Climate Variability and Rural Livelihoods: How Households Perceive and Adapt to Climatic Shocks in the Okavango Delta, Botswana

OLUWATOYIN DARE KOLAWOLE, MOSEKI RONALD MOTSHOLAPHEKO, BARBARA NTOMBI NGWENYA, AND OLEKAE THAKADU

Okavango Research Institute, University of Botswana, Maun, Botswana

GAGOITSEOPE MMOPELWA

Department of Environmental Science, University of Botswana, Gaborone, Botswana

DONALD LETSHOLO KGATHI

Okavango Research Institute, University of Botswana, Maun, Botswana

(Manuscript received 26 February 2015, in final form 17 January 2016)

ABSTRACT

Climate variability and change have adverse effects on agricultural production and other livelihood strategies of the rural households. The paper hypothesizes that rural households naturally devise means of overcoming the challenges currently posed by climate variability. The research article addresses the question of how rural households apply local knowledge of weather forecasting in adapting to climate variability in the Okavango Delta. It specifically probes, among others, the extent to which climate variability has affected agricultural production over the last 10 years in the area. A multistage sampling procedure was used to select a total of 592 households from eight rural communities. Key informant interviews, focus group discussions, and a stakeholder workshop were used to obtain demographic, socioeconomic, psychosocial, and climatic information. Households used both natural animate and inanimate indicators to predict the weather. To enhance household adaptation to climatic events, indigenous knowledge weather forecasters (ethnometeorologists) engaged in discussions with community members on their observation and interpretation of local weather conditions. Households devised adaptation strategies including the selection and preservation of drought-resistant, early maturing seeds, and shift in farming calendars to overcome the vagaries of weather patterns. Local and farming communities had a favorable perception about the accuracy of indigenous knowledge in weather forecasting (ethnometeorology) and therefore continue to utilize this knowledge system in weather forecasting. Most households perceived that change in weather patterns had a direct relationship with the decline in agricultural outputs over the last 10 years. Households' experiential knowledge and ability to quantify their losses in farm yields as a result of climate-related problems provide an important insight for policy makers on how to address the impact of climate variability in the Okavango Delta, Botswana, and in similar social ecological contexts.

1. Introduction

Climate variability and change are global phenomena, which have become a big challenge to humankind (IPCC 2013). Whereas climate change is a relatively new phenomenon, climate variability has always affected households in the past. Admittedly, as the impacts of climate change are becoming more pronounced, they may have adverse environmental impacts in the future. In observing the influence of climate change on climate variability, attention may be paid to the distinct variations noticeable in global or even local weather conditions (Sachs 2009; IPCC 2007). The second half of the twentieth century witnessed an unprecedented rise in global atmospheric temperature, and this is expected to

Corresponding author address: Oluwatoyin Dare Kolawole, Okavango Research Institute, University of Botswana, P/Bag 285 Maun, Botswana.
E-mail: tkolawole@ori.ub.bw

DOI: 10.1175/WCAS-D-15-0019.1

Publisher's Note: This article was revised on 21 March 2016 to correct a typographical error that appeared throughout the article.

continue if mitigation measures are not devised (IPCC 2007, p. 2).

Although Africa will largely bear the burden of climate variability and change (Schaeffer et al. 2013), it contributes less to greenhouse gas emission (GHG) compared to other continents. Droughts and floods are increasingly being witnessed in continental Africa in the recent times, and this will likely have an adverse effect on human livelihoods and productive infrastructures in the future (Noble 2007). More importantly, there are indications that climate change effects on agriculture will be severe in marginal areas such as dry lands or areas with low soil fertility (Bates et al. 2008; Olesen and Bindi 2002).

Agriculture, which is highly sensitive to changes in weather conditions, is one of the key livelihood activities of the rural households in developing countries, though the nonfarm sector is increasingly becoming important (Pande and Akermann 2008; Altieri and Koohafkan 2008; Bryceson 2002; Ellis and Allison 2004). In southern Africa, including Botswana, most of the households do not depend exclusively on farming but on a portfolio of livelihood activities such as formal and informal employment and fishing (Kgathi and Motsholapheko 2011; Kgathi et al. 2013). Because a large proportion of livelihood activities are natural resource based, a small change in weather conditions can have a devastating effect on the welfare of rural households in developing countries (Altieri and Koohafkan 2008; Musemwa et al. 2012). The combined effects of poverty, low-level technology, and the vulnerability of smallholders' mode of production to climate change present a daunting challenge for their adaptive capacity (Mutekwa 2009). Given their vulnerable socioeconomic situations, resource-poor households are likely to experience "double exposure," which is the interaction of global, political, and economic changes with climatic risks and their effects on households and development opportunities (Eakin 2005). Nonetheless, rural households have always devised local strategies for overcoming various vagaries of weather conditions (Kolawole et al. 2014). For example, in some parts of semiarid India, farming households respond to low yields by using indigenous seeds and crop varieties that are more high yielding and drought resistant than hybrid seed available in the markets (Pande and Akermann 2008). In animal husbandry, rural households respond to climate change effects through the use of disease-resistant local breeds. In South Africa, local cattle breeds such as the Nguni have been found to be well adapted to poor-quality grazing conditions (Musemwa et al. 2012).

During periods of chronic drought in southern Africa (including Botswana), it was observed that rainmakers engage in backyard rituals and other practices to induce rainfall but would "ascend to special hills to perform special rituals" when all other attempts had failed (Huffman 2009, p. 1; see also Gewald 2002; Landau 1993). But as ethno- or traditional meteorology[1] is becoming "extinct" (Mogotsi et al. 2011), the practice of rainmaking and the legitimacy of rainmakers in parts of Botswana today is perceived as either disappearing, displaced, or undervalued even where remnants exist (Dennis 1978; Dube 2014; Newel 2010). Although the efficacy of such rituals is debatable, they indicate the level of attachment that local communities had with the environment. Their disappearance may equally indicate the generally weakened attachment to the environment and, therefore, a reduced ability of local communities to interpret symbols and predict weather events. However, rural households in Bobirwa subdistrict (Bobonong) and southern and northwestern Kgalagadi in Botswana demonstrate complex understanding of the variations in ecosystems and utilize their indigenous knowledge systems to develop traditional farming systems that are adaptable to their environment (Dougill et al. 2010; Mogotsi et al. 2011). For example, flood recession farming households in the Okavango Delta plough their fields under rain-fed conditions or plough within shallow river channels where soil moisture is available from the relatively high water table (Motsholapheko et al. 2012a). This indeed partly buttresses the claim of de Jalón et al. (2014) that in southern Africa, South Africa and Botswana had the "highest likelihood of adoption of farm-level adaptation strategies."

A recent study has indicated that future climate change is likely to increase the frequency and severity of climate variability in the Okavango Delta as is the case in other arid and semiarid regions (Kgathi et al. 2013; IPCC 2013). The way in which rural households currently adapt to climate variability will assist policy makers in developing adaptation policies and strategies for addressing future climate change risks (IPCC 2013). According to the IPCC (2013), these strategies and policies may include "reducing vulnerability and exposure to the current climate variability." The midterm review of the Okavango Delta Management Plan (Botswana) indicates that there is currently limited understanding of how future climate change is likely to affect wetland-based ecosystem services (fisheries, wildlife, and ecotourism) in the Okavango Delta and how households and governments are likely to adapt to

[1] Ethno- or traditional meteorology literally means the indigenous approaches wielded by local people in predicting and "interpreting local weather conditions in any given locality or remote community" (see Kolawole et al. 2014, p. 44).

its impacts [United States Agency for International Development (USAID) 2013].

Adger et al. (2009) posit that systematic undervaluation of places and culture is among the factors underlying social limits to climate variability and change adaptation. Buttressed by many scholars' viewpoints about the complementary roles that local knowledge plays in climate variability and change studies (see Ifejika-Speranza et al. 2010; Orlove et al. 2010), some had suggested that there was a need for collaborative research on indigenous farming systems and technologies between locals and scientists (den Biggelaar 1991; Nyong et al. 2007). Simelton et al. (2013) opine that adaptation policies are unlikely to be successful if scientists, policy makers, practitioners, and local communities perceive weather changes differently. Therefore, local knowledge and experiences of adaptation to climate change must be captured and their context understood by national governments (Pande and Akermann 2008). Then anticipatory adaptation planning can build on the unique experiences of local people. In other words, development and context-specific adaptation policies are crucial for mitigating the risks posed by climate variability and change, particularly in agrarian economies (see special issue of *Climate Policy*, 2008, Vol. 8, No. 2; Mendelson and Dinar 2009).

The paper therefore addresses the following pertinent issues: 1) the extent to which climate variability has affected agricultural production in the Okavango Delta over the last 10 years and implications on climate change, 2) the types of local adaptation strategies adopted by rural households, 3) the extent to which farming households' decision-making is guided by personal experience and scientific seasonal weather forecasts, and 4) the types of indigenous weather forecasting indicators used by households in the Okavango Delta.

2. Conceptual underpinning

a. *Climate variability and change*

In common parlance, while climate change is witnessed in the long-term alterations in climatic elements, climate variability is the short-term fluctuations experienced in weather patterns in a given geographical location. Whereas climate change is defined by the IPCC (2014, p. 1760) as "a change in the state of the climate that can be identified. . .by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer," climate variability refers to the "variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events" (IPCC 2014, p. 1761). Studies indicate that although climate change is a long-term phenomenon, the impacts of which may currently not be clearly identifiable in some areas around the world, observations of major changes in short-term variations in weather patterns, which are key indicators of climate variability, may serve as indicators that the climate is changing (IPCC 2007). Clearly, both climate variability and change could create climatic shocks for vulnerable farming communities.

b. *Climatic shocks, vulnerability, and adaptation*

Climatic shocks are large, exogenous, unexpected, and irregular climate-induced disturbances (e.g., drought, floods), which result in loss of welfare because they destroy assets (Pearce et al. 1989, p. 40; Ellis 2000, 40–47; Martin and Bargawi 2005, p. 8). The extent to which shocks impact human welfare depends on the vulnerability and resilience of households (Martin and Bargawi 2005, p. 8). Vulnerability refers to internal conditions of the household that make it unable to withstand the impacts of climatic shocks, and it is defined as "a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity" (IPCC 2001, p. 995).

In this paper adaptation to the impacts of climate variability and change is "a process, action or outcome in a system in order for the system to better cope with, manage or adjust to some changing condition, stress, hazard, risk or opportunity" (Smit and Wandel 2006, p. 282). For adaptation to occur there should be a stimulus that offsets the system resulting in a change that enables the affected system to endure and overcome the impact. Adaptation can occur *ex ante* or in anticipation of a shock; it can also be *ex post* or in response to a shock (Ellis 2000). Adaptation of any system to climate variability and change is linked to system vulnerability (Smit and Wandel 2006).

3. Materials and methods

a. *Study area*

The Okavango River and Delta in Ngamiland District is part of a large northern drainage system that includes the Chobe and Linyanti River basins. The Okavango Delta system provides perennial water sources that support riparian and nonriparian livelihood activities (see Fig. 1). Ngamiland District has a total population

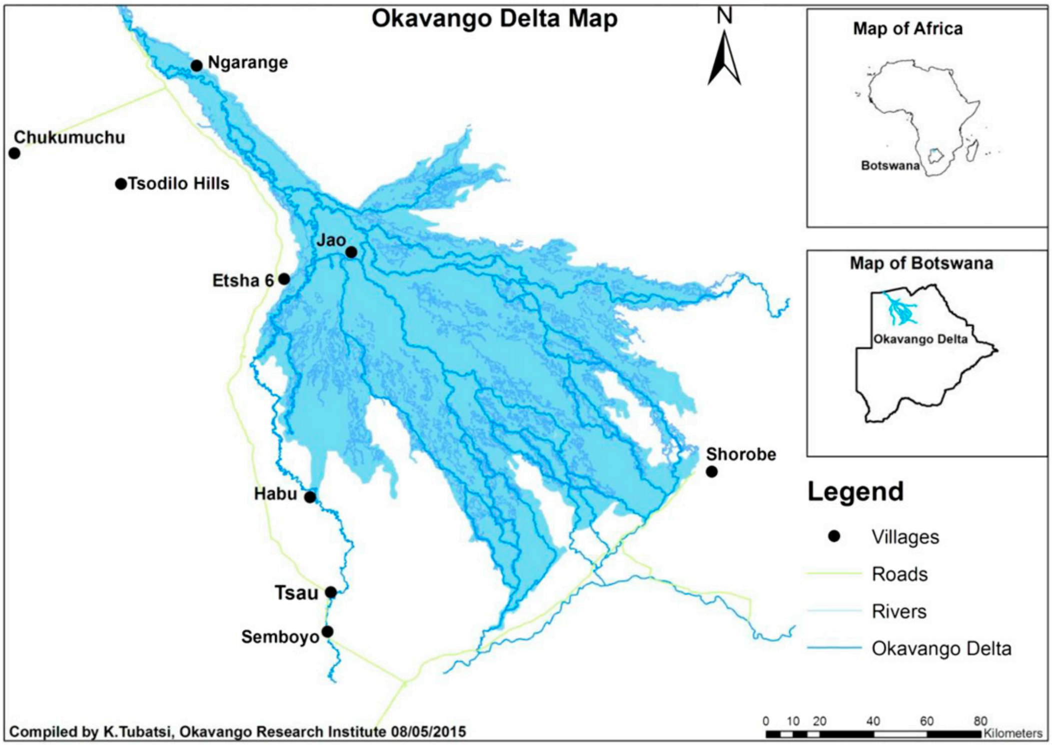

FIG. 1. Map of the Okavango Delta showing riparian communities sampled for the study and where research activities took place [courtesy of Geographical Information System (GIS) Laboratory, Okavango Research Institute, University of Botswana].

of 152 284 people with an estimated intercensal growth rate of about 2% for the period 2001 to 2011 (Central Statistics Office 2011; Gwebu et al. 2014). The district has a diversity of cultures and ethnic groups who distinctively pursue various livelihood activities and resource use patterns. The ethnic groups of Ngamiland include Batawana, WaYei, Hambukushu, BaSarwa, BaXhereku, BaSubiya, and BaKgalagadi. The main livelihood activities in the study area include arable farming (flood recession and dry land farming), livestock farming, formal employment, fishing, and basket making (Motsholapheko et al. 2012b). Although the majority (75%) of households rely on rain-fed agriculture, about 25% of them practice flood recession crop cultivation known as Molapo farming (Vanderpost 2009). Total crop failure is common, especially under rain-fed conditions. In 2002, the long-term average yields in Ngamiland District have been reported to be 162 kg ha^{-1} for maize, 121 kg ha^{-1} for sorghum, 144 kg ha^{-1} for millet, and 28 kg ha^{-1} for pulses (Bendsen 2003). In 2012, however, the yields per hectare harvested increased for sorghum, millet, and pulses, while it decreased for maize [see Table 1] (Statistics Botswana 2014). The yield trend for maize both within Ngamiland District and the entire country decreased during the same period. The yields for all the crops in the district were lower than the national averages except for millet, which was higher. The inverse trend in the yields for maize and millet may have been due to rainfall patterns; while low rainfall causes low maize yields, it is the opposite for millet, which has high yields in low rainfall seasons. Even though variations exist from year to year due to the extent of flooding, crop yields under Molapo farming are generally higher than those under rain-fed cultivation and could be as high as 1800–2900 kg ha^{-1} for sorghum (Bendsen 2003). Crop yields are mainly affected by insufficient rainfall, wildlife damage, pest and disease, and so on.

Given that livestock farming (mainly cattle) distribution is more concentrated in one area than the other in Ngamiland District, it is also a common livelihood activity in the study area. Cattle are used as sources of meat, income, and draft power. They are also used for payment of bride price (Lobola or bogadi). The management of cattle is under a communal system, and foot and mouth disease (FMD) outbreaks are common. The disease makes it difficult for households to access external markets.

In summary, the people of Ngamiland District are among the poorest in Botswana, despite the fact that the area is endowed with diverse natural resources and in

TABLE 1. Ngamiland district yields harvested per hectare (2002 and 2012). (Source: Bendsen 2003; Statistics Botswana 2014.)

Type of crop	Yields harvested (kg ha^{-1})[a] 2002	2012	National averages (kg ha^{-1})[a]
Sorghum	121	90	308
Maize	162	111	134
Millet	144	285	228
Pulses	28	113	154

[a] The figures are averages for smallholder agriculture.

TABLE 2. Villages and total number of households sampled. (Source: Field survey (2011/12); CSO 2011; Kolawole et al. 2014.)

Serial no.	Village	Total number of households (HHs)	25%–30% of HHs (n = 592)
1	Semboyo	118	30
2	Habu	161	40
3	Tsau	494	124
4	Etsha 6	821	221
5	Jao	60	19
6	Ngarange	332	95
7	Tsodilo	78	23
8	Chukumuchu	128	40
Total		2192	592

addition to Botswana being a middle income country with a gross national income per capita of $7720 (U.S. dollars) in 2012 (World Bank 2013). For instance, the proportion of the households below the poverty datum line was estimated at approximately 46% in Ngamiland West and about 23% in Ngamiland East compared to the national average figure of 19.3% (Statistics Botswana 2013).

b. *Sample design and selection*

Using a multistage sampling procedure, a total of 592 households were selected from eight rural communities in the Okavango Delta (see Table 2). A fair representation of the delta was ensured by sampling three communities from the distal and lower delta areas (Semboyo, Habu, and Tsau), two from the middelta area (Jao and Etsha 6), and three from the upper panhandle area (Ngarange, Tsodilo, and Chukumuchu).

c. *Data instruments and pretesting*

First, household heads were engaged in preliminary field visits (through a participatory methodology approach) to acquaint them with the intention of the research. Interview schedule, key informant interviews, and the interview guide (for focus group discussions) were used to obtain quantitative and qualitative data from the households (see Gill et al. 2008; Orlove et al. 2010; Ifejika-Speranza et al. 2010). The research instruments were validated through a test–retest method within two weeks (10 to 24 November 2011) in the Shorobe community (see Fig. 1). The results of the test–retest surveys were compared in order to ensure the consistency of the instruments. Minor corrections were made in the survey instruments after the pretest exercises. Close- and open-ended questions, which addressed demographic/economic, psychosocial, institutional, and environmental issues, were constructed in the interview schedules. Most questions were in the ordinal rating of a 5-point Likert-type scale. Household heads were asked to indicate their level of agreement/disagreement to a set of items/statements relating to their perceptions on weather phenomena. Guided focus group discussion (FGD) sessions were organized for 27 household heads that had extensive farming experience. These individuals were divided into two groups of 14 and 13 members, respectively (see Stewart and Shamdasani 1990). The discussions were tape recorded and then transcribed for analysis. A knowledge-validating workshop was conducted from 16 to 17 August 2012 to provide feedback and allow farming households to validate the findings (see Kolawole et al. 2012). Nonetheless, it is noteworthy that respondents' ethnometeorology and perceptions about weather events (and how they impact farm outputs) were recorded as provided by the household heads and they were not verified (see Ifejika-Speranza et al. 2010).

d. *Data collection*

The field survey was undertaken in late 2011. With assistance from trained enumerators, quantitative and qualitative data were collected from the households' heads. The aim was to obtain the households' viewpoints on their roles and those of scientists regarding knowledge production in weather forecasting and the implementation of a joint collaborative project on climate variability and change. A total of 592 household heads were asked to respond to a set of statements on how they perceive the efficacy and relevance of scientific weather forecasting in comparison with ethnometeorology. The statements were placed on a 5-point Likert scale of "5 = strongly agreed," "4 = agreed," "3 = undecided," "2 = disagreed," and "1 = strongly disagreed." Additionally, qualitative information was obtained through key informant interviews, focus group discussions, and stakeholder knowledge-validating sessions (see also Kolawole et al. 2012). Workshop participants were assigned to discuss specified climate risk issues and to establish the impacts on agricultural production, with focus on crops and animal draft power. After establishing the impacts, the participants were tasked to indicate the extent and

TABLE 3. Crop/agricultural system and climate impact matrix (n = 27). [Source: Global Change System for Analysis Research and Training (START) workshop, 2012.]

Agricultural production	Climate risks									
	Drought	High floods	Low floods	Heavy rainfall	Wet spell	Dry spells	Cold spells	Hot spells	Shifting seasons	Wild fires
Animal draft power	−3	−3	+2	−3	+2	−3	+1–2	+1–2	−2	−3
Germination failure	−3	−3	+3	−3	−3	+/−1	−3	−3	−1	0
Crop failure	−3	−3	+3	−3	+/−2	+1/−2	0	−3	0	0
Maize harvest	−3	−3	+2	−3	−2	−1	0	0	−1	−3
Sorghum harvest	−3	−3	0	−3	−2	+1	0	0	−1	−3
Millet harvest	−2 + 1	−2	0	−3	−2	+2	0	0	−1	0
Melon harvest	+2/−1	−2	0	−1/+2	+/−1	+2	0	0	−1	0
Legume harvest	+/−1	−2	+2	0	0	−2	0	0	−1	0

effect (positive or negative) of the impacts using the scale below:

- +/− 3: Positive/negative high impact.
- +/− 2: Positive/negative medium impact.
- +/− 1: Positive/negative low impact.
- 0: No impact.

The value indicates the level of impact while the sign (+/−) indicates the effect of the impact (Kolawole et al. 2012).

e. Data analysis

Quantitative data from close-ended questions were compiled, coded, and analyzed using SPSS, version 21. Data were organized and summarized using basic descriptive statistics such as frequencies, percentages, and tables. Household heads' perceptional statements obtained and rated on a 5-point Likert scale range of strongly agreed (SA = 5 points), agreed (A = 4), undecided (U = 3), disagreed (D = 2), and strongly disagreed (SD = 1) were computed to determine respondents' average score on weather forecasting knowledge. The perceptional statements were also analyzed using chi-square tests to determine their associations with household characteristics such as gender, education level, and age of respondents. Qualitative data from the open-ended questions and participant observation were analyzed using theme identification techniques. Responses to specific open-ended questions were collated and themes identified; the interpretation and conclusions were drawn from the emerging themes.

4. Results

a. Demographic attributes of households

The majority (64%) of the household heads (n = 592) were female, indicating that the impacts of climate variability and change may affect more female-headed households than male-headed ones. The average age of the respondents was 51 yr, and about 25% of the household heads were older than 65 yr. This may indicate a changing trend of declining youth participation in agricultural farming compared to nontraditional forms of livelihood activities such as formal employment. While 43.8% of households did not attend any formal or nonformal education, only 3.2% had post-secondary education. Some 18.4% obtained a Secondary School Certificate, while only 5.1% did not finish secondary education. Only 5.4% of the smallholders attended adult literacy class. Generally, most households in the study area did not acquire requisite education, with an estimated 43% possessing such skill (Bendsen 2003). The average household size was about four persons, with a minimum of one person (6.6%) and maximum of nine persons (21.6%). Because of the low educational and modern skills, households may be depending on agriculture for subsistence, with limited capacity to adapt in case agricultural production fails because of climatic conditions (see also, Kolawole et al. 2012).

b. Impacts of climate variability on agricultural output

Based on the responses of farming household members (n = 27) during a workshop session, Table 3 shows that there is a mixture of positive and negative effects of climatic and hydroclimatic variations on agricultural production in the delta (Kolawole et al. 2012). Feedbacks provided show that droughts, high floods, heavy rainfall, shifting seasons, and wild fires have high negative impacts on agricultural production and related assets. These findings corroborate those of Hernandez et al. (2015) in central Argentina, where farmers rank drought and flood as the "main adverse climate factors." Low floods, characterized by low inflow, dry flood plains and inadequate water in most river channels of the

Okavango Delta, tend to have medium to high positive impacts on draft power, germination, and legume harvest but have no impact on other crops, which thrive under low moisture conditions. Inadequate draft power results from limited grazing in the flood plains, whereas reduced arable production results from limited moisture for flood recession cultivation. Cold and hot spells have a high negative impact on crops, save for maize, sorghum, millet, melons, or legumes. Wet spells result in a mixture of positive and negative impacts on different agricultural assets and produce. For instance, draft power is positively impacted as there is abundant grazing for livestock. Certain melon and bean varieties also flourish under wet conditions. As participants indicated during the workshop session, understanding these different climate risks may help households to adequately cope with the inclement situation by ensuring that appropriate measures are used and the right decisions are made.

Based on their personal experiences and perceptions about the link between the decline in farm yields and climate variability over a period of 10 yr (Kolawole et al. 2012), about 76% of the household heads (n = 592) interviewed stated that persistent fluctuations in weather conditions had negatively impacted farm yields. Nonetheless, 24% of them did not see any relationship between farm output decline and climate variability. Specifically, households' reactions varied in terms of the farm losses incurred because of climate variability over the years. For instance, one of the household heads interviewed in Etsha 6 community (see Fig. 1) said that ''my outputs in beans and pumpkins production dropped considerably in 2010 while I lost 8 goats in that same year.'' Another farmer in Ngarange community reported that ''I got only 2 bags of maize in 2011 as compared to the 10 bags produced in 2002.'' Elsewhere, another farmer reported that there had been a steady decline in his farm outputs over the years; he had indicated that he obtained only 5 bags (50 kg each) of sorghum as compared to the 10 bags (50 kg each) obtained in year 2000, while he also lost 10 cattle within 2000–11 period. To another hapless farmer, his yearly sorghum harvest of 10 bags (50 kg each) had dropped to only 2 bags by the year 2008. Also, another farmer indicated that his normal harvest had increasingly dropped over the last 5 yr from 15 × 50 kg bags of maize to only 5 × 50 kg bags in 2011. A farmer who was interviewed in another location indicated that his harvest of 60 × 50 kg bags of millet dropped to only 10 bags within 10 yr. Also, 42 household heads (~7.1%) said that there had been a zero harvest within the last three farming years. A farmer based in the Tsau community rhetorically opined that ''we just come empty handed from our fields.''

The drop in farm outputs over a period of 3 yr is succinctly captured by a farmer also in the Tsau community who said that ''I got 2 bags of millet in 2009; 1.5 bags in 2010; and nothing at all in 2011.'' Another female farmer said that she got 20 × 50 kg bags of maize in 1995. And since that year, she hardly harvested a bag of maize. One of the household heads indicated that he harvested about 1500 pieces of watermelons in 1998 but was only able to harvest about 75 pieces in year 2010. Some of the households could not estimate their losses but were only able to indicate that they were too high to fathom. Close to a half of the household heads (45%) indicated that they had recorded 80%–99% losses in 10 yr. We argue that the drop in farm outputs may have been due to a combination of factors, including climate variability. Diverse reasons were adduced by household heads for the decline in farm yields. Some respondents in all eight communities studied perceived that whatever happened was in the hands of God—''He determines everything'' (see also Ifejika-Speranza et al. 2010). Specific causes indicated by all the households (100%) included change in weather patterns and the environment, crop damage by livestock and wildlife, pests (including birds), diseases, and poor crop management. In some cases, heavy rainfall and flooding led to poor production in some years; torrential rainfall accompanied by thunderstorm and strong winds destroyed crops, which invariably led to crop losses. Elsewhere in one of our study locations, a farmer associated extreme high temperature conditions and heat wave with abortion in cattle. Essentially, households' claims on weather fluctuations are further buttressed by the findings in the hydrological and other data derived from the Okavango region (Maun, Kasane, and Shakawe) in the last 10 years (Kolawole et al. 2012; Kolawole et al. 2014). This confirms our hypothesis that change in climatic conditions and weather patterns had a direct relationship with the decline in agricultural outputs in the study area.

c. *Problems, causes, present coping strategies, and opportunities*

Table 4 shows that with the exception of herd overstocking (due to inadequate land), household heads had different coping strategies for different challenges they faced (Kolawole et al. 2012). They could not access external markets for livestock and therefore could not significantly reduce their stocks. The participants also lamented the increase in the number of elephants, which raid crops, and other human–wildlife conflicts as reflected in wild cats' predations on livestock and buffaloes' incursions in grazing areas, thus exacerbating the

TABLE 4. Natural elements/indicators used to predict weather conditions (group 1; n = 14). (Source: START workshop, 2012.)

Condition	Indicators
Drought	Moon, left orientation (August, September, October)
	Low rains with high temperatures and intense heat
	Drying of flowers and early wilting and exfoliation of flowers
	Sightings of springhare (*ntlole*) and ant-bear (*thakadu*) during the day
	Drying of pools and water bodies
	Moon without halo (*Kgwedi e sena pitso*)
	Strong easterly winds
	Abundance of stars predicting hunger
	Presence of many butterfly
	Presence of ostriches roaming in the vicinity of settlements
	Failure of trees to flower
Heavy rainfall	Moon with halo (*Kgwedi e nale pitso*)
	Trees (*mokoba, matlhare a mosheshe,* and *mogaugai*)
	Grass (*modikangwetsi*)
	Abundance of fruit in shepherd's tree: *Boscia albitrunca* (*motlopi*)
	Immediate flooding of river channels
	Certain birds species (e.g., *otongora*)
	Millipedes
	Anthropods (*Khukhwane ya modimo*)
	Frogs
	Sand snail (*Monyopi wa naga*)
	Strong winds (storms)
High floods	Flooding of certain river channels
Hot spells	Whirlwind
Shifting seasons	Delayed rainy season
	Extreme cold
	Flooding
Wild fires	Underground peat fires (*Semombo–mosinyane*)
Dissemination	Consultations among elders and knowledge holders
	Festivals (rituals)
	Consultations among hunters

problems associated with FMD of cattle. Workshop participants (comprising some household heads, weather scientists, community elders, government officials, and others) identified the decrease in arable agricultural activities as a major challenge resulting from low rainfall, pests, little knowledge on suitable seeds for specific seasons, low interest in farming activities among households, multiple commitments to other means of livelihoods, and low crop prices. Related coping strategies identified by the participants are (i) early planting of crops, which enabled households to benefit from the moisture from early rains; (ii) securing temporary jobs from the Ipelegeng program (the labor-intensive public works initiative), which cushions households from crop losses due to drought; and (iii) obtaining government compensation for crops damaged by wildlife. Workshop participants also opined that there was need for (i) households to plough/plant on time in order to benefit from early rains; (ii) the government to properly schedule labor-intensive public works that may distract people from concentrating on arable farming, particularly during the ploughing season; (iii) households to continue to use indigenous drought-tolerant seeds in addition to those provided by the government; (iv) the government to review crop prices, in order to improve farmers' benefits from crop sales; (v) the Ministry of Agriculture to continue informing the public of government programs for arable farming; and (vi) the agricultural extension department to implement public education and sensitizations on appropriate seed varieties for specific seasons. According to the workshop participants, improved awareness of government programs and knowledge on seed varieties can improve access to government programs and enable farmers to adopt the use of drought-resistant crops, leading to improved capacity to adapt to the impacts of climate variability.

d. How households perceive and utilize scientific weather forecasting

The majority (82.4%) of the household heads (n = 592) during the interview (see Kolawole et al. 2012) opined that "[u]nlike western science, formal education or training is not needed to acquire skills in local weather forecasting." Most of the households (94%) either agreed or strongly agreed that "local knowledge in weather prediction does not need any sophisticated tools or equipment" as it applies in scientific weather forecasting. The aforementioned perceptions did not show any associations with household characteristics like age, education level, and gender of respondents. Whereas some 45% of the respondents agreed or strongly agreed that "[s]cientific weather forecast cannot be relied upon as it fails most of the time," a total of 49% either disagreed or strongly disagreed with the statement. This perception showed a highly significant association with the age of respondents (Pearson's Chi-square = 32.8, degrees of freedom = 16, and $p = 0.008$) at 0.05 level of significance. Whereas a relatively high proportion of respondents in the younger age group 31 to 40 yr (33%) strongly disagreed with this statement, low proportions of their older counterparts in the age groups 41 to 50 yr (23%), 51 to 60 (13%), and 65 yr and over (21%) strongly disagreed. These latter groups also had higher proportions of respondents who strongly agreed with this statement than their younger counterparts. This indicated that older groups generally perceived modern weather forecasting as unreliable compared to the relatively young age groups who have a different perspective about the efficacy of scientific weather predictions, probably because of their exposure to western education through which they may have acquired a form of secondary habitus (see Wacquant 2013; Bourdieu 1977; Kolawole 2014a). Although it was expected that this perception would also have some association with the household characteristics of gender and level of education, no significant associations were observed in the available data.

About 56% of the households either agreed or strongly agreed with the statement that ''[l]ocal approaches to weather prediction are always accurate and as such are the best in making the right decisions in farming activities.'' A total of 36% of respondents either disagreed or strongly disagreed with the statement. In line with Onyango's (2009) and Ouma's (2009) viewpoints, key informants indicated that local people have a strong opinion that their weather knowledge is more reliable than those of weather scientists (meteorologists) as they do not even know what weather science entails. Overall, the average score for the household heads was 3.86 (from a total of 5 points) with a standard deviation of ±0.58 (see also Kolawole et al. 2012). Thus, the relatively high mean score implies that households in the Okavango Delta utilized local knowledge in weather forecasting rather than relying totally on scientific information.

e. Households' decision on farming practices/activities

Responding to a set of Likert items (statements) on how they make farming decisions, 55% of the households heads ($n = 592$) either disagreed or strongly disagreed that ''I do not respect the weather forecasts provided by the Department of Meteorological Service (DMS) and as such do not base my farming decisions on them.'' While 43.8% of them either agreed or strongly agreed that ''[t]he weather forecast by the DMS is the last thing I will revert to in making quality farming decisions,'' some 47.8% did not. Only 8.4% of the respondents had no opinion on this. Whereas about 45% of the respondents opined that ''I only accord respect to local approaches to weather prediction in making decisions because meteorological service predictions are not always accurate,'' about 47% of them held a contrary opinion about the statement. The implication of this finding is that the respondents are somewhat polarized on the matter. Nonetheless, 52% of the respondents believed that a ''combination of both scientific and local approaches to weather prediction greatly helps in making good farming decisions.'' A substantial percentage (57.2%) of the household heads agreed that the ''[s]cientific approach to weather forecasting should only be complementary or supplementary to local approach in making farming decisions.'' While some 38.4% of the households either agreed or strongly agreed that ''[i]n making farming decisions, local approach should not be supplementary/complementary to scientific approach of weather forecasting but should be treated as more important than scientific approach,'' about 51% of them either disagreed or strongly disagreed with the statement.

Inferentially, the majority of the households would prefer to work with scientists from the DMS in order to alleviate possible shocks arising from climate variability and change. This again buttresses the Botswana community people's willingness to adopt any adaptation strategies (see de Jalón et al. 2014) that they perceive as useful to them. For instance, one of the respondents, as reported in Kolawole et al. (2012, p. 49), remarked:

> We trust the knowledge of our people. However, there seems to be a meeting point between indigenous approaches to weather prediction and scientific approaches. We welcome a situation where community people and weather scientists will have the opportunity to work together in mitigating climate change and variability (a village elder in Ngarange).

f. Natural elements/indicators used to predict weather conditions

The two groups were tasked to discuss indigenous weather conditions and highlight indicators used to predict or forecast those conditions (see Kolawole et al. 2012). However, the second group composed of 13 participants further indicated how community people would respond to the indicators, which they identified when the need arose. All local names are in Setswana language. The results of the two groups are presented in Tables 5 and 6.

Local communities demonstrated diverse ways through which they observed, predicted and forecast certain weather conditions (Kolawole et al. 2012). They observe the trees, fruiting patterns/development, galaxies (position and orientation of stars in the sky), moon, drying up of river channels, intensity of rains, type and color of clouds, and vegetation status. As shown in Tables 5 and 6, the identified indicators used in forecasting weather conditions in the delta are similar to those in the findings of Orlove et al. (2010) and Ifejika-Speranza et al. (2010) in southern Uganda and semiarid areas of Kenya, respectively. The groups' deliberations presented a clearer picture of some indicators

TABLE 5. Problems, causes, present coping strategy, and opportunities ($n = 27$). (Source: START workshop, 2012.)

Problem (problem definition)	Cause (floods, drought, temperature fluctuations, changing seasons, etc.)	Present coping strategy (What is the community doing currently to cope with the problem or its impacts?)	Opportunity (What else can be done by the community or other stakeholders to cope and or mitigate against the problem?)	Actors (By who? This will help steer some discussion between stakeholders.)
Lack of markets for cattle	Diseases	Bartering	Review of policies for sale of livestock in Ngamiland	Ministry of Agriculture; Ministry of Wildlife, Environment, and tourism; Non-government organizations; community members
	Regulations and policies governing sale of cattle	Subsistence	Develop beef storages	
		Resignation to fate	Vaccination of cattle for FMD	
Overstocking	Lack of markets	Nothing	Search for other markets for Ngamiland beef	Livestock farmers
			Review of prices for sale of cattle at BMC to encourage selling by farmers	Farmers Association
			Supplementary feeding	Ministry of Agriculture
Land degradation	High elephants population		Public education, within villages, and at educational institutions	Ministry of Agriculture
	Wild fires	Public education on wild fires	Culling of elephants	Ministry of Education
		Construction of fire breaks		
	High livestock numbers			Public
	Dearth of rainfall			
Decreasing arable agriculture	Low rainfall	Plough/plant on time	Plough/plant on time	Balemisi (Agric. extension officer)
	Pests	Temporary jobs at Ipelegeng	Stoppage of activities that distract people from concentrating on arable farming (e.g., Ipelegeng)	Ministry of Agriculture
	Lack of knowledge regarding suitable seeds for specific seasons	Compensation	Use indigenous seeds that are drought tolerant	
	Low morale among farmers		Review crop prices	
	Commitment in Ipelegeng (social welfare activities)		Inform the public on government programs for arable farming	
	Low crop prices		Public education and sensitizations on appropriate seed varieties for specific seasons	

considered useful for short-term forecasting and those, which are meant for long-term predictions. In sections 4f(1)–4f(3), we present the viewpoints of community leaders on certain indicators as commonly held by the community people.

1) ANIMALS, BIRDS, AND INSECTS

Specifically, an elder (an arbiter) in Ngarange community as reported in Kolawole et al. (2012, p. 72) commented:

> [c]ertain animals, insects and birds serve as useful weather indicators. For example, a rainy year is imminent if wildebeests (*Kgokong*) give birth in large numbers. Also, the flight pattern of bees could be used to predict whether the rains would be abundant or not in a given season; it is a year of less rain or dryness if they are seen fly towards the direction of the west, but otherwise if seen fly to the east direction. Dryness is imminent if the honeybee bird is seen fly close to the ground. However, the season will be full of abundant rains if it flies higher. Also, a year of good rains is predicted when beetles are frequently seen prior to and during rains. (A village arbiter in Ngarange community.)

2) STARS AND TOADS

Another elder (also an arbiter) from Ngarange community, who participated in the workshop (see Kolawole et al. 2012, p. 73), commented thus:

TABLE 6. Natural elements/indicators used to predict weather conditions and actions to take (group 2; n = 13). (Source: START workshop, 2012.)

Weather condition	Indicators	Use of information
Drought	Stunted fruits (e.g., tsaudi, mogoro, and mochaba)	Public discussions on alternative livelihoods options
	Stars/galaxies out of their normal positions (e.g., selemela)	Preservation of seeds
	Drying up of rivers	
High/low floods	Low or high rains	Relocation/migration
High rainfall	Abundant first rains	Preparedness for plough season
	Fruiting of trees	
	Thick black clouds originating from the east	
	Thick black rolling clouds	
Veldt fires	Dense vegetation	Public announcements advising community members to be cautious not to cause wild fires

. . .There are some particularly bright stars, which are usually referred to as female and male stars; seeing them together is a good sign of abundant rainfall. Nonetheless, if they are seen moving away from each other in different directions, this symbolizes a year of drought. When toads (*Matametu*), which are noted for staying in the pans, are heard croaking. . . , it is a sign of good rains. But if they are not heard quite often, this is a clear sign of rain scarcity. (A village elder in Ngarange.)

. . .Regarding the movement of stars (*Naledi*), sighting two bright stars often on the west axis of our village typifies a clear sign of low rainfall in a given year. Conversely, there will be plenty of rainfall if the stars are spotted on the east axis. (A village elder in Jao community.)

3) TEMPERATURE, WIND, SUN, THUNDERSTORMS AND CLOUD COVER

Natural elements such as temperature, wind, sun, and cloud are also used as indicators. A community elder, as reported in Kolawole et al. (2012, p. 73), remarked:

In a situation where the month of October is unbearably hot, this indicates that there will be less rain in the given year or season. Also, when the occurrences of early rains are brief but do not last for too long and they are accompanied by thunderstorms, this indicates that there will be less rain in the year in question. This signal serves as a guide for making decisions on farming. (Jao community elder.)

Broadening the scope of the use of natural indicators, an elder from Ngarange community commented (Kolawole et al. 2012, p. 73):

. . .good wind flows typifies an imminent abundant rainfall season. The color of the sun is also a good predictor of weather. The nature or pattern of cloud cover is a good predictor as well. Poorly developed clouds, which appear thin and scattered at the advent of the raining season is an indication of less rainfall. Nonetheless, rains would be abundant when clouds are thick and properly developed. . .We had traditional doctors/dancers who seasonally review the weather by occasionally calling for meetings or dances. Through divinations (*Ditaola*) and songs, they could communicate with the Ancestors who reveal what the season portends. In terms of weather conditions, the year is usually reviewed in the month of August through special traditional dances and use of *Ditaola.* (A village arbiter in Ngarange community; see also, Kolawole et al. 2012.)

5. Discussion: Implications for climate change

Climate variability and its effects on agricultural production are intricately linked with the kind of adaptation strategies devised by rural households to overcome the challenges they face because of the uncertainties in weather conditions. The local strategies these farmers devise (through the use of indigenous knowledge) are in turn borne out of environment-related experiences, which they have acquired over many years. Thus, the study examined the climate variations observed by rural households, the levels of climatic impacts on farm-based livelihood activities, and the specific crops (maize, millet, sorghum, watermelon, etc.) that were affected. The households' experiential knowledge and ability to provide in situ data on the magnitude of and trends in farm losses resulting from climate variability over many years provide an important insight on the impact of the phenomenon in the Okavango Delta, Botswana. The local-level climatic variations revealed patterns that were unfamiliar to the households in the area. These include the generally confusing nature of the onset and end of the rain season. The apparent confusion over the types of seasonal shifts, as observed by households in this study, indicates the level of uncertainty, which they are likely to face in future. Since this study is premised on households' personal experiences within a period of only 10 yr, which is a relatively short time on which to base climate change studies, we can only hypothesize that the seasonal shifts observed could be due to climate change. Shifting of seasons is a commonly observed climate change–related phenomenon in other parts of the world. For instance, in India farming households observed that during the monsoon season, rains are delayed by several weeks and they are not as evenly distributed in time as they used to be (Pande and Akermann 2008). It should be noted that the impacts of climate variability are difficult to differentiate from those of climate change in many parts of the world (IPCC 2013). However, some of the impacts may be identified from previously unknown events or effects, which may have not been experienced in the observable past.

Intricately connected with and embedded in their cultural and socioecological environment (Bronfenbrenner 1979), rural households observe and interact with their immediate surroundings to generate indigenous knowledge systems, including ethnometeorology. Thus, the study further revealed various ways in which households could forecast the weather by observing propagation and behavioral patterns among flora and fauna, respectively. These indicators of short-term climatic variations have been used by households for a very long time and have enhanced rural households' relative success in both arable and livestock farming under very difficult climatic conditions. Some of these long-term observations may be useful for weather and climate monitoring. Observation of some changes in animal and plant responses to climatic conditions can also reveal early signs of climate change impacts. For instance, observation of change in a study of 1634 plant species on four continents established that wild plants responded to climatic temperature changes by 8.5-fold for flowering and 4.5-fold for leafing, faster than scientific experiments initially estimated (Wolkovich et al. 2012). Future climate change may also increase the intensity and frequency of climate variability in the Okavango Delta. According to Kgathi et al. (2013), the future flows of the Okavango River are expected to be lower than those of the twentieth century as a result of climate change. Despite the fact that the interannual and pluriannual variability in flood levels is expected to continue to occur, it is likely that there will be reduced frequency of high flood levels and an increase in the severity of desiccation. These may decrease economic growth, exacerbate poverty, and ultimately decrease human welfare.

This study also revealed that certain observations of weather and early warning signals emanated from community-level interpretations and discussions that ultimately informed response options, including livelihood choice, decisions for relocation and migration, and the preservation of seeds to avert losses. These observations also influenced households' decisions on seasonal forecast in relation to production activities in a given farming season. The current findings corroborate those of other studies, which established that indigenous early warning was well understood by local communities and often enhanced effective responses to shocks (Howell 2003). If such knowledge is blended with scientific weather forecasts, appropriate decisions for planning can be made. For instance, when weather scientists observe and interpret weather conditions based on modern science, they can discuss these with the communities to identify commonalities and help local communities develop effective adaptation strategies. Besides, the process of engaging with local communities might enhance rural capacity development, which in the long run could drive sustainable rural development; endogenous capacity development enhances knowledge and skill acquisitions necessary for mobilizing community resources for developmental purposes (Kolawole 2014b; United Nations 2009; Lele 1975).

Modeling of climate scenarios is awash with uncertainty, which can be reduced if certain observations made over many decades are factored in. Some long-term observations of plants, insects, frogs, and other fauna as revealed in this study demonstrate the wide range of observations, which can help modern scientists in the monitoring of climate change impacts at various scales. Modern methods for scientific modeling and early warning have often ignored indigenous knowledge, which invariably downplay the importance of local people's wisdom in understanding the complexity and mystery of certain natural phenomena. For instance, Bernard and Moetapele (2005) confirm that hydrological models developed for the delta used only biophysical observations of flooding patterns without factoring in human actions as possible influencing factors of the flooding patterns of the delta. The exclusion of such information suggests that local communities' understanding of and actions on climate variability are either peripheral or of no importance and, therefore, ignored in policy making.

6. Conclusions

The paper analyzed the effect of climate variability on agricultural production in the Okavango Delta over the last 10 years. It identified a number of local adaptation strategies adopted by rural households. The research also investigated how farming households' personal experiences and scientific seasonal weather forecasts guided the choices made during farming operations. It also identified the types of indigenous weather forecasting indicators used by the rural households in the area.

This study revealed that climate variability and other related factors had adverse impacts on agricultural production and related assets. The coping strategies adopted by households included early planting of crops, securing temporary social welfare scheme jobs, and obtaining government compensation for crops damaged by wildlife. Findings in this paper indicated that households mostly relied on the natural phenomena they observed within their immediate environment, and they used the information, which they well understood, for decision-making. If such information is known and integrated into scientific weather forecasts, then households will better understand the importance of weather information. The uncertainty of the indicators known to households can also be reduced, resulting in a win–win scenario for households, scientists, and decision-makers.

Indigenous knowledge and observation of some plant and animal behavior can serve as early detectors of climate change impacts and may therefore be valuable in setting scenarios for coping with and adapting to climatic shocks. Early detection of climate impacts through indigenous knowledge can therefore serve as a basis for vulnerability assessment and early preparation for climate variability and change impacts. If it is known that certain plants and animals may respond in certain ways to some conditions, then planning for rural household adaptation can be done based on these early indicators of change in climatic conditions. Some of the plants and animals observed can be used as indicators in environmental monitoring. The evidence emanating from indigenous knowledge can help modern scientific analysts determine future trends and enhance sustainable adaptation to climate variability and change. More importantly, households' astuteness in quantifying the impacts of climate variability on crop and animal production over a period of 10 yr in the delta provides the basis for effective policy formulation and implementation in addressing the problem in Botswana and other similar ecological climes.

Acknowledgments. We thank START and the U.S. National Science Foundation (NSF) for awarding us the 2011 Grants for Global Environmental Change Research in Africa. We also acknowledge the assistance and roles of our field technical officers, Ronald Mothobi and Wilfred Khaneguba, in producing the report from which this paper emanates.

REFERENCES

Adger, W. N., and Coauthors, 2009: Are there social limits to adaptation to climate change? *Climatic Change*, **93**, 335–354, doi:10.1007/s10584-008-9520-z.

Altieri, M. A., and P. Koohafkan, 2008: *Enduring Farms: Climate Change, Smallholders and Traditional Farming Communities*. Environment and Development Series, Vol. 6, Third World Network, 63 pp.

Bates, B. C., Z. W. Kundzewicz, S. Wu, and J. P. Palutikof, Eds., 2008: Climate change and water. IPCC Tech. Paper VI, 214 pp. [Available online at http://ipcc.ch/pdf/technical-papers/climate-change-water-en.pdf.]

Bendsen, H., 2003: The dynamics of land use systems in Ngamiland: Changing livelihood options and strategies. University of Botswana, Harry Oppenheimer Okavango Research Centre Tech. Rep., 28 pp.

Bernard, T., and N. Moetapele, 2005: Desiccation of the Gomoti River: Biophysical process and indigenous resource management in northern Botswana. *J. Arid Environ.*, **63**, 256–283, doi:10.1016/j.jaridenv.2005.02.001.

Bourdieu, P., 1977: *Outline of a Theory of Practice*. Cambridge University Press, 248 pp.

Bronfenbrenner, U., 1979: *The Ecology of Human Development: Experiments by Nature and Design*. Harvard University Press, 330 pp.

Bryceson, D. F., 2002: The scramble in Africa: Reorienting rural livelihoods. *World Dev.*, **30**, 725–739, doi:10.1016/S0305-750X(02)00006-2.

Central Statistics Office, 2011: 2011 Botswana population and housing census. Central Statistics Office, Ministry of Finance and Development, Preliminary Results Brief, accessed 29 September 2012. [Available online at http://ecastats.uneca.org/aicmd/Portals/0/Census%202011%20Preliminary%20%20Brief%20Sept%2029%202011.pdf.]

de Jalón, S. G., A. Iglesias, and A. P. Barnes, 2014: Drivers of farm-level adaptation to climate change in Africa: An evaluation by a composite index of potential adoption. *Mitig. Adapt. Strategies Global Change*, 1–20, doi:10.1007/s11027-014-9626-8.

den Biggelaar, C., 1991: Farming systems development: Synthesizing indigenous and scientific knowledge systems. *Agric. Hum. Values*, **8**, 25–36, doi:10.1007/BF01579654.

Dennis, C., 1978: The role of "Dingaka tsa setswana" from the 19th century to the present. *Botswana Notes Rec.*, **10**, 53–66. [Available online at http://www.jstor.org/stable/40979537.]

Dougill, A., E. D. G. Fraser, and M. S. Reed, 2010: Anticipating vulnerability to climate change in the dryland pastoral systems: Using dynamic systems model for the Kalahari. *Ecol. Soc.*, **15**, 17. [Available online at http://www.ecologyandsociety.org/vol15/iss2/art17/.]

Dube, M. W., 2014: Translating "Ngaka": Robert Moffat rewriting an indigenous healer. *Stud. Hist. Ecclesiasticae*, **40**, 157–172. [Available online at http://hdl.handle.net/10500/13705.]

Eakin, H., 2005: Institutional change, climate risk, and rural vulnerability: Cases from central Mexico. *World Dev.*, **33**, 1923–1938, doi:10.1016/j.worlddev.2005.06.005.

Ellis, F., 2000: *Rural Livelihoods and Diversity in Developing Countries*. Oxford University Press, 273 pp.

——, and E. Allison, 2004: Livelihood diversification and natural resource access. FAO Livelihood Support Programme Working Paper 9, 46 pp. [Available online at ftp://ftp.fao.org/docrep/fao/006/AD689E/AD689E00.pdf.]

Gewald, J., 2002: El Negro, El Niño, witchcraft and the absence of rain. *Pula: Botswana J. Afr. Stud.*, **16**, 37–51.

Gill, P., K. Stewart, E. Treasure, and B. Chadwick, 2008: Methods of data collection in qualitative research: Interviews and focus groups. *Br. Dent. J.*, **204**, 291–295, doi:10.1038/bdj.2008.192.

Gwebu, T. D., T. Baakile, and G. Mphetolang, 2014: Population distribution, structure, density and policy implications in Botswana. Population and Housing Census 2011 Analytical Rep., Statistics Botswana, 2–16.

Hernandez, V., V. Moron, F. Fossa Riglos, and E. Muzi, 2015: Confronting farmers' perceptions of climatic vulnerability with observed relationships between yields and climate variability in central Argentina. *Wea. Climate Soc.*, **7**, 39–59, doi:10.1175/WCAS-D-13-00062.1.

Howell, P., 2003: Indigenous early warning indicators of cyclones: Potential application in coastal Bangladesh. Benfield Hazard Research Centre Rep., Disaster Studies Working Paper 6, 10 pp.

Huffman, T. N., 2009: A cultural proxy for drought: Ritual burning in the Iron Age of southern Africa. *J. Archaeol. Sci.*, **36**, 991–1005, doi:10.1016/j.jas.2008.11.026.

Ifejika-Speranza, C., B. Kiteme, P. Ambenje, U. Wiesmann, and S. Makali, 2010: Indigenous knowledge related to climate variability and change: Insights from droughts in semi-arid areas of former Makueni District, Kenya. *Climatic Change*, **100**, 295–315, doi:10.1007/s10584-009-9713-0.

IPCC, 2001: *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. Cambridge University Press, 1032 pp.

——, 2007: *Climate Change 2007: Synthesis Report*. Cambridge University Press, 103 pp. [Available online at https://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_full_report.pdf.]

——, 2013: Summary for policymakers. *Climate Change 2013: The Physical Science Basis*, T. F. Stocker et al., Eds., Cambridge University Press, 3–29.

——, 2014: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects.* V. R. Barros et al., Eds., Cambridge University Press, 688 pp. [Available online at http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-PartB_FINAL.pdf.]

Kgathi, D. L., and M. R. Motsholapheko, 2011: Livelihood activities and income portfolios in rural areas of the Okavango Delta, Botswana. *Rural Livelihoods, Risk and Political Economy of Access to Natural Resources in the Okavango Delta, Botswana*, D. L. Kgathi, B. N. Ngwenya, and M. B. K. Darkoh, Eds., Nova Science Publishers, 35–54.

——, G. Mmopelwa, C. Vanderpost, P. Wolski, and M. R. Motsholapheko, 2013: Impacts of desiccation on ecosystem services and household adaptation in the Okavango Delta, Botswana. *Biodiversity Ecol.*, **5**, 263–277, doi:10.7809/b-e.00280.

Kolawole, O. D., 2014a: Habitus: How cultural values shape local communities' perceptions about flood in the Okavango Delta of Botswana. *Flooding: Risk Factors, Environmental Impacts, and Management Strategies*, M. R. Motsholapheko and D. L. Kgathi, Eds., Nova Science Publishers, 87–107.

——, 2014b: Whither sustainable rural development? A critical exploration of remote communities in and around the Okavango Delta, Botswana. *Span. J. Rural Dev.*, **5**, 99–114, doi:10.5261/2014.GEN3.09.

——, P. Wolski, B. N. Ngwenya, G. Mmopelwa, and O. Thakadu, 2012: Engaging farmers and climatologists in adaptation to climate variability and change in the Okavango Delta of Botswana. Global Change Systems for Analysis, Research and Training Global Environmental Change (GEC) Research Program in Climate Change, Agriculture, and Food Security Tech. Rep., 105 pp. [Available online at http://www.start.org/download/gec11/kolawole-final-report.pdf.]

——, ——, B. Ngwenya, and G. Mmopelwa, 2014: Ethno-meteorology and scientific weather forecasting: Small farmers and scientists' perspectives on climate variability in the Okavango Delta, Botswana. *Climate Risk Manage.*, **4–5**, 43–58, doi:10.1016/j.crm.2014.08.002.

Landau, P. S., 1993: When rain falls: Rainmaking and community in a Tswana village, c. 1870 to recent times. *Int. J. Afr. Hist. Stud.*, **26**, 1–30, doi:10.2307/219185.

Lele, U., 1975: *The Design of Rural Development: Lessons from Africa*. Johns Hopkins University Press, 246 pp.

Martin, M., and H. Bargawi, 2005: Protecting Africa against "shocks." *Protecting the Poor: Global Financial Institutions and the Vulnerability of Low-Income Countries*, J. J. Teunissen and A. Akkerman, Eds., FONDAD, 42–71.

Mendelson, R., and A. Dinar, 2009: *Climate Change and Agriculture: An Economic Analysis of Global Impacts, Adaptation and Distributional Effects*. Edward Elgar, 246 pp.

Mogotsi, K., A. B. Moroka, O. Sitang, and R. Chibua, 2011: Seasonal precipitation forecasts: Agro-ecological knowledge among rural Kalahari communities. *Afr. J. Agric. Res.*, **6**, 916–922.

Motsholapheko, M. R., C. Vanderpost, and D. L. Kgathi, 2012a: Rural livelihood and household adaptation to desiccation in the Okavango Delta, Botswana. *J. Water Climate Change*, **3**, 300–316, doi:10.2166/wcc.2012.048.

——, D. L. Kgathi, and C. Vanderpost, 2012b: Rural livelihood diversification: A household adaptive strategy against flood variability in the Okavango Delta, Botswana. *Agrekon*, **51**, 41–62, doi:10.1080/03031853.2012.741204.

Musemwa, L., V. Muchenje, A. Mushunje, and L. Zhou, 2012: The impact of climate change on livestock production amongst the resource-poor farmers of third world countries: A review. *Asian J. Agric. Rural Dev.*, **2**, 621–631.

Mutekwa, V. T., 2009: Climate change impacts and adaptation in the agricultural sector: The case of smallholder farmers in Zimbabwe. *J. Sustainable Dev. Afr.*, **11**, 237–256.

Newel, K., 2010: Hosanna, the Bakalanga rainmaking dance. *Mmegi Online*, 22 October 2010. [Available online at http://www.mmegi.bw/index.php?sid=6&aid=5835&dir=2010/October/Friday22.]

Noble, I., 2007: The changing climate—What we know, what we will never know, and what we are learning. *Environment Matters: Annual Review*, World Bank, 14–17. [Available online at http://siteresources.worldbank.org/INTENVMAT/64199955-1203372965627/21654310/EMatters_07.pdf.]

Nyong, A., F. Adesina, and B. Osman Elasha, 2007: The value of indigenous knowledge in climate change mitigation and adaptation strategies in the African Sahel. *Mitig. Adapt. Strategies Global Change*, **12**, 787–797, doi:10.1007/s11027-007-9099-0.

Olesen, J. E., and M. Bindi, 2002: Consequences of climate change for European agricultural productivity, land use and policy. *Eur. J. Agron.*, **16**, 239–262, doi:10.1016/S1161-0301(02)00004-7.

Onyango, M., 2009: Kenya rainmakers called to the rescue to combat climate change. *The Himalayan Times*, 20 September 2009. [Available online at http://thehimalayantimes.com/news-archives/latest/kenya-rainmakers-called-to-the-rescue/.]

Orlove, B., C. Roncoli, M. Kabugo, and A. Majugu, 2010: Indigenous climate knowledge in southern Uganda: The multiple components of a dynamic regional system. *Climatic Change*, **100**, 243–265, doi:10.1007/s10584-009-9586-2.

Ouma, G., 2009: Stories from the field: Linking traditional and modern forecasting in western Kenya. Climate Change Adaptation in Africa Program 2008–09 year in review, accessed 11 November 2010. [Available online at http://r4d.dfid.gov.uk/PDF/Outputs/ClimateChange/CCAA_AR_2008-9_Forecasting_in_western_Kenya.pdf.]

Pande, P., and K. Akermann, 2008: Adaptation of small scale farmers to climatic risks in India. Sustainable Agriculture Information Network Rep., 101 pp. [Available online at http://www.sustainetea.org/downloads/file/27-adaptation-of-small-scale-farmers-to-climatic-risks-in-india.html.]

Pearce, D. W., A. Markadya, and E. B. Barbier, 1989: *Blueprint for a Green Economy*. Earthscan, 192 pp.

Sachs, J. D., 2009: *Common Wealth: Economics for a Crowded Planet*. Penguin, 400 pp.

Schaeffer, M., F. Baarsch, S. Adams, K. de Bruin, L. De Marez, S. Freitas, A. Hof, and B. Hare, 2013: Africa adaptation's gap: Climate-change impacts, adaptation challenges and costs for Africa. AMCEN, UNEP, and Climate Analytics Tech. Rep., 44 pp. [Available online at http://www.unep.org/pdf/AfricaAdapatationGapreport.pdf.]

Simelton, E., and Coauthors, 2013: Is rainfall really changing? Farmers' perceptions, meteorological data, and policy implications. *Climate Dev.*, **5**, 123–138, doi:10.1080/17565529.2012.751893.

Smit, B., and J. Wandel, 2006: Adaptation, adaptive capacity and vulnerability. *Global Environ. Change*, **16**, 282–292, doi:10.1016/j.gloenvcha.2006.03.008.

Statistics Botswana, 2013: Botswana core welfare indicators survey 2009/10: Main report. Statistics Botswana Rep., 259 pp.

——, 2014: 2012 annual agricultural survey report. Statistics Botswana Rep., 177 pp.

Stewart, D. W., and P. M. Shamdasani, 1990: *Focus Groups: Theory and Practice*. Sage, 153 pp.

United Nations, 2009: Decisions by topic: Rural development. United Nations Sustainable Development Knowledge Platform, Commission on Sustainable Development, E/CN.17/2009/19, accessed 26 November 2013. [Available online at http://sustainabledevelopment.un.org/index.php?menu=1263.]

USAID, 2013: Mid-term review and gap analysis of the Okavango Delta management plan. United States Agency for International Development, the Permanent Okavango River Basin Water Commission (OKACOM), and the Directorate for Infrastructure and Services, Water Division of the SADC Secretariat, SAREP Tech. Series Vol. 5, 161 pp. [Available online at http://pdf.usaid.gov/pdf_docs/PA00K8FD.pdf.]

Vanderpost, C., 2009: Molapo farming in the Okavango Delta. Harry Oppenheimer Okavango Research Centre, University of Botswana Fact Sheet 7/2009, acessed 16 September 2010. [Available online at http://www.orc.ub.bw/downloads/FS7_molapo_v1.pdf.]

Wacquant, L., 2013: Homines in extremis: What fighting scholars teach us about habitus. *Body Soc.*, **20**, 3–17, doi:10.1177/1357034X13501348.

Wolkovich, E. M., and Coauthors, 2012: Warming experiments underpredict plant phenological responses to climate change. *Nature*, **485**, 494–497, doi:10.1038/nature11014.

World Bank, 2013: World development report 2014: Risk and opportunity—Managing risk for development. World Bank Rep., 362 pp.