence, undermine the relevance of such knowledge systems in their current state. A gradual pattern of convergence and rising dominance of *Wulungyia* is observed. Sunshine intensities have increased significantly and remain high across all seasons in the local calendar year, including the peak of the rainy season. Such high-intensity sunshine is unbearable for farm work during the day, affects crop yields and human health. These findings on sunshine changes corroborate some other research findings. According to Farauta *et al.* (2011), high sun intensity in northern Nigeria resulted in reduced crop yields among farmers. Unlike Ghana, the smoke-like cover in the sky was reported to become more extreme over the years in Northern Nigeria. This study showed that high-intensity sunshine caused damages and or posed challenges in harvesting root and tuber crops such as yam, *yiiria* and potatoes. These food crops easily rot under intense sunshine and lead to high post-harvest

losses. High sunshine also causes some crops to wilt and flowering plants to shed off flowers prematurely. These findings corroborate work of Gyampoh *et al.* (2009) who found that intensive sunshine caused crops and vegetables to wilt and ripe prematurely, and thus, affecting yields and sales of crop produce in rural communities in the Offin River basin of Ghana. Thus, while the findings largely corroborate those of other studies in respect of agriculture vulnerability to high sunshine, an additional value is the demonstrated relevance of indigenous knowledge for analyzing and enabling understanding of changes in sunshine in contemporary times.

The results also show increases in temperature and an increase in the duration of the warm season during the year. High temperatures occur during the warm season from January to May. These high temperatures affect farm work and general life in many ways. According to Gyasi *et al.* (2006), high temperatures in northern Ghana compel people to sleep outside their rooms or sleep with their windows and doors opened at night. Even for southern Ghana, in the Ejura-Sekyedumase District, majority of people believed temperatures had become warmer in recent years than in the past (Kemausuor *et al.*, 2011). Similarly, De Pinto *et al.* (2012) note that temperatures were higher in northern Ghana than any other part of Ghana. They project that temperatures could further increase between 1.0 and 3.0°C in 2060 and between 1.5 and 5.2°C in 2090. Similarly, Obeng and Assan (2009) report that temperature trends in northern Ghana in particular suggest gradual increase of 1.9°C, over the period 1962-2002. These findings are consistent with the findings of Bryan *et al.* (2010) and Ogalleh *et al.* (2012) who note that temperatures in Ghana were increasing, worsening drought conditions, impacting negatively on crop farming, water and water resources. Further evidence corroborates temperature increases in Ghana and the negative impact on development. Temperatures across Ghana are increasing and resulting in low crop yields and high prices in foodstuff (Gyampoh and Asante, 2011) and for northwestern Ghana, high temperatures are adversely affecting the production of root and tuber crops (Sagoe, 2006). In general, the coterminous occurrence of high-intensity sunshine and temperature had a doubling adverse effect on people and their livelihoods. The findings reveal increasing warming, intensity and duration of occurrence of both climatic elements and consequently, increasing vulnerability to these observed trends.

The findings also reveal uncertain patterns in wind directions, increased intensity and severer damaging effects of rainstorms in recent times than in the past. These findings corroborate findings from other studies. Gyampoh and Asante (2011) found that strong winds accompanying rainfall in most parts of northern Ghana caused destruction to farms, affecting crops such as maize, millet and yam. In addition, they cause damage to economic trees, including *shea* and *dawadawa* trees and disrupt livelihoods of people who depend on these natural resources. Furthermore, the *Teso* people of Eastern Uganda observed changes in the direction of winds associated with rains and that the intensity of these winds had increased over the years (Egeru, 2012). Several researchers have attributed these changes to climate change as in strengthened westerly winds since the 1960s (Trenberth *et al.*, 2007) and intensification of North East winds since the 1970s (Mörner *et al.*, 2004). Other studies found mixed trends of decreasing and increasing wind speed in Coastal Tanzania since 1972 (Dubi, 2001); complete changes in direction of winds in Tanzania (Mahongo *et al.*, 2011); and the observation among local people in the Laikipiaa District of Kenya that there have been significant changes in winds since the 1960s and that such changes have destroyed farms and crops resulting in poor yields (Ogalleh *et al.* (2012).

8. Conclusion

The paper concludes that the current generation of smallholder farmers is more vulnerable to climate change than the past generation, the era of grandparents. In particular, the current

generation is exposed to higher intensity sunshine, temperature and wind and consequently, is affected the most by the damaging effects of these climatic hazards on their livelihoods, especially, smallholder agriculture, housing and health. The CRA process revealed two important lessons. First, it illustrated the relevance of indigenous knowledge systems for vulnerability assessments and second, it underpinned the need for adaptation of such knowledge if it is to sustain farmer efforts at climate change adaptation at community levels within the context of global change.

9. Implications for climate change adaptation planning

This paper advocates an endogenous development (ED) approach to CCAP through implementation of the national policy framework in Ghana and where similar conditions prevail in Sub-Saharan Africa. For most of Sub-Saharan Africa, there is already a decentralized system of local governance and this provides an appropriate institutional framework closer to local populations for implementing an ED approach to CCAP. This process should start with effective community mobilization and education on vulnerability to climate change and for mobilizing and triggering participatory community response to CCAP. Such an approach will enlist community commitment, build on existing knowledge systems and engender sustainability in climate change response. In this context, we put forward specific policy interventions for CCAP.

First, the promotion of pro-poor integrated soil and water conservation measures will be critical for supporting climate change adaptation given that the local populations are mainly smallholder farmers. One of the key vulnerabilities is exposure to high sunshine intensity, temperature and an exacerbating effect on drought with profound adverse effects on farming and life in general. Thus, soil and water conservation for crop production is critical. In the context of poverty, chemical fertilizers are economically out of reach for most smallholder farmers. Thus, the policy orientation should be to promote agronomic and organic practices in soil and water conservation as a more practical, inclusive and sustainable path to adapting smallholder agriculture to climate change.

Second, improving access to water for irrigation and gardening, and for domestic use such as cooking, bathing and laundry will also be critical to adaptation among smallholder farmers. Although Africa has a great irrigation potential, a greater part of that potential has not been developed mainly because of the lack of investments. If Africa is to adapt to climate change, it must develop its irrigation potential to support smallholder production. In addition to investing in community-based irrigation schemes, individual farmer initiatives have pointed to significantly low cost and practical innovations that can be supported. Lessons from research projects (e.g. supporting smallholder farmers' decision-making: Managing trade-offs and synergies for sustainable intensification project) reveal that smallholder farmers are establishing gardens in valley fields and irrigating vegetables with water from manually excavated shallow wells. This has increased agriculture production for such farmers and improved incomes and nutrition for household members. With little extension support, many more smallholder farmers could tap into this potential for production during the dry season. Aside agriculture, improving access to water will facilitate multiple domestic uses and bring relief to the most vulnerable, including the aged, children, women and girls in particular.

Third, promoting appropriate building architecture and technology will also be critical for enhancing adaptation to high sunshine and temperature exposure. Thus, building on and improving local architectural designs and use of local materials with less heat absorption properties will be useful for enhancing adaptation. Some indigenous architectural designs and building materials have proven resilient and enabled smallholder farming households adapt to extreme climate for generations. Thus, improving courtyards and safety of rooftops

for sleeping at night, improving ventilation through bigger windows through improved architectural designs is critical for CCA.

Furthermore, planting and protection of trees around homes and farms for the purposes of serving as windbreaks can reduce the damaging effects of storms to housing. In the case of farms, agro-forestry, planting hedge plants around farms and promotion of farmer managed natural regeneration can reduce vulnerability. Economic trees can provide additional benefits such as shades, fruits and income.

Finally, this paper recommends that gender mainstreaming, community advocacy and education be promoted as cross cutting policy issues and mainstreamed into the policy measures put forward. These must be reinforced through gender analysis and gendered approaches for addressing inequalities and promoting inclusive climate change adaptation for development.

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Three-stage quantitative approach of understanding household adaptation decisions in rural Cambodia

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Received 24 January 2019
Revised 6 May 2019
22 July 2019
Accepted 25 October 2019

Abstract

Purpose – A better understanding of the processes that shape households' adaptation decisions is essential for developing pertinent policies locally, thereby enabling better adaptation across scales and multiple stakeholders. This paper aims to examine the determinants of household decisions to adapt, it is also possible to target factors that facilitate or constrain adaptation. This helps to identify key components of current adaptive capacity, which leads to important insights into households' competence to adapt in the future.

Design/methodology/approach – This paper takes a full-pledged approach examining factors and processes that shape households' climate adaptation decision-making in rural Cambodia at three levels: adaptation status, adaptation intensity and choices of adaptation strategy. The three-stage analyses are materialized by applying the double hurdle model and multivariate probit model, which provides a potential way to systematically assess household adaptation decision-making in rural settings.

Findings – Results show a high level of involvement in adaptation among local households who are facing multiple stressors including climatic risks. The findings suggest that perceived climate change influence

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Financial support under the Erasmus Mundus Joint Doctorate (EMJD) Programme, Forest and Nature for Society (FONASO), the Research Council of the Danish Ministry of Foreign Affairs National Natural Science Foundation of China: (71603126) and International Cooperation (71911530164) are gratefully acknowledged. The authors would like to express their gratitude for the assistance provided by the Royal University of Agriculture (RUA) in Cambodia and Mr. Poun Sokheoun during the fieldwork, and the support of the Cambodia Development Resource Institute (CDRI), and the Greater Mekong Sub-region Environment Operations Center (GMS EOC) who assisted in producing the map. Above all, the authors would like to thank the villagers and commune officials in the study sites, who generously shared their time and knowledge. We would also like to thank Carsten Smith-Hall, Hasan Moinuddin and Edmond Dounias for their insightful comments and suggestions on earlier drafts.

International Journal of Climate Change Strategies and Management
Vol. 12 No. 1, 2020
pp. 39-58
Emerald Publishing Limited
1756-8692
DOI 10.1108/IJCCSM-01-2019-0004

households' decisions in both adaptation status and intensity. Access to financial credit, farmland size, water availability and physical asset holdings are identified as key factors promoting the adoption of more adaptation measures. To facilitate adaptation, collective effort and support at community level is important in providing knowledge based climate information dissemination and early warning systems. Public sector support and development aid programs should focus on positive triggers for targeted community and household adaptation.

Originality/value – The study, to the authors' best knowledge, is one of the first studies to investigate the determinants of local adaptation decision-making systematically in Cambodia. It also provides a comprehensive approach to improve understanding of adaptation decision-making processes by exploring how various capital assets are associated with different stages of adaptation decisions. The findings contribute to policy implications enlightening adaptation planning at multi-scales with knowledge of key factors, which enhance local adaptive capacity to reduce climate change vulnerability.

Keywords Adaptive capacity, Southeast Asia, Climate change, Rural livelihoods, Adaptation decision

Paper type Research paper

1. Introduction

It is generally acknowledged that the poor in developing countries are vulnerable to shocks and crisis with limited adaptive capacity; and climate change induced adverse impact is one of the many stressors they may face, due to higher dependence on climate-sensitive income sources (e.g. agricultural and natural resource-based) (Mertz *et al.*, 2009; Piya, 2019). The importance of using bottom-up approaches to examine socio-economic aspects of climate change at the local level has been highlighted by recent research to acknowledge context-specific vulnerability and capacity to adapt in a dynamic social-ecological system confronted with multiple drivers of change (Piya, 2019). Adaptation, defined as the adjustment in the system to a new or changing environment (i.e. climatic stimuli in the context of climate change) (Evers and Pathirana, 2018; Smit *et al.*, 2000; Smit and Wandel, 2006), not only can be planned and initiated by the government but also requires autonomous adjustments at the household and community level (Smit *et al.*, 2000).

Adaptive capacity is defined as the ability of a system to moderate the potentially adverse impacts of climate change and take advantage of arising opportunities (IPCC, 2007). Several conceptual frameworks have characterized its elements as related to a composite of socio-economic, technological, informational, institutional and psychological factors (Grothmann and Patt, 2005; Yohe and Tol, 2002). In the context of rural livelihoods, these factors are interpreted in a sustainable livelihood approach as portfolios of capital assets (i.e. natural, human, financial, social and physical) that households can build up to tackle risks, including climate risks (Li *et al.*, 2016; Piya, 2019; Scoones, 1998). Thus, adaptation to climate change and variability is regarded as an intrinsic part of households' overall risk management strategies in rural reality. A better understanding of the processes that shape households' adaptation decisions is essential for developing pertinent policies locally, thereby enabling better adaptation across scales and multiple stakeholders. By examining the determinants of household decisions to adapt, it is also possible to target factors that facilitate or constrain adaptation. This helps to identify key components of current adaptive capacity, which leads to important insights into households' competence to adapt in the future (Füssel and Klein, 2006).

Studies on socio-economic aspects of climate change has gained momentum in the past decade. There is limited empirical evidence concerning the determinants of households' adaptation decisions (Below *et al.*, 2012; Vincent, 2007). A few studies have examined what drives discrete choices of adaptation by investigating the factors that affect the option of

whether to adapt (Deressa *et al.*, 2011; Maddison, 2007) or various but mutually exclusive adaptation choices (Bryan *et al.*, 2013; Deressa *et al.*, 2009; Gbetibouo *et al.*, 2010; Molua, 2009; Waibel *et al.*, 2018) or the probability of one household carrying out multiple adaptation measures (Piya *et al.*, 2013). Other studies have addressed what influences the depth of adaptation, i.e. how many adaptation practices were implemented by individual households (Below *et al.*, 2012; Esham and Garforth, 2012; Gong *et al.*, 2018). The majority of these studies focus on rural communities in Africa (Bryan *et al.*, 2013; Deressa *et al.*, 2009; Gbetibouo *et al.*, 2010), with a few in Asia (Gong *et al.*, 2018; Piya *et al.*, 2013; Wang *et al.*, 2010) and rarely in Southeast Asia (Waibel *et al.*, 2018).

In this study, we incorporated the above considerations and research gaps from previous studies and investigated three dimensions of household adaptation decisions in the case study of Cambodia, following Noltze *et al.* (2012) (Figure 1). These are:

(1) adaptation status, referred to as whether any adaptation has been undertaken by the household or not; if yes;

(2) adaptation intensity, defined as the extent (how many adaptation measures) to which adaptation has been performed; and

(3) adaptation strategy, referred to categories of specific adaptation measures undertaken by households that are classified into different themes of adaptation actions.

The geographic focus of the study is Cambodia. As one of the recipients of financial support from the least developed countries fund, Cambodia has begun to launch adaptation actions nation-wide (D'Agostino and Sovacool, 2011). The existing literature reports mostly on experiences from specific adaptation projects in Cambodia (D'Agostino and Sovacool, 2011; Ly *et al.*, 2012; Sovacool *et al.*, 2012), while little has been done to examine adaptation decisions and practices from local actors' perspective (Resurreccion *et al.*, 2008). This paper aims to conduct a systematic analysis on what factors influence households' adaptation decisions in rural Cambodia at three dimensions:

(1) adaptation status;

(2) adaptation intensity; and

(3) adaptation strategy (category).

The study, to our knowledge, is one of the first studies to investigate the determinants of local adaptation decision-making in Cambodia. It also provides a comprehensive approach to improve understanding of adaptation decision-making processes by exploring how

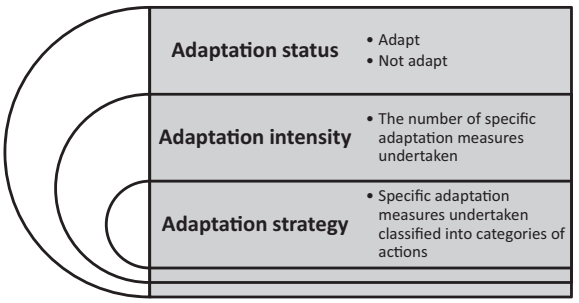

Figure 1.
Conceptual framework of household adaptation decisions in the study

various capital assets are associated with different stages of adaptation decisions. The findings contribute to policy implications by enlightening adaptation planning at multi-scales with knowledge of key factors, which enhance local adaptive capacity to reduce climate change vulnerability.

2. Material and methods

2.1 Study sites

Cambodia is anticipated to be severely affected by climate change, as agriculture is a major pillar of its economy. A decrease of 10-20 per cent in rice yields for the 2020s is projected without adaptation under climate change scenarios (Kim *et al.*, 2018). In this study, fieldwork was undertaken in 15 villages in three communes in Cambodia: Takaen in Kampot Province, Sangkae Satob in Kampong Speu Province and Tum Ring in Kampong Thom Province (Figure 1), which were initially selected in 2008 for the studies of the Poverty Environment Network (PEN, 2007). The studied communes cover a total land area of 70,082 hectares with a population of 23,460 (NCDD, 2010). The majority is Khmer; other ethnic minority groups include Souy and Khmer Muslim. Site selection criteria included:

- large areas, which have been deforested within the last 10-15 years (agricultural frontier); and
- the presence of some degree of reliance on environmental products at the household level.

The sites are all located in the lowlands, including the transition area between lowlands and mountains, and reflect the variations in rainfall patterns and other climatic characteristics.

More specifically, Takaen Commune is located in the coastal cardamom area. Annual rainfall is relatively high, ranging from 2,600 to 3,200 mm. Sangkae Satob Commune is located in the transition zone between the northern Cardamom mountain range and the lowlands of Tonle Sap Lake. The dry season is shorter than four months with low annual rainfall ranging between 800 and 1,400 mm. Tum Ring Commune is a lowland area in a remote part of Kampong Thom Province. The area experiences a relatively long and intensive dry season that lasts for more than four months. Annual rainfall ranges from 1,400 to 2,000 mm with an average of 1,700 mm (Ra *et al.*, 2011) (Figure 2).

Rural livelihoods in the study areas are a combination of subsistence and cash income-oriented activities with the transition to a more diversified livelihood portfolio. Agricultural production remains the most important component of local livelihoods. The collection of forest and other environmental products also contributes significantly to household income portfolio (Ra *et al.*, 2011). Seasonal and long-term migration and remittances are becoming important for livelihood strategies. Major climate risks in the study area are droughts and minor floods (Bylander, 2015; Nguyen *et al.*, 2009), which have a direct impact on rice and other crop productivity. In general, there are no irrigation systems at the study sites, and paddy fields located at higher elevations and away from water bodies are at increased risk of drought and dry spells.

2.2 Data collection

Participatory group discussions and structured household questionnaire surveys were used as primary data collection methods. Data collection and handling followed the procedures developed by the PEN (Angelsen *et al.*, 2011). A total of 600 households were randomly selected initially in 2008, with 200 households in each study site and 40 households in each of the 15 villages (corresponding to 10-30 per cent of households in each village). Of the originally

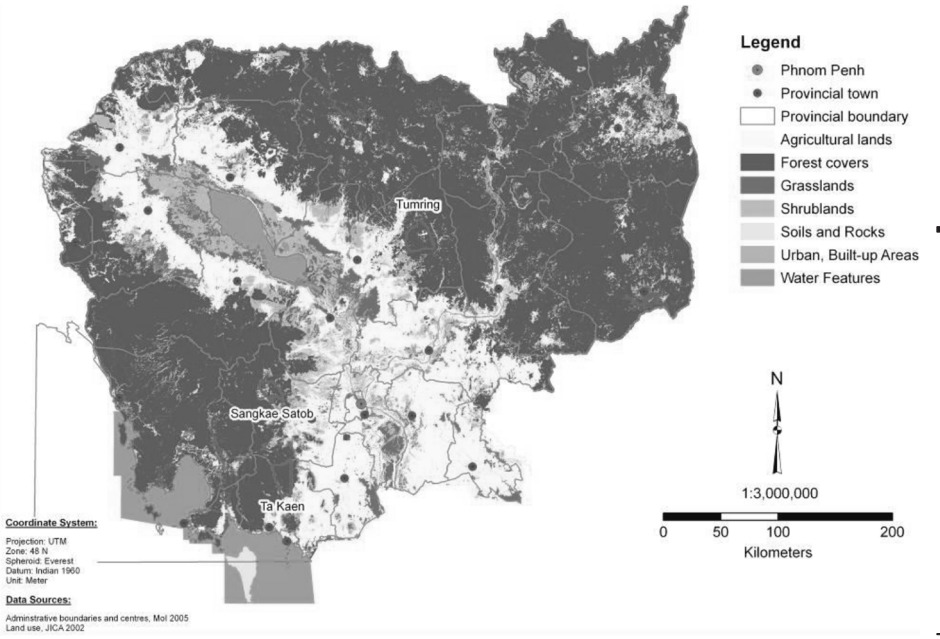

Figure 2.
Locations of selected study sites

selected 600 households, 586 households participated in the second wave of the structured household surveys in January of 2013, where the questions for this study on climate change perception and adaptation were incorporated (which was not part of the study in 2008).

The structured questionnaire focussed on households' observations and perception of climate variability and extreme events, past experience of livelihood risks/shocks (especially climate risks and impacts on livelihoods) and adaptation behaviours and decisions, as well as five capital asset holdings and income sources. Experienced local research assistants and enumerators participated in pre-testing of the questionnaire and the survey process. Participatory group discussions were conducted prior to household surveys to gather contextual and qualitative information as inputs to detailed household survey questionnaire design (e.g. to identify localized adaptation measures). Two villages from each study site were selected for group discussions, reflecting diversified climate risks and livelihood strategies. Groups representing different genders and age and a diversity of livelihood strategies discussed the vulnerability and adaptation matrix, seasonal calendar and historical timelines in six of the villages using interactive flip chart tables and drawings facilitated by local research assistants.

2.3 Empirical models

Probit models and Heckman sample selection probit models have been used by previous studies to investigate the decision of households to adapt or not (Deressa *et al.*, 2011; Maddison, 2007). However, adaptation is not simply a yes or no decision, and binary models fail to consider the intensity of adaptation or the relationship between different measures (Noltze *et al.*, 2012; Piya *et al.*, 2013). Continuous models or count models were also used to analyse adaptation intensity (Below *et al.*, 2012; Esham and Garforth, 2012). In our study, we are interested in both decision stages: firstly, the decision to adapt or not, and secondly, the

degree of intensity with which households undertake adaptation measures. Thus, this study uses a double hurdle model (Cragg, 1971), more specifically a Poisson count data hurdle model (Mullahy, 1986) to operationalize the two-stages of the decision-making process in the rural communities in Cambodia, and the approach has been applied in the context of agricultural technology adoption (Langyintuo and Mungoma, 2008; Noltze *et al.*, 2012; Tambo and Abdoulaye, 2012).

$$y_{i1}^{*} = x_i^{'}\alpha + \mu_i \tag{1}$$

$$y_{i2}^{*} = z_i^{'}\beta + \omega_i \tag{2}$$

Adopted from Noltze *et al.* (2012), equation (1) examines the binary decision to undertake any adaptation measures, whereas the number of adaption measures the household has practiced is represented by equation (2). y_{i1}^{*} and y_{i2}^{*} are the two latent variables of adaptation status (whether to adapt any) and intensity (how many measures undertaken). $x_i^{'}$ and $z_i^{'}$ are vectors of household characteristics and asset capital variables (Table I), which determine the adaptation decisions, and α and β are coefficients to be estimated. μ_i and ω_i represent the respective error terms, which are assumed to be independent and distributed as $\mu_i \sim N(0,1)$ and $\omega_i \sim N(0,\sigma^2)$. More specifically, the first decision stage regarding whether to adopt any adaptation measures ($y > 0$) is estimated by a binomial logistic regression model; while the second decision stage is based on a conditional distribution of the number of adaptation measures adopted, given $y > 0$ (Greene, 2008). The two-part likelihood function used in the model estimation is described in details in Jones (1989) and Noltze *et al.* (2012).

Further, this study uses a multivariate probit model (MVP) to analyse the determinants of individual adaptation strategy among the studied households in rural Cambodia. MVP enables modelling the probability of choosing more than one adaptation strategy option simultaneously, which overcomes the limitation of the multinomial logit model with strict assumption of independence of the irrelevant alternatives (Piya *et al.*, 2013). The same set of explanatory variables were used for the double hurdle model and the MPV model, which allows the investigation of how specific factors affect different decision stages and types of adaptation strategy.

$$Z_{ij} = X_i\beta + \varepsilon_i, \quad i = 1, \ldots, \quad n \tag{3}$$

Following Piya *et al.* (2013) and Tabet (2007), the MVP model is described as equation (3) above. Where $i = 1, \ldots, n$ are the individual household observations, $j = 1, \ldots, J$ are the available distinct binary adaptation responses; $Z_{ij} = (Z_{i1}, \ldots, Z_{ij})'$ presents a *J*-variate normal vector of latent variables and X_i is a matrix of covariates composed of explanatory variables, which influence a household's decision regarding adaptation choices; $\beta = \left(\beta_1^{'}, \ldots, \beta_J^{'}\right)$ is a matrix of unknown regression coefficients, ε_i is a vector of residual error distributed as multivariate normal distribution with zero means and unitary variance; $\varepsilon_i \sim N(0,\sum)$ where $\sum$ is the variance-covariance matrix.

$$Y_{ij} = \left\{ \begin{array}{ll} 1 & \textit{if } Z_{ij} > 0; \\ 0 & \textit{otherwise} \end{array} \right\} \quad i = 1, \ldots, n \quad \textit{and} \quad j = 1, \ldots, \quad J. \tag{4}$$

Let $Y_{ij} = (Y_{i1}, \ldots, Y_{ij})$ denote the J-dimensional vector of observed binary responses taking values {0, 1} on the *i*-th household. The relationship between Z_{ij} and Y_{ij} is described in equation (4). For further information on the model specification (i.e. likelihood function and correlation matrix), see Piya *et al.* (2013) and Cappellari and Jenkins (2003).

Variable	Expected sign	Description	Capital assets	Mean	SD
Age of HH head	+	Age of household head in years	Human capital	44.90	11.99
Age^2 (of HH head)	−	Age (of household head) squared	Human capital	2159	1149
HH size	+	Number of household members	Human capital	5.14	1.76
Female-headed HH	−	Household is female headed: 0 = male; 1 = female	Human capital	0.18	0.39
Education of HH head	+	Number of years in school completed by the household head	Human capital	3.43	3.17
Health status (sickness)	−	Number of family members who are in bad health	Human capital	0.33	0.98
Perception of climate change	+	Household perceived changes of extreme climate events (i.e. flood, drought)	Human capital	0.96	0.21
Past experience with drought	+	The average loss of paddy production during drought year (in percentage) compared with normal production year	Human capital	0.24	0.28
Farmland area	±	Area of cultivated farmland (hectares)	Natural capital	1.14	1.34
Access to water	+	Amount of water available to household farmland: 1 = low availability or too much water; 2 = moderate; 3 = good for agricultural production	Natural capital	2.09	0.80
Physical assets	+	The current value of all physical assets owned by the household (in million Riel local currency)	Physical capital	4.87	7.82
Access to market	−	Distance to the nearest main road (in kilometers)	Physical capital	0.11	0.62
Access to credit	+	Number of financial sources household able to access (i.e. formal banks and government programs/ village development fund, self-organized saving groups, informal credit from relatives or friends)	Financial capital	2.04	0.67
Trust	+	General trust among people living in the village/community: 1 = no; 2 = partly; 3 = yes	Social capital	2.47	0.55
Sangke Satob	±	Household located in Sangke Satob commune: 1 = Yes; 0 = otherwise	Social, natural, physical capital	0.34	0.48
Tum Ring	±	Household located in Tum Ring commune: 1 = Yes; 0 = otherwise	Social, natural, physical capital	0.32	0.47

Table I. Explanatory variables selected for the empirical models

2.4 Model variables

In the first decision stage – adaptation status, we use the dummy variable (Yes/No), which indicates whether households have taken any adaptation measures. Adaptation intensity is calculated using the simple unweighted sum of adaptation measures households have adopted. We assume that each adaptation measure is equally important depending on the location where it is implemented. All the adaptation measures are then categorized into five broader adaptation strategy categories (Figure 3) as the dependent variables for the MPV model.

The choice of explanatory variables was based on the literature review and results from participatory group discussions (Table I). Mixed results have been reported in the literature

Figure 3.
Categorization of adaptation measures into five adaptation strategies

regarding the impacts of age on adaptation, showing both increased and decreased propensity to conduct different adaptation measures (Deressa *et al.*, 2009; Hassan and Nhemachena, 2008; Piya *et al.*, 2013). In this study, we expect that older households are more likely to adapt as they are more experienced in farming. However, we also hypothesize that intention to adapt drops above a certain age threshold given that households have more limited energy and ability to implement adaptation or that they have less need to adapt given reduced consumption. Thus, age-squared is included in the model. The literature also shows varying relations between household size and the uptake of adaptation measures. For instance, larger families were found more likely to carry out soil and water conservation practices (Bryan *et al.*, 2013) and labour intensive measures such as multiple cropping (Hassan and Nhemachena, 2008). In this study, we expect that households with more family members will be more inclined to adapt and conduct strategies that require a larger pool of labour supply such as livelihood diversification. Moreover, the literature has well-documented gender-specific adaptation measures on account of the differential access of men and women to assets, education, credit and information, which is very much decided by the specific context where adaptation occurs (Below *et al.*, 2012; Bryan *et al.*, 2013; Deressa *et al.*, 2009). In this study, we also expect major variances in adaptation decisions, intensity and types of strategies with regard to gender, and less adaptation practiced by female-headed households. Education is another important factor in promoting adaptation and the adoption of agricultural technology (Maddison, 2007; Tambo and Abdoulaye, 2012). We hypothesize a positive impact of education on adaptation as more schooling may enhance households' capabilities to approach, interpret and make use of information pertinent to adaptation. The health conditions of households have seldom been considered when elaborating adaptation decisions in the current literature. In this study, we incorporate this variable (i.e. number of family members who are in bad health) in the analysis and hypothesize that it negatively affects adaptation as it not only reduces the effective labour supply, but also that households may be forced to divert part of their time and money to care for members in need.

Several studies have found that households' perceptions of climate change (changes in long-term temperature, precipitation and climate variability such as drought) and its related impacts are positive and significant determinants of adaptation decision-making

(Comoé and Siegrist, 2013; Deressa *et al.*, 2011; Deressa *et al.*, 2009; Esham and Garforth, 2012). As drought and flood have been reported as the most frequent and concerned extreme climatic events in the study areas (95.6 per cent of the interviewed households observed irregular flood and drought patterns in recent years), this study focuses on investigating the perception and awareness of the frequency and magnitude of changes regarding these two climatic events. We expect that households, which notice such changes in climate will tend to adapt and with greater intensity with diverse measures to prevent losses or to take advantage of opportunities. We further study the impact of past experience with climate risks on adaptation behaviour measured in terms of crop harvest losses to previous droughts. Theoretical models have underlined past personal experience as an important catalyst of adaptation (Grothmann and Patt, 2005). In this study, we assume that households, which have had bad experiences with climate change events in the past will tend to undertake adaptation using various measures.

The literature has demonstrated mixed effects of farmland area on adaptation, depending on the type of adaptation measures being explored. Households with larger size of farmland were found more likely to change crop varieties, conduct soil and water conservation measures and plant trees (Bryan *et al.*, 2013; Piya *et al.*, 2013; Waibel *et al.*, 2018), while those with less farmland appeared to be supportive of adopting multiple crop or crop-livestock systems with irrigation (Hassan and Nhemachena, 2008). We hypothesize that the farmland area is positively associated with propensity to adapt and adaptation intensity, which increases the probability of uptake of all adaptation strategies except for livelihood diversification. Furthermore, we consider the effect of access to water on adaptation decisions. Bryan *et al.* (2013) found that access to irrigation enables changing crop type. In this study, we expect that improved access to water stimulates adaptation, in particular strategies managing crops, water and farmland. The literature also suggests that the availability of machinery drives adaptation (Below *et al.*, 2012). In this study, we assume that households, which are richer in physical capital including production machinery (e.g. tractors) and telecommunication devices (e.g. mobile phones), relate positively to various adaptation decision-making processes.

Various studies have noted the significance of access to market in facilitating adaptation of a diverse nature, given the essential role of the market for information gathering and sharing (Below *et al.*, 2012; Hassan and Nhemachena, 2008; Maddison, 2007; Tambo and Abdoulaye, 2012). In this study, access to market is controlled by the distance to the nearest main road. It is expected that households located further away from the main road are less likely to adapt. Similarly, the indispensable role played by access to credit in boosting adaptation in a variety of ways is well documented in the literature (Below *et al.*, 2012; Deressa *et al.*, 2009; Hassan and Nhemachena, 2008; Piya *et al.*, 2013). We hypothesize that households with more sources to accumulate financial capital at their disposal are better able to purchase inputs and invest in costly strategies if needed, and therefore, more likely to adapt with an expanded range of strategies including those in this study. It has been established that different forms of social capital (e.g. social networks, informal institutions) act as key stimulants of adaptation by providing critical conduits to transfer finances and information(Adger, 2003; Wolf *et al.*, 2010), as well as forming common collaborative frameworks. In this paper, we used the level of trust among households as a proxy for social capital, and assume that it is positively associated with different types of adaptation decision-making.

As adaptation is highly context-specific (Smit and Wandel, 2006), we included location dummies to capture the heterogeneity in biophysical and socio-economic conditions across communities, and expect that adaptation decisions vary significantly among households

residing in different geographical zones, as reported in other studies (Deressa *et al.*, 2009; Hassan and Nhemachena, 2008; Piya *et al.*, 2013; Tambo and Abdoulaye, 2012).

3. Results

3.1 Descriptive statistics

Over 80 per cent of the household survey respondents observed a decrease in total annual rainfall and irregular shifts in rainfall patterns during recent years. Local communities often associate the increased climate risks with loss of forests due to logging, agricultural land conversion and large-scale economic land concessions. The results show that the majority of households have undertaken a variety of adaptation strategies in the study area (Table II). The number of households, which reported no adaptation measures accounted for only five per cent of the sample. On average, households undertook over three adaptation measures (*mean* = 3.17, *sd.* = 2.04, *range* = 0-12) out of a total of 18 diversified local practices. Among the five groups of adaptation strategies, crop management practices, such as adjusting crop varieties and types, improving seedlings and shifting planting dates, were most commonly practised by households (81 per cent). Measures constituting key components of farmland management, such as enhancing soil fertility and pest control, were also widely used (53 per cent). Other groups of strategies included managing agricultural products, which was aimed primarily at strategic processing and marketing (e.g. crop and livestock products) (37 per cent), diversifying livelihoods that focussed on using other natural resources (e.g. fish ponds) and engaging in non-farm activities (e.g. small businesses and migration for remittance) (23 per cent), water resource management strategies, which consist of water and flood control (e.g. drainage), as well as improving access to water for agriculture (e.g. pumps) (20 per cent).

The main groups of adaptation practices adopted by households varied across the three study sites. Households in Takaen and Sangke Satob were more similar in terms of adaptation patterns, except for the frequency of practicing water management. The application of water management was more prevailing in Takaen than in Sangke Satob. While crop management remained the most prevalent group of measures adopted by households in Tum Ring, like in the other two provinces, product management was another key adaptation category, which was ranked second in terms of frequency.

3.2. Results from the logit-Poisson hurdle model

Before going into the discussion of determinants of adaptation, we tested the specifications of the logit-Poisson hurdle model against its alternatives to justify its use. First, the Poisson model was compared to the negative binomial regressions model (Long and Freese, 2001). We found no over-dispersion of the data based on the insignificant

Table II. Adaptation strategies adopted by households in the study area

Adaptation measures	Takaen (n = 200)	Sangke satob (n = 201)	Tum ring (n = 185)	Total (n = 586)
Crop management	173 (87)	167 (83)	135 (73)	475 (81)
Water management	20 (10)	54 (27)	43 (23)	117 (20)
Farm products management	62 (31)	73 (36)	81 (44)	216 (37)
Livelihood diversification	55 (28)	40 (20)	38 (21)	133 (23)
Farmland management	137 (68)	118 (59)	56 (30)	311 (53)

Note: Percentage of households adopting a specific type of adaptation presented in parenthesis

coefficient estimated, which reflected unobserved heterogeneity among observations. This suggests that the Poisson model was in favour. We proceeded to test the two-stage decision model against the single Poisson regression. To do so, we used a likelihood- ratio (LR) test (Greene, 2008), considering that the Poisson model is nested in the double hurdle model given its generalized specification. The result was highly significant ($LR\ \chi^2\ (17) = 43.83$, $p = 0.0004$), thereby rejecting the null hypothesis that the Poisson model was appropriate.

Table III presents the results from the double hurdle model exploring the factors that influence the two-stage household adaptation decisions: whether to adopt any adaptation measures and, if so, how many. Perceived climate change (i.e. drought and flood) and improved access to water for farmland have positive and significant effects on both adaptation decision stages. At the first decision stage, the positive effect of age and a negative effect of age squared show that the probability of adaptation increases with age of household heads; however, when household heads reach a certain age, the effect of age lessens. Other factors that influence the first stage of decision-making include health status and access to market and services. The results show that the poor health of family members may constrain households to adapt; this was expected as participation in different kinds of adaptation is most likely to be labour intensive. Proximity to a main road with better access to market and other services facilitates household adaptation. Regarding the intensity of adaptation, households with more farmland are more likely to adopt a larger number of adaptation measures. We also found that physical asset accumulation and better access to credit have a positive effect on household adaptation intensity. Households with higher crop sensitivity (loss of productivity) because of drought undertake more adaptation measures.

	Decision to adapt		Intensity to adapt	
Variable	Coefficients	*p*-value	Coefficients	*p*-value
Sangke Satob (1/0)	−0.838	0.334	0.076	0.179
Tum Ring (1/0)	−2.321***	0.007	0.202**	0.018
Female headed HH (1/0)	−0.473	0.332	−0.103	0.165
Age of HH head (year)	0.267**	0.033	−0.007	0.622
Age^2 (of HH head)	−0.002*	0.056	0.000	0.578
HH size (persons)	0.148	0.261	0.004	0.817
Education of HH head (year)	0.095	0.251	0.000	0.987
No. of sick persons (persons)	−0.209*	0.067	−0.022	0.496
Farmland area (ha)	0.255	0.693	0.052***	0.002
Farmland access to water	0.844**	0.001	0.230***	0.000
Distance to main road (km)	−0.460*	0.051	0.037	0.265
Physical assets (million Riel)	−0.008	0.582	0.006***	0.008
Trust among community	−0.418	0.355	0.040	0.480
Access to credit	−0.473	0.193	0.092**	0.025
Perception of climate change	1.263**	0.037	0.503**	0.021
Past experience with drought	1.868	0.252	0.364***	0.000
Constant	−3.819	0.148	−0.224	0.615
Number of observations	586			
Wald χ^2 (16)	83.41			
p-value	0.0000***			
Log pseudo-likelihood	−1,121.8267			

Notes: HH means household; ***; **; * Significant at 1, 5 and 10 % level, respectively

Table III.
Parameter estimates of the logit-Poisson hurdle model

3.3. Results from the multivariate probit model model

The validation of adopting the MVP model – assessing all equations simultaneously instead of the independent assessment of individual equations – was suggested in the significant result of the LR test (χ^2 (10) = 45.05, p = 0.0000). The estimated correlation coefficients (ρkj) among various groups of adaptations were highly significant for 7 out of 10 combinations. The positive signs implied that the adoptions of these multifaceted adaptation strategies are complementary, indicating households often chose more than one adaptation strategy.

Table IV shows the results from the MVP model examining the determinants of households' choices of adaptation strategies, and we found that adoptions of different adaptation strategies are not significantly influenced by the same set of variables. Similar to the two-stage decision-making, better access to water for farmland often provides an incentive to households to adopt crop management, farm product management and farmland management adaptation strategies. The higher extent of crop productivity loss due to drought seems to have a significant positive effect on adopting strategies such as farm product management, water management and farmland management. Farmland size is positively associated with the adoption of crop management and farm product management strategies, while physical asset accumulation seems to facilitate farm products and water management strategies.

While there are factors supportive of several types of adaptations, other factors were found to facilitate only one specific type of adaptation. Human capital and household characteristics seem to only affect the choice of livelihood diversification strategy. Senior male-headed households with a higher education are more likely to diversify or shift to other livelihood alternatives (e.g. running a small business, a migrant worker for remittance), while bad health of family members becomes a barrier to this type of adaptation strategy. Interestingly, households adopting the livelihood diversification strategy often own fewer physical assets, probably because less physical capital is required and they liquidate these assets to invest in non-farm activities. Notably, perception of climate change seems to only influence adaptation of crop management. Trust among people in the community shows a positive and significant effect on undertaking crop management strategies, which underlines the fact that communication and information sharing networks may facilitate the most practiced crop management measures.

4. Discussion

The analyses provide some insights into households' adaptation strategies and their determinants in rural Cambodia. The findings suggest a high level of adaptation involvement among local households with three adaptation measures undertaken on average. This may be explained by the way in which adaptations were addressed and elicited. Indeed, rural households always have to adapt under various situations and risks, and often undertake measures as part of traditional farming practices without regarding them as "adaptation" (Nyong *et al.*, 2007). Given the context of rural livelihoods faced with multiple drivers of change including climate change, adaptation measures adopted by the households in the study area are not necessarily limited to those solely initiated in response to climate change risks, unlike other research (Deressa *et al.*, 2011). In fact, households' adaptation are often conducted to fulfil multiple objectives as an essential part of the overall risk management, which holds particularly true for rural households, who are constantly confronted with diversified stressors (O'Brien and Leichenko, 2000). For instance, some of the adaptation measures reported in our study are mainly climate-related, such as flood water control; while others, such

Variable	Crop management		Farm products management		Water management		Livelihood diversification		Farmland management	
	Coefficients	*p*-value	Coefficients	*p*-value	Coefficient	*p*-value	Coefficient	*p*-value	Coefficient	*p*-value
Sangke Satob (1/0)	−0.083	0.631	0.169	0.214	0.721***	0.000	−0.212	0.150	−0.255*	0.059
Tum Ring (1/0)	0.092	0.611	0.617***	0.000	0.831***	0.000	−0.318*	0.060	−0.812***	0.000
Female headed HH (1/0)	0.234	0.174	−0.027	0.855	−0.076	0.655	−0.398***	0.016	−0.191	0.206
Age of HH head (year)	−0.001	0.897	0.003	0.465	0.003	0.602	0.009*	0.056	−0.006	0.235
HH size (persons)	0.006	0.865	−0.021	0.496	0.039	0.297	−0.002	0.960	0.041	0.188
Education of HH head (year)	−0.007	0.750	−0.006	0.711	−0.007	0.752	0.053***	0.006	0.006	0.743
No. of sick persons (persons)	−0.037	0.558	0.055	0.368	−0.086	0.284	−0.251**	0.044	−0.088	0.136
Farmland area (ha)	0.385***	0.000	0.089**	0.046	0.026	0.579	−0.051	0.386	0.086	0.186
Farmland access to water	0.392***	0.000	0.108	0.154	0.305***	0.000	0.096	0.226	0.220***	0.002
Distance to main road (km)	−0.083	0.396	0.024	0.812	−0.111	0.150	0.038	0.697	−0.053	0.651
Physical assets (million Riel)	0.006	0.516	0.015*	0.050	0.015**	0.044	−0.024**	0.046	0.001	0.880
Trust among community	0.245**	0.037	−0.125	0.208	−0.056	0.632	−0.057	0.596	0.005	0.960
Access to credit	−0.091	0.374	0.190**	0.025	0.235**	0.031	−0.073	0.387	0.108	0.214
Perception of climate change	1.141***	0.000	0.415	0.161	0.661	0.148	−0.244	0.384	0.189	0.506
Past experience with drought	0.014	0.958	0.395*	0.050	0.664***	0.002	0.147	0.529	0.374*	0.068
Constant	−1.755***	0.003	−1.602***	0.002	−3.608***	0.000	−0.613	0.263	−0.559	0.272

(*continued*)

Table IV.
Parameter estimates of the MVP model

Table IV.

Correlation coefficients		
	Coefficient	*p*-level
ρ_{21}	0.171*	0.037
ρ_{31}	0.111	0.237
ρ_{41}	−0.139	0.102
ρ_{51}	0.026	0.750
ρ_{32}	0.208***	0.006
ρ_{42}	0.182**	0.016
ρ_{52}	0.144**	0.040
ρ_{43}	0.280***	0.001
ρ_{53}	0.216***	0.005
ρ_{54}	0.189**	0.011
Number of observations	586	
Draws	100	
Wald χ^2 (75)	400.33	
p-value	0.000***	
Log pseudolikelihood	−1,493.5462	

Notes: Likelihood ratio test of $\rho_{21} = \rho_{31} = \rho_{41} = \rho_{51} = \rho_{32} = \rho_{42} = \rho_{52} = \rho_{43} = \rho_{53} = \rho_{54} = 0$, χ^2 (10) = 45.0472 and *p*-value = 0.0000; ***; **; * Significant at 1, 5 and 10 % level, respectively. HH means household

as changing crop variety and type, are generally beneficial in terms of increasing productivity and profitability, in the meantime reducing risks from different sources (i.e. climate and market).

In this study, we have demonstrated that perceived climate change drives households' adaptation behaviour. An awareness of climate change is regarded as an important factor or even a prerequisite for adaptation, which is highlighted by quite a few theoretical and empirical studies (Deressa *et al.*, 2011; Maddison, 2007). The results from our study; particularly the positive association found between perceived climate change and adaptation decisions provide further evidence that households, which are aware of climate change adapt more readily in a variety of ways. Thus, enhancing awareness of climate change and adaptation among households through capacity building and information dissemination can be an effective approach to promote adaptation. Our study also found that past experience with climatic risks plays a significant role in motivating adaptation; households, which bore heavier crop losses during previous droughts are more likely to adapt with greater intensity and use strategies aimed at protecting (e.g. water and farmland management) or expanding crop production. This finds support in other studies (Koerth *et al.*, 2013; Weinstein, 1989), where personal experience with past damages was found to be a key predictor of self-protective actions against natural hazards. In the study areas where households have poor access to climate information and weak adaptation capacity, knowledge-based information and early warning mechanisms are important for effective community-based and household-level adaptation. Herein, some potential incentive packages are necessary with the support of the private sector (such as the public-private partnership with telecommunication firms) to use mobile technology for weather forecasts, early flood and drought warnings (similar to market information network for farmers via mobile phones or fund transfers via mobile network).

According to our finding, farmland size does not seem to be significantly associated with the decision to adapt, but households with large size of farmland tend to undertake more adaptation measures, especially those related to crop management practices and agricultural product processing and marketing. An associated issue is that insecure land tenure may become a barrier to farmers allocating land or making investments in certain adaptation measures, such as water management infrastructure, as pointed out by many studies (Maddison, 2007; Piya *et al.*, 2013). Farmland access to water is found to be a critical factor in our study, which influences adaptation status and intensity decisions, as well as adaptation strategy choices regarding farmland, water and crop management. This complies with other findings about the significant impact of access to irrigation on adaptation (Bryan *et al.*, 2013). In the studied communities, crop production is mainly rain-fed agriculture and irrigation systems are not available. Appropriate water management facilities and technologies should, therefore, be promoted and enhanced to facilitate the adoption of agriculture-related adaptation options in the study area.

Households located closer to the main road and with better access to market and services are found most likely to adapt in our study, which is largely in line with other studies (Below *et al.*, 2012; Deressa *et al.*, 2011; Maddison, 2007). However, proximity to the main road is not significantly associated with adaptation intensity or any adaptation strategy choices. Possible reasons for this could be weak infrastructure and a lack of facilities in general in the study areas. This indicates that poor access to inputs, technologies and information, together with high transaction and opportunity costs, constitute critical entry barriers to further participation in adaptation (Hassan and Nhemachena, 2008; Piya *et al.*, 2013). Our findings also suggest that household physical assets serve as a significant contributor to adaptation intensity and promote the adoption of water and agricultural product

management strategies, while its impact is negatively significant on the adoption of livelihood diversification strategy (e.g. small business, migratory work for remittance). Possible explanations may lie in that diversification has a lower demand for these assets or that these assets could actually be transformed into financial capital for investment in other non-farm activities.

There exists ample empirical evidence for credit availability as an influential factor in facilitating local adaptation (Below *et al.*, 2012; Bryan *et al.*, 2013; Deressa *et al.*, 2011; Hassan and Nhemachena, 2008; Piya *et al.*, 2013; Tambo and Abdoulaye, 2012), and it is further substantiated through our study that better credit accessibility enables households to undertake more adaptation measures, especially in water management and farm product management strategies in the local communities. To facilitate adaptation, investments and support could be directed to microcredit schemes, a social fund for community-based adaptation and weather-based insurance.

Our study suggests that male-headed, well-educated households and household members who are in good health are more likely to adapt by means of livelihood diversification. The result echoes the findings of other studies (Bryan *et al.*, 2013), where men – because of their stronger financial situation and better access to information/resource use – tended to adopt certain adaptation strategies (e.g. change animal feed). The result also confirms the positive effect of education on varied adaptation behaviours disclosed by others (Deressa *et al.*, 2009; Tambo and Abdoulaye, 2012). The analyses indicate that continuous investment in education and medical care systems, as well as measures that empower women should be emphasized as a key policy option in the study area to strengthen households' adaptive capacity. Furthermore, we found that trust among households is one of the key motivators for implementing crop management strategies in the study area. This may be because of that trust serves as the basis for social networking and information sharing about farming practices and crops among community members. Our study coincides with other studies, which highlight the essential role of social capital in the uptake of adaptation (Comoé and Siegrist, 2013; Esham and Garforth, 2012). Consequently, policies, which aim to reinforce community institutions and bonds are considered an effective means to facilitate adaptation to climate risks.

The significant coefficients of location dummies indicate that households living in different geographical settings used local-specific adaptation approaches, which was also found in other studies (Bryan *et al.*, 2013; Deressa *et al.*, 2009; Piya *et al.*, 2013). This implies that no one-size-fits-all adaptation strategy could be used across all communities. The formulation of adaptation strategies needs to be tailored to the local context and accommodate the specific needs and constraints of targeted communities (Bryan *et al.*, 2009). It is important to understand the fundamental process and drivers regarding adaptation at the community and household levels.

The three-stage analytical approach applied in our study provides a potential way to systematically assess household adaptation decision-making in other rural settings. However, site-specific selection of variables is needed to allow for the incorporation of local and contextual considerations. The method of using the unweighted sum of adaptation measures may not be a good reflection of the relative importance and contribution of different options towards enhanced adaptive capacity. This could be further refined in future research using objective weighting schemes derived from e.g. principal component analysis (Li *et al.*, 2016). Moreover, this study did not investigate the effectiveness or the associated costs and benefits of particular adaptation options, which points to future research in this area.

5. Conclusion

This study took a systematic approach to exploring the determinants of household adaptation decision-making from three dimensions, namely, adaptation status, adaptation intensity and choices of adaptation strategy. Key capital assets that determine household adaptation behaviours, which were identified through the double hurdle model and MVP model analyses, correspond well with the hypothesized results and existing empirical studies, and contribute to the literature with new angles and in-depth results at various adaptation decision-making stages. This paper provides an analysis of households' own autonomous adaptation measures practiced at present, although the speed and magnitude of climate-induced changes may seriously challenge their adaptive capacity in the future. Considering the significant influence of households' climate change perceptions on adaptation, actions should be taken to promote channels of climate information dissemination and sharing (e.g. through dialogues) at the village and sub-district levels. In this study, potential interventions derived from influential factors for adaptation decisions include improvement of rural infrastructure and services (i.e. education, healthcare, market facilities), the strengthening of local institutions and social capital, development and promotion of water management facilities and technologies, as well as micro-credit and insurance mechanisms. More importantly, adaptation strategies and actions should be tailored to the local context and mainstreamed into existing community development policy and planning process, involving multi-stakeholders.

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Household resilience to climate change hazards in Uganda

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Received 3 October 2018
Revised 20 January 2019
1 May 2019
29 May 2019
3 August 2019
21 August 2019
Accepted 11 October 2019

Abstract

Purpose – As climate change shocks and stresses increasingly affect urban areas in developing countries, resilience is imperative for the purposes of preparation, recovery and adaptation. This study aims to investigate demographic characteristics and social networks that influence the household capacity to prepare, recover and adapt when faced with prolonged droughts or erratic rainfall events in Mbale municipality in Eastern Uganda.

Design/methodology/approach – A cross-sectional research design was used to elicit subjective opinions. Previous studies indicate the importance of subjective approaches for measuring social resilience but their use has not been well explored in the context of quantifying urban resilience to climate change shocks and stresses. This study uses 389 structured household interviews to capture demographic characteristics, social networks and resilience capacities. Descriptive and inferential statistics were used for analysis.

Findings – The ability of low-income households to meet their daily expenditure needs, household size, and networks with relatives and non government organizations (NGOs) were significant determinants of preparedness, recovery and adaptation to prolonged droughts or erratic rainfall events.

Practical implications – The results imply that policymakers and practitioners have an important role *vis-à-vis* encouraging activities that boost the ability of households to meet their daily expenditure needs, promoting small household size and reinforcing social networks that enhance household resilience.

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This research was supported by SIDA (331).

International Journal of Climate Change Strategies and Management
Vol. 12 No. 1, 2020
pp. 59-73
Emerald Publishing Limited
1756-8692
DOI 10.1108/IJCCSM-10-2018-0069

Originality/value – Even the low-income households are substantially more likely to prepare for and recover from prolonged droughts or erratic rainfall events if they can meet their daily expenditure needs. This finding is noteworthy because the poorest in society are generally the most vulnerable to hazards.

Keywords Resilience, Drought, Urban, Networks, Rainfall, Demographic

Paper type Research paper

1. Introduction

Urban resilience against climate change shocks and stresses has become an important issue in the contemporary world (Bozza *et al.*, 2015). As climate change is increasingly manifesting through prolonged droughts, erratic rainfall events, storms and floods threatening to severely affect developing countries (Walshe *et al.*, 2018), urban households are likely to suffer most because people and infrastructure are concentrated in urban areas (Bozza *et al.*, 2015; Taedong and Taehwa, 2016). Thus, the determinants of household resilience in urban areas warrant investigation to guide suitable interventions (Boyd and Juhola, 2014). In this study, household resilience is defined as the capacity of a household to prepare, recover and adapt or change its source of income or livelihood if needed when faced with climate change shocks and stresses (Jones and Tanner, 2015).

Several studies have indicated the importance of demographic characteristics and social networks in influencing household resilience to shocks and stresses (D'Errico and Di Giuseppe, 2018; IPCC, 2015; Jones and Samman, 2016). In its Fifth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC, 2015) highlighted demographic characteristics such as age, gender, income and health status to shape the resilience capacities of urban households. In the context of resilience to food insecurity in Uganda, D'Errico and Di Giuseppe (2018) found that highly educated households are more resilient than low educated households while female headed households are less resilient compared to male headed households. Jones and Samman (2016) assessed resilience capacities and demographic factors that influence resilience to floods in Tanzania and reported that knowledge of previous floods, believing floods to be a serious problem and age were more important than other factors.

Social networks with relatives, friends, non government organizations (NGOs) and the government act as first responders during times of shocks and stresses (Aldrich and Meyer, 2014; Tawodzera, 2012; Tippens, 2016). This is because social networks can help in terms of the provision of loans, gifts, emotional support and early warnings, which are important for enhancing resilience (Aldrich and Meyer, 2014). To elaborate, Tawodzera (2012) reported that networks with friends and relatives were significant in enhancing household resilience to food insecurity in Harare. Similarly, Tippens (2016) revealed that the resilience of urban refugees to psychological stress in Nairobi was enhanced by establishing networks with NGOs.

Overall, the extant literature provides a wealth of knowledge on salient factors, which may enhance resilience to different types of shocks and stresses e.g. floods (Jones and Samman, 2016), food insecurity (D'Errico and Di Giuseppe, 2018; Tawodzera, 2012) and psychological stress (Tippens, 2016). However, studies have generally restricted predictors to objective demographic and economic factors (D'Errico and Di Giuseppe, 2018) or focused solely on the role of social networks (Aldrich and Meyer, 2014; Sadri *et al.*, 2017; Tawodzera, 2012; Tippens, 2016). This study endeavors to fill this gap by using a broad subjective approach that simultaneously explores multiple potential predictors in the context of climate-related shocks and stresses. Therefore, in line with Jones and Samman (2016), it is assumed herein that subjectively perceived resilience capacities are essential for understanding resilience.

The study investigates demographic characteristics and social networks that may influence the household capacity to prepare, recover and adapt or change their source of income or livelihood if needed when faced with prolonged droughts or erratic rainfall events in Mbale municipality in Eastern Uganda. In line with the global call by the United Nations International Strategy for Disaster Reduction (UNISDR, 2015), this work is framed in terms of the following research question:

RQ1. Which demographic characteristics and social networks influence household resilience capacities when faced with prolonged droughts or erratic rainfall events?

In the past four decades, the globe has experienced unprecedented warming with average temperatures rising from 0.65°C to 1.06°C above pre-industrial levels (IPCC, 2015). This has exacerbated several climate change shocks and stresses such as prolonged droughts, heavy precipitation events, and floods, which have threatened to severely affect urban areas especially those in Sub-Saharan Africa (Boyd and Juhola, 2014). In the context of Uganda, Nsubuga and Rautenbach (2018) indicated a significant rise in air temperatures, increased droughts and dry spells, increased intensity of precipitation events and floods in October, November, December and January. The negative effects of these climate change shocks and stresses are particularly apparent in Uganda's urban areas located on the lower slopes of high mountains (UNDP, 2013). This illuminates the need for empirical assessments in the urban areas of Uganda to ascertain important determinants of household resilience to climate change shocks and stresses. Hitherto, only a few resilience studies have been conducted in Uganda with a focus on the urban context (Dobson *et al.*, 2015; D'Errico and Di Giuseppe, 2018). Moreover, there has been a dearth of attention to how demographic characteristics and social networks influence household resilience to climate change shocks and stresses. Therefore, this study presents an important research agenda that may have a potential policy impact by helping to provide knowledge that can improve Uganda's level of resilience to climate change shocks and stresses – this country was ranked 147 out of 178 countries in terms of resilience by Warner *et al.* (2015).

Herein, climate change shocks refer to sudden and rapid disturbances caused by extreme weather conditions (The Rockefeller Foundation/Arup, 2016), while climate change stresses refer to slow processes whose cumulative effects are felt after a long time (The Rockefeller Foundation/Arup, 2016).

The remainder of the paper proceeds as follows. The theoretical framework is presented in Section 2. In Section 3, the data and methods are described before the exploration of the results in Section 4. Conclusions and recommendations are provided in Section 5. Information concerning the survey instrument is relegated to the Appendix.

2. Theoretical framework

The concept of resilience emanates from the ecological stability theory proposed by Holling (1973, p. 14), who in his seminal work defined resilience as "the measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables." Beyond ecology, resilience has also been conceptualized in other research domains e.g. engineering and materials science (Holling, 1996) and climate change disasters (Bozza *et al.*, 2015). Resilience generally means the capacity of a system or community that is exposed to hazards to resist, accommodate, and recover in a timely and efficient way, and the capacity to adapt or change its essential basic structures and functions (UNISDR, 2015). However, debates and disagreements do exist to the extent that the resilience concept is sometimes contested not only between different fields of study but also within frameworks and indices of the same field of study. Notwithstanding, the socio-ecological

frameworks and indices developed to measure urban resilience to climate change shocks and stresses measure common capacities although not limited to the capacity to prepare, recover, and adapt or change (Lindsey *et al.*, 2018).

The capacity to prepare describes the ability of households to anticipate and lessen the effects of climate change shocks and stresses; the capacity to recover describes the ability to absorb and continue thriving; while the capacity to adapt or change describes the ability of a household to adjust and modify its sources of income or livelihoods if needed and take advantage of new opportunities presented by prolonged droughts or erratic rainfall events (Aldrich and Meyer, 2014; Jones and Tanner, 2015).

Most of the extant urban resilience frameworks and indices use objective approaches that make use of secondary socioeconomic and biophysical data sets as proxies for understanding resilience factors (Chun *et al.*, 2017). However, such data sets are often lacking in developing countries (Jones and Tanner, 2015). Thus, operationalizing objective resilience approaches is currently not possible in much of the world. To circumvent this challenge, subjective resilience approaches that obtain data using surveys to elicit local knowledge for measuring social resilience have recently been suggested (Jones and Tanner, 2015). Subjective resilience approaches capture context-specific issues by using cognitive self-evaluation of resilience capacities, following a bottom-up approach (Jones and Tanner, 2015). However, as much as subjective approaches may complement objective methods, their use has not been well explored particularly in quantifying the resilience capacities of urban households to climate change shocks and stresses. Thus, in assessing the resilience of households to prolonged droughts or erratic rainfall events in Mbale municipality, this study adopts a subjective resilience framework proposed by Jones and Tanner (2015) and used by Lindsey *et al.* (2018). This framework is premised on a bottom-up process, which relies on peoples' cognitive self-evaluation of the factors that are most important in contributing to household resilience (Lindsey *et al.*, 2018). Moreover, focus is placed on context-specific issues such as social networks (with friends, relatives, NGOs and government), demographic characteristics (gender, age, household size, gender of household head, education, income and the ability of a household to meet its daily expenditure needs) and perceived capacity to prepare, recover and adapt or change, which are significant in determining household resilience (Aldrich and Meyer, 2014; Lindsey *et al.*, 2018). While subjective resilience assessments have particular weaknesses, they can provide valuable insights, which need to be considered alongside objective resilience approaches (Jones and Tanner, 2015).

3. Data and methods

3.1 Study area

The study was conducted in Mbale municipality in Eastern Uganda (Figure 1) between August-September 2017. Mbale municipality was selected based on its location in a mountainous disaster prone area characterized by erratic rainfall events, flash floods in low lying areas and high rates of urban population growth imposing pressure on land and social service provision (Kansiime *et al.*, 2013; UBOS, 2016; UNDP, 2013). Reports also indicate that several droughts have affected the area e.g. in 1979/1980, 1993/1994, 1996, 1999, 2011/2012, 2013 and 2016/2017 (NEMA, 2010; OXFAM, 2017). These droughts exacerbate problems of water access, quality and affect crop yields leading to increased food prices. To further hamper the resilience capacities of households, Mbale municipality is located in a region of Uganda characterized by low social economic status, high poverty levels and vulnerability to climate-related shocks (Dobson *et al.*, 2015). Understanding which demographic factors and social networks are important in enhancing preparedness, recovery and adaptation is thus urgent to build requisite resilience (Kansiime *et al.*, 2013).

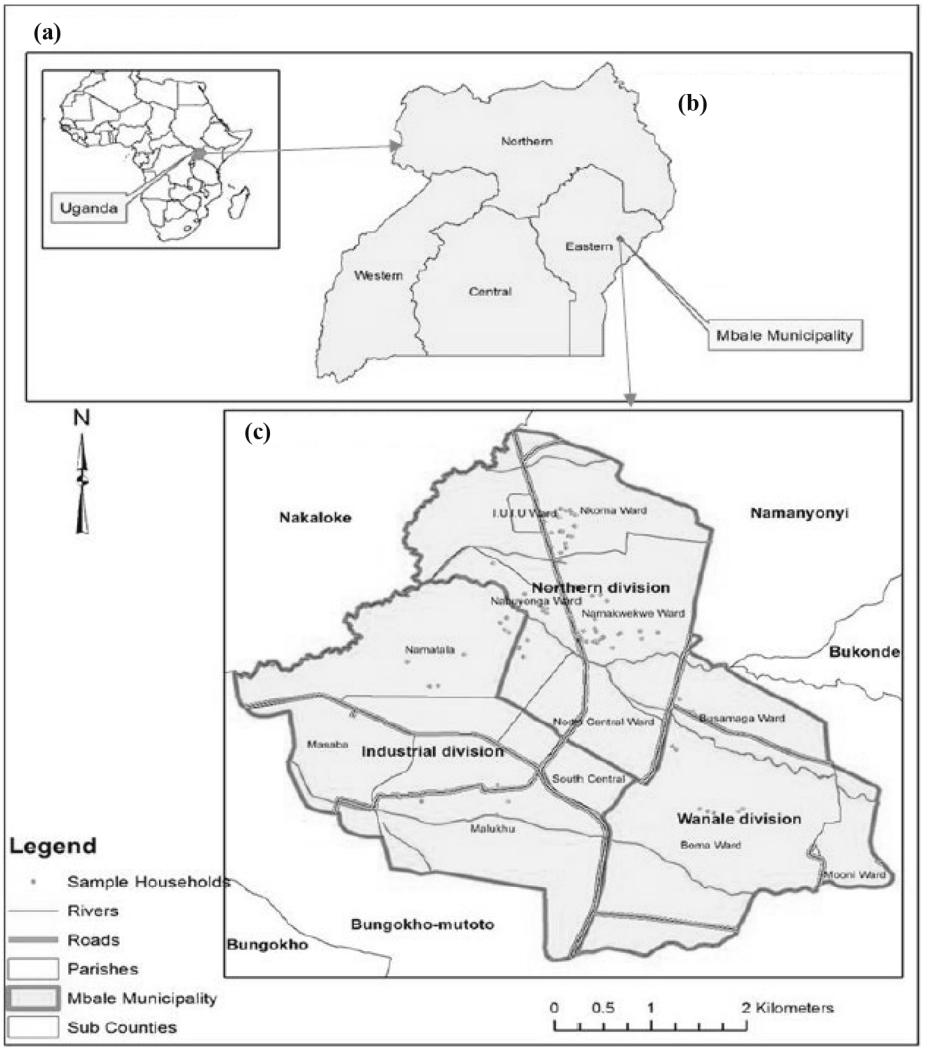

Figure 1.
Study area location in Eastern Uganda

Notes: Map generated using geographical information systems with data from UBOS (2014); (a) Uganda in Africa; (b) Mbale Municipality in Uganda; (c) Mbale Municipality

Mbale municipality comprises three divisions i.e. Wanale, Industrial and Northern divisions with a total population of 92,857 in the year 2014 (UBOS, 2016). These three divisions are further demarcated into 14 wards. The municipality experiences a humid tropical climate with bimodal rainfall from March to June and from September to November, while dry seasons occur from December to February and in July (UNDP, 2013). For the period between 1960 and 2009, the average annual rainfall was 1,500 mm and the average annual temperature was 23°C (Mbale District Local Government Statistical Abstract, 2012).

3.2 Data collection

A cross-sectional survey research design was used with a multi-stage sampling procedure. Multi-stage sampling was instituted because of its flexibility, cost-effectiveness and comprehensiveness (Bennett and Iiyanagec, 1988). The first stage involved a purposive selection of seven of the 14 wards spanning the three divisions in Mbale municipality. These wards were selected taking into consideration sensitivity and fragility to prolonged droughts, erratic rainfall events that often cause flash floods and population characteristics (UNDP, 2013; UBOS, 2016). The second stage involved random sampling of households to identify respondents to a structured household interview questionnaire (n = 389). Random sampling was deemed appropriate at this stage because every household in the selected wards is likely to be affected by prolonged droughts or erratic rainfall events. The sample size was statistically determined following Yamane (1967) at a 5 per cent level of precision [equation (1)].

$$n = \frac{N}{1 + N\ (e)^2} \tag{1}$$

Where:
n = sample size;
N = total population of households based on census data (UBOS, 2016); and
e = the level of precision.

The number of households sampled from each ward was proportionately determined based on census data (UBOS, 2016). Consequently, 129 households were sampled in Namatala ward, 79 in Namakwekwe, 58 in Nkoma, 50 in Nabuyonga, 46 in Malukhu, 11 in Boma and 19 in Busamaga west. Closed-ended questions were used because they provide an expeditious instrument for data collection, coding, interpretation, quantification and comparison of outcomes across space (Jones and Tanner, 2015). The data collection tool (Appendix) was pre-tested and consent from the participants was obtained before engaging them in the study. The data collected consisted of perceptions on the severity of prolonged droughts or erratic rainfall events; perceptions on household resilience capacities when faced with prolonged droughts or erratic rainfall events; and household demographic characteristics and social networks.

3.3 Data analysis

Descriptive statistics were used to explore perceptions on the severity of prolonged droughts or erratic rainfall events, resilience capacities and perceived spatial distributions of resilience capacities in the three divisions of Mbale municipality[1]. In terms of inferential statistics, linear regression was used to investigate, which demographic characteristics and social networks are significant predictors of household capacity to prepare, recover and adapt or change when faced with prolonged droughts or erratic rainfall events. This type of regression model was used because the predictor and outcome variables are linearly related[2].

In linear regression Models 1-3 (Table II) the outcome variables were, respectively, the ability of households to prepare, recover and adapt or change their source of income or livelihood if a prolonged drought or erratic rainfall event occurred. The predictor variables were demographic characteristics (i.e. gender and age of the respondent, monthly income of household head, household size, the gender of household head, the ability of a household to meet its daily expenditure needs and education level of the respondent). An interaction effect between income and the capacity of a household to meet its daily expenditure needs is also included. The effect of meeting daily expenditure needs on the ability to prepare, recover and adapt is expected to depend on household income.

In linear regression Models 4-6 (Table II), the outcome variables were, respectively, the household capacity to prepare, recover and adapt or change while social networks (i.e. networks with friends, relatives, NGO's and government) were added to the set of predictor variables, alongside the demographic characteristics[3].

3.4 Sample characteristics

Households constituted the unit of analysis while the respondents were adult members of the household. The average age of respondents was 34 years of age with a range between 18 to 80 years of age. A slim majority of respondents were male (55 per cent). Next, 45 per cent of respondents had completed secondary education; 21 and 14 per cent had completed primary and tertiary education, respectively; 18 per cent had completed university studies. In terms of occupation, 45 per cent of the respondents were traders, 26 per cent were public servants, 18 per cent were farmers and 18 per cent had no form of occupation. Most households were headed by men (76 per cent). The average household size was five members with a range between 1 to 24 members. In terms of income, 37.5 per cent of respondents earned between $27 and $79 per month, 32.1 per cent earned less than $26, 16.2 per cent earned above $132 and 14 per cent earned $80 to $131. In the industrial division of Mbale municipality, 44 per cent of respondents earned less than $26 per month. Most households in the municipality survive on a daily expenditure of less than $2.6 (59 per cent), 28 per cent spent $2.9-$5, 9 per cent spent $5.5-$8, while only 4 per cent spent above $8.

4. Results and discussion

4.1 Perceptions of households regarding the severity of prolonged droughts or erratic rainfall events

Households were asked to report how serious the problem of prolonged droughts or erratic rainfall events are to their households (Table I). Overall, 63 per cent of respondents reported that prolonged droughts or erratic rainfall events have been a serious problem to their households, while 37 per cent reported that this is not likely to be a serious problem. This finding is likely to reflect the impacts of recent prolonged droughts in 2013 and 2016/2017, which were associated with water scarcity and high temperatures with deleterious impacts on crop yields, and consequently, leading to high prices of agricultural-related commodities (OXFAM, 2017). Similarly, Mohammed *et al.* (2018) reported an increase in prolonged droughts in Ethiopia in the past two decades.

4.2 Perceived capacity of households to prepare, recover and adapt or change

Most respondents perceived their households to be unlikely to prepare (59 per cent), unlikely to recover (53 per cent) and unlikely to adapt or change (56 per cent) their source of income or livelihood when faced with prolonged droughts or erratic rainfall events (Figure 2). This is

Table I. Household perceptions of the severity of prolonged droughts or erratic rainfall events in Mbale municipality from 2013 to 2017 (n = 389)

Response	(%)
Likely to be a serious problem	63
Unlikely to be a serious problem	37
Total	100

likely to be because of the low socio-economic status of residents in the region and low social service provision (Dobson *et al.*, 2015), which increases the vulnerability of the population. Similarly, Lindsey *et al.* (2018) reported that most of the population in Tanzania was less likely to prepare, recover and adapt to flood events.

4.3 Demographic characteristics and social networks influencing the household capacity to prepare, recover and adapt or change

Linear regressions of demographic characteristics that could be determinants of households' resilience revealed that as household size increases, the household's capacity to prepare decreases (−0.0319**; Table II, Model 4). This finding corroborates with a report by D'Errico and Di Giuseppe (2018), who found that household size is inversely related to household resilience to food insecurity in Northern, Eastern and Central Uganda.

In terms of the interactive effect between income and households' ability to meet their daily expenditure needs and how this influences households' resilience capacities (Table II, Models 1-3), this needs to be interpreted through marginal effects, in this case, the effect of a household's ability to meet its daily expenditure needs on resilience capacities for the different categories of income. Figure 3 illustrates how the marginal effect of a household's ability to meet daily expenditure needs changes with increasing income. The effect is significantly different from zero for low household incomes *vis-à-vis* the capacity to prepare and recover. This implies that the lowest income households are substantially more likely to prepare for and recover from prolonged droughts or erratic rainfall events if the household is able to meet daily expenditure needs[4]. This finding is particularly relevant in this context as the poorest in society are generally the most vulnerable (Eriksen and O'Brien, 2007). Thus, this suggests a more nuanced approach may be warranted concerning arguments that would assume income alone determines the extent of resilience. It is possible that low-income households may be engaged in alternative non-cash activities such as subsistence livestock rearing, subsistence crop farming and other activities, which do not directly translate to income but help the household to satisfactorily meet its daily expenditure needs[5].

Moving on, the results also suggest that gender has a significant effect on households' ability to adapt or change (0.242**) its source of income or livelihood if needed when faced with prolonged droughts or erratic rainfall events (Table II, Model 6). This finding implies that men are more capable of adapting or changing compared to their female counterparts who are in most cases more vulnerable because of their socio-economic and political confines (Shabib and Khan, 2014). In many African traditions, women have less access to

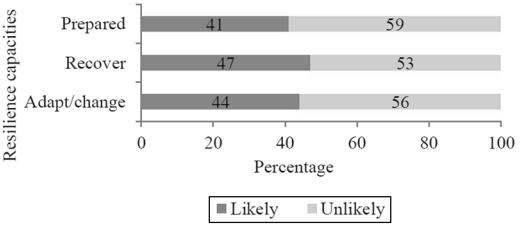

Figure 2.
Household capacities to prepare, recover and adapt or change their source of income or livelihood if needed when faced with prolonged droughts or erratic rainfall events in Mbale municipality in Eastern Uganda (n = 389)

Variable	Model 1 Prepare	2 Recover	3 Adapt/change	4 Prepare	5 Recover	6 Adapt/change
Gender	0.0477 (0.0877)	0.133 (0.0993)	0.265** (0.112)	0.0243 (0.0882)	0.0950 (0.100)	0.242** (0.113)
Age	−0.00293 (0.00322)	−0.00530 (0.00361)	−0.00419 (0.00412)	−0.00210 (0.00324)	−0.00413 (0.00363)	−0.00260 (0.00413)
Household size	−0.0342** (0.0140)	−0.0304* (0.0159)	−0.00884 (0.0179)	−0.0319** (0.0141)	−0.0270* (0.0159)	−0.00211 (0.0180)
Household head	−0.0593 (0.0954)	−0.0283 (0.108)	−0.182 (0.122)	−0.0578 (0.0953)	−0.0146 (0.108)	−0.192 (0.121)
Education	0.0374 (0.0422)	0.00928 (0.0477)	0.0103 (0.0544)	0.0396 (0.0423)	0.0181 (0.0478)	0.0255 (0.0543)
Expenditure	0.584*** (0.144)	0.323** (0.161)	0.320* (0.185)	0.552*** (0.145)	0.266 (0.163)	0.243 (0.186)
Income = 1	0.186 (0.124)	0.0481 (0.140)	0.0589 (0.159)	0.205 (0.125)	0.0501 (0.140)	0.0225 (0.159)
Income = 2	0.337* (0.202)	0.0644 (0.224)	−0.00166 (0.256)	0.336* (0.203)	0.0248 (0.226)	−0.0758 (0.256)
Income = 3	0.460 (0.312)	0.286 (0.348)	0.431 (0.424)	0.458 (0.311)	0.308 (0.347)	0.406 (0.421)
Exp × income = 1	−0.386** (0.193)	−0.0362 (0.216)	−0.308 (0.247)	−0.406** (0.193)	−0.0320 (0.216)	−0.241 (0.247)
Exp × income = 2	−0.348 (0.263)	0.150 (0.297)	−0.124 (0.336)	−0.367 (0.267)	0.188 (0.300)	−0.0594 (0.339)
Exp × income = 3	−0.499 (0.344)	−0.148 (0.385)	−0.802* (0.464)	−0.472 (0.344)	−0.149 (0.384)	−0.790* (0.463)
Nets_Friends				−0.0104 (0.0878)	0.00419 (0.0983)	0.0810 (0.112)
Nets_Relatives				0.178** (0.0884)	0.248** (0.0994)	0.147 (0.113)
Nets_NGO				−0.0106 (0.119)	0.0109 (0.134)	0.346** (0.153)
Government				0.179 (0.121)	−0.0348 (0.137)	−0.183 (0.157)
Constant	1.327*** (0.185)	1.457*** (0.209)	1.362*** (0.237)	1.177*** (0.198)	1.265*** (0.225)	1.143*** (0.253)
Observations	383	377	378	383	377	378
R^2	0.107	0.082	0.033	0.125	0.100	0.058

Note: Unstandardized coefficients are reported with standard errors in brackets: ***$p < 0.01$, **$p < 0.05$ and *$p < 0.1$

Table II.
Linear regressions exploring demographic characteristics and social networks as determinants of household's capacity to prepare, recover and adapt or change when faced with prolonged droughts or erratic rainfall events in Mbale municipality

socioeconomic resources, which constrains their ability to adapt. Meinzen *et al.* (2010) reported unequal distribution of assets in developing countries, biased toward men. This renders women less capable of adapting or changing (Resurrección, 2013). This finding is in line with the work by Nabikolo *et al.* (2012), carried out in Eastern Uganda, who revealed a significant influence of gender on adaptation to climate change shocks and stresses.

The age of the respondent, the type/gender of the household head and respondents' level of education had no significant effects on resilience capacities. The insignificance of age deviates from the findings of Bandura (1977), who reported that younger people have a higher level of motivation to act on perceived shocks and stresses and can easily diversify their livelihood activities, and thus, are more capable of adapting compared to older people. Similarly, insignificance in terms of the gender of the household head and respondents' education deviates from the findings of D'Errico and Di Giuseppe (2018), who reported that male headed households and more educated people were relatively more resilient to food insecurity.

Moreover, results show that social networks with relatives have a significant positive effect on the household capacity to prepare (0.178**) and recover (0.248**) (Table II, Models 4 and 5). Aldrich and Meyer (2014) reported that relatives can speed up or improve recovery with financial and non-financial support.

Furthermore, social networks with NGOs (Table II, Model 6) have a significant positive effect on the capacity to adapt or change the source of income or livelihood if needed when faced with climate change shocks and stresses (0.346**). The significant positive influence of networks with NGOs on the household capacity to adapt or change testifies to the positive impact of these organizations in Mbale municipality. Several NGOs operating in the municipality including but not limited to World Vision (which builds schools, toilets, water sources and provides food and education for the vulnerable), Compassion International (which provides school fees, shelter and other basic needs) and Child Restoration Outreach (which helps the vulnerable with meeting basic needs, lends money to women for business purposes, provides art and craft training for women and promotes games and sports). The importance of NGOs suggested by the results resonates with Sadri *et al.* (2017) in Indonesia, who indicated that stronger personal networks with NGOs and relatives positively influence people's resilience capacities[6]. Networks with friends and government did not have a significant effect

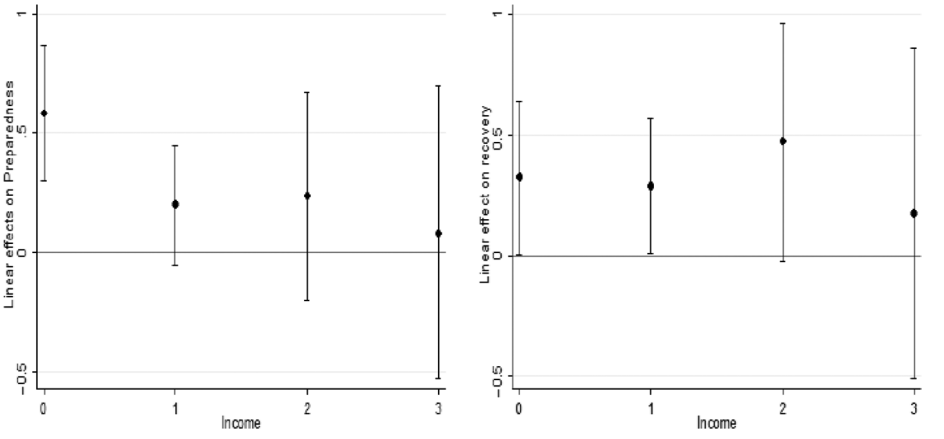

Figure 3.
Marginal effect of household's capacity to meet daily expenditures with increasing income (no significant effect for capacity to adapt or change)

Note: No significant effect for capacity to adapt or change

on household capacity to prepare, recover and adapt. In sum, the results imply that tight horizontal networks (with relatives) are a very important resource for households, while looser horizontal networks (with friends) do not appear to affect resilience significantly in Mbale municipality. Vertical ties that link households to NGOs can contribute positively to household resilience, particularly when it comes to assisting households to adapt to climate-related hazards, as they may not be capable to do so by themselves. In contrast, networks with the government do not appear to have been beneficial to household resilience in the present case. This could be due to an overall lack of ties with the government, but cannot be fully explained given the nature of the survey instrument and the questions included therein.

4.4 Spatial distribution of perceived household resilience capacities in the three divisions of Mbale municipality

Assessment of resilience capacities in the three divisions (Figure 4) revealed that most households in Wanale division perceived themselves to be likely to be well prepared (73 per cent), compared to 43 per cent of households in Northern division and 34 per cent of households in the industrial division. In total, 80 per cent of households in Wanale division perceived themselves to be likely to recover compared to 48 per cent of households in Northern division and 40 per cent of households in industrial division. In total, 50 per cent of households in Wanale division were likely to adapt or change their source of income or livelihood compared to 46 per cent of households in Northern division and 41 per cent of households in industrial division. Therefore, a greater proportion of households in industrial division perceived themselves to be unlikely to prepare, recover and adapt compared to their counterparts in Wanale and Northern divisions. This indicates a spatial differentiation of resilience capacities across Mbale municipality. This could be because the majority of households in industrial division are of low-income and composed of a high number of in-migrants driven by aridity from Karamoja sub-region in the North-Eastern part of Uganda. The fact that a greater proportion of households from Wanale division perceived themselves to be likely to prepare, recover, and adapt or change could be because a high proportion of households in Wanale division are high-income earners, and hence, likely to have the resources needed for preparedness, response and recovery.

5. Conclusions and recommendations

Findings suggest that prolonged droughts and erratic rainfall events are a serious problem for households in Mbale municipality. Indeed, most households perceived themselves to be

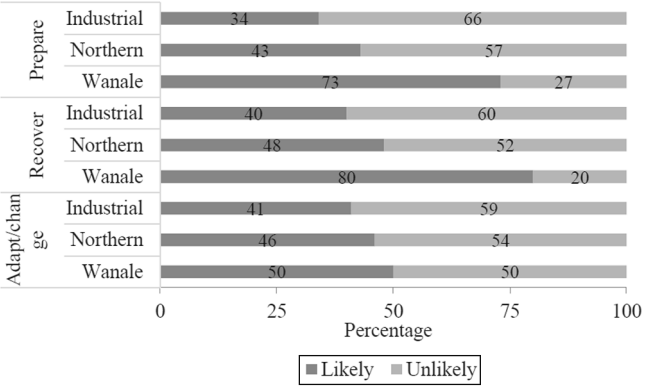

Figure 4.
Spatial distribution of perceived household resilience capacities in the three divisions of Mbale municipality in Eastern Uganda (n = 389)

unlikely to prepare, recover and adapt or change in the face of prolonged droughts or erratic rainfall events. This finding is inextricably linked to the low socioeconomic status and low level of development in the region and there is thus a need for government and households to scale up strategies to enhance resilience capacities.

Results imply that a mixture of demographic and social factors can explain the variance in household resilience capacities when faced with prolonged droughts or erratic rainfall events. Gender has a significant effect on the household's ability to adapt or change, whilst household size better explains the capacity to prepare. The ability of households to meet their daily expenditure is particularly important for low-income households (below $80/month for recovery and below $26/month for preparedness) and can have a substantial effect on household capacity to prepare and recover, which thus offers a more nuanced approach to arguments that would assume income alone decides over the degree of resilience. Social networks with relatives had a significant effect on the capacity to prepare and recover, while networks with NGOs exhibited a significant effect on household capacity to adapt or change.

Furthermore, households in the industrial division perceived themselves to be the least resilient compared to households in Northern and Wanale divisions. Thus, there is spatial heterogeneity across the municipality in terms of likelihood to be resilient.

Based on the findings in their totality, salient recommendations for policymakers and practitioners include encouraging small household size and activities that can boost households' abilities to meet their daily expenditure needs so as to increase their resilience capacities. Furthermore, the importance of social networks implies that policymakers and practitioners should promote social networks that shape household resilience to enhance preparedness, recovery and adaptation. In addition, the spatial heterogeneities in resilience capacities revealed by the results suggest a need for policymakers to direct more resources to parts of the municipality with low resilience.

Finally, the study tested the demographic and social factors that influence household resilience capacities. It provides insight into what factors may be most relevant to investigate further in future research. Future work needs to continue using multi-dimensional approaches to systematically investigate and understand household resilience to climate-related shocks and stresses in Uganda and in other developing countries that are exposed to similar climate-related hazards.

Notes

1. Pearson's correlation was used to quantify relationships between capacities to prepare, recover and adapt or change. Positive, but not strong, associations were revealed in all cases ranging from 0.465 between the capacity to prepare and recover through to 0.136 between the capacity to recover and adapt or change.
2. Where applicable, baselines in all models are formed by the lowest value of the variable scales.
3. To test the robustness of the linear regression results, a logistic regression model was estimated with a dichotomous variable (unlikely/likely) for all three resilience capacities. This is because the logistic regression model circumvents potential restrictions of linear regression with scales that are not metric. Additionally, other regression models were estimated without households' ability to meet their daily expenditure included as a predictor variable. This was undertaken to explore whether monthly income is significant in influencing resilience capacities.
4. For higher income categories, the household's ability to meet its daily expenditure needs has an insignificant effect. This could be explained by the fact that prices increase dramatically during droughts, implying that households may not be able to meet their daily expenditures needs when faced with such events, but they are able to do so under normal conditions. This complication could not be

taken further into account in this study, but future research along those lines would be interesting and fruitful.

5. When households' ability to meet their daily expenditure is not considered in the model, monthly income has a significant positive effect on household capacity to prepare (0.120***) and recover (0.116***). This suggests that high income households have more capacity in these respects than low-income households.
6. Logistic regression of demographic characteristics and social networks that influence resilience capacities showed similar findings except for the significance of gender in household capacity to adapt or change and networks with relatives for household capacity to recover.

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Appendix. Household interviews: preamble and questions

Dear respondent,

This questionnaire is designed to generate information for a study on demographic characteristics and social networks as determinants of household resilience to prolonged drought or erratic rainfall in Mbale Municipality in Eastern Uganda. It will be used strictly for research purposes and the information gathered will be kept confidential. We kindly request your time to answer the questions that follow and thank you for you cooperation.

1. Locational/Spatial Information: Division……, Parish …… Ward …….
GPS coordinates: Northing…… Easting……, Elevation…….

Section A: Household characteristics

2. Household type (1) Male headed (0) Female headed
3. In which monthly income category do you fall (in UGX)? (0) Less than 100,000 (1) 101,000-300,000 (2) 301,000-500,000 (3) 501,000 and above.
4. Is your household able to meet all the daily expenditure needs of its members? (1) Yes (0) No.
5(a). How many people are in your household? ..... (b) What is your age? .....
(c) What is your gender[2]? ....., marital status[2]? ....., highest education level[4]? ……

Section B: Household resilience capacities against prolonged droughts and erratic rainfall events.

6. If a prolonged drought or erratic rainfall event occurred, how likely is it that your household would be well prepared in advance? (0) Not at all likely, (1) Not very likely, (2) Very likely, (3) Extremely likely.
7. If a prolonged drought or erratic rainfall event occurred, how likely is it that your household could recover fully within 6 months? (0) Not at all likely, (1) Not very likely, (2) Very likely, (3) Extremely likely.
8. If prolonged droughts or erratic rainfall events became more frequent, how likely is it that your household could change its source of income or livelihood if needed? (0) Not at all likely, (1) Not very likely, (2) Very likely, (3) Extremely likely.
9. In the past 5 years, how likely a problem has prolonged droughts or erratic rainfall events been to your household? (0) Not at all likely, (1) Not very likely, (2) Very likely, (3) Extremely likely.
10. Which of the following are sources of help to your household during times of hardship caused by prolonged droughts or erratic rainfall events? (a) NGOs, (b) Friends, (c) Relatives, (d) Government (local, regional, and/or central government)

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https://www.emerald.com/insight/1756-8692.htm

Received 19 November 2018
Revised 22 February 2019
14 April 2019
28 May 2019
16 July 2019
6 August 2019
Accepted 13 August 2019

Construction of China's low-carbon competitiveness evaluation system

A study based on provincial cross-section data

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Abstract

Purpose – As the contradiction between economic development, resource and environment has become increasingly prominent, low-carbon competitiveness has received worldwide focus. This study aims to examine low-carbon competitiveness in 31 provinces (cities and regions) of China.

Design/methodology/approach – An evaluation index system for low-carbon competitiveness in China has been constructed, which is composed of 25 economic, social, environmental and policy indicators. To study the state of low-carbon competitiveness and resistance to China' development of low-carbon competitiveness, this study uses a combination of the catastrophe progression model, the spatial autocorrelation model and the barrier method.

Findings – China' low-carbon competitiveness gradually decreases from coastal to inland areas: the Tibet and Ningxia Hui autonomous regions are the least competitive regions, while the Shandong and Jiangsu provinces are the most competitive areas. The spatial correlation of the 31 provinces' low-carbon competitiveness is very low and lacks regional cooperation. This study finds that the proportion of a region' wetland area, the proportion of tertiary industries represented in its GDP and afforestation areas are the main factors in the development of low-carbon competitiveness. China should become the leader of carbon

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This research is supported by the National Social Science Foundation of China (Grant No. 18AJY010), and China Fundamental Research Funds for the Central Universities (Grant No. 310422107).

International Journal of Climate Change Strategies and Management
Vol. 12 No. 1, 2020
pp. 74-91
Emerald Publishing Limited
1756-8692
DOI 10.1108/IJCCSM-11-2018-0076

competitiveness by playing the leading role in the Eastern Region, optimizing the industrial structure, improving government supervision and strengthening environmental protection.

Originality/value – The paper provides a quantitative reference for evaluating China' low-carbon competitiveness, which is beneficial for environmental policymaking. In addition, the evaluation and analysis methods offer relevant implications for developing countries.

Keywords Low-carbon competitiveness, Obstacle factor diagnosis, Catastrophe progression method, Spatial autocorrelation, China

Paper type Research paper

1. Introduction

The development of a low-carbon economy is currently a worldwide goal. In particular, developed countries are fostering low-carbon economies to powerfully heighten national competitive advantages, as they strive to develop low-carbon industries and technologies. With the accelerating pace of China's urbanization, industrialization, agricultural modernization and information technology development, economic and social development continues to confront serious resource and environmental problems, such as the shortage of water resources, poor air quality standards and low energy efficiency. Therefore, China's "Twelfth Five-Year Plan" clearly identifies scientific development as its main focus. Hastening the transformation of patterns of economic development is the plan's main initiative with the goal of building a resource-saving and environmental-friendly society. In 2015, the Fifth Plenary Session of the 18th CPC Central Committee proposed that China should adhere to the path of green development, affluent living and better ecology. In addition, China should promote the establishment of a green, low-carbon and circular development industrial system; the construction of a modern low-carbon energy system that is safe and efficient; and the formation of an intensive resources perspective that focuses on saving and recycling resources. Thus, enhancing the competitiveness of low-carbon will help China achieve sustainable development and the construction of an ecological civilization.

In 2003, the British White Paper "Our Energy Future: Creating a Low-carbon Economy" first proposed the concept of "low-carbon economy," stressing that greater economic output can be obtained by reducing pollution and consumption. A competitive low-carbon economy can create lasting economic value through low-carbon technologies, products and services (Lee *et al.*, 2010). Scholars in China and abroad have studied low-carbon issues from three main perspectives. The first is the relationship between carbon emissions, energy consumption and the country's ageing population. Studies have shown that energy consumption is the source of carbon emissions, and an ageing population may reduce carbon emissions (Ramanathan, 2006; Soytas *et al.*, 2007; Dalton *et al.*, 2008; Puliafito *et al.*, 2008). The second consideration is the importance of carbon and energy tax policies. Carbon and energy tax policies can lead to low-carbon production and lifestyles and promote economic development (Nakata and Lamont, 2001; Cheng *et al.*, 2007; Hughes and Strachan, 2010). The third perspective is the relationship between the low-carbon economy and a country's competitiveness. A low-carbon economy can reinforce the national economy and enhance national competitiveness (Lee *et al.*, 2007; Strachan *et al.*, 2008).

In 2009, however, economists began filling the gaps in the literature regarding the competitiveness of low-carbon initiatives, as the extant literature had primarily focused on the construction of a theoretical index system (Lee *et al.*, 2010; OECD, 2011). Evaluation methods were then the main component of the analysis (Jin and Shouhu, 2013), including the gray correlation analysis method (Chen *et al.*, 2012) and the analytic hierarchy process method (Feng, 2011; Pan and Wang, 2013). These studies found that the overall low-carbon

competitiveness of China showed an increasing trend year over year, with the low-carbon competitiveness of Beijing, Shanghai, Tianjin and Chongqing exceeding the average level of China and gradually forming a pattern that declined from the coastal to the inland provinces. However, these methods have strong subjectivity. Empirical analyses are primarily conducted with national comparisons or the specific analysis of a city or region, and certain analyses involve industries and enterprises. There is currently a lack of research on low-carbon competitiveness differences between the regions of a single country.

Based on the existing literature, this paper first details the construction of a low-carbon competitiveness evaluation index system involving the economy, society, the environment and policy to comprehensively measure the level of competitiveness. To overcome evaluation subjectivity, our study uses the catastrophe progression method proposed by Chinese scholar Du Xingfu; this can sequence the importance of all indices. The weight of each index is then determined using the principal component analysis method, and the low-carbon competitiveness of 31 provinces in China is calculated. Combined with the improved diagnosis of the obstacle indicator model, this allows us to deeply understand obstacles to certain provinces' low-carbon competitiveness development. Furthermore, we use the spatial autocorrelation model to analyze the distribution of low-carbon competitiveness to provide new ideas and new research for the development of Chinese low-carbon competitiveness.

2. Materials and methods

2.1 Catastrophe progression method

The catastrophe progression method avoids the weight of each index in the quantitative calculation and overcomes the limitation of subjective weighting. It also considers the relative importance of each evaluation index, increases scientificity and rationality and makes the calculation simple and accurate. Therefore, this study uses the principal component analysis method to scientifically determine the primary and secondary indicators. The catastrophe progression method is used to evaluate low-carbon competitiveness. The specific steps involved are as follows:

(1) Establish the mutation evaluation system.

(2) Determine the type of mutation in each level of the index system. According to the basic principle of the catastrophe progression method, there are seven types of catastrophe systems. This paper involves the cusp, dovetail and butterfly catastrophe systems.

$$\text{Cusp catastrophe system model}: \ h(x) = x^4 + \ \alpha x^2 + \beta x$$

$$\text{Dovetail catastrophe system model}: \ h(x) = \frac{1}{5}x^5 + \frac{1}{3}\ \alpha x^3 + \frac{1}{2}\beta x^2 + \ \gamma x$$

$$\text{Butterfly catastrophe system model}: \ h(x) = \frac{1}{6}x^6 + \frac{1}{4}\ \alpha x^4 + \frac{1}{3}\beta x^3 + \frac{1}{2}\ \gamma x^2 + \ \varepsilon x$$

h(x) represents the potential function of state variable x. State variables x coefficients of α, β, γ and ε represent the control variables of state variables. If only one indicator is divided into two sub-indices, the system is a cusp catastrophe system; if an indicator is divided into three sub-indices, the system is a dovetail

catastrophe system; if an indicator is divided into four sub-indices, the system is a butterfly catastrophe system (Chen and Yang, 2013).

(3) Derive the normalized formula using a staging catastrophe equation.

Based on catastrophe theory, all critical points of potential function h(x) are composed of the equilibrium surface U. The equation of surface U is obtained by calculating the first derivative of h(x), namely, h(x)' = 0. The singularity set of the potential function is obtained by calculating the second derivative of h(x), that is, h (x)" = 0. The h(x)' = 0 and h(x)= 0 can eliminate x; then we obtain a bifurcation set equation.

For the cusp catastrophe system model:

From h(x)'= 0, we obtain $4x^3+2\alpha x + \beta = 0$, namely, $2x(2x^2+\alpha)+\beta = 0$①; from h (x)= 0, we obtain $12x^2+2\alpha = 0$, namely,$x^2 = -\frac{\alpha}{6}$ ②. Bringing equation ② into equation ①, we can obtain $x = -\frac{3\beta}{4\alpha}$ ③. Bringing equation ③ into equation ①, then $8\alpha^3 + 27\beta^2 = 0$, whereby we can know $\alpha = -6x^2$, $\beta = 8x^2$. Therefore, the normalized formula of the cusp catastrophe system is:

$$x_\alpha = \alpha^{\frac{1}{2}}, x_\beta = \beta^{\frac{1}{3}}$$

Similarly, the normalized formula of the dovetail catastrophe system is:

$$x_\alpha = \alpha^{\frac{1}{2}}, x_\beta = \beta^{\frac{1}{3}}, x_\gamma = \gamma^{\frac{1}{4}}$$

The butterfly catastrophe system is:

$$x_\alpha = \alpha^{\frac{1}{2}}, x_\beta = \beta^{\frac{1}{3}}, x_\gamma = \gamma^{\frac{1}{4}}, x_\varepsilon = \varepsilon^{\frac{1}{5}}$$

where x_α is the corresponding value of α; similarly, x_β, x_γ, x_ε.

(4) Analyze the evaluation subject comprehensively with the advantage of a normalized formula and the principal component analysis method.

The first principal component of the principal component analysis method represents the direction of the sample data and is most relevant to the original variables. Therefore, in practice, each component of the characteristic vector corresponding to the maximum characteristic value can be used as the index weight, and the importance of each index is sorted.

Two different evaluation criteria for each control variable calculation are the complementary criterion and the non-complementary criterion.

(1) *Complementary criterion*: If there is a clear interaction between the various control variables, we calculate the mean value of each control variable.

(2) *Non-complementary criterion*: If there is no clear correlation between each control variable, we take the minimum value of each control variable.

For example: if variables C1, C2 and C3 obey the complementary criterion, $D_1 = \left(\sqrt[2]{C_1} + \sqrt[3]{C_2} + \sqrt[4]{C_3}\right)/3$; if variables C1, C2 and C3 obey the non-complementary criterion,$D_1 = \min\left(\sqrt[2]{C_1}, \sqrt[3]{C_2}, \sqrt[4]{C_3}\right)$.

2.2 Spatial autocorrelation model

The spatial autocorrelation is divided into local autocorrelation and global autocorrelation. Global spatial autocorrelation is used to detect the spatial patterns of the entire region, using Moran's I index to reflect the space-related degree.

Moran's I calculation formula:

$$\text{Moran's I} = \frac{\sum_{i=1}^{n}\sum_{j\neq i}^{n} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{s^2 \sum_{i=1}^{n}\sum_{j\neq i}^{n} w_{ij}}$$

$s^2 = \frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2$; $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$; w_{ij} is the spatial weight matrix, reflecting the relationship of provinces (cities and regions). $w_{ij} = \begin{cases} 1 \text{ when the province i and province j are adjacent} \\ 0 \text{ when the province i and province j are not adjacent} \end{cases}$, $i = 1,2,\ldots,n$; $j = 1,2,\ldots,n$. x_i is the observed value of province *i*. *n* is the number of provinces (cities and regions).

Moran's I is in the range [−1,1]. A value close to 1 indicates the presence of a strong positive spatial correlation between provinces (cities and regions); a value close to −1 indicates that there is a negative spatial correlation between provinces (cities and regions) and equal to 0 represents spatial uncorrelation.

It is difficult to detect the unit spatial association pattern in geographically different locations using global spatial autocorrelation analysis. Strong and significant global spatial autocorrelation may mask the correlation feature of a sub-sample that does not, in fact, exist. Occasionally, the local spatial correlation is opposite to the global spatial correlation.

Local Moran's I calculation formula:

$$\text{Moran's } I_i = \frac{(x_i - \bar{x})}{s^2}\sum_{i=1}^{n} w_{ij}(x_i - \bar{x})$$

Moran's I_i is the correlation coefficient of province i. Moran's $I_i > 0$ denotes that the low-carbon competitiveness of province i and of adjacent provinces are similar. Moran's $I_i < 0$ denotes that the low-carbon competitiveness of province *i* and of adjacent provinces are converse.

In the four quadrants of Moran's I scattered point diagram, the first quadrant is a high-high (H-H) gathering area, indicating that the low-carbon competitiveness of the province (city and region) and of the adjacent provinces (cities and regions) are at a relatively high level, with a spatial diffusion effect. The second quadrant is a low-high gathering area (L-H), representing that the competitiveness of the province (city and region) is low and the competitiveness of neighboring provinces (cities and regions) is high, with the transitional spatial-related area performance. The third quadrant is a low-low gathering area (L-L), indicating that the low-carbon competitiveness of the province (city and region) and of the adjacent provinces (cities and regions) are relatively weak, with slow growth performance of the spatial correlation zone. The fourth quadrant is a high-low gathering area (H-L), representing that the low-carbon competitiveness of the province (city and region) is strong and the competitiveness of neighboring provinces (cities and regions) is weak, which exhibits a polarization spatial effect.

2.3 Obstacle diagnosis model

In the low-carbon competitiveness evaluation process, on the one hand, we attempt to understand the development of low-carbon competitiveness in China. On the other hand, we

analyze the factors that hinder the stable improvement of low-carbon competitiveness in the economic and social development process and conduct a pathological analysis to explore the root of the problems. We combine the obstacle diagnosis model with a normalized formula in the catastrophe system.

We calculate the degree of deviation indicators:

$$I_{ij} = 1 - x_{ij}$$

I_{ij} is the deviation of index j in province i and x_{ij} is the standardized score of index j in province i.

Then, we calculate the catastrophe progression of the index deviation, which is the obstacle degree of the upper layer index system after normalization. At the same time, using the normalized formula to calculate the obstacle level of each layer index, we can obtain the provincial low-carbon obstacle data of each subsystem and conduct an in-depth analysis. However, the non-complementary criterion for calculating the degree of obstacle is changed to "take the big from the small."

2.4 Data sources

This paper selects 31 Chinese provinces (cities and regions) as the research object and establishes a low-carbon evaluation system that contains 25 indices, all of which are from the 2008-2014 "China Statistical Yearbook," the "China Environment Yearbook" and the "China Environment Statistical Yearbook."

3. Constitution of the index system

In reference to the existing papers on the low-carbon economy (Jin and Shouhu, 2013; Feng, 2011; Cheng *et al.*, 2015; Li *et al.*, 2015), 25 indices are selected from the four sub-systems of economy, society, environment and policy; therefore, the low-carbon competitiveness evaluation system is established to accurately appraise the low-carbon competitiveness status of 31 Chinese provinces. The specific index system is shown in Table I.

Where, coal consumption of 10,000 renminbi (RMB) industrial output = industrial coal consumption/industrial output value.

Fuel oil consumption of RMB10,000 industrial output = industrial fuel oil consumption/industrial output value.

Electricity consumption of RMB10,000 gross domestic product (GDP) = electricity consumption/GDP.

We select 2007, 2009, 2011 and 2013 as the four time points; as the unit is not uniform among the indicators and forward indices are standardized based on the minimum of the sample. The specific formula is as follows:

$$x_{ij} = \frac{X_{ij} - X_{min}}{X_{max} - X_{min}}$$

Additionally, reverse indices are standardized based on the maximum of the sample, as follows:

$$x_{ij} = \frac{X_{max} - X_{ij}}{X_{max} - X_{min}}$$

Table I.
Low-carbon competitiveness index

Total target layer	Target layer	Intermediate layer	Index layer	Forward or reverse
Low-carbon competitiveness	Economic system (A1)	Economic and industrial benefits (B1)	The percentage of tertiary industry in GDP (C1)	Forward
			Growth rate of tertiary industry (C2)	Forward
			Per capita GDP (C3)	Forward
		Energy consumption (B2)	Coal consumption of RMB10,000 industrial output (C4)	Reverse
			Fuel oil consumption of RMB10,000 industrial output (C5)	Reverse
			Electricity consumption of RMB10,000 GDP (C6)	Reverse
		Investment of environment and technology (B3)	The proportion of science and technology expenditure in fiscal expenditure (C7)	Forward
			The proportion of energy saving and environmental protection expenditure in fiscal expenditure (C8)	Forward
	Social system(A2)	Low-carbon life (B4)	Total annual passenger traffic volume of public steam (electric) vehicle (C9)	Forward
			The number of buses which per 10,000 people own (C10)	Forward
			Gas penetration rate in city (C11)	Forward
		Pollution control efforts (B5)	Processing capability of wastewater treatment facilities (C12)	Forward
			Comprehensive usage rate of general industrial solid waste (C13)	Forward
			Treatment rate of life garbage (C14)	Forward
			The total investment in environmental pollution control (C15)	Forward
	Environmental system (A3)	Low-carbon environment (B6)	Park green area of urban per capita (C16)	Forward
			The proportion of wetlands in precinct (C17)	Forward
			Urban garden green space area (C18)	Forward
		Increasing carbon sequestration basis (B7)	Percentage of forest cover (C19)	Forward
			Afforestation area (C20)	Forward
	Policy system (A4)	Institutional settings (B8)	Number of national and provincial environmental protection agencies (C21)	Forward
			Number of environmental protection agencies at all levels (C22)	Forward
		Enforcement (B9)	Number of projects to implement environmental impact assessment (C23)	Forward
			Number of Chinese People's Political Consultative Conference and National People's Congress recommendations (C24)	Forward
			Number of letters and visits have been completed(C25)	Forward

Notes: Economic and industrial benefits, energy consumption, pollution control efforts and institutional settings in middle layer use complementary criterion. Low-carbon life, low-carbon environment, increasing carbon sequestration basis and enforcement in middle layer use non-complementary criterion. Economic system, social system, environmental system and policy system in target layer use complementary criterion

Based on standardization, we use the principal component analysis method to rank the indices in the index layer. According to the complementary and non-complementary criteria, we calculate the value of each index in the intermediate layer through normalized formulas. At the same time, to prevent the aggregation phenomenon of the intermediate layer indices obtained by the mutation series method, the intermediate layer indices are standardized again. Then, the indices are ranked by importance according to principal component analysis, and the value formula and the normalized formula are applied to obtain the index value of the target layer. The above method is followed until the low-carbon competitiveness level is obtained.

4. Results analysis

4.1 Low-carbon competitiveness of China

We use the average of the competitiveness of China's 31 provinces as the overall level of China's low-carbon competitiveness (Table II). From 2007 to 2013, China's low-carbon competitiveness steadily increased. The 2008 financial crisis did not hinder the development of China's low-carbon competitiveness, but accelerated the emergence of high-energy consumption and high-pollution industries and promoted the transformation of China's economic development model. In 2009, China's low-carbon competitiveness increased by 0.59 percentage points compared with 2008, and in 2011, China's low-carbon competitiveness increased by 2.03 percentage points compared with 2009. However, in 2013, China's low-carbon competitiveness increased by only 0.06 percentage points from 2011. This is mainly because China entered a comprehensive deepening reform stage. The industrial structure entered a period of deep adjustment, and the advantageous surplus capacity gradually shifted to the emerging developing economies; thus, the development speed of low-carbon competitiveness slowed. However, the State Council of China issued the "Twelfth Five-Year Plan" for energy development, in which a carbon tax has been included in the environmental protection tax law for the first time; in addition, sewage charges have increased. These measures further strengthen the sustainable development of China's low-carbon industry.

4.2 Low-carbon competitiveness of provinces (cities and regions)

In 2007, in terms of low-carbon competitiveness, Jiangsu, Shandong, Zhejiang, Hebei and Beijing ranked as the top five. These five provinces (cities and regions) actively promoted green manufacturing; shutdown projects with high-energy consumption, such as flat glass, crude steel, electrolytic aluminum, pig iron and other high-pollution and high-energy consumption projects; and vigorously developed high-tech industries and equipment manufacturing. The five provinces (cities and regions) continued to improve the structure of the three industries, and tertiary industry in the five provinces (cities and regions) has developed rapidly, with an annual growth rate exceeding 13 per cent. Moreover, these provinces took the lead in wind power generation, photovoltaic power generation and other fields of energy in China. Guizhou, Hainan, Xinjiang Uygur, Ningxia Hui and Tibet had the lowest low-carbon competitiveness. The economic growth of the five provinces (regions) mainly depended on the development of the secondary industry, which represented an

Table II.
China's low-carbon competitiveness in 2007-2013

Year	2007	2009	2011	2013
Value	0.8658	0.8709	0.8886	0.8891

increasing proportion of GDP. The industrial structure of the five provinces (regions) was mainly dominated by heavy chemical industries, and the technology research, introduction and absorption capacity of energy production and utilization were lower than the national average, especially in the fields of transportation, power, chemicals and metallurgy, which led to greater constraints and pressure to improve low-carbon competitiveness. From the perspective of China as a whole, the low-carbon competitiveness of the eastern coastal areas was stronger than that of the central and western provinces (cities and regions). Additionally, the competitiveness of Sichuan, Shaanxi and Hubei provinces in the central area was much higher than other parts of the Midwest; thus, they formed a "high-low-high-low" ladder distribution. Tibet and Xinjiang were subject to their economic development and technological innovation levels and unable to take full advantage of their natural resources; therefore, their low-carbon competitiveness was below the average level of China.

In 2009, the low-carbon competitiveness of Jiangsu, Shandong, Guangdong, Liaoning and Zhejiang provinces ranked in the top five, as Guangdong and Liaoning provinces enhanced their competitiveness by improving the policy system. In the 21st Century, Guangdong promulgated the "Pearl River Delta Environmental Protection Special Planning," the "Guangdong Unit GDP Energy Consumption Evaluation System Implementation Plan," the "Development Plan of Nine Industrial Industries in Guangdong Province" and the "Development and Reform Planning for the Pearl River Delta Region." Furthermore, WWF Hong Kong Branch, The Climate Group, Hong Kong Productivity Council and Netherlands ECOFYS Company all support the "Low-carbon Projects for Pearl River Delta Production." All these initiatives have greatly promoted the rapid rise of the low-carbon economy in Guangdong and significantly improved its competitiveness. In contrast, Liaoning Province incorporated ecological province construction into the provincial target responsibility assessment system, and 65 agriculture-related counties (districts) and 14 cities launched ecological city (county and district) planning. At the same time, with the approval of the State Council, the development and opening of the Liaoning coastal economic zone has emerged as a national development strategy, emphasizing the elimination of outdated production capacity, promoting industrial restructuring and upgrading and forming an advanced manufacturing-oriented modern industrial system. Thus, the low-carbon competitiveness of Liaoning significantly increased, surpassing Zhejiang. However, Guizhou, Hainan, Ningxia Hui, Xinjiang Uygur and Tibet continued to occupy the last five low-carbon competitiveness positions. With continuous economic growth, the environment and resources of these five provinces (regions) became increasingly unable to bear the pollution and excessive resource consumption caused by traditional economic growth; however, the traditional pattern of economic development possessed inertia and rigidity, leading the low-carbon economy into difficulties. Overall, the low-carbon competitiveness level of the Bohai Sea Region was higher than that of other regions; the low-carbon competitiveness of the central regions had increased significantly, while low-carbon competitiveness in the northwestern provinces (regions) developed slowly and continued to lag far behind other provinces (cities).

In 2011, the Chinese provinces (cities and regions) with the best low-carbon competitiveness were Guangdong, Shandong, Jiangsu, Liaoning and Hebei provinces. During the period of the "Eleventh Five-Year Plan," Hebei invested in many biomass power generation projects; the methane recovery power generation of municipal waste incineration and landfill gas methane recovery power generation for Hebei saved significant amounts of energy. Furthermore, China General Nuclear Power Corporation, China Energy Conservation and Environmental Protection Group, China Longyuan Power Group Corporation and other large enterprises had entered Chengde and Zhangjiakou, building

large wind farms. Through "China Power Valley" industrial projects, Baoding became China's low-carbon urban development project pilot; thus, dramatically increasing the low-carbon competitiveness of Hebei. The low-carbon competitiveness of Qinghai, Hainan, Shanghai, Ningxia Hui and Tibet were the lowest in China. Guizhou accelerated the development of ecological agriculture, integrating information technologies and biotechnologies into conventional agricultural technologies, mainly strengthening the production of special new agricultural products. The province promoted four integrated reforms of mineral resource allocation, which involved coal phosphorus, coal-fired electricity, coal steel and coal aluminum and improved the bidding mechanism for minerals, land and other resources, thus significantly improving the province's low-carbon competitiveness, separating it from the inadequate low-carbon group. In 2011, the high value cluster of Chinese low-carbon competitiveness appeared in the Bohai Sea Region and on the Southeast Coast; however, the low-carbon development of Jiangxi, Tibet and Ningxia Hui lagged behind, becoming areas of China's low-carbon competitiveness "depression."

In 2013, Jiangsu, Guangdong, Shandong, Zhejiang and Liaoning provinces led China in low-carbon competitiveness. Zhejiang deeply implemented transformation and upgrading measures, including "four-for-three," "five water cohabitation" and "one split and three changes." In Zhejiang province, strategic emerging industries and high-tech industries accounted for 23.5 per cent and 25.6 per cent of the industrial added value. Additionally, Zhejiang actively developed low-carbon buildings and built 450 million square meters of energy-efficient buildings. Thus, the low-carbon competitiveness of Zhejiang again exceeded that of Liaoning. The low-carbon competitiveness of Ningxia Hui, Qinghai, Hainan, Shanghai City and Tibet lagged behind other regions. The low-carbon competitiveness of Shanghai City was constrained by the low-carbon environment and carbon sinks; however, that of the remaining four provinces (regions) was subject to their energy consumption capacity. In 2013, the low-carbon competitiveness of the eastern coastal areas remained at a high level; however, that of Hebei and Fujian provinces weakened dramatically, while that of midwestern China also declined.

In summary, from 2007 to 2013, the peak zone for China's low-carbon competitiveness extended from Shandong and Jiangsu provinces to the Bohai Sea Region, then moved into the eastern coastal areas and the Yangtze River Basin. At the same time, the low-carbon competitiveness of Southwest China improved significantly, while the low-carbon competitiveness of Northeast China remained stable. Currently, the Tibet, Ningxia Hui, Guizhou and Jiangxi province are the regions with the lowest competitiveness in China and their development lagged far behind the Chinese national average (Figure 1).

4.3 Spatial correlation analysis of low-carbon competitiveness

In this paper, we use GeoDa (spatial analysis software) to calculate global Moran's I of low-carbon competitiveness in China from 2007 to 2013 and to calculate the first-order adjacency matrix to determine the spatial weight matrix.

From Table III, we can observe that the value of Moran's I increased significantly from 2007 to 2009, which showed that the spatial correlation of China's provinces (cities and regions) was enhanced, and there was an obvious global spatial agglomeration effect on China's low-carbon competitiveness. However, after 2009, Moran's I value decreased rapidly, nearly to zero, indicating that China's spatial agglomeration effects of low-carbon competitiveness disappeared, the spatial correlation of regional low-carbon competitiveness weakened and the activities of low-carbon interactive development decreased. Each province (city and region) independently conducted low-carbon development, which was not conducive to the overall development of China's low-carbon economy.

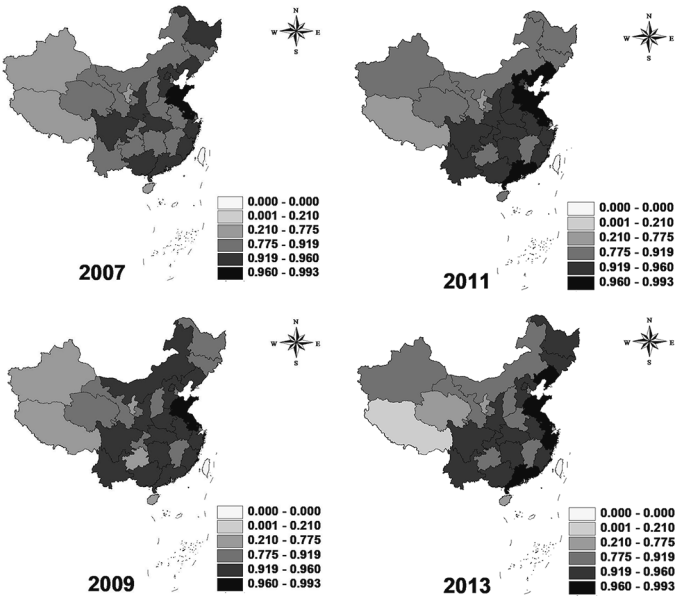

Figure 1.
Low-carbon competitiveness of China in 2007-2013

Table III.
China's Moran's I of low-carbon competitiveness in 2007-2013

Year	2007	2009	2011	2013
Moran's I	0.2236	0.2332	0.0270	0.0629

As can be observed from Table III, the majority of Chinese provinces are distributed in the high-high gathering area and 61.29, 67.74, 64.52 and 67.74 per cent of 31 Chinese provinces have a conspicuous positive spatial correlation in the respective four periods. At the same time, the spatial agglomeration phenomena first expands, then shrinks, before reaching stability.

High-high gathering areas are mainly concentrated in the three northeastern provinces, the Bohai Sea Region and the Southeast Coast (Table IV). This district has a high level of economic development, reasonable industrial structure and layout, high-quality personnel and advanced technologies. These features can effectively improve the utilization efficiency of resources and the environment, meet strict environmental regulations, promote the rapid development of a low-carbon economy and show a moderate trend for diffusion, the scope of which is mainly in the Inner Mongolia, Hubei, Hunan, Guizhou and Chongqing City.

Low-high gathering areas are mainly concentrated in Shanxi, Guizhou and Ningxia Hui (Table IV). The five provinces (regions) are located in the plateau regions, which are rich in mineral resources. These regions must bear a large amount of the environmental and resource costs of China's rapid economic development process, and have not focused on ecological compensation in undertaking the industrial transfer process of Eastern China. Therefore, low-carbon competitiveness is much lower than in neighboring provinces (cities and regions). If the radiation-driven effect of high- and low-carbon competitiveness in the

surrounding areas can be used effectively, the low-carbon level of these gathering areas will increase dramatically.

Low-low gathering areas are distributed across China's western regions (Table IV). These regions are located in inland China, with no location advantage, where it is difficult to obtain external resources. The main feature of these areas is that the industrial structure is highly dependent on the resources and energy, and the level of science and technology is relatively inadequate, which leads directly to problems such as the inefficient use of energy resources and the destruction of the environment. Simultaneously, as the key national energy bases, Xinjiang and Gansu should strive to improve energy saving regarding the transportation, construction and mining industries, fully use local resources and rebuild a low-carbon industrial system to enhance competitiveness.

High-low gathering areas include Yunnan, Sichuan and Shaanxi (Table IV). These three provinces have natural resource advantages, a high forest coverage rate, rapid tertiary industry development and convenient public transportation; therefore, low-carbon competitiveness is higher here than in surrounding areas. High-low gathering areas are typically polarized, and the low-carbon cooperation mechanisms between these provinces and adjacent areas are not perfect. Additionally, the gathering areas lack a reasonable layout and extension of the industrial chain. Therefore, such a development mode is not conducive to the improvement of China's low-carbon competitiveness.

4.4 Obstacle factor diagnosis

Based on China's low-carbon competitiveness, we calculate the obstacle degree of the index layer and the intermediate layer to understand the constraints of China's low-carbon competitiveness development.

4.4.1 Obstacle factor in the intermediate layer. From a holistic perspective, the main obstacles to the development of China's low-carbon competitiveness are the realization of a low-carbon environment, enforcement and low-carbon lifestyles. First, China's implementation of environmental policy started late; therefore, the policy system remains imperfect and implementation is low. Second, the economy is in a transitional period, and industries with high-carbon emissions remain the pillars of China's economic growth; thus, the level of environmental pollution is relatively high. Third, the per-capita income level remains low and is unable to effectively improve living standards. In addition, the economic and industrial benefits and investment in the environment and technology have played an increasingly small role in hindering the development of China's low-carbon competitiveness. Thus, we can observe that China's emphasis on environmental protection has increased significantly and the initial results of low-carbon development have been revealed.

From the perspective of each province, in 2007-2013, the main obstacles for Hebei, Shanxi, Liaoning, Jilin, Heilongjiang and Anhui provinces regarding low-carbon competitiveness were economic and industrial benefits, low-carbon lifestyles, low-carbon environments and enforcement. The economic hindrance in Hebei, Shanxi and Jilin provinces was gradually enhanced over this period and the economy of the three provinces mainly relied on traditional heavy industry with high pollution and energy consumption. As low-carbon competitiveness was mainly restricted by the economic structure, the three provinces should accelerate the optimization and upgrading of the industrial structure to promote the rapid development of tertiary industry. The obstacle degree of the policy enforcement of the above six provinces was reduced, while the environmental restraint of the policy system was strengthened in 2007-2013.

The main obstacles for the Inner Mongolia, Jiangxi, Henan, Guangxi Zhuang and Shaanxi regarding low-carbon competitiveness were economic and industrial benefits,

Table IV.
Spatial clustering of low-carbon competitiveness (2007-2013)

Gathering area	Year 2007	2009	2011	2013
High-High(H-H)	Tianjin, Jiangsu, Shandong, Beijing, Anhui, Zhejiang, Jiangxi, Liaoning, Henan, Guangdong, Chongqing, Jilin, Fujian, Hebei, Heilongjiang, Inner Mongolia, Hubei, Guangxi and Hunan	Heilongjiang, Shandong, Henan, Jiangsu, Anhui, Hubei, Zhejiang, Jiangxi, Hunan, Fujian, Guangxi, Guangdong and Jilin Liaoning, Tianjin, Shaanxi, Inner Mongolia, Chongqing, Hebei, Shanghai and Beijing	Heilongjiang, Shanxi, Shandong, Henan, Jiangsu, Anhui, Hubei, Zhejiang, Jiangxi, Hunan, Fujian, Guangxi, Guangdong, Jilin, Liaoning, Tianjin, Inner Mongolia, Chongqing, Hebei and Beijing	Heilongjiang, Shanxi, Shandong, Jiangsu, Anhui, Hubei, Zhejiang, Jiangxi, Hunan, Guizhou, Fujian, Guangxi, Guangdong, Jilin, Liaoning, Tianjin, Shaanxi, Inner Mongolia, Chongqing, Hebei and Beijing
Low-High(L-H)	Shanxi, Ningxia, Guizhou, Hainan and Shanghai	Shanxi, Ningxia, Guizhou and Hainan	Ningxia, Tibet, Guizhou, Hainan and Shanghai	Ningxia, Henan, Hainan and Shanghai
Low-Low(L-L)	Xinjiang, Tibet, Qinghai and Gansu	Xinjiang Uygur, Tibet, Qinghai and Gansu	Xinjiang, Qinghai and Gansu	Xinjiang, Tibet, Qinghai and Gansu
High-Low(H-L)	Yunnan, Shaanxi and Sichuan	Yunnan and Sichuan	Yunnan, Shaanxi and Sichuan	Yunnan and Sichuan

investment in the environment and technology, low-carbon life, low-carbon environment and enforcement. The obstacle degree of economic and industrial benefits and investment in technology and the environment in Henan and the Inner Mongolia increased in 2007-2013. This finding indicates that the two provinces (regions) with a low industrial level have prominent economic structural contradictions and weak independent innovation capabilities. This finding also indicates that the development of a modern service industry in these areas is lagging, and the restrictive roles of the environment and resources has become prominent. Therefore, the tasks of energy saving and environmental protection remain arduous. In recent years, the obstacle degree of investment in the environment and technology in Shaanxi has risen, indicating that Shaanxi focuses insufficiently on science, technology and environmental protection and has poor energy and resource utilization efficiency. Additionally, the province's technological innovation capacity needs to be improved. However, the public transport facilities in Jiangxi are relatively inadequate; the role of energy-saving and emission reduction is not significant and the garden green space area is small, leading to an inhibitory effect on a low-carbon environment.

The main obstacles of low-carbon competitiveness in Hubei, Hainan, Chongqing City, Guizhou and Yunnan are investment in the environment and technology, low-carbon life, low-carbon environment and enforcement. The six provinces have had many problems, such as a low level of industrialization, unbalanced urban and rural development, an irrational industrial structure and resources and environmental pressures. Furthermore, weak technological innovation fatigue, an extensive pattern of development and increasing social conflicts have all contributed to the low level of these provinces' low-carbon competitiveness.

Because the low-carbon competitiveness of Gansu, Qinghai, Xinjiang Uygur, Ningxia Hui and Tibet was lower than others, the nine aspects of the obstacles are relatively high. The obstacle degree of investment in the environment and technology and enforcement in Gansu increased. The obstacle degree of pollution control efforts and institutional settings in Qinghai rose; and the obstacle degree of investment in the environment, technology and enforcement also rose. The impeditive role of economic and industrial benefits and environmental and technological investments was strengthened. In addition to increasing the carbon sequestration basis, the impeditive role of the other eight aspects in the Tibet increased. Therefore, in the western region, transportation infrastructure continued to be inadequate and the environment remained fragile. The irrational economic structure and weak capacity for self-development capacity have not improved. In 2007-2013, the development gap with other regions continued to expand.

The development of obstacle factors in the intermediate layer in other provinces was more balanced. In accordance with the development direction, these provinces were divided into three clusters. The first cluster with increasing carbon sequestration basis as its core included Jiangsu, Zhejiang, Shandong and Guangdong provinces, which increased the afforestation area and the forest coverage rate. The second cluster contained Beijing City, Tianjin City and Shanghai City, which should increase the environmental supervision, strengthen the role of environmental policy constraints and expand the size of the urban green space area. The third cluster included Fujian and Sichuan provinces, which could increase environmental and technological investments, heighten the utilization efficiency of resources and reduce carbon emissions, thus improving the environment.

4.4.2 Obstacle factor in index layer. As the index system involves 25 indicators, to further research the main obstacle factors of China's low-carbon competitiveness, we list the top three obstacle factors in accordance with the size of the obstacles, as shown in Table V.

In 2007-2009, the main obstacle factors for Chinese low-carbon competitiveness were the number of projects that implement environmental impact assessment projects, the

Region	Item	Indicators order 2007 1	2007 2	2007 3	2009 1	2009 2	2009 3	2011 1	2011 2	2011 3	2013 1	2013 2	2013 3
Beijing	Obstacle indicators	C_{20}	C_{17}	C_{22}	C_{20}	C_{17}	C_{12}	C_{12}	C_{20}	C_{17}	C_{12}	C_{17}	C_{20}
Tianjin	Obstacle indicators	C_{20}	C_{8}	C_{23}	C_{8}	C_{20}	C_{23}	C_{20}	C_{24}	C_{12}	C_{20}	C_{23}	C_{24}
Hebei	Obstacle indicators	C_{24}	C_{1}	C_{7}	C_{24}	C_{7}	C_{17}	C_{17}	C_{7}	C_{1}	C_{17}	C_{1}	C_{6}
Shanxi	Obstacle indicators	C_{4}	C_{10}	C_{25}	C_{4}	C_{10}	C_{24}	C_{10}	C_{17}	C_{18}	C_{17}	C_{2}	C_{18}
Inner Mongolia	Obstacle indicators	C_{10}	C_{7}	C_{23}	C_{10}	C_{7}	C_{17}	C_{10}	C_{17}	C_{12}	C_{2}	C_{10}	C_{17}
Liaoning	Obstacle indicators	C_{2}	C_{20}	C_{17}	C_{20}	C_{17}	C_{10}	C_{17}	C_{1}	C_{8}	C_{17}	C_{1}	C_{8}
Jilin	Obstacle indicators	C_{20}	C_{24}	C_{12}	C_{20}	C_{24}	C_{25}	C_{20}	C_{23}	C_{12}	C_{17}	C_{12}	C_{1}
Heilongjiang	Obstacle indicators	C_{14}	C_{24}	C_{23}	C_{14}	C_{23}	C_{7}	C_{23}	C_{14}	C_{12}	C_{7}	C_{17}	C_{24}
Shanghai	Obstacle indicators	C_{20}	C_{19}	C_{8}	C_{8}	C_{20}	C_{22}	C_{8}	C_{21}	C_{20}	C_{8}	C_{21}	C_{20}
Jiangsu	Obstacle indicators	C_{19}	C_{20}	C_{1}	C_{20}	C_{19}	C_{1}	C_{20}	C_{19}	C_{1}	C_{20}	C_{19}	C_{1}
Zhejiang	Obstacle indicators	C_{20}	C_{17}	C_{8}	C_{20}	C_{9}	C_{17}	C_{20}	C_{17}	C_{8}	C_{20}	C_{17}	C_{8}
Anhui	Obstacle indicators	C_{20}	C_{17}	C_{3}	C_{20}	C_{17}	C_{10}	C_{1}	C_{20}	C_{17}	C_{1}	C_{17}	C_{3}
Fujian	Obstacle indicators	C_{8}	C_{20}	C_{17}	C_{20}	C_{17}	C_{18}	C_{17}	C_{8}	C_{18}	C_{17}	C_{20}	C_{18}
Jiangxi	Obstacle indicators	C_{1}	C_{7}	C_{23}	C_{7}	C_{23}	C_{18}	C_{23}	C_{1}	C_{7}	C_{17}	C_{1}	C_{10}
Shandong	Obstacle indicators	C_{1}	C_{8}	C_{19}	C_{1}	C_{10}	C_{7}	C_{1}	C_{17}	C_{19}	C_{17}	C_{19}	C_{1}
Henan	Obstacle indicators	C_{1}	C_{17}	C_{10}	C_{1}	C_{10}	C_{17}	C_{1}	C_{21}	C_{17}	C_{1}	C_{17}	C_{10}
Hubei	Obstacle indicators	C_{23}	C_{17}	C_{18}	C_{17}	C_{23}	C_{7}	C_{23}	C_{17}	C_{18}	C_{17}	C_{1}	C_{21}
Hunan	Obstacle indicators	C_{21}	C_{23}	C_{17}	C_{23}	C_{17}	C_{18}	C_{17}	C_{12}	C_{18}	C_{17}	C_{18}	C_{7}
Guangdong	Obstacle indicators	C_{5}	C_{8}	C_{20}	C_{5}	C_{20}	C_{17}	C_{17}	C_{20}	C_{12}	C_{17}	C_{20}	C_{21}
Guangxi	Obstacle indicators	C_{17}	C_{3}	C_{8}	C_{17}	C_{7}	C_{3}	C_{17}	C_{1}	C_{10}	C_{17}	C_{1}	C_{10}
Hainan	Obstacle indicators	C_{21}	C_{12}	C_{23}	C_{21}	C_{25}	C_{23}	C_{21}	C_{23}	C_{24}	C_{15}	C_{21}	C_{25}
Chongqing	Obstacle indicators	C_{17}	C_{25}	C_{12}	C_{17}	C_{10}	C_{12}	C_{17}	C_{12}	C_{22}	C_{17}	C_{12}	C_{23}
Sichuan	Obstacle indicators	C_{17}	C_{23}	C_{7}	C_{17}	C_{7}	C_{23}	C_{17}	C_{23}	C_{1}	C_{17}	C_{1}	C_{3}
Guizhou	Obstacle indicators	C_{3}	C_{11}	C_{16}	C_{3}	C_{25}	C_{16}	C_{3}	C_{11}	C_{17}	C_{3}	C_{17}	C_{18}
Yunnan	Obstacle indicators	C_{17}	C_{25}	C_{3}	C_{17}	C_{3}	C_{18}	C_{17}	C_{3}	C_{18}	C_{17}	C_{3}	C_{18}
Tibet	Obstacle indicators	C_{7}	C_{9}	C_{12}	C_{7}	C_{23}	C_{12}	C_{23}	C_{12}	C_{13}	C_{7}	C_{21}	C_{15}
Shaanxi	Obstacle indicators	C_{24}	C_{17}	C_{23}	C_{17}	C_{13}	C_{18}	C_{17}	C_{12}	C_{18}	C_{17}	C_{1}	C_{18}
Gansu	Obstacle indicators	C_{23}	C_{2}	C_{18}	C_{18}	C_{25}	C_{23}	C_{14}	C_{23}	C_{18}	C_{14}	C_{3}	C_{17}
Qinghai	Obstacle indicators	C_{18}	C_{25}	C_{22}	C_{18}	C_{19}	C_{23}	C_{7}	C_{15}	C_{18}	C_{6}	C_{23}	C_{24}
Ningxia	Obstacle indicators	C_{6}	C_{9}	C_{2}	C_{6}	C_{22}	C_{23}	C_{2}	C_{4}	C_{6}	C_{4}	C_{22}	C_{23}
Xinjiang	Obstacle indicators	C_{19}	C_{25}	C_{17}	C_{2}	C_{19}	C_{17}	C_{19}	C_{18}	C_{12}	C_{19}	C_{17}	C_{12}

Table V.
Obstacle value of China's low-carbon competitiveness in index layer

afforestation area, the proportion of science and technology expenditure and the number of buses per 10,000 people. Environmental impact assessment projects mainly affected the low-carbon levels of the northwest, northeast and the middle reaches of the Yangtze River. The afforestation area restricted the improvement of low-carbon status in areas that included the Yangtze River Delta, the southeast coast, the Bohai Sea Region and the northeastern region. The influence of the proportion of science and technology expenditure in the total fiscal expenditure extended from Hebei, the Inner Mongolia, Jiangxi, Sichuan and Tibet to the northeast, southwest and the other nine s around the Bohai Sea Region. The restricted area of bus ownership per 10,000 people also extended from Shanxi, the Inner Mongolia and Henan to North China, Northeast China and the middle reaches of the Yangtze River.

In 2010-2013, the proportion of GDP attributable to tertiary industry, the capacity of wastewater treatment facilities, urban garden green space areas and afforestation were the main factors in China's low-carbon competitiveness. The radiation range of the proportion of tertiary industry in GDP was from North China, the middle and upper reaches of the Yangtze River area to Northeast China, Southwest China, Northern China, and the Yangtze River Basin. The affected areas of the processing capability of wastewater treatment

facilities from 11 provinces located in the Northeast, the Northwest, Bohai Rim Region, the middle and upper reaches of the Yangtze River area decreased to Beijing City, Jilin, Chongqing City and Xinjiang Uygur. The scope of the urban garden green space area from the southwest, northwest and middle reaches of the Yangtze River changed to the southwest and northwest. The influence portion of the afforestation area remained unchanged; this was the area of Beijing-Tianjin, the southeast coast and the Yangtze River Delta.

In 2007-2013, the most important factor for restricting the development of China's low-carbon competitiveness was the proportion of wetlands in a precinct. Additionally, in 2007, 2009, 2011 and 2013, the number of provinces affected by this index was 14, 14, 19 and 24, respectively, involving most parts of China. It can be observed that the wetland has become an obstacle to enhancing low-carbon competitiveness in all Chinese provinces. For a long time, wetlands played an extremely important role in supporting the sustainable development of China's economy and society. However, the problems of wetland infrastructure occupancy, reclamation, overfishing and pollution remained very serious. Therefore, the long-term planning of wetland protection should be further improved to comprehensively enhance the overall level of wetland protection in accordance with China's main functional area planning and the requirements of comprehensive management of mountains, forests, fields and lakes. We should focus on strengthening the supervision and protection of internationally and nationally important wetlands, national wetland parks, coastal wetlands and trans-regional and inter-basin wetlands. At the same time, a diversified investment mechanism should be established to broaden the sources of funding for wetland protection, promoting the establishment of an ecological compensation system.

5. Conclusions and suggestions

5.1 Conclusions

Based on the evaluation of low-carbon competitiveness, we apply the catastrophe progression model to actual analysis using 31 provinces (cities and regions) to study the current situation of China's low-carbon competitiveness. Low-carbon competitiveness in China from the East[1] to the West[2] gradually decreases. The Tibet and Ningxia Hui have the lowest low-carbon competitiveness, while regions with the greatest low-carbon competitiveness range from Shandong and Jiangsu provinces to the east coast and the Yangtze River Basin in China. The spatial autocorrelation model showed that the global Moran's I value of China's low-carbon competitiveness increases first, then decreases and finally approaches zero. The spatial correlation of low-carbon competitiveness is extremely low, and each province is in a state of independent development. At the same time, the phenomenon of high-value agglomeration appears in the northeast, the Bohai Sea Region and the Southeast coast; low-value gathering areas are the Xinjiang Uygur, the Ningxia Hui and Gansu. Finally, through obstacle factor diagnosis, we also find that the development of low-carbon competitiveness in China is mainly restricted to economic, industrial, environmental and technological benefits. Additionally, hindrance from wetlands is most significant, affecting more than half of the 31 provinces (cities and regions). The inhibitory effect of the environment is gradually weakening; the impeditive function of the economy is becoming increasingly prominent.

In summary, the steady improvement of China's low-carbon competitiveness will further stimulate the momentum of sustainable development; help strengthen the implementation of environmental protection policies; promote the transformation of industries into energy-saving, low-carbon and high-efficiency industries; expand the scope of high-tech applications; and facilitate the international transfer of China's advantageous surplus capacity, enhancing China's position in the global value chain.

5.2 Suggestions

The following suggestions are proposed as methods for promoting the development of low-carbon competitiveness:

First, China should fully champion the leading role of the eastern region in driving economic growth and should strengthen regional cooperation and promote the sustained, well-coordinated, stable development of each province (city and region). As the eastern region has higher low-carbon competitiveness than the central and western regions, it is necessary to reasonably guide the transfer of labor, capital and technology from the eastern regions to the central and western regions to promote the low-carbon competitiveness of the central and western regions through advanced experience and radiation effects. In addition, the central and western regions should strengthen their cooperation and exchanges with eastern regions, actively introduce advanced personnel and technologies, embrace the strategic opportunity of Western Development and follow a sustainable development path.

Second, China should optimize its industrial structure and develop low-carbon industries. Above all, China should increase the threshold for entry into "high-carbon" industries to reduce the number of enterprises with high-energy consumption, material consumption and carbon emissions. China should then promote industry and product profit lines and form brands and sales networks to enhance core competitiveness. Finally, China should develop modern service industries and high-tech industries and transform traditional industries that involve cement, chemicals and steel using advanced technology to reduce the carbon intensity of the GDP.

Third, China should enhance government supervision and strengthen environmental protections. With economic development, each province (city and region) should focus on ecological protection and transfer resource use patterns to achieve the intensive and economical use of energy and resources. China should also comprehensively manage and oversee the government effectively, constantly improving the protection of the environment, forest resources and wetlands, and realizing the spatial development and protection of land resources. Furthermore, China should reduce the loss of mineral, forest and other natural resources, improve the carrying capacity of the environment, make reasonable use of the market mechanism and reduce the cost of emissions reduction and environmental protections. Thus, the above measures could accelerate the development of China's low-carbon competitiveness.

Notes

1. China East includes Beijing City, Tianjin City, Hebei, Shandong, Jiangsu, Shanghai City, Zhejiang, Fujian, Guangdong and Hainan.
2. China West includes Sichuan, Yunnan, Guizhou, Tibet, Chongqing City, Shaanxi, Gansu, Qinghai, Xinjiang Uygur, Ningxia Hui, Inner Mongolia and Guangxi Zhuang.

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Received 18 April 2019
Revised 9 June 2019
Accepted 16 August 2019

Does aging and off-farm employment hinder farmers' adoption behavior of soil and water conservation technology in the Loess Plateau?

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Abstract

Purpose – Based on the survey data of 1,152 households in three provinces of Shaanxi, Gansu and Ningxia on the Loess Plateau, this paper aims to empirically analyze the impact of aging and off-farm employment on farmers' adoption behavior of soil and water conservation technology. This paper analyzes the moderating effect of social network and the mediating effect of technological cognition in this impact relationship.

Design/methodology/approach – Based on the above analysis, the second part of this paper is based on relevant theories and constructs a theoretical model of the relationship of aging, off-farm employment, social network, technology cognition and farmers' adoption behavior of soil and water conservation technology. The third part introduces research methods, variable selection and descriptive statistics analysis of variables. The fourth part, based on the data of Shaanxi, Gansu and Ningxia provinces in the Loess Plateau in 2016, empirically analyzes the impact of aging, off-farm employment and social network on the farmers' adoption behavior of soil and water conservation technology. This paper further examines the moderating effect of social network and the mediating effect of technology cognition in this influence relationship. Finally, based on the findings of the empirical study, this paper puts forward countermeasures and suggestions.

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This work is supported by the National Natural Science Foundation of China (Project Nos. 71673223 and 71973105). The authors extend their sincere thanks to the editors of the journal and the anonymous reviewers for their valuable comments and suggestions that have significantly improved the manuscript.

Conflicts of interest: The authors declare no conflicts of interest.

International Journal of Climate Change Strategies and Management
Vol. 12 No. 1, 2020
pp. 92-107
Emerald Publishing Limited
1756-8692
DOI 10.1108/IJCCSM-04-2019-0021

Findings – First, aging and off-farm employment have a significant negative impact on farmers' adoption behavior of soil and water conservation technology, while social network has a significant positive effect. Second, social network has alleviated the effect of aging and off-farm employment on restraining farmers' adoption behavior of soil and water conservation technology. Third, aging and off-farm employment have restrained farmers' cognition of soil and water conservation technology. Social network has promoted farmers' cognition of soil and water conservation technology. Social network plays a moderating role in the impact of aging and off-farm employment on farmers' cognition of soil and water conservation technology. Technology cognition plays a mediating role in the impact of social network on farmers' adoption behavior of soil and water conservation technology.

Originality/value – This paper integrates the aging, off-farm employment and social network into the same analytical framework and reveals their impact on farmers' adoption behavior of soil and water conservation technology and its action mechanism, which enriches the impact of human capital and social network on farmers' adoption behavior of soil and water conservation technology. Then taking the social network as a moderator variable, the paper verifies its moderating effect on the relationship of aging, off-farm employment and farmers' adoption behavior of soil and water conservation technology. Farmers' technology cognition should be included in the analysis framework to examine the impact of aging, off-farm employment and social network on farmers' cognition of soil and water conservation technology. Taking the technology cognition as a mediator variable, the paper verifies its mediating effect on the relationship of aging, off-farm employment and farmers' adoption behavior of soil and water conservation technology.

Keywords Social network, Aging, Off-farm employment, Soil and water conservation technology, Technology cognition

Paper type Research paper

1. Introduction

China is one of the countries with the most serious soil erosion in the world. The Loess Plateau is the most serious area of soil erosion in China. The Loess Plateau is facing serious ecological and environmental problems such as soil erosion. Farmers' unreasonable agricultural production activities aggravate soil erosion and restrict the sustainable development of agriculture. Practice shows that soil and water conservation technology can promote rural economic development, increase land productivity and farmers' income (Shao and Jiang, 2008), reduce soil erosion and poverty (Kuang and Luo, 2010). Therefore, promoting soil and water conservation technology is the main way to control soil erosion in the Loess Plateau. However, in reality, the adoption rate of soil and water conservation technology in the Loess Plateau is low, and the effect is not ideal, which puts the popularization of water and soil conservation technology in a dilemma (Liu *et al.*, 2009).

Farmers are the main body of agricultural management and the direct adopters and beneficiaries of soil and water conservation technology. However, with the continuous development of the social economy and urbanization, rural areas are facing increasingly serious problems of aging and labor transfer. The National Statistics Bureau's third National Agricultural Census's main data bulletin shows that, in 2016, 33.6 per cent of the agricultural production and operation personnel were 55 years old or more. Only 19.2 per cent of them aged 35 years old or younger. The situation of rural population aging is serious. At the same time, the huge income gap between urban and rural areas leads to the transfer of the rural labor force. The migrant workers monitoring survey report showed that the total number of migrant workers in 2016 was 281.71 million, an increase of 4.24 million over 2015, (i.e. an increase of 1.5 per cent). Then, does rural aging and off-farm employment hinder farmers' adoption behavior of soil and water conservation technology in the Loess Plateau and make the extension of soil and water conservation technology in a dilemma?

In view of the reasons for the low adoption rate of soil and water conservation technology, scholars at home and abroad have conducted a lot of research. The results show that the main factors affecting farmers' adoption behavior of soil and water conservation technology are individual characteristics, family management characteristics and environmental factors and so on (Zhong and Huang, 2004; Kassie *et al.*, 2013; Zhang *et al.*, 2015; Ji, 2017). However, under the new situation of rural aging and non-agricultural transfer of rural labor force, the influence of rural aging and off-farm employment on farmers' adoption behavior of soil and water conservation technology should also be paid enough attention, because the level of human capital plays an important role in the promotion and application of agricultural technology (Schultz, 1964). At present, most studies focus on the influence of education level on farmers' technology adoption behavior. However, there are few studies concerning the impact of rural aging and off-farm employment on farmers' technology adoption behavior. In recent years, with the development of social network theory, relevant scholars began to pay attention to the role of social network in the adoption of agricultural technology (Wang and Lu, 2015). Research shows that social network mainly influence farmers' technology adoption behavior through social learning, information acquisition (Qiao *et al.*, 2017), service complementarity and help support mechanisms (Genius *et al.*, 2014). However, during popularization of soil and water conservation technology, how does social network affect farmers' adoption behavior of soil and water conservation technology? Under the background of rural aging and non-agricultural transfer of the rural labor force, can social network effectively improve the human capital constraints of rural aging and off-farm employment on technology adoption? This aspect of research is rare. In addition, farmers' technology cognition will affect farmers' technology adoption behavior (Li *et al.*, 2017). Aging and off-farm employment will affect farmers' technology cognition (He and Zhang, 2014). Thus, we investigate whether aging and off-farm employment will affect farmers' adoption behavior of soil and water conservation technology through influencing farmers' cognition of soil and water conservation technology. That is, we want to determine whether technology cognition plays a mediating role in the impact of aging and off-farm employment on farmers' technology adoption behavior, and whether social network plays a moderating role in the impact of aging and off-farm employment on farmers' cognition of soil and water conservation technology, and then affect farmers' technology adoption. To the best of the authors' knowledge, this research does not yet exist in the literature.

Based on the above analysis, Section 2 of this paper is based on relevant theories, and constructs a theoretical model of the relationship of aging, off-farm employment, social network, technology cognition and farmers' adoption behavior soil and water conservation technology. Section 3 introduces research methods, variable selection and descriptive statistics analysis of variables. Using 2016 data of Shaanxi, Gansu and Ningxia provinces in the Loess Plateau, Section 4 empirically analyzes the impact of aging, off-farm employment and social network on farmers' adoption behavior of soil and water conservation technology. We then further examine the moderating effect of social network and the mediating effect of technology cognition on this aforementioned relationship. Finally, based on the findings of the empirical study, we put forward countermeasures and suggestions. The contributions of this paper are as follows:

- This paper integrates aging, off-farm employment and social network into the same analytical framework, and reveals their impact on farmers' adoption behavior of soil and water conservation technology, along with its action mechanism, which enriches the impact of human capital and social network on farmers' adoption behavior of soil and water conservation technology.

- This paper adds the interaction items of aging and social network, off-farm employment and social network. The goal is to verify if social network can effectively improve the human capital constraint of rural aging and off-farm employment on soil and water conservation technology adoption, that is, we test the moderating effect of social network.
- Farmers' technology cognition should be included in the analysis framework, to examine the impact of aging, off-farm employment and social network on farmers' cognition of soil and water conservation technology. We test whether aging, off-farm employment and social network will affect farmers' technology adoption behavior through farmers' cognition of soil and water conservation technology, that is, we test the mediating effect of farmers' technology cognition.

2. Theoretical analysis

2.1 Impact of aging on farmers' technology adoption behavior

Academia has focused on the impact of aging on agricultural output performance and land productivity. However research on the impact of aging on the adoption of agricultural production technology is rare. Li and Zhao (2009) showed that the aging of agricultural labor is not conducive to the adoption of agricultural technology. Meanwhile, Yang (2018) showed that the aging of agricultural labor will inevitably bring about the weakening of agricultural human capital, which will hinder the adoption of green production technology. Finally, Li *et al.* (2017) showed that household age has a significant negative effect on farmers' adoption behavior of conservation tillage.

2.2 The impact of off-farm employment on farmers' technology adoption behavior

Through combing the literature, we found that off-farm employment mainly affects technology adoption by changing family income and labor quantity.

Off-farm employment will affect farmers' technology adoption through the "labor force effect." It mainly includes the loss effect of agricultural labor force and the improvement effect of human capital. Ma *et al.* (2004) revealed that labor shortage is one of the factors that restrict water and soil conservation investment. Zhou (2010) showed that migrant workers return to home provide opportunities for the implementation of biotechnology. Moreover, Han (2017) believed that entrepreneurs returning home are more focused on new technology applications. It has injected a new impetus into the transformation and upgrading of agriculture, improving quality and increasing efficiency. At the same time, labor mobility aggravating the aging of the agricultural labor force will inhibit farmers' technology adoption (Lin and Deng, 2012).

Off-farm employment will also affect farmers' technology adoption through the "income effect." The income growth brought by off-farm employment can expand the income constraint boundary of family members so that they can buy more capital-intensive and labor-saving agricultural production factors, increase the number of agricultural workers and introduce new production technologies (Qian and Hong, 2016). However, some scholars have come to different conclusions. Ma *et al.* (2004) and Wu *et al.* (2004) showed that the higher the degree of concurrent farming, the non-agricultural income becomes the main source of income. Therefore, farmers will reduce investment in water and soil conservation. Ultimately, it is not yet clear whether the increased income from off-farm employment can make up for the loss caused by the labor force transfer and thus effectively enhance the adoption of technology.

As seen from the above analysis, off-farm employment has a positive and negative impact on farmers' technology adoption behavior (Figure 1). The comprehensive effect of off-farm employment on farmers' adoption behavior of soil and water conservation technology needs to be further tested.

2.3 Influence of social network on farmers' technology adoption behavior

Academic circles have studied this from different angles. Through combing the existing literature, we found that social network mainly affect the adoption behavior of farmers through social learning, information acquisition (Qiao *et al.*, 2017), service complementarity and helper support mechanisms (Genius *et al.*, 2014).

2.4 Alleviating the impact of social network on the relationship between aging, off-farm employment and farmers' soil and water conservation technology adoption behavior

Aging and off-farm employment exists the weakness of labor supply, cognitive ability and agricultural investment, which restrict farmers' adoption behavior of soil and water conservation technology. Related studies show that social network can break through this constraint and promote farmers' technology adoption. In view of the aging problem, Yang (2018) showed that social network mitigate the negative impact of aging on farmers' adoption behavior of green production technology. Furthermore, in view of the shortage of labor force caused by the transfer of labor force, social network can help farmers to get support from workers and promote technology adoption behavior (He *et al.*, 2016).

2.5 Mediating effect of technology cognition

He and Zhang (2014) showed that farmers' age has a negative impact on value perception of resource agricultural waste recycling. Wang and Gu (2012) showed that farmers with agricultural income as the main source of income have a higher perception of environment. Li *et al.* (2017) showed that farmers' cognition of water-saving irrigation technology promote farmers to adopt water-saving irrigation technology. Social network not only directly affect farmers' willingness to adopt low-carbon agriculture technology, but also have an indirect effect on farmers' willingness to adopt low-carbon agriculture technology through perceived usefulness (Hu, 2016). Aging has a negative impact on technology cognition. Through social network, farmers often communicate with other farmers; and learning from other people's technical experiences increases one's cognition of technology (Yang, 2018). It can be seen

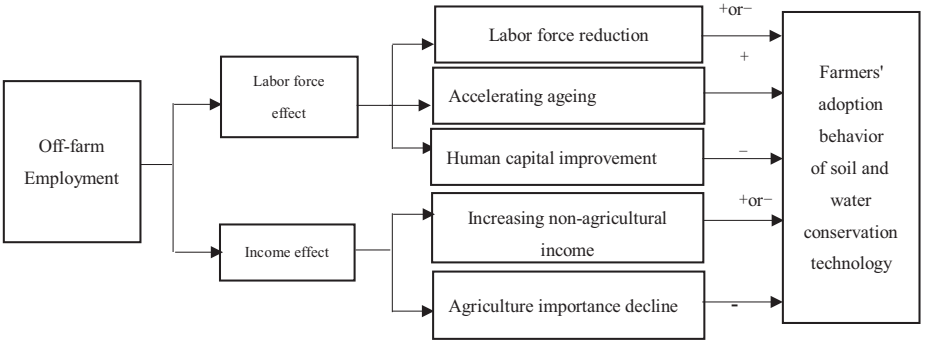

Figure 1.
Influencing mechanism of off-farm employment on farmers' adoption behavior of soil and water conservation technology

that aging and off-farm employment may affect farmers' technology adoption by influencing farmers' technology cognition. At the same time, social network can alleviate and deepen farmers' cognition of technology and promote technology adoption.

Based on the above theoretical analysis, this paper constructs models including aging, off-farm employment, social network, technology cognition and farmers' adoption behavior of soil and water conservation technology (Figure 2).

3. Data sources, variable selection and model methods

3.1 Data sources

The data used in this study came from the large-scale field survey conducted by the project team in the Loess Plateau from October to November 2016. Shaanxi, Gansu and Ningxia provinces were selected as the research areas. Sample selection was representative. The concrete reasons are as follows. First, according to the national soil and water conservation plan (for 2015-2030) promulgated by the State Council in 2015, of the 23 key national soil erosion prevention areas and 17 key management areas identified in China, the Loess Plateau region accounted for 7 and 5 respectively, which was a large proportion, mostly distributed in Shaanxi and Gansu provinces. Second, in 1998, the construction of a soil and water conservation demonstration zone in Xifeng city of Gansu Province and Suide County of Shaanxi Province played a typical exemplary role in the areas of governance and development. Since the implementation of the World Bank's loan project for soil and water conservation in 1994, systematic and complete scientific work systems have been established for project management, investment operation, monitoring evaluation and technology popularization. It has played a good role in guiding the management of soil and water conservation and ecological environment construction in the Yellow River basin. The government provided preferential policies such as preferential technical services and material supply, and further mobilized the community to invest in soil and water conservation. Three provinces (regions) have implemented the Grain for Green project, which compensates farmers who participate in afforestation. Third, the research area is not only the main area of agricultural development in the Loess Plateau, but also a serious area of soil erosion. Farmers are greatly affected by soil erosion. Soil erosion is related to food security. Farmers adopt certain soil and water conservation technologies to control soil erosion. Thus the study of farmers' adoption behavior of soil and water conservation is of great practical significance.

A combination of cluster, stratified and random sampling was used to select the research areas, namely: Mizhi County, Yuyang District and Suide County in Yulin city of Shaanxi

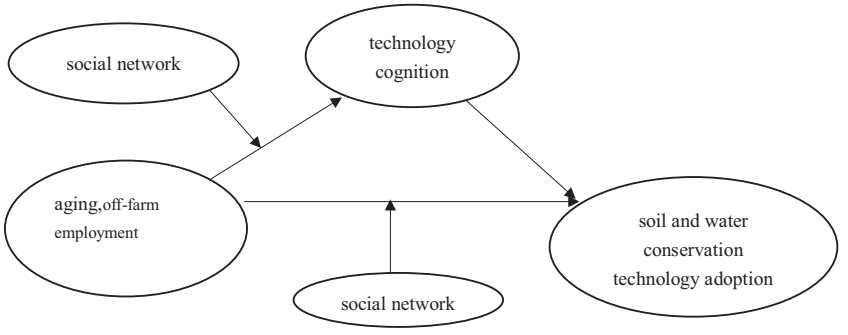

Figure 2.
Influence mechanism of aging, off-farm employment, social network and technology cognition on farmers' adoption behavior soil and water conservation technology

Province; Xifeng District and Huan County in Qingyang city of Gansu Province; and Yuanzhou District, Pengyang County and Xiji County in Guyuan city of Ningxia Province. Through the stratified random sampling method, we selected one to five towns in each of the above counties, and each town randomly selected two to five villages. Then, each village randomly selected 15-20 farmers. The survey sample eventually included 8 counties, 30 towns, 72 villages and 1,200 farmers in 3 provinces (Shaanxi, Gansu and Ningxia). The survey was a one-on-one interview with farmers. Finally, 1,152 valid questionnaires were obtained, and the effective rate of the questionnaire was 96 per cent. The survey mainly included the characteristics of farmers and family endowments, social network, farmers' cognition of soil and water conservation technology and the adoption of soil and water conservation technology. The basic situation of sample farmers is shown in Table I. As shown in Table I, 96.7 per cent of the households interviewed are male. Because men have certain final decision-making power in the family, men's wishes can represent the final decision-making intention of the family. A total of 58.07 per cent of the respondents were over 51 years old, the trend of the aging of rural labor force was obvious, 89.83 per cent of them were junior middle school students and below, and the education level was generally low. A total of 42.45 per cent of the farmers interviewed were engaged in off-farm employment, and the level of household farming was relatively high. The proportion of household labor force in 2-4 households was 78.82 per cent, at a medium scale level. The proportion of agricultural income is relatively low, and 70.66 per cent of rural households' income mainly comes from non-agricultural income. Farmers have a higher degree of concurrent business. From the characteristics of the sample farmers, we can see that the sample farmers show the basic characteristics of low education level, aging and low proportion of agricultural income.

The specific distribution of sample farmers and the technical application of soil and water conservation for farmers in counties (districts) are shown in Table II. According to the

Variable	Classified	Household	Ratio/(%)
Gender	Men	1,114	96.7
	Female	38	3.3
Age	Under 30 years old	21	1.83
	31-40 years old	128	11.11
	41-50 years old	334	28.99
	50 years old and above	334	58.07
Labor quantity	1 and below	94	8.16
	2	451	39.15
	3	201	17.45
	4	256	22.22
	5 and above	150	13.02
Education level	Illiteracy	250	21.70
	Primary school	267	23.18
	Junior middle school	519	45.05
	High school	109	9.46
	College graduate or above	7	0.61
Agricultural income ratio	25% and below	600	52.08
	25-49%	214	18.58
	50-74%	128	11.11
	75% and above	210	18.23
Off-farm employment	Yes	489	42.45
	No	663	57.55

Table I.
The basic situation of the sample farmers

survey, 63.63 per cent of the sample farmers adopt engineering soil and water conservation technology.

3.2 Variable settings and descriptive statistical analysis

- *Dependent variable*: The dependent variable of the model built in this study is whether the farmers adopt the engineering soil and water conservation technology. This is measured by asking farmers whether they adopt engineering soil and water conservation technology.
- *Core explanatory variables*: Off-farm employment-referring to the relevant research practice, this paper uses the proportion of household non-agricultural income to total household income to represent off-farm employment. Aging – the head of household aged 60 or older is an elderly farmer, assigned a value of 1, and the head of household aged less than 60 years old is a non-aged farmer, assigned a value of 0.
- *Moderating variable*: Social network – Referring to the relevant literature and theory (Wang and Lu, 2015), this paper divides the social network into three dimensions: so, network learning, network interaction and network reciprocity can be expressed as social network factors. Increasing production value cognition, increasing income value cognition and improving ecological environment value recognition can be expressed as technology cognition factors..
- *Mediator variable*: Technology cognition – The measurement of technology cognition is estimated through three aspects: increasing production value cognition, increasing income value cognition and improving ecological environment value cognition. Social network and technology cognition variables were measured on a five-point Likert scale.
- *Control variables*: This paper selects farmers' educational level, gender, number of agricultural machines, cultivated land area, whether they are village cadres, government investment, severity of soil erosion and other variables as control variables.

Variable definitions and statistical descriptions are shown in Table III.

Table II. Distribution of sample farmers' adoption behavior of soil and water conservation technology

Province	County (district)	No. and proportion of sample households (%)	No. and proportion of households adopting soil and water conservation technology (%)
Shaanxi	Mizhi County	228 (19.79)	82 (35.96)
	Yuyang District	75 (6.51)	15 (20)
	Suide County	80 (6.94)	17 (21.25)
Gansu	Xifeng District	185 (16.06)	88 (47.57)
	Huan County	200 (17.36)	178 (89)
Ningxia	Yuanzhou District	151 (13.11)	140 (92.72)
	Pengyang County	200 (16.06)	185 (92.5)
	Xiji County	33 (2.86)	28 (84.85)
Total	–	1,152	733 (63.63)

Variable	Variable specification	Mean	SD
Dependent variable			
Soil and water conservation technology adoption	Whether a farmer has adopted or not? Yes = 1 and no = 0	0.64	0.48
Core explanatory variables			
Aging	The age of the head of household: age >60 years old = 1 and age < 60 years old = 0	0.30	0.46
Off-farm employment social network	The proportion of non-agricultural income to total household income	0.65	0.33
Network learning	Do you often communicate with others about soil and water conservation measures? 1 = never, 2 = occasionally, 3 = generally, 4 = often and 5 = very frequently	2.35	1.27
Network interaction	Do you often walk with your relatives and friends? 1 = never, 2 = occasionally, 3 = generally, 4 = often and 5 = very frequently	2.37	1.22
Network reciprocity	Is the information and guidance provided by neighbors useful? 1 = never, 2 = occasionally, 3 = generally, 4 = often and 5 = very frequently	3.06	1.21
Technology cognition			
Increase production value cognition	1 = no effect, 2 = less effect, 3 = general, 4 = greater effect and 5 = very large effect	3.48	1.01
Increase revenue value cognition	1 = no effect, 2 = less effect, 3 = general, 4 = greater effect and 5 = very large effect	3.39	1.02
Improving ecological environment value cognition	1 = no effect, 2 = less effect, 3 = general, 4 = greater effect and 5 = very large effect	3.78	0.84
Control variables			
Educational level	Illiteracy = 1, Primary school = 2, Junior middle school = 3, High school = 4 and College graduate or above = 5	2.44	0.95
Gender	1 = male and 0 = female	0.97	0.18
Agricultural machines quantity	Number of household farm machinery (unit)	0.44	0.55
Village cadres	Yes = 1 and no = 0	11.01	10.95
Cultivated land area	Your cultivated and land area (mu)	0.18	0.38
Government investment	Yes = 1 and no = 0	0.64	0.499
Severity of soil erosion	Soil erosion severity perception: 1 = no soil erosion, 2 = less serious, 3 = general, 4 = more serious and 5 = very serious	2.57	1.12

Table III.
Variable definitions and statistical descriptions

3.3 Reliability and validity of variables

In this paper, we use SPSS22.0 to test the consistency of the two latent variables (social network and technology cognition) and examine their credibility. It is generally believed that when the Cronbach's alpha is greater than 0.6, the data is reliable. The Cronbach's alpha value of the social network was 0.646, and the technology cognition Cronbach's alpha was 0.830; both are over 0.6. This shows that the observation index has good consistency and the reliability of the questionnaire is relatively high. Then, Kaiser-Meyer-Olkin (KMO) test and Bartlett's sphere test were used to carry out validity analysis, to test the degree of proximity between measured and real values. By testing, it was found that the KMO was 0.66 (which is greater than 0.6), and the Bartlett's sphere test value was significant at the 1 per cent level, indicating that the variable has higher validity and can be used in factor analysis. Principal

component analysis was used to extract the common factors, with the characteristic value greater than 1 as the extraction standard (Table IV). It can be seen that two principal components can be extracted, which account for 67.136 per cent of the total variance.

Table V shows that each index's load on the corresponding factor is much larger than on the cross-load of other factors. It shows that each index can effectively reflect its corresponding factors.

3.4 Research methods

Referring to Wen Zhonglin's mediation effect test method (Wen and Ye, 2014), the basic regression equation is as follows:

$$TA_i = \alpha AGE + \beta LT + \delta SN_i + \theta X_i + \varepsilon_i \quad (1)$$

$$VC_i = \alpha' AGE + \beta' LT + \delta' SN_i + \theta' X_i + \varepsilon_i' \quad (2)$$

$$TA_i = \alpha'' AGE + \beta'' LT + \delta'' SN_i + \theta'' X_i + \gamma VC_i + \varepsilon_i'' \quad (3)$$

In the above formula, TA means that the farmers adopt water and soil conservation technology, AGE means aging, LT indicates off-farm employment, SN indicates social network and VC indicates technology cognition. X_i is the selected control variable, $\alpha, \alpha', \alpha'', \beta, \beta', \beta'', \gamma$ are the regression coefficients of the corresponding variables and $\varepsilon_i, \varepsilon_i', \varepsilon_i''$ are the disturbance terms.

In this paper, we use Formula (1) to examine the direct impact of aging, off-farm employment and social network on farmers' adoption behavior of soil and water conservation technology. Then, on the basis of Formula (1), we add the interaction items of

	Initial eigenvalue			Extracting squared sum loading			Rotation squared sum loading		
Component	Total	Variance (%)	Cumulative (%)	Total	Variance (%)	Cumulative (%)	Total	Variance (%)	Cumulative (%)
1	2.522	42.028	42.028	2.522	42.028	42.028	2.233	37.224	37.224
2	1.506	25.108	67.136	1.506	25.108	67.136	1.795	29.911	67.136
3	0.805	13.411	80.547						
4	0.579	9.644	90.191						
5	0.423	7.044	97.235						
6	0.166	2.765	100.00						

Table IV. Total variance of the explanation and factor contribution rate

Factor	Factor 1	Factor 2
Network learning	0.068	*0.838*
Network interaction	0.131	*0.828*
Network reciprocity	0.046	*0.602*
Increase production value cognition	*0.906*	0.145
Increase revenue value cognition	*0.902*	0.151
Improving ecological environment value cognition	*0.758*	−0.003

Table V. Component matrix after rotation

aging, off-farm employment and social network to examine the moderating effect of social network on aging and off-farm employment affecting farmers' adoption behavior of soil and water conservation technology. Next, we use the Formula (2) to test the direct influence of aging, off-farm employment and social network on farmers' cognition of soil and water conservation technology. We add the interaction item of aging, off-farm employment and social network on the basis of Formula (2) to test the moderating effect of social network on aging and off-farm employment affecting farmers' cognition of soil and water conservation technology. Formulas (2) and (3) test the mediating effect of farmers' cognition of soil and water conservation technology.

4. Estimated results and analysis

In this section, we use Stata14.0 software to estimate models. The results are shown in Table VI. In Table VI, Model 1 is the estimation result obtained from Formula (1). Model 2 is an estimate of the interaction between aging and social network. Model 3 is an estimate of the interaction between off-farm employment and social network, this model investigates the moderating effect of social network on the impact of aging and off-farm employment on farmers' adoption behavior soil and water conservation technology.

4.1 Effects of aging, off-farm employment and social network on farmers' adoption behavior of soil and water conservation technology

In Table VI, Model 1's estimated coefficient of aging is negative and at a 1 per cent significance level, indicating that aging can inhibit farmers' adoption behavior of soil and water conservation technology. According to the survey, 71.9 per cent of farmers who are under 50 years old adopt soil and water conservation technology.

	Model 1		Model 2		Model 3	
Variable	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error
Aging	−0.613***	0.163	−1.706***	0.414	−0.619***	0.164
Off-farm employment	−0.775**	0.259	−0.771**	0.261	−1.195***	0.297
Social network	0.279***	0.075	0.271***	0.075	0.262**	0.076
Aging × social network	–	–	0.344**	0.118	–	–
Off-farm employment × social network	–	–	–	–	0.077**	0.026
Educational level	−0.021	0.021	−0.018	0.021	−0.020	0.021
Gender	−0.032	0.389	−0.066	0.393	−0.026	0.393
Agricultural machinery quantity	0.186	0.143	0.154	0.144	0.132	0.145
Cultivated land area	0.109***	0.012	0.106***	0.012	0.109***	0.012
Village cadres	−0.055	0.197	−0.034	0.198	−0.043	0.198
Government investment	1.053***	0.145	1.079***	0.146	1.089***	0.146
Severity of soil erosion	0.201**	0.069	0.209**	0.069	0.203***	0.069
Constant	−1.801**	0.563	−1.747**	0.568	0.077**	0.026
LR chi^2	351.54		360.02		359.91	
Prob > chi^2	0.0000		0.0000		0.0000	
Pseudo R^2	0.2328		0.2385		0.2384	
Log likelihood	−579.3948		−574.70385		−574.75934	

Notes: ** and *** respectively represented significant tests at 5 and 1% levels

Table VI.
Model estimation of the impact of aging, off-farm employment and social network on farmers' adoption behavior of soil and water conservation technology

The proportion of farmers 51-65 years old adopting water and soil conservation technology was 62.3 per cent, and the proportion of farmers who were 65 years or older adopting soil and water conservation technology was 43.64 per cent. It can be seen that the proportion of farmers adopting soil and water conservation technology decreases with age. The estimated coefficient of off-farm employment is negative, and statistically significant at 1 per cent, indicating that off-farm employment can inhibit farmers' adoption behavior of soil and water conservation technology. We found that for farmers with less than 50 per cent of the proportion of their non-agricultural income, 73.76 per cent adopt water and soil conservation technology. Meanwhile, for farmers with more than 50 per cent of the proportion of their non-agricultural income, 58.86 per cent adopt water and soil conservation technology. It can be seen that with the increase in the proportion of non-agricultural income, the proportion of farmers adopting soil and water conservation technology declines. Furthermore, social network was statistically significant at 1 per cent, and the estimated coefficient was positive, indicating that social network significantly improved farmers' adoption behavior of soil and water conservation technology.

4.2 Social network alleviate the influence of aging and off-farm employment on farmers' adoption behavior of soil and water conservation technology

Model 2 is an estimate of the interaction between aging and social network. The coefficient of interaction item (aging × social network) is significantly positive and at the significance level of 5 per cent, indicating the moderating effect of social network on aging. Model 3 is an estimate of the interaction between off-farm employment and social network. The coefficient of interaction item (off-farm employment × social network) is significantly positive and at the significance level of 5 per cent, indicating the moderating effect of social network on off-farm employment.

4.3 Mediating effect of technology cognition

Another problem that this article is interested in whether the impact of aging and off-farm employment on cognition soil and water conservation technology is one of the mechanisms of its negative impact on farmers' adoption behavior of soil and water conservation technology. That is, whether technology cognition has a mediating effect on this process. In this section, we use Stata14.0 software, and the results are shown in Table VII, Model 1 is the estimation resulting from Formula (2). Model 2 is an estimation of the interaction between aging and social network. Model 3 is an estimate of the interaction between off-farm employment and social network to investigate the moderating effect of social network on the relationship of aging and off-farm employment on farmers' technology cognition. To further examine the promoting effect of farmers' technological cognition on the adoption of soil and water conservation technology through social network, we should examine the mediating effect of technology cognition. The estimated results are shown in Table VIII.

4.4 The influence of aging, off-farm employment and social network on farmers' cognition of soil and water conservation technology

In Table VII, Model 1 has a negative estimated coefficient of aging that is statistically significant at the 10 per cent level, indicating that aging can inhibit farmers' soil and water conservation technology cognition. The estimated coefficient of off-farm employment is negative and is statistically significant at the 10 per cent level, which indicates that off-farm employment can restrain farmers' soil and water conservation technology cognition, that is, the higher the proportion of non-agricultural income, the lower the farmers' soil and water conservation technology cognition. Social network was statistically significant at 1 per cent, and the estimated coefficient was positive, indicating that social network significantly

Variable	Model 1 Coefficient	Model 1 Standard error	Model 2 Coefficient	Model 2 Standard error	Model 3 Coefficient	Model 3 Standard error
Aging	−0.229*	0.128	−1.160***	0.317	−0.238*	0.128
Off-farm employment	−0.394*	0.202	−0.386*	0.202	−0.792***	0.227
Social network	0.279***	0.075	0.390***	0.060	0.379***	0.060
Aging × social network	–	–	0.290**	0.090	–	–
Off-farm employment × social network	–	–	–	–	0.078***	0.021
Educational level	−0.004	0.016	−0.001	0.016	−0.002	0.016
Gender	0.286	0.312	0.249	0.312	0.294	0.312
Agricultural machinery quantity	0.168	0.109	0.138	0.109	0.119	0.109
Cultivated land area	0.023***	0.005	0.021***	0.005	0.022***	0.005
Village cadres	0.182	0.149	0.208	0.150	0.193	0.149
Government investment	0.316***	0.112	0.334**	0.113	0.336**	0.113
Severity of soil erosion	0.008	0.052	0.017	0.052	0.009	0.052
LR chi^2	126.51		137.15		141.26	
Prob > chi^2	0.0000		0.0000		0.0000	
Pseudo R^2	0.0441		0.0478		0.0493	
Log likelihood	−1,371.2155		−1,364.9836		−1,362.9306	

Notes: *, ** and *** respectively represented significant tests at 10, 5 and 1% levels

Table VII.
Model estimation of the impact of aging, off-farm employment and social network on farmers' cognition of soil and water conservation technology

Variable	Coefficient (standard error)
Core explanatory variables	
Social network	0.199* (0.077)
Technology cognition	0.539*** (0.092)
Control variables	Controlled
Pseudo R^2	0.2571
Log likelihood	−561.00934
LRχ^2	388.31
Prob > chi^2	0.0000

Notes: * and *** respectively represented significant tests at 10 and 1% levels

Table VIII.
Effect of social network and technology cognition on farmers' adoption behavior of soil and water conservation technology

improved farmers' cognition of soil and water conservation technology. A possible explanation for this is that, the wider the social network of farmers, they can be easer to get resources, information and social support from the government, research institutes and other extension agencies. This can deepen their understanding of soil and water conservation technology. They can better understand the value of soil and water conservation technology. Additionally, in a social network, many farmers are willing to share their experiences and the effects of technology, which can improve farmers' cognition of soil and water conservation technology.

4.5 Social network alleviating the impact of aging and off-farm employment, on farmers' cognition of soil and water conservation technology

In Model 2, the coefficient of interaction between aging and social network is significantly positive at the 5 per cent level, indicating the mitigating effect of social network on aging. Meanwhile Model 3's coefficient of interaction between off-farm employment and social network is significantly positive at the 1 per cent level, indicating the mitigation effect of social network on off-farm employment.

As shown in Table VIII, the estimation coefficient of social network is positive, and is significant at the 10 per cent level. The estimated coefficient of technology cognition is positive, and is significant at the 1 per cent level. The results show that social network can directly affect farmers' adoption behavior of soil and water conservation technology, and it can indirectly affect farmers' adoption behavior of soil and water conservation technology by affecting farmers' technology cognition. In other words, technology cognition has a mediation effect on the impact of social network on farmers' adoption behavior of soil and water conservation technology.

5. Conclusions and enlightenment

Based on a rural survey data in the Loess Plateau consisting of 1,152 farm households in Shaanxi, Gansu and Ningxia provinces, this article empirically analyzes the effects of aging, off-farm employment, social network and technology cognition on farmers' adoption behavior of soil and water conservation technology. The main conclusions are as follows: first, aging and off-farm employment restrained farmers' adoption behavior of soil and water conservation technology. Social network has promoted farmers' technology adoption behavior. Second, social network has alleviated the effect of aging and off-farm employment on restraining farmers' soil and water conservation technology adoption behavior. Third, aging and off-farm employment restrained farmers' soil and water conservation technology cognition, social network plays a role in alleviating the relationship of aging and off-farm employment on farmers' cognition of soil and water conservation technology. Technology cognition plays a mediating role in the impact of social network on farmers' adoption behavior of soil and water conservation technology.

Based on our findings, the following policy implications are drawn. First, under the background of aging, we should actively build public social networking platforms, cooperative organizations, mutual aid agencies, activity centers and clubs in the community to create conditions for the younger farmers to assist the older farmers. So as to improve the human capital of the aged labor force and promote the technology adoption rate of the aged labor force. Second, while promoting this technology, the government should broaden the social network of farmers so that farmers can make full use of resources such as political party members and village cadres, as well as agricultural cooperatives in organizations. This would also help promote technology adoption. Third, we should publicize the benefits of soil and water conservation technology and strengthen farmers' technology cognition. Through mutual communication of such benefits between farmers within the social network, farmers' cognition of technology can be improved; farmers exchanged the benefits of soil and water conservation technology, thus increasing the adoption of conservation technology. Fourth, under the background of labor transfer, guiding land transfer to improve farmers' technology adoption behavior.

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Received 22 October 2018
Revised 13 March 2019
25 May 2019
2 July 2019
Accepted 4 September 2019

Overcoming barriers to climate smart agriculture in India

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Abstract

Purpose – This paper aims to report on a case in which encouraging climate-smart agriculture in the form of better irrigation techniques in India can contribute to both climate change mitigation and adaptation goals by improving resource-use efficiency. It provides grounded institutional analysis on how these transformations can occur.

Design/methodology/approach – The authors based their research on three complementary approaches: institutional, sociological and technical. The institutional approach analyzed actors and interests in the water-energy nexus in India via over 25 semi-structured key informant interviews. The sociological approach surveyed over 50 farmers and equipment suppliers for insight into technology adoption. The technical component analyzed water and energy consumption data to calculate potential benefits from transitioning to more efficient techniques.

Findings – Because policymakers have a preference for voluntary policy instruments over coercive reforms, distortions in policy and market arenas can provide opportunities for embedded actors to leverage technology and craft policy bargains which facilitate Pareto superior reforms and, thereby, avoid stalemates in addressing climate change. Enlarging the solution space to include more actors and interests can facilitate such bargains more than traditional bilateral exchanges.

Practical implications – The analysis provides insights into crafting successful climate action policies in an inhospitable institutional terrain.

Originality/value – Studies about climate change politics generally focus on stalemates and portray the private sector as resistant and a barrier to climate action. This paper analyzes a contrary phenomenon, showing how reforms can be packaged in Pareto superior formats to overcome policy stalemates and generate technology-based climate and environmental co-benefits in even unpromising terrain such as technologically laggard and economically constrained populations.

Keywords India, Energy, Politics, Sector, Irrigation, Climate smart agriculture

Paper type Research paper

1. Introduction

Agricultural production is particularly relevant to climate change management strategies from both mitigation and adaptation perspectives. Agricultural and livestock production contributes almost one-quarter of global human-induced greenhouse gas (GHG) emissions according to the Food and Agriculture Organization (FAO, 2009), but discussions about

International Journal of Climate Change Strategies and Management
Vol. 12 No. 1, 2020
pp. 108-127
Emerald Publishing Limited
1756-8692
DOI 10.1108/IJCCSM-10-2018-0072

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mitigation tend to focus overwhelmingly on the energy and transport sectors. Consequently, climate-related research about food production in developing countries is mostly centered on adaptation, notwithstanding that decarbonization – addressing both long- and short-lived GHG – can be both immediate and cost-effective, have a large impact on emissions and simultaneously contribute to making these systems more resilient (Fay *et al.*, 2015).

With regard to adaptation, models of potential changes in water availability and the impacts of temperature increases on irrigation requirements and crop productivity raise several and severe concerns about the impact of climate change on food security, especially given the fact that the global population is expected to increase by 25 per cent to almost ten billion by 2050 and, again, according to FAO estimates, crop production would need to increase by up to 70 per cent to feed this population (FAO, 2009). If current trends are not addressed, within just a few decades, the majority of the world's population could face food and water shortages.

The good news is that technologies and practices for better water management and climate-smart agriculture (CSA) in general do exist, but the bad news is that their diffusion is slow and limited. For example, in India, a technology – drip irrigation (DI) – which can address water and electricity wastage exists and is already known to policymakers, administrators and farmers in the region. However, DI (where water is delivered directly to the roots of the plant as opposed to flooding the fields) has not spread enough to fulfill its potential, and flood irrigation remains more prevalent (Grant Thornton, 2016).

While CSA in the tropics has been recognized to have the potential to provide adaptation and mitigation benefits, what is less known are the kinds of transformations in policies, institutions and funding, which are required to facilitate their adoption (Harvey *et al.*, 2014). Understanding the dynamics which underlie the diffusion of an innovation in this context, therefore, remains an important piece of the puzzle that determines which climate action initiatives can take hold and the processes by which they do so.

In this paper, the authors seek to provide some grounded analysis on how transformations in technology use and practice can occur and to show how it is possible to take advantage of the presence of substantial distortions in many policy and market arenas to leverage technology and craft policy bargains which facilitate Pareto superior reforms, i.e. reforms in which no party is worse off and at least one party is better off (Mornati, 2013). Merely identifying where such distortions exist, however, is insufficient to actually realizing such putative gains. Winners from policy changes do not automatically or often compensate the losers and, thus, reforms which are Pareto superior in theory are not so in practice. As a result, the key participants need to craft bargains for using the resources "wasted" through policy distortions to compensate those stakeholders who incur costs in making climate-positive changes in technology use and behavior. This requires an intensive political mobilization. What forms do these bargains take, who are the principal actors in these processes and what are the politics behind the crafting of these bargains are some of the questions which are key to unlocking the potential for more climate-positive initiatives.

The need for research that is aimed at overcoming policy stalemates and facilitating changes in technology and practice is important in India where distortions in irrigation-related policies and practices cause widespread water and electricity wastage. The largest direct contributor to agricultural emissions in India is livestock, but as approximately two-third of India's emissions come from energy production, and agriculture consumes about a quarter of this production, addressing wastage in this sector could reduce a substantial portion of food-system related emissions in India (USAID, 2014). Addressing this would not only help India reduce its carbon footprint, it would, at the same time, help Indian agriculture prepare for the water stress that climate change models predict.

The paper is organized as follows: in the following section, the research is contextualized to the current academic discussions over climate change inaction and the role possibilism in conceptualizing escape paths from low-level stalemates is presented. Section 3 presents the case and methodology of the paper. In Section 4, the causes of previous policy reform inaction are analyzed, while in Section 5, the authors show how the main actors were able to construct superior bargains for overcoming institutional stalemates over CSA. Section 6 concludes with some policy and practice-relevant discussions.

2. The politics of climate change management

2.1 The politics of inaction

The research on the politics of climate change adaptation and mitigation, especially in developing countries, is often pessimistic. While technologies which would reduce the carbon footprint of many economic activities do exist, these are usually viewed as expensive and a competitive drag (Helm *et al.*, 2012). The ability to free-ride on climate action by others is also tempting (Gollier and Tirole, 2015). Moreover, developing countries, who feel the industrialized nations owe a carbon debt (Martinez-Alier, 2002), do not want to sacrifice potential economic growth to address emissions and often view demands to do so as neocolonial (Agarwal and Narain, 1991). For these countries, climate change adaptation is a more pressing concern, though even these are spottily addressed and often waiting for donor funding (Betzold, 2015). Donors, on the other hand, even when they have the funds to contribute to adaptation measures, lack the political will or the administrative capacity to support massive and sustained action in this arena, and when they do, it is often with attached conditionalities which seek to impinge on basic governance processes in the receiving country (Molenaers *et al.*, 2015). This blunts their focus and effectiveness. For these reasons, even though it is becoming increasingly clear that avoiding climate action is a false economy, knowledge about climate change is not translating into sufficient action.

In the case of India, a large emitter though not in per capita terms, climate research shows the country is increasingly vulnerable to recurrent natural disasters, primarily droughts and floods (Brenkert and Malone, 2005). The human and financial costs of these disasters take a steady toll on the country's social and economic fabric. Conservative estimates of India's average annual losses from natural disasters are US$10bn (UNISDR, 2015) or about 0.5 per cent of its gross domestic product (GDP). Even though fewer lives are lost nowadays because of better disaster preparation protocols, the emotional and economic costs borne by the population, especially the poor, are huge. Between 2009 and 2014, the Government of India spent about US$7.5bn on disaster response and relief, which means only a small proportion of the actual losses of over US$50bn were covered. These conditions are not new – India has always been subject to droughts and floods – but the scientific consensus is that these events are becoming more intense and frequent because of climate change (Diffenbaugh *et al.*, 2017; Kumar *et al.*, 2006). Yet, the politics of climate change in India are dominated by an unwillingness to take substantial and immediate action to address even adaptation needs let alone to engage in climate change mitigation where the domestic politics – focused on development, resistant to pressures which can be perceived to impinge on national sovereignty and convinced of the ethical foundations of the common-but-differentiated responsibility (CBDR) principles for climate action – permit little scope for combating emissions at the expense of economic growth (Tankha and Rauken, 2015).

2.2 The politics of possibilism

While the macro-politics of climate change with its diversity of actors and interests and array of veto points have long been in focus, an interesting new literature on the regional

and local is emerging and highlighting how international and national action is often outshined by sub-national initiatives, for example, in cities, which are replacing or circumventing (in)action at higher levels of government (Jordan *et al.*, 2015; Betsill and Bulkeley, 2006; Barber, 2013). While much of this literature focuses on outcomes, equally important are the processes and politics by which these outcomes are obtained. Indeed, in its latest assessment, the Intergovernmental Panel on Climate Change (IPCC), recognizing that transformation in climate actions depends in substantial measure on both the available technologies and the social processes or politics which govern their deployment and adoption, has begun to emphasize the study of the processes of decision-making to address mitigation and adaptation, especially in its political dimensions (IPCC, 2014).

Other researchers have noted how politics plays a critical role in opening (or closing) spaces for action (Eriksen *et al.*, 2015), though much of the critical literature in this sphere as it relates to developing countries relies on tropes of elite control to explain dysfunction rather than progress. Less common are nuanced approaches to the study of power relations within society which focus on embedded politics, such as by Migdal (2001) and Evans (1995), to understand how superficially powerful elites, individuals as well as organizations and institutions, still have to game, negotiate and compromise with a multiplicity of subaltern actors to maintain their position. While these approaches are also often used to explain dysfunction in reform endeavors, they can be more useful in explaining the kinds of possibilism to which Hirschman (1971) once alluded. In geography, possibilism refers to the ability of human agency to surpass the limits set by the environment, while in politics, the term has a more conservative orientation and represents a belief in attempting only the realistically achievable. In development studies, Hirschman (1971) inverted the approach, arguing that possible avenues of escape from (the more-easily modeled) low-level equilibrium are unique, unexpected, possible rather than probable. In doing so, he argued for creative human agency to overcome deterministic pessimism and a reliance on fixed sequences.

Compromises, negotiations and shared understandings, thus, provide a critical window to observe how actors and interests at multiple levels can be reconciled to stitch together climate-positive alliances. In this vein of studying local, nuanced and negotiated political processes to understand how knowledge and innovation transpire into planning processes for adaptation and mitigation, which overcome veto points, the role of interstitial actors who mediate needs and resources among different groups in society is only infrequently addressed. In the academic literature, the interstitial actors which are investigated are usually the non-governmental and civil society organizations which mediate flows among governments, donors and communities, but their reach and effectiveness is by the nature of the organizations and their funding necessarily limited and rarely have they had transformational and large-scale impacts (Banks *et al.*, 2015; Bebbington and Farrington, 1993). Considerably less prominent is the literature on the political roles of the private corporate sector (Tienhaara, 2014), which is usually characterized or caricaturized as a veto point in the politics to address climate change rather than viewed as a contributor to climate-positive action. Here, the mainstream literature has theorized on how corporations wield power in their various dimensions – structural, instrumental and discursive – in the environmental arena (Fuchs, 2007), and complementary empirical research has illustrated how corporations generally force or reinforce the hard negotiation positions of governments through lobbying and by diffusing an economic impacts discourse (Newell and Paterson, 1998). How and which types of corporations may contribute positively to sustainability transitions is rarely addressed, and the few studies which have investigated the role of corporations in these processes have done so almost exclusively within the thematic

categories of corporate social responsibility and green marketing, the latter frequently criticized as merely greenwashing (Walker and Wan, 2012; Laufer, 2003).

The lack of positive corporate contributions to climate change mitigation and adaptation is a surprising gap in the research agenda. For example, if we look closely at the politics of climate change negotiations in India, which is known for adhering strictly to the CBDR principles in climate change mitigation negotiations, we find that their preoccupation with the development imperative also means that if engaging with climate change can create economic opportunity, the political and bureaucratic apparatus will have incentive to mobilize in favor of actions which directly or indirectly address mitigation. Indeed, one of the few commitments India has made has been to reducing the carbon intensity of its production, thereby seeking improvements in the production processes, but not limiting their growth options. In the course of this research, in fact, the authors came across senior administrators who spoke about making several trips to various European capitals in connection with climate change negotiations, always inquiring about the possibilities for accessing climate-friendly technologies (though these were invariably politely rebuffed on grounds of intellectual property and appropriateness)[1]. Yet, the assumption that investments in technology will enable societies to maintain and improve living standards while maintaining the viability of ecosystems is implicit in many parts of the commitments regime being negotiated. Such technological possibilism, which forms the basis of the United Nation's Sustainable Development Goals, such as Goal 12 on Sustainable Consumption and Production (Gasper *et al.*, 2019), requires not just appropriate policies from the state, but also and especially of the private corporate sector which now plays critical roles in technical innovation and its deployment into the market, particularly in terms of scalability (Arora *et al.*, 2004). Here, the gap in the literature is considerable, especially in its empirical dimensions, and a case-based approach such as the one presented in this paper has the potential to elucidate the practices embedded in policy spaces in a manner which can contribute to both theoretical development and strategy replication.

3. Case details and methodology

The research presented in this paper is framed around the case of sugarcane cultivation in the western Indian state of Maharashtra. This is one of the most important crops in India, generating US$16bn in annual sales and employing over 50 million farmers in its cultivation, not to mention millions of others in associated activities such as sugar refining and marketing (Solomon, 2011). Sugarcane cultivation is, therefore, very political.

Sugarcane is also a very thirsty crop – to irrigate 1 ha. of sugarcane requires around 20,000 l of water in Maharashtra (GoI, 2012; Shrivastava *et al.*, 2011). On the one hand, this leaves it vulnerable to climate change, as droughts of increasing frequency will take a toll on production. On the other hand, given the state of irrigation management in India, a considerable amount of water needed in the production of sugarcane and other crops comes from groundwater extracted by electric pumps, which results in a substantial amount of emissions. Improving the efficiency of irrigation systems, thus, can serve both mitigation and adaptation needs. This issue is also becoming urgent, as conflicts over the increasingly scarce water resources in the region are becoming ever more frequent. This is particularly relevant to sugarcane as it is reported that the crop is planted on only about 4 per cent of Maharashtra's land, but consumes over 70 per cent of its irrigation supplies (Mohan, 2015).

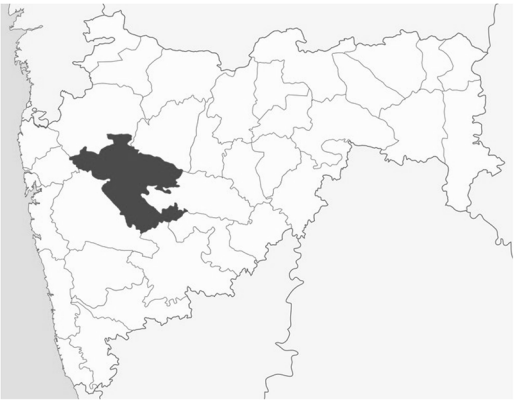
3.1 Location

Maharashtra has a population of 114 million spread over an area similar to that of Germany. Within Maharashtra, the authors studied sugarcane cultivation in Ahmednagar district

(see Figure 1). Located about 250 km east of Mumbai, this district is Maharashtra's largest as well as one of its poorest. It lies in the rain shadow of the Western Ghats, receiving an average monsoon rain of 497 mm (but, since 2014, rainfall has been less than 400 mm)[2]. Despite being a "thirsty crop," almost 80 per cent of Maharashtra's sugarcane is actually cultivated in drought-prone districts such as Ahmednagar, which means reliance on irrigation, particularly groundwater irrigation, is significant. Within Ahmednagar district, the authors based their study in two of its 14 talukas (a sub-district administrative unit), Rahuri and Shirampur (Table I). Both talukas fall in the water-scarce part of the district, receiving 478 and 470 mm of the annual rainfall, respectively (see Note 2).

3.2 Data collection

The research for this paper was based on three complementary approaches: institutional, sociological and technical. The institutional approach consisted of organizational research on electricity and irrigation management in India (for which the authors also leveraged their experience with previous empirical research in these arenas). This included an analysis of the key actors in the water-energy nexus in India to determine the distribution of interests and institutional capacities. As part of this analysis, dozens of semi-structured key informant interviews were conducted with:



Source: Own elaboration

Figure 1.
Case study area – Ahmednagar district, Maharashtra, India

No.	Features	Shrirampur	Rahuri
1	Area of taluka	1,307 ha	1,554 ha
2	Total population	5,883	9,089
3	Number of households	1,188	1,807
4	Literacy levels	78% male 59% female	74% male 56% female
5	Number of government canals	700 ha	787 ha
6	Land use of wells (with electricity)	597 ha	661 ha
7	Total irrigated area	1,297 ha	1,487 ha
8	Un-irrigated area	10 ha	7 ha

Source: Census of India (2011)

Table I.
Shrirampur and Rahuri

- public officials in electricity, irrigation, agriculture and general administration in Maharashtra;
- representatives of the cooperative sugar factories (which is the main organizational form of sugarcane production and processing in Maharashtra); and
- private sector agents who are engaged with irrigation systems manufacture and distribution.

The sociological approach consisted of field research among farmers and equipment suppliers. For this, the authors surveyed sugarcane farmers about irrigation practices and experiences with DI in the two talukas mentioned above. Prior to conducting this survey, the authors trialed it on a smaller scale in another district in the state. The technical research consisted of gathering and analyzing data on irrigation requirements and energy production and emissions to calculate the potential benefits from transitioning to more efficient irrigation techniques. These data were obtained from various national and state government agencies and cross-checked against estimates obtained from the survey of farmers in Ahmednagar. The authors combined these three research strands to analyze the roles played by different actors in generating climate co-benefits.

4. The politics of inaction in irrigation reform

The broad contours of the problem of irrigation and electricity management in India are well-known (Tankha *et al.*, 2010; Singh, 2006) and will only be briefly sketched here. At one end, canal irrigation infrastructure, which traps and distributes surface water, e.g. from rivers, is poorly constructed and badly maintained by the agricultural departments in most parts of the country. This has led farmers to rely on groundwater using electric pumps. At the other end, the state electricity companies have been running perennially colossal deficits and are unable to keep up with the growing demand for electricity because state governments have responded to the problems in surface irrigation infrastructure by providing massive energy subsidies for farmers in the form of cheap or even free electricity as well as subsidies to purchase pumps.

A third dimension to this problem is that groundwater irrigation has now become the primary source of irrigation in India, rather than being a safety net to be deployed when there is drought. It is estimated that 40 million ha are irrigated by borewells and 80 per cent of irrigation requirements are met through groundwater (Shrivastava *et al.*, 2011). This accounts for over 75 per cent of groundwater extraction, the rest being used by households and industry. With the progressive depletion of aquifers, watertables have collapsed and borewells now have to go down as far as 300 m, a depth at which aquifers can recharge only very slowly. In Maharashtra, as in much of the rest of India, most watersheds are now classified as over-exploited, and the problem is worse in the drought-prone districts[3].

At the same time agriculture soaks up US$1bn in electricity subsidies annually, 63 per cent of which is cross subsidized by industry. The debt incurred by the various state electricity companies is now around US$80bn or about 5 per cent of India's GDP, this in spite of multi-billion-dollar bailouts in 2001 and 2011 (Pargal and Banerjee, 2014). Perennially running huge financial deficits, which impede their ability to invest in infrastructure and proper maintenance, power companies also have high levels of transmission and distribution losses. This wasted generation leads to increased emissions intensity of production, a problem which is compounded by the fact that coal-burning thermal plants are the mainstay of Indian power generation. In addition, in dealing with power shortages, many consumers are forced to self-supply with generators, which is economically and environmentally even more inefficient.

In the case of Maharashtra, a quarter of the power supplied by its electricity distribution company (MSEDCL) goes to agriculture, but this generates only 12 per cent of the company's revenue. Even these figures do not state the true extent of the subsidies received by farmers because the state government provides MSEDCL US$0.03 per kWh of subsidy reimbursement. In fact, of the US$0.09 per kWh average cost of supply, farmers are billed only US$0.02 per kWh, but with the collection efficiency at only 37 per cent, MSEDCL collects less than one cent per kWh supplied to farmers[4].

Reforming these sectors has been difficult. It is not that the problem is not recognized or researched. The Government of India has itself constituted several committees (Vadnere, Mendigiri, Kulkarni, and Upage Commissions) to study the problem and issue recommendations (which have mostly not been implemented) and power sector reform in India is a perennial favorite of the World Bank. However, none of the scores of studies on irrigation and electricity management and reform in India have managed to chart a feasible reform trajectory because the reforms invariably proposed variations on themes of rational pricing of water and electricity (Ray, 2007).

The arguments for treating irrigation water or electricity as scarce economic resources to be priced accordingly are as intellectually attractive as they are politically and administratively infeasible. In spite of the trend toward increasing urbanization (often encouraged or facilitated by government), among all the large developing countries, India remains, by far, the most dependent on agriculture, which contributes 15 per cent to the country's GDP (World Bank, 2019). Comparably, in Brazil, agriculture contributes only 5 per cent to GDP, while in China, agriculture's contribution is 8 per cent (World Bank, 2019). India's population is also more rural, about 66 per cent, than the other two countries which have rural populations of 14 and 42 per cent, respectively (World Bank, 2015). The numbers of people involved in agriculture are thus a potent political force. Proposals for significantly higher water and electricity rates are viewed almost universally among the political class as an easy issue around which to mobilize opposition and agitation. In addition, many administrators believe that farmers have genuine claims on assistentialist programs. Several public sector officials the authors interviewed mentioned how overcoming food crises in the 1970s and the green revolution were built upon policies of rapid and subsidized infrastructure expansion, indicating a strong socialization of this narrative among the civil servants. One power sector veteran also mentioned that before flat-rates were introduced for agricultural power, electricity inspectors would often harass poor farmers, leading politicians to promise reprieves as a potent vote attractor[5]. Consequently, government departments are not energetic in collecting even the mostly symbolic and relatively nominal electricity and irrigation water charges, and currently, there are around US$200m of arrears in irrigation water tariff collection in Maharashtra[6].

A related complication which is almost never discussed in the context of agricultural reform is that the elimination of various supports and subsidies would lead to increasing and more volatile food prices which would have severe repercussions – economic as well as political – in urban India as well, especially among those who spend a substantial part of their income on food. Thus, to move to more market-rational agricultural and power sectors, the government would have to implement a series of complex and politically challenging reforms more or less simultaneously to dampen the propagation of negative resonance throughout the system. In a highly competitive political system such as India's, such several, contentious and simultaneous reforms are unlikely, because a separately organized and multi-participant political opposition would have to be tackled and overcome for each particular reform. These kinds of wicked problems – as such systemically complex situations are referred to – thus require a very different kind of policy approach than market

rationality. Not surprisingly then, one of the senior bureaucrats the authors spoke with commented that "agriculture is like religion, you can't touch it[7]".

As a result, though subsidized power to farmers costs the Indian state billions every year and additional billions are spent on the increasingly more frequent drought-relief programs, successive governments have not invested more attention and funds in water management institutions, organizations and infrastructures. Even if they were unable to increase spending, the government could have redistributed funds among different departments to improve overall efficiency and productivity, such as by shifting some funds from electricity departments to fund irrigation improvements which reduce demands for subsidized power. However, interviews with public officials at all levels revealed that there is little to no coordination among various government departments. The electricity, irrigation and agricultural departments simply do not speak to each other beyond the most routine field-level meetings, and there is no joint strategizing at higher levels[8]. To some extent this is surprising, given that:

- the political leadership exercises close control over administrative departments and, hence is able, if it so chooses, to overcome and over-rule organizational silos; and
- The senior leadership of all the departments comes from the same pool of IAS officers who in their careers constantly move across departments and so should not be beholden to narrow organizational interests[9].

Deterministic pessimism about the potential for reform is, thus, understandable in our case.

5. The politics of possibilism in drip irrigation

5.1 Drip irrigation: Great promise, slow progress

Motivations to adopt an innovation obviously depend on the quantum of benefits that it provides. Several technical studies have enumerated the potential benefits of DI. These can be classified under seven categories (Table II), but the main benefits are obviously water and energy savings. Given that there are approximately one million ha under sugarcane

No.	Benefits	Remarks
1.	Water use	Plot studies indicate sugarcane cultivation under DI uses 44 to 55 per cent less water than under flood irrigation
2.	Electricity use	Water-use efficiency translates directly into reduced electricity use in fields which are irrigated by groundwater pumping. Electricity savings can be between 25 and 50 per cent
3.	Fertilizer use	DI requires less fertilizer because flood irrigation washes away a substantial amount of the fertilizer that is applied to the crop
4.	Crop yield	In experimental plots, it has been found that a 23 per cent productivity increase can be obtained by DI in sugarcane cultivation in Maharashtra
5.	Drought resilience	As drip-irrigated sugarcane requires less water, the crop can be more effectively watered under drought conditions
6.	Soil maintenance	Flood irrigation results in increasing soil salinity, and this has been verified in several sugarcane cultivation areas of Maharashtra
7.	Labor use	DI requires less labor and, moreover, this can be planned in more convenient ways. For example, during field research, farmers indicated that flood irrigation sometimes has to be done at night when there is a heightened danger of animal attacks.

Table II.
Putative benefits of DI

Sources: Postel *et al.* (2001), Narayanamoorthy (2004), Surendran *et al.* (2016), World Bank (2006), own research

cultivation in Maharashtra, the potential energy savings translate into approximately one million metric tons of reduced emissions per crop cycle, while water savings potentially amount to 160 million m^3 for the current levels of production (Table III).

The figures recorded in the tables are indicative, as agricultural innovations are imperfectly fungible and not without associated collateral problems such as, in this case, groundwater depletion. Nevertheless, the experience with DI reported by our respondents is positive. Both talukas recorded increasing profitability deriving from a combination of higher yields and a reduction in labor and fertilizer costs. In the case of fertilizers, for example, farmers observed that US$300 is required for three acres under flood irrigation, whereas the corresponding expense is US$40 for fields under DI. They also reported savings in electricity use, though given that they use standard pumps and pay the standard subsidized electricity charge levied on all farmers, they often have not derived much financial benefit from switching to DI.

While the Indian Government began to promote DI in 1980s, beginning with the establishment of a National Committee on the Use of Plastics in Agriculture, and has steadily increased the budgets and the land brought under DI (the 2015 Union Budget allocated over US$1.5bn for micro-irrigation schemes), progress has been slow: despite delivering tangible benefits to farmers and receiving policy attention, DI is still practiced in only 1 per cent of the groundwater irrigated area.

Our field research pointed toward a combination of two inter-related factors which determine why DI uptake has been slow:

- what March and Olsen (2009) called the *logic of appropriateness* (decisions made on the basis of considerations of tradition rather than potential benefits); and
- the limited resources available to the state to introduce and promote DI.

Given the role education is supposed to play in the diffusion of innovations (Rogers, 1962) and the fact that younger farmers are more educated, the authors were initially surprised to find in their field surveys that younger farmers were less likely to have installed DI. It was only after further investigation that the authors were able to discover that in the case of the younger farmers, it was their fathers who still took the major decisions on farming matters and, in this case, prevented their sons from adopting DI systems. This observation was later confirmed by both administrators and the DI suppliers, who concurred on the role of intergenerational dynamics. "Although I have a PhD in agricultural science," explained one agricultural research scientist, "my father does not believe he needs to go against what has

No.	Energy requirements and emissions	Results
1	MW required to irrigate 1 ha of sugarcane under flood/furrow irrigation with groundwater (per crop cycle)	3,000-4,000 kWh per ha
2	MW required to irrigate 1 ha of sugarcane with micro/DI (per crop cycle)	1,700-3,000 kWh per ha
3	Energy savings per ha per crop cycle	Approximately 1 MWh of energy saved per ha per crop cycle by DI
4	Average emissions per MW coal-fired electricity plants in Western India	1,000 kg
5	Avoided emissions per crop cycle in Maharashtra	1,000kg CO_2 × 1,000,000 ha = 1 million metric tons

Sources: Narayanamoorthy (2004), Surendran *et al.* (2016), own calculations

Table III. Energy and emissions data of DI and flood irrigation systems

worked well so far, and so he won't allow us to install a DI system in our fields"[10]. In interviews with senior management of India's largest DI supplier, another important theme emerged – averseness to taking on debt. "If a farmer has debt," the authors were told, "no one would like to marry into that family." The existence of such strong social pressures helps explain the extent of farmer suicides when monsoons and crops fail. Both these observations indicate that what farmers consider appropriate may not be based on straightforward calculations of costs and benefits.

Upgrading farming systems with technologies which require capital infusion, therefore, face considerable hurdles. To overcome traditionalist hesitancy, a new logic of what is appropriate must be developed, and this requires intensive work with farmers to convince them to make the switch. The manpower resources required are concomitantly high. Moreover, in precarious socio-economic environments, where targeted means-based support and emergency programs are inexistent, market-based solutions such as credit extension are more problematic for the vulnerable, for they may end up being more exposed to the effects of crop failure.

Meanwhile, the role of the state in diffusing innovations can be divided into two major spheres (Moon and Bretschneider, 1997). First, the state can provide the information which potential adopters need to make informed decisions, thus reducing information asymmetries. Second, the state can influence the economics of the decision-making process by offering subsidies for the adoption of technologies (or penalize undesirable practices through regulation or charges), in a sense internalizing the positive socioeconomic externalities generated by the innovation and sustaining the innovation until it is able to make for itself a compelling economic case for rapid and widespread diffusion. In both of these tasks, the authors found problematic tendencies, though also partial successes in the case of DI diffusion.

When the authors began their research, they were expecting to analyze a rather traditional and straightforward institutional environment in which the main actors were the elected politicians, bureaucrats, agricultural extension officers (AOs) and farmers. Instead, the authors found that the role of DI equipment manufacturers was much broader and more critical than that of being mere product suppliers. The authors were expecting to find that AOs were playing the central role in demonstrating and proselytizing DI to sugarcane farmers. However, farmers indicated to them that they had minimal contact with the AOs. At most, the AOs dropped by once a month on a perfunctory visit. Unless there is a government scheme, the farmers informed us, the AO has no business to conduct, and because government schemes are mostly for dryland agriculture, AOs do not interact much with sugarcane cultivators. Even the cooperative sugar factories, around which sugarcane cultivation is organized in Maharashtra, were doing little to promote DI in spite of the fact that DI was a stated government priority[11]. Notably, not one of the farmers the authors interviewed indicated any influence of government officials in promoting DI. Indeed, one informant reported that the Gram Panchayat (elected village-level governing council) in Rahuri had recently organized a micro-irrigation program in collaboration with the agriculture department, but the farmers did not find the presentations credible or persuasive. Instead, the farmers reported that the main credible activities of demonstrating DI are being done by the suppliers of these systems. The largest DI supplier, in fact, has a small army of agricultural graduates penetrating into each village to demonstrate the benefits of micro-irritation systems[12]. As this supplier has grown over the past 25 years, it now employs close to as many agricultural graduates as the government itself. Interviews with these graduates revealed that quite a few of them had indeed left government to work for the supplier, and those that had done so reported that they were able to reach more

farmers and provide more concrete help through the company than in their previous employment with the government.

Thus, in terms of the first responsibility – reducing information asymmetries – diffusion activities, although originally developed by the government, are now being expanded more by the DI suppliers. In a sense, this could even be seen as a successful incubation by the state[13] wherein an initial phase of incentives has led to a sustainable commercially viable activity run autonomously of the state, though this may have been more the result of neglect than a purposive strategy.

With regard to subsidies, the other major component of state intervention in the promotion of DI, the authors found descriptions and responses of farmers' experience to be fairly consistent. The average time reported for receiving the subsidy was 1.5 years, and the average amount received was 40 per cent to 50 per cent of total costs, though, in Shrirampur, some farmers reported that in the early years of DI it could take more than five years to get the subsidy. In the case of subsidies too, the DI supplier, realizing that sales would suffer because farmers were unsure about how long it would take to get the subsidies, assumed a central role as it would provide the system at the subsidized price, apply for the subsidy on behalf of the farmers and receive the money directly from the government, in effect extending free credit to the farmers. On the one hand, it could be argued that concerns about falsification in the submission of bills and other forms of corruption force the government to take a cautious approach to approving subsidy applications, which is compounded by the shortage of personnel to process the applications. On the other hand, it could also be argued that those responsible for approving payments purposely delay approvals to obtain rents. The CEO of the largest DI supplier in India says his firm is increasingly shifting strategies to market the systems on the basis that just the increased production of crop from DI will be enough to pay for the system in about three years, and to facilitate this, it has set up an agricultural non-banking finance company with anchor financing from the International Finance Corporation to provide loans for the purchase of the systems. Nevertheless, weaning the system away from subsidies is difficult. Field-level sales agents interviewed still emphasized the importance of the subsidies in clinching sales, and the farmers themselves noted that they would find it hard to switch irrigation systems without subsidies.

5.2 The Pareto superior bargain

The low-level equilibrium trap in the irrigation water-electricity nexus in India is easily modeled here (Kimmich, 2016), but to understand how these equilibria are overcome, we must look closely at how actors maneuver around limiting conditions. Within this environment of coordination failure, the Maharashtra Government recently announced plans to promote the use of solar-powered agricultural pumps[14]. According to this program, in its first phase, the state government aims to distribute 500,000 solar pumps to farmers. By leveraging financing available from the Ministry of New and Renewable Energy, the program aims to subsidize more than 80 per cent of the cost of the pumps. These solar pumps are designated as replacements for conventional electric powered pumps, which should in effect reduce electricity demands on the state power grid (thereby freeing up power availability for other consumers) as well as reduce the financial burden on state electricity companies by taking subsidized farmers off-grid. Such a program could encourage even more intense groundwater extraction, but the pumps come with associated DI systems which would increase water use efficiency. While the program is expensive – at the rate of US$6,000 per pump, the program would cost US$3bn – it should be viewed in the context of the fact that the Maharashtra Government already spends about US$1.7bn annually on power subsidies.

The key feature of this initiative is that for the principal stakeholders the program is substantially Pareto superior. Farmers are not threatened by losing access to cheap power, power subsidies can be reduced over the long term, helping the ongoing reform efforts in the electricity sector, and much of the cost to the exchequer will be balanced by savings in subsidies. The associated environmental benefits derive from both reduced emissions as solar power replaces coal-based generation and micro-irrigation increases water-use efficiency. Meanwhile, other growing sectors of the economy will be able to receive more reliable, cheaper and less carbon-intensive electricity.

5.3 Crafting the bargain

As Tables II and III show, DI by itself would have created similar Pareto superior benefits, but the market uptake for DI sets has been slow because of low levels of finance and prioritization. Coupling micro-irrigation with solar pumps enlarged the potential support coalition and also accessed new channels of finance by enlarging the solution space to incorporate not just the economically struggling agriculture sector, but also the more powerful industrial interests around energy.

It may appear that the appearance of significant and urgent needs had finally convinced the government to overcome previous barriers to coordination and devise a coordinated response across sectors, but during the course of field investigations, the authors discovered that the plan for introducing solar pumps had been devised by the same firm which produces micro-irrigation systems and, then, intensively marketed to the state government[15].

What explains why such a program was devised by a private sector corporate actor rather than the administration itself? The organization theory on innovation activities provides some clues on where to look. It has long been theorized that capacity constraints in organizations limit their innovativeness, and that slack resources are necessary for organizations to make investments in innovation (Bourgeois, 1981). Even though resource-constrained organizations may be even more in need of innovation to overcome their limitations, too little slack discourages experimentation, which by definition begins with uncertain possibilities of success (Nohria and Gulati, 1997) and is, therefore, considered an unaffordable luxury. Moreover, tightly wound organizations experience higher levels of internal conflict, which is also unfavorable to innovation (March and Olsen, 1983).

These hypotheses fit in well with our case findings. The Indian state, in contrast to its commonly conceptualized image as a bloated one, is in reality over-extended. After decades of employment freezes, the staffing levels with respect to the population that needs to be served are quite low and falling[16]. This was alluded to by several informants throughout the government who said that there has been a *de facto* hiring freeze in many departments, and that agricultural departments especially are being increasingly de-emphasized[17]. Moreover, with weak agency controls and high levels of both public choice and rent-seeking, the fact is that even if staffing levels had been nominally adequate many personnel do not exert themselves. This means that the ones who do are even more over-extended. Because organizational budgets and other resources are severely constrained in comparison to the task environment which they face, administrative departments do not proactively engage in cooperative behavior or coordinated strategies. Indeed, they are more likely to engage in turf and budget-protective behavior and, more importantly, to demonstrate reluctance in taking on new responsibilities[18]. Rather than institutional rules and culture, therefore, it is the limited capacities of the state in combination with the large amounts of claims it must process which create the conditions wherein the state is no longer the *locus* for policy innovation.

With governments constrained in their strategic planning, spaces become available for other actors to offer solutions, though how these spaces are opened and constructed is difficult to model. The concept of possiblism, focusing on how solutions are innovated and stitched together, is useful in analyzing such situations. As noted previously, in our case, the equipment supplier emerged as a key supplementary actor to state structures for DI in terms of both technical outreach and subsidy delivery. In the case of the solar pumps, the supplier again replicated these functions and, in addition, extended the solution space to involve other government agencies and interests to attract new resource flows, including the attention of administrators and policymakers, the last actually being an important and scarce resource. Acting at the boundaries between different segments of government and citizens (farmers) and between different administrative organizations (irrigation, agriculture and electricity), the equipment supplier became an interstitial node which is supplying the connective tissue at programmatic and project levels to bring together different interests that are represented in the broadly defined categories of state and society. This interstitial role consisted of more than merely facilitating a pass-through of resources. While the DI supplier began several decades ago as an equipment supplier responding to modest government-induced demand, it has since progressively added to its original function as it has grown commercially. It has assumed the major responsibility for demonstrating the equipment, which incorporates not just a marketing function but also an educational or knowledge dissemination one. Further, it assumed an administrative function when it began to simplify and centralize the subsidy distribution process. Finally, the supplier has now also assumed a policy innovation function by managing local-level claims and privileges in the process of providing a packaged solution, thereby combining the functions of policy as well as commercial entrepreneurship.

An enabling condition can be recognized in the embeddedness of the DI supplier in local networks which allows it to pick up on quiet signals and work incrementally in developing a series of sequential solutions which are optimized to the prevailing demands and resource distributions of the principal stakeholders. As a long-term actor in the agricultural sector, the DI supplier has access to the research regarding both DI and solar-power agricultural pumps, intimate knowledge of farmers' attitudes and needs and resources they have available and ongoing contact with government personnel at all levels. The idea of using solar-powered agricultural pumps combined with DI systems did not originate with the DI supplier. Several studies investigating the technical and economic feasibilities of such systems have been conducted all over the world, including in South Asia and India (KPMG, 2014; Hossain *et al.*, 2015; Shouman *et al.*, 2016). This enables it to perform a bridging function that builds on accurately perceiving needs and resources to package a bundle of solutions. Its key contribution as an interstitial actor here is not the execution of a demonstration project to establish the viability of a technological approach (through a demonstration project, properly controlled or otherwise), but instead it is the execution of the more difficult task of deploying an innovation at a large and sustained scale. In highlighting this embeddedness, the authors note that this case also inverts the logic generally followed in what Boehmer–Christiansen (2002) noted as the intellectual efforts of the World Bank and Global Environment Facility to facilitate investments in sustainable development based on the "search for markets by Northern money and expertise." This might also explain why, for example, donor-based initiatives to introduce new technologies to less industrialized developing countries may never move beyond the confines of the projects which finance them.

6. Discussion and conclusions

Framing policy initiatives using the concept of possibilism, this paper contributes to the ongoing development of this literature by demonstrating how reforms can be packaged in

Pareto superior formats to overcome policy stalemates and generate technology-based climate and environmental co-benefits in even unpromising terrain characterized by large technologically laggard and economically constrained populations. In our case, it facilitates CSA practices which have large payoffs in both adaptation and mitigation.

The authors have also identified certain enabling conditions: the first, of course, was the technology itself which had gone beyond the proof-of-concept. Here, the state played a critical role in the early stages of technology introduction to the country in the absence of which a DI industry would probably not have emerged to the extent that it has. The second was an enlargement of the solution space to interests and funds in associated sectors which helped overcome lethargy in the principal arena of action. The third was the opening up of the policy innovation space to the actors beyond the state. To some extent, this depended on the presence of an established and embedded local entity, which in turn depended on the existence of a potential and long-term market for the innovation, the latter, in fact, having been created by the state. Thus, one of the main and stable roles of the state has been to provide open-ended market assurances to convince the relevant actors to make the necessary investments in production capabilities and facilities. Meanwhile, the role of the private actors evolved to include the labor-intensive functions of awareness raising and demonstration, a role in which it has displaced the state. In addition, the private actors have also evolved to assume the policy development role from the state and to facilitate the creation of multi-stakeholder platforms for innovation diffusion.

In addition, the authors have shown the preference policymakers have for voluntary policy instruments over coercive reforms and how the private sector has responded to this challenge. The case of DI is not unique in terms of realizing potential Pareto optimal bargains. Take, for example, the case of the smog which now regularly paralyzes New Delhi in November. Here, the *New York Times* reported that the smog is caused to a large extent by farmers burning rice fields in the neighboring states, and that in this case too, a technological solution is was available – a seeder which can plant wheat without needing to dispose the straw left over after the rice harvest – but farmers said they could not afford it (Anand, 2016). Here too, it turns out that the government is offering a 50 per cent subsidy, but the availability of funds and uptake remain low.

In investigating this case, the authors also find an interesting example of the emergence of more complex networks of polycentric governance linking private sector and governments in which the former plays a more clearly defined interstitial role in mediating claims and solutions between citizens and the state, developing policy solutions for the state and even executing the program[19]. While some scholars have investigated the role of corporations in addressing environmental problems (Levy and Newell, 2005), they have focused mostly on the global scale. This paper has extended the research to more micro-level interventions, though of course, astute readers would have noticed that the motivations of the various actors in our case did not stem primarily from environmental concerns. Very often, climate and environmental action will emerge from or be based on initiatives that are not at all climate-centric in their intent and, indeed, given that climate change is not often high on the agenda of the political and administrative structures of developing countries, a "climate first" approach to tacking climate change may be self-limiting because of the political noise it generates. Yet, this paper shows how economic and environmental and climate co-benefits may still be realized through the exercise of judicious self-interest and by broadening the potential problem and solution spaces to bring in to bear extra resources and coalitional interests.

Notes

1. Interview with former delegate of India's climate change negotiating team, currently Divisional Commissioner in Maharashtra (November 2015) and with former member (from the Indian Administrative Service – IAS) of committee which drafted India's National Action Plan on Climate Change (October 2014).
2. http://ahmednagar.gov.in/html_docs/rainfall_information_of_district.htm, (accessed 1 November 2016).
3. Interviews with former Additional Commissioner, Maharashtra Groundwater Surveys and Development Agency (November 2015), and Chief Engineer, Vidarbha Irrigation Development Program (December 2015).
4. This information was provided by Maharashtra Electricity Regulatory Commission via personal communication.
5. Interview with former Chairman, Central Electricity Regulatory Commission, November 2015.
6. Comptroller and Auditor General of India report, 2014. www.saiindia.gov.in/sites/default/files/audit_report_files/Maharashtra_Report_3_2014_chap_6.pdf, (accessed 1 October 2016).
7. Interview with Secretary Irrigation, Maharashtra Water Resources Department, November 2015. Similar ideas were communicated in interviews with the Divisional Joint Director (Agriculture), Additional Chief Secretary (Agriculture) and Commissioner, (Agriculture), Government of Maharashtra (December 2015).
8. Interview with Senior Engineer, Maharashtra Water Resources Department, Commissioner (Agriculture), and Additional Chief Secretary (Agriculture), Government of Maharashtra (December 2015).
9. All the IAS officers the authors interviewed confirmed that they invariably represent the interests and viewpoints of the organizations to which they are posted, and that these change as often as their postings. Given that their average tenure in any given department never exceeds three years, it is not that they develop an affinity for any given departmental viewpoint. Although they recognize the need for and lack of coordination, they were unable to articulate why they did not do so. While exploring this theme is beyond the scope of this research, the authors flag it as an important and interesting item for future research.
10. Interview with agricultural scientist, Jain Irrigation, December 2015.
11. From interviews at a sugar cooperative factory in Baramati district, and with the Director General of the Vasantdada Sugar Institute (the government's premier sugar research institute), Pune, India.
12. In our research, the authors had interactions with the largest DI supplier in India, Jain Irrigation, which has over 10,000 employees and an annual turnover of around US$1bn. The next largest DI supplier in India, Netafim, has a little less than half that many employees and annual revenues of around US$100m.
13. Indeed, DI in India probably would have been much more marginal had it not been for central government support to import the technology from Israel in the 1980s.
14. www.livemint.com/Industry/DUaYl2Icsqjgqp0PWGkBGL/Maharashtra-to-invite-tenders-to-supply-solar-pumps-to-farme.html. Accessed January 14, 2015.
15. While the authors were shown several of the technical reports and documents submitted by the supplier to the state government, they were asked not to cite the documents and maintain to some confidentiality about the contents.
16. Based on Reserve Bank of India statistics. See www.rbi.org.in/scripts/PublicationsView.aspx?id=15804. Accessed 15 November, 2016.

17. Interviews with Additional Chief Secretary (Agriculture), Government of Maharashtra (November 2015).
18. Similar ideas were stated in three Interviews with different senior administrative officials, from the Maharashtra Water Resources Department, Department of Agriculture and Divisional Commissioner, Nagpur, 2014-2015.
19. This experience is not unique, but part of an emerging trend. For example, the second largest DI supplier in India also has a multi-million-dollar contract with a neighboring state to expand irrigation networks. www.bloomberg.com/news/articles/2014-01-23/netafim-to-build-largest-india-s-drip-irrigation-project, Accessed 1 November 2016.

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Received 14 September 2018
Revised 28 February 2019
29 May 2019
Accepted 25 June 2019

Learning adaptation to climate change from past climate extremes:

Evidence from recent climate extremes in Haryana, India

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Abstract

Purpose – Conservation agriculture-based wheat production system (CAW) can serve as an *ex ante* measure to minimize loss due to climate risks, especially the extreme rainfall during the wheat production season in India. This study aims to examine whether farmers learn from their past experiences of exposure to climate extremes and use the knowledge to better adapt to future climate extremes.

Design/methodology/approach – The authors used data collected from 184 farmers from Haryana over three consecutive wheat seasons from 2013-2014 to 2015-2016 and multivariate logit model to analyse the driver of the adoption of CAW as an *ex ante* climate risk mitigating strategies based on their learning and censored Tobit model to analyse the intensity of adoption of CAW as an *ex ante* climate risk mitigation strategy. Farmer's knowledge and key barriers to the adoption of CAW were determined through focus group discussions.

Findings – The analysis shows that the majority of farmers who had applied CAW in the year 2014-2015 (a year with untimely excess rainfall during the wheat season) have continued to practice CAW and have increased the proportion of land area allocated to it. Many farmers shifted from CTW to CAW in 2015-2016.

International Journal of Climate Change Strategies and Management
Vol. 12 No. 1, 2020
pp. 128-146
Emerald Publishing Limited
1756-8692
DOI 10.1108/IJCCSM-09-2018-0065

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Practical implications – While farmers now consider CAW as an *ex ante* measure to climate risks, a technology knowledge gap exists, which limits its adoption. Therefore, designing appropriate methods to communicate scientific evidence is crucial.

Originality/value – This paper uses three years panel data from 184 farm households in Haryana, India, together with focus groups discussions with farmers and interviews with key informants to assess if farmers learn adaptation to climate change from past climate extremes.

Keywords Climate change adaptation, Conservation agriculture, *Ex* ante risk coping strategy, Learning from past climate extremes, Turbo happy seeder

Paper type Research paper

1. Introduction

Wheat (*Triticum aestivum* L.) is the most important cereal crop in India and is grown in about 29 million ha (Majumdar *et al.*, 2013). It is a staple food, supplying about 61 per cent of India's protein requirement (Sapkota *et al.*, 2014) and its assured supply is essential for national food and nutrition security. Analysis of trends in wheat production shows that yields have stagnated, as the beginning of the twenty-first-century with various possible causes including climate change and climate variability (Saharawat *et al.*, 2010; Majumdar *et al.*, 2013; Jat *et al.*, 2016). Therefore, to cope with increasing climate risk, wheat production systems need to be more robust and resilient to buffer the effects of extreme climate events (Jat *et al.*, 2014; Sapkota *et al.*, 2015; Jat *et al.*, 2016; Aryal *et al.*, 2018a; Sapkota *et al.*, 2018; Aryal *et al.*, 2019).

Conservation agriculture-based wheat production system (CAW), based on the principle of minimum soil disturbance, continuous ground cover and appropriate crop rotation, provides an alternative to the conventional system to enhance the resilience of agriculture to climate variability through better adaptation to climate change (Aryal *et al.*, 2016), reduce GHG emissions (Aryal *et al.*, 2015; Sapkota *et al.*, 2015; Kakraliya *et al.*, 2018) and reduced air pollution through the elimination of residue burning (NAAS, 2017; Tallis *et al.*, 2017). A recent study (Aryal *et al.*, 2016) in Haryana, India showed that CAW better copes with climatic extremes than the conventional tillage-based wheat production system (CTW). The study found that wheat yield during the bad year (defined in terms of untimely excess rainfall during grain development) was 4.89 Mg ha^{-1} under CAW while it was only 4.23 Mg ha^{-1} under CTW.

As the knowledge gained from past experience to extreme climate events are critical to design and implement climate risk adaptation plans (Parry *et al.*, 2007; Wise *et al.*, 2014), one crucial question is whether farmers in Haryana adapted their wheat production system and adopted CAW based on their experience of climate extreme events during 2015 wheat season. This is because learnings derived from their own experience (i.e. learning by doing) and from neighboring farmers (i.e. noticing/communicating/social networks) is one of the important determinants of technology adoption (Cameron, 1999; Bandiera and Rasul, 2006; Crane-Droesch, 2018). Empirical research confirms that farm households learn from the choices made by other farmers and do the same (Besley and Case, 1994; Foster and Rosenzweig, 1995; Munshi, 2004). Therefore, it is important to understand whether farmers who experienced that CAW performed better under climate extremes during the 2015 wheat season, learned from their experience and increased the land area dedicated to CAW the following year. Although a technically viable *ex ante* climate risks reduction and coping strategy in agriculture, the use of CAW instead of CTW by farmers for this purpose is unknown. Understanding whether farmers gradually learn from past climate extreme events and adopt *ex ante* risk reduction measures provides with vital insights into farmer behaviour in relation to climate change adaptation.

Another important issue is that unlike other new technologies, CAW has economic benefits and a shorter gestation period (i.e. the time gap between initial investment and return). This is because the machinery needed for CAW [i.e. Turbo happy seeder (THS)] is readily available on rent and does not require large up-front investment.

Against this background, using three years panel data from 184 farm households in Haryana, India, together with focus groups discussions with farmers and interviews with key informants, this study seeks to address the following questions:

- Do farmers learn from past experience (for farmers who continued CAW adoption over a period of three years) and from their neighbors (for those who were non-adopters until 2014-2015 wheat season and adopted in 2015-2016 after observing that their neighbors benefited by CAW in both bad and normal year)?
- If not, why are farmers cautious about expanding the area under CAW even though it copes better with untimely excess rainfall and has a higher economic benefit compared to CTW? and
- What are the potential implications for future design of climate change adaptation in agriculture? This paper presents an empirical analysis of climate-adaptive decision-making by farm households using real-world situations.

2. Extreme climate events in wheat season, loss of crop yield and public burden

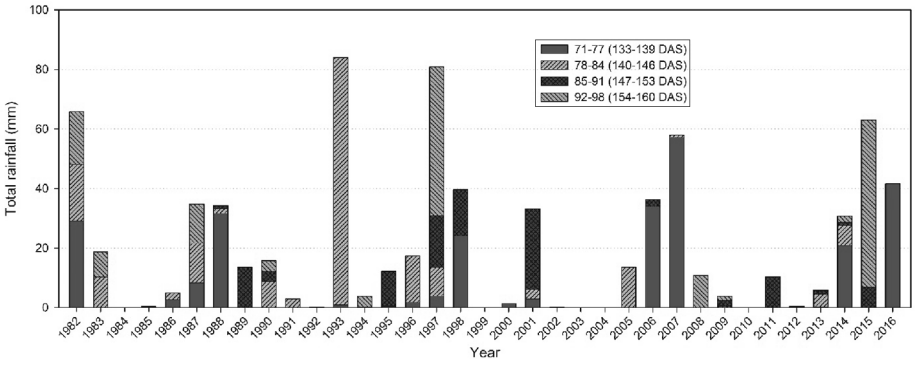
Climatic variability, especially rainfall variability (i.e. both drought and excess rainfall) and end-of-season high temperatures severely impact wheat production in India. Many studies have demonstrated negative effects of high temperature during wheat maturity period, i.e. "terminal heat" in India (Jat *et al.*, 2009; Lobell *et al.*, 2012; Tashiro and Wardlaw, 1989; Samra and Singh, 2004; Gupta *et al.*, 2010).

Early planting can help wheat escape terminal heat but increases the probability of loss due to high rainfall during the harvesting stage. Winter rains are largely unpredictable and rainfall immediately after irrigation is the most detrimental as it results in prolonged waterlogging leading to a yellowing of leaves and stunted growth of wheat. Waterlogging during the grain-filling stage also causes blackening of the wheat ear-head and loss of grain fill (Aryal *et al.*, 2016). Even if grain filling occurs, it will lead to substantial yield loss due to shriveled and light-weighted grains. Rainfall during maturity can increase the moisture content of the grains, making them unsuitable to sell directly from the field. Analysis of long-term rainfall data (1982-2016) from the study sites reveals that critical stage of wheat maturity received intensive rainfall in 10 out of 34 years (Figure 1).

Conservation agriculture (CA) has been advocated as one of the solutions to address higher temperature stress in wheat production by advancing wheat planting dates, by conserving soil moisture through reduced run-off and evaporative losses and by changing the thermal properties of the soil surface (Sapkota *et al.*, 2015). CA not only conserves moisture during drought conditions but also enhances infiltration and percolation of water in the event of excess rainfall. Retention of residue in CA also controls soil erosion, which otherwise would occur in the event of an intense downpour.

3. Study area and data

In this study, authors used the panel data collected from 184 wheat farmers of Karnal district, Haryana for three consecutive wheat seasons of 2013-2014, 2014-2015 and 2015-



Notes: Within the wheat maturity period (on average, 133-160 days after sowing, i.e., 71-98 Julian days), each stack shows the intensity of rainfall within a week. Rainfall of more than 20 mm in a week during this period is considered undesirable (bad) in terms of excess rainfall

Figure 1. Distribution of weekly rainfall during the wheat maturity period from 1982-2016 in the study area

2016. Data were collected from 10 village clusters (scattered over 15 villages) of Karnal district.

In the survey of 2014-2015, a total of 208 (50 per cent each from CAW adopter and no-adopter) farmers were surveyed. Same farmers were also surveyed in the 2015-2016 season. However, as 24 farmers had changed location, the sample size for the current study was reduced from 208 to 184. The data encompasses the information on major household characteristics, market and location characteristics, areas under CAW and CTW, production inputs, crop management, and grain yield under these two alternative wheat production systems. Authors have data for three consecutive years.

Haryana is selected as the study area for the following reasons. Firstly, it suffered from untimely excess rainfall in the year 2014-2015 during the wheat production season, which damaged the wheat crop over 0.5 million ha in the state (Government of Haryana, 2015). As a compensation to the farmers suffering from crop loss, Haryana Government spent about Rs. 11bn[1] (i.e. US$174.72mn) in 2015 (Government of Haryana, 2015). Therefore, any alternative wheat production system that reduces the wheat crop damage due to such climatic risks can significantly reduce the farmers' loss and also the economic burden of the government. Secondly, in Haryana, many farmers follow CAW and in the focus group discussion (FGD) in 2014-2015 (Aryal *et al.*, 2016), farmers reported that CAW suffered less from untimely excess rainfall as compared with CTW. Thirdly and most importantly, a study in Haryana by Aryal *et al.* (2016) compared wheat yield in both bad and good years and concluded that CAW performed better than CTW in both years. Therefore, it is important to understand if this knowledge was well communicated among the farmers and if farmers considered CAW as an *ex ante* adaptation measure to extreme rainfall during the wheat production season in Haryana.

4. Analytical framework and estimation issues

This study uses both quantitative and qualitative methods for the analyses of the data and in-depth understanding of CAW adoption from learning. Using mixed methods – econometrics methods to rigorously analyse the CAW learning data and FGD to probe deeper to understand farmers' views and experience about CAW managed to bring forth issues, which otherwise

would be overlooked. The main focus was whether farmers learn from past experiences, and also from their social networks (Bandiera and Rasul, 2006; Hanna *et al.*, 2014; Crane-Droesch, 2018) and the importance of learning in the adoption process (Cameron, 1999).

4.1 Quantitative methods

This study applies two robust econometric methods for quantitative analysis. It used a multinomial logit model to analyse the farmers' adoption of CAW as an *ex ante* climate risk mitigating strategies based on their learning and a censored Tobit model to analyse the driver of the intensity of adoption of CAW as an *ex ante* climate risk mitigation strategy. (For details on multinomial logit and censored Tobit models, see Greene, 2003 and Wooldridge, 2010).

4.2 Qualitative methods

This study uses micro-interlocutor analysis (MIA) for analysing information obtained from FGD organized in Shambli village of Karnal district (Haryana). In MIA, information from the FGD is analysed by delineating participants who respond to each question, the order of responses and the nature of responses (e.g. focussed and unfocussed) and also the nonverbal communication used by each of the FGD participants (Sovacool *et al.*, 2017; Onwuegbuzie *et al.*, 2009). Using this method, the current study better conceptualizes the role of conversation analysis in analysing data collected from FGD.

The FGD concentrated on the two types of questions, i.e. general questions related to farmers knowledge and perception on climate change in agriculture, and more focussed questions on CAW and its adoption as an *ex ante* risk coping measure. The general questions on farmers' knowledge and perception are as follows:

- Is climate change a major problem in agriculture?
- Do you believe that some agricultural interventions can reduce the impacts of climate change on agriculture?

The questions on CAW and its adoption as an *ex ante* climate risk coping measure are:

- Do farmers know that some practices help adapt to climate extremes, and thus, can be used as an *ex ante* climate risk coping strategies?
- Does CAW better cope with extreme rainfall during the wheat harvesting period?
- Is CAW cost-effective and more productive compared to CTW?
- Have you used CAW? What are the major reasons for adoption or non-adoption of CAW?

Through FGD targeted at CAW, authors managed to gather extremely useful information from the participants, which are usually missed by pure quantitative methods.

5. Results and analysis

5.1 Descriptive statistics

5.1.1 Description of the variable used in the study. Table I presents the summary statistics of the variables used in the study. The average age of household heads is 41 years for both adopters and non-adopters of CAW, which indicates that most of the farmers were middle years of age. Result also shows that a large majority of the household (approximately 95 per cent) were literate and further segregation of the education level of the household head shows that 44 per cent of the household head had completed higher secondary level of education (i.e. Grade 12) and 25 per cent had completed secondary level (Grade 10), and 28

Variables	Mean	SD	Minimum	Maximum
Household characteristics				
Age of HH head (in yr.)	41.15	10.41	18	68
Young farmer dummy (i.e., HH head < 35 years)	28.37	45.18	0	1
Human capital				
Literate HH head				
Education of HH head	94.62	36.17	0	1
Primary education (base category: illiterate)	27.72	–	–	–
Secondary education (base category: illiterate)	24.46	–	–	–
Higher secondary and above (base category: illiterate)	43.48	–	–	–
Farm assets				
Land owned (ha)[a]	6.56	7.33	0.8	48
Own tractor	76.28	38.47	0	1
Own ZT drill machine	14.45	35.25	0	1
Social capital and training	–	–	–	–
Membership in cooperatives/institutions (Yes = 1)	36.45	47.24	0	1
Training (CA/soil and water management) (Yes = 1)	15.71	39.15	0	1
Constraints				
Use of weather information (Yes = 1)	52.43	50.07	0	1
Lack credit for agriculture (Yes = 1)	13.94	34.71	0	1
Lack of knowledge on CAW (Yes = 1)	65.49	41.32	0	1
Lack THS machine (Yes = 1)	72.11	44.59	0	1
Perception to climate change	–	–	–	–
Perceive CAW copes with climate extreme (Yes = 1)	59.12	41.54	0	1
Accessibility				
Distance to market (in Km)	4.86	3.29	1	18
Distance to extension service centre (in Km)	6.68	2.93	1	20
Distance to agricultural cooperatives (in Km)	2.06	1.49	0	10
Distance to nearest ZT service providers (in Km)	4.38	4.33	0	22
Number of Sample households (by village)				
Anjanthali/Balu	28	–	–	–
Badarpur/Dabkolikala	24	–	–	–
Bastada/Kutail	14	–	–	–
Chorpura	20	–	–	–
Daha/Uncha Saman	18	–	–	–
Gangar	20	–	–	–
Padhana/Sandhir	24	–	–	–
Pujam	20	–	–	–
Shambli	20	–	–	–
Taraori	20	–	–	–

Notes: [a]Values in the table refer to percentages unless stated; and of the total sample households, only 21 households have more than 10 ha of land. If we omit those households, the average land ownership is 3.83 ha with a standard deviation of 2.66 ha. Only seven households have more than 20 ha of land; THS = Turbo Happy Seeder

Table I.
Summary statistics of variables used in the analyses

per cent had completed primary level of schooling. The education level of the household head plays a critical role in the adoption of technology as it increases the level of awareness and has implication of adopting agricultural technology.

The average land holding size of the sampled households was 6.56 ha; the adopter farm household had 6.6 ha compared to only 4.8 ha for non-adopters of CAW. The majority of the

sample households owned tractors (approximately 76 per cent), which indicates that a significant proportion of the sampled households have pursued some form of farm mechanization. In the study area, about 14 per cent of the farm households owned zero-till (ZT) drill machine. Among CAW adopters, only five have their own THS, capable of seeding over previous crop residues. Therefore, most of the farmer rent machines required for CAW. Membership in cooperatives is essential for knowledge sharing and also for working together with a common interest and the results show that only 36 per cent of the sampled farm households affiliated with cooperatives, suggesting that it is crucial to increase membership in cooperatives. About 15.7 per cent of the farm household had received training on CA management, and of the total adopters, approximately 30 per cent of households have taken some kind of training in CA. Use of weather information is vital for farm households, but the data shows that in the study area only 52 per cent of the households used the weather data. The analysis also shows that about 14 per cent of the households did not have access to agricultural credit, 66 per cent lacked knowledge of CAW, and 72 per cent lacked access to THS machines. In total, 59 per cent of the total sample households perceive that CAW helps in coping with climate extreme whilst the analysis on the accessibility shows that the area under study is well connected; the average distance to the market, extension service, agricultural cooperatives and ZT service provider 4.86, 6.68, 2.06 and 4.38 km.

5.1.2 Wheat yield under conservation agriculture-based wheat production system and conventional tillage-based wheat production system. Table II provides information on the yield difference between CAW and CTW over three seasons. It is noteworthy that the wheat yield is significantly higher under CAW as compared to CTW in both normal and bad years. Wheat yield under CAW was higher by 0.41 Mg ha^{-1} in 2013-2014 (normal year), 0.66 Mg ha^{-1} in 2014-2015 (bad year) and 0.33 Mg ha^{-1} in 2015-2016 (normal year) all significant at 1 per cent level of significance. The result also shows that the yield is higher and significant at 1 per cent in normal compared to the bad year for both CAW and CTW practicing farm households; however, the difference in the wheat yield between normal and bad years is higher for CTW compared with CAW, which indicates the compared to CTW, CAW does better in reducing the yield shock in the bad year. This is consistent with the findings of Aryal *et al.* (2016), and thus, provides a strong basis to examine why farmers are not shifting from CTW to CAW. The shifting from CTW to CAW is the consequence of the out-performance of CAW over CTW in terms of wheat yields over considered years.

5.1.3 Trend of land operated and allocated to conservation agriculture-based wheat production system. The share of total operated land allocated to CAW has substantially increased over a period of three years (Table III), indicating that many farmers have learned from their own experience and neighbors experience and have adopted CAW as an *ex ante* climate risk coping measure. Most importantly, a sharp increase in the percentage of the total operated land allocated to CAW among its adopters was observed in the year 2015-2016 compared to the year 2014-2015. The average proportion of land allocated to CAW was 19.84 per cent in 2013-2014, 28.93 per cent in 2014-2015 and it was 69.29 per cent in 2015-2016. From this analysis, it can be inferred that CAW was increasingly recognized as an important practice to minimize the loss due to climate risk.

5.1.4 Summary of farmer learning from past experience of climate extremes during the wheat season. Understanding whether farmers learn from past experiences (here, from past climate extreme event, which occurred during the 2014-2015 wheat season in the study area) and how they learn has important implications in designing policies to scale out the farming technologies (Cameron, 1999). Table III presents the distribution of farmers by their learning status. Approximately, 34 per cent of the farm households did not learn from the past

Wheat production system	Average wheat yield (Mg ha^{-1})			Yield difference		*t*-test	
	2013-2014: normal year (A)	2014-2015: bad year (B)	2015-2016: normal year (C)	A-B	C-B	A-B	C-B
CAW	5.46 (0.052)	4.89 (0.056)	5.13 (0.031)	0.57[a]	0.24[e]	7.55***	4.71***
CTW	5.05 (0.58)	4.23 (0.066)	4.82 (0.028)	0.82[b]	0.59[f]	9.38***	5.17***
Yield difference between CAW and CTW (Mg ha^{-1})	0.41[c]	0.66[d]	0.31[g]	–	–	–	–
t-test	5.19***	7.59***	7.34***	–	–	–	–

Notes: ***Refers to significant at 99 per cent confidence level; observations are combined observations; standard errors are reported in parentheses. CAW and CTW refer to conservation agriculture-based wheat and conventional tillage-based wheat, respectively; [a]Yield loss due to climatic risk (untimely rain at the ready to harvest stage of wheat crop) in CAW between year 2013-2014 and year 2014-2015; [b]Yield loss due to climatic risk (untimely rain at the ready to harvest stage of wheat crop) in CTW between year 2013-2014 and year 2014-2015; [c]Yield gap between CAW and CTW in a normal year, i.e., in year 2013-2014; [d]Yield gap between CAW and CTW in bad year (here, year with untimely rain at the ready to harvest stage of wheat crop), i.e., year 2014-2015 – address climatic variability; [e]Yield gain because of the adoption of CAW in year 2015-2016 (normal year) compared to year 2014-2015 (Bad year); [f]Yield difference between the good year 2015-2016 and bad year 2014-2015 under CTW; [g]Yield gap between CAW and CTW in normal year, i.e., in the year 2015-2016

Table II.
Wheat yield (Mg ha[1]) under alternative production systems

Year	No. of households[a]	Share of land allocated to CAW (average)
Adoption of CA-based wheat production system (CAW) by year		
2013-2014	104	19.84
2014-2015	104	28.93
2015-2016	139	69.29
Learning from past experience of climate extreme		
Learning from past climate extremes	No. of farm households	–
No learning[b]	63	–
Learning from own experience[c]	77	–
Learning from neighboring farmers experiences[d]	44	–
Total	184	-

Table III.
Learning from past experience on the adoption of CA-based wheat production system (CAW)

Notes: [a]Of the total sample of 208 households, 104 were the adopters of CAW in the years 2013-2014 and 2014-2015. In 2015-2016, 44 households who were non-adopters in the previous years started CAW, and hence, the number of CAW adopters increased to 139 households; [b]this includes farmers who have not adopted CAW in their land in both 2014-2015 and 2015-2016, and also farmers who have adopted CAW in 2014-2015 but have not increased the share of land under it in 2015-2016; [c]this includes farmers who applied CAW in their land in 2014-2015 and increased the share of land allocated to CAW in their total operated land in 2015-2016; [d]This includes farmers who did not apply CAW at all in their land in 2014-2015 but applied it in some or total land operated by them in 2015-2016

experience, 42 per cent learned from their own experience and 24 per cent learned from the neighbouring farmers experiences, which shows that the largest proportion (65 per cent) of the farmers learned about the climate extremes either from their own experience or the experience of the neighbouring farmers.

5.2 Econometrics analysis and result

5.2.1 Analysis of farmer learning from past experience to climate change adaptation in agriculture. Table IV (left panel) presents the results from the multinomial logit model on the factors influencing the learning from experience on climate change adaptation in agriculture among the farm households in the study area. The dependent variable is a categorical variable with three outcomes, i.e. no learning, learning from own experience, learning from neighboring farmers' experiences. As these outcomes are mutually exclusive, application of the multinomial logit model is one of the most preferred methods for econometric analysis. In the model, authors have used the outcome "no learning" as the base category, which means the findings are in comparison to those farm household heads who did not learn from past climate extreme events at all. The results show that age, education, training, and perception about technology matters for learning. Authors checked the robustness of the results with different specifications of the model- in the Model A authors used the age of the household head, and in Model B authors replaced the age of the household head with young farmer under 35 years, and authors also included the interaction term "young farmer and training".

The results show that the effect of age is negative and significant at 1 per cent level for learning from neighbours, indicating that the older farmers are less likely to learn about adaptation to climate change from neighbours. In the Model B, the result shows that the coefficient of the young farmer is positive and significant for both learnings from own experience and learning from neighbours, indicating that young farmers are more likely to learn about climate change adaptation. Education enables individuals to learn quickly. The

Table IV. Analysis of factors determining farmer learnings to adapt to climate change

Variables	Analysis of factors determining farmer learnings to adapt to climate change (marginal effects from multinomial logit model): base outcome (no learning)				Analysis of the intensity of learning from experience to adapt to climate change (Tobit model)		
	Learning from own experience		Learning from neighbours				
	Model A	Model B	Model A	Model B	Specification A	Specification B	Specification C
Demographic							
Age of HH head	−0.038(0.026)	–	−0.045***(0.016)	–	−0.045**(0.021)	–	–
Young farmer dummy	–	0.096***(0.023)	–	0.116**(0.052)	–	0.126***(0.027)	–
Human and social capital							
Primary educationa	0.305(0.224)	0.278(0.214)	−0.105(0.225)	−0.115(0.205)	0.078(0.107)	0.079(0.109)	0.105(0.125)
Secondary educationa	0.115***(0.037)	0.105***(0.031)	0.095***(0.024)	0.094***(0.022)	0.095***(0.027)	0.097***(0.031)	0.083***(0.024)
Higher secondary and above[a]	0.035**(0.016)	0.031**(0.014)	0.043**(0.021)	0.041**(0.019)	0.045**(0.021)	0.041**(0.018)	0.041**(0.020)
Training	0.388***(0.131)	0.311***(0.126)	0.151(0.377)	0.151(0.374)	0.266***(0.072)	0.295**(0.121)	0.316***(0.107)
Lack knowledge	−0.437***(0.119)	−0.437***(0.119)	−0.132**(0.078)	−0.137***(0.076)	−0.311***(0.119)	−0.301***(0.119)	−0.332***(0.078)
Membership in cooperatives	0.256***(0.041)	0.210***(0.062)	0.326***(0.112)	0.265***(0.098)	0.097(0.109)	−0.019(0.125)	0.152(0.110)
Farm assets							
Land owned (ha)	0.291***(0.087)	0.263***(0.087)	0.288***(0.088)	0.267***(0.078)	0.014**(0.006)	0.024***(0.007)	0.017***(0.007)
Own tractor	0.545(0.779)	0.545(0.779)	−0.936(0.624)	−0.936(0.624)	0.011(0.127)	−0.021(0.140)	−0.021(0.122)
Access to facilities and infrastructure							
Distance to market	−0.021(0.094)	−0.021(0.094)	−0.077(0.110)	−0.077(0.110)	−0.017(0.017)	0.000(0.019)	−0.002(0.016)
Distance to extension centre	−0.131(0.112)	−0.127(0.102)	−0.116(0.096)	−0.099(0.106)	0.009(0.017)	−0.028(0.020)	0.011(0.017)
Lack credit	−0.348(0.427)	−0.378(0.429)	−0.224(0.814)	−0.234(0.802)	−0.422(0.547)	−0.573(0.627)	−0.049(0.563)
Distance to ZT service provider	−0.603***(0.231)	−0.617***(0.214)	−0.184***(0.054)	−0.181***(0.049)	−0.099***(0.035)	−0.106***(0.037)	−0.082**(0.034)
Perception of CAW on adaptation to climate change							
Perception on CAW	0.201***(0.044)	0.193***(0.039)	0.211***(0.054)	0.212***(0.054)	0.400***(0.108)	0.459**(0.192)	0.419**(0.131)
Interaction terms young farmer and training							
Young farmer*training[b]	–	0.263***(0.103)	–	0.171***(0.063)	–	–	0.191***(0.022)
Constant	5.905***(2.108)	5.835***(1.108)	4.873***(1.814)	4.894***(1.753)	−0.581(0.632)	0.272(0.627)	0.147(0.616)
Sigma constant	–	–	–	–	0.441***(0.037)	0.454***(0.042)	0.480***(0.039)
Pseudo R^2	–	–	–	–	0.317	0.323	0.341
Number of observations	184	184	184	184	184	184	184

Notes: [a]Base category is illiterate; [b]interaction term between young farmer and training; ***significant at 1 per cent; **significant at 5 per cent; *significant at 10 per cent, standard errors are reported in parentheses

result shows that the household whose head has completed secondary and higher secondary and above are more likely to learn about climate change adaptation from their own experience and from neighbour in both Models A and B compared to a household headed by an illiterate farmer. The coefficient of the training dummy is positive and significant for learning from own experience in both Models A and B indicating that the household, which receives some kind of training in conservation agriculture has a higher probability of learning about climate change from their own experience. Lack of knowledge dummy is negatively associated with learning from experience and learning from neighbours in both Models A and B, which indicates the importance of information and knowledge in technology adoption. Similarly, other studies have also found that the lack of knowledge and insufficient information are causes of low adoption of CA by smallholder farmers in Southern Africa (Holden and Lunduka, 2014; Holden and Quiggin, 2017). The coefficient of the dummy membership in cooperatives is positive and significant at 1 per cent level of significance for learning from own experience and learning from the neighbour about climate change adaptation for both Models A and B.

The land area (ha) owned by the farm household is positive and significant (at 1 per cent level of significance) for learning from own experience and neighbour experience about climate change adaptation signifying that land holding of the household plays a critical role in learning about climate change adaptation. Land is the primary asset of the farm household, which influences their livelihood and income; therefore, those household with larger land assets are keen to learn and adopt any technology, which influences the farm productivity. Studies have shown that poor farmers tend to be risk-averse and that this constrains their uptake of new technologies (Dercon and Christiaensen, 2011; Karlan *et al.*, 2014). Though the tractor is also a key asset, it turned out to be insignificant in determining the learning outcome for the adoption of climate change adaptation.

All variables for access to facilities and infrastructure turned out to be insignificant except distance to ZT service provider. The distance to ZT service provider was negative and significant at 1 per cent level of significance for learning from own experience and learning from neighbours' experience for both Models A and B, signifying that farther the ZT service provider is, the less likely that the farmer will learn about climate change adaptation.

Perception of CAW is a critical determinant of farmers' learning about climate change adaptation. The results show that the farmers who perceive that CAW helps in combating climate change are most likely to learn both from their own experience and from the experience of their neighbour. The interaction between dummy young farmer and training is positive and highly significant, indicating that the young farmers who receive training are most likely to learn from their own experience and from the neighbour.

5.2.2 Analysis of intensity of learning from experience. In the current study, the intensity of learning is measured by the proportion of total operated land under CAW (i.e. land under CAW/total land). As many farmers have applied CAW on a part of their total operated land, the dependent variable ranging from 0 to 1 (0 if the farmer does not practice CAW and 1 if the farmer applied CAW on their entire operated land). For such data structure, standard censored Tobit model is used to assess the determinants of its intensity. The result of the pooled Tobit model is provided in Table IV (right panel). To test the robustness of the result, the authors estimated three Tobit models. In Model A, authors used the age of the household, and in Model B, authors replaced it with the young farmer and the interaction term (young farmer and training), and in Model C, authors used only the interaction of young farmer and training. The findings show that farmer's intensity of learning from experience to cope with climate change is negatively associated with age, i.e. older farmers

are less likely to learn from experience. The coefficient of the young farmer in Model B is positive and significant at 1 per cent, which similarly indicates that young farmer are more likely to learn from the experience.

Education of the household head appears to influence the intensity of learning from experience. The coefficient of the secondary and higher secondary and above is positive and significant at 1 per cent, which means that intensity of learning is higher for those households with a secondary and higher secondary and above level of education compared to illiterate. As envisaged, the training on CA technology is also positive and significant at 1 per cent level of significance; therefore it can be concluded that training plays a vital role in influencing farmers to increase the intensity of learning about CA technology. Lack of knowledge turns out to be a major constraint in the intensity of learning about the climate change coping mechanism. The coefficient of the lack of knowledge is positive and significant at 1 per cent level of significance. The membership dummy is insignificant in influencing the intensity of learning.

As the land is a primary asset of the farmers, the study found that the landholding critically influences the farmer learning about the mechanism to cope with climate change. The result shows that the intensity of learning for farm household increases with the increase in the land asset. However, tractor ownership is not a significant driver of learning about climate change adaptations.

Amongst all factors related to access to facilities and infrastructures, only distance to ZT service centre turns out to be significant drivers of the intensity of learning about adaptation to climate change. The coefficient of the distance to ZT service centre is negative and significant at 1 per cent level of significance highlighting that the closer a household is to the ZT service provider the more probable that the intensity of learning increases. The perception of CAW is a critical determinant of the intensity of learning to cope with climate change. The farmers who perceive that CAW helps in coping with climate change are more likely to learn compared to those who do not believe that CAW helps in coping against climate change risk. The coefficient of the perception on CAW is positive and significant at 1 per cent level of significance in all three Models A, B and C. The interaction terms of young farmer and training is positive and significant at 1 per cent level of significance, highlighting that the intensity of learning is higher for young farmers who have received training on CA technology.

5.3 Results of the focus group discussion with farmers and key informants survey

About 57 per cent of the total participants in the FGD consider that CAW can better cope with extreme rainfall during the wheat season, and they consider the primary reason behind this is the better root system. However, they reported the need for better management of CAW as it requires proper timing of weed management. This is where the significant knowledge gap exists and the major reason why some of the participants do not agree with the agronomists working in their area.

Nearly 23 per cent of the participants are not convinced that CAW really serves as a climate risk mitigation measure and also doubt the economic benefits. They were of the opinion that several factors affect the yield and found it hard to believe that CAW alone was the reason behind the lower losses observed in a bad year, i.e. 2014-2015.

Farmers reported that the majority of the extension workers' recommendations are based on high-input intensive agriculture, and such practices are not suitable for CA-based systems. According to them, farmers/local cooperatives/local custom hiring service providers who work with external agricultural projects are more informative than the government extension service providers. As a result, farmer-to-farmer communication is the

dominant method to transfer the knowledge on CAW, which suggests the need for better training of extension staff on CAW.

Young farmers are more enthusiastic about CAW and also about the mechanization of agriculture. However, they are worried about declining farm size, which may reduce the benefits of CAW. Authors also discussed why young farmers are more inclined towards CAW as compared to relatively older ones. Some old farmers replied that "today's youth are better than us in using modern communication technology, such as mobile apps and internet". They added that "young farmers can access new information easily, which is beyond our capacity. This is mainly because of increasing technological innovations over time".

Overall, there is a positive response to CAW. Nevertheless, there is a need for closer integration between agricultural scientists, farmers, and government and private extension service providers to reduce the knowledge gap on CAW and to improve local knowledge. The major problems highlighted by the farmers are as follows:

- *Farmers' knowledge gap*: CAW is knowledge-intensive and requires the operation of modern machinery. There is a regular improvement in available machines for zero tillage. For example, the original ZT drill machine could not seed wheat in the presence of rice straw on the field, but the THS can perform this task. Changing from one type of machine to another requires a flow of information. This also requires new knowledge to operate the machine together with its proper calibration. Farmers' also focussed on the need for a replacement facility for old ZT drill machines when a new improved version is available on the market. Almost 25 per cent of the participants were not convinced that CAW performed better than the conventional practice and insisted that the weed problem was challenging to address in CAW. This aspect of CAW warrants further research and development.
- *Narrow window for farmers and service providers for operating THS*: The time gap between paddy harvesting and planting of wheat in North-West India is 7-10 and 15-20 days in fields planted with basmati/scented and coarse rice, respectively. If farmers cannot access the THS on time for seeding, the field loses soil moisture resulting in low germination of wheat, eventually causing a yield penalty.
- *Machine service and technological backstopping*: At the time of wheat sowing, service providers are unable to meet the demand of every farmer as the numbers of custom hiring services are limited north-west India.
- *Small farmers*: Almost 70 per cent of the farmers are smallholder. They have no economic capacity to purchase the THS and mostly rely on custom hiring services. Most of the farmers have traditional machinery (normal multi-crop planter and ZT machine, and 35 horsepower (Hp) tractor) for wheat sowing. There is a need to replace these machineries with the new ones (THS and tractor with >50Hp as THS requires high-power tractor). Any further improvement in CAW machinery needs further investment from farmers to use the improved version, and it is not profitable to buy a new machine every time. Provision of better custom hiring services is the only option for marginal and small farmers as agriculture is no longer a profitable venture for them.
- *Attitude*: For several years, farmers have been using clean cultivation. As the field sown with THS looks untidy during the first 45 days of crop growth, many farmers do not like it and so can be reluctant to change; a change in mindset is therefore needed.

- *Weed management*: Existing combine harvesters used for harvesting rice are not equipped with a straw management system (SMS), and thus, it leaves behind the loose residue in a swath. Due to the unavailability of labour on time, the manual spreading of loose residues before using THS is delayed. Because of this, in few cases (depending on management history of the fields), weeds emerge before wheat seeding and are covered by the residues, thereby escaping the herbicides droplets/drifts. In such cases, application of herbicides may not match with the crop stage, and weed control becomes difficult.
- *Germination problem due to soil compaction caused by machinery*: Most of the farmers use the combine harvester for rice harvesting, and because of the heavy weight of the combine harvester, it causes soil compaction below the rear wheels, which farmers report cause poor germination and emergence of wheat. It is also not possible with the THS to seed wheat on an uneven soil surface. This requires better understanding and planning in the use of the combine harvester so that operations are timed for when soil moisture conditions are optimal.

6. Discussion and policy implications

The findings of this study have important policy implications. Given that the majority of farmers believe that CAW contributes to climate change adaptation, removing barriers to adoption can help enhance farmers' income with and without climatic extremes. Hence, identifying and strengthening existing institutions rather than creating new ones is required to enhance the adoption of CAW. Despite some barriers to adopt CAW, the knowledge on CAW is spreading among farmers, primarily through farmer-to-farmer communications and farmers meeting in the local farmer clubs. Based on the findings, the authors suggest the following to promote CAW:

- *Facilitate farmer-to-farmer communication*: Facilitating farmer-to-farmer communication are crucial components in improving farmers' knowledge on CAW and its uptake. These findings corroborate other findings (Aryal *et al.*, 2018c, 2018a, 2018b; Fisher *et al.*, 2018), which reported that farmer-to-farmer communication plays a major role in the adoption of climate-smart agricultural practices. Therefore, policy should focus on the importance of learning in technology diffusion and provide support to educational/training facilities related to CAW rather than merely focussing on input subsidy. Effective communication increases farmers' capacity to adapt to extreme climate events and minimizes the financial burden of the government in terms of compensatory payments, which could otherwise be used for nutrition/food security.
- *Improve custom hiring services of CAW machineries*: Insufficient custom hiring of THS is one of the major constraints to farmer adoption of CAW in the study area. Although the Government of India has introduced a scheme of about Rs. 11.5bn to incentivize *in situ* management of crop residues through subsidies that mainly target the THS and the SMS (Government of India, 2018), a broader policy to enhance the capacity to manufacture the required number of machines at the local level is essential. In 2014-2015, the number of THS was only 600, while about 5800 THS are required to cultivate 0.35 m ha of agricultural land in Haryana state alone (Lohan *et al.*, 2018).
- *Revise crop loss compensation policy*: In the climate extreme event of the 2014-2015 wheat season, the Government of Haryana compensated only those farmers whose

crop yield loss was more than 30 per cent. This acted as a disincentive for farmers using CAW as their losses were less than those using conventional practices. Therefore, the compensation policy should also consider wheat production practices and not just a measure of losses.

- *Private sector involvement*: Engaging the private sector and the business community is essential for the rapid expansion of this innovative technology. Local government bodies help create a favourable environment to actively engage multiple private actors including farmers, civil society members and businesses by creating governance networks and conducive policies (Mees, 2017; Sovacool *et al.*, 2017; Tallis *et al.*, 2017).

7. Conclusion and way forward

CAW, which has been adopted by the farmers primarily to reduce production costs, is now being adopted as a climate risk coping measure. The findings show that farmers learn climate change adaptation through their own experience and through the experiences of their neighbours. Several factors determine these learnings and their use for climate risk adaptation. Farmer learning and uptake of new technology is not only related to the characteristic of technology but also how well the technology fits the farming system and its impact on farmers' livelihood. Even though the technology has no investment risks, other factors related to the technology and farmers can largely influence its uptake.

Learning/communication was found to be the most crucial factor for CAW adoption. Therefore, providing support to agricultural education programmes for farmers rather than focussing solely on input subsidies and credit should be a major target for policy. A transformational change in agriculture is possible through better institutional support and improved service provision for CAW-based technologies. Climate change adaptation in agriculture, therefore, needs to focus on various other issues related to farm household and market characteristics, along with technology development. Designing an appropriate strategy to communicate scientific evidence to farmers, reshaping compensation policies and strengthening local extension institutions are essential.

At the local level, farmer-to-farmer communication was found to be a critical factor in promoting technology adoption (i.e. in the current study, learning from past experiences to cope with climate extremes). Targeting young farmers and training them to be lead farmers for new agricultural technology dissemination can substantially enhance CAW adoption.

Climate change adaptation in agriculture through technology adoption is a crucial topic and has multiple dimensions. Therefore, future research at multiple locations is necessary to address the issues further at a broader scale and to generalize its impacts in different states of India.

8. Acknowledgement

The authors acknowledge the support of the CGIAR research programs (CRPs) on Climate Change, Agriculture and Food Security (CCAFS) and Wheat Agri-Food Systems (CRP WHEAT) for this study. CCAFS is supported from CGIAR fund donors and bilateral funding agreements (for details visit, https://ccafs.cgiar.org/donors). The CRP WHEAT receives W1&W2 support from the Governments of Australia, Belgium, Canada, China, France, India, Japan, Korea, Netherlands, New Zealand, Norway, Sweden, Switzerland, U.K., U.S.A., and the World Bank. The views expressed here are those of the authors and do not necessarily reflect the views of the funders or associated institutions. The usual disclaimer applies, and the authors are responsible for any remaining errors and inferences.

Note

1. The exchange rate for the year 2015 is: Indian rupees (INR) 1 = US$0.016.

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Climate change vulnerability assessment for Can Tho city by a set of indicators

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Received 9 January 2018
Revised 8 May 2018
9 September 2018
26 March 2019
9 July 2019
22 July 2019
Accepted 23 July 2019

Abstract

Purpose – The city of Can Tho, located on Vietnam's Mekong Delta, has been identified as one of the nation's most vulnerable sites for adverse climate change-induced impacts. Can Tho's policymakers are faced with tackling these challenges but lack the necessary tools and funds to properly address the situation. The study aims to develop a set of indicators to assess the degree of climate change vulnerability so that policymakers can determine which of Can Tho's districts are most in need of attention, and then propose the best options for climate change adaptation activities.

Design/methodology/approach – The indicators, including quantifications of exposure, sensitivity and adaptive capacity, were categorized in three tiers, from 1 to 3, to reflect their importance with regard to the situation. The higher tier indicators comprised a number of lower tier indicators, which were developed based on real-life, practical situations at the local level.

Findings – The results showed that the Thoi Lai District, with a vulnerability indicator estimated at 0.59, is more vulnerable to the impacts of climate change than other districts because of its lower adaptive capacity and higher sensitivity. In contrast, Ninh Kieu District's climate change indicator of 0.24 demonstrates it has higher resilience to climate change impacts.

Originality/value – This study showed that the set of indicators developed provides a promising approach for supporting local policymakers in Can Tho to actively respond to climate change-related challenges, and that this approach has the potential to be upscaled for other cities in Vietnam.

Keywords Climate change, Vulnerability indicators, Mekong Delta

Paper type Case study

1. Introduction

Located in the Mekong Delta region, Can Tho is Vietnam's fourth largest city, with a population estimated at 1.4 mn. The rapidly growing urban metropolis is divided into nine

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International Journal of Climate Change Strategies and Management
Vol. 12 No. 1, 2020
pp. 147-158
Emerald Publishing Limited
1756-8692
DOI 10.1108/IJCCSM-01-2018-0003

districts: Ninh Kieu, O Mon, Binh Thuy, Cai Rang, Thot Not, Vinh Thanh, Co Do, Phong Dien and Thoi Lai (Figure 1). As the city has developed, the climate change-induced effects have threatened its sustainability. According to the Can Tho Climate Change Coordination Office, natural disasters such as tropical storms, drought, salt intrusion, climate extremes, among others, have occurred with increasing frequency and unpredictability over the past two decades. Salt intrusion was never previously observed in Can Tho, whereas the salinity in the city's central Hau River was measured at 2000 mg/L in 2016 (Vietnam Ministry of Science and Technology, 2016). According to the updated climate change scenarios released by the Vietnam Ministry of Natural Resources and Environment, if the sea level rises by 1meter, 20 per cent of the city's area will be under water [Vietnam Ministry of Natural Resources and Environment (MONRE), 2016]. Women and children, ethnic minorities and the elderly are most vulnerable to these effects.

The local government, well aware of the situation, has sought to develop proper measures with which to respond, but a lack of tools to identify what level of vulnerability the different areas of the city are facing has prevented policymakers from acting effectively. The development of such tools, therefore, is crucial to providing the local government with support in this matter.

According to the Intergovernmental Panel on Climate Change (IPCC, 2007), vulnerability to climate change is defined as the degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change. This vulnerability is a function of the nature, intensity and extent (range) of climate change and is affected by the sensitivity and adaptability of a system to fluctuations in the environment.

Studies on vulnerability assessment are generally divided into first- and second-generation approaches (UNFCCC, 2007; Hahn *et al.*, 2009). The first-generation approach, also known as the "climate change" or "top-down" approach, is designed to understand the long-term impacts of climate change. In contrast, the "second generation" approach, also known as the "climate change adaptation" or "bottom-up" approach, focuses on adaptation and community involvement (UNFCCC, 2007) (Figure 2).

The top-down approach focuses on assessing long-term climate risks over several decades, often extending to the year 2100, and frequently based on climate change scenarios. The top-down approach can provide important information for decision-making and focuses more on the impacts of climate change on the environment. However, this approach does not clearly demonstrate local interaction and adaptability (UNFCCC, 2007).

The bottom-up approach, which is based on local coping strategies, indigenous knowledge and technology, local capacity and the ability of communities and governments to cope with current climate fluctuations, has also been launched in recent years. For this approach, many researchers have used the definition of climate change, sensitivity and adaptability to quantify vulnerability (Sullivan, 2002; O'Brien *et al.*, 2004; Vincent, 2004; Ebi *et al.*, 2006; Thornton *et al.*, 2006; Polsky *et al.*, 2007). This approach is useful in developing specific strategies and policy implementation but does have some limitations. First, these studies, based on secondary data, may change the structure of research, according to data availability (Sullivan and Meigh, 2005). Second, errors or omissions in a secondary information data set can cause difficulties in sensitivity analysis (Hahn *et al.*, 2009). Third, future climate change issues are not well-integrated in this approach (UNFCCC, 2007).

Both top-down and bottom-up approaches have advantages and disadvantages. In some cases, if researchers are more concerned about the long-term impacts of climate change, the top-down approach would be more appropriate. In other cases, the bottom-up approach would be more useful, for example, if researchers were interested in short-term climate

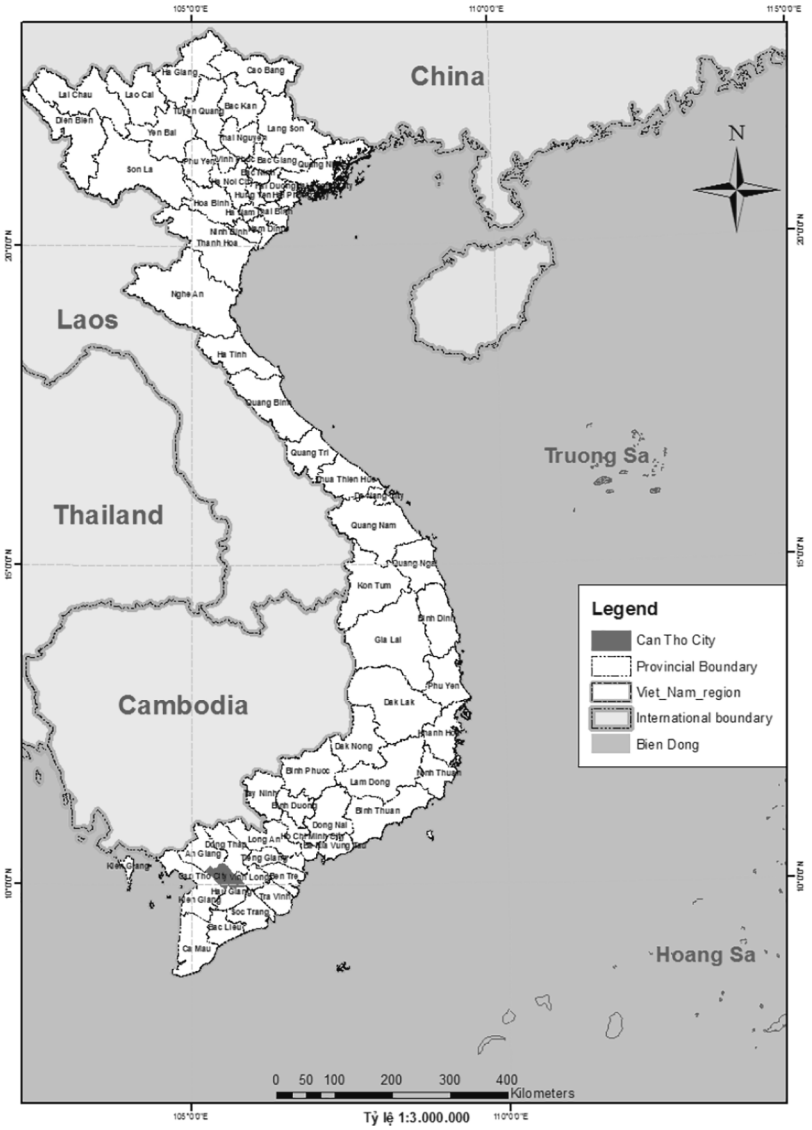
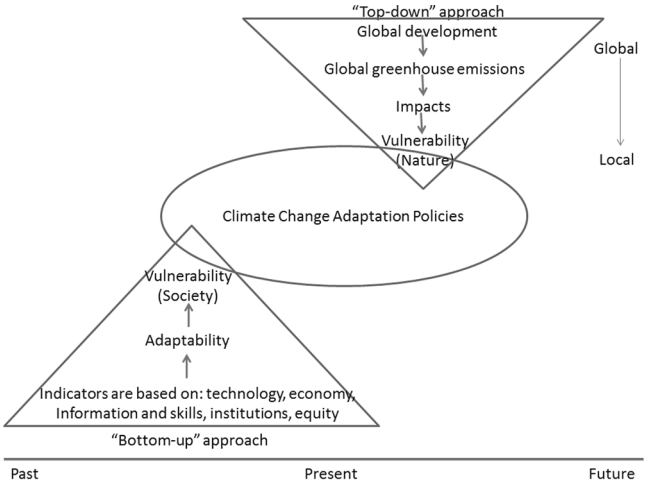


Figure 1.
Geographical location of Can Tho

change. It is now clear, however, that this traditional division into two approaches, top-down and bottom-up, is no longer valid. The integration of climate projections and adaptation decisions into vulnerability assessments is necessary to meet the priority of needs, both in the context of community-based action as well as disaster-risk reduction (UNFCCC, 2007).

Recently, a number of researchers have performed indicator-based vulnerability assessments, namely, De Brito *et al.* (2017), El-zein and Tonmoy (2017), Fatemi *et al.* (2017), Hazbavi *et al.* (2018), Kumar *et al.* (2016), Senapati and Gupta (2017) and Tapia *et al.* (2017). The set of indicators used were based on a combination of the two approaches mentioned



Source: Dessai and Hulme (2004)

Figure 2.
A top-down and bottom-up approach for assessing vulnerability

above. Most of those studies were implemented for countries or cities located in Europe, Australia, South America or the Middle-East region. Few studies of indicator-based vulnerability assessment were performed for Asia and no case studies were conducted for Vietnam, even though this region and country, respectively, are likely to be most affected by climate change and sea-level rises. Therefore, the objective of the current research was to develop a scientifically based set of vulnerability indicators, and apply this set of indicators for a city in Vietnam.

2. Methodology

According to the intergovernmental panel on climate change (IPCC) definition, vulnerability can be expressed as a function of exposure, sensitivity and adaptation capacity:

$$\boldsymbol{V = f(E, S, AC) = f\,(exposure\ level, sensitivity, adaptive\ capacity)}$$

Where *exposure* is defined as the nature and extent to which a system is affected by particular weather conditions; *sensitivity* is the level of an affected (directly or indirectly) system of interest or disadvantage caused by climate-related stimuli; and *adaptive capacity* measures adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects, to moderate harm or exploit beneficial opportunities.

2.1 Approach

This research applied the IPCC definition of vulnerability and was simultaneously based on Hahn *et al.* (2009), Yusuf and Francisco (2009) and the method of Iyengar and Sudarshan (1982) to develop a set of vulnerability indicators for Can Tho City in Vietnam. In addition, the indicators were developed based on SMART criteria and data available for Can Tho City; the five SMART criteria include: specific (S), measurable (M), achievable (A), relevant (R) and time-phased (T).

In total, a set of 33 vulnerability indicators were developed and tailored to the situation in Can Tho; they included six exposure indicators, 19 sensitivity indicators and eight

indicators for adaptive capacity. These indicators were developed in consultation with national experts from the Ministry of Agriculture and Rural Development, MONRE and local policymakers. The indicators represent a mixture of top-down and bottom-up approaches. The "exposure indicators" are linked more closely to the top-down approach, whereas the "sensitivity" and "adaptive capacity" indicators are more aligned with the bottom-up approach. The complete list of indicators is shown in Table I.

A composite vulnerability indicator (CVI), therefore, consists of three main indicators (Tier I indicators): exposure level (E), sensitivity (S) and adaptive capacity (AC). Each Tier I indicator includes a number of Tier II indicators, and each Tier II indicator is made up of a number of Tier III indicators. The identification of indicators at Tiers II and III was based on a combination of information from the literature and actual experience.

In the present study, the authors used data from 2013 and compared them with the annual average data for the period 1980-1999 to calculate the vulnerability indicators, thus obtaining the exposure index (E) for the current conditions.

2.2 Calculation methods

As each Tier II indicator is calculated in different units, it is necessary to calibrate each of these indicators to the same standard system.

If an increase in the value of a Tier III indicator results in an increase in vulnerability, then the normalization value is calculated according to equation (1):

$$\boldsymbol{s} = \frac{s - s_{min}}{s_{max} - s_{min}} \tag{1}$$

Where s = a Tier III indicator; s_{min} = the minimum value of a Tier III indicator; and s_{max} = the maximum value of a Tier III indicator.

In contrast, if an increase in the value of a Tier III indicator results in a decrease in vulnerability, the functional relationship is decreased, and the normalized value is calculated using equation (2):

$$\boldsymbol{s} = \frac{s_{max} - s}{s_{max} - s_{min}} \tag{2}$$

Where s = a Tier III indicator; s_{min} = the minimum value of a Tier III indicator; and s_{max} = the maximum value of a Tier III indicator.

The value of Tier III indicators is used to calculate the value of each Tier II indicator, using equation (3):

$$\boldsymbol{M} = \frac{\sum_{i=1}^{n} S_i}{n} \tag{3}$$

where M = the value of a Tier II indicator; s_i = as defined in equation (1) or (2); and n = the number of Tier III indicators that comprise a Tier II indicator.

Based on the value of the Tier II indicators, the value of a Tier I's contributing factor (CF) can be calculated according to equation (4):

$$\boldsymbol{CF} = \frac{\sum_{i=1}^{n} M_i}{n} \tag{4}$$

Where CF = Tier I indicators as defined (exposure, sensitivity and adaptive capacity); M_I = Tier II indicators that constitute CF; and n = number of Tier II indicators that comprise a Tier I indicator.

Table I.
A set of indicators for vulnerability assessment

No.	Tier I indicators	Tier II indicators	Tier III indicators	Unit	Data source
1	Exposure (E)	Extreme events (E1)	Average number of storms and tropical depressions (E1-1)	–	Statistical yearbooks for nine districts in Can Tho City during 2013
2			Average number of floods (E1-2)	–	
3			Heavy rain (E1-3)	mm	
4		Climate variation (E2)	Increase in annual average temperature (E2-1)	°C	
5			The change in annual rainfall (E2-2)	%	
6		Sea-level rise (E3)	Sea-level rise (E3-1)	cm	Vietnam's climate change and sea level of MONRE (2016)
7	Sensitivity (S)	Water resources (S1)	Change in potential evaporation compared with a baseline period (S1-1)	%	Results from the CROPWAT model
8			Change in flow compared with a baseline period (S1-2)	%	Results from the MIKE NAM model
9		Society (S2)	Population density (S2-1)	Person/km^2	Statistical yearbooks of nine districts in Can Tho City during 2013
10			Water use per capita (S2-2)	l/person.day	
11			Female rate (S2-3)	%	
12			Poverty rate (S2-4)	%	
13			Unemployment rate (S2-5)	%	
14		Agriculture (S3)	Area of agricultural land (planted area of paddy, planted area of annual industrial crops and planted area of perennial industrial crops) (S3-1)	Thous. ha	
15			Yield of crops (yield of paddy, annual industrial crops and perennial industrial crops) (S3-2)	quintal/ha	
16			Output value of agricultural production (S3-3)	dong (billions)	
17			Livestock population (S3-4)	Head	
18			Rural population (S3-5)	Person	
19		Forestry (S4)	Area of forest (S4-1)	ha	

(*continued*)

No.	Tier I indicators	Tier II indicators	Tier III indicators	Unit	Data source
20			Output value of forestry (S4-2)	dong (billions)	
21		Aquaculture (S5)	Area of water surface used for aquaculture (S5-1)	ha	
22			Number of vessels for offshore fishing (S5-2)	Piece	
23			Output value of fishing (S5-3)	dong (billions)	
24		Industry (S6)	The number of different industrial activities (S6-1)	activities	
25			Industrial output value (mining and quarrying, manufacturing, electricity, gas and water supply) (S6-2)	dong (billions)	
26	Adaptive Capacity (AC)	Communication (AC1)	Number of telephone subscribers/100 persons (AC1-1)	%	
27			Number of Internet subscribers/100 persons (AC1-2)	%	
28		Social-infrastructure (AC2)	Number of health establishments (AC2-1)	–	
29			Number of doctors (AC2-2)	Person	
30			Number of schools (AC2-3)	School	
31			Working-age population (AC2-4)	Person	
32			Upgraded rural roads (AC2-5)	km	
33			Irrigation constructions (AC2-6)	Construction	

Table I.

When Tier I indicators of exposure, sensitivity and adaptability are calculated, the composite vulnerability indicator can be determined based on the value of the three CFs according to equation (5):

$$\boldsymbol{CVI} = \frac{E + S + (1 - AC)}{3} \tag{5}$$

where CVI = a composite vulnerability indicator that uses the IPCC definition of vulnerability; E = the exposure value; S = the sensitivity value; and AC = the adaptive capacity value.

2.3 Data and assumptions

The data used in this study were primarily provided by the Can Tho Statistics Office. Climate data were provided by the Vietnam Institute of Meteorology Hydrology and Climate Change. Water resources data were derived from results based on a hydrological model (MIKE NAM).

In this study, equal weights were applied to all indicators that together comprised the composite vulnerability indicator.

3. Results and discussion

This study has shown that each of Can Tho's districts is experiencing very similar levels of vulnerability to climate change. Only Ninh Kieu, a large residential district with a variety of important socio-economic, educational, medical and security facilities, scored low on the vulnerability indicator. All other districts are facing moderate levels of vulnerability. Thoi Lai and O Mon Districts show high levels of exposure to climate change, so the proportion of affected people represented by these two areas is quite large. At the same time, these two areas with high vulnerability reflect other indicators, such as high poverty rates, a high proportion of ethnic minorities, low literacy rates, poor health and low awareness of the issues around climate change compared with other local authorities. Therefore, Thoi Lai and O Mon districts have been ranked as the two most vulnerable districts (Table II, Figure 3).

It can be seen that Co Do, Thot Not and Vinh Thanh districts have the highest levels of sensitivity because these districts have the largest areas of agricultural and aquacultural production. In addition, all three of these districts are located in low-lying areas that are frequently affected by flooding.

Table II.
Values for exposure, sensitivity, adaptive capacity and composite vulnerability indicators for districts in Can Tho city

No	District	Vulnerability indicator			
		E	S	AC	CVI
1	Ninh Kieu	0.30	0.30	0.88	0.24
2	O Mon	0.56	0.35	0.29	0.54
3	Binh Thuy	0.40	0.28	0.18	0.50
4	Cai Rang	0.35	0.14	0.21	0.43
5	Thot Not	0.33	0.42	0.34	0.47
6	Vinh Thanh	0.09	0.41	0.37	0.38
7	Co Do	0.24	0.49	0.19	0.51
8	Phong Dien	0.44	0.31	0.23	0.51
9	Thoi Lai	0.67	0.37	0.28	0.59

The industrial and service sectors are considered to be two areas that are not as sensitive to the impacts of climate change as the agriculture and fisheries sectors. Of the nine districts analyzed, climate change has imposed the most significant impact on industrial areas in Binh Thuy. In Co Do district, although there is not a lot of industrial land, the rate at which industrial land is being affected by climate change is high. The greater the contribution of a district to the gross domestic product from these two sectors, the less likely they are to be sensitive to climate change. The industry and services of Binh Thuy district are relatively developed, which is a factor that lowers the degree of sensitivity in that district. In contrast, the industry and services of Co Do district are underdeveloped; hence, the sensitivity in this district is high.

To provide policymakers with an efficient means to view which areas of the city are most vulnerable, it is necessary to present the data graphically, as in other studies that included indicator-based vulnerability assessments. For example, Tapia *et al.* (2017) calculated the vulnerability index for 571 European cities; they did not, however, include exposure factors. The vulnerability map in that study was also presented based on the value of degrees of vulnerability, ranging from high level (> 0.75), medium to high level (median to 0.75), medium to low level (0.25 to median) and low level (< 0.25).

Following consultation with national and local experts, the values of composite vulnerability indicators in this study were divided into two levels (Figure 4):

(1) Low (CVI < 0.35), represented by pink.

(2) Medium ($0.35 \leq$ CVI < 0.75), represented by red.

Figure 4 shows that only Ninh Kieu district was identified as an area with low vulnerability to climate change. All other districts in Can Tho show a similar CVI, at the medium level. Thai Lai is recognized to be the district that is most vulnerable to climate change in Can Tho. Decision makers and planners in Can Tho will need to pay more attention and develop suitable measures to enhance the resilience of Thai Lai district to the impacts of climate change.

4. Conclusion

Climate change has emerged as a major threat to both natural systems and socio-economic activities in Can Tho, particularly in the agriculture, water resources and

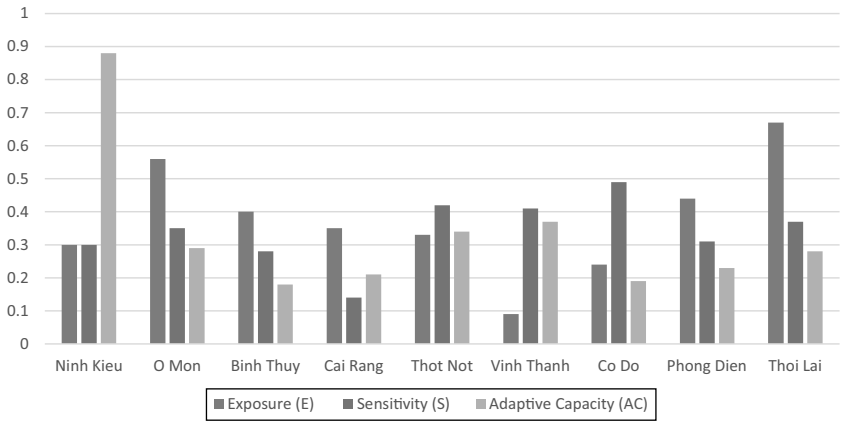


Figure 3.
Comparison of E, S and AC values among Can Tho city's districts

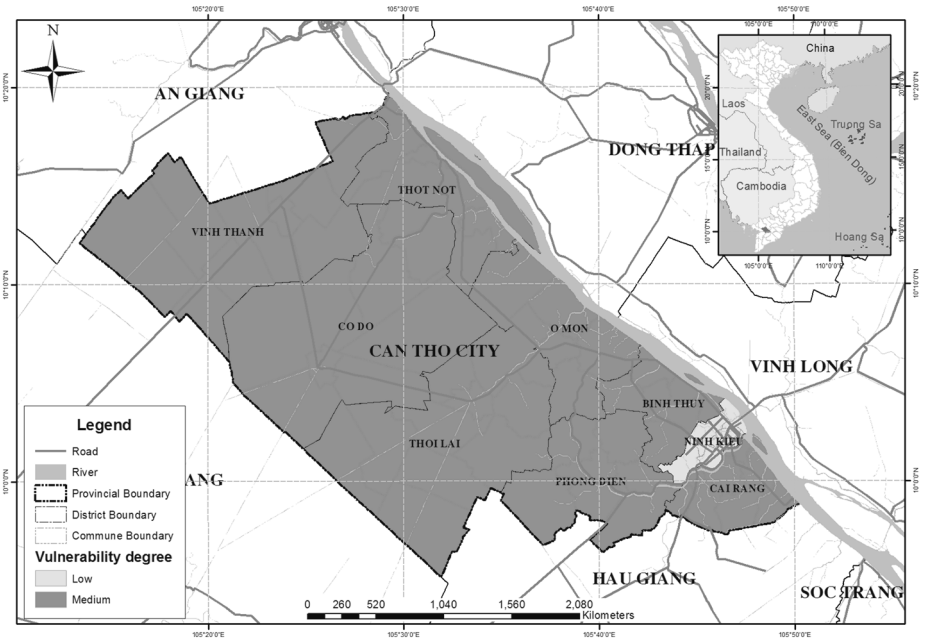


Figure 4.
Vulnerability assessment for districts of Can Tho city

energy sectors. Women and children, ethnic minorities and the elderly are the most vulnerable to these effects. O Mon, Co Do, Phong Dien and Thoi Lai districts are predicted to have the highest vulnerability to climate change impacts among the nine districts and should therefore be prioritized for adaptive investments, such as increasing the area of green spaces, building water-storage areas, combining floodplains and wetland parks, preserving biodiversity and planning for biodiversity conservation to improve environmental resilience. In summary, the pilot calculations described here show that the indicator set used provides an intuitive view, facilitating managers to easily delineate those areas with the highest vulnerability and in greatest need of investment. The set of indicators used is also highly applicable because most of the input data are taken from the local statistical yearbook, which is published annually. Therefore, this set of indicators could be scaled-up for other cities and/or provinces in Vietnam and undergo continuous improvement.

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