Investigating possible impact of climate change on sugarcane production in KwaZulu-Natal, South Africa

by

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Submitted in fulfilment of the academic requirements of

Master of Science

in Agrometeorology

School of Agricultural, Earth and Environmental Sciences

College of Agriculture, Engineering and Science

University of KwaZulu-Natal

Pietermaritzburg

South Africa

November 2016

PREFACE

The research contained in this dissertation was completed by the candidate while based in the Discipline of Agrometeorology, School of Agricultural, Earth and Environmental Sciences of the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Pietermaritzburg Campus, South Africa. The research was financially supported by Transnet National Ports Authority.

The contents of this work have not been submitted in any form to another university and, except where the work of others is acknowledged in the text, the results reported are due to investigations by the candidate.

Signed: Prof. M.J. Savage (Supervisor)

Date: 26 January 2017

DECLARATION 1: PLAGIARISM

I, Bonga Benson Sithole, declare that:

(i) The research reported in this dissertation, except where otherwise indicated or acknowledged, is my original work;

(ii) This dissertation has not been submitted in full or in part for any degree or examination to any other university;

(iii) this dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons;

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a) their words have been re-written but the general information attributed to them has been referenced;

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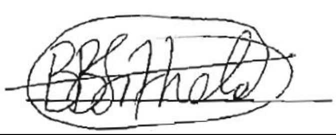

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Date: 14 November 2016

ABSTRACT

The KwaZulu-Natal Department of Agriculture, Environmental Affairs and Rural Development in 2010 undertook to investigate the vulnerability of KwaZulu-Natal to climate change which identified various sectors of the economy in the region that are impacted by climate change. The aim of the current study was to investigate the possible impact of climate change on sugarcane production in KwaZulu-Natal. The main objective of the study was to identify and synthesize current knowledge, scientific literature and data relating to specific aspects of climate change in KwaZulu-Natal, South Africa. In order to achieve the objectives of the study, a questionnaire was developed to ascertain sugarcane farmers' awareness about climate change. Based on questionnaire data, the study reveals that sugarcane farmers are aware of the effect of climate change on sugarcane production. Cane growers are also aware of their activities that contribute to climate change. Climatological data for the region were collected and analyzed through the Decision Support System Agro-tech Transfer (DSSAT) daily crop model to assess possible climate change impacts on sugarcane production. Daily rainfall, solar radiation, wind-speed, air temperature (minimum and maximum) and dew point temperature data for various sugarcane mill supply areas were collected from the South African Sugar Research Institute. RClimDex (1.0) software was used to determine if climate change did occur for the period 1966 to 2016. The climate data sets were positive to climate change with respect to daily maximum air temperature, daily minimum air temperature, daily rainfall, daily dew point temperature and daily solar radiation. The impact of climate change on sugarcane production in KwaZulu-Natal has been recognized as the main cause for yield reduction. No major decline in sugarcane production has been noted in KwaZulu-Natal for those farmers practicing irrigation and improved management. The study also demonstrates an increase in the amount of trash on sugarcane in the latter years of the study period. In general, the approach presented in this study encompassed and assessed the effect of climate change on sugarcane production with inclusion farmers perception can be considered as a strategic issue on existing climate change concern in KwaZulu-Natal province. Further research about what measures have been implemented by other countries in addressing climate change is recommended.

ACKNOWLEDGMENTS

I dedicate the success of this study to God Almighty through Christ Jesus, my Lord and Saviour who has blessed me enough with life and all the necessary resources to sustain it. My thanks go to my study supervisor, Prof. M.J. Savage for guidance and encouragement. To my personal DSSAT tutors, Mr. Matthew Jones and Dr Abraham Singels, my personal tutor in MicroSoft EXCEL, Mr. Sean Knox, my personal tutor in MS Word, Mr. Vishern Beakam and my fellow student, Jonathan Pasi for his advice in crop modelling, Mr. Richard Nicholson, Ms. Ingrid Mthembu, my IT Specialist, Mr Suran Sukdav, KZN Provincial Department of Environmental Affairs and all cane growers who participated in this study. This study was not going to be successful without your contribution. Many thanks to South African Sugar Research Institute Library for granting me access to the library resources. Special thanks go to Transnet National Ports Authority for funding this study and giving me some time-off to pursue this study. Last but not least I would like to thank my family, my 91-year old grandmother (Ms. Albertina MaNtuli Sithole), my parents, all my siblings, my wife Ms Siyabonga Sithole and my kids Smile Demoh, Sfundo Befu, Aphile Sgemegeme and Ayabonga Sdumo for giving me time to pursue this study at their expense.

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CHAPTER 1: INTRODUCTION

1. Study motivation and background

During the second half of the 20th century, the relationship between humans and the environment became a topic of widespread concern (Fuggle and Rabie, 1992). Changes in climatic trends in South Africa in particular over KwaZulu-Natal (KZN) region are being noticed together with wetting conditions during the Summer season. Climate change is most likely to have an effect on agriculture and food security across the globe in one way or another (Slingo et al., 2005). The specifics of the climate change impact will depend on how the impacts translate into factors that determine the capability and value of ecosystems (Fischer et al., 2002). Climate related risks in southern Africa could potentially threaten the livelihoods of all communities, especially those that are resource dependent for their survival (Vogel and Reid, 2005).

Sugarcane industries worldwide are located in regions of uncertain and variable climate. Dealing with this climatic variability is important to profitable and sustainable sugarcane production because stability of income from year to year affects the risk of farming and milling operations (Pulwarty et al., 2001). In view of the fact that even though the sugar industry depends on rainfall and irrigation, climate variability has a major impact not only on sugarcane and sugar production but also on the economy of the nation. In most of Africa, the role of climate is infrequently integrated into development policy and investment decision making (Pulwarty et al., 2001). There is increasing information on the negative impact to crop yields of extremely high air temperatures and rainfall at important stages of crop development. Agriculture will itself impact on the climate system and therefore a greater understanding of these feedbacks is necessary (Slingo et al., 2005). The KwaZulu-Natal Department of Agriculture, Environmental Affairs and Rural Development in 2010 undertook to investigate the vulnerability of KwaZulu-Natal to climate change. This vulnerability study identified various sectors of the economy that are impacted by climate change in KwaZulu-Natal. This study will focus only on sugarcane production in KwaZulu-Natal. Sugarcane is a major land use in the region and it competes with other crops together with industrial and domestic water users for water resources (Schmidt, 2001). In South Africa, sugarcane area occupies about 432000 ha under a wide range of climatic and soil conditions (Meyer et al., 1996). The South African sugar industry makes an important contribution to the national economy, generating an annual direct income of R6 billion annual direct income (Mqadi, 2005). Therefore it is important to focus on a research to relate the sugarcane production and the effect of changes in climate in KwaZulu-Natal region.

The issue of climate change is important and of global concern. The use of fossil fuels to meet the world's energy needs contributes to an increase in greenhouse gases (GHG) concentrations. There is a widespread view that the increase in the concentration of the GHGs including carbon dioxide, water vapor, nitrous oxide and methane is leading to climate change with adverse effects on the environment. An analysis of food and water supplies and economic growth in South Africa leads to the realization that climate variability plays a major role (Jury, 2001). Climate change refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persist for an extended period, typically decades or longer (IPCC Assessment Report, 2013). Climate change refers to any change in climate over time and space, whether due to natural variability or as a result of human activity.

The increase in atmospheric carbon dioxide concentration and changes in associated climatic variables will likely have a major influence on regional as well as international crop production (Abraha and Savage, 2006). Global mean surface air temperatures over the oceans and land have increased significantly over the last 135 years (IPCC Assessment Report, 2013). Global climate change patterns including impacts on rainfall, extreme weather events and sea level rise, rather than just moderate air temperature increases are considered to be the signs of climate change. Changes in both the mean and the variability of climate, whether naturally forced or due to human activities, pose a threat to crop production globally (Slingo et al., 2005). Water is a scarce resource in many areas of South Africa where sugarcane competes for water with other crops as well as industrial and domestic water users (Schmidt, 2001). According to the IPCC Assessment Report (2013), the indicators of climate change are evident from observations of increases in global average air and ocean temperatures, widespread melting of snow, changes in precipitation, changes in atmospheric water vapour and rising global average sea level.

The period of 2000 to 2012 ranks among the warmest years in the instrumental record of global surface temperature since 1850 (IPCC Assessment Report, 2013). During the period 2007 to 2009, spells of extreme low air temperatures accompanied by heavy snowfall, and spells of extreme high air temperatures were experienced in KwaZulu-Natal (Thornhill et al., 2009). There has been an increase in global average surface temperature and a rise in the global sea level attributable to the decrease in the northern hemisphere snow cover (IPCC

Assessment Report, 2013). The period between 2014 and 2015 was characterized by high temperatures and dry spells. Water levels in dams decreased to below normal and water restrictions were implemented by water users and water bodies. The sugar industry was severely affected and this had an impact on salaries of the sugar industry employees (M. Jones, pers. comm. 2015). An increase in spatially-averaged temperature anomaly was noted from 2012 to 2015 for the globe, northern hemisphere and southern hemisphere. The northern hemisphere had a spatially averaged temperature anomaly value of 1.13 ^{o}C in 2015 compared to the global spatially averaged temperature anomaly of 1.12 ^{o}C. The southern hemisphere had the lowest spatially averaged temperature anomaly of 0.60 ^{o}C in 2015 (Peterson and Vose, 1997). This may be attributed to the fact that there is more water mass in the southern hemisphere compared to the northern hemisphere where there is more land mass.

1.1 Climate change definition

The generic definition of the term "climate" is the change in the prevailing weather conditions over a long period of time. Climate is the meteorological conditions that exist in a particular region. Climate can therefore be defined as the composite or generally prevailing weather conditions of a region averaged over a series of years. The change of climate over time whether due to human activities or natural variability is termed climate change (Mqadi, 2005). Climate change is a challenge that is defining the current era. It is perceived as the most difficult challenge that is facing humanity today. It is a threat to all living species of earth including humans. The global community has acknowledged the fact that climate change is a problem for every citizen of the world (Raubenheimer, 2011).

The concentration of the GHGs has an impact on how the earth's atmosphere absorbs and retains solar radiation. The main source of carbon dioxide is burning of fossil fuels by human activities whereas nitrous oxide and methane mainly result from agricultural activities. Carbon dioxide is considered to be the main human cause of global warming since it has a very long atmospheric lifetime. It circulates around the world easily and therefore international co-ordination is required for regulating CO_2 emissions (Victor, 2011). Global warming became a concern in the late 1980s. Ozone layer depletion by CFCs was noticed in the early 1970s. This led to the change of mindset and identification of other global problems, including global warming (Perlmutter et al., 2011). GHG emissions that are human-induced affect the climate (IPCC Assessment Report, 2013). According to Victor (2011), it is a myth that global warming is an environmental problem but rather rooted in economics. Most of the underlying causes and consequences of global warming and nearly all policies that can assist in solving this matter are rooted in economics because even though some GHGs are produced through natural processes, human economic activities also contribute to the production of the GHGs.

1.1.1 Possible indicators of climate change

The indicators of climate change include physical responses such as changes in surface temperature, precipitation, ocean, land, ice and in sea level (IPCC Assessment Report, 2013). However, one of the problems that climate change brings is that weather will become more unpredictable. Rain may be more infrequent, but rain storms may be more severe as well (Schulze, 2007) and wind storms could be more severe. This is important because people depend on the typical weather for their human activities, for examplesuch as growing crops, raising animals, collecting water and forest products and managing cities and towns.

According to Schulze (2007), the changes in weather will affect other areas of our daily lives namely:

- flooding and erosion of coastal areas – glacier ice melts raise the sea level and affect low lying coastal areas;
- drought, desertification, shortage of drinking water – dry areas receive less rain, making them even drier;
- more difficulty growing crops due to little or too much rain;
- coral bleaching – coral whitens and can become destroyed by an increase in sea temperature, storms and flooding or sedimentation thus causing a decrease in fish habitat;
- loss of biodiversity, plant and animal migration because the climate no longer supports them; spread of disease – for example, malaria and other insect-borne diseases from insects because insects can survive in new environments created by weather changes;
- damage to homes, land and infrastructure from more severe storms or flooding.

1.2 Statement of the problem

Crop farmers are failing to cope well with the extreme weather conditions associated with climate change. It is important to identify any risks that may have a negative impact on food supply so as to improve the positive effects that may be associated with climate change and improve food production.

The scientists of Working Group II of the Intergovernmental Panel Climate Change (IPCC) in 2013 predicted that increases in GHG concentrations will result in an increase in both mean temperatures of about 2 ^{o}C and precipitation levels by 2050, causing a significant climate change throughout the world (IPCC Assessment Report, 2013). The changes in air temperature and precipitation result in adverse changes in land and water systems that will subsequently affect agricultural productivity (Mqadi, 2005). Around the globe, seasons are shifting with air temperatures and sea levels increasing at different rates (Mqadi, 2005). The extent to which climate change induces variations in the natural resource sectors may affect the agricultural sector and demonstrates the interdependence between human activities and the environment. Farmers are forced to sell their farm equipment and engage in other strategies that further drive them into poverty in an attempt to cope with extreme weather events and variations (Thorlakson, 2011). Climate change could cause geographical shifts in specific climate zones. Many researchers use various tools for producing possible data sets, for example in determining the extent of climate change for a given data set for a specific area a RClimDex system is commonly applied in Southern Africa (Zhang and Yang, 2014).

1.3 Aim

The aim of the study is to investigate the possible impact of climate change on sugarcane production in KwaZulu-Natal in order to promote food security in KwaZulu-Natal through understanding current climate trends. The research also aims to assess the perception of sugarcane farmers to climate change.

1.4 Specific Objectives

The specific objectives of this study are to:

- identify and synthesize current knowledge, scientific literature and data relating to specific aspects of climate change on sugarcane production in KwaZulu-Natal using the Decision Support System Agrotechnology Transfer (DSSAT) model and RClimDex software.
- identify strategic issues of concern and areas most at risk from the effects of climate change;
- ascertain the level of farmers' awareness of the effect of climate change on sugarcane in KwaZulu-Natal;

1.5 Organization of the study

The study is organized into six chapters. The first chapter consists of the introduction and the aims and objectives of the study. It also gives a general background to the study. Chapter 2 focuses mainly on the literature review and includes a review of DSSAT. Chapter 3 comprises the data methodology used in conducting the study. The questionnaire analysis and the results are included in Chapter 4. The results achieved through DSSAT are found in Chapter 5. The last chapter (Chapter 6) consists of the conclusions drawn from the data analysis. The findings of the study and the recommendations are also included in Chapter 6.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

In this chapter, the climate of KwaZulu-Natal is discussed. The chapter also provides a review of related literature on the subject of climate change and sugarcane agriculture. Literature related to Decision Support System Agrotechnology Transfer model is also reviewed. The chapter also details the importance of sugarcane agriculture in the region and its contribution to the gross domestic product (GDP). Historical natural disasters that have affected the region are explored. Weather systems' impact on the climate of the region is discussed. The vulnerability of KwaZulu-Natal to climate change is discussed together with the adaptation measures of both the region and Africa as a whole. Possible mitigation measures are evaluated in this chapter. Climate change related policies in South Africa are also highlighted. Sugarcane producing areas in the region are identified together with climate requirements for sugarcane production.

2.2 Cane yield

There are various factors that determine cane yield in a given year. The long-term environmental capability (climate and soil) provides the underlying basis whereas seasonal climate causes deviations around the long-term climatic variables means. According to Singels et al. (2005), other factors that may cause systematic divergence of yields changing in climatic conditions, soil degradation, technological improvement and harvest age reduction. The amount of sugar produced is impacted directly by climate. Rainfall, radiation and air temperature are the three main climatic elements affecting crop yield (Keating and Wilson, 1996). These climatic variables are also crucial along with other biophysical and cultivar parameters in crop yield model simulations for evaluating the effect of climate change.

2.3 Climatic requirement for growing sugarcane

Climate is rarely considered as an important natural resource available for economic and social growth until a major event disrupts agriculture (Abraha and Savage, 2006). Sugarcane is grown from latitude 36 ^{o}N to 31 ^{o}S, and with altitude varies between sea level to about 1000 m or more across the world. (Bielski, 1957). The KwaZulu-Natal province is located on the east coast of South Africa. The region experiences a subtropical type of climate with relatively stable air temperatures averaging around 21 ^{o}C (Thornhill et al., 2009). Barnes (1974) indicated that the most ideal climatic conditions for better production of sugarcane are:

- high incidence of solar radiation;
- frost free season to aid crop ripening;
- a summer season without hurricanes.

2.3.1 Air temperature

There is a general consensus among scientists that the air temperature for South African sugar producing areas is expected to rise by 2 to 3 ^{o}C over the next 50 years, with rainfall generally decreasing and becoming more variable. Hence climate change is receiving increased attention (Schmidt and Purchase, 2002). Sugarcane growth is closely related to air temperature. The ideal temperature for sugarcane farming is 27 ^{o}C (Moore and Botha, 2014). The region experiences an average of 320 days of sunshine a year with air temperatures ranging from 16 ^{o}C to 25 ^{o}C in winter and from 23 ^{o}C to 33 ^{o}C in summer between September and April. January is the hottest month with an average daily air temperature of about 32^{o}C. The climate of the region is also influenced by the warm Mozambique current of the Indian Ocean which results in warm surface waters flowing south along the coast causing warm sea temperatures throughout all seasons (Ridderinkhof and De Ruijter, 2003). Along the north coast of the region conditions become more subtropical. Inland and further east of the great escarpment, air temperatures decrease with increasing altitude. The weather and climate of the region is mainly affected by the coastal lows and Berg winds in winter due to its coastal geographic position (Jury et al., 2001).

2.3.2 Rainfall

Water availability is a major factor affecting sugarcane yield (Russell, 2012). Sugarcane requires a total annual rainfall between 1100 and 1500 mm during growth followed by a dry period for ripening. High rainfall is not desirable during ripening because it compromises sucrose quality (Bielski, 1957). Rainfall also hampers harvesting and transport operations. More rainfall is experienced during November (126.6 mm), December (124.9 mm) and January (124 mm). The total annual rainfall experienced during 2000 and 2010 was 963.8 mm (South African Weather Services, 2016). It is therefore due to this reason that irrigation is practiced in some sugarcane plantations in the region particularly the northern areas.

2.3.3 Humidity and solar radiation

There is a variation in relative humidity of between 45 and 65 % for the region with limited water supply favourable for sugarcane ripening (Russell, 1990). Vegetative growth is favoured by high humidity with warm weather. Generally more solar radiation promotes increased sugar yields. Sunshine facilitates growth and ripening (Russell, 1990).

2.3.4 Frost and wind

Sugarcane is sensitive to extremely cold weather since it inhibits bud sprouting in ratoons and hinders cane growth. Cane leaves and meristem tissues die at low temperatures between 1 and 2 ^{o}C (Dsapatsva, 2015). Wind-speeds of more than 60 km h^{-1} are also harmful to mature sugarcane and causes sugarcane stalk breakage and lodging of sugarcane. Transpiration is accelerated by wind and leaves are damaged (Dsapatsva, 2015). In addition the sugarcane leaves transpire more water vapour with increasing wind and the leaves are exposed to drier conditions and easily damaged. Thus, frost and windy conditions could reduce yield and quality.

2.4 Soil requirement

Soil provides nutrients, water and anchorage to the growing sugarcane plant. Sugarcane can grow in diverse soil types ranging from sandy soils to clay loam and heavy clays (Russell, 2012). Sugarcane thrives in well-drained soil; however good maintenance of proper biological, chemical and physical conditions is necessary to improve the quality of sugarcane and to facilitate sugarcane plant growth. Soil pH plays an important role in sugarcane cultivation. Sugarcane can tolerate a soil pH between 5 and 8.5. Liming is needed if sugarcane is grown in a soil with a pH less than 5 (Jones and Singels, 2013). Acid soils are not favourable for sugarcane growth and are commonly found in areas with high rainfall. The quality, yield and growth of sugarcane are adversely affected by soil acidity (Russell, 2012).

2.5 Soil structure and texture

Soil is composed of different types of particles with different particle sizes. Most soil particles originate from rock disintegration and from animal and plant residues (Kramer, 1969). There are various pores among soil particles. These pores are filled with air when the soil is dry and they are filled with water when the soil is wet. Soil supports life and living organisms are found in the soil for example, roots, worms, beetles, larvae, etc. Soil particles that are larger than 1 mm are classified as gravel; soil particles between 0.5 to 1 mm are classified as sand; soil particles with the size between 0.002 to 0.5 mm are classified as silt and soil particles of the size less than 0.002 mm are classified as clay (US Department of Agriculture, 2016). The grouping of soil particles according to their sizes or porous compounds is referred to as soil structure. It is the arrangement of soil by pores and cracks (Kramer, 1969). Unlike soil texture, soil structure is not permanent. Water enters the soil through the infiltration process thus changing the colour of the soil to become darker as it is wetted. The amount of water that soil holds after drainage has ceased is called drained upper limit (Kramer, 1969). Water is held against force of gravity and may be removed through evaporation.

2.6 Soil water content

The soil water content indicates the level of water available in the soil (Kramer, 1969). Coarse textured soils have larger pores in between thus more water will infiltrate through coarse textured soil. Fine textured soils have smaller pores in between thus less water will infiltrate through fine textured soils (US Department of Agriculture, 2016). The infiltration rate is higher in dry soils than it is in wet soils. During the irrigation process or rain shower, the soil pores will be filled with water and they are said to be saturated and there is no air left in the soil. In order to survive, plants need water and air; therefore some plants suffer when soil is saturated for more than 2 to 5 days (Kramer, 1969). Percolation is the process whereby part of the water present in the larger pores will move downward after rain or irrigation has stopped. Air will replace the drained water. In sandy soils, drainage is completed within a few hours, whereas in clay soils, drainage may take 2 to 3 days (Kramer, 1969). When large soil pores are filled with both water and air while the smaller pores are filled with only water, the soil is said to be at its field capacity. At field capacity, the soil is considered to be good to facilitate crop growth (US Department of Agriculture, 2016). Gradually, the soil will dry out as water is gradually taken up by plant roots or evaporation. When the soil becomes dryer, it becomes difficult for plant roots to extract water from the soil and at a certain point, the water uptake by a plant is not sufficient to meet the needs of the plant. This leads to the plant losing its freshness and it wilts. The leaves change colour from green to yellow and finally the plant dies. At this stage the soil water content where the plant dies is said to be a permanent wilting point (Kramer, 1969). Burk and Dalgliesh (2008) defined drained upper limit (DUL) as the amount of water that a particular soil holds after drainage has practically ceased. The quantity of water per unit bulk volume that is tightly held by the substrate that plant roots cannot absorb, and may eventually wilt due to water unavailability is referred to as the lower limit (LL) (Savage et al., 1996). The water holding capacity for different soil textures is shown in Table 2.1. Understanding soil parameters at various depths can be considered an important process in simulating yields using crop models.

Table 2.1 Water holding capacity for different soil textures (modified from Burk and Dalgliesh, 2008)

Textural class	Water holding capacity % (inches)
Coarse sand	5 (20.32)
Fine sand	8 (45.72)
Silt loam	10 (83.82)
Fine sandy loam	11 (86.36)
Silt clay loam	12 (66.04)
Silt clay	12 (66.04)
Clay	13 (71.12)
Loamy sand	14 (96.52)
Sandy loam	15 (106.68)

2.7 De-weeding

Young sugarcane needs plenty of soil water and protection from weeds. Farmers use a cultivator implement attached to a tractor to break up the soil and uproot weeds (Singels et al., 2013). When the sugarcane is taller, sunlight cannot reach the ground thus preventing most weed growth. Sugarcane monoculture, inorganic fertilization and sugarcane burning result in soil degradation and consequent decline in cane yield in the long term (Singels et al., 2005). Thus de-weeding is a common practice in growing sugarcane and maintain better yields during dry season.

2.8 Historical natural disasters that have affected KwaZulu Natal

Sugarcane over the years had been exposed to some natural disasters which may have affected its production. It is therefore necessary to discuss some of the natural disasters that have been experienced by the KwaZulu-Natal province.

2.8.1 Tropical cyclone Domoina

In 1984, a severe tropical storm called Domoina caused a 100-year return period flood in South Africa and record rainfall in Swaziland (Jury et al., 1993). Domoina was the fourth-named storm of the season. According to Jury et al. (1993), Domoina developed on 16 January 1984 off the northeast coast of Madagascar. On January 21, Domoina struck eastern Madagascar and it was the third storm in six weeks to affect Madagascar. Collectively, the storms caused 42 deaths and $25 million in damage (Jury et al., 1993). On 28th of January , the storm made landfall in southern Mozambique, and slowly weakened over land due to friction. Domoina crossed into Swaziland and later eastern South Africa bringing heavy rains and strong wind before dissipating on the 2nd February. Domoina resulted in heavy rainfall that accounted for 40 % of the annual total rainfall in Maputo (Jury et al., 1994). The cyclone Domoina moved over the area in a south-easterly direction during 29 January to the 2nd of February 1984. Rainfall in excess of 350 mm was measured in Jozini at Makhathini Research Station for the period of five days (Rossouw, 1985). Floods in the country destroyed over 50 small dams and left widespread crop damage just before the summer harvest. The rains caused the worst flooding in over 20 years in Swaziland, which damaged or destroyed more than 100 bridges and disrupted transport, leaving areas isolated for several days (Rossouw, 1985). In South Africa, rainfall peaked at 950 mm, which flooded 29 river basins, notably the Pongola River, leaving the river with an altered course after the storm. Extreme flooding caused the Pongolapoort Dam to reach 87 % of its capacity (Jury, 2002).

2.9 Climate change and sugarcane production

The climate change vulnerability study conducted on farms in Muden in KwaZulu-Natal revealed that 43 % of the farmers were not warned of the extreme climate to be experienced in the area; hence they were not prepared for such an event (Reid et al., 2005). There was a 37 % decline in sugarcane production yield during this extreme climate period and 32 % of the farmers did not receive help of any kind from the authorities. About 62 % of farmers experienced loss and 33 % did not recover at all from the loss associated with the extreme climate (Reid et al, 2005). These findings reveal that there is a need for authorities to improve their role in supporting sugarcane farmers in preparing for adaptation to climate change and extreme climate. Currently, there are no management options that are uniquely suited for adaptation to climate change that would be measurably different to those already employed for coping with contemporary climate variability (Schulze, 2005). The only substantive difference is whether one adopts a more conventional and incremental *no regrets approach,* where no regrets measures are those whose benefits equal or exceed their cost to society, these are measures worth doing anyway, or whether one adopts a more anticipatory *pre-cautionary principle*, these are a process through which stakeholders influence and share control over development initiatives, the decision and resources which affect them. This is a process which can improve the quality, effectiveness and sustainability of projects and strengthen ownership and commitment of government and stakeholders (Schulze, 2005).

2.10 Contribution of sugarcane to South Africa's economy

Sugarcane is one of the major contributors to the economy of KwaZulu-Natal (Bates, 1979). There are 26000 registered sugarcane farmers predominantly in KwaZulu-Natal and there are six milling companies with 12 sugarmills operating in the cane growing regions of KwaZulu-Natal these are Pongola, Umfolozi, Felixton, Amatikulu, Darnal, Gledhow, Maidstone, Sezela, Umzimkulu, Dalton, Noodsburg and Eston. The sugar industry produces an average of 2.2 million tons of sugar per season and almost 75 % of the produced sugar is sold to local markets in the Southern African Customs Union (SACU) (Singels et al., 2013). According to Singels et al. (2013), only 25 % of sugar produced is sold to foreign markets in Africa, Asia and USA. In South Africa, sugarcane is grown on about 400000 ha under a wide range of climatic and soil conditions. The group of grey sandy soils known as Entisols, is the most extensive and accounts for 60 % of the total area under sugarcane (Meyer et al., 1996). Sugarcane is a major land use in KwaZulu-Natal and competes with other crops, as well as industrial and domestic water users for water resources (Schmidt, 2001). According to Schulze (2007), about 432000 ha of land in RSA is under sugarcane plantations, with about 325000 ha harvested annually. South Africa ranks 13th in the world list of countries that produce sugarcane. Approximately 72 % of the sugarcane fields are under dry-land cultivation, these are rain-fed, with the remaining 28 % under irrigation. KwaZulu-Natal grows dry-land cane (97 %) with smaller pockets in the Eastern Cape and Mpumalanga. KwaZulu-Natal also grows 72 % of irrigated sugarcane (mainly on the Pongola and Mfolozi flats in the northeast of the province) and the remaining 28 % in Mpumalanga (Schulze, 2007). According to Singels et al. (2005), the sugar industry in South Africa provides jobs to approximately 85000 people directly and a further 265000 indirectly (for example, in the fertilizer, fuel, chemical, transport, food and services sectors), while a further 1000000 are dependent on the sugar industry. Sugarcane makes up approximately 15 % of the gross value of field crops produced in South Africa (Schulze, 2007) and as such, the industry exports sugar to the value of approximately R2 billion annually. Average sucrose content of the South African crop is approximately 13.5 %, varying from 11.9 to 13.8 % and inversely related to the year's rainfall. It takes approximately 8.5 ton of sugarcane to produce one ton of sugar (Schulze, 2007).

2.11 KwaZulu-Natal vulnerability and adaptation to climate change

Southern African ecosystems and societies are likely to be most vulnerable to projected climate change (Jury, 2002). Bauer and Scholz (2010) define vulnerability as a function of character, rate and magnitude of climate change and variation to which the system is exposed, its adaptive capacity and its sensitivity. Vulnerability is considered to be a function of exposure, sensitivity and adaptive capacity, with the latter, in turn, dependent on wealth, technology, education, information, skills, infrastructure, access to resources and stability as well as management capabilities (Schulze et al., 2011). Vulnerability is therefore a combination of interactions between socio-economic conditions which include infrastructure, poverty and income distribution together with their institutional context for example, governance quality, rule of law and decentralization. According to Bauer and Scholz (2010), in developing countries the poor depend on the direct use of natural resources for their survival and most of such resources depend on climate. Vogel and Reid (2005) suggested that the poor have less buffer capacity to cope with economic damage caused by natural disasters and therefore adaptation strategies development is the responsibility of the authorities from both national and international levels. The risk controlling means and dangers require a joint action and public expenditure in critical areas such as adequate infrastructure, early warning systems, research technology development, deployment, changes in decision-making procedures in the public realm and advice for risk groups (Jury, 2001).

Anthropogenic climate change may have negative impacts on aquatic ecosystems and will ultimately affect the supply and quality of freshwater lakes and rivers throughout the world. Environmental pollution, water storage and diversion together with aquatic systems are expected to experience the added stresses of global climate change (Schulze et al., 2011). Most studies agree that emission trading and the clean development mechanism reduces the abatement cost (Bierman et al., 2012). There is an urgent need for international assistance that builds on practical reasoning with regard to adaptation in sub-Sahara Africa. The application of *polluter pays principle* suggests that since Africa is perceived as the continent that is least responsible for GHG emissions, the cost inflicted on Africa by anthropogenic climate change should be borne by the predominantly industrialized states (Ziervogel et al. (2010). During the 2010 Cancun meeting, rich countries agreed to provide $100 billion as Green Climate Fund to help poor countries take measures to adapt to climate change (Vogel and Reid, 2005). The United Nations Framework Convention on Climate Change has adopted the principle that large-scale external support is needed by least developed countries of the world to adapt to climate change (Archer and Pierrehmbert, 2011). Ziervogel et al. (2010) suggested that vulnerability of rural population differs from urban populations in that urban populations have high dependence on and integration into cash economies and concentrated nature of settlements.

Most African countries largely rely on donations from rich developed countries due to financial constraints, low technological capacity, low levels of economic development and high level of poverty (Carter, 1996). Role players in developing adaptation strategies develop plans in isolation whereas much of the action required to support adaptation can only emerge from a dialogue on capacity development between all scales and levels (Downing et al., 1997). According to Bauer and Scholz (2010) integration of climate science into risk management strategies is the critical component of resilient adaptation strategy. The climate change vulnerability study conducted in Muden, KwaZulu-Natal, revealed that 43 % of the farmers were not warned of the extreme climate to be experienced in the area. Hence they were not prepared for such an event. There was a 37 % decline in sugarcane production yield during this extreme climate period and 32 % of farmers did not receive help of any kind from the authorities. About 62 % of farmers recovered from the loss and 33 % did not recover at all from the loss associated with the extreme climate (Reid et al., 2005). These findings reveal that there is a need for authorities to improve their role in supporting sugarcane farmers in preparing for adaptation to climate change.

2.11.1 Climate change adaptation challenges for Africa

Africa has the lowest GHG emissions but it is impacted by climate change the most (Ziervogel et al., 2010). Adaptation to the unavoidable impacts of climate change will need to get strong support from the international community and involve all stakeholders including the private sector. Adaptation to climate change should be understood as a continuous process which addresses current climate variability, extremes and future climate risks (Downing et al., 1997). In Africa and in developing countries in general, actions by local communities that are most directly affected play a vital role. While agriculture has traditionally been the focus of attention on climate change impact, nearly every sector is sensitive to climate change and will need to adapt to future conditions (Fischer and Velthuizen, 1996). Adaptation must be approached across all sectors and should no longer be perceived as only the responsibility of the environment ministry (Carter, 1996). Involving the Ministry of Finance is important to reflect adaptation efforts in the budget. Climate observations and data management play important roles in disaster management and climate adaptation strategies. Practical implementation of climate change adaptation requires a deeper understanding of the barriers, motivation, and incentives to adaptation both by African governments and the donor community. According to Hulme et al. (1995), the main barriers among others include:

- the lack of adequate human and institutional capacity to deal with uncertainties;
- lack of guidance and political will to deal with the issue;

- conflict with competing agendas;
- often driven by external partners and
- aversion to change difficulties in working with non-state bodies and local communities.

2.11.2 Adaptation measures for Ethekwini Metro and KZN

Climate change has budget and economic implications in the Ethekwini Municipality. The Ethekwini Municipality has developed a benefit-cost model in order to prioritise the municipality's adaptation options on the basis of economic efficiency in order to achieve the greatest good with a limited budget (B. Dale, pers. comm. 2013). The model represents a decision-support tool to reduce subjectivity and wasteful expenditure in climate change decision-making. It does not substitute the role of good decision makers. The model was developed in collaboration with municipal officials and took into account the problems associated with previous applications of economic instruments to climate change decisions, namely inadequate handling of inherent uncertainty and the assumption that a single social discount rate can be used to reflect perceptions of an entire population across all possible futures: predicting a damage function (these are what damage will occur, when it will occur and what the consequences will be) and quantifying this damage in terms of GDP impact (B. Dale, pers. comm. 2013).

2.12 Resilience to climate change

The word "resilience" is derived from a Latin word "resi-lire" meaning to bounce back (Davoudi, 2012). Data collection must be improved at a local municipal level in order to increase agricultural reliance on climate change (Murari et al., 2002). New agricultural practises are used to improve resilience to climate change. Drought-resistant crops are planted and new cultivation methods are applied to improve resilience to climate change (Murari et al., 2002). Better access to financial services coupled with crop insurance can help in improving resilience to climate change if these services are equally available to sugarcane farmers. A political-will, transparency, leadership and consultation play an important role in promotion of climate change resilience through improved governance (Murari et al., 2002). Various programs aimed at the protection of the ecosystem are required to enhance resiliency. Co-operation between national, provincial and local government is important. Capacity building on climate change issues is required for government, communities, non-governmental organisations and industries.

2.13 Climate change mitigation efforts and policies

The United Nations began formal negotiations about global warming in the late 1980s. New treaties like the United Nations Framework Convention on Climate Change (UNFCCC) which was signed in Rio de Janeiro in 1992 and the Kyoto Protocol of 1997 in Kyoto (Japan) were both signed under certain terms and principles driven by sustainability (Thornhill et al., 2009). The UNFCCC acknowledged that climate change was real and caused by human activities directly linked to land use such as deforestation and the burning of fossil fuels. It therefore committed parties of the United Nations Convention to two types of actions to address climate change (Victor, 2011). Those are mitigation (which aims at reducing GHG emissions to prevent climate change) and adaptation (which refers to taking action to adapt the climate change to which the world is already experiencing). The Kyoto Protocol however was seen as an amendment of the UNFCCC. It strongly went into effect in 2005 when it was ratified by countries which are responsible for at least 55 % of the total GHG emission (Thornhill et al., 2009). Furthermore the aim of this legally binding document was to achieve stability of GHG concentrations in the atmosphere at levels that would prevent negative anthropogenic influences on the climate system but had no impact in curbing the emissions that cause global warming (Victor, 2011).

Promoting clean cooking, heating and biofuels are other approaches that can be used to limit GHG emissions. Avoiding deforestation is another way to limit GHG emissions. According to Mqadi (2005) deforestation is responsible for 20 % of annual global CO_2 emissions and constitutes the main source of GHG from many developing countries. Assisting Africa's development of its largely unexploited hydropower potential would help to meet its objective of increasing energy access while limiting GHG emissions (Fischer et al., 2002). Less than 4 % of Africa's hydropower potential is currently utilized. Combating climate change is vital to the pursuit of sustainable development; equally, the pursuit of sustainable development is integral to lasting climate-change mitigation (Fischer et al., 2002). Focussing on the reduction in emissions of methane and nitrous oxide may be a solution to global warming since these two green-house gases have much larger global warming potential than that of CO_2.

2.14 Climate change and related policies in South Africa

According to Raubenheimer (2011), there are two key documents of national level importance on policy which incorporated issues of climate change and water resources in South Africa that exist, these are the National Climate Change Response Strategy for South Africa (NCCRS), drafted in September 2004 by the Department of Environmental Affairs and Tourism (DEAT) and the National Water Resource Strategy (NWRS) drafted in

September 2004 by the National Department of Water Affairs and Forestry. These documents address specifically national priorities and objectives with respect to climate change. NWRS addresses water resources management in a national context, but does contribute a few short sections towards the integration and accounting of climate change into water resource policy and management (Schulze et al., 2011).

2.14.1 The national climate change response strategy for South Africa

The Department of Environmental Affairs and Tourism (DEAT) drafted the South Africa's National Climate Change Response Strategy (NCCRS) in September 2004. The main objective of the strategy is to support the policies and principles laid out in the Government White Paper on Integrated Pollution and Waste Management, as well as other national policies including those relating to energy, agriculture and water (Thornhill et al., 2009). It seeks to recognise international realities of climate change, and incorporate the resulting international commitments in recognition of the present day economic and social realities which characterise the South African context (Schulze et al., 2011). This strategy highlights ten key issues within its framework of integrating climate change considerations into government policy and legislation, these are:

- supporting national and sustainable development;
- adapting to climate change;
- developing a sustainable energy programme;
- meeting international obligations;
- integration of climate change responses in government;
- domestic legal obligations;
- climate change related education and training;
- research development and demonstration;
- inventories of GHG and air pollutants and
- accessing and managing financial resources in climate change.

Although separated into ten strategic focal areas, the NCCRS has been developed to facilitate the integration of climate change recommendations such that the suggested adaptations and strategies are mutually supportive across sectors (Schulze et al., (2011), 2005).

2.15 Climate change convention

Article 3 of the convention consists of the list of principles upon which the common but differentiated approach is based. It also includes the agreement that the parties take precautionary measures to predict, anticipate, prevent or minimize the causes of climate change. According to Thornhill et al. (2009), the principles include the following:

- countries must be involved in all international climate change discussions;
- developed countries should provide financial aid and technology to developing countries to implement mitigation and adaptation measures;
- sustainable development and poverty alleviation must not be hampered by policy on climate change but environmental damage must be reduced;
- climate change is a global issue that needs to be approached globally but developed countries must accept responsibility for addressing the issue.

Article 4 of the convention states that all countries that endorsed the convention must:

- develop, update and publish national inventories of anthropogenic emissions;
- formulate, implement and update national and regional programs containing measures to mitigate climate change;
- promote and co-operate in the development and transfer of technology that controls, reduces or prevents anthropogenic emissions of GHG;
- co-operate in preparing for adaptation to the impacts of climate change;
- take climate change considerations where possible in economic, social and environmental policies with the aim to minimize effects on public health, economy and environmental quality;
- promote and co-operate in timeous sharing of technological, scientific, legal and socio-economic information;
- report to the Conference of Parties;
- promote and co-operate in education, training and public awareness.

The convention authorizes Annexure 1 countries to implement the policies and measures needed to mitigate climate change jointly with other parties and established procedures in terms of which the criteria for joint implementation would be determined.

2.16 Contribution of agriculture to South African economy

The South African sugar industry (SASI) generated about R12 billion in 2012 and is one of the world's leading cost-competitive producers of high quality sugar (Singels et al., 2013). South Africa as a country constitutes only 4 % of the African continent. The country produces around 30 % of African continent's maize, nearly 30 % of the continent's sugarcane, around 20 % of the continent's mutton and beef and around 30 % of African wheat (Schulze, 2007). The agricultural sector contributes 3.7 % to the South African Gross Domestic Product (GDP) and contributes 7.5 % of the formal labour force. However with the strong forward and backward links into the economy, the agro-industrial sector contributes 15

% to the GDP. Currently 10 million ha of the cultivated land accounts for 8 % of the land size of South Africa. Agriculture employs over 940000 employees and makes up to 8 % of exports contributing R20 billion out of R240 billion in 2004 (Schulze, 2007). Increased capacity for utilizing climate predictions in management decisions would be beneficial to the sugarcane industry and needs to be further pursued, given the present and anticipated impacts of climate variability on sugarcane and other agricultural crops (Pulwarty et al., 2001).

2.17 DSSAT model: the evolution

There is a higher demand for scientific agricultural information due to an increase in demand for agricultural products. This may compromise natural resources such as land and water. The Decision Support System Agrotechnology Transfer model (DSSAT) was originally developed by a network of international group of scientists working together in the International Benchmark Sites Network for Agrotechnology Transfer project (IBSNAT). DSSAT has been in use worldwide by scientific researchers for over 30 years (Jones et al., 2003). DSSAT was recently used by Knox et al., (2010) in reporting that expected climate change in the 2050s could increase irrigation requirements for sugarcane by more than 9 % while sucrose yields were expected to increase by 15 % (Jones et al., 2013). Schulze and Kunza (2010) used DSSAT to report rainfed sugarcane yield increase of 15 to 40 tons per hectare.

DSSAT incorporates more than 16 different crops with software that facilitates application and evaluation of crop models for different intended purposes to yield scientific results. It is a collection of independent software programs that work together with crop simulation models at its central point (Jones et al., 2003). DSSAT version 4.6 has the ability to simulate most crops' growth including sugarcane. The Canegro model has been used widely in research. The first Canegro model was included in version 3.5 of the DSSAT (Singels et al., 2002). The Canegro model has evolved since then due to various amendments designed to suit the needs of various specific research groups. The challenge with the evolution of Canegro model is that the amendments made to the software were neither incorporated nor integrated into DSSAT (Singels et al., (2002)). In 2006, the leading sugarcane research groups and industries recognised the challenges and implemented a project to address these challenges. This project resulted in the establishment of DSSAT version 4. According to Singels et al., (2008), there are six tasks that the project focussed on, namely:

- compile a user manual for DSSAT to help DSSAT users;
- ensure that the Canegro code to the DSSAT version 4 is reorganized;

- ensure that a new DSSAT Canegro model is evaluated with the dataset from countries like South Africa, Zimbabwe, Australia and United States of America;
- ensure documentation of code and concepts of the model experiments;
- ensure verification of results of the model against the existing Canegro for a set of simulation runs;
- perform sensitivity analysis of key processes including crop water uptake, accumulation of biomass and partitioning, soil changes, development of canopy, variety traits, weather and management.

The DSSAT crop model has therefore evolved to facilitate more efficient new scientific advances, applications, maintenance and documentation. The new version of DSSAT is called cropping system model design (CSM). It is a modular structure in which components are separated along scientific discipline lines and are structured to allow easy replacement or addition of modules designed to enhance its functionality (Jones et al., 2003). DSSAT has the ability to simulate growth and development of sugarcane crops. The South African Sugarcane Research Institute (SASRI) also uses DSSAT to forecast sugarcane yield for SASI (Sithole et al., 2010). Reliable predictions and understanding of impacts of climate change on sugarcane are required to plan adaptation strategies (Jones et al., 2013).

2.17.1 DSSAT cropping system model description

The DSSAT crop system model has the ability to simulate development, yield and growth of a crop growing on a uniform area of land under prescribed management together with soil water changes, carbon and nitrogen over time (Jones et al., 2003). According to Jones et al. (2013) the important approaches of DSSAT are to:

- facilitate cooperation among different model development groups where each can focus on specific modules as building blocks for increasing the scope and utility of the crop system model;
- divide modules along disciplinary lines;
- define clear and simple interfaces for each module;
- document and maintain the code it is facilitated;
- allow integration of other components such as livestock and intercropping through well-defined module interfaces;
- link modules written in different programming languages together;
- cater for comparison of different models by enabling individual components to be plugged or unplugged with little impact on the main program or other modules.

Weather, soil and plant make the primary module for DSSAT. Together these components describe the time changes in the soil and plants found on a single land unit in response to weather and management (Jones et al., 2013). Each program has six operational steps namely season initialization, run initialization, rate calculations, daily output, integration and summary output. Together these operational steps form the main program. Seasonal and daily logos are constituted of output, integration, rate calculations and seasonal initialization. The Land Unit Module is called by the main program to perform each step of processing and in turn calls each of the primary modules (Jones et al., 2003). Weather constitutes environmental modifications. Management includes planting, harvesting, irrigation, fertilizer application and residue replacement. Soil dynamics, soil temperature, soil water and soil nitrogen and carbon are included in soil. The diagram of database, application and support software and their use with crop models for applications in DSSAT is included in Figure 2.1. DSSAT uses three different files to generate the desired output namely a weather file (FileW), soil file (FileS) and experiment file (FileX).

2.17.2 Weather module

Daily weather data were accessed by the weather module in DSSAT. This module reads weather values from the weather file (Jones et al., 2003). The following variables are required for good sugarcane modelling namely maximum air temperature, solar radiation, dew point temperature, wind-speed and relative humidity (Jones and Singels, 2008). WeatherMan software is used by DSSAT user to enter weather data. Wind-speed and dew point temperature are mainly required for the calculation of evapotranspiration (Jones and Singels, 2008).

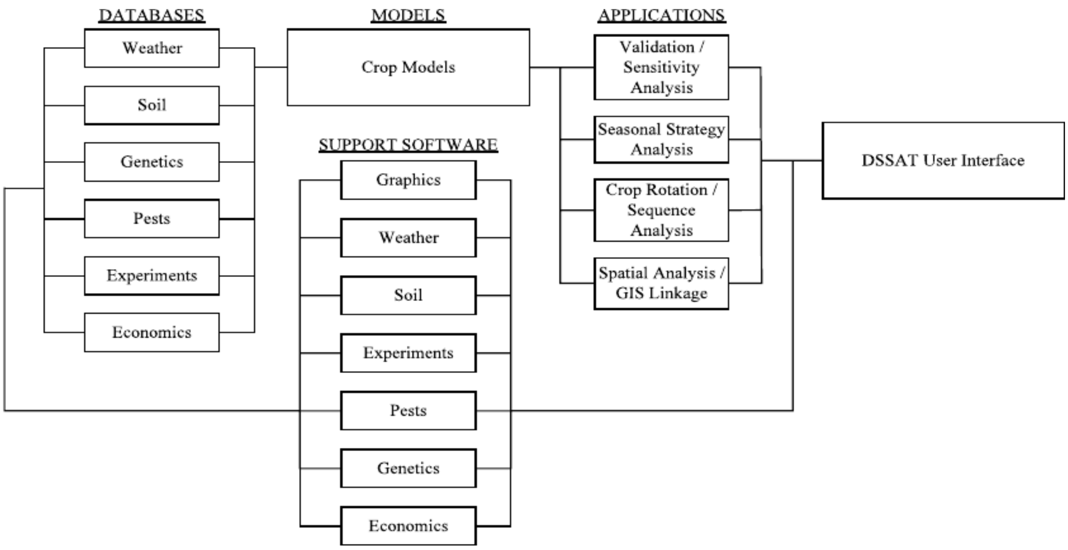

Figure 2.1: Diagram of database, application and support system and their use with crop models for applications in DSSAT (Jones et al., 2003).

2.17.3 Soil module

The soil module is used to integrate information from soil water, soil temperature, soil dynamics and soil carbon and nitrogen sub modules (Jones et al., 2003). This information is represented as soil profile that is homogeneously horizontal and consists of numerous vertical soil layers. Even though each soil layer has its own specific chemical and physical characteristics, Canegro uses only physical aspects of the soil. DSSAT uses SBuild program to create soil files (Jones and Singels, 2008). Each soil has its unique name and its unique code. Scientists adapted a soil water balance model developed for CERES-Wheat by Ritchie and Otter (1985) for use in DSSAT. It is a one-dimensional model that computes daily changes in soil water content by soil layer due to rainfall and irrigation (Jones et al., 2003). In order to compute soil water infiltration during a day, surface runoff is subtracted from rainfall that is received on that specific day (Jones and Singels, 2008). Infiltration and runoff are computed by adding the amount of irrigation applied on a specific day. DSSAT therefore compares the amount of water passing through any layer with the saturated hydraulic conductivity of that layer. Soil organic matter (SOM) and nitrogen balance are simulated by DSSAT using SOM module which is converted into modular structure (Jones et al., 2003).

2.17.4 Soil-plant-atmosphere module

Daily evaporation and plant transpiration are computed by the soil-plant-atmosphere module. This module also computes root water uptake of each soil layer. Plant, atmosphere and soil inputs are brought together and the module computes light interception by the canopy, actual soil evaporation, evapotranspiration (ET) and plant transpiration (Jones and Singels, 2008). The module requires daily weather values, current soil water content and all soil properties to produce accurate results.

2.17.5 Management module

This module controls field operations by calling sub modules. The operations controlled by management module are planting, harvesting, irrigation, fertilizer application, crop residue and organic material (Jones and Singels, 2008). The experiment input file is used. Harvesting and planting can be done in specific seasons and on specific dates. Harvesting is done when the crop has matured enough to be harvested or when the soil weather conditions are favourable for the harvesting machine to be used.

2.18 Data requirements for DSSAT

A minimum data set is needed by DSSAT model for its operation, these are site data where the model is to be operated, daily weather data experienced during the plant growth cycle, and management data for the crop (Jones et al., 2003). In instances where not all weather data are available for a particular site and a particular time period, the integrity of the minimum data set is maintained by using data of the nearby sites.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Sugarcane producing areas of KwaZulu-Natal

The study was carried out at sugarcane producing areas in KwaZulu-Natal (KZN), South Africa (Figure 3.1). The KwaZulu-Natal province is located on the east coast of South Africa. The region experiences a subtropical type of climate with relatively stable air temperatures averaging around 21 ^{o}C (Thornhill et al., 2009).

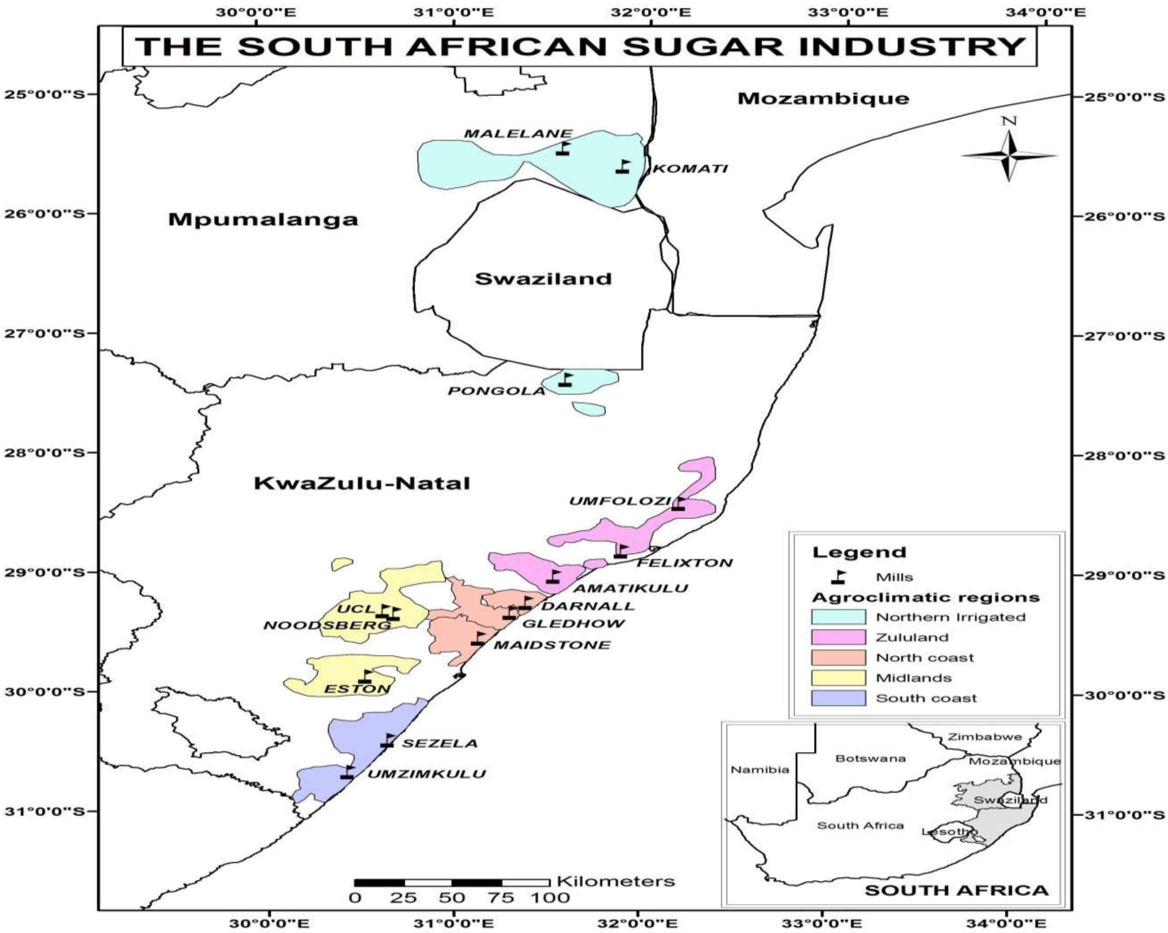

Figure 3.1: Map of the study area locating different agroclimatic regions, with their geographic co-ordinates and sugarcane mills spots. The area is situated in the east coast of South Africa along the Indian Ocean (Singels et al., 2013).

There are 12 sugarmills in KwaZulu-Natal as shown in Figure 3.1. Most sugarmills are located along the coastline with the exception of Dalton, Noodsburg, Eston and Pongola mills. UMgungundlovu District Municipality is home to Dalton, Eston and Noodsburg sugarmills. Dalton and Eston are found in Dalton in the vicinity of Umshwathi Local Municipality. Umzimkulu and Sezela sugarmills are located in Ugu District Municipality towards the border of Eastern Cape Province. Maidstone Mill is found near oThongathi within the boundaries of Ethekwini Metro. Ilembe District Municipality is home to Gledhow, Darnal and Amatikulu sugarmills along the coast. The Felixton sugarmill is stationed along the N2 Road in the Uthungulu District Municipality. Umkhanyakude District Municipality is home to Umfolozi sugarmill in Matubatuba. Pongola sugarmill is found in Zululand District Municipality in Pongola along the N2 Road towards the border of KwaZulu-Natal and Swaziland.

3.2 Data collection

3.2.1 Biophysical data

The KwaZulu-Natal province is located on the east coast of South Africa. The region experiences a subtropical type of climate with relatively stable air temperatures averaging around 21 ^{o}C (Thornhill et al., 2009). The main climatic factors that control sugarcane growth, yield and quality are air temperature, relative humidity and solar radiation (Barnes, 1974). The ideal climate for production of sugarcane is as follows (Barnes, 1974):

- high incidence of solar radiation and adequate rainfall;
- frost free season to aid crop ripening;

a summer season without hurricanes.Historical daily weather data (minimum and maximum air temperature, solar radiation, dew point temperature, wind-speed and rainfall) from four sugarmills in KwaZulu-Natal, namely Pongola, Umfolozi, Amatikulu and Noodsburg were collected and analyzed through DSSAT model version 4.6. The selection of the four sugarmill was based on their geographic position so as to represent the entire province of KwaZulu-Natal. Sugarcane production data are readily available on DSSAT software. Historical daily weather data from 1967 to 2015 were obtained from South African Sugar Research Institute (SASRI) in Mount Edgecombe."

A list of sugarmills of KwaZulu-Natal together with their altitude and geographic co-ordinates is included in Table 3.1.

Table 3.1 List of sugarmills of KwaZulu-Natal together with their altitude and geographic co-ordinates

Sugarmill	Altitude (m)	Co-ordinates
Amatikulu	31	29^{o}03'05"S and 3 ^{o}32'06"E
Dalton	1071	29^{o}20'38"S and 30^{o}37'55"E
Darnal	70	29^{o}16'20"S and 31^{o}22'25"E
Eston	799	29^{o}20'38"S and 30^{o}45'38"E
Felixton	18	28^{o}50'25"S and 31^{o}54'19"E
Gledhow	40	29^{o}21'14"S and 31^{o}17'42"E

Maidstone	67	29^{o}32’00”S and 31^{o}07’11”E
Noodsburg	1015	29^{o}22’09”S and 30^{o}45’38”E
Pongola	277	27^{o}23’14”S and 31^{o}37’37”E
Sezela	72	30^{o}24’26”S and 30^{o}39’37”E
Umfolozi	18	28^{o}27’15”S and 32^{o}12’48”E
Umzimkulu	31	30^{o}43’55”S and 30^{o}26’35”E

3.2.2 Questionnaire data

A total of 122 questionnaires were distributed to farmers from various sugarcane producing areas of KwaZulu-Natal province. The experiences and opinions of 122 randomly selected farmers were treated as representative of the views and experiences of sugarcane farmers in KwaZulu-Natal.

A questionnaire was developed to ascertain sugarcane farmers’ awareness of climate change (Appendix B). Ten different farmers per sugarmill were randomly selected from the farmers’ association. A central contact person per sugarmill was established through South African Cane-Growers Association. Each farmer was allocated a number out of which ten numbers were randomly selected from each sugarmill representing the ten sugarcane farmers from each mill. The questionnaires were accompanied by a cover letter addressed to each respondent explaining the research process and the aim of the questionnaire and giving a deadline for posting of the completed questionnaire (Appendix A). According to a self-completion method, the respondents filled in the answers by themselves. The completed questionnaires were posted by the respondents to the central contact person in their respective sugarmills. The central contact person then channeled the completed questionnaires to the University of KwaZulu-Natal (Agrometeorology Discipline). To improve respondent return number, the researcher remained in constant communication with each central contact person through telephonic and E-mail.

One hundred and six questionnaires were completed and returned. Six of them in which the most of the vital information not provided were excluded from the survey. The name of the municipality or the name of the closest sugarmill was not specified in seventy six questionnaires and was therefore excluded from the analysis. The questionnaires data was mainly qualitative in nature; hence descriptive statistics (frequency distribution) was implemented to describe the different aspects of the respondents. The sugarcane production response to climate change was also compared to the soil type for the particular area.

3.3 Data analysis

Out of 122 questionnaires distributed, 106 questionnaires were completed and returned. Six of the returned questionnaires were partially completed with most of the vital information not provided. Hence these were excluded from the survey. Seventy six respondents did not specify the name of the municipality or the name of the closest sugarmill. This information was therefore excluded from the analysis. The sugarcane production response to climate change was also compared to the soil type for the particular area. The responses from the questionnaires were analyzed and were plotted in a graph. The findings of the questionnaires were included in the results in Chapter 4 of the study. Inferential analysis was used with the data that were obtained from the use of questionnaires.

3.4 The Model Application: DSSAT

The DSSAT model was applied for the study because of its ability to model sugarcane. Professor G. Hoogenboom from United States was contacted via e-mail so as to obtain permission to use the model. A link was received from Prof. Hoogenboom and it was downloaded and saved on a computer. Date format was changed to month-day-year format.

3.4.1 Weather file (FileW)

Historical daily weather data for the study area were loaded into DSSAT using the WeatherMan software as a new file because there are many other weather station data that are already loaded by different DSSAT users in the software before. Date format on the daily data were changed to year and day of the year. Data were transferred from Excel spreadsheets to Notepad and then were imported from Notepad into DSSAT model using a data import tool from DSSAT. . The imported data were verified by confirming their units on the headings using the column property editor. Once data were loaded for a particular weather station, they were given a unique four letter code which was used by DSSAT to recall that specific weather station and also assisted in identifying the weather station. The geographic co-ordinates for each weather station were then loaded in the station parameters of DSSAT together with the altitude in meters. The climate class selected was humid sub-tropical climate. For the purpose of the study, each weather station file was saved as a single file at the expense of saving as a yearly file. This helped in ensuring that there was a single file consisting of weather data from the first year to the last year of the loaded data. Yearly file saves annual data for each year of the weather station where each year was saved as a single file. The loaded weather data were scanned to ensure that it had no defects. Maximum air temperatures of above 40 ^{o}C were identified by DSSAT as above normal by DSSAT and were substituted by average air temperatures. Once all the above-mentioned steps were completed, it was important to click on refresh button of the model to ensure that the loaded data appeared on the model and were captured correctly.

3.4.2 Soil file (FileS)

Soil data were obtained from the University of KwaZulu-Natal Library (Pietermaritzburg Campus) and the actual soil data collected from SASRI were loaded into DSSAT using the SBuild tool of DSSAT. The following information was required to load a soil profile:

- General information includes the name of the country, site name, institute code, latitude and longitude for the area
- Surface information includes soil colour, drainage, slope percentage, runoff potential and fertility factor.

The input table for SBuild was loaded with data pertaining to soil depth (cm), soil texture (%), organic carbon percentage, pH, cation exchange capacity and nitrogen percentage. After loading all soil input data, DSSAT automatically generated surface parameters. Each soil profile was given a unique name for identification purposes.

3.4.3 Management file

XBuild was used to load the management file in DSSAT. The management file is also referred to as experiment file. The name of the site to be simulated was used as the experiment name in DSSAT. Each experiment file had an experiment identifier which constituted crop name, site code, year of simulation, institute code, and experiment number. The general information required was of people these are the name of the person running the model, address and the site name. FileX constituted environment, management, treatments and simulation options. The environment aspect included fields, soil analysis, environmental modifications and initial conditions. Each file was given an eight character field identifier. Weather file for a specific weather station was selected from the list of weather files in DSSAT. Soil data together with drainage information were also available on the field section of SBuild. The measurement date was loaded on the initial conditions section of the environment option. This was the date in which the simulation started. The type of the crop to be simulated these are sugarcane, was selected from the initial conditions section. Soil analysis date, determination method and soil analysis layers were loaded on the soil analysis section. The pH was used as the determination method. Phosphorus and potassium were not considered. The NCo376 cultivar was used. In the Pongola mill supply area, irrigation is practiced to supplement rainfall. Hence sprinkler irrigation was also accounted for in the model. The other three selected mills supply areas are only rain-fed; hence no irrigation was catered for in the model. Ammonium nitrate fertilizer banded beneath the surface at 200 mm depth was selected. The tillage method used was planter row. The planting period was set to run from April and October of each year with each crop to mature at 12 months from planting time. Sugarcane is planted in April and October and hence the two planting seasons were included in each year. Each planting season was assigned to its own treatment consisting of a cultivar, plant, harvest and simulation control. Simulation for each site was started on a specified date based on the available weather data. The crop model used was Canegro Sugarcane and it was instructed to read from the weather file. Different soil types react differently to various climate conditions. A summary of homogeneous climate zones is listed in Table 3.2. The model was run and the output files were copied from Notepad and pasted on an Excel spreadsheet to generate results. Daily output data were then consolidated into annual data. The outcome of the model forms part of Chapter 5 of the study. A summary of homogeneous climate zones is listed in Table 3.2.

Table 3.2 Summary of climate zones for the sugarmill supply area (Bezuidenhout and Singels, 2007).

Mill supply area	Annual heat unit (^{o}C d)	Annual rainfall (mm)	Annual solar radiation (MJ m^{-2})
Amatikulu	3919	1018	7350
Dalton	2764	983	8095
Darnal	3882	1007	7244
Eston	2894	827	7586
Felixton	4180	1168	7384
Gledhow	3399	963	7294
Noodsburg	3068	639	8607
Pongola	4151	627	8496
Sezela	3664	980	7269
Umfolozi	4312	948	7655
Umzimkulu	3597	1079	6920
Uthongathi	3429	955	7371

3.5 Use of RClimDex

RClimDex (1.0) software was used to ascertain if there was climate change in the study area during the study period. Daily minimum and maximum air temperature and daily rainfall data were loaded into RClimDex software to generate output.

CHAPTER 4: FARMERS' PERCEPTION ASSESSMENT

4.1 Biographical information for cane growers

The study reveals a gender imbalance in cane growers with males dominating the industry by 93 % and female cane growers only 7 %. On the other hand, the study shows that there is hope for the progress of the industry since there are young farmers who are active in the industry with 8 % of respondents aged between 20-29 years (Table 4.1). The majority of the cane growers who participated in the study are aged between 51 and 60 years and it is believed that they are experienced in sugarcane agriculture. Another 15 % of the participants are the most experienced group of respondents aged between 71 years and 80 years old. The study shows that 15 % of the respondents are residing in urban areas whereas 85 % are residing in rural areas where sugarcane plantation occurs. The educational levels of the respondents vary (Table 4.2) but most respondents having post matric diplomas (23 %) and Bachelor's degree (38 %). In general, there was a diverse of respondents in both age categories and educational levels.

It is noted with interest that 38 % of the respondents are in possession of a university degree while 8 % are in possession of a postgraduate degree and 23 % of them have a post-matric (post-grade 12) qualification, it is assumed that these respondents have scientific knowledge of sugarcane farming. The study reveals that some of them commenced farming in 1966 and they have experienced the climatic pattern over the years. The youngest of them commenced farming in 2012. There is a high percentage of farmers at 83 % who are fully aware of the size of the area they are cultivating to produce sugarcane. The 64 % of respondents have increased the size of the land they are cultivating. All respondents are using fertilizers to maximise production. The study also reveals that all respondents are using herbicides in their cane fields. Only 42 % of respondents rely on irrigation to supplement rainfall, while 58 % of cane growers rely on rain-fed sugarcane production.

Table 4.1 Age group percentage of respondents who participated in the study (n = 100)

Age group	Percentage (%)
20-29	8
30-40	8
41-50	23
51-60	38
61-70	8
71-80	15

Table 4.2 Education level of respondents who participated in the study (n = 100)

Educational level	Percentage (%)
Grade 11 or lower	8
Grade 12	8
Post matric diploma	23
Bachelor's degree	38
Postgraduate	8

4.3 Respondents' experience on sugarcane production in KwaZulu-Natal

4.3.1 Years of good harvest experienced by respondents

From the results (Figure 4.2), it is important to note that 23 % of respondents in both 2013 and 2014 received good harvests followed byyear 2012 that was indicated as a year of good harvest by 15 % of respondents. Further 8 % of respondents in all years of 1999, 2004, 2008 and 2010 received good harvests. The main reasons identified by respondents as contributing factors to good harvests received are listed in Table 4.3. According to respondents the main factor for good harvest was the good rains with early application of fertilizers (19 %). Good soil preparation and frost free condition also showed as contributing factor for better harvest. Supplimentary irrigation during dry periods and fertilization can play a big role in improving sugarcane yields.

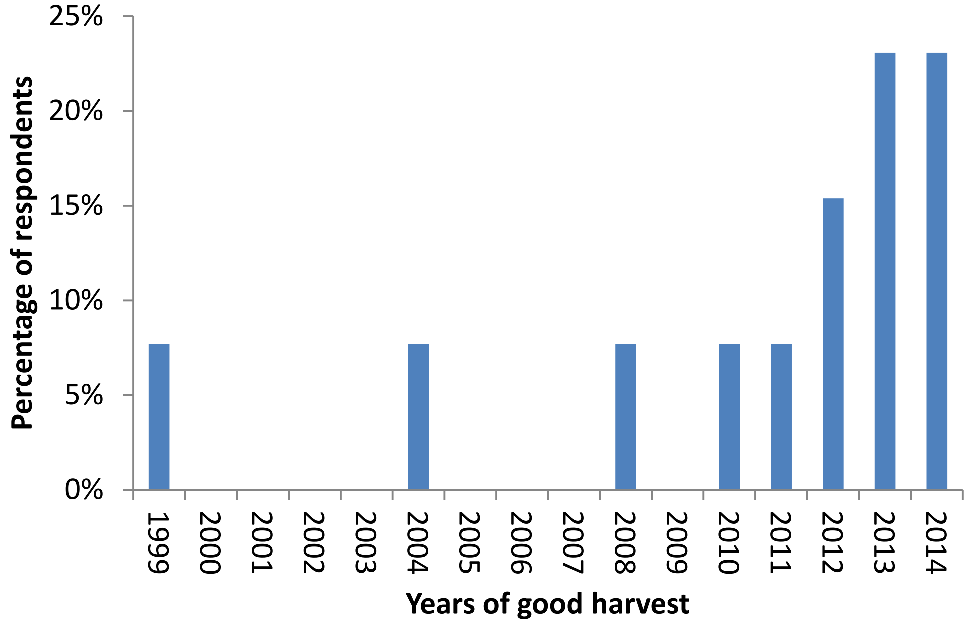

Figure 4.1: Percentage of respondents receiving good harvests from year 1999 to 2014.

Table 4.3 Factors contributing to good harvest received by respondents in 1999, 2004, 2008, 2010, 2011, 2012, 2013 and 2014 (n = 100)

Contribution factors	Percentage of respondents (%)
Good rainfall	23
Early application of fertilizers	19
Good soil preparation	12
No frost	11
De-weeding	9
Gapping	8
Applying herbicides	6
Installation of pivot irrigation	3
Liming	2
Ratoon management in time	2
Top dressing	2
Application of fertilizers according to soil recommendations	1
Eradication of cynodon	1
Good winding	1

4.3.2 Years of below-normal harvest experienced by respondents

It is noted with interest that for the years in which some respondents experienced good harvest, some also experienced below-normal harvest. Year 2014 was identified by 35 % of respondents as the year of below-normal harvest with year 2011 identified by 18 % of respondents also as the year of below-normal harvest (Figure 4.3). Year 2004 was identified by 11 % of respondents as the year in which they experienced below-normal harvest. The remaining respondents identified 1999, 2008, 2010 and 2012 as years in which the respondents received below-normal harvest. The reasons cited by respondents for the below-normal harvest are listed in Table 4.4.The two extremes of no rain and flooding events showed to give below normal harvests according to respondents' view. On the same way 12 and 14 % of the respondents showed to give weight for hail damages and intermittent droughts on the production season. However, respondents did not mention fertilizer applications for below normal harvests.

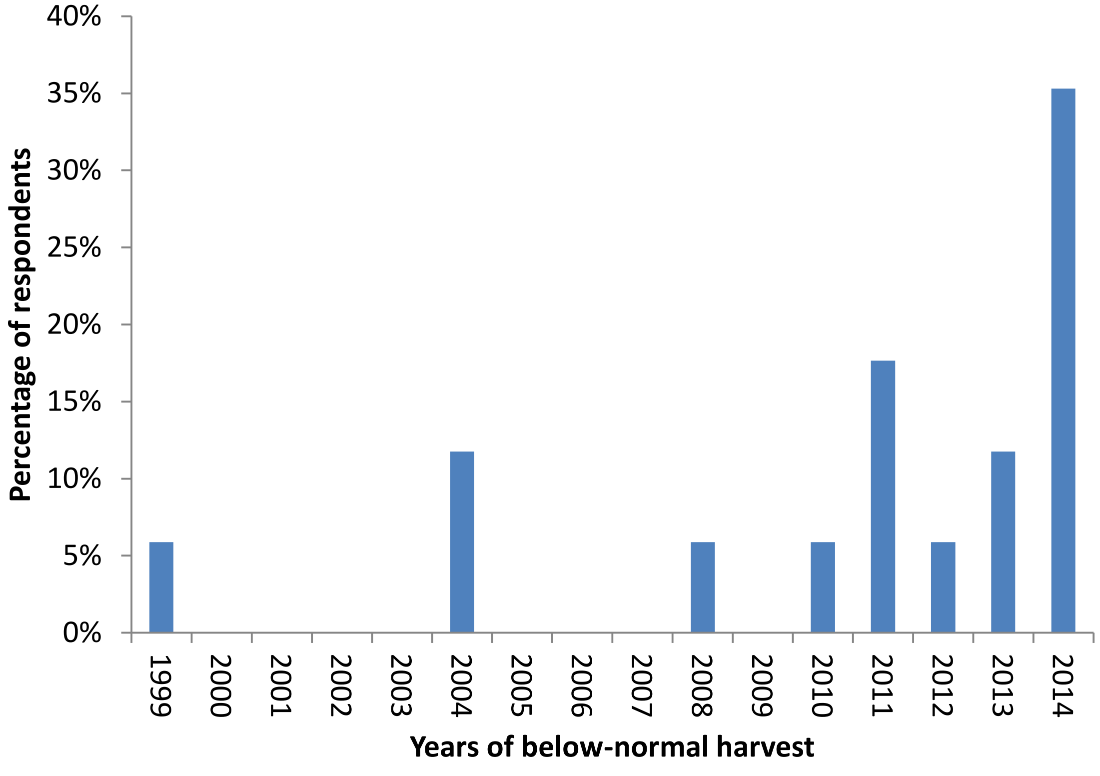

Figure 4.2: Percentage of respondents receiving below-normal harvests from year 1999-2014.

Table 4.4 Factors contributing to below-normal harvest received by respondents in 1999, 2004, 2008, 2010, 2011, 2012, 2013 and 2014 (n = 100)

Factor	Percentage of respondents (%)
No rain from February to November	34
Flooding conditions from December to late January	31
Hail	14
Drought	12
Frost	9

4.4 Climatic factors and support from government

All respondents indicated that they are fully aware of the climatic factors that play a role in sugarcane production. However, there are different views about the support offered by the KwaZulu-Natal provincial government to cane growers to maximise their production. Most respondents (75 %) believe that the provincial government is not offering sufficient support to respondents, 17 % believing that the government is offering sufficient support and 8 % of the respondents are not sure if the government is offering enough support to cane growers (Table 4.5). This is the indication for the interaction between the government and cane growers with regard to climatic factor to boost their production. Thus the consideration of the effect of climate change in sugarcane production is one of the priority for sugar industries.

Table 4.5 Respondents' opinion on the support offered by the provincial government to cane growers to maximise their production (n = 100)

Respondents' response	Percentage (%)
No	75
Yes	17
Cannot say	8

4.5 Recommendations

There are various recommendations made by respondents about the type of assistance the government could offer to cane growers (Table 4.6). The greater percentage of respondents is concerned about the lack of subsidized insurance for climate related losses and some respond (9 %) for research focus to address climate change. Only 1 % recommends prayer as the solution that provides moral value in every respect. Other respondents give sensible recommendations but seem hard to implement to obtain instant solutions.

Table 4.6 Recommendations made by respondents on type of assistance farmers expect from provincial government in addressing climate change (n = 96)

Recommendation	Percentage of farmers (%)
Subsidized insurance for climate related losses	11
Research about what other countries are doing to address climate change	9
Subsidy to farmers depending on jobs they provide to people	9
Subsidize sugarcane farmers	8
Government must close the gap between itself, sugarmills and small-scale farmers	7
Drought relief funds	6
Favourable tariffs for "green energy production"	6
Compensation for on-farm alien invasive weeds and animal control. This is an on-going cost to farmers which is neglected	5
Be aggressive in supporting "working with water" project	4
Establishment of irrigation centres	4
Sugarmills management withholds information so as to leave small-scale farmers misinformed.	4
The provincial government is unaware of what is occurring with rural communities for example, farming equipment bought by the provincial government in support of farmers has been left to rot unused on premises at certain agricultural offices.	4

Some fertilizers bought by government in 2012 have yet to be distributed to sugarcane farmers	
Use bio-fuel instead of fossil fuel	4
Enforcement of compliance with regulations factors affecting climate	3
Fuel rebates	3
Government must address population explosion (immigration)	3
Better management of wetlands and catchments in state owned land and tribal land	2
Provide training on water conservation to sugarcane farmers	2
Reforestation (planting of trees)	2
Prayer	1

There are different views on climate of the past 40 years with 69 % of the cane growers stating their dissatisfaction with the climate and only 31 % stating that they are satisfied with the climate of the past 40 years in relation to sugarcane production. The reasons cited by respondents as the source of their dissatisfaction about the present climate compared to the past 40 years are presented in Table 4.7. In a question about significant changes in climate in the past 40 years, 75 % of respondents believed that there were changes. It is assumed that the 25 % of respondents who believe that there are no changes are the new cane growers who recently joined the industry and hence only 75 % is included in Table 4.8.

Table 4.7 Reasons cited by respondents as a source of their unhappiness about present climate compared to the past 40 years (n = 100)

Reason	Percentage of respondents (%)
Erratic rainfall	14
Low and sporadic summer rainfall	12
Scorching sun	11
Late rainfall	9
Frequent drought	8
Downward trend of solar radiation	7

Erosion of fertilizers due to flooding conditions	7
Less frequent rain	8
Global warming	6
Severe frost	6
Rainfall distribution that has deteriorated dramatically	5
Erratic weather pattern	4
More violent and devastating storms	3

Even though 25 % of respondents believe that there has been no change in climate in the past 40 years, it is noted that all respondents are fully aware of activities that are contributing to climate change (Table 4.9). It is important also to note that despite all the climatic challenges that the respondents are facing, 67 % of them are still encouraging their children to continue practising sugarcane production. The respondents also acknowledge and believe that they do have a role to play in addressing climate change (Table 4.10).

Table 4.8 Significant changes noted by respondents in the past 40 years (n = 75)

Change	**Percentage of respondents (%)**
Long period without rain in a year	18
Higher temperatures	12
Recent years have received almost no rain from February to December	8
Droughts are common	7
Less summer rainfall	7
Similar weather conditions for both summer and winter	7
Erratic weather	5
Irregular and unpredictable seasonal changes	5
More rain was experienced in summer during earlier years than present	4
Frost	2

Table 4.9 Activities identified by respondents as contributing to climate change (n = 100)

Activity	Percentage of respondents (%)
Burning of fossil fuels	36
Deforestation	28
Over-utilisation of natural resources	17
Air pollution from human activities	13
Use of ozone depleting chemicals	6

Table 4.10 Contribution by respondents in addressing climate change (n = 92)

Contribution	Percentage of respondents (%)
Look for alternatives to sugarcane burning	18
Use energy efficiently	11
Conserve natural resources	9
Apply fertilizers correctly	8
Unite and form their own bank to provide loans to farmers	8
Good field layout	7
Plant trees	6
Avoid veld-fires and support “working on fire”	5
Practise crop rotation	5
Practise waste recycling and re-use	5
Be aggressive in implementing “working for water” projects	4
Use sustainable farming practises	4
Use environmentally friendly herbicides	2

However, it is noted with concern that eight respondents believe that their activity has little impact on climate change hence only 92 % of respondents is catered for in Table 4.10**.**

4.6 Summary

Data collected from respondents were analysed through tables and graphs in this chapter. A total of one hundred questionnaires were analyzed. Gender imbalance was noted with males dominating sugarcane farming. Involvement of youth in sugarcane farming was also noted as a positive factor symbolising hope for the industry. The results show that the respondents possess some form of formal education. Factors contributing to below-normal harvest and to good harvest were also explored. The respondents show some awareness of climatic factors contributing to either good or below-normal harvest. A significant change in climate for the past forty years was noted by respondents. Recommendations by respondents on the type of assistance expected from the government were also explored. Respondents demonstrated awareness of activities contributing to climate change. Respondents identified their contribution in addressing climate change.

CHAPTER 5: DSSAT MODEL AND RCLIMDEX

5.1 Stalk height

According to Bieleski (1957), a sugarcane plant has 8 to 16 stems at full growth. The subtended leaves dry out and die as the sugarcane plant grows and matures. Umfolozi has the tallest stalks compared to Amatikulu and Pongola with Noodsburg having the shortest stalks (Figure 5.1). There was a decrease in stalk height for Umfolozi between 1969 and 1971. During the earlier years of the study (1971), Amatikulu had the shortest stalk height but it improved between 1972 and 1973 from 2.8 m to 4 m. It is also noted that in 1971, Umfolozi stalk height was about 4.5 m. It has improved between 1973 and 1975 to 5 m and has been consistent throughout the study period. Pongola has been consistently above 4 m throughout the study period. An increase in stalk height is noted in Amatikulu in 1998 to 2001 and in 2011 but decreased to its normal height from 2012. The average stalk height for the study area during the study period is 4 m. According to Van Dillewijn (1952), in tropical regions where variations in air temperature and day length are small but which are characterized by the occurrence of alternating dry and wet seasons, cane growth is largely governed by the amount and seasonal distribution of rainfall.

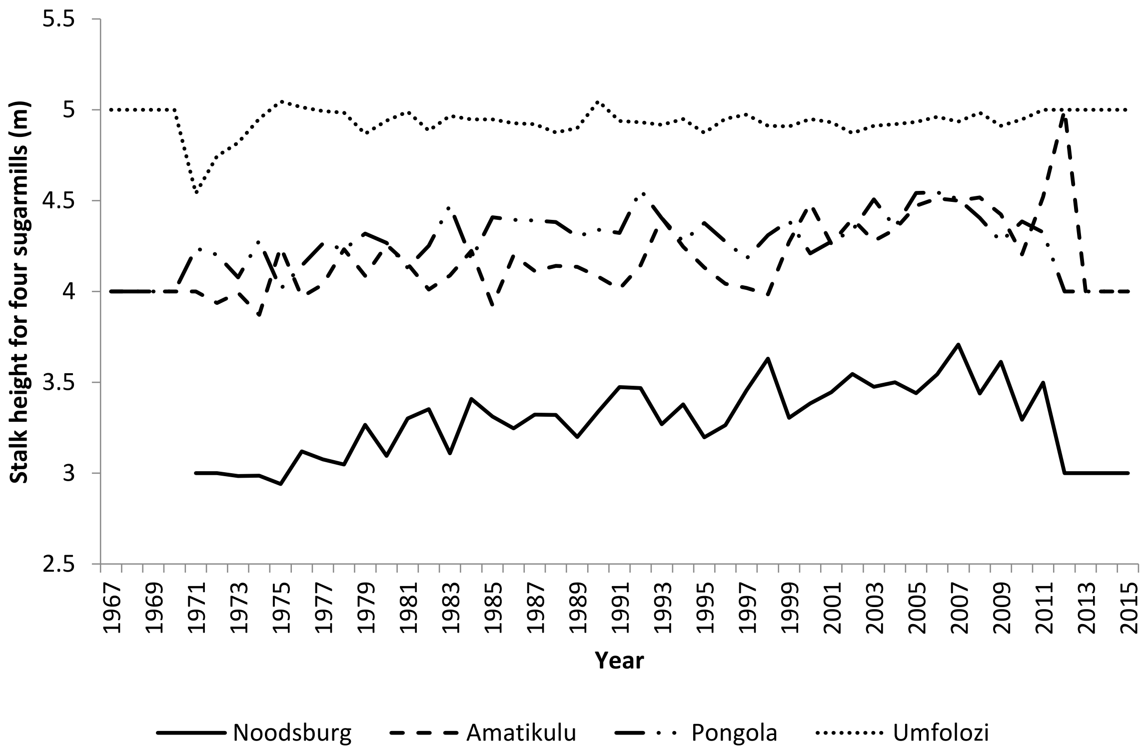

Figure 5.1: Line graph showing stalk height for sugarcane plant. The graph shows four selected sugarmills of KwaZulu-Natal.

5.2 Harvest index

According to Moore and Botha (2014), the period of rapid culm growth during the 12-month growing season spanning from shoot emergence to harvest occurs during periods of high solar radiation and near-optimum temperatures. The highest harvest index ever recorded during the study period is 15.8 t/t recorded in Amatikulu in 1974 with the lowest harvest index recorded at 3.7 t/t in Noodsburg in 1973 and Pongola in 1994 and 1998 (Figure 5.2). Amatikulu and Noodsburg have generally higher harvest indices compared to Pongola and Umfolozi. On average, the highest harvest index was recorded in 1974 at 10.2 t/t and the lowest was recorded in 1973 at 5.8 t/t (Figure 5.3).

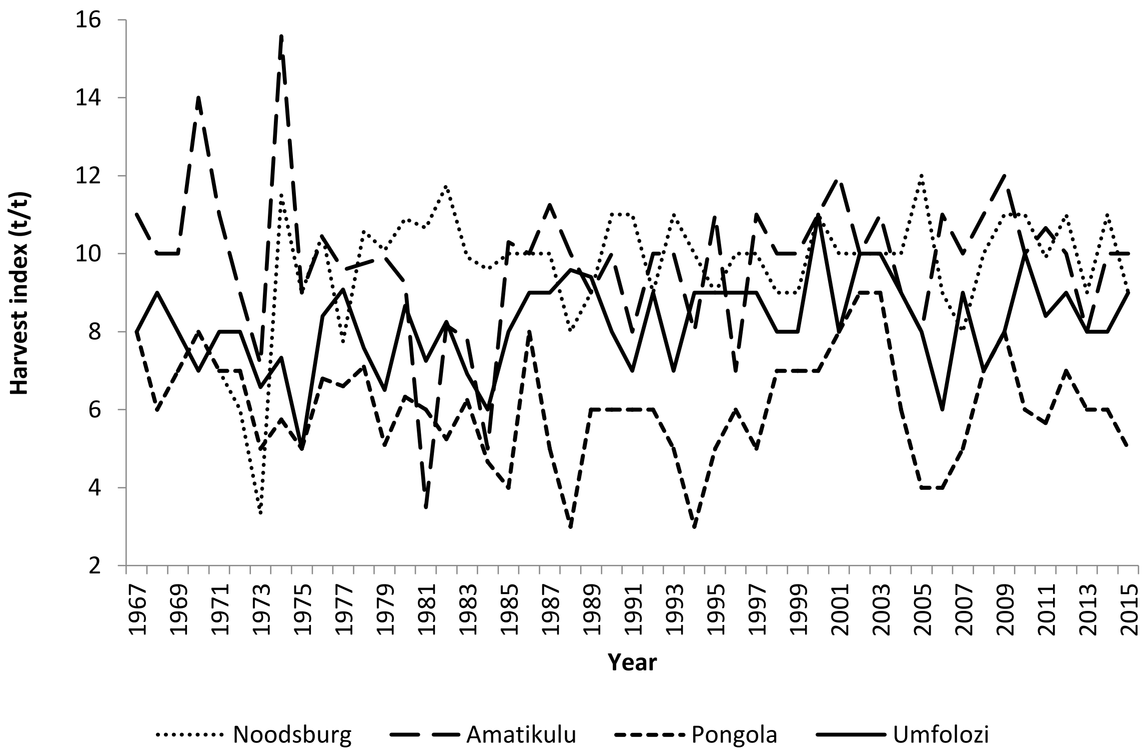

Figure 5.2: Line graph showing harvest index for sugarcane production for the study period as generated through DSSAT software. The graph shows the harvest index for the four selected sugarmills of KwaZulu-Natal.

5.3 Sucrose tonnage produced

According to Moore and Botha (2014), the anatomy and morphology of sugarcane underpin the specialized ability of the plant to accumulate large amounts of sucrose. Winter ratoons are characterized by high cane yields with relatively low sucrose content. Amatikulu cane showed high sucrose mass with the highest tonnage recorded in 1974 at 2900 tons ha^{-1} (Figure 5.4). Ironically the lowest tonnage for Amatikulu was recorded in 1973 at 500 tons ha^{-1}. Noodsburg has the second highest sucrose mass with the highest recorded in 1973 also at around 2900 tons ha^{-1}. Pongola has the lowest sucrose mass with its highest recorded in 2003 at about 1700 tons ha^{-1}. The lowest sucrose mass ever recorded during the study period is about 240 tons ha^{-1} recorded in Pongola in 1988. It must be noted that Pongola is the only mill supply area that practices irrigation. It has been recognized that suspending or reducing irrigation water of well-irrigated crops for a period before harvesting can increase the sucrose content (Moore and Botha, 2014). The average sucrose mass for the study area is fluctuating with the highest peak recorded in 1974 in both Noodsburg and Amatikulu mills (Figure 5.5).

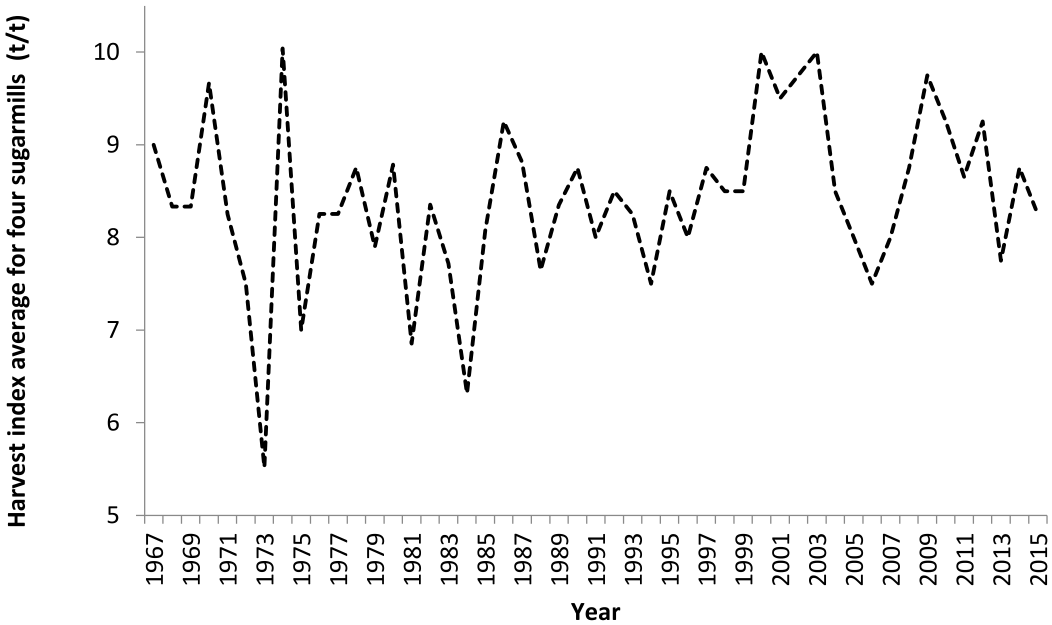

Figure 5.3: Line graph showing an average harvest index of sugarcane production for all four selected sugarmill supply areas in KwaZulu-Natal.

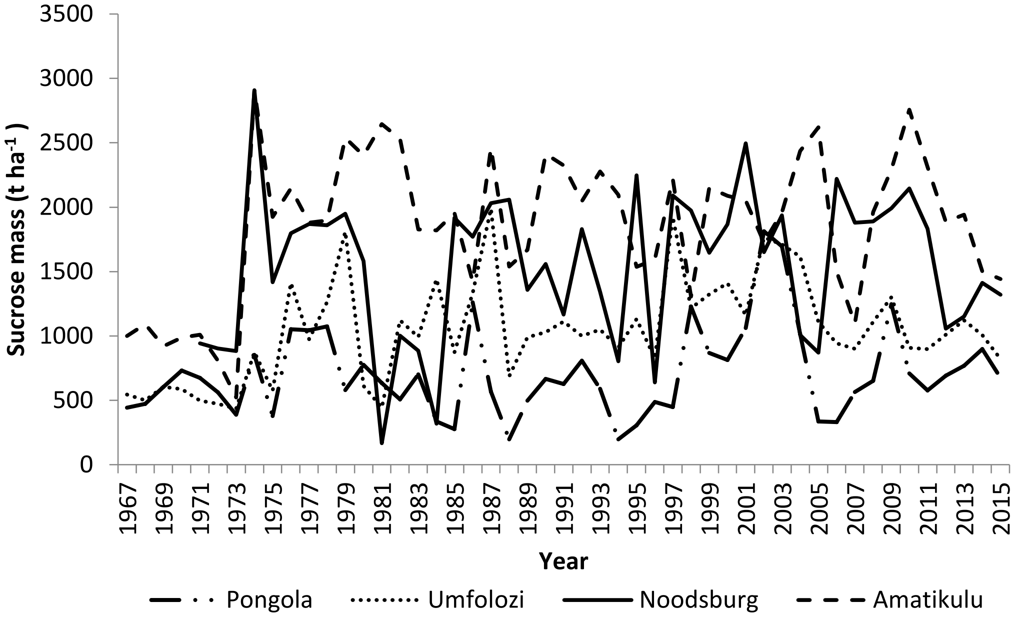

Figure 5.4: Line graph showing sucrose mass per hectare for the all four selected sugarmill supply areas in KwaZulu-Natal.

5.4 Trash produced in four sugarmills

Trash from a previous crop harvest can reduce wasteful evaporation from the soil surface. This can increase the efficiency of use of limited water resources for agricultural production (Olivier and Singels, 2012). Sugarcane residues contain large amounts of nutrients. Hence sugarcane burning is discouraged because more nutrients and dry matter are lost even though mineral constituent remains in the ash (Nxumalo, 2015). Trash is therefore regarded as an asset rather than extraneous matter. In KwaZulu-Natal, the removal of trash has been a matter of controversy (Van Dillewijn, 1952). It was discovered that trash removal gives rise to a quicker germination whereas tillering is greater where the trash remains and results in an increased weight of cane at harvest. The desirable option is to harvest sugarcane green using crop residues as a mulch layer instead of practicing sugarcane burning (Olivier et al., 2010). There is limited knowledge of how trash blanket affects the surface energy balance. This restricts sugarcane researchers from making recommendations on trash management. Olivier et al. (2010) used the formula $R_n - G = LE + H$ to explain the energy balance where R_n is the net irradiance, less soil heat flux (G) is the energy available to drive various physiological and physical processes. The balance between incoming and reflected solar irradiance and outgoing and returned infrared irradiance is called net irradiance. It is used mainly for heating of the soil (soil heat flux G), evaporation of water (latent energy flux, LE) and heating of the atmosphere above the soil (sensible heat flux, H). About 3250 tons ha^{-1} of trash was found on sugarcane in 1971 to 1973 in Noodsburg (Figure 5.5). Generally Umfolozi has more trash than Noodsburg, Pongola and Amatikulu. A notable decrease in trash mass was seen in 1985 to 1987, 1991 to 1993 and 2003 to 2005 in Umfolozi. Pongola has an overall smaller mass of trash with the maximum recorded at 1000 tons ha^{-1} in 1984. The number of green leaves present on a stalk is governed by two factors, these are the rate at which leaves are produced and the longevity of the individual leaf. Mature leaves die and young ones are added. Research conducted in many sugarcane-producing areas of the world indicates that retaining trash after green sugarcane harvesting can improve cane yield in lower rainfall areas (Olivier and Singels, 2015). Trash improves soil health these are micro-organism activity, nutrient status and organic matter (Olivier and Singels, 2015). However, there are some negative impacts that are also associated with trash. These include insect pests such as trash worm. These vary based on the season of harvest, the ratoon number (crop class) and the amount of trash material present. The highest total tons per hectare of trash per hectare recorded during the study period were 1900 recorded in 1972 (Figure 5.6). Statistically, the increase is insignificant.

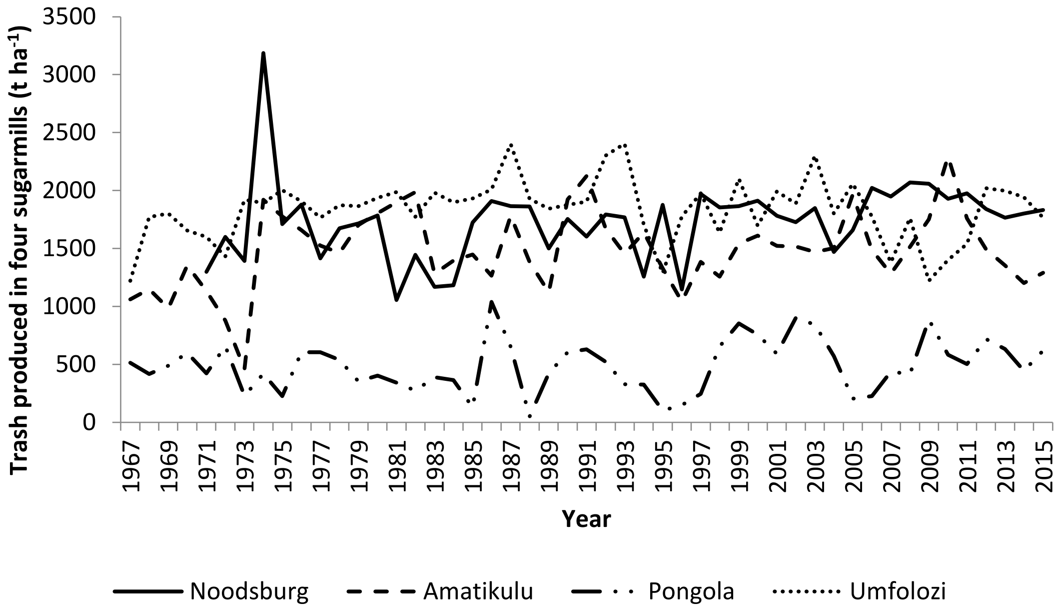

Figure 5.5: Line graph showing simulated trash produced (t ha^{-1}) using DSSAT for the study period 1967 – 2015 for four selected sugarmill supply areas in KwaZulu-Natal.

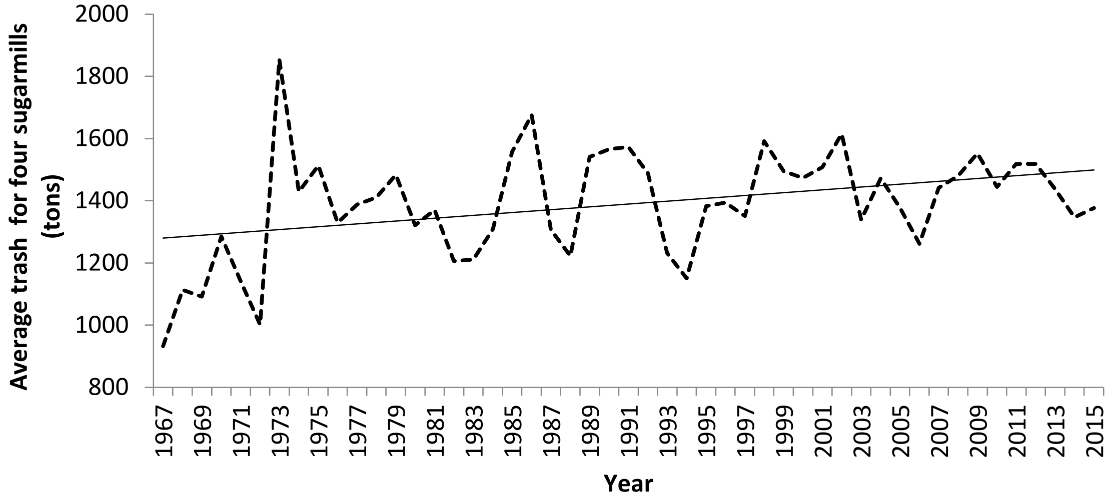

Figure 5.6: Line graph showing total tons per hectare of trash for four sugarmill supply areas in KwaZulu-Natal.

5.5 Application of RClimDex to investigate climate change

RClimDex (1.0) software (Zhang and Yang, 2004) was used to determine if there was climate change in the study area during the study period. Annual daily rainfall, minimum daily air temperature and maximum daily air temperature data were loaded into the RClimDex (1.0) software to generate output.

5.5.1 Amatikulu

Maximum air temperature has been increasing from 1967 to 1980 in Amatikulu (Figure 5.7). The maximum air temperature stabilized from 1980 to 1988. An increase is noted in maximum air temperature from 1988 to 2015. Maximum air temperature has increased from around 26 ^{o}C to 27 ^{o}C during the study period at Amatikulu. Minimum air temperature has been on a constant increase from around 14 ^{o}C to above 15 ^{o}C from 1967 to 1998 (Figure 5.8). The minimum air temperature shows some stability above 15 ^{o}C from 1998 to 2015.

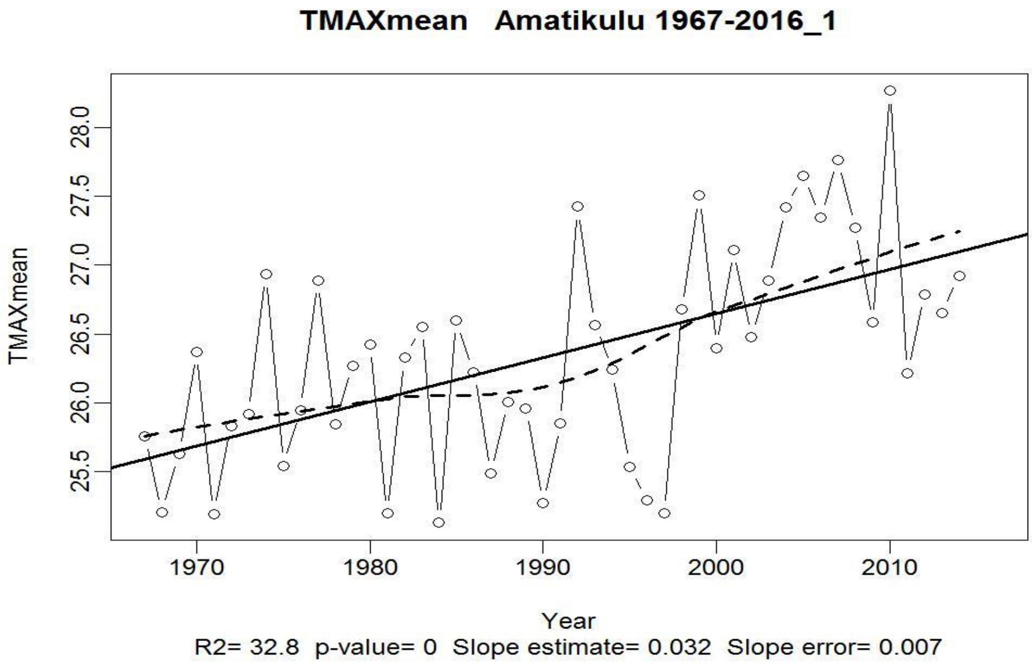

Figure 5.7: Line graph showing maximum air temperature for Amatikulu over the years from 1967 to 2015. The graph was generated through RClimDex software to determine if there was climate change over the years. (adapted from Zhang and Yang, 2004).

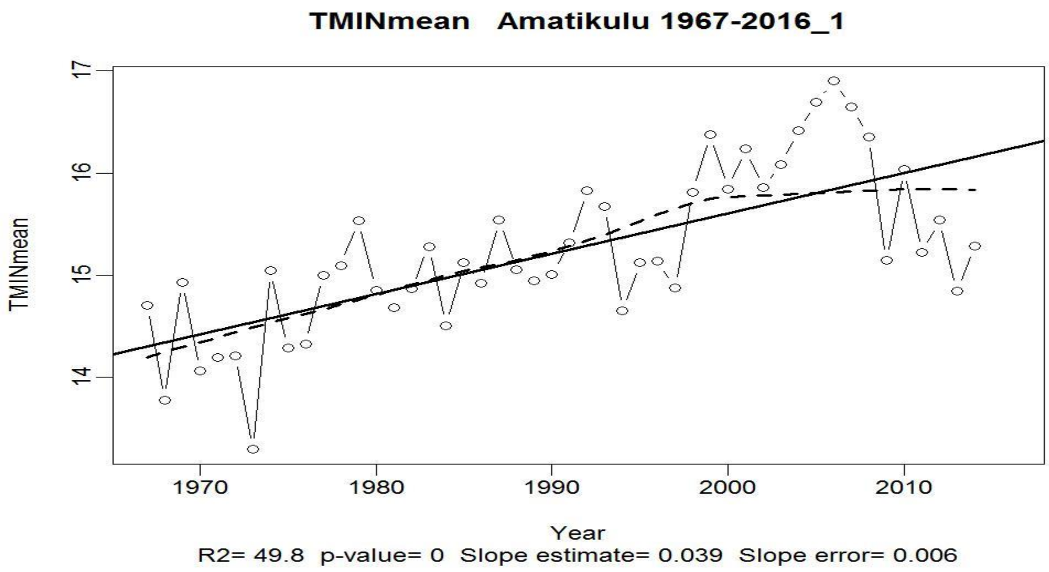

Figure 5.8: Line graph showing minimum air temperature for Amatikulu over the years from 1967 to 2015. The graph was generated through RClimDex software to determine if there was climate change over the years. (adapted from Zhang and Yang, 2004).

5.5.2 Noodsburg

In Noodsburg, maximum daily air temperature shows an increase from 1971 to 1985 (Figure 5.9). There was a slight decrease from 1985 to 1990. There was a constant increase in the minimum temperature from 1971 to 2000. The graph shows minor dip in minimum temperature from 2000 to 2015 (Figure 5.10). Generally, maximum daily air tempuratures has been increasing. This confirms that there was climate change during the study period.

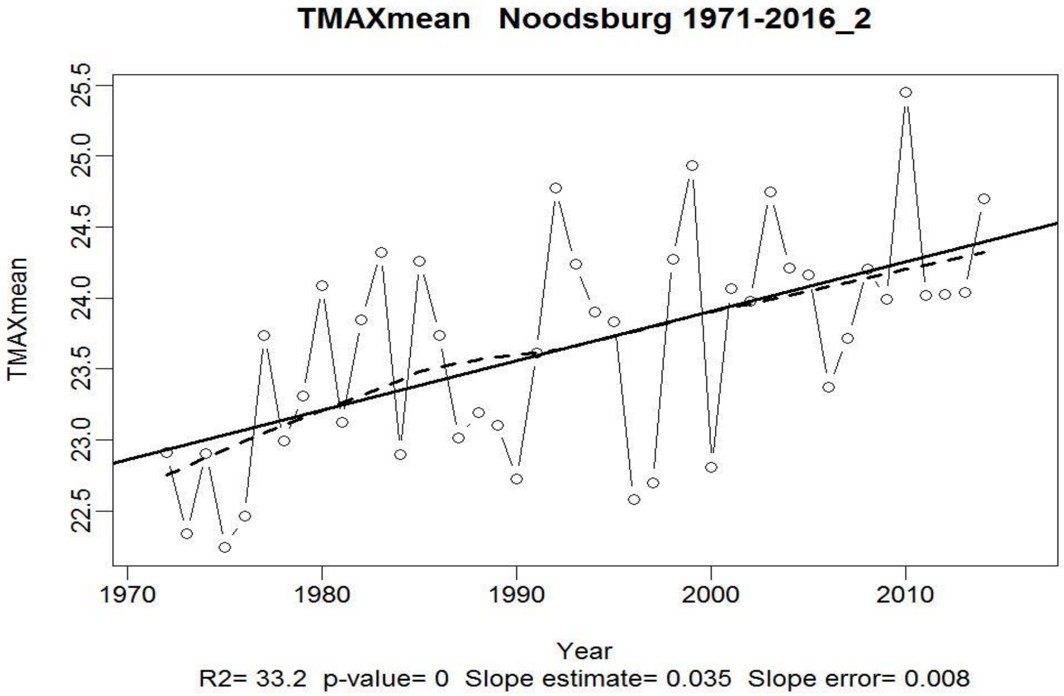

Figure 5.9: Line graph showing maximum air temperature for Noodsburg over the years from 1970 to 2015. The graph was generated through RClimDex software to determine if there was climate change over the years. (adapted from Zhang and Yang, 2004).

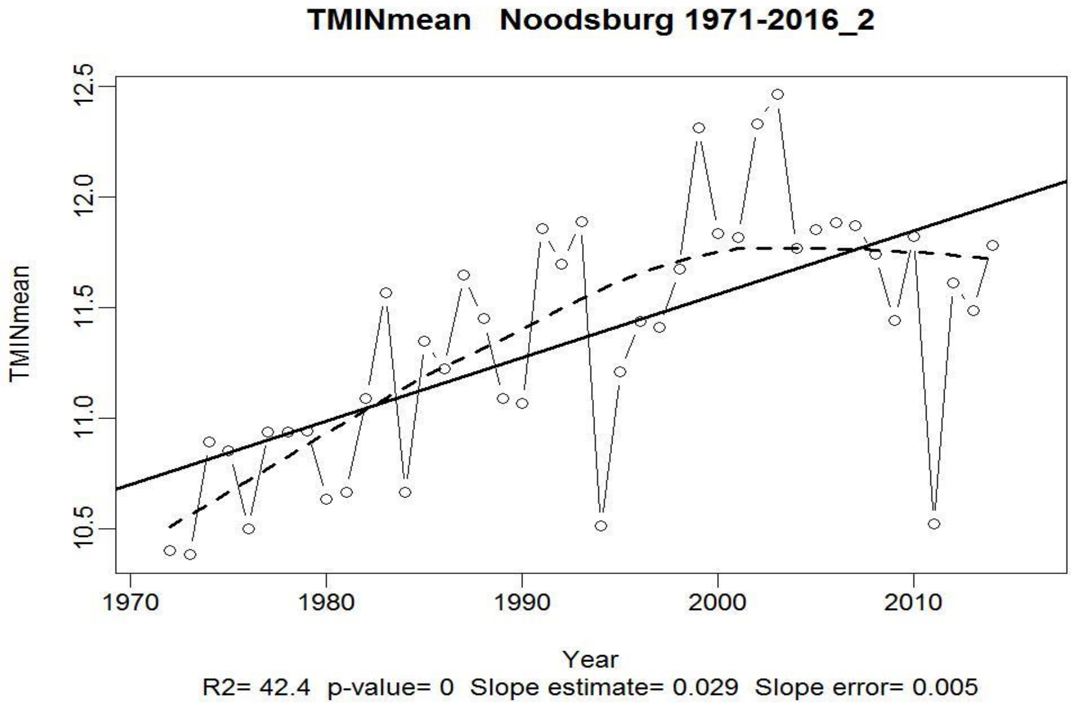

Figure 5.10: Line graph showing minimum air temperature for Noodsburg over the years from 1970 to 2015. The graph was generated through RClimDex software to determine if there was climate change over the years. (adapted from Zhang and Yang, 2004).

5.5.3 Pongola

The maximum air temperature in Pongola has been constantly increasing from 1967 to 1990 (Figure 5.11). An exponential increased in maximum air temperature has been observed from 1990 to 2015 to more than 28.5 ^{o}C in Pongola. The minimum air temperature has shown an increase from above 14.5 ^{o}C to 15.5 ^{o}C from 1967 to 1990 (Figure 5.12). A slight decrease in minimum air temperature has been noted from 1990 to 2015 where minimum air temperature is steadily decreasing back to 15 ^{o}C.

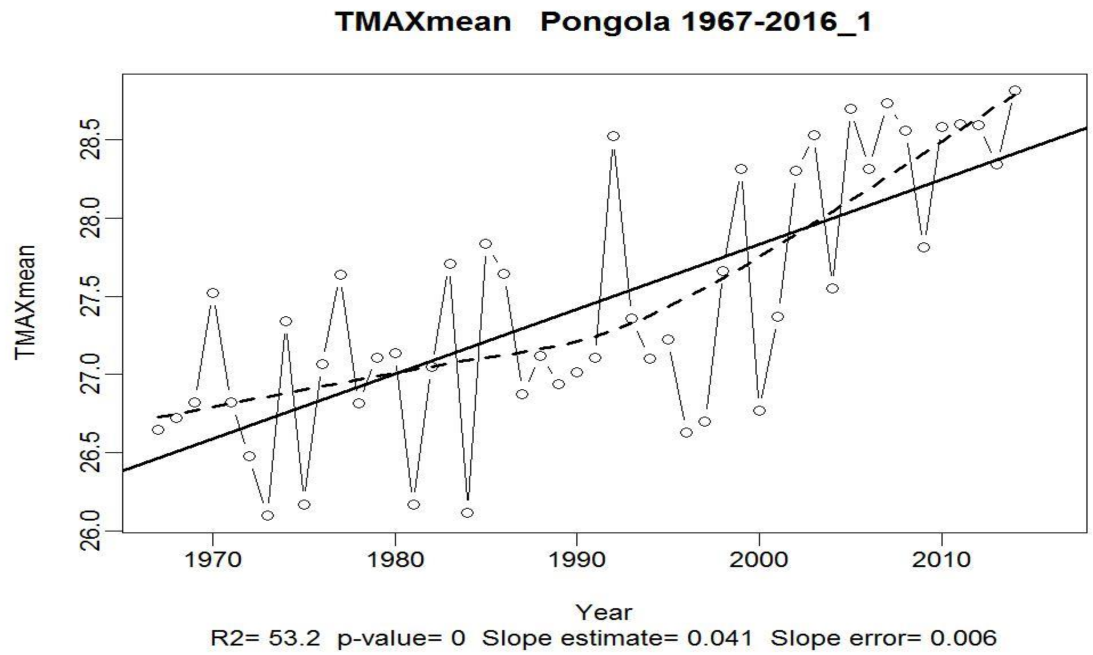

Figure 5.11: Line graph showing maximum air temperature for Pongola over the years from 1967 to 2015. The graph was generated through RClimDex software to determine if there was climate change over the years. (adapted from Zhang and Yang, 2004).

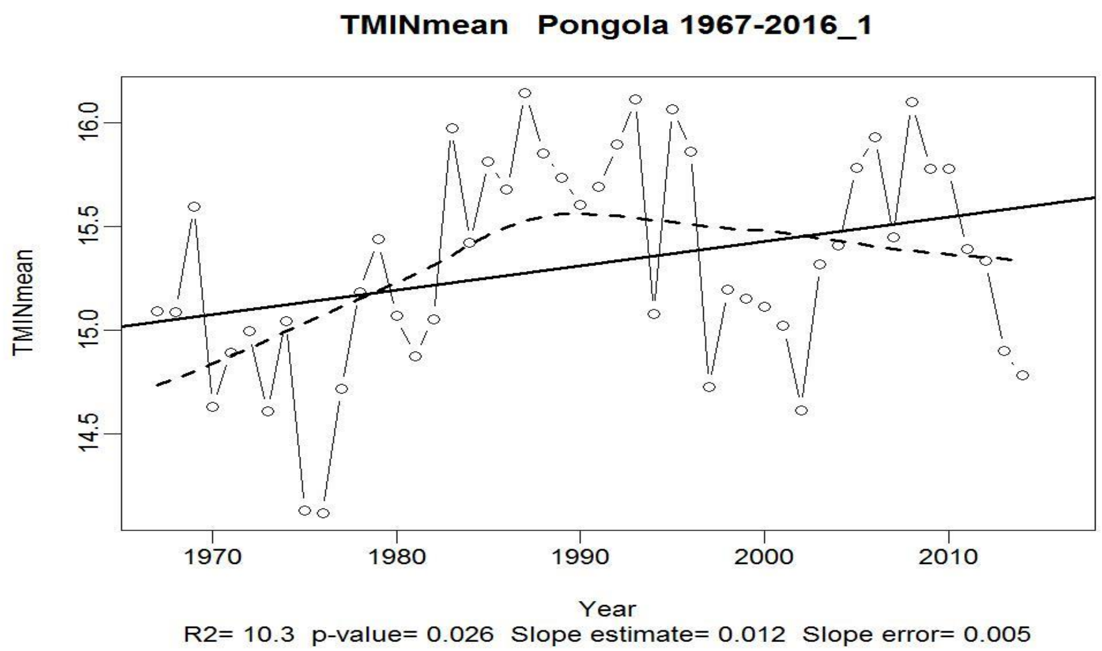

Figure 5.12: Line graph showing minimum air temperature for Pongola over the years from 1967 to 2015. The graph was generated through RClimDex software to determine if there was climate change over the years. (adapted from Zhang and Yang, 2004).

5.5.4 Umfolozi

In Umfolozi, maximum air temperature has decreased from just above 28 °C to 27.5 °C from 1966 to 1990 (Figure 5.13). An increase in maximum air temperature is noted from 1993 to 2015 in Pongola. In 2015, the maximum air temperature was above 28 °C.

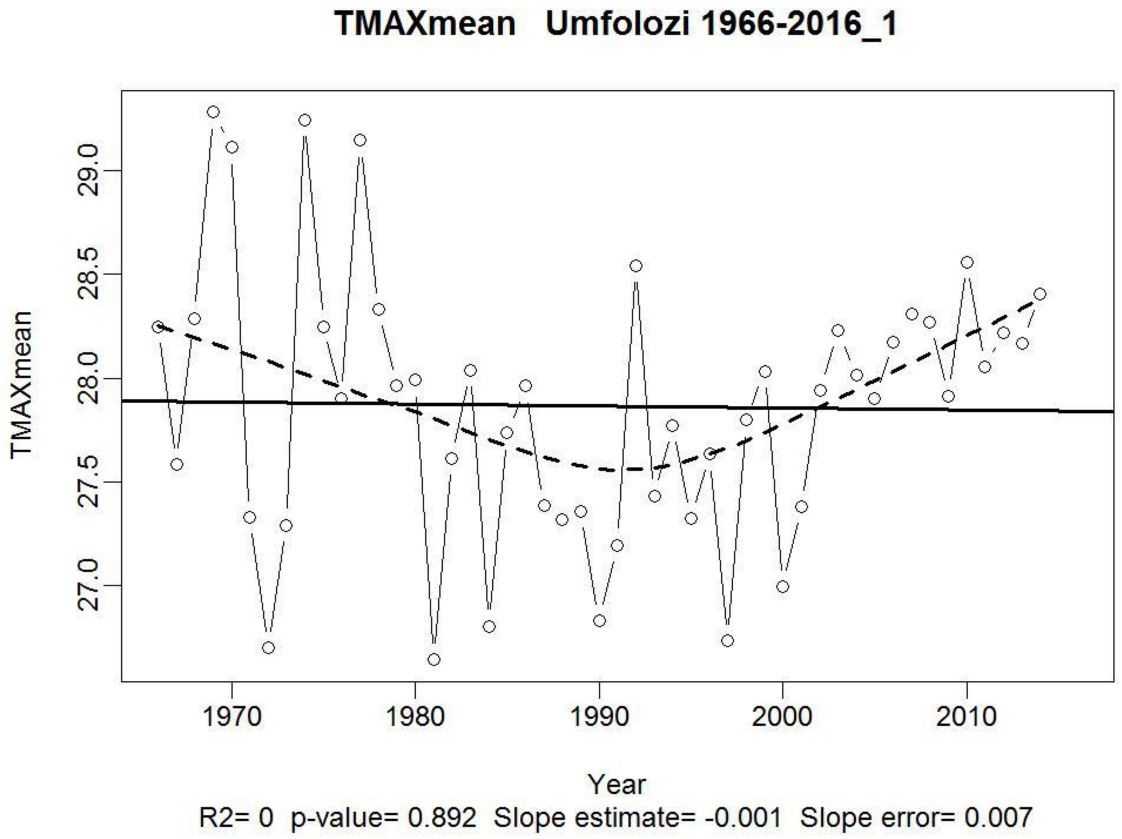

Figure 5.13: Line graph showing maximum air temperature for Umfolozi over the years from 1967 to 2015. The graph was generated through RClimDex software to determine if there was climate change over the years. (adapted from Zhang and Yang, 2004).

Minimum air temperature has been on constant decline from just above 17.5 °C in Umfolozi from 1966 to 1992 (Figure 5.14). A sharp decrease in minimum air temperature was noted from 1992 to 2015 in Umfolozi to below 16 °C.

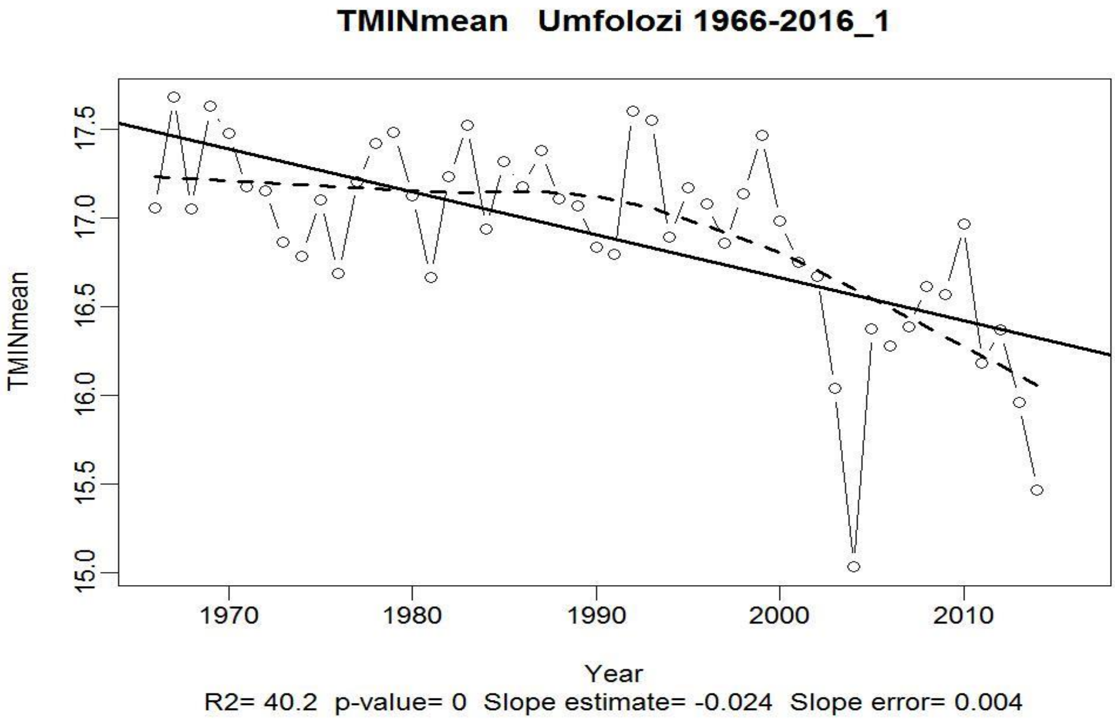

Figure 5.14: Line graph showing minimum air temperature for Umfolozi over the years from 1967 to 2015. The graph was generated through RClimDex software to determine if there was climate change over the years. (adapted from Zhang and Yang, 2004).

5.6 Summary

The focus of this chapter is on main results of the model and RClimDex outputs. Stalk height of the sugarcane in the selected sugarmills was discussed. Comparison of stalk height for four sugarmills was drawn with Noodsburg proven to have shortest stalk height and Umfolozi with the tallest stalk height throughout the study period. Harvest index was also scrutinized in this chapter. The highest harvest index was recorded in Amatikulu with the lowest harvest index recorded in Noodsburg and Pongola. Amatikulu cane has generally high sucrose mass From the RClimDex outputs, the result shows a positive relationships between the long-term climatic data and effect on climate change.

CHAPTER 6: CONCLUSIONS, RECOMMENDATIONS AND FUTURE RESEARCH

6.1 Findings

Weather data collected and analyzed were positive to climate change. The study reveals that sugarcane farmers are aware of the effect of climate change on cane production. Cane growers are also aware of their activities that contribute to climate change; hence they also acknowledge that they have a role to play in addressing climate change. Most farmers have formal education. About 38 % of sugarcane farmers who participated in the study believe that good rainfall is the main factor that contributes towards good harvest. Poor rainfall received between November and February was identified by 34 % of sugarcane farmers as the main contributing factor resulting in below-normal harvest with 31 % identifying flooding conditions from December to late January. Long periods without rain and higher temperatures have been identified by the study as the significant changes to the current climate. The study revealed that 75 % of sugarcane farmers are not satisfied with the support they are receiving from the provincial government to maximize their production. There is poor communication between small-scale sugarcane farmers and government. DSSAT Output reveals that Umfolozi Mill Supply Area has the tallest stalk height and Noodsburg has the shortest stalk height. It is helpful to the planter to have knowledge of the origin and composition of the soil which forms the land in which his crops are grown. It is important to know its basic characteristics in regard to cultural methods, fertilizer responses, crop production, level of fertility and how it can be improved or maintained. Avalon soil type has responded positively to climate change. Valrivier arniston soil type in Pongola requires that weather elements be supplemented by irrigation. An increase in stalk height is noted in Amatikulu between 1998 and 2001. The average stalk height for the KwaZulu-Natal province is 4 m. The Amatikulu mill supply area has generally high sucrose mass content with the highest tonnage recorded in 1974 at 2900 tons. The study reveals that Pongola has the lowest sucrose mass tonnage per hectare with its highest tonnage recorded at 1700 tons in 2003. Climate change was investigated through RClimDex (1.0) software and the results indicated that there was climate change over the study period in the study area. In Amatikulu, both maximum and minimum air temperatures have been increasing during the study period. Both maximum and minimum air temperatures also increased in Noodsburg, with the minimum air temperature started to drop from 11.5 ^oC in 2000 to 2015. The maximum air temperature in Pongola had been increasing during the study period with an exponential increasing noted from 1990 to 2015. The minimum air temperature in Pongola also increased from 1967 to 1990. A slight decrease in minimum temperature occurred from 1990 to 2015. In Umfolozi, maximum air temperature has decreased from just above 28 ^oC to 27.5 ^oC from 1966 to 1990.

An increase in maximum air temperature is noted from 1993 to 2015 in Pongola. In Umfolozi, the minimum air temperature has been on constant decline from just above 17.5 ^{o}C from 1966 to 1992. A sharp decrease in minimum air temperature was noted from 1992 to 2015 in Umfolozi to below 16 ^{o}C. In Umfolozi, maximum air temperature has decreased from just above 28 ^{o}C to 27.5 ^{o}C from 1966 to 1990 and started to increase from 1993 to 2015. The following objectives of the study were achieved:

- identification and synthesizing current knowledge, scientific literature and data relating to specific aspects of climate change in KwaZulu-Natal.
- investigating the possible impact of climate change on sugarcane production in KwaZulu-Natal.
- investigating the perception of sugarcane farmers of climate change.
- ascertaining the level of farmers' awareness of the effect of climate change on sugarcane in KwaZulu-Natal;

6.2 Future possibilities

Further studies on improving effective communication between provincial government and sugarcane growers are necessary with regard to the effect of climate change. Further research about what measures have been implemented by other countries in addressing climate change is recommended. Climate change is a global issue which is a result of natural and human activities. Hence it is important for countries to share information on how to deal with climate change. About 11 % of the sugarcane farmers who participated in the study recommended subsidized insurance for climate-related losses. It is important to note that drought relief funds have been identified as the recommendation by the sugarcane farmers to address the issue of climate change. This applies pressure on provincial government in terms of budget. More engagements between provincial government and sugarcane farmers are recommended in addressing the issue of drought relief funds. Sugarcane burning has been identified as one reason for a decline in sugarcane yield in the long term. This opens opportunities for further research on the matter. Resource conservation and efficient use of energy has been identified as critical in reducing human contribution to climate change. This can be achieved if more funding is made available to sugarcane farmers. The study also revealed that sugarcane farmers must unite to form their own bank which will be used as a source of funding to provide loans to farmers. More research is recommended in finding ways to improve mass sucrose content for Pongola. The impact of alien invasive weeds and animals was identified by the study as having a great negative impact on sugarcane farming costs. More studies are required to determine the possible impact of alien invasive plants and animals on sugarcane production. This will also help in identifying the possible suitable and effective projects that can be implemented in addressing this matter thus leading to job opportunities and increased food security. It is noted with interest that alternatives to sugarcane burning are identified by the study as a critical contribution that sugarcane farmers can make.

6.3 Final comments and summary

The climate data set were positive to climate change. The importance of assessing climate change impacts on sugarcane production using crop simulation models was noted. The impact of climate change on sugarcane production in KwaZulu-Natal has been recognized as the main cause for yield reduction. No major decline in sugarcane production has been noted in KwaZulu-Natal for those farmers practicing irrigation and improved management. The study also demonstrates an increase in the amount of trash on sugarcane in the later years of the study period. This is attributed to the increase in air temperatures during the latter years. In general, the approach presented in this study encompassed and assessed the effect of climate change on sugarcane production with inclusion farmers perception can be considered as a strategic issue on existing climate change concern in KwaZulu-Natal province.

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APPENDICES

APPENDIX A

Questionnaire cover letter[1]

Bonga B. Sithole

Agrometeorology Discipline

Room 120 Rabie Saunders Building

University of KwaZulu-Natal

P/Bag X01

Scottsville

3209

Dear Sir/Madam

I am a registered as a postgraduate student for Masters in Science in Agrometeorology at the University of KwaZulu-Natal, Pietermaritzburg Campus. My research project entails investigating the possible impacts of climate change on sugarcane production in KwaZulu-Natal.

The purpose of the questionnaire is to collect data from the commercial sugarcane farmers in KwaZulu-Natal. The aims of the study are to identify:

- the impact of climate change on sugarcane production in KwaZulu-Natal Province.
- to promote food security in KwaZulu-Natal through understanding current climate trends.
- to improve the adaptability of sugarcane to climate change.
- to ascertain farmers' awareness about the effect of climate change on sugarcane in

[1] For enquires with respect the ethical clearance, please contact: Mariette Snyman, HSSREC Research Office, Tel: 031 260 8350, Email: snymanm@ukzn.ac.za

KwaZulu-Natal.

On completion, the study will assist in ascertaining the possible impacts of climate change on sugarcane production in KwaZulu-Natal. This will prompt further research on the subject and will make recommendations to farmers on how to adapt to climate change. Recommendations will be made to government on adaptation measures. The study will also help the government to identify the type of assistance that is required by the sugarcane farmers to adapt to climate change. To this end I humbly request that you complete the following questionnaire regarding your experience in sugarcane farming in KwaZulu-Natal. It should take no longer than 20 minutes of your time. Although your response is of utmost importance, your participation in this survey is entirely voluntary.

Please do not enter your name or contact details on the questionnaire. It remains anonymous. Information provided by you remains confidential and will be reported in a graph and summary format only.

Kindly return the completed questionnaire in the postage paid return envelope within two weeks after receipt. The dissertation with the results of this survey will be available at the University of KwaZulu-Natal on request after the completion of the study. Should you have any queries or comments regarding this survey, you are welcome to contact me telephonically on 081 030 9330 or 082 466 8032 or 031-361 8547 or via email at Bonga.Sithole@transnet.net

Yours sincerely

____

Bonga B. Sithole

University Student

UKZN Ethical clearance Ref#: HSS/0753/014

APPENDIX B

Questionnaire

PLEASE ANSWER THE FOLLOWING QUESTIONS BY CROSSING (X) THE RELEVANT BLOCK OR WRITING DOWN YOUR ANSWER IN THE SPACE PROVIDED.

EXAMPLE of how to complete this questionnaire:

Your gender?

Male	1
Female	2 X

Section A

Background information

This section of the questionnaire refers to background or biographical information. Although the researcher is aware of the sensitivity of the questions in this section, the information will allow the researcher to compare groups of respondents. Once again, be assured that your response will remain anonymous. Your co-operation is appreciated.

1. Name of your District Municipality

____

2. Name of the nearest sugarmill.

____

3. Gender

Male	1
Female	2

4. Age (in years)

5. Race

Asian	1
Black	2
Mixed race	3
White	4

6. What is your highest educational qualification?

Grade 11 or lower (Std 9 or lower)	1
Grade 12 (Matric, Std 10)	2
Post-Matric Diploma or Certificate	3
Bachelor’s Degree	4
Postgraduate Degree	5

7. Do you reside in an urban or rural area?

Urban	1
Rural	2

Section B

This section explores your habits and preferences with regard to sugarcane farming methods.

1. In which year did you start commercial sugarcane farming?

____

2. Do you know the actual size of the land you are farming?

Yes	1
No	2

3. Have you increased your farming land size since you began farming?

Yes	1
No	2

4. Do you use fertilizers?

Yes	1
No	2

5. Do you use herbicides?

Yes	1
No	2

6. Do you use irrigation (or fertigation)?

Yes	1
No	2

7. In which year(s) did you receive good harvest from your sugarcane fields?

____

8. What do you think contributed to the increase in your harvest during the year mentioned in 7 above?

____

____

____

____

____

9. In which year(s) did you receive less harvest from your sugarcane fields?

____

10. What do you think contributed to the reduced harvest during the year mentioned in Question 9 above?

____

____

____

____

____

11. Do you know what climatic factors play a role in sugarcane production?

Yes	1
No	2

12. Do you believe that the government is offering sufficient help to farmers to maximise their sugarcane production?

Yes	1
No	2
I cannot say	3

13. Are you happy with the climate of the past ten years compared to past 40 years in relation to your sugarcane production?

Yes	1

No	2

If no, please say why.

____

____

____

____

____

14. Is there any significant change in climate that you have noticed in the past years 40 in relation to your sugarcane production?

Yes	1
No	2

If yes, please describe the change.

____

____

____

____

____

Section C

Irrespective of your answer to Question 14, please answer the following questions

15. Are there any activities which you think are a cause for climate change?

Yes	1
No	2

If yes, list those activities.

____

____

____

____

____

16. Will you or do you encourage your children to continue practising sugarcane farming considering the climate?

Yes	1
No	2

17. Please list recommendations on the type of assistance farmers might expect from government in addressing climate change.

____

____

____

____

____

18. Please list recommendations on the role farmers must play in order to address climate change.

____

____

____

Thank you for your co-operation in completing this questionnaire. Kindly return the questionnaire to the address below. Should you wish to receive a copy of the findings of the questionnaire, please email me at:

Bonga.Sithole@transnet.net

Bonga B. Sithole

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Agrometeorology Discipline

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University of KwaZulu-Natal

P/Bag X01

Scottsville

3209

Dear Mr. Qwabe

Please find the questionnaires as per our telephonic conversations. Kindly distribute them to commercial farmers. It can take not more than 20 minutes to complete. I humbly request that the questionnaires must be returned to you once it has been completed so that they can be posted together. I will pay for postage.

Thanking you in advance for your assistance.

Regards

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