Declaration

I, Lunga Simelane, declare that this research report is my own unaided work. It is being submitted in partial fulfilment for the Degree of Master of Science in Environmental Studies at the University of the Witwatersrand. It has not been submitted before for any degree or examination in any other university.

______________________________ 25 February 2009

Lunga Simelane

Dedication

I would like to dedicate this work to my brother, Simanga Simelane. We have done it again big brother, and I thank you from the bottom of my heart.

Acknowledgements

First of all I would like to thank God who has given me the energy to work on the study. The success of the study is also due to efforts of other individuals who have made inputs to the study in one way or the other. I am highly indebted to my supervisor, Professor Coleen Vogel, who was patient with me and gave me undivided attention, advice, and guidance in carrying out the study. I am grateful to the constructive comments that she gave me to make the study a success. I would also like to appreciate the assistance she gave me towards attaining financial support as part of a grant from the Water Research Commission.

My heartfelt thanks also goes to the people I worked with at Ubombo Sugar Company, and Royal Swaziland Sugar Corporation. Of note are Dr Sipho Nkhambule and Mr Njabulo Mazibuko at Ubombo Sugar, and Dr Ndlovu at RSSC. I would like to thank them for willingly assisting me in carrying out the study, and unreservedly giving me all the information that I requested from them.

Last but not least I would like to thank my family for their support and prayers. I would like to thank my mother Mrs B. Simelane for always believing in me, my brother Simanga Simelane for just being the wind beneath my wings, my sisters, Ncamsile, Winile and Dombo for their undying support, and my brothers, Musa, Sibusiso (late), and Thoba for being there for me.

Abstract

Climate change and variability is a reality and its impacts have led to issues of climate change being placed high on the international agenda. Sectors highly affected by climate change include agriculture, water and energy, and health. The need to respond to climate change has therefore been realized to be eminent. Response to climate change includes mitigation and adaptation. Mitigation mainly involves efforts taken towards stopping or reducing the causes of climate change. Adaptation includes efforts to reduce the impacts of climate change.

The focus of the study is on adaptation strategies employed in the agricultural sector, with a particular focus on the sugar industry in Swaziland. Two major sugar companies in Swaziland were investigated, that is Ubombo Sugar Company, and Royal Swaziland Sugar Corporation (RSSC). The study set out to ascertain if climate change is an issue that needs attention within the industry. It is for this reason that the study first set out to determine the perceptions and understanding of climate change within the industry. The industry's response to climate change was also investigated. Adaptation options, both planned and unplanned, were also examined. The findings reflect that indeed climate change is considered a threat to the industry, though it may not be as significant as other multiple stressors that are more imminent, like sugar price volatility. The findings also reflect that the industry is actually responding to climate change in an effort to reduce its impacts on on-farm operations. Strategies include planting drought-tolerant cane varieties and using more water-efficient irrigation systems, amongst others. In the study these strategies are investigated in relation to each on-farm operation, from planting to harvesting and transportation to the mill. On the whole the study adds to the existing body of knowledge in the subject of climate change, by not only investigating the impacts of the phenomenon, but putting more focus on what economic sectors are doing to counter the impacts, with agriculture being the focus of this study.

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Chapter One: Introduction

1.1 Introduction

The impacts of global environmental change have led to the realization that there is a need for affected sectors to start acting and responding to these changes. Climate change and variability have become the primary environmental concern of the twenty first century (Munasinghe and Swart, 2005). This is because of the significant impacts it has on a number of socio-economic sectors. Amongst others, sectors that are highly impacted upon by climate change include agriculture, energy and health. Munasinghe and Swart (2005) suggest that the potential impacts and mitigation of climate change need to be analysed in the context of sustainable development, which encompasses these affected sectors.

Responding to climate change can be examined at the policy level, including national and international levels. This sets the wider framework for action to be undertaken in terms of responding to climate change. Response can also be examined in terms of mitigation and adaptation (Fig. 1). Figure 1 illustrates the linkage between policy response and mitigation and adaptation.

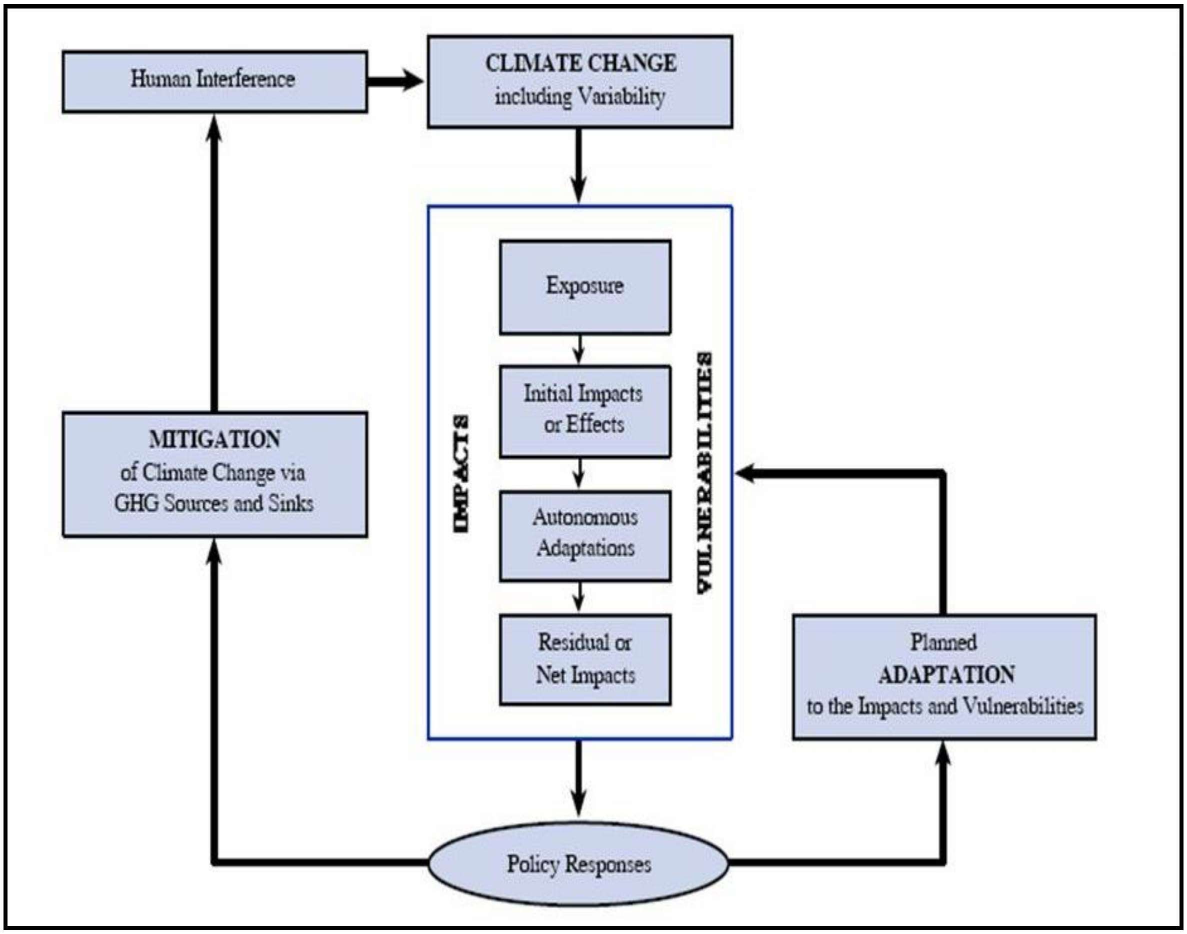

Figure 1: Places of Adaptation in Climate Change (*Source: Smit et al., 1999)*.

Of the sectors significantly affected by climate change, this study focuses on one; agriculture. Agriculture is one sector that is seen to be highly sensitive to climatic changes and variations (see Parry, 1990; Burroughs, 2001; Gitay *et al.*, 2001; Vogel, 2005).

The study has a focus on the sugar industry in Swaziland. The industry is of major importance in the economic development of the country. Over the years it has contributed significantly to the country's GDP. It is the biggest employer and export earner for Swaziland (Swaziland Review, 2008). Two major sugar estates in the country are of interest. These are the Royal Swaziland Sugar Corporation (RSSC) and Ubombo Sugar. These two are the only sugar producers in the country. The study investigates how these companies are responding to apparent changes and variations in the climate. The response is examined firstly in terms of the perceptions held in the industry on climate change; and secondly in terms of the adaptation strategies being implemented to cope with the phenomenon.

1.2 Objectives of the Study

The objectives of this study are to:

- Examine current perceptions of agricultural production managers, within the sugar industry in Swaziland, to the challenges and threats posed by climate variability and change.
- Identify some existing and potential strategies and/or mechanisms, both short-term and long-term strategies, used in the sugar industry to adapt to climate variability and change, also with reference to their effectiveness.

1.3 Rationale for the Study

Climate change is a reality, and is affecting physical, biological, and human systems (see Lamb, 1968; Burroughs, 2001; Burroughs, 2001; Gitay *et al.*, 2001; Scott *et al.*, 2001; Rosenzweig *et al.*, 2007). Scientists have modelled and presented studies on the causes of climate change, which themselves range from natural changes to human-induced climatic changes. The impacts of climate change may be significant for agriculture, water, ecosystems, human settlements, and human health (Boko *et al.*, 2007). At an international level, climate change has been recognized as a threat to sustainable development, particularly in developing countries (DEAT, 2004). With regards to agriculture, which is the focus of the study, climate change will severely compromise production and food security, particularly in Africa (Boko *et al.*, 2007). In South Africa, for instance, maize production is identified as one of the areas of highest vulnerability to climate change, thereby needing a variety of adaptation measures (DEAT, 2004).

Embedded within climate change is climate variability, a phenomenon that is also critical when examining climate change. In the recent IPCC report, it is asserted that climate change may be perceived through the impacts of extremes (see Trenberth *et al.*, 2007). Temperature extremes, frequent droughts, downward trends in the amount of precipitation have all been observed to be consistent with climate change, particularly the warming of climate (see Trenberth *et al.*, 2007). Climate in the Southern African region is highly variable. In examining rainfall quantities in the sub-Saharan African region, the South African Weather Service, for example, reveals some variability in the amount of rainfall to be received within the region with some areas recording above normal and others below normal between August and December 2008 (see Fig. 2).

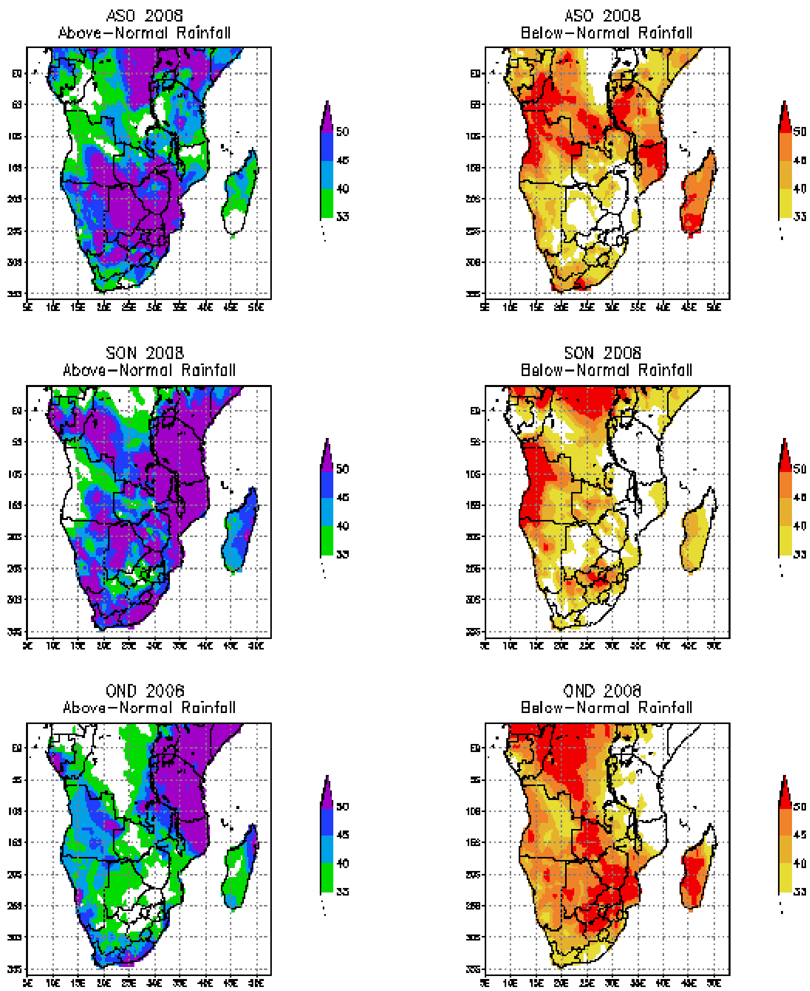

Figure 2: Rainfall projections for the sub-Saharan region for the months Aug – Dec 2008 ***(Source: South African Weather Service).***

The urgency to understand how farmers are currently adapting to such variable environmental conditions is thus high, particularly measures that assist producers in decision making in the context of scientific uncertainty. Suggested future climatic changes for instance, as projected in the latest IPCC report, could include temperature increases, drying in much of the subtropics particularly, and extremely warm, wet and dry seasons, (see for example Christensen *et al.*, 2007).

African farmers are currently coping with climate variability and change, having developed several adaptation options over time to cope with climate risks (Boko *et al.*, 2007). With a country like Swaziland heavily dependent on agriculture, it becomes necessary to gain insight on what is presently being done to counter the stresses that face agricultural industries. Research into the specific ways in which farmers are adapting to climate change and variability is crucial (Rosenzweig and Hillel, 1995). Such research initiatives may even assist policy makers to shape national policies towards enhancing efforts made in the agricultural sector to cope with even future climate change. It is in this logic that this study was conducted.

The rainfall data for Swaziland show that there is significant variability in the amount of precipitation received in the country. In the lowveld, the area under study, over a period of 45 years, shows some significant variation that can be observed in the amount of rainfall received in the region. The annual average rainfall for the lowveld is the lowest of all the country's regions, at 450 – 500mm (Matondo *et al.*, 2005). The year 2002, recorded the lowest rainfall ever received in the region over the 45 year period (see Fig 3). From 2004 to 2006, a steady decline in the amount of rainfall received in the region can also be observed (Fig. 3).

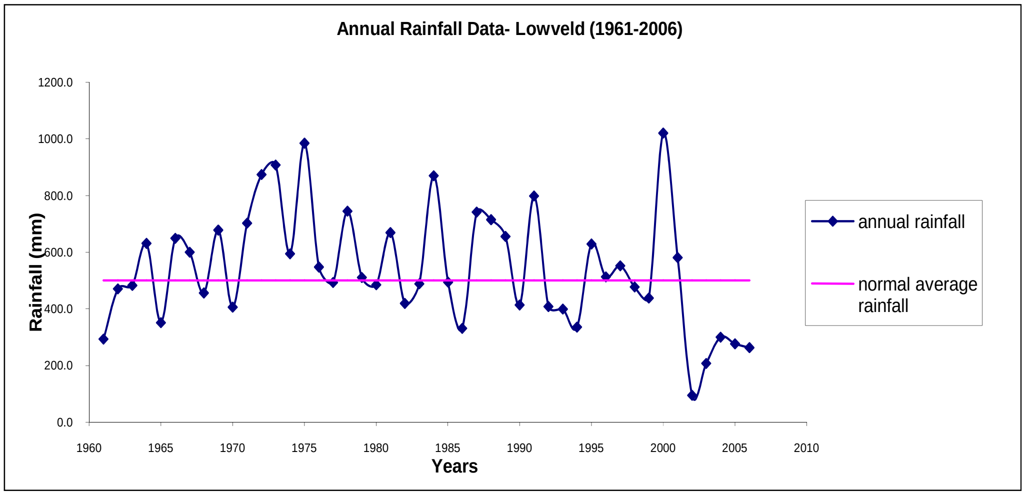

Figure 3: Annual Rainfall Data for the Lowveld in Swaziland (1961-2005) - ***Source: Meteorology Department of Swaziland.***

The rainfall data (Fig. 3) suggest that the sugar industry in Swaziland, being located in the lowveld is faced with climate variability. In a period of two years rainfall decreased from being the highest received in the 45 year period to being the lowest received (2000 – 2002). Understanding how to flexibly adjust and adapt to these variations in the climate of the region, therefore, becomes necessary for the sugar industry in Swaziland.

Also of importance to the industry in terms of adaptation are the intra-seasonal climatic variations. These are climatic fluctuations with periods longer than the synoptic scale, but shorter than the seasonal time scale (Kijazi and Reason, 2005). Monthly precipitation statistics like the number of rain days and the intensity of rain (Hewitson and Crane, 2006) become important in the farming operations of the industry. Thus enhanced intra-seasonal climate information can assist farmers in decisions regarding planting, fertilizing, pesticide application, and irrigation demand (Kijazi and Reason, 2005). Notwithstanding recent observations, the vagaries of climate change still present considerable challenges to the agricultural sector.

It is important then to determine the adaptation mechanisms or strategies currently used in the industry to adapt to these inter-annual and also intra-seasonal climatic variations. In this study a preliminary investigation of some adaptation strategies that enable the sugar industry to withstand the climatic variations is done. The cost-effectiveness of those mechanisms and strategies currently employed to manage climate variability and change is of particular interest. The information obtained in the study will be necessary to forge a way forward for the sugar industry in Swaziland, and other agribusinesses in the country.

1.4 Summary

As a way of introduction to the study this chapter briefly discussed the background on climate change and variability as topics of global concern. The need to respond to climate change and variability has been introduced in the chapter with the mitigation and adaptation options outlined. Agriculture as an affected sector was also introduced, with a brief indication of the bias of the study towards the sugar industry in Swaziland. The objectives of the study in terms of examining perceptions within the industry and identifying coping strategies employed, were outlined. The rationale of the study, which lays the basis of why the study is of significance, was also provided in this chapter.

In Chapter 2 literature on the subject of climate change is presented and examined. The literature ranges from discussing climate change within the African context, its implications on agriculture as a sector, and the adaptation thereof, to the role of governments through policy interventions. This literature provides the theoretical framework of the study.

Chapter Two: Literature Review

2.1 Introduction

In this chapter a brief review of literature on climate change and variability, and agriculture is provided. This literature forms the basis in terms of informing the study on debates and arguments around climate change, and its relation to agriculture in particular. The literature therefore ranges from climate change implications for Africa, to its implications for agriculture and to the role of policy in intervening to manage stresses associated with climate change, particularly on agriculture. The literature also highlights thinking on the concepts of vulnerability, adaptive capacity, and adaptation.

2.2 Climate Change and Africa

In the recent IPCC report (Climate Change, 2007), it is asserted that climate change and variability may be perceived through the impacts of extremes (see Trenberth *et al.*, 2007). Temperature extremes, frequent droughts, downward trends in the amount of precipitation have all been observed to be consistent with climate change, particularly the warming of climate (Trenberth *et al.*, 2007).There is however some level of uncertainty on the relationship between long-term climate change, variability in particular, and more frequent extremes. In table SPM 3 of the of the Climate Change 2007 synthesis report by the IPCC, the likelihood of future trends of most extreme weather phenomena/events is projected between 66% and 90% as they are projected as either *likely* or *very likely* when basing it on projections for the mid to late 21st century (see Bernstein *et al.*, 2008). For Africa, projections suggest that warming is very likely to occur, with annual rainfall likely to decrease over most parts of the continent, but with a likelihood of an increase of the mean annual rainfall in East Africa (see Christensen *et al.*, 2007). Determining precise linkages between climate change and variability still requires more detailed investigation. Notwithstanding these uncertainties, preparation for reducing risks to a sector like agriculture, already beset by notable stresses, could enhance overall resilience to change.

Africa's climate is controlled by complex maritime and terrestrial interactions that produce a variety of climates across a range of regions (Boko *et al.*, 2007). The continent is warmer than it was 100 years ago, with the six warmest years occurring since 1987, 1998 being the warmest (Hulme *et al.*, 2005). On the global scale, there has also been an increase in temperatures, by 0.32 ºC in the period 1978 – 1997, with the warmest years falling in the 1990s (Burroughs, 2001). Temperature has not been the only climatic parameter that has been observed to be changing. Precipitation has experienced significant and more complicated change (Boko *et al.,* 2007). Some spatial and temporal rainfall variability has been observed in the continent (Hulme *et al.*, 2005), with inter-annual variability being large over most of Africa and substantial multi-decadal variability for some regions (Boko *et al.*, 2007). Economic development in Africa is significantly controlled by climate, particularly in the agricultural and water resources sectors, at regional, local and household scales (Boko *et al.*, 2007). Changes therefore in climate can be expected to have significant implications for Africa in terms of economic development of the continent.

Climate change as a phenomenon has some implications for the developing countries, most of which are negative. Rosenzweig and Hillel (1995) state that studies have found that developing countries are more vulnerable to climate change, and these in most cases are located in the lower, warmer latitudes. Africa is the most vulnerable continent to climate change (Schneider *et al.*, 2007). This vulnerability is worse in some regions of the continent by virtue of the multiple dimensions of climate change (Yohe *et al.*, 2007). Factors such as widespread poverty, recurrent droughts, inequitable land distribution, and overdependence on rain-fed agriculture have made the African continent to be particularly vulnerable to the impacts of climate change (Desanker *et al.*, 2001). The impacts of concern are related to water, health, agriculture, ecosystems, and settlements and infrastructure (Boko *et al.*, 2007). These sectors are essential for the development of the African continent, particularly within the framework of sustainability. If these sectors are impacted upon by climate change, it translates to implications to sustainable development in the continent. Impacts on water resources, for instance, may affect sustainable development and put at risk issues like poverty reduction and child mortality (Kundzewicz *et al.*, 2007).

In their Third Assessment Report (TAR), the Intergovernmental Panel on Climate Change indicated future warming across the African continent (IPCC, 2001). This was indicated to be in the range of 0.2 ºC per decade to more than 0.5 ºC per decade with the greatest warming over the semi-arid margins of the Sahara and central southern Africa (Desanker *et al.*, 2001). In their most recent report, the IPCC maintain that it is highly likely that heat waves will be more intense, more frequent and longer lasting, with cold episodes decreasing significantly in a future warmer climate (Meehl *et al.*, 2007). Extreme events, such as droughts, may thus be more frequent requiring further attention because of their implications for numerous African countries (Boko *et al.,* 2007). In the event of a drought for instance, water resources may be expected to decline, and this would in turn impact negatively on food security (agriculture) and human health (sanitation). In Africa, millions of people already suffer the impacts of extremes such as droughts and floods (Boko *et al.,* 2007).

Good evidence exists for a close relationship between the concentration of carbon dioxide in the atmosphere and long-term climate fluctuations (Graves and Reavey, 1996). Also, increasing greenhouse gas accumulation in the global atmosphere and increasing regional concentrations of aerosol particulates are now understood to have detectable effects on the global climate system (Santer *et al.*, 1996 in Hulme *et al.*, 2005).

In their recent summary report (2007), the IPCC (Working Group II) concludes that the net annual costs associated with the impacts of climate change are likely to increase over time as global temperatures increase (see Adger *et al.*, 2007). Doing nothing about climate change therefore, could prove to be extremely costly (Maunder, 1989). The question with regard to Africa would be; what can Africa do? If greenhouse gas emissions are the major cause for global warming, is Africa emitting significant amounts that could perhaps be reduced? The developed world is normally seen as the major player in causing the problems of global warming. In looking at sub-Saharan Africa, for instance, Justice *et al.* (2005) argue that sub-Saharan Africa contributes little to global warming, is powerless to prevent climate change, and is thus merely left to respond to it. This assertion suggests that the role of sub-Saharan Africa, in this case, in the 'game' is to deal with the consequences.

Responding to climate change for Africa would perhaps best translate into efforts to adapt. Adaptation and mitigation are discussed in detail further in the chapter. These concepts are defined as those set of actions aimed at reducing the *impacts* of climate change (Munasinghe and Swart, 2005), and those sets of actions aimed at reducing the *causes* of climate change (Houghton, 2004), respectively.

As alluded to in the literature, agriculture is one sector that is highly affected by the impacts of climate change. The next section of this chapter therefore attempts to briefly examine the role of agriculture in African economies, before actually moving into the detail of the implications of climate change on agriculture.

2.3 The role of Agriculture in African Economies

To date a number of African countries have large numbers of their populations highly dependent on agriculture for their livelihood, both in terms of commercial and subsistence. Agriculture has thus become undoubtedly the most important sector in the economies of most non-oil exporting African countries (Natural Resources Conservation Service, 1995). In terms of contributing to the GDP, export earnings and employment for most sub-Saharan African countries, the prominence of the agriculture sector remains unchallenged (Kidane *et al.*, 2006). Practical Action/PELUM (2005) see agriculture as constituting the backbone of most African economies; being the largest contributor to GNI, the biggest source of foreign exchange, and the main generator of savings and tax revenues.

In many sub-Saharan African countries the role of agriculture as a major source of foreign exchange and an engine for overall development through linkages with the manufacturing sector remains unchallenged (Kidane *et al.,* 2006). Agro-based industries are in prominence in sub-Saharan Africa (Kidane *et al.*, 2006). The impact of agricultural growth on the rest of the economy, particularly in Africa, is still significant and evident even though there have been questions on the strength of the linkages (DFID, 2005).

Because of its size and composition, agriculture cannot only be seen as an engine for economic growth but also as a means for reducing poverty and inequality (Diao *et al.*, 2006). This is particularly relevant for most of Africa given the widespread poverty in the continent. Practical Action / PELUM (2005) assert that the majority of the poorest people in rural areas in Africa are engaged in agriculture. DFID (2005) assert that agriculture's potential can be realized and is critical to poverty reduction. In pursuing the Comprehensive Africa Agriculture Development Programme (CAADP), therefore, under NEPAD, African governments are recognizing the importance of agriculture to increasing prosperity (Practical Action / PELUM, 2005).

African agriculture is however in crisis (Practical Action / PELUM, 2005). Most African countries have not yet met the requirements for a successful agricultural revolution, and productivity in African agriculture seriously lags behind the rest of the world (Diao *et al.*, 2006). The success of the agricultural economy in a given region or country will depend on the interplay of the set of dynamic factors specific to each area (Rosenzweig and Hillel, 1995). Stresses like climate change, in the form of increased extreme weather patterns, particularly more frequent and prolonged droughts, is expected to further impact negatively on Africa's agriculture (Practical Action / PELUM, 2005).

The role of agriculture in Africa, as it has been briefly discussed in this literature, is significant. It is still a critical sector in Africa in terms of economic growth and poverty reduction. Its contribution to most African countries' GDP is still recognized as significant. It is therefore still very much the mainstay of most African populations. The success of this sector is therefore critical for Africa. Any stresses to the sector need to be analysed and well understood so that they can be mitigated against, or have their impacts reduced. Climate change and variability comes up as one of the major stresses that threaten the success of agriculture in African countries. The next section of the literature review therefore, focuses on what scholars and commentators have recognised as major implications of climate change on agriculture.

2.4 Implications of Climate Change and Variability on Agriculture

Agriculture is the one sector of human economic activity that is highly affected by climate change in the form of extremes like droughts and floods (see Parry, 1990; Burroughs, 2001; Gitay *et al.*, 2001; Vogel, 2005). There is growing concern about the impacts of climate change and its variability on agricultural production worldwide (Tubiello *et al.*, 2007). This is mainly due to the fact that it is one sector that is highly dependent on climate for its success. Temperature and precipitation are essential climatic factors for agricultural production (Schlenker *et al.*, 2007). Any changes therefore in these factors of agricultural activity result in changes in the output of farming. High temperatures and highly variable precipitation patterns combined with an increase in the frequency of extreme events such as droughts and floods tend to depress yields and increase production risks in regions across the world (Tubiello *et al.*, 2007). The developing world is the most vulnerable to the impacts of climate change on agriculture, with insufficient rainfall being the main limit in these areas (Parry, 1990, Tubiello *et al.*, 2007).

Farmers in most parts of the world have increased their awareness of climate change and its implications on agricultural production. Coffee farmers from the Soconusco region of Southern Chiapas, Mexico have, for instance, noticed that rains begin later after the dry season, and come in lower quantities, which threaten plant survival and delays annual flowering (Lin, 2007). Forecasting has therefore become a critical tool for farmers as they prepare for climate change (Bohn, 2003; Lin, 2007).

The implications of climate change in agriculture can be examined in terms of its impacts on water, soil, and pests and diseases. Water and soil are considered as the natural inputs necessary for agricultural activity. They are in other words natural resources upon which agricultural production is based. They form part of the factors of production for agriculture. Pests and diseases are some of the constraints that are faced in agriculture. In other words the availability of water and good soils and the reduction of pests and diseases are critical for the success of agriculture.

2.4.1 Water

Any agricultural activity is highly dependent on the availability of water. Water is actually the key driver and a precious input to agricultural production (Fischer *et al.*, 2007). It is a natural resource that constitutes part of the factors of production for agriculture (Kundewicz *et al.*, 2007). In crop production, like sugar cane, water is used for irrigation purposes. In Swaziland, for instance, irrigation is the major consumer of water, at 96% (Matondo, *et al.*, 2005). In animal husbandry it is necessary for animal feed growth and for animal drinking. The major source of water, particularly surface water, is rainfall. In most parts of the world, however, surface water has tended to be a scarce resource, such that the demand for water across all users exceeds the amount that is readily available (Mendelsohn, 2006). In Africa, for instance, the population trends and patterns indicate that countries will exceed the limits of their economically usable, land-based water resources (Boko *et al.*, 2007).

In the hydrological cycle, changes in precipitation (rainfall) have very significant implications for water resources (Arnell *et al.*, 2001). Changes in precipitation relate to type, amount, frequency, intensity, and duration (Trenberth *et al.*, 2007). More precipitation generally means more water, and the opposite would be true for less precipitation. Climate change extremes therefore would significantly modify water availability and this would have significant implications for agriculture. Rosenzweig and Hillel (1995) note that agriculture of any kind is strongly influenced by the availability of water and climate change will modify rainfall, evaporation, runoff, and soil moisture storage. The scarcity of water is however expected to increase over time (Mendelsohn, 2006), and this is in the wake of the continuously changing climatic conditions. In studying three catchments in Swaziland (Komati, Mbuluzi, and Ngwavuma), Matondo, *et al*. (2004) concluded that stream flow in these catchments will be low under climate change conditions.

The assumption that future climate would be the same as the past had always influenced water planning and management of the past (Gleick, 1997). In the wake of the apparent changes and variations in climate, however, there has been a need for water planning to shift from this assumption. These climatic changes will alter the hydrologic cycle in a variety of significant ways, and there is a broad scientific consensus on this fact (Gleick, 1997). Water resources planning for the future should therefore take climate change into account (Schulze and Perks, 2000).

Drought-stricken areas would have less water available for irrigation, as there would be minimal to zero rainfall. This then would mean high evaporation, less runoff, and reduced soil moisture storage. In plant biological processes, scarce water means most plants will close their stomata to avoid drying out thereby reducing transpiration and affecting photosynthesis, which results in limited growth (Parry and Carter, 1988). The demand for water for irrigation would also be projected to rise (Rosenzweig and Hillel, 1995). This then would have some cost implications as well for agriculture. These would be in terms of pumping the water, which in extreme cases would have to be obtained from underground. Rosenzweig and Hillel (1995) allude to the fact that with drier conditions, more energy will be needed to pump water, making the practice of irrigation more expensive, particularly because more water will be required per acre. Rosenzweig and Hillel (1995) also note that frequent droughts not only reduce water supplies but also mean that more water will be needed for plant transpiration.

The implications of climate change on water, as an input for agriculture, are that water will decrease, particularly with warmer climates, thereby increasing its demand. Biological processes in plants in warmer climates also tend to require much water for transpiration purposes, which tends to be scarce. Agricultural production in these conditions is greatly affected because without enough water crops die due to the affected biological processes that have to take place in individual plants. It is perhaps on this premise that Warrick and Riebsame (1983) argue that in a resource context, like water, climate could be viewed as another factor of production, with a change in climate analogous to a resource scarcity.

In terms of water management, climate change implies that strategies should be able to anticipate and even accommodate the extra stress it may place on managing water (Schulze and Perks, 2000). This suggests that hydrological modelling should take into consideration possible climatic changes, as these could affect hydrological processes such as stream-flow and runoff. The modelling of water resources in the context of climate change also may assist in going beyond predicting the impacts of climate change to developing adaptation strategies (Ringius, *et al.*, 1996 in Schulze and Perks, 2000). An assessment on the Orange and Mgeni Catchments revealed that climate change had significant impacts on the flows in these catchments (Schulze and Perks, 2000). It is therefore apparent from the literature that the implications of climate change on water are in terms of its availability, its management, and in terms of present designs for hydraulic structures. Climatic changes, in particular temperature increases, deplete water sources thereby calling for strategic management of the available water resources.

In Swaziland, it is envisaged that with climate change, the country will experience a reduction in stream flows, requiring the development of policies and strategies that will promote water conservation practices (Matondo, *et al.*, 2005). In studying the Mbuluzi catchment, for example, which feeds the Mnjoli Dam (a reservoir used primarily for storing irrigation water for sugar cane), Schulze and Dlamini (2005) conclude that with a $2^{o}C$ temperature increase coupled with 10% reduction in precipitation, inflows to the reservoir will reduce by 34% in median years. In 1 in 10 dry years, inflows to Mnjoli are simulated to reduce by 47% with outflows to downstream Mozambique reduced by similar amounts (Schulze and Dlamini, 2005). It is then essential for long-term planning for water resource projects in countries like Swaziland to incorporate climate change uncertainties (Matondo *et al.*, 2004). Water use efficiencies should be optimised, and water obligations with downstream user countries, like Mozambique in the case of Swaziland, be re-negotiated (Schulze and Dlamini, 2005).

2.4.2 Soil

Climate is the most important factor influencing soil formation, affecting the soil type through its weathering effects and indirectly as a result of its influence on vegetation (Kabubo-Mariara and Karanja, 2007). The productivity of land in agricultural terms is dependent on good soils. Good soils are judged in terms of their capability to hold water (in acceptable quantities) and in terms of their fertility. Parry and Carter (1988), in examining at semi-arid regions, state that aside from water, the level of soil nutrients is perhaps the most important factor limiting crop yields. Soils could therefore be affected by climate change in terms of reduction in the level of soil nutrients. Warmer conditions in particular are likely to speed the natural decomposition of organic matter and to increase the rates of other soil processes that affect fertility (Rosenzweig and Hillel, 1995). Yield responsiveness to nutrients in the soil is as well strongly influenced by climate, particularly rainfall (Parry and Carter, 1988).

Concerns around the rate of evapotranspiration also come into play when looking at the effects of climate change on soils, particularly soil moisture. Evapotranspiration will increase in higher temperatures, thereby resulting in more depletion of soil water (Graves and Reavey, 1996). The overall effects of climate change on soil organic matter levels will depend on how it affects soil moisture, particularly in the summer season (Olesen and Bindi, 2002).

2.4.3 Pests and Diseases

Climate change implications on agriculture can also be manifested in the spread of pests and diseases. The NRCS (1995) states that weed and insect pest ranges could be expected to shift with changes in climate and rises in temperatures. This means that pests and diseases will manifest themselves more in certain climatic conditions. For instance, the proliferation of insect pests is more manifest in warmer climates (Rosenzweig and Hillel, 1995). Drought-stricken areas therefore would be expected to be plagued with a number of pests and diseases that would impact negatively on crops grown.

Overall, the implications of climate change on agriculture as a whole are profound. The detrimental effects of climate change in the form of extreme weather patterns, particularly droughts, are expected to be further felt on agriculture (Practical Action / PELUM, 2005). Graves and Reavey (1996) suggest that it may not yet be possible to make accurate predictions about changes that might occur in the regional climate, yet it is likely that such changes will have a profound effect on agricultural output, with important social ramifications.

It is nonetheless worth noting that climate change is not the only strain that is faced by agriculture. In actual fact, though significant, climate change could be seen to be aggravating other problems faced agricultural production. Of particular significance could be the pricing of agricultural commodities, like sugar in the case of the sugar industry. The politics involved in the pricing of sugar, particularly by the EU, have been seen to be such that it affects sugar producers, in particular those from the less developed countries (Oxfam, 2002). This is seen in what the Oxfam terms ‘Europe’s sugar regime’, in which Europe has become the largest exporter of sugar despite the high costs of production. This, according to the Oxfam, is made possible through subsidies for exports from the EU. This has then meant that the less developed countries (LDCs) struggle in the sugar market despite their low cost production (Oxfam, 2002).

The implications of climate change on agriculture are profound, as noted in the literature. The major inputs for agricultural production (water and soil) are negatively affected by climate change and variability. The literature noted that as a sector, agriculture is one of the most sensitive to climate change. In other words, agriculture is one sector that is vulnerable to climate change and variability. The ability to cope with the phenomenon becomes crucial. The next section of the literature discusses the concepts of vulnerability, adaptive capacity, and adaptation in the context of climate change.

2.5 Vulnerability, Adaptive Capacity, and Adaptation to Climate Change

The concept of vulnerability is important in examining the impacts and the adaptation required for a system to climate change and variability. This concept refers to the degree to which systems are susceptible to, and unable to cope with adverse impacts of climate change (Schneider *et al.*, 2007). It is a function of a system's sensitivity to climate change and variability (Schneider *et al.*, 2001). Brooks *et al.* (2005), however, notes the fact that context is also critical when examining the concept of vulnerability. For instance developing countries, for a number of reasons, tend to be more vulnerable to the climate change impacts than developed countries (see for example, Mirza, 2003, Thomas and Twyman, 2005). Dow and Wilbanks (2003), for instance, argue that inadequate infrastructures; limited disaster planning and response capability; and low levels of economic diversification are some of the reasons poorer countries are highly vulnerable to climate change extremes impacts. There are also some factors that determine the vulnerability of a system. These are mainly dependant on the nature of the system and the type of hazard in question (Brooks, *et al.*, 2005).

Vulnerability is in most cases related to adaptive capacity (see Alberini *et al.*, 2005; Brooks *et al.*, 2005; Thomas and Twyman, 2005; Yohe *et al.*, 2007). Brooks and Adger (2005) view adaptive capacity as the property of a system to adjust its characteristics or behaviour, in order to expand its coping range under existing climate variability, or future climatic conditions. A related definition is that it is the ability or potential of a system to respond successfully to climate variability and change, including adjustments in behavior, resources and technologies (Adger *et al.*, 2007). These views of adaptive capacity suggest that it is something that is within a system. It is, in the context of climate change, that which is possessed by a system to allow it to cope with the hazards of climate change and climate variability. It caters for the extremes of climate change and variability, such as droughts and floods. When linking this concept of adaptive capacity and that of vulnerability, it would suggest that the vulnerability of a system to climate change is highly dependant as well on its adaptive capacity. The more the adaptive capacity of a system, the less would be its vulnerability to the impacts of climate change. The reciprocal may also be true, in which case a region's overall vulnerability may determine its capacity to cope, respond and adapt to climate risk (Reid and Vogel, 2006)

The adaptive capacity of a system is also a determinant of whether it will be able to adapt to climate change impacts. When examining the concept in its practicality, Brooks and

Adger (2005) argue that it is about the ability to design and implement effective adaptation strategies. Adaptation in itself consists of adjustments in practices, processes, or structures such that changing climatic conditions are taken into account (Schneider *et al.*, 2001). This involves sets of actions that will reduce the impacts of climate change (see Houghton, 2004; Munasinghe and Swart, 2005). Unlike mitigation, which is aimed at reducing the causes of climate change (Houghton, 2004), adaptation reduces the impacts of climate change.

Adaptation will rely on a set of available resources that are represented by a system's adaptive capacity (Brooks and Adger, 2005). Such resources, according to Brooks and Adger (2005) could be natural, financial, institutional or human as they might include elements like access to ecosystems, information, expertise, and social networks. Lindseth (2004) and Naess *et al.* (2005) in Adger *et al.* (2005) recognize such things as the available technology, regulatory systems and knowledge of future climate risk as crucial elements in determining the capability of a system to adapt to climate change. The effectiveness and efficiency of an adaptation action would mainly depend on these elements. In looking at effectiveness and efficiency in adaptation, Adger, *et al.* (2005) argue that the former is about whether an adaptation action achieves its set objectives, whilst the latter is about the cost-benefit of an adaptation action.

Dessai *et al.* (2005) bring in two further concepts of adaptation. These are responsive and anticipatory adaptations. Responsive adaptations are seen as being mainly driven by extreme weather events like floods and droughts (Dessai, *et al.*, 2005). Anticipatory adaptations on the other hand are about planning in advance for the impacts of climate change so that the negative impacts of hazards can be mitigated and the benefits enhanced (Scheraga and Grambsch, 1998 in Dessai *et al.*, 2005). Future climate information is crucial for the success of anticipatory adaptations. Climate forecasts would therefore play a crucial role in these kinds of adaptations. The unreliability, and in some instances the unavailability of climate forecasts or predictions, which would allow the formal estimation of the probability of climate impacts has hindered the success of anticipatory adaptations.

With an understanding of the concepts of vulnerability, adaptive capacity and adaptation, it is then important to examine how agriculture, as a sector of interest in the study, is coping with climate change and variability. It is a sector that is highly sensitive to changes in climate as noted in the literature. It is a sector that can be highly vulnerable to climate change, and its adaptive capacity becomes crucial. Understanding adaptation strategies for the sector therefore becomes paramount. The concept of adaptation has in actual fact emerged as an important theme in research and strategic planning dealing with agricultural implications of climate change and variability (Smithers and Blay-Palmer, 2001). The next section briefly examines how agriculture, as a sector, is adapting to climate change and variability.

2.6 Agricultural Adaptation to Climate Change and Variability

With seemingly zero options for agriculture to avoid climate change and its effects, particularly in developing countries, there is therefore a need for agricultural production to adapt to climate change as means of coping with the phenomenon. Societies, organisations, and individuals have, according to Adger *et al.* (2005), adjusted their behaviour in response to past climatic changes; with many more societies contemplating adapting to altered future climatic conditions. Adaptation to current climate variability and extremes can produce benefits as well as forming a basis for coping with future climatic change (Smit *et al.*, 2001).

There are adaptive actions that may be taken to lessen or overcome adverse effects of climate change on agriculture (see Parry, 1990; Rosenzweig and Hillel, 1995). Agriculture will adjust in two broad ways: changes in land-use and changes in management (Parry, 1990). Land-use changes according to Parry will include changes in farmed area; changes in crop type; and changes in crop location. Changes in management, as asserted by Parry, would include changes in irrigation; changes in fertilizer use; control of pests and diseases; soil drainage and control of erosion; changes in farm infrastructure; and changes in crop and livestock husbandry. Other changes will be in terms of planting schedules, crop genetic characteristics, heat tolerance, vulnerability to pests, and sensitivity to pesticides (Rosenzweig *et al.*, 2004). Graves and Reavey (1996), argue along the same lines as Parry (1990) by asserting that one way in which farmers adapt to climate change is by altering the crops grown or the methods of cultivation. The assumption in this case is that farmers can grow crops that are more resistant to prevailing climatic conditions, and use farming methods that will counter the stresses of climate change and variability.

The general agreement in terms of agricultural adaptation to climate variability and change is that there will be a need for increased and efficient irrigation (in warmer climates); conservation of soil moisture; alteration of planting and harvesting timing, reduction of erosion problems; and the use of additional fertilizers to improve soil fertility (see Rosenzweig and Hillel, 1995 and Graves and Reavey, 1996). With regards to irrigation for instance, effective irrigation systems, particularly the drip systems, have facilitated both more agricultural activity and a broader range of activities than local climatic conditions would otherwise permit (Smithers and Blay-Palmer, 2001). Another dimension that could be used as an adaptive response would be the breeding of heat- and drought-resistant crop varieties by utilizing genetic resources that may be better adapted to new climatic and atmospheric conditions (Rosenzweig and Hillel, 1995).

Whilst adaptation is arguably already taking place, and is a viable option in coping with climate variability, its complexities need to be better appreciated. For instance changing planting schedules and changing crop varieties does not ensure equal levels of production or quality, nor can it guarantee equal profits for farmers (Rosenzweig and Hillel, 1995). Rosenzweig and Hillel also note that increased irrigation may lead to groundwater depletion, soil salinization, and waterlogging; and can even be a costly practice.

Throughout the literature it has been noted that the implications of climate change are significant. Climate change impacts for Africa as a continent are significant. Agriculture as a sector (with a significant role for African economies) is also significantly impacted upon by climate change and variability. Responding to climate change through adaptation has been discussed for agriculture as a sector. All these interventions usually occur either at national or regional contexts. The role for governments in addressing climate change impacts therefore becomes crucial. Governments in this case are responsible for creating enabling environments for such interventions such as adaptation to take place. With regard to agriculture, governments play a major role in encouraging farmers and agribusinesses to employ sustainable adaptation strategies. In the next section, which is the last of this chapter, focus is on the role of policy as put in place by governments, in intervening in climate change impacts, with particular reference to agriculture.

2.7 Policy Interventions for Climate Change

The evident impacts of climate change require that governments act pro-actively and put instruments in place that will assist in countering the phenomenon. There is need for governments to understand the impacts of climate change on their nations and be prepared to respond effectively to these impacts (Justice *et al.,* 2005). Such responses would include policies that counter the impacts of climate change. Schneider (1983) argues that policy responses should include the possibility to adapt, prevent, or even attempt to ameliorate the build-up of carbon dioxide and its consequences. In essence climate policy should also involve a portfolio of adaptation and mitigation actions, which include technological, institutional, and behavioural options (Klein *et al.,* 2007).

At the policy level, obstacles to change are created by supporting prices of crops that are not well suited to a changing climate, by providing disaster payments when crops fail, and by restricting competition through import quotas (Rosenzweig and Hillel, 1995). This demonstrates that governments may, in addition to developing new policies, need to also review their present policy framework if climate change is to be addressed at the policy level. New policies should be designed in ways which facilitate rather than hinder adaptive decisions (Urwin and Jordan, 2008). Adaptation measures embedded within climate change policies could, by design, enhance adaptive capacity of communities and economies, thereby reducing their vulnerabilities and risks (Yohe *et al.,* 2007). Trade policies, in terms of crop pricing for instance, may need to be reviewed, such that the crops that can adapt to the changing climate are given priority, and failing crops are not compensated for (Rosenzweig and Hillel, 1995).

Adams *et al.* (1999) bring in another dimension to government policies and their intervention to climate change. They argue that over the long run, government policies can affect not only prices and farmer behaviour but also the tools and strategies that farmers use in adapting to climate change. Government policies therefore in this case should be developed and reviewed such that they incorporate and support the adaptation strategies and tools that farmers use in coping with climate change. Such support, for instance, could in the form of incentives and capacity building for the farmers.

The cooperation amongst governments, particularly in a region also comes into play in the interventions by governments to climate change. Regional cooperation could create 'win-win' in both economic integration and in addressing the adverse effects of climate change (Denton *et al.*, 2002, in Klein *et al.*, 2007). This is what Rowlands (2005) calls *regional* approaches as opposed to *national* approaches in responding to climate change. Rowlands' justification for regional approaches is that it allows for greater understanding of a particular phenomenon, particularly because natural processes, like climate change, do not always respect national borders. In terms of policy therefore, this line of argument would advocate for policy and decision-makers to consider what is being done on a regional and even global level in terms of addressing climate change and its impacts. present, the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol are the principal institutional frameworks by which climate policy is developed at the global level (Klein *et al.,* 2007). Trade policies that allow the promotion climate extremes resistant crops to be prioritised in terms of markets would work better at the regional and global levels. Their formulation therefore would be better targeted at this level.

The role of government in addressing climate change and supporting mitigation and adaptation strategies is very significant. Mendelsohn (2006) argues that there is actually little role for governments in agricultural adaptation per se. This suggests that rather than governments being directly involved in developing adaptation strategies for agriculture, they can only create an enabling environment for these strategies to be developed. A policy framework that would allow for mitigation and adaptation systems could be put in place. Governments can for instance influence markets, allocate surface water, provide crop insurance or simply subsidize farming (Mendelsohn, 2006).

Through policies, governments can make important interventions in addressing the impacts associated with climate change in the form of weather extremes. Farmers and agricultural businesses are dependent on policy frameworks from their governments in order to cope with the vagaries of climate in the form of extremes. These frameworks, whether at national or international level should be created such that they enabling rather than inhibiting local and regional level adaptation options (Thomas and Twyman, 2005). Climate change monitoring and information dissemination to farmers would be critical in policy intervention by governments, while knowledge on adaptation measures could encourage both short and long-term adaptation to climate change (Kabubo-Mariara and Karanja, 2007).

2.8 Conclusion

This chapter has briefly drawn from the works of other commentators on the subject of climate change, particularly in terms of adaptation. The focus has been on the relationship between climate change and agriculture, with discussions on the implications of climate change and variability on agriculture, and agricultural adaptation to climate change being of major importance. The literature has reflected that indeed climate change has significant implications for Africa as a continent, and agriculture as a sector, particularly when coupled to other multiple 'drivers' of change in the sector. It has also been revealed in the literature that agriculture as a sector is responding to climate change through employing adaptation strategies to reduce the impacts of climate change and variability. The role of governments through policy development has also been realised to be critical in the reduction of the impacts of climate change.

The next chapter aims to put the study into context in terms of providing a background on the study area. The chapter also describes the methods used in conducting the study. The literature consulted has been of major importance in terms of employing some of the techniques that were used in most of the studies that form the literature.

Chapter Three: Background and Methods

3.1 Introduction

In this section of the study, the area in which the study was conducted, the Lubombo region of Swaziland, is described, particularly the region's physical geography. This covers the location and topography, climate, and hydrology. A background on agriculture in the Swaziland, particularly sugar cane husbandry, which is mainly concentrated in the Lubombo region, is also provided in this section. The chapter then provides a description of the methods used in the study to gather the required data.

3.2 Location and Topography

Swaziland is a land-locked country bordered by South Africa and Mozambique. It has a total area of 17,363 km^2, and has an absolute location or position at 26 30 S, 31 30 E. The Lubombo district constitutes the eastern part of the country covering an area of approximately 5856.6 km^2 (see figure 4). Swaziland has four distinct physiographic regions. These are the highveld, middleveld, lowveld and the lubombo plateaux (see figure 5). These are distinguished by elevation and relief (Murdoch, 1972). The topography of the country consists of mountains, hills and plains mainly in the east to west cross-section of the country, giving rise to valleys, plateaux and basins (Swaziland's National Report on Climate Change, 2000). The Lubombo region is mainly covered by the lowveld and the lubombo plateaux, and this is where the sugar industry in Swaziland is concentrated.

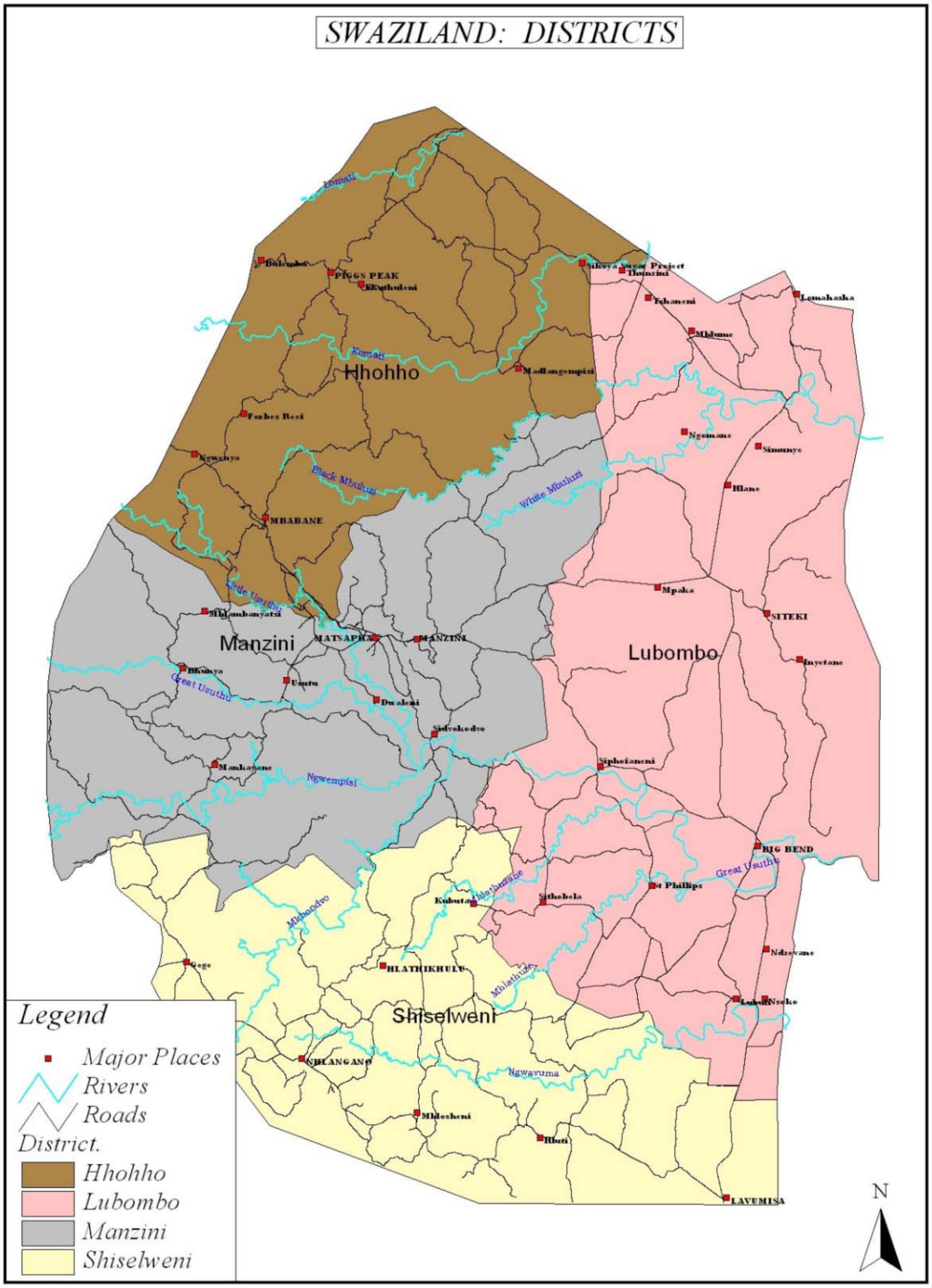

Figure 4: The Districts of Swaziland ***(Source: Meteorology Department of Swaziland).***

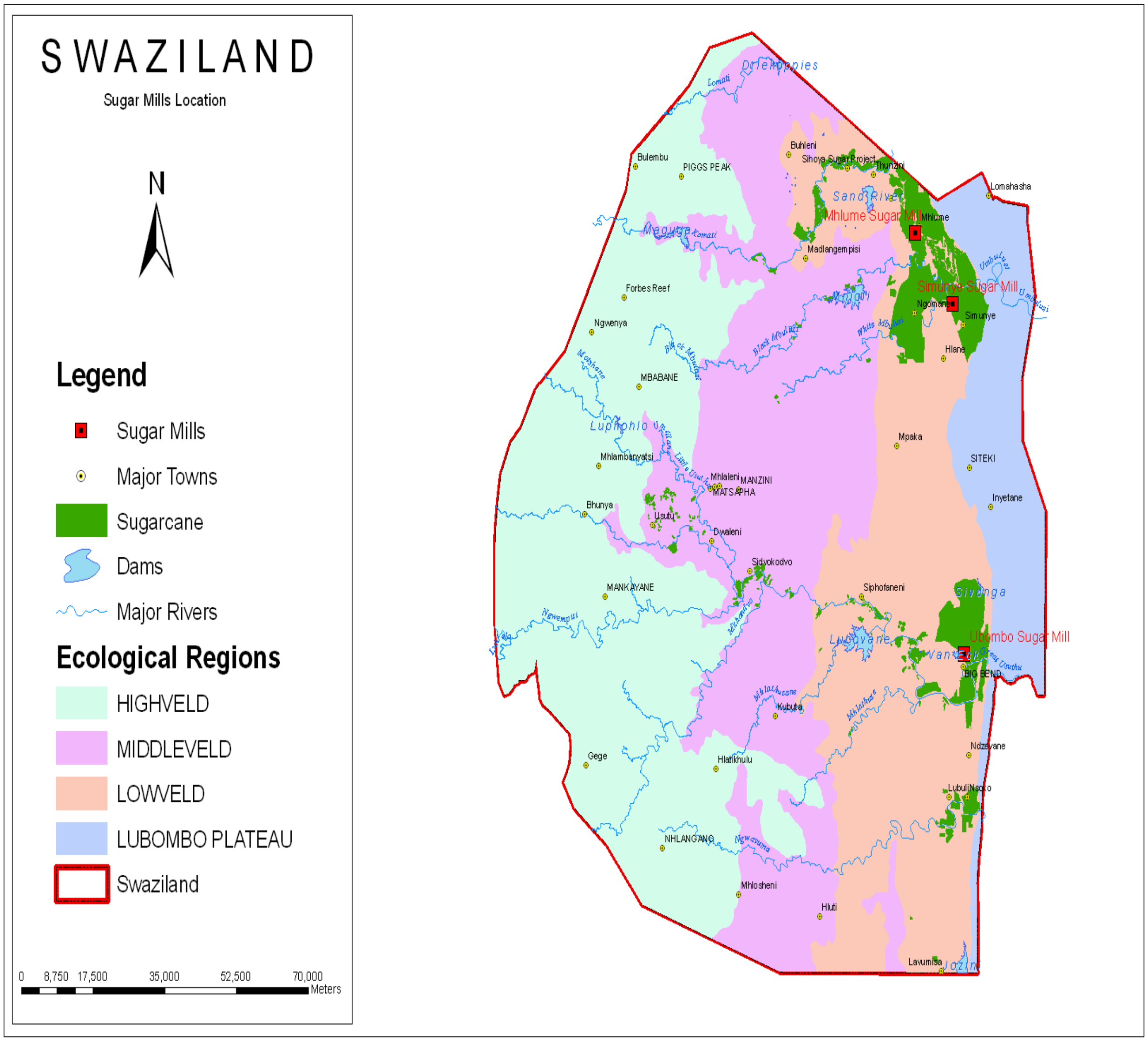

Figure 5: Physiographic Regions of Swaziland *(Source: Meteorology Department of Swaziland).*

3.3 Climate

Swaziland is normally characterized by a sub-tropical climate, with hot and wet summers, and cold and dry winters (Murdoch, 1972). Temperatures in the country vary from 0 °C in mid-winter nights to 33 °C in mid-summer (Swaziland's National Report on Climate Change, 2000). The mean annual rainfall ranges from about 1500mm in the highveld to a little less than 500mm in the lowveld (Swaziland's National Report on Climate Change, 2000). The Lubombo region is characterised by the highest mean temperatures, and the lowest annual rainfall. Average temperatures in the Lubombo go up to 22.4 ^{o}C whilst mean annual rainfall received in the region tends to be 500mm or less (Swaziland's National Report on Climate Change, 2000). Table 1 gives the mean annual rainfall and temperature by physiographic region.

Table 1: Mean annual rainfall and temperature by physiographic region

Physiographic Region	Annual Rainfall (mm)	Annual Temperature (^{o}C)
Highveld	1500 – 900	17.6 – 16.3
Middleveld	810 – 580	20.5 – 19.3
Lowveld	> 500	22.4 – 21.3
Lubombo	710	19.2

(Source: **Swaziland's National Report on Climate Change, 2000*)***

3.4 Hydrology

Swaziland is characterized by four major river basins in terms of hydrology. These are the Great Usuthu, Komati, Mbuluzi and Ngwavuma basins. The first three contribute significantly to sugar-cane irrigation in the country. The Mbuluzi, for instance, feeds into the Mnjoli Dam, which is used to irrigate more than 24000 ha of sugar-cane (Schulze and Dlamini, 2005). Besides the Ngwavuma basin, all the river basins flow through the Lubombo District, thus their contribution to sugar cane irrigation which is concentrated in the Lubombo District. Table 2 shows the four river basins and their catchment areas.

Table 2: Swaziland River Basin and their Catchment Areas

River basin	Catchment area (km^2)
Great Usuthu	12903
Komati	7423
Mbuluzi	3065
Ngwavuma	1305

(Source: **Swaziland's National Report on Climate Change, 2000*)***

3.5 Agriculture in Swaziland

Agriculture in Swaziland, like in most African countries, is practised for both subsistence and commercial reasons. Subsistence is mainly practised on what is referred to as Swazi Nation Land (SNL), where there is communal ownership of the land, held in trust by the *ingwenyama* (king) for the Swazi nation (Swaziland Review, 2008). Commercial farming on the other hand is mainly practised on what is referred to as Title Deed Land (TDL), comprising mainly individual tenure commercial plantations, estates, ranches and farms (Swaziland Review, 2008).

Agriculture is one of the major driving forces in the economy of Swaziland. The commercialisation of agriculture has led to agriculture contributing significantly to the country's GDP, with figures ranging between 8 and 10 percent over the years (Swaziland Review, 2008). The sugar industry in particular has contributed significantly in terms of agricultural contribution to the GDP. This has even led to sugar in Swaziland being referred to as 'the real Swazi gold'. Such is the importance of the industry in the country.

There are two sugar companies based in Swaziland. One is the Royal Swaziland Sugar Corporation (RSSC), and it has two mills, Mhlume Sugar Mill and Simunye Sugar Mill. The other company is Ubombo Sugar Limited, and it has one mill in Big-Bend. These companies are in the lowveld in terms of the climatic zones of Swaziland, and regionally they are along the Lubombo Plateau. These companies contribute directly to the economy of the country through the exportation of sugar, thus bringing foreign currency, and also through the paying of government taxes. They also contribute indirectly through providing employment for the Swazi people.

The sugar industry in Swaziland is not entirely restricted to the two sugar companies. Though the companies are the only ones with the mills, there are some small-scale farmers who also grow sugar-cane for commercial purposes. These work closely with the companies in that they sell their sugar cane to them. The small-scale farmers are thus also part of the sugar industry of Swaziland and are affected by any stresses to the industry as a whole. With the sugar prices going down for instance, these farmers are usually the hardest hit as they get little, in monetary terms, per ton of sugar cane they sell to the mills. In terms of coping to these stresses, however, there may be differences between the small-scale farmers and the big companies. This would be a result of technological and financial factors, which differ for these two players in the sugar industry. The companies, for example, have better technological and financial means to cope to any stresses in the industry. So coping strategies for the big industries and the small-scale farmers would be expected to differ in significant ways.

3.6 Research Methodology

According to Kitchin and Tate (2000) the methodology used in research constitutes a set of procedures, which can be used to investigate a phenomenon or situation. The methodological procedures used in the study were selected based on an epistemological point of view on the subject of adaptation to climate change. Epistemology constitutes assumptions about what we can know about a phenomenon and how we can know it (Kitchin and Tate, 2000). In determining the procedures used therefore in the study to investigate the phenomenon of adaptation to climate change the questions “what can we know about the phenomenon?” and “how can we know it?” were asked. It is in this context therefore that the methodology employed helped frame the objectives set in the study.

3.6.1 Data Collection

The study uses both *primary* and *secondary* data. Primary data according to Leedy (1997) are the data that lie closest to the source of the ultimate truth. These are generated by the researcher in the field (Kitchin and Tate, 2000). Secondary data on the other hand are generated by somebody else (Kitchin and Tate, 2000). In the study, existing data, the interpretations of other scholars as well as interviews were used to provide information.

3.6.1.1 Primary Data

For the purposes of this study, primary data are those that were collected directly through undertaking some fieldwork. There are two methods that were used to collect this data, namely interviews and observations.

3.6.1.1 (i) Interviews

According to Kitchin and Tate (2000), the interview is probably the most commonly used qualitative technique. The study relied mostly on interviews as a means of collecting data in the field. The approach used in conducting the interviews was to use an interview guide with semi-structured questions (see Appendix 1). This allowed for the interview to be more guided without restricting the interviewee's responses. Explanations to questions that required further probing to the respondents were also possible in using this approach.

Interviews were conducted to gather information on perceptions on climate change and variability within the sugar industry. These were also used to gather information on the adaptive strategies that are put in place to counter the impacts of climate change and variability.

Ethics

Every research project undertaken has ethical issues associated with it, particularly when people are directly involved as participants (Kitchin and Tate, 2000). As the interviews meant interacting with human subjects as participants in the study, there was a need to follow some ethical procedures in carrying out the interviews (Appendix 2). Leedy (1997) states that ethics are concerned with the consideration of fairness, honesty, openness of intent, disclosure of methods, the ends for which the research is intended, and an informed willingness on the part of the subject to participate voluntarily in the research activity.

In the study a deliberate attempt was made to follow what Leedy (1997) alludes to. Before the interviews were conducted, the participants in the study were given an information sheet detailing what the study is about and the ends for which it was meant, and were then invited to voluntarily participate in the study (see Appendix 2).

Key Informants

For the interviews, some key informants within the sugar industry were identified and interviewed. These were mainly the companies' personnel involved particularly in on-farm activities, including sugar-cane growing, harvesting and transportation to the mill. They are of particular importance because they directly depend on climatic conditions for their activities, crop yield, and the quality of the cane in terms of sucrose content. Bohn (2003) gives eight operations and decisions affected by climate in sugar cane growing. These are:

- Ripping and land preparation
- Irrigation scheduling
- Water management issues
- Harvesting
- Burning
- Ripening
- Dry-off

- Yield and estimates

These operations given by Bohn (2003) fall squarely to the responsibility of those involved in the on-farm activities (growing of sugar cane) of the industry. The key informants in this regard therefore were the crop production managers (agronomists) of the two companies under study. Irrigation engineers were also interviewed as well as water management specialists employed in the two companies. Also, because the farms are sub-divided into sections, with each section having a manager, the section managers were also interviewed. The companies have 24 section managers combined, 7 from Ubombo Sugar and 17 from RSSC. Twenty section managers participated in the study. These constituted all 7 from Ubombo and 13 from RSSC. Four could not participate due to their non-availability. Eight senior managers were also interviewed. These were the crop production managers (one from each company), irrigation engineers (two from each company), and irrigation agronomists (one from each company). Further details have been omitted as per ethics requirements followed.

3.6.1.1 (ii) Observation

In this case the researcher observed the activities that take place within the operations of the two companies. For the purposes of this study the researcher observed on-farm activities. The focus was on the methods of farming, farm infrastructure and the general operations and management that is performed on-farm. Because the study was focusing on adaptation strategies employed in the sugar industry, this method of data collection was necessary as it allowed the researcher to observe the strategies as they were implemented on the ground.

3.6.1.2 Secondary Data

Secondary data in this study consists of information obtained from already available data. In other words, these are data that the researcher will not collect first-hand. Sources of this kind of data, according to Singleton *et al*.(1993) may be placed in five broad categories: (1) public documents and official records (2) private documents; (3) mass media; (4) physical, nonverbal materials; and (5) social science data archives. The first two categories were used in the study for secondary data, as the study relied on the company documents for data like yield records.

3.7 Conclusion

In conclusion, this chapter highlighted the context of the study. The methodology, including aspects on how the data required in the study was collected was also outlined. Both primary and secondary data were collected with a dependence on interviews and observations for the former, and company documents and records for the latter. The methodology was crucial to the study in the sense that it led to a logical extraction of data required in the study, in a manner appropriate for the nature of the study. The methods used were able to extract both qualitative and quantitative data that were required in the study. The results of the data collected are presented and analysed in the next chapter (Chapter Four) with discussion and conclusions in Chapter Five.

Chapter Four: Results and Analysis

4.1 Perceptions and Understanding of Climate Change and Variability in the Sugar Industry

4.1.1 Introduction

One would argue that perceptions on global environmental change as a whole do determine action taken towards mitigating the changes, or lesser still adapting to them. In the case of climate change, perception would be seen as a necessary pre-requisite for adaptation (de Wit, 2006). The corporate world's understanding and perceptions of some of the environmental phenomena are very crucial in determining the strategies employed in mitigating these changes. The agricultural sector is one of the major economic sectors that are highly impacted upon by global environmental change. There is therefore a need for such sectors to have proper understanding and perceptions on such changes, for them to act appropriately to counter the impacts of changes on their operations.

4.1.2 Agricultural Managers' Perceptions on the challenges and threats of climate change in the sugar industry

Agricultural mangers in the two companies under study were interviewed to determine their understanding and perception on climate change. Of major interest was the need to determine whether they perceived climate as an important factor for production in their operations, and also their perceived challenges and threats posed by climatic changes and variations to the on-farm operations of the industry. Firstly the managers were asked to rank climate amongst other determining factors of production in the industry. This was meant to ascertain the perceived importance of climate as a factor of production in relation to other factors of production. The managers' perceptions on the importance of climate amongst other factors of production are presented in figures 6 and 7 for Ubombo Sugar, and RSSC, respectively.

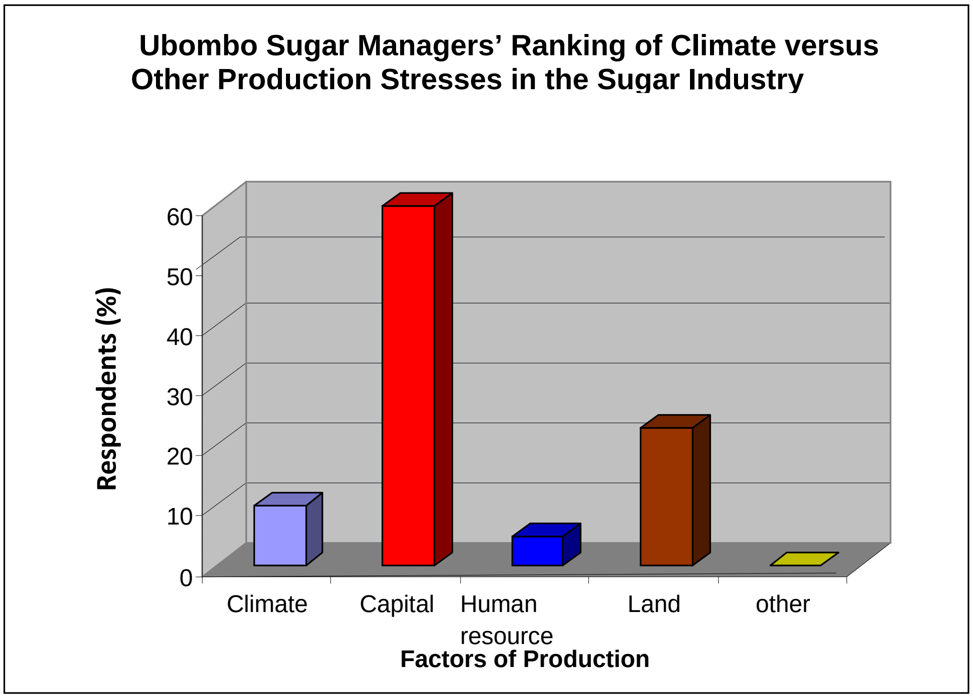

Figure 6: Ubombo Sugar agricultural managers' perceptions on importance of climate in the sugar industry *(Source: Fieldwork, 2007)*.

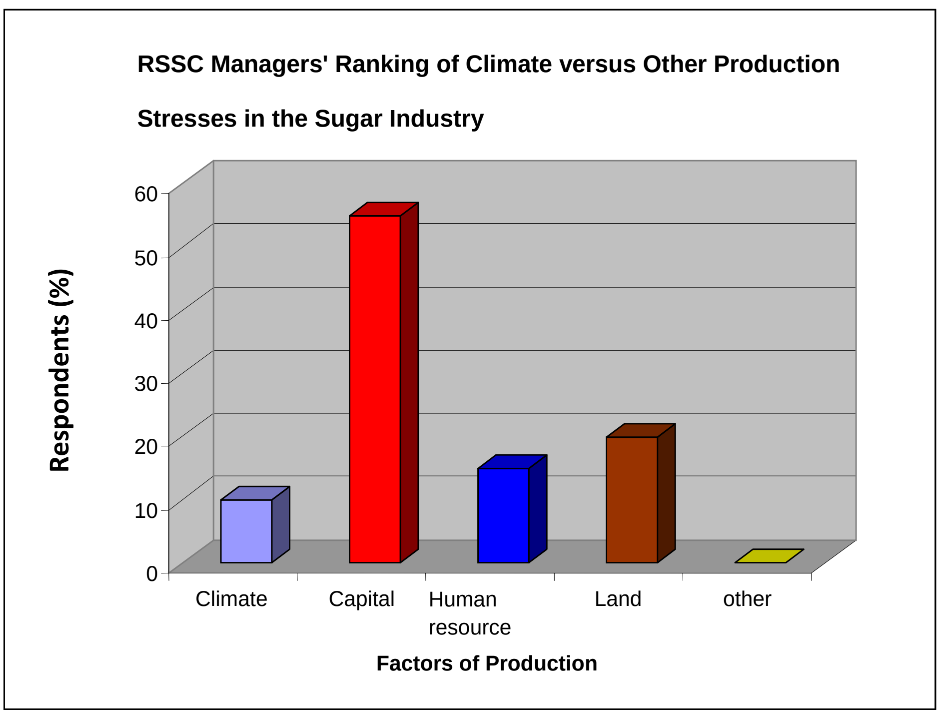

Figure 7: RSSC agricultural managers' perceptions on importance of climate in the sugar industry *(Source: Fieldwork, 2007)*.

The results from the two sugar companies reflect that although climate is considered an important factor for production in the industry, there are more important factors that they consider in their operations. For instance in both companies, more managers ranked capital as the most important factor, whilst less than 20% of the managers interviewed actually ranked climate as the most important factor.

The interviews with the managers also reflect that there have been some noticeable variations in the climate pattern of the region at a local scale. The majority of the mangers interviewed do acknowledge that indeed there have been some significant changes in the weather patterns of the region in recent years. These have been both intra-seasonal and inter-seasonal changes in climate. The changes were perceived of mainly in terms of two climatic parameters, that is, rainfall and temperatures. Table 3 reflects the perceived changes in the two parameters and the frequency of responses by the interviewed managers in both companies.

Table 3: Managers' Perceptions on Changes in Climatic Patterns

Perceived Change	Frequency of Response (% of Respondents)	
	Ubombo Sugar	RSSC
No Change	0	0
Lower amounts of rainfall	75	69
Irregularity in timing of rains	92	94
Warmer temperatures	83	81
More frequent droughts	83	88

(Source: Fieldwork, 2007)

These results indicate that agricultural managers in the two sugar companies recognize that changes in some of the climatic parameters that are of importance to the sugar industry are occurring. More managers believe that in recent years the rainy seasons have been irregular. Observations by most of the managers indicate high intensity rains for shorter and irregular periods. Temperatures are believed to have also increased over the years, with more frequent drought years. The period between the years 2001 to 2005 has been, according to some of the managers, characterised by lower than normal rainfall amounts.

It was also important to determine whether the managers viewed these changes as being significant or not. The managers ranked the changes in terms of whether they were of high, medium or low significance. The results of the perceived significance of the climatic changes are presented in figures 8 and 9 for the two companies under study.

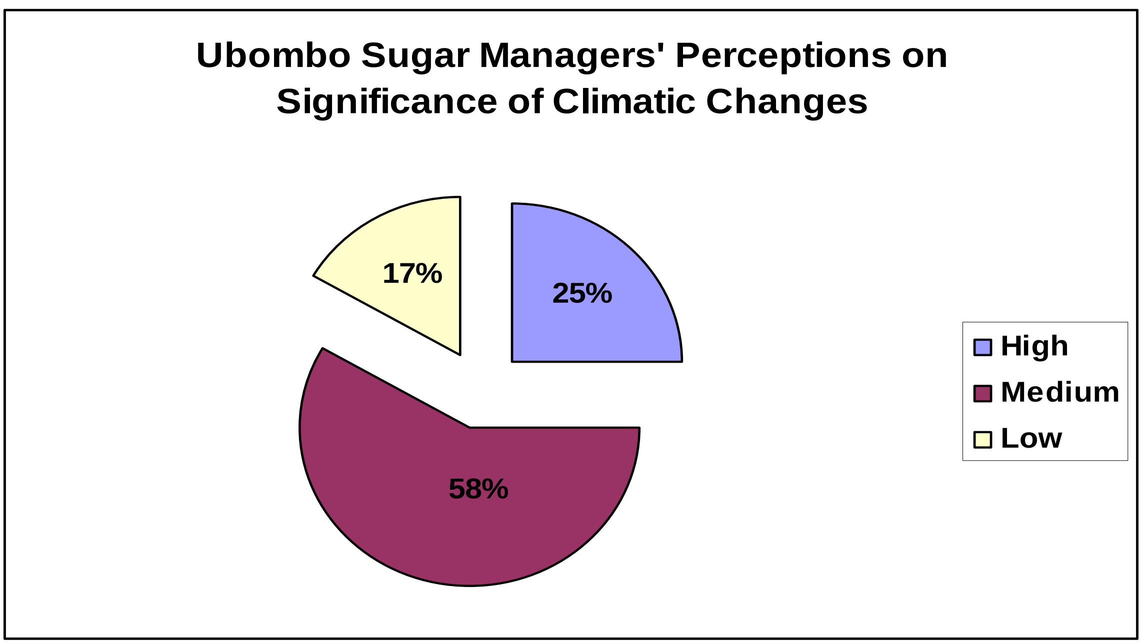

Figure 8: Ubombo Sugar agricultural managers' perceptions on significance of observed climatic variations *(Source: Fieldwork, 2007).*

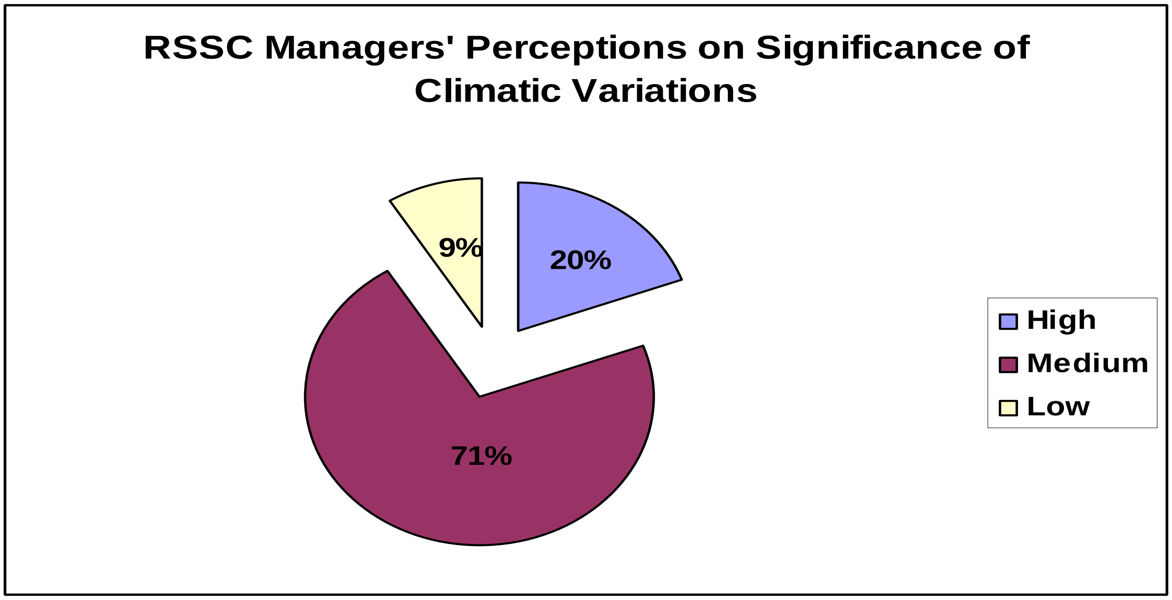

Figure 9: RSSC agricultural managers' perceptions on significance of observed climatic variations *(Source: Fieldwork, 2007).*

The results reflect that a majority of the managers in both sugar companies consider the climatic changes as of being some significance, with more than 50% of the interviewed believing they are, at the least, of medium significance.

The changes and variability of climate has posed some challenges in the operations of the sugar industry. These changes are perceived to be worsening. The challenges were viewed at in terms of the short-term, that is, the difficulties that the industry is faced with presently in terms of the climatic changes and variability. The threats on the other hand were viewed in terms of the long-term, that is, the future challenges that are likely to be experienced by the industry as a result of the changes in climate. Tables 4 and 5 represent the responses by agricultural managers in the two companies in terms of the challenges and threats posed by climate change to the industry, respectively.

Table 4: Climate Change Challenges in the Sugar Industry

Challenges	Frequency of Response (% of Respondents)	
	Ubombo Sugar	RSSC
Insufficient water supply (for irrigation)	100	100
Stunted cane plant growth	83	75
Reduction in yields	100	100
Reduction in sucrose levels (during rains at crop maturity level)	58	56
Lack of understanding amongst personnel on climate change as a phenomenon	25	0

(Source: Fieldwork, 2007)

Table 5: Perceived threats of climate change in the sugar industry

Threats	Frequency of Response (% of Respondents)	
	Ubombo Sugar	RSSC
Increase in water scarcity	100	100
Reduced land area under cultivation	42	50
Increased land degradation	33	0

(Source: Fieldwork, 2007)

The data gathered reflects that all managers in both companies realize climate change as posing a major challenge in terms of water supply. They perceive a situation in the long term where water scarcity will increase to unbearable levels. Reduction in yields is also a major challenge that all managers recognize as a result of changes in the climatic conditions. Some managers also perceive that per capita cultivated land area will have to be reduced as the amount of water available for irrigation would have decreased to the levels that not all the area that is currently supplied be accommodated.

4.1.3 Climate Information Used in the Sugar Industry

The sugar industry relies on certain climatic information in carrying out most of the farm operations. Most of the information gathered is mainly short-term in nature. The trends in the climatic parameters are, however, used as a basis to determine any long-term change or variation in the climate. The observation is in terms of intra-seasonal and inter-seasonal variation. Agricultural managers listed some of the information that is useful for on-farm operations. Forecasts also play a major role in planning and scheduling of activities in the industry. Forecast information is used both short-term and long-term. The sources of this kind of information range from companies' weather stations to internet sources. Table 6 represents useful climatic information as mentioned by the agricultural managers in the two companies. The temporal scale in which the information is used is also presented in the table.

Table 6: Climate Information Used in the Sugar Industry in Swaziland

Climate Information	Source	Temporal Scale
Temperature (min/max)	Companies' weather station	Short-term
Relative humidity	Companies' weather station	Short-term
Wind speed	Companies' weather station	Short-term
Sunshine hours	Companies' weather station	Short-term
Rainfall	Companies' weather station	Short-term
Weather Forecasts	Swaziland Meteorology Department, internet	Short and long-term

(Source: Fieldwork 2007)

This information according to the managers allows better decision making in terms of the on-farm activities. It allows determination of activities such as when to irrigate, and water requirements. It also allows for harvest planning and crop yield forecasting.

4.2 Adaptation to Climate Change and Variability in the Sugar Industry

4.2.1 Introduction

Climate change and variability is happening, and is posing some challenges to the sugar industry. Managers in the industry acknowledge the changes and their associated challenges and threats. The need to act is evident, and the sugar industry is responding to climate change and variability. It is these responses that form the focus of this section of the study. The focus is on the operations of the sugar industry, the challenges faced in each operation in relation to climate change and the adaptation strategies thereof. Three major phases are discussed in this section. These are planting, irrigation, and harvesting.

4.2.2 Adaptation Strategies Employed in the Planting Phase

With regard to sugar cane the planting phase can be defined in two ways. In the first instance it would constitute planting the first crop, that is, the seed cane. In the second instance it would constitute it would constitute managing the successive regenerating crops, referred to as ratoons. The planting phase would also include fertilizer application and weed control (through trash management or application of herbicides). Figure 10 shows a ratoon field being sprayed with herbicide for weed control. Fertilizer is applied as soon as the field rows are visible. It is best to apply in spring when the weather is getting warmer, particularly for ratoon fields whose cane was cut in winter. Planting in the sugar industry is therefore mainly done during spring and autumn. These seasons are ideal because they are neither too hot nor too cold. Planting requires mean air temperature to be above 22^{o}C. Lower temperatures tend to result in slow crop growth.

Figure 10: A ratoon field being sprayed with a herbicide *(Source: Fieldwork, 2007).*

With the climatic changes and variations that take place, the need to adjust the operations in the planting phase becomes eminent (for example, Rosenzweig and Hillel, 1995). The adjustment is usually in terms of either a change in the operation itself or a change in the timing of the operation. In the sugar industry of Swaziland, drought is usually the major climatic problem that is encountered. Through observation and interviews in the field, some strategic adjustments in the planting phase were observed that are a means to cope with the climatic changes and variability. Table 7 represents the adaptation strategies that are employed in each of the main operations that are performed in the planting phase of sugar cane.

Table 7: Climatic change impacts and adaptation response in sugar cane planting stage operations

Operation	Impact of climatic change	Adaptation Response
Planting	Slow crop growth	Synchronizing planting with optimum temperature Prioritizing planting of varieties more tolerant to warmer and dry conditions.
Trash Management (weed control)	Worsen the weed problem	Application of herbicides Hand-removal of weeds
Fertiliser Application	Loss of fertilizer through runoff during highly intense rains. Excessive nutrient content in the soils once they receive moisture.	Apply fertilizer through drip irrigation Non-application of fertilizer during droughts

(Source: Fieldwork, 2007).

The cost-effectiveness of the adaptation responses as well as their temporal effectiveness was also of interest in the study. As obtaining financial figures in terms of the costs and returns in employing each strategy proved impossible, agricultural managers were therefore requested to rate the cost-effectiveness of each strategy in a scale of 1 – 10, with 10 indicating most cost effective. The average of the ratings by the different managers was taken as the rate in terms of the cost-effectiveness of each strategy. The results of the ratings, and whether each strategy is long-term or short-term are presented in table 8.

Table 8: Cost-effectiveness and temporal effectiveness of adaptation strategies employed in the planting phase operations

Operation	Adaptation Response	Cost effectiveness	Temporal effectiveness
Planting	Synchronizing planting with optimum temperature	6	Short-term
	Prioritizing planting of varieties more tolerant to warmer and dry conditions.	7	Long-term
Trash Management (weed control)	Application of herbicides	5	Short-term
	Hand-removal of weeds	5	Short-term
Fertiliser Application	Apply fertilizer through drip irrigation	8	Long-term
	Non-application of fertilizer during droughts	4	Short-term

(Source: Fieldwork, 2007)

The results reflect that adjustments are being made in the sugar industry within the planting phase of the on-farm activities. Most of these however, though relatively cost-effective according to the managers, are short-term interventions. They are meant to address a presently prevailing situation. There may therefore be a need to move towards more long-term strategies, particularly with the perceptions that the climate is indeed changing, and is doing so at a much significant rate.

4.2.3 Adaptation Strategies Employed in the Irrigation Phase

Irrigation is meant to supplement rainwater, thereby improving agricultural productivity and lengthening the growing season (Nhemachena and Hassan, 2007). The irrigation phase is probably by far the most directly affected phase in the sugar industry in terms of climatic changes. This is because it is directly linked to water, a resource that is highly sensitive to climate change and variability mainly because of its high dependence on prevailing climatic conditions. The amount of precipitation received determines the amount of water available for irrigation. As alluded to in the literature changes in precipitation (rainfall) have very significant implications for water resources (see Rosenzweig *et al.*, 2007).

The two sugar companies under study depend on two major rivers for irrigation water. Ubombo Sugar uses water from the Great Usuthu River, whilst RSSC uses water from the Komati River. These rivers are two of the biggest catchment rivers in Swaziland. The Usuthu has a catchment area of 12903 km^2, whilst the Komati has a catchment area of 7423 km^2 (Swaziland's National Report on Climate Change, *year not stated*). In recent years however, these catchments have seen a decline in the amount water they have. Figure 11 shows a picture of the Great Usuthu, taken during the fieldwork.

Figure 11: A section of the Great Usuthu River ***(Source: Fieldwork, 2007).***

Like in the planting phase, the need to adapt in the irrigation phase within the sugar industry is evident in light of the diminishing water resource. In the irrigation phase adaptation constitutes mainly adjustments in the timing of irrigation, and most importantly in the irrigation systems employed. With regards to the timing the sugar companies, particularly Ubombo Sugar employ what they call The Drought Strategy. The drought strategy constitutes twelve scenarios, as presented in table 9.

Table 9: Strategies employed in different drought scenarios in Ubombo Sugar

Scenario	Strategy	% of normal water consumption
1	Normal irrigation	100
2	Irrigate alternate furrows and stopping some sections	87
3	Give one round of irrigation to recently cut fields and then delay irrigation to stem elongation	86.5
4	Extend dry-off for older cane to 3xTAM	84
5	Delay planting of fallow fields until water situation improves	78 – 84 (depending on the month)
6	Non-irrigation of fields to be ploughed out later in the season	70 – 76
7	Stopping irrigation for worst performing 10% of fields in terms of yields.	63
8	Stopping irrigation to furrow and dragline fields requiring more than two lifts	50
9	Stopping irrigation for furthest 10% of remaining furrow and dragline fields	46
10	Stopping irrigation for furthest 20% of remaining furrow and	37

	dragline fields, and furthest 5% of fields under Centre Pivots	
11	Stopping irrigation for furthest 10% furrow fields, 10% dragline fields, and 5% of fields under Centre Pivots	33
12	Stopping all irrigation and save water for factory	0

(Source: Fieldwork, 2007)

Since the establishment of the company, it was gathered during the fieldwork that the worst scenario that the company (Ubombo Sugar) has ever experienced with regard to water shortage is scenario 6. With more frequent droughts however it is envisaged that strategies for much worse drought scenarios may have to be implemented.

With regard to the irrigation systems, the companies are investing in more water efficient irrigation systems. Three irrigation systems are commonly used in the sugar industry of Swaziland. These are furrow, sprinkler, and centre pivot irrigation systems. These three are commonly found in the two sugar companies under study. Figures 12, 13, and 14 show the furrow, sprinkler, and centre pivot irrigation systems, respectively.

Figure 12: A sugar-cane field under furrow irrigation *(Source: Fieldwork, 2007).*

Figure 13 : **A sugar-cane field under sprinkler irrigation *(Source: Fieldwork, 2007).***

Figure 14: A sugar-cane field under centre-pivot irrigation *(Source, Fieldwork, 2007).*

There is a fourth irrigation system that is used in the industry. This is the drip irrigation system which can either be surface or sub-surface. This however is found only in RSSC. These irrigation systems are of different efficiencies, with some being more efficient than others in terms of water use. Drip irrigation (particularly subsurface) is for instance, considered to be more efficient in terms of water use. It constitutes 20% water saving when compared to the sprinkler system, for instance, which translates to a saving of 280mm/ha/yr (Matondo *et al.*, 2005). Centre pivot is as well considered to be more efficient than sprinkler and furrow. Furrow is the most wasteful irrigation system, as it uses more water. Figures 15 and 16 represent the amount of area covered by each irrigation system in the two sugar companies or estates; that is RSSC and Ubombo Sugar, respectively.

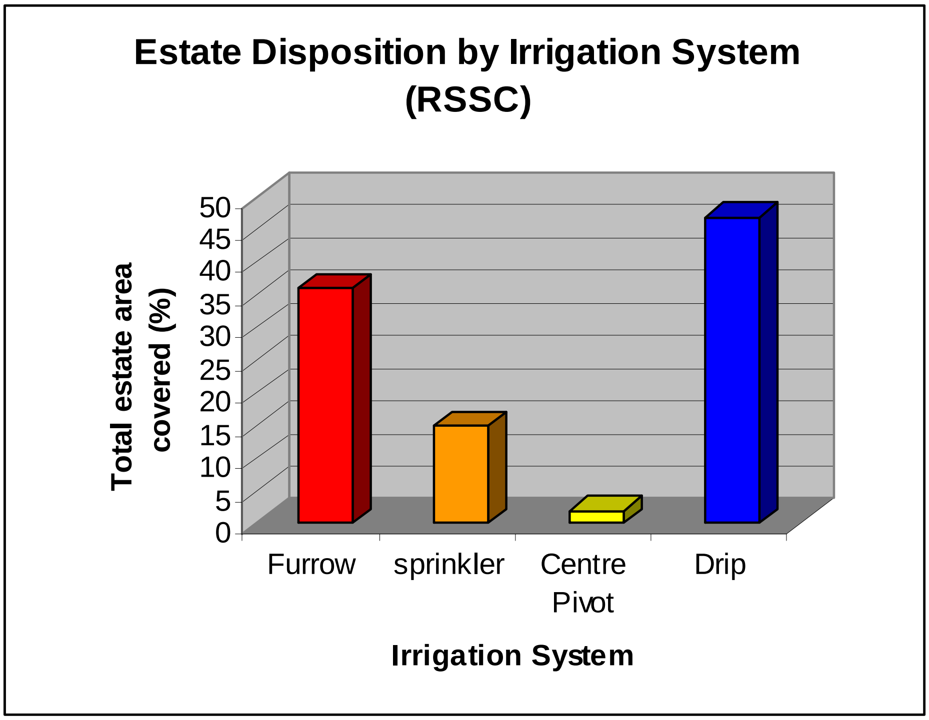

Figure 15: RSSC estate disposition by irrigation system *(Source: Fieldwork, 2007)*.

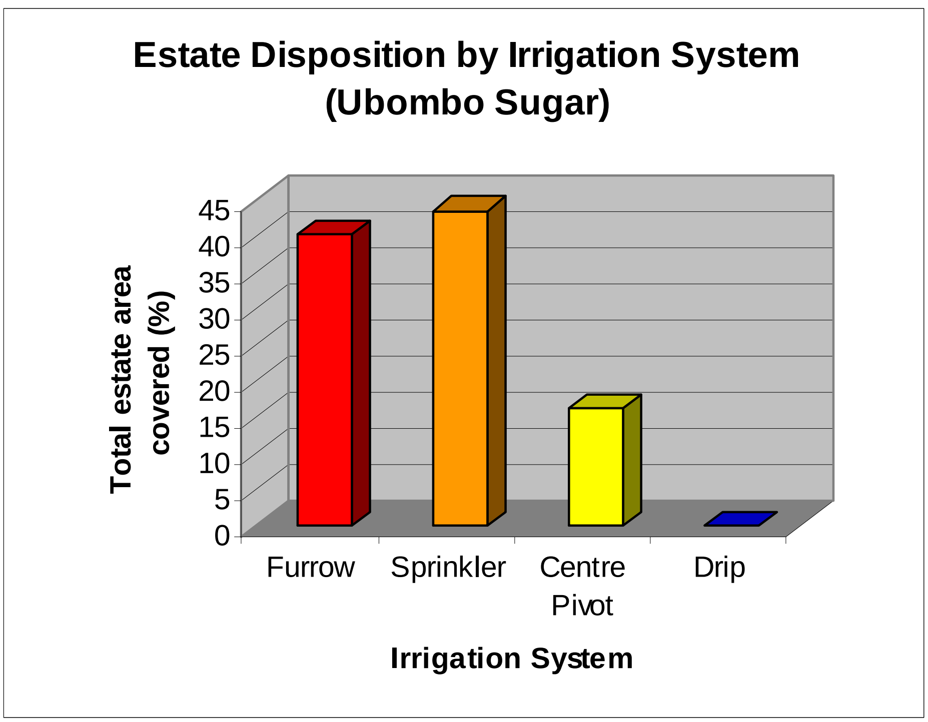

Figure 16 : Ubombo Sugar estate disposition by irrigation system *(Source: Fieldwork, 2007)*.

The results reflect different prioritization in the two companies in terms of investment on the irrigation systems. RSSC are evidently investing more on the drip irrigation system as opposed to Ubombo who are still heavily relying on furrow, whereas it is the most wasteful. Almost half the estate at RSSC (about 10,000 ha) is under drip irrigation as opposed to 0% at Ubombo. According to one irrigation engineer who was interviewed, Ubombo is mainly prioritizing investment in terms of irrigation towards the centre-pivot. This is mainly because it is cheaper to procure and maintain as opposed to drip irrigation which is significantly expensive to procure.

The two sugar companies do respond to climatic changes in rather different ways when it gets to the irrigation stage. Ubombo Sugar mainly relies on rationing of irrigation water during droughts, thereby a documented drought strategy in place. RSSC on the other hand do not have something like a documented drought strategy, but rather focus on investing in expensive irrigation systems that use minimal water whilst at the same time giving enough for sugar cane to grow effectively. These strategies are all geared towards the industry adapting to the climatic changes that have led to a reduction in water required for irrigating a crop that is highly demanding in terms of water. For Swaziland as a whole, water saving will come from efficient use of irrigation water (Matondo *et al.*, 2005)

4.2.4 Adaptation Strategies Employed in the Harvesting Phase

The harvesting phase is the last phase of the on-farm activities in the sugar industry. It usually takes place between April and December. Beyond the harvesting phase, production activities mainly move towards milling of the sugar cane into sugar and other by-products. The harvesting phase constitutes four main operations. These are ripening, burning, cutting, and transportation to the mill. Figure 17 shows the cutting operation of the harvesting phase. The cane, as reflected in the figure, has already gone through burning.

Figure 17 : Sugar-cane Harvesting *(Source: Fieldwork, 2007).*

The harvesting phase is mainly affected by wet conditions rather than dry conditions. Dry conditions are in fact necessary for the operations within the harvesting phase to be effectively and efficiently carried out. Intra-seasonal and inter-seasonal variations in the climatic conditions are therefore the main stress for the operations within the harvesting phase. The irregularity of rainfall is mainly the major factor affecting operations within the harvesting phase. Intense rainfall that falls within the harvesting period generally means delays in carrying the harvesting operations. With the climatic variations being a reality, the sugar industry has to respond to the impacts. Table 10 shows some of the impacts of the climatic variations on each harvesting operation and the adaptation thereof.

Table 10: Climatic variation impacts and adaptation responses in harvesting operations

Operation	Climatic variation impact	Adaptation response
Ripening	Wet conditions mean continued plant growth, thereby reducing sucrose content	Based on climatic forecasts, target the dry period for ripening purposes
Burning	Wet conditions delay the start of burning	Shift burning dates to dry periods.
Cutting	Difficult for cane cutters to work during heavy rains	Undertake cane cutting during the dry periods
Transportation to the mill	Wet conditions make it difficult for trucks to move easily in the cane fields. Trucks tend to get stuck on the loose and wet soil.	Heavy trucks do not move in-field during wet periods. Cane is taken manually to trucks parked on harder surfaces within the farm.

(Source: Fieldwork, 2007)

As reflected in table 10, adaptation in the harvesting phase mainly involves changing or adjusting the dates for carrying out the harvesting operations. Climatic information, particularly forecasts, plays a major role in assisting farm managers on the dates to carry out the different operations. Whether a certain date will be suitable for burning, for instance, depends on the prevailing weather conditions.

4.3 The effectiveness of the Adaptation Strategies Employed in the Sugar Industry (Comparison of Normal Years and Drought Years)

The effectiveness of an adaptation response relates to its ability to achieve its intended objectives (Adger, *et al.*, 2005). In the case of the sugar industry the intended purpose or objective of the adaptation strategies employed is to achieve good yields, thereby translating to significant profits for the companies.

Adaptation strategies are employed as a means of normalising the yields obtained in an 'abnormal' season. Abnormal season in Swaziland's sugar industry are the ones characterised by droughts. To determine the effectiveness of the adaptation strategies employed in the sugar industry, focus was placed on the drought years in relation to the normal years. Yield data from the 1991/2 season to the 2005/6 season was obtained to ascertain the differences between the drought years and the normal years. The drought seasons were identified as the 1991/2, 2001/2, and 2004/5 seasons. Figure 18 reflects the yield data obtained for Ubombo Sugar. Due to inaccessibility of this kind of data from RSSC, only the Ubombo Sugar data was used for the study.

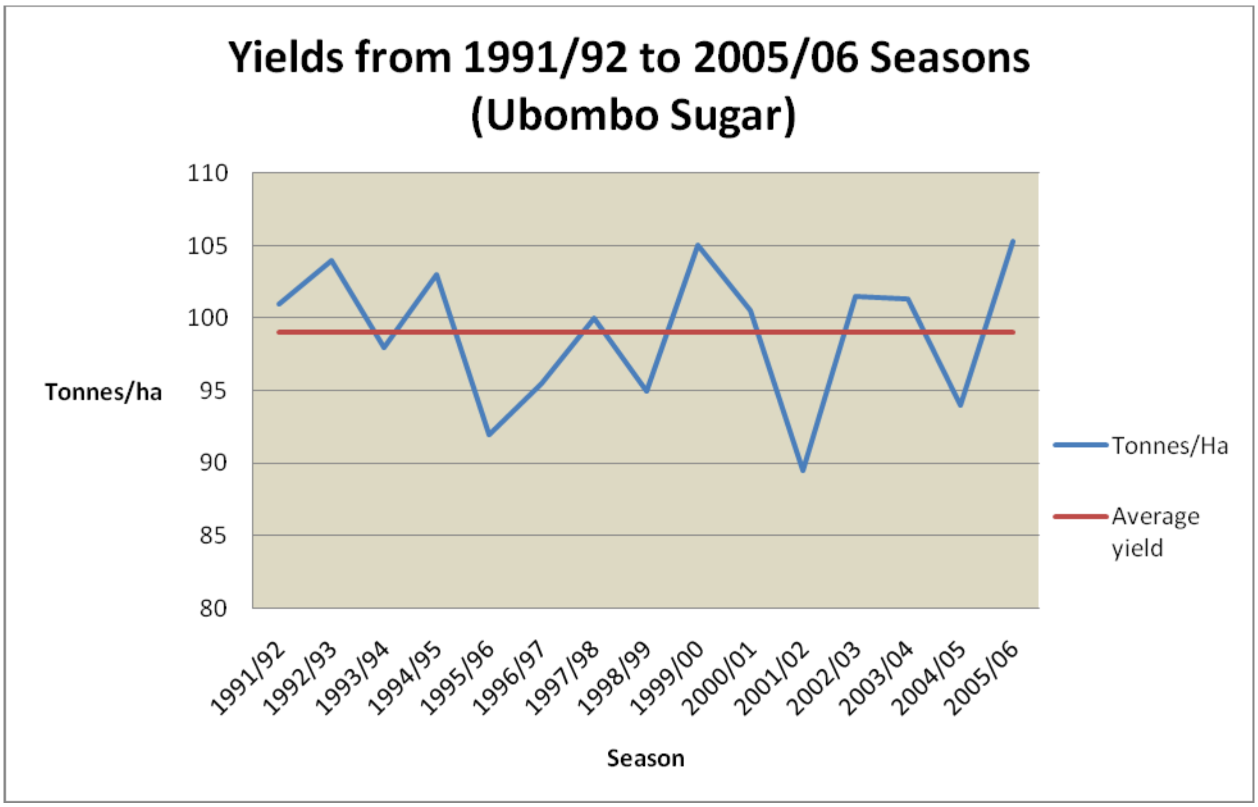

Figure 18 : Ubombo Sugar Yields (1991/92 – 2005/06) – ***Source: Fieldwork, 2007.***

The yield data for the 15 years under focus reflect an average of 99.06 tonnes/ha as reflected in figure 18. The results presented in the figure reflect that some of the drought years were above average in terms of the yields obtained, with some normal years below average. This of course could be a result of a number of other factors besides the climatic conditions. The area under cane for instance could have an effect on the total yields obtained in a season.

These results reflect that the adaptation strategies employed in some drought years are significantly effective, when one looks at the deviation of the yields obtained in these years from the average. Season 1991/2 which was said to have been a drought year during the interviews was in actual fact above the average in terms of the yields obtained. This however is attributed to other reasons. The major reason as gathered during the interview was that during the 1991/2 season the Usuthu River (the main source of irrigation water) did not have as many users as in the later years like the year 2002. The increase in small-scale farmers along the Usuthu River has resulted in the over-allocation of irrigation water from the river. The worst season in terms of yields (2001/2) was significantly below the average, with 9 tonnes/ha less than the mean. Like the 1991/2 season, the 2001/2 season was a drought year, and the effects of the drought in terms of the yields were significant mainly because the main source of irrigation water had too many users by this period.

4.4 Conclusion

This chapter has been a presentation of the results obtained from the field. One focus area for the study has been on the perceptions of agricultural managers in the two companies on climate change and variation. The results obtained reflect that climate change, though not the highest in terms of priority is taken as a serious challenge and threat to the operations of the sugar industry in Swaziland. Rainfall and temperatures are two major climatic parameters that are perceived to have undergone some significant variation and change over the years. Rainfall is perceived to be reducing and there has been a noticeable irregularity in the timing of the rainy season. Temperatures are perceived to be increasing with more frequent droughts observed over the last few years. Most of the managers interviewed perceive these changes as being significant for the operations of the sugar industry. The changes are seen to have implications for irrigation, cane plant growth and consequently result in reduced yields.

The other focus for the study was on adaptation strategies employed in the sugar industry as a response to a varying and changing climate. Interest was also on the effectiveness of these strategies in terms of yields obtained, particularly during the drought years. The results reflect that indeed some strategies are put in place within the industry to reduce the impacts of climate change and variability. These are both short-term and long-term. They are applied in all the on-farm operations of the industry, from planting to harvesting. They involve shifts in the timing of the operations to suit the climatic conditions, and also using more efficient technologies, water saving irrigation systems. Relating yield responses during the drought years to the normal years indicates some effectiveness in strategies employed, with the deviation from the average only the worst in the 2001/02 season at 9 tonnes/ha below the average. Conclusions that have emerged from this research are presented in Chapter 5.

Chapter Five: Discussion and Conclusion

This study has been an effort to examine the relationship between industrial commercial agriculture and climate change and variability in Swaziland. Countries like Swaziland, that are still developing, still rely on agricultural production as a means of reducing poverty, and a link to the wider economy (see DFID, 2005). Agriculture is one of the most sensitive sectors to climate change mainly because of its high dependence on conducive climatic conditions for its success (see Parry, 1990; Burroughs, 2001; Vogel, 2005; and Tubiello *et al.*, 2007). Many countries in Africa are considered to be the most vulnerable to climatic risks (see Boko *et al.*, 2007; Hellmuth, *et al.,* 2007; Schneider *et al.*, 2007, Yohe *et al.*, 2007). This vulnerability tends to have implications the livelihood assets which constitute human, social, financial, physical and natural capitals, as reflected in the IDS' Sustainable Rural Livelihood Framework (Scoones, 1998 in Solesbury, 2003).

With the evident impacts of climate change and variability, the need to act is apparent. Action has to be taken at international, national, and organisational scales. This study has examined what action is being taken at an organisational level in response to climate change and variability impacts on agricultural production. First and foremost, decision-makers perceptions within the sugar industry in Swaziland on climate change had to be examined. The study shows that indeed climate change and variability is considered to be a challenge on the on-farm operations of the industry. However as a factor of production, climate is not considered to be the most important. Decision-makers in the form of the agricultural managers who participated in the study, ranked factors such as capital and land as most important. This is similar to Eakin's (2005) study in rural Mexico, in which farmers were keen to discuss the effects of the variable climate on their produce, but were more interested in the North American Free Trade Agreement which was perceived to be eliminating their opportunities to sell their harvests. This reflects a perception that climate change and economic change are unrelated and independent of each other, as noted by Eakin (2005). This set of relationships clearly requires more research.

The perceived changes as reflected in the study are in support of those identified in most of the literature. Of importance is the fact that all the managers that participated in the study do acknowledge some observed change in the climatic parameters they rely on for production. Rainfall is one major parameter that has been observed to be highly variable in the industry. The majority of the managers interviewed acknowledge a reduction in the amounts of precipitation received in the last few years, with even more alluding to variation in the timing of the rains. This has also been observed by farmers in other parts of the world. In Mexico, coffee farmers in the region of Southern Chiapas have observed that rains begin later at the end of the dry season and in lower quantities (Lin, 2007). Increased temperatures and frequent droughts have also been a noticeable change within the sugar industry. Temperatures have been perceived to have been warmer over the last few years, particularly the period between 2001 and 2005. In many areas globally, the year 2005 was one of the two warmest years on record, with 1998 ranking first, and 2002 – 2004 ranking 3rd, 4th and 5th (Trenberth *et al.*, 2007). The perceptions therefore, as reflected in the study, appear to be consistent with other similar available assessments. These changes are considered to be relatively significant and are of concern in the operations of the sugar industry in Swaziland.

In terms of the perceived challenges and threats of climate change and variability, the study shows that, of major concern to the industry is the reduction in water supply for irrigation purposes, which has implications on yields obtained. As a threat to the industry, water scarcity is perceived to have the likelihood of getting worse in future with the current trends of climate change and variability. Indeed Matondo *et al.* (2005) and Schulze and Dlamini (2005) in studying the flows of three big catchments in Swaziland (Komati, Mbuluzi, and Ngwavuma) project that under climate change the flows of these rivers will be reduced. The Komati and Mbuluzi are predominantly used for irrigation in Swaziland, particularly sugar-cane (Swaziland's National Report on Climate Change, 2000, Schulze and Dlamini, 2005).

The perceptions as reflected in the study are of major importance in terms of the view of climate change in an industry that has a major role to play in the economy of Swaziland. The way decision-makers perceive climate change and variability may also be of significance to policy formulation at national level because of the influence of the sugar industry in Swaziland. Of importance, however, in terms of these perceptions is whether the changes are considered to constitute a changing climate system or just a variation in the climatic parameters necessary for production. This is because there may be a risk that the climatic parameters are generally viewed in isolation, and not as part of a system. This may in turn lead to non-holistic interventions in terms of mitigation and adaptation, and also in terms of policy formulation at national level. Clearly this area requires much more research, both in terms of understanding and modelling of the climate system and how information is used to manage complex risks.

The sugar industry in Swaziland is in many respects responding to climate change. There are a number of strategies that are put in place to cope with the impacts of climate change and variability. Climate change and variability affects almost all the activities within the on-farm operations. The coping strategies put in place may thus serve as a means of adapting to the reality of the climatic changes in the longer term. Adaptation to climate change in the sugar industry occurs at all phases of on-farm activities or operations, from planting to harvesting. Strategies are employed in response to changes in the climatic conditions. In every phase of on-farm activities there are ideal climatic conditions that need to prevail. These however are getting more difficult to attain, thereby the need to have strategies to allow operations to be done with almost the same effectiveness as when good climatic conditions prevail.

- In the planting phase the study has established that strategies employed by the companies in the sugar industry include synchronizing planting with optimum temperatures, planting tolerant varieties and the use of herbicides. These findings are consistent with Parry (1990), Graves and Reavey (1996) Graves and Reavey (1996) and Rosenzweig *et al.* (2004) in which they argue that agriculture will adjust to climate change in terms of land-use and farm management. Rosenzweig *et al.* (2004) actually alludes to changes in planting schedules and adaptation of crop genetic characteristics such as maturity class, heat tolerance, vulnerability to pests, and sensitivity to pesticides. Fertiliser application, particularly in the case of RSSC, is applied through the drip system to ensure effectiveness and efficiency in use. Parry (1990) did argue that this should be expected as agricultural management practices respond to a changing climate.

- Adaptation in the irrigation phase as realised in the two sugar companies under study mainly involves shifts towards more water-efficient irrigation system. Effort is made within the industry to invest in water saving and efficient systems. At RSSC about half of their estate is under drip irrigation, which is a system that is highly efficient when properly managed and is one system that saves significant amount of water. The centre-pivot system is also one in which the companies under study were discovered to be making significant investments on. At Ubombo Sugar more investment is put to centre-pivot as opposed to the drip. This is due to the affordability of the system to procure and maintain. Though not as efficient as drip, it is a system that is considered to be relatively efficient in terms of water consumption. This technological advancement in the irrigation system is as well to be expected as the realisation of water scarcity increases (see Matondo *et al.*, 2005 and Fischer *et al.,* 2007)

- The drought strategy as established in Ubombo sugar is also a reflection of how the industry is preparing itself for climate risks in the form of extremes. The strategy is a tool used as a response to prevailing climatic conditions in a season. When linking it to Dessai *et al*.'s (2006) two concepts of adaptation, the strategy represents what they call responsive adaptation as opposed to anticipatory adaptation. The responsiveness is in the fact that it is a strategy that is used in response to a certain magnitude of a drought. It would perhaps be necessary for the companies within the sugar industry in Swaziland to examine how they can plan for climatic uncertainties. Anticipatory adaptation is a concept that needs to be explored within the industry.

- In the harvesting phase, the study shows that adaptation is in response top wet conditions during the harvesting period. The irregularity of rains as perceived within the industry tends to impact significantly on the operations carried out during harvesting. Operations such as ripening, burning, cane-cutting, and transportation to the mill tend to be affected during wet periods. The need to shift dates to dry periods for carrying out these operations become imminent.

Some phases are more affected by the climatic changes than others. These tend to require more rigorous strategies to be employed. The irrigation phase is particularly highly affected because of the direct dependence of water availability on precipitation. With low amounts of precipitation as a result of persistent droughts, irrigation adjustments tend to be a necessity to accommodate water shortages. Water management strategies are put high on the agenda of the two sugar companies thereby water efficient irrigation systems put in place

On the whole climate change and variability has significant implications for agriculture as a whole in Swaziland, and the sugar industry in particular. The need to respond to the reality of climate change within the industry is apparent, and it is indeed responding. The study on the two major sugar estates in the country has revealed that investment is being made towards strategies that would assist the industry cope with climate change. Irrigation technology that allows efficient use of water is gradually being adopted in the industry. Drought-tolerant varieties are also being adopted as a means to cope with climate change and variation. These responses reflect that adaptive capacity of the industry in Swaziland. The internal resources that are necessary for effective adaptation need to be strengthened within the industry. Such resources include finance, access to technological innovation, and the human resource. Effort should be made to capacitate the human resource of these companies, particularly the decision-makers, on the impacts and threats of climate change on the industry as a whole. The study has shown that climate change and variability in the sugar industry is affecting operations and effort is being made to reduce the associated impacts through adaptation. Planning the adaptation is critical for the industry and there may be need for sugar companies to adopt Dessai *et al.*'s (2006) concept of anticipatory adaptation. However, it is clear that a better understanding of the complex interactions between climate and other factors and the portfolios of responses that may be required to manage complex risks is still required.

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Appendices

Appendix 1: Interview Guide Used in the Study

Part A

1. From the company's perspective, is climate considered as one of the factors of production? Yes □ No □

i) If yes how would it be ranked amongst other factors of production in the company in terms of importance (rank the following factors with 1 being the most important)

Capital □

Human Resources □

Land □

Climate □

Other □

ii) If no, what role, if any, does climate play in the farm operations of the sugar industry?

2. What climatic information is useful to the company, and for what purposes is it used?

3. Which sources does the company depend on in terms of the climatic information?

4. Has there been noticeable variations in the climate of the region from the company's perspective since its establishment? Yes □ No □

i) If yes,

A. are these intra-seasonal or inter-seasonal or both?

B. Of what significance have they been? High □

Medium□

Low□

C. Which years were the worst in terms of the climatic variations?

D. How have they impacted on the operations of the company?

E. How is the company adapting to these variations? What measures are put in place to operate within the variations?

5. Has the climate of the region changed since the establishment of the company?

Yes □ No□

If yes,

A. what has been the change?

From which year has the change been noticeable?

6. Do you consider climate change a threat in the sugar industry? Yes□ No □

i) If yes,

A. How big is the threat? High □

Medium □

Low □

B. Is it an immediate threat or future threat? Immediate □

Future □

C. What strategies, if any, are being put in place to counter the threat of climate change?

ii) If no, why is it not considered a threat?

Part B: Please fill in the table below

Operation	Time of year	Necessary climatic conditions	Impact of variation in climate	Adaptation response	Adaptive effectiveness of response (scale of 1 – 10)	Cost – effectiveness of strategy (scale of 1-10)	Temporal effectiveness of strategy (long-term or short-term)
Planting							
Trash Management							
Fertilizer							

Application (Basal Dressing)							
Irrigation Scheduling							
Weeding (herbicide application)							
Hand weeding							
Fertilizer Application (top-dressing)							
Ripening							
Dry-off							
Removal of irrigation equipment							
Burning							
Harvesting							
Transportation to the mill							
Other							

Appendix 2: Ethics Protocol