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Some Aspects of Agricultural Vulnerability to Climate Change in the KwaZulu-Natal Midlands, South Africa: A Systematic Review

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ABSTRACT The present study uses a systematic review method to document the extent of agricultural vulnerability to climate change (CC) in the midlands region of KwaZulu-Natal, South Africa. With regard to exposure, the CC detection literature suggests that the region is a hotspot of CC, and most climate model projections show warming and wetting trends towards the end of the 21st century. The sensitivity of farming systems is high due to high population density, large share of small-scale farmers, low rate of irrigation, and susceptibility to land degradation. The highly diversified cropping portfolios in the region are the major sources of resilience. The adaptive capacity is compromised by lack of access to public infrastructure, lower liquidity and income prospects, rural exodus, skills shortage, and limited inter-household cooperation. Policymakers should, therefore, devise a regional CC communication strategy, promote crop diversification and irrigation water governance, and mainstream CC adaptation in the rural development objectives.

INTRODUCTION

According to the fifth assessment report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), there is increasing consensus among the scientific community that climate change (CC) is occurring and many natural-resource-dependent economic sectors are likely to be affected by its impacts (Stocker et al. 2013). Sectoral impact assessments showthat the world's primary agricultural production is adversely affected by CC, particularly by increasing climatic variability (Porter et al. 2014). Assessments of vulnerability of world agriculture suggestthat the negative effects of CC affect more severely the smallholder and subsistence farmers in developing countries due to their over-reliance on natural resources, and the congruence of multiple shocks andstresses that affect their livelihoods and constrain their adaptive capacity (Easterling et al. 2007).

In South Africa, global warming has altered not only the overall magnitude of rainfall and temperatures, but also their seasonal distributions and inter-annual variability (Rouault and Richard 2003; Warburton et al. 2005;Crétat et al. 2012). A recent macro-level assessment of agricultural vulnerability to CC by Gbetibouo et al. (2010) suggested that the impacts of CC have not been evenly distributed across different provinces. Unlike in other provinces, such as Western Cape and Gauteng, the agricultural sector in the KwaZulu-Natal (KZN), Eastern Cape, and Limpopo provinces has higher scores of vulnerability. The sensitivity of KZN agriculture, in particular, is compounded by higher population density coupled with a larger share of small-scale farmers, over-reliance on rain-fed agriculture, and acute levels of land degradation. The provincial adaptive capacity is confounded by lower literacy rates, higher HIVprevalence, and inadequate access to infrastructure. Therefore, the KZN province should be of priority to CC response policy makers in South Africa.

Research Problem and Objective

Notwithstanding the importance of Gbetibouo et al.'s (2010) insights for informing the regional policy focus, it is a common argument that such macro-level assessments of vulnerability can mask substantial variability in micro and meso-level exposures, sensitivities and responses (Thornton et al. 2006). In a certain re-

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gion, there might be considerable heterogeneity in local climate, farming systems, and adaptive capacity. With this consideration, the purpose of the present study is to document some aspects of climate-related agricultural vulnerability in the midlands region of KZN. To that end, the study uses a systematic literature review method to provide an eclectic discourse about the extent of regional exposure, agricultural systems' sensitivity and adaptive capacity.

The remainder of the study is sub-divided into four sections. The subsequent methodological section describes briefly the study area, the analytical framework, and the systematic review method. It is followed by a section presenting the existing research evidence on the extent of exposure, sensitivity and adaptive capacity of farming systems in the region. The last two sections respectively draw some concluding remarks and outline some recommendations for policy and research.

METHODOLOGY

Description of the KZN Midlands Agro-ecology

The midlands region of the KZN province is an inland area stretching between the low lying coastal strip of the Indian Ocean and the high altitudes of the Drakensberg escarpment (see Fig. 1). Based on the Koppen climate classification (Peel et al. 2007), the KZN midlands is located in the subtropical oceanic climate zone, marked by cool and dry winters and mild sum-

Fig.1. Geographical regions of the KwaZulu-Natal province, South Africa
Source: http://www.roomsforafrica.com/

mers. This region is one of the country's three principal agro-ecological regions (*viz*. the summer Highveld plateau in the Free State, the winter rainfall region of the Western Cape, and the Highveld and Midlands regions of KZN) (Benhin 2006).

The KZN midlands region has 876,049 hectares of the land surface (Mkhabela and Materechera 2003). The landscape matrix in this region is dominated by commercial forestry in the wetter slopes of the Karklo of mountain range and the Blinkwater mountain in the north-western quadrants, whilst commercial and subsistence-crop production and livestock farming are the dominant land uses in the low-lying, drier areas (Lawes et al. 2004). As shown by various agro-climatic suitability maps, this region is an optimal growth area for perennial crops such as sugarcane (Schulze and Kunz 2010), commercial forestry (Warburton and Schulze 2008), and sub-tropical fruits such as avocado and granadilla (Schulze and Kunz 1995; Allemann and Young 2006).

Conceptual Structuring of the Review

The IPCC defines vulnerability as "the degree to which a bio-physical or socio-economic system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes" (Schneider et al. 2007: 783).Vulnerability is viewed as an aggregate term comprising exposure, sensitivity, and adaptive capacity (Adger 2006). The empirical literature approaches vulnerability assessment from two perspectives: the vulnerability variable assessments and the indicator approach.The vulnerability variable assessment consists of measuring and assessing the changes in selected variables of a system attributed to sets of specific stressors, based on a number of metrics (Luers et al. 2003). Not withstanding the importance of this method, its metrics cannot sufficiently capture all the dimensions of vulnerability (Luers et al. 2003). The indicator approach measures vulnerability by combining a set of proxy indicators with different relative weights (Gbetibouo et al. 2010). The weighting is based on subjective or statistical methods.

To document the aspects of agricultural vulnerability to CC in the KZN midlands, the present study adopts the indicator approach. Following Gbetibouo et al. (2010), the indicators chosen for the review are presentedin Table 1. The extent of exposure is indicated by detected and projected climatic trends. With regard to the sensitivity of farming systems, populationdensity is used to indicate the number of people who could be at climate risk, whilst share of small-scale farmers portrays the associated socio-economic vulnerability in the form of small farm sizes, low capitalization and technology adoption rates, and multiplicity of livelihood stressors. Irrigation represents the resilience of small-scale farming systems. Crop diversification indicates the advantages of variance in the effects of rainfall and temperature on heterogeneous cropping patterns (Bradshaw et al. 2004; Reidsma and Ewert 2008; Reidsma et al. 2010). Land degradation indicates the quality of land, that is, its productivity and sustainability under CC conditions.

To portray the regional adaptive capacity, physical capital indicates the relative access to markets in times of climatic crisis. Financial assets represent economic diversification that reduces the susceptibility to CC. Access to human capital indicates the relative availability and quality of labour to mitigate the effects of CC. Social capital portrays the relative access to social networks to overcome the challenges associated with remoteness and isolation such as access to information, credit, and collective action.

Systematic Review Approach

To apply the indicator approach to the investigation of agricultural vulnerability in the KZN midlands, the present study uses a sys-

Table 1: Selected indicators for the assessment of agricultural vulnerability to CC

Exposure	*Sensitivity*	*Adaptive capacity*
• Detected CC • GCM projections	• Rural population density • Share of small-scale farmers • Irrigation • Crop diversification • Land degradation	• Access to physical capital • Access to financial capital • Access to human capital • Access to social capital

Source: Based on Gbetibouo et al. (2010) typology.

tematic review of the empirical literature. The method consists of identifying and synthesizing peer-reviewed research evidence relevant to a certain research problem (Bronson and Davis 2011). Searches were conducted using the University of KwaZulu-Natal (UKZN) online database. For general literature, the Google Scholar® search engine was also used. However, in some cases, the search resorted to grey literature, that is, research works that cannot be found through the conventional channels such as publishers and scholarly literature databases.

The search led to an inventory of over 60 peer-reviewed journal articles, reports, and unpublished theses. A concept-centric approach was used to classify and synthesize the collected literature. Based on the proposed indicator framework, the studies were grouped, summarized and analysed in accordance with the three aspects of vulnerability to CC.

OBSERVATIONS AND DISCUSSION

Exposure to Climatic Changes in the KZN Midlands

Detection of CC

The existing literature shows that the local climate has exhibited clear signs of warming and wetting trends. As an evidence, a comparative analysis of the 1950 - 1970 vs. 1980-2000 periods' temperatures and runoffs by Warburton et al. (2005) unveiled two clear clusters of warming, *viz.* the midlands and south coast regions of KZN, and some areas in the Western Cape province. The study revealed that historical records of clusters of stations in the KZN midlands exhibit increasing trends in annual means of daily minimum temperatures and summer means of daily maximum temperatures, increasing and decreasing number of days per year of below the 10th percentile of winter daily minimum and summer daily maximum temperatures, as well as decreasing and increasing trends in the number of frost occurrences and heat units, respectively, per season.

The hydrological modelling of Warburton et al. (2005) further showed an increasing trend in accumulated annual total of rainfall-driven daily river flows, and higher ratios of later (1980 – 1999) to earlier (1950 – 1969) highest annual accumulated runoffs in ten years.

CC Model Projections

Other CC researchers have primarily focused on climate projection under different scenarios. Based on a set of high-resolution scenarios created through the process of downscaling, Engelbrecht et al. (2011) derived regional climate response to the larger scale atmospheric dynamics. Based on the CSIRO's Conformal-Cubic Atmospheric Model (C-CAM) ensemble under the A2 emission scenario, the study projected temperature increase ranging from 2^0C to 3^0C, coupled with -10% drying and pockets of 10% wetting trends over the KZN province for the period 2071- 2100 relative to 1961-1990. For the KZN midlands region, based on the regional climate scenarios derived from GCMs of AR4, Lumsden et al. (2009) showed evident patterns of 10% to 20% increase in precipitation towards the last quarter of the 21st century.

Sensitivity of Farming Systems in the KZN Midlands

Rural Population Density and Share of Small-scale Farmers

The midlands region of KZN is inhabited by approximately 1.6 million people (Mkhabela and Materechera 2003). This figure brings the population density to about 182.6 inhabitants per km^2, which is by far more than the provincial population density of about 110 people per km^2. Therefore, if no major responsive policy actions are taken, a large cross-section of inhabitants could face significant risks associated with climatic changes.

Estimates suggest that nearly 80% of the KZN midlands' population are small-scale, dryland farmers. About 86% of them cultivate maize on less than 2 hectares of communal land, mainly for household consumption (Mkhabela and Materechera 2003). For this region, Abraha and Savage (2006) reported that maize grain yield response to a scenario of '2 X CO_2+2^0C' and +10% rainfall could range from +6% (for early planting) to +10% (for late planting). However, their simulation suggested that any increase in temperature beyond +2^0C (corresponding a 50-day reduction in the average growing season length compared to the baseline) could lower the grain yield to a level of 7% below baseline yield, even under a +20% rainfall scenario. Therefore, small-scale farmers' vulnerability to food insecurity is acutely pronounced in this region.

Only few farmers practice market-oriented farming such as sugarcane and forest production. Research shows that these land uses could be resilient under projected climatic changes. Schulze and Kunz (2010) and Warburton and Schulze (2008), based on ECHAM5/MPI-OM GCM, projected major gains in climatically optimum growth areas for dryland sugarcane and eucalyptus in some interior and western parts of the region by the intermediate (2046-2065) and distant futures (2081-2100).

Irrigation

Despite the fact that the majority of the region's inhabitants are dryland farmers, the northern part of the region hosts one of the largest small-scale irrigation schemes in the province. The Tugela-Ferry irrigation scheme along the Thukela river covers an area of approximately 840 hectares of high-potential soils, and currently over 540 hectares are under cultivation by nearly 1000 producers (Cousins 2013). On average, a household in the small-scale irrigation scheme has 0.27 hectare of farmland under irrigation (Muchara et al. 2014).

Based on ten regionally downscaled future climate projections, an assessment of the CC impacts on the hydrology of the Thukela River by Graham et al.(2011) showed a significant signal for an increase in river runoff, particularly towards the end of the 21st century.

However, following the irrigation management transfer from government agencies to water users, access to water by scheme members has been challenged by issues of siltation, cracks, leaks and dysfunctional holding dams resulting from inadequate maintenance and repair work since the 1960s (Cousins 2013). Muchara et al. (2014) reported that 63% of farmers in the scheme lack any formal training in irrigation water management, and more than 17% do not currently participate in irrigation water management at all. Inadequate access to irrigation water increases household's working time budget (Reid and Vogel 2006), with adverse impacts on small-scale farmers' welfare and food security (Sinyolo et al. 2014a, 2014b). If the weak or dysfunctional institutional governance of irrigation water is not addressed, therefore, it could prevent small-scale farmers from taking advantage of projected increases in river runoff.

Crop Diversification

To the vast majority of small-scale farmers lacking access to irrigation water, crop diversification offers a simple form of agricultural risk mitigation. Empirical studies show that household cropping portfolios in the region are highly diversified. In the Mkhambathini Local Municipality, for example, Kisaka-Lwayo and Obi (2012) reported a Herfindahl Index of crop diversification[1] ranging between 0.23 (among non-organic farmers) and 0.89 (among partially certified organic farmers). The diversification comprises a mixture of annual crops such as taro, potatoes, green beans, maize, chillies and peas, with semi-perennials such as sugarcane and bananas. Similar crop diversification patterns were reported in the small-scale farming systems of the Tugela-Ferry irrigation scheme in the Msinga District (Mkhabela 2005). Mixed crop-livestock production is also a common aspect of farming systems in the region (Ndoro et al. 2014a, 2014b; Ndoro and Hitayezu 2014).

Therefore, land use constitutes an important aspect of resilience in small-scale farming systems in the midlands region. Indeed, Mkhabela (2005) found that technical efficiency of vegetable-based farming systems increased with intensity of crop diversity (from combinations of two to six crops). It is noteworthy, however, that, in the KZN midlands region, crop diversification is not a response to perceived CC, but rather a mechanism to manage other sources of risk pertaining to price uncertainty, access to input and output markets, and labour availability (Kisaka-Lwayo and Obi 2012). Indeed, for the region, a qualitative investigation by Wilk et al. (2013) revealed that whilst commercial farmers reacted to bad years by expanding and diversifying into other crops, small-scale farmers often responded by specializing in farming maize only (due to economic constraints), thereby decreasing their resilience.

Land Degradation

Estimates suggest that around 35% of the region's land surface is arable, and 20% is considered to harbour soils of high agricultural potential (Mkhabela and Materechera 2003). However, land degradation is a major concern for ecological sustainability in South Africa, particularly for small-scale farming systems operating on communal lands. An index combining water, soil and vegetation degradation compiled by Hoffman and Ashwell (2001) indicated that, generally, the KZN midlands have light to moderate land degradation indexes, although the north-eastern parts of the region (where small-scale, subsistence farming is concentrated) show severe degradation scores. Wessels et al. (2007) further showed that the rate of degradation in the region has been moderately increasing.

The acute land degradation in communal land areas is partly a legacy of the segregationist apartheid regime that relocated subsistence farming to 'homeland' areas, often characterised by steeper slopes (Meadows and Hoffman 2003; Palmer and Bennett 2013). However, Wessels et al. (2007) showed that CC is the most significant confounding factor. They showed that areas with higher rainfall variability also experienced high variability in net primary vegetation production, particularly in and around communal land areas. In the future, based on the downscaling of the Climate Systems Model (CSM) and the Genesis model, Meadows and Hoffman(2003) showed that the projected wetter summers in the KZN midlands region could indicate a high risk of land degradation in the former homelands due to steeper slopes, uncontrolled grazing, and intensive cultivation, particularly during hotter periods.

Adaptive Capacity

Access to Physical Capital

The region has good road networks and access to the provincial (R33) as well as national highways (N3) linking its municipalities to major economic centres such as Pietermaritzburg and Durban. However, small-scale farmers in communal land areas have little access to such facilities. A recent study by Dinkelman (2011) showed that, on average, farmers in communal lands of KZN travel 37km to the nearest tarred road. In the Swayimana and Umzumbe districts, for example, Hendriks and Lyne (2003) showed that small-scale farmers walk on average 35km to reach the nearest tarred road, and less than 8% of farmers owned a vehicle. Hendriks and Lyne (2003) further showed that only 12% of households had access to electricity, and farmers had to travel more than 9km to reach the nearest public telephone. As Matungul et al. (2001) contended, this lack of access to public and private infrastructure severely constrains their ability to participate in the market economy. Consequently, without external intervention, the ability of the midlands farmers to absorb and recover from climate-related shocks and stresses remains constrained.

Access to Financial Assets

With an acute lack of access to infrastructure, smallholder agriculture in the KZN midlands is not commercialized. In the Muden area, Reid and Vogel (2006) found that households' annual farm income averages 1,265 South African Rand (ZAR) (currently equivalent to US$ 111), compared to off-farm incomes of ZAR7, 400 or US$ 654 per year. However, they also show that social grants of about ZAR650 (equivalent to US$57) per month constitute a considerable proportion of household incomes. Similar findings were reported by a recent study conducted by Sinyolo et al. (2014b) among small-scale farmers around the Tugela Ferry irrigation scheme, showing that annual farm income ranges from ZAR312 or US$27 (non-irrigators) to ZAR15,341 or US$1,357 (irrigators), compared to an off-farm income range of ZAR42,332 or US$3,746 (non-irrigators) to ZAR36,333 or US$3,215 (irrigators).

A study conducted by Graham and Darroch (2001) showed that lower liquidity and income prospect, coupled with land tenure insecurity, and lack of technical and managerial capabilities have constrained farmers' access to agricultural credit. They found that less than 10% of farmers participated in agricultural credit markets as borrowers. In addition to the lack of credit access, Hendriks and Lyne (2003) found that saving rates in this area are negligible, as household expenditures almost equate incomes. Among groups of land reform beneficiaries, Shinns and Lyne (2004) showed that most of the household financial assets are kept in the form of livestock due to its relatively high liquidity. The lack of access to credit and overreliance on transfers from government heightens the levels of farmers' vulnerability to CC.

Access to Human Capital

The relatively low levels of incomes in the regional agricultural economy coupled with the geographical proximity of major urban centres in the area are a source of an increasing trend in outward migration. Even though households in the KZN midlands tend to have more than six members (Matungul et al. 2001; Sharaunga et al. 2013), many economically active men leave communal land areas to work in major urban centres, leaving women, children and the elderly to work the land (Hoffman and Ashwell 2001; Denis and Ntsimane 2006). For example, a survey by Hendriks and Lyne (2003) conducted in two communities of Swayimana and Uzumbe districts revealed that between 65% and 77% of households had migrant members.

Consequently, estimates have suggested that nearly 90% of farm workers in this region are women, elderly and uneducated (Reid and Vogel 2006). In the Tugela-Ferry irrigation scheme, for example, the farm household surveys by Sinyolo et al. (2014b) and Muchara et al. (2014) revealed that the majority of farm household heads are ageing (>56 years) and uneducated (<3 years of formal education) women. Early farm household surveys conducted in the KZN midlands had reported similar figures (Matungul et al. 2001). Yet, in this region the HIV prevalence among women is 37%, and more than 80% of the 1% TB patients are HIV co-infected (Gandhi et al. 2010).

The poverty of agricultural extension services in this region is also noteworthy. In the Msinga District, Sinyolo et al.(2014b) reported rates of participation in extension programs ranging from 35% (of non-irrigators) to 70% (of irrigators). In the Impendle and Swayimana Districts, Matungul et al. (2001) found that, on average, a farm household had received only one extension visit or training per year.

The rural exodus and lack of household capabilities, coupled with the lack of access to finance and dysfunctional land markets often lead to underutilization of land. This situation creates acute allocative inefficiencies and equity issues, whereby those who have capabilities to use land resources more economically and those willing to lease or sell their land plots are hindered (Crookes and Lyne 2003). Consequently, poverty in the KZN midlands tends to be associated with household demographics. Shinns and Lyne (2005), for example, found that households with the lowest per capita income and wealth tended to be female-headed and larger in terms of membership. They further showed that asset-rich households had more skills (in terms of high school matriculation), whilst income-rich households had lower dependency ratio.

Access to Social Capital

Amongst small-scale farmers in South Africa, studies have shown that social capital is more cognitive than structural, that is,it is founded more on trust, traditions, norms and values rather than on tangible local organizations and networks (Jordaan and Grové 2013). In the Muden area, for example, a study by Reid and Vogel (2006) showed that despite the existence of social structures around agriculture (such as block and water management schemes), inter-household cooperation in terms of farm production and property right enforcement is at low levels. The authors argued that the ineffectiveness of social capital structures is due to the lack of interest in farming by most economically active sections of the populace. With higher levels of transaction costs faced by small-scale farmers in agricultural marketing, the lack of cooperation is found to be a significant challenge to agricultural commercialization and hence farm income generation (Matungul et al. 2001).

CONCLUSION

The objective of the present study was to provide information about the CC-related vulnerability of farming systems in the midlands region of KZN. Based on the indicator approach, the paper adopted a research synthesis method to gather and analyse the existing research evidence ontheextent to which the agricultural sector in the region is vulnerable to CC. This review unveiled some key aspects of exposure, sensitivity and adaptive capacity of farming systems in the region.

With regard to exposure, clear warming trends have been detected, and most climate model outputs have projected enhanced warming and wetting trends towards the end of the 21st century. The reviewed research evidence further suggested that this acute exposure overlaps with highly sensitive farming systems, indicated by high population densities, high rates of small-scale farming, low irrigation rates, and susceptibility to land degradation. In spite of such acute levels of sensitivity, the highly diversified crop portfolios constitute the major aspect of the resilience of the farming systems. The synthesis also suggests that the adaptive capacity of rural people in the KZN midlands is confounded by inadequate access to infrastructure (for example, roads and electricity), rural exodus, skills shortages, poor health status, and lack of cooperation among farmers.

RECOMMENDATIONS

These evidence-based insights have considerable implications for CC adaptation policy and research in South Africa. First, the evidence signifies the importance of formulating a region-specific CC response policy, focusing on the facets of vulnerability that are more pronounced, and leveraging upon the current aspects of farming systems' resilience. Given the high levels of exposure to CC, the provincial agricultural extension policymakers should devise regional CC communication strategies using participatory, bottom-up approaches.

Policymakers should also promote crop diversification in the region to reduce sensitivity and enhance the resilience of farming systems. They should also secure appropriate institutional environments through which irrigation water governance and enforcing mechanisms can thrive. Since most aspects of adaptive capacity are inherently associated with the socio-economic status of the local population, policymakers should adopt a climate mainstreaming approach, whereby CC adaptation measures are assessed in the general rural development policy objectives.

These strategies, however, need to be supported by empirical results that are spatially and temporally representative. Under such acute exposure to CC, there is need for empirical studies to investigate farmers' perceptions about CC. Such endeavours should link the perceptions with actual meteorological observationsto assess their correctness and identify the root causes of any discrepancies. With regard to sensitivity, empirical studies are needed for understanding the crop diversification behaviour in the region in order to devise policy strategies for the resilience. For long-term resilience, given the existent challenges related to irrigation water management, studies need to explore other land-based adaptation measures such as land use change. However, given the multifunctional nature of agricultural land use, there is a need to investigate not only the proximate drivers of adoption of climate-resilient land uses in the region such as sugarcane and timber production, but also the trade-off between the various criteria of land use evaluation.

The information contained in the present study, however, has one noteworthy limitation. Whilst the indicators of exposure go as far as the end of the 21st century, most of the indicators of sensitivity and adaptive capacity are evaluated within the historical or current conditions, assuming that the existing socio-economic conditions would persist. Therefore, it would be desirable to discuss the potential impacts of future climatic changes within the context of plausible future socio-economic scenarios. The scenarios should capture region-specific agriculture and economic development conditions that are consistent with the assumptions used to generate CC simulations.

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NOTE

[1] The Herfindahl Index of crop diversification take values between zero (representing complete diversification) to one (reflecting complete specialization) (Bradshaw et al. 2004)

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