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## A Bayesian approach towards facilitating climate change adaptation research on the South African agricultural sector

JK Musango<sup>1</sup> & C Peter<sup>1</sup>

### Abstract

*Evaluating the range of proposed adaptation measures to combat the sensitivity of agriculture to climate change effects involves evaluating complex interactions between human and natural systems. Integrated strategy-making and implementation in the agricultural sector to reduce the risks posed by climate change requires the consideration of multiple, interdisciplinary factors and the sensitivities of their inter-relationships. Lack of information on the sensitivity of agricultural activities to climate change in Africa hampers climate change adaptation research on the region. In water scarce South Africa, the growth of the agricultural sector is threatened by projected decreases in water availability due to climate change. This paper shows how Bayesian networks may be used to facilitate cross-disciplinary participation in elucidating these sensitivities. Bayesian networks provide a graphical framework for mixing quantitative and qualitative information and can be characterised using information associated with varying degrees of uncertainty. This enables a variety of domain experts to test key driver-response interactions through sensitivity analysis and enables visualisation of the complex inter-relationships between inter-disciplinary variables resulting from the impacts of climate change scenarios on South African agriculture. The ability to represent the sensitivities between key variables for which varying degrees of data-scarcity and uncertainty occur provides agricultural sector researchers with a facilitation tool that may help visualise and formulate climate change mitigation strategies. The results presented here illustrate the extreme sensitivity of water-scarce South African agricultural sector to projected climate change impacts and provides a framework in which tradeoffs between activities can be preliminarily assessed in strategy-making for adaptation.*

**Keywords:** Climate change adaptation; water utilization; Bayesian approach

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## **1. Introduction**

### **1.1 Background**

The agricultural sector is the dominant water-user in water-scarce South Africa (DWA, 2002). South African agricultural and agro-ecological systems are therefore believed to be extremely vulnerable to the projected impacts of climate change on water availability (Mendelsohn *et al.*, 2000). While water availability is projected to increase in the Eastern escarpment, it is expected to decrease to the west (Midgley *et al.*, 2005) and to decrease overall. Furthermore, temporal shifts in rainfall patterns may further decrease the required water volumes needed in critical periods of agricultural production. Stakeholders, user-groups and decision-makers are becoming increasingly concerned with the impact of climate change upon the agricultural sector. Agriculture is an important factor in ensuring food security in the region while the sector is already under considerable stress and South African farmers have limited access to capital and technology. The main effect of climate change on semi-arid or tropical agro-ecological systems is a significant reduction in crop yield, which may well force large regions of marginal agriculture out of production in Africa. Such a reduction in crop yield will also place more pressure and higher demand for more conversion of lands, extraction of water supply sources for irrigation, introduction of more new exotic plant and animal species, more intensive use of chemical inputs and hence pollution and environmental damage, erosion, etc. seriously accelerating biodiversity loss and extinction. Subsistence farmers are more vulnerable than commercial farmers under projected climate change scenarios.

### **1.2 The need and what have others done about it?**

A balanced analysis of the impact of climate change on agricultural production in Africa and the efficacy of alternative adaptation measures is urgently required. Presently, a lack of context related data on the sensitivity of African agriculture to climate change has led to sensitivities measured in the United States being used to predict the effects of climate change in African regions. For instance, Mendelsohn *et al.*, (2000) made use of proxy values derived for studies on climate sensitivity in the US in a project based in Africa. They developed a simulation to understand the potential effects of climate change on African agriculture and appear to be the first researchers to measure the climate sensitivity of agriculture in Africa. In addition, Reilly (1999) expresses the need for a clearer understanding of the effectiveness of adaptation measures and evaluation of a greater number of climate change scenarios. Studies on climate change impacts in Africa rarely explore what adaptations

would be efficient for either the farmers or the governments (Reilly, 1999). This is central to addressing the current lack of coherent and inclusive approaches in Africa to combat resultant uncertainty in several key aspects such as magnitude, timing and regional distribution of anticipated climate change impacts and possible threats to agriculture and the environment. This highlights the serious deficiencies in the research on climate change impacts in Africa given the importance of efficient adaptation measures in developing countries.

### **1.3 What will we do about it?**

In an attempt to improve contextual understanding of climate change impacts in South Africa this paper uses available South African data to determine the sensitivity of selected irrigated crops to changes in rainfall and evaporation and demonstrates how possible adaptation measures may be compared.

### **1.4 How will we go about it and why?**

We demonstrate the usefulness of employing Bayesian networks to understand the sensitivities between the environmental, social and economic variables that may be impacted by climate change in the South African agricultural sector (i.e. sensitivity of socio-economics of agricultural sector activities and environmental flow requirements to climate change). The methodology for employing Bayesian networks to facilitate an Integrated Water Resource Management (IWRM) type of approach has been developed in a regional study of the water intensive activities conducted in the Incomati Basin. The Bayesian model developed in this study indicates that the sensitivity of main agricultural activities (sugar cane, horticulture, maize) and forestry to decreases in rainfall. This region experiences higher rainfall than other areas in South Africa. We therefore expect that at a national scale the sensitivity of agricultural sectors to climate change impacts in South Africa will be more pronounced. Key South African water intensive agricultural activities (sugar cane, maize, wheat, and fruit & nut farming) and forestry are evaluated in terms of their water use and direct and indirect benefits derived in the economy for different climate change scenarios.

## **2 A brief overview of South African agriculture**

South African agriculture is of a highly dualistic nature, where a developed commercial sector co-exists with a large number of subsistence (communal) farms. Agriculture is well diversified with field crops, livestock and horticulture. Agriculture's share of the GDP declined from about 20 percent in

1930s to about 12 percent in the 1960s and to less than 7 percent in the 1990s. Agriculture sector provides for most domestic needs, and South Africa exports corn, wool, sugar, peanuts, tobacco and other farm products. Although the country is said to be self-sufficient in food production, about 14 million people are said to be vulnerable to food insecurity (National Treasury, 2003).

Agricultural production has suffered from cyclical droughts since the seventeenth century, and generally the best rain is in the Western Cape and along the coast of KwaZulu-Natal. The rest of the country is dry. Given that 50 percent of South African water is used in agriculture, climate change will have a significant impact on agriculture because of its dependence on irrigation. A question arises as to the ability to cope with the changing climatic conditions to minimise the risk of food insecurity. It is important to point that the understanding of the relationships of climatic change effect to agriculture production will provide better adaptive measures.

## **2.1 How does a changing climate influence South Africa?**

The South African Country Study on Climate Change, carried out in the late 1990's, identified the Northern and Western Cape Provinces as being most at risk from projected climate change-induced warming and rainfall change (Midgley *et al.*, 2005). The distribution of the impact of climate change in South Africa will vary across the provinces. Based on current projections the changing climate may affect the agriculture sector in the following ways:

- Reduction in crop yields and agriculture productivity.
- Increased evidence of pest attacks.
- Limitation on the availability of water.
- Exacerbation of drought periods.
- Reduction of soil fertility.
- Low livestock productivity and high production cost.
- Availability of human resource.

The staple food in South Africa, maize, is particularly susceptible to drought. Climate change is therefore expected to worsen food supply. The impact of these adverse climate changes on agriculture is exacerbated by lack of adapting strategies, which are increasingly limited due to the lack of institutional, economic and financial capacity to support such actions.

The vulnerability to climate change and its inability to adapt to these changes may be devastating to the agriculture sector, the main source of livelihood to the majority of the population. The utmost concern should therefore be a

better understanding of the potential impact of the current and projected climatic changes on South African agriculture and to identify ways and means to adapt and mitigate its detrimental impact.

### 3. Methodology

#### 3.1 Introduction to Bayesian networks

Bayesian networks use a probabilistic propagation algorithm (Bayes Rule) to estimate what state a variable is most likely to be in, given the states of the variables that it is conditionally dependent on. If it is conditionally dependent upon a variable then an arc (or edge) is used to represent this relationship between two 'nodes' in software interfaces such as Hugin developer. The node may represent any kind of variable (a process, an event or class) as long as it can be described in terms of a set of states in which it may exist. Variables of differing degrees of uncertainty from various sources (expert opinion, empirical data or numerical models) may be used to populate probability tables that capture the conditional dependence of a variable upon others. Bayesian networks have been described comprehensively in the literature by many authors (e.g. Bromley *et al.*, 2005, Baran & Jantunen, 2004) that an interested reader can refer to for more in-depth understanding.

#### 3.2 Constructing the model

A Bayesian model<sup>2</sup> is developed that links direct and indirect value-add (VAD) derived from each dominant water intensive activity within the agricultural sector to the water-usage for each activity. Various climate change scenarios may be assessed by decreasing rainfall and increasing evaporation of run-off. The effects of damming and population increase are also included and the net water-usage resulting from various growth strategies of activities within the agricultural sector may be assessed against projected decreases in water availability due to climate change. Furthermore, the impact of climate change and the growth strategies of agricultural sectors upon the ecological flow requirements and hence ecological integrity may be assessed. Figure 1 is the Bayesian network constructed for the South African agriculture.

The model is constructed in a way that it can compare the potential Total VAD that can be obtained without considering the impact of climate change and the actual total VAD that is acquired with climate change. This is clearly demonstrated in Figure 1.

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<sup>2</sup> Hugin Software is used to construct the model.

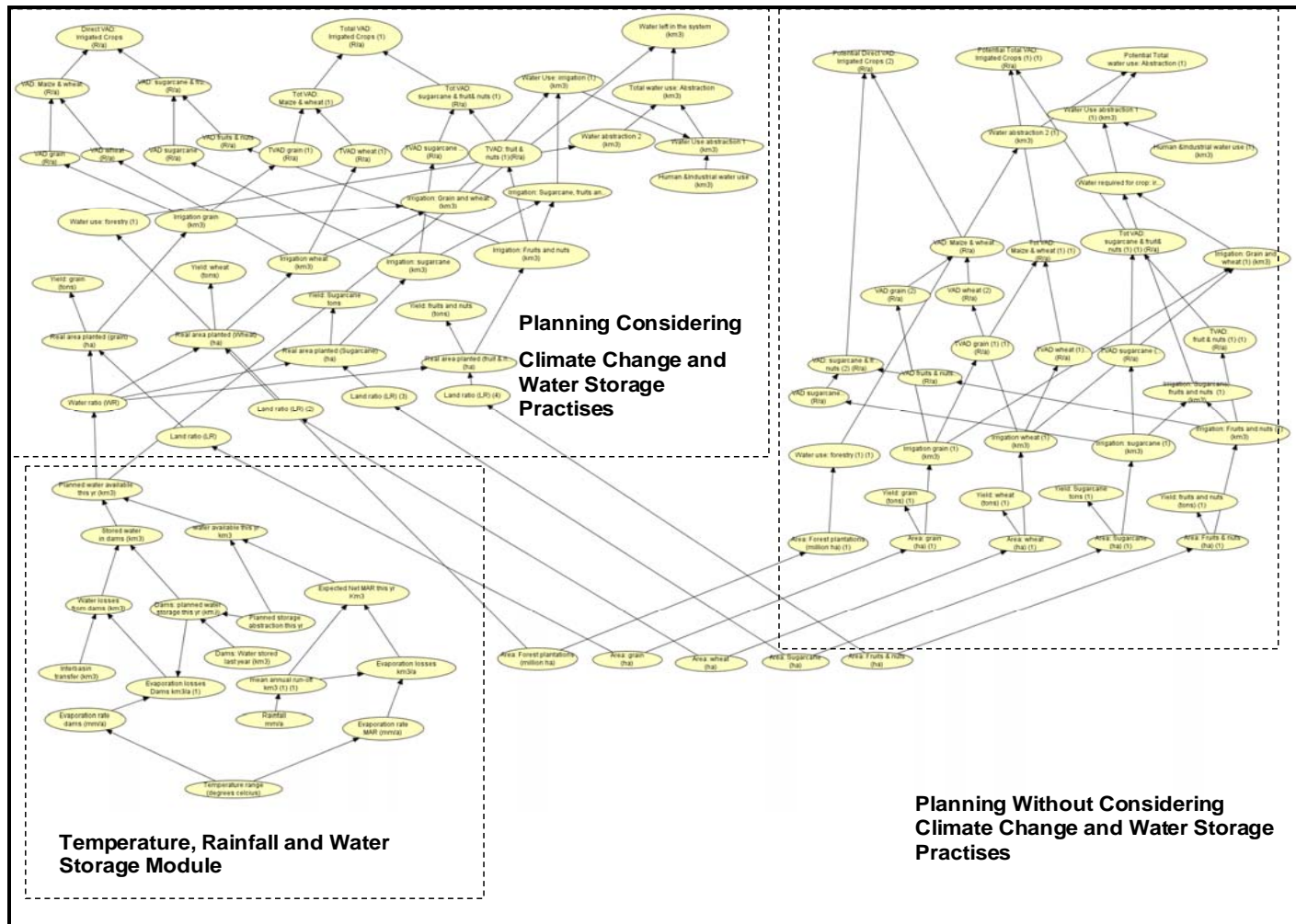


Figure 1: Bayesian network constructed for South African agriculture

### 3.3 Populating the model

We evaluate the water use of key agricultural activities (sugar cane, maize, wheat, and fruit & nut farming) and forestry using values derived for activities conducted in the Incomati Basin by Sengo *et al.*, (2004). Water use estimates are used to derive approximations of direct and total economic Value Add (VAD) using economic multipliers derived by Hassan (2003) in a study of water intensive activities in the Crocodile catchment. The results are verified using known crop yields and associated incomes (FAO Aquastat, 2005) in South Africa. The results derived for direct and indirect VAD and water use for each activity considered are verified in this way, but it is the relative differences between these values that are more important. The Bayesian model helps elucidate trends, patterns, thresholds and sensitivities and relative differences in values are of more concern than actual precision in outputs. Figure 2 represents a sample of the populated Bayesian network.



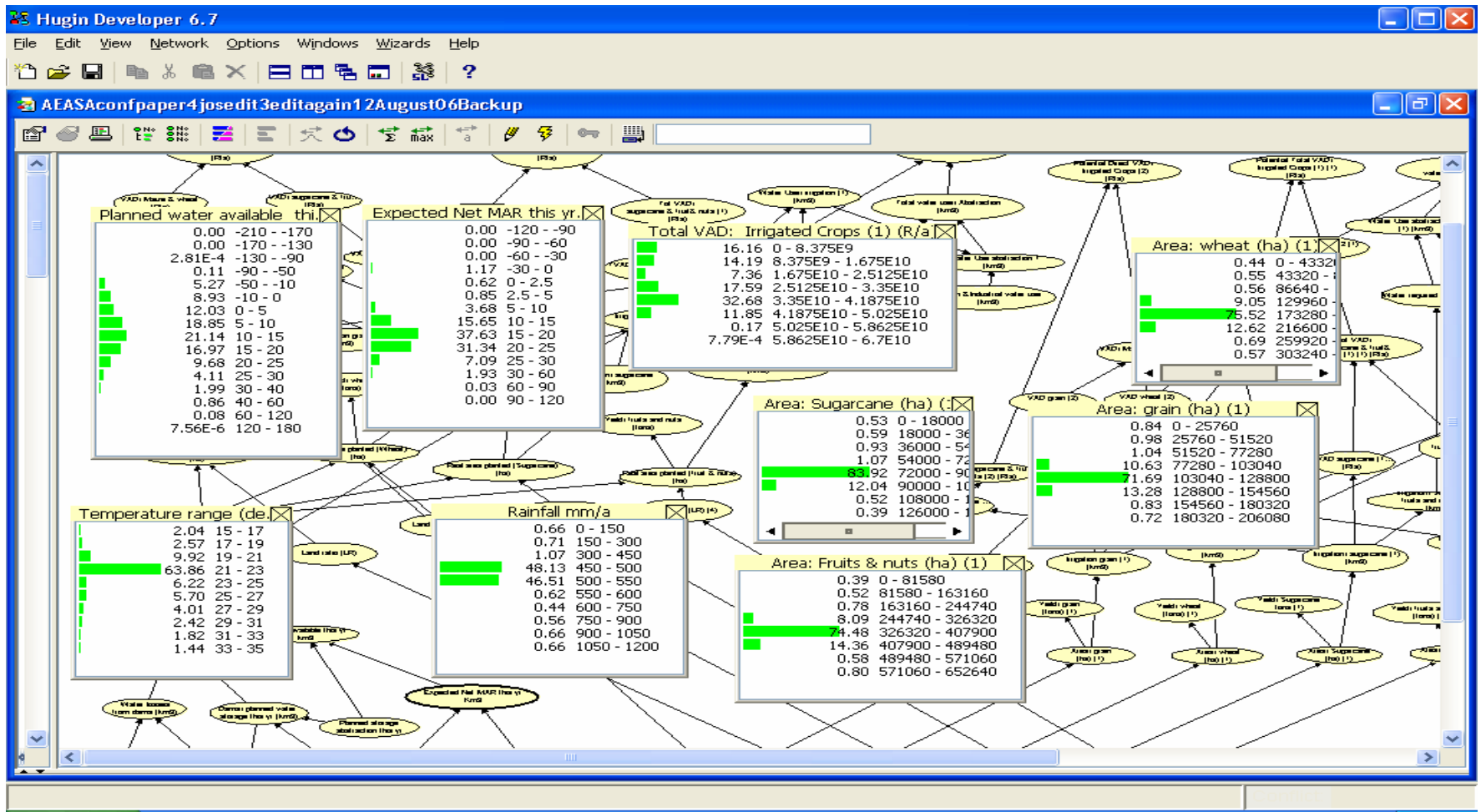


Figure 2: Sample of populated Bayesian network

## 4 Results

We do not present definitive predictions for the system but illustrate how this approach may be used to obtain insight into the sensitivities of the system to parameterization, scale and thresholds of variables

### 4.1 Climate change projections on the Total VAD of selected irrigated agricultural crops

Table 1 shows the initial states and different scenarios of climate change projections. The initial states are the calibration of the variables to their current states. On the other hand, scenarios are the deviations from the initial state and describe the sensitivity to changes in state of a variable or variables.

**Table 1: Climate change projection scenarios**

Initial states	Scenario 1	Scenario 2	Scenario 3	Scenario 4
<b>Temperature range (de...</b> 2.04 15 - 17 2.57 17 - 19 9.92 19 - 21 63.86 21 - 23 6.22 23 - 25 5.70 25 - 27 4.01 27 - 29 2.42 29 - 31 1.82 31 - 33 1.44 33 - 35	<b>Temperature range (de...</b> 0.00 15 - 17 0.00 17 - 19 0.00 19 - 21 0.00 21 - 23 100.00 23 - 25 0.00 25 - 27 0.00 27 - 29 0.00 29 - 31 0.00 31 - 33 0.00 33 - 35	<b>Temperature range (de...</b> 0.00 15 - 17 0.00 17 - 19 0.00 19 - 21 0.00 21 - 23 100.00 23 - 25 0.00 25 - 27 0.00 27 - 29 0.00 29 - 31 0.00 31 - 33 0.00 33 - 35	<b>Temperature range (de...</b> 0.00 15 - 17 0.00 17 - 19 0.00 19 - 21 100.00 21 - 23 0.00 23 - 25 0.00 25 - 27 0.00 27 - 29 0.00 29 - 31 0.00 31 - 33 0.00 33 - 35	<b>Temperature range (de...</b> 0.00 15 - 17 0.00 17 - 19 0.00 19 - 21 0.00 21 - 23 100.00 23 - 25 0.00 25 - 27 0.00 27 - 29 0.00 29 - 31 0.00 31 - 33 0.00 33 - 35
<b>Rainfall mm/a</b> 0.66 0 - 150 0.71 150 - 300 1.07 300 - 450 48.13 450 - 500 46.51 500 - 550 0.62 550 - 600 0.44 600 - 750 0.56 750 - 900 0.66 900 - 1050 0.66 1050 - 1200	<b>Rainfall mm/a</b> 0.66 0 - 150 0.71 150 - 300 1.07 300 - 450 48.13 450 - 500 46.51 500 - 550 0.62 550 - 600 0.44 600 - 750 0.56 750 - 900 0.66 900 - 1050 0.66 1050 - 1200	<b>Rainfall mm/a</b> 0.00 0 - 150 0.00 150 - 300 100.00 300 - 450 0.00 450 - 500 0.00 500 - 550 0.00 550 - 600 0.00 600 - 750 0.00 750 - 900 0.00 900 - 1050 0.00 1050 - 1200	<b>Rainfall mm/a</b> 0.00 0 - 150 0.00 150 - 300 0.00 300 - 450 0.00 450 - 500 100.00 500 - 550 0.00 550 - 600 0.00 600 - 750 0.00 750 - 900 0.00 900 - 1050 0.00 1050 - 1200	<b>Rainfall mm/a</b> 0.00 0 - 150 0.00 150 - 300 0.00 300 - 450 0.00 450 - 500 100.00 500 - 550 0.00 550 - 600 0.00 600 - 750 0.00 750 - 900 0.00 900 - 1050 0.00 1050 - 1200
<b>Expected Net MAR thi...</b> 0.00 -120 - -90 0.00 -90 - -60 0.00 -60 - -30 1.17 -30 - 0 0.62 0 - 2.5 0.85 2.5 - 5 3.68 5 - 10 15.65 10 - 15 37.63 15 - 20 31.34 20 - 25 7.09 25 - 30 1.93 30 - 60 0.03 60 - 90 0.00 90 - 120	<b>Expected Net MAR thi...</b> 0.00 -120 - -90 0.00 -90 - -60 0.00 -60 - -30 0.44 -30 - 0 0.22 0 - 2.5 0.20 2.5 - 5 4.53 5 - 10 33.64 10 - 15 44.13 15 - 20 14.68 20 - 25 1.10 25 - 30 1.05 30 - 60 0.00 60 - 90 0.00 90 - 120	<b>Expected Net MAR thi...</b> 0.00 -120 - -90 0.00 -90 - -60 0.00 -60 - -30 0.43 -30 - 0 0.53 0 - 2.5 0.80 2.5 - 5 27.75 5 - 10 47.45 10 - 15 21.43 15 - 20 1.47 20 - 25 0.13 25 - 30 0.00 30 - 60 0.00 60 - 90 0.00 90 - 120	<b>Expected Net MAR thi...</b> 0.00 -120 - -90 0.00 -90 - -60 0.00 -60 - -30 0.05 -30 - 0 0.02 0 - 2.5 0.02 2.5 - 5 0.06 5 - 10 5.01 10 - 15 39.76 15 - 20 45.59 20 - 25 9.44 25 - 30 0.04 30 - 60 0.00 60 - 90 0.00 90 - 120	<b>Expected Net MAR thi...</b> 0.00 -120 - -90 0.00 -90 - -60 0.00 -60 - -30 0.06 -30 - 0 0.02 0 - 2.5 0.02 2.5 - 5 1.66 5 - 10 29.94 10 - 15 47.71 15 - 20 19.47 20 - 25 1.09 25 - 30 0.02 30 - 60 0.00 60 - 90 0.00 90 - 120
<b>Planned water availabl...</b> 0.00 -210 - -1 0.00 -170 - -1 2.81E-4 -130 - -90 0.11 -90 - -50 5.27 -50 - -10 8.93 -10 - 0 12.03 0 - 5 18.85 5 - 10 21.14 10 - 15 16.97 15 - 20 9.68 20 - 25 4.11 25 - 30 1.99 30 - 40 0.86 40 - 60 0.08 60 - 120 7.56E-6 120 - 180	<b>Planned water availabl...</b> 0.00 -210 - -1 0.00 -170 - -1 4.66E-5 -130 - -90 0.04 -90 - -50 5.89 -50 - -10 14.72 -10 - 0 19.49 0 - 5 24.21 5 - 10 19.40 10 - 15 10.27 15 - 20 3.85 20 - 25 1.16 25 - 30 0.58 30 - 40 0.38 40 - 60 0.02 60 - 120 2.17E-7 120 - 180	<b>Planned water availabl...</b> 0.00 -210 - -1 0.00 -170 - -1 4.51E-5 -130 - -90 0.11 -90 - -50 14.10 -50 - -10 23.20 -10 - 0 23.39 0 - 5 21.17 5 - 10 11.97 10 - 15 4.45 15 - 20 1.26 20 - 25 0.30 25 - 30 0.06 30 - 40 0.00 40 - 60 3.68E-5 60 - 120 4.14E-13 120 - 180	<b>Planned water availabl...</b> 0.00 -210 - -1 0.00 -170 - -1 2.86E-6 -130 - -90 0.00 -90 - -50 1.19 -50 - -10 5.05 -10 - 0 9.00 0 - 5 18.39 5 - 10 24.57 10 - 15 21.82 15 - 20 12.87 20 - 25 5.19 25 - 30 1.82 30 - 40 0.07 40 - 60 9.97E-4 60 - 120 2.57E-11 120 - 180	<b>Planned water availabl...</b> 0.00 -210 - -1 0.00 -170 - -1 5.94E-6 -130 - -90 0.01 -90 - -50 4.28 -50 - -10 13.28 -10 - 0 18.75 0 - 5 24.85 5 - 10 21.15 10 - 15 11.74 15 - 20 4.43 20 - 25 1.20 25 - 30 0.31 30 - 40 0.01 40 - 60 2.74E-4 60 - 120 3.08E-12 120 - 180
<b>Total VAD: Irrigated C...</b> 16.16 0 - 8.375 14.19 8.375E9 7.36 1.675E10 17.59 2.5125E10 32.68 3.35E10 11.85 4.1875E10 0.17 5.025E10 7.79E-4 5.8625E10	<b>Total VAD: Irrigated C...</b> 23.49 0 - 8.375 21.79 8.375E9 8.87 1.675E10 17.48 2.5125E10 21.12 3.35E10 7.20 4.1875E10 0.06 5.025E10 2.64E-4 5.8625E10	<b>Total VAD: Irrigated C...</b> 40.63 0 - 8.375 24.65 8.375E9 7.42 1.675E10 13.17 2.5125E10 10.60 3.35E10 3.51 4.1875E10 0.02 5.025E10 6.22E-5 5.8625E10	<b>Total VAD: Irrigated C...</b> 7.74 0 - 8.375 11.44 8.375E9 7.46 1.675E10 19.29 2.5125E10 39.70 3.35E10 14.18 4.1875E10 0.19 5.025E10 8.72E-4 5.8625E10	<b>Total VAD: Irrigated C...</b> 20.35 0 - 8.375 21.25 8.375E9 9.18 1.675E10 18.40 2.5125E10 23.05 3.35E10 7.72 4.1875E10 0.06 5.025E10 2.37E-4 5.8625E10








It is projected that by 2025, the temperature in South Africa will rise by 2.5-3°C from the average temperature. The rainfall is also expected to increase in some parts of the country and decrease in others as well. Using these projections, the scenarios in Table 1 are explained below:

- **Scenario 1:** Increase average temperature by 3°C  
The expected MAR, planned water available and the total VAD of the selected irrigated crops are significantly sensitive to the change.
- **Scenario 2:** With an increase in average temperature by 3°C and decrease average annual rainfall from 500mm/a to 375mm/a, the sensitivity of the above-mentioned variables to this change is more significant than in scenario 1.
- **Scenario 3:** Increase in rainfall by 100mm/a  
When rainfall increases by 100mm/a and the temperature remains at the current value, the probability that the planned water available is 15-20km<sup>3</sup>/a and the total VAD of irrigated crops is 3.35-4.1875E10 are slightly higher by 3.5% and 7% respectively than the probabilities in the initial states.
- **Scenario 4:** Increase average temperature by 3°C and increase rainfall by 100mm/a  
An increase in temperature as projected reverses the results in scenario 3. The probability that the total VAD of irrigated crops is 3.35-4.1875E10 is slightly lower by 9% than the probability in the initial state. On the other hand, the model shows that the planned water available lies between 5-10km<sup>3</sup>/a. This indicates that, as long as the temperature rises, the planned water available and the total VAD will be low because the high temperature will increase the rate of evaporation, which is already very high for the region.

#### 4.2 Potential Total VAD and the Total VAD

- **Scenario 5:** The model shows that, without considering the climate change, the potential total VAD that can be obtained when 160% of the current area of irrigated crops is planted is 5.8625E10 – 6.7E10. However, this is not the case with the climate change which shows the actual Total VAD that can be obtained is 3.35E10 – 4.1875E10. This demonstrates the importance of taking into account of climate change projections in planning.

**Table 2: Comparison of Potential total VAD and Actual total VAD**

Initial states		Scenario 5	
<b>Area: grain (ha)</b> 0.84 0 - 25760 0.98 25760 - 51520 1.04 51520 - 77280  10.63 77280 - 103040 11.69 103040 - 128800 13.28 128800 - 154560 0.83 154560 - 180320 0.72 180320 -		<b>Area: grain (ha)</b> 0.00 0 - 25760 0.00 25760 - 51520 0.00 51520 - 77280 0.00 77280 - 103040 0.00 103040 - 128800 0.00 128800 - 154560 100.00 154560 - 180320	
<b>Area: wheat (ha)</b> 0.44 0 - 43320 0.55 43320 - 86640 0.56 86640 - 129960 9.05 129960 - 173280  15.52 173280 - 216600 12.62 216600 - 259920 0.69 259920 - 303240 0.57 303240 -		<b>Area: wheat (ha)</b> 0.00 0 - 43320 0.00 43320 - 86640 0.00 86640 - 129960 0.00 129960 - 173280 0.00 173280 - 216600 0.00 216600 - 259920 100.00 259920 - 303240	
<b>Area: Sugarcane (ha)</b> 0.53 0 - 18000 0.59 18000 - 36000 0.93 36000 - 54000 1.07 54000 - 72000  63.92 72000 - 90000 12.04 90000 - 108000 0.52 108000 - 126000 0.39 126000 -		<b>Area: Sugarcane (ha)</b> 0.00 0 - 18000 0.00 18000 - 36000 0.00 36000 - 54000 0.00 54000 - 72000 0.00 72000 - 90000 0.00 90000 - 108000 100.00 108000 - 126000	
<b>Area: Fruits &amp; nuts (ha)</b> 0.39 0 - 81580 0.52 81580 - 163160 0.78 163160 - 244740  8.09 244740 - 326320 14.48 326320 - 407900 14.36 407900 - 489480 0.58 489480 - 571060 0.80 571060 -		<b>Area: Fruits &amp; nuts (ha)</b> 0.00 0 - 81580 0.00 81580 - 163160 0.00 163160 - 244740 0.00 244740 - 326320 0.00 326320 - 407900 0.00 407900 - 489480 100.00 489480 - 571060	
<b>Potential Total VAD: Irrigated C...</b> 3.75E-5 0 - 8.375 0.02 8.375E9 0.72 1.675E10  14.67 2.5125E11 3.04 3.35E10 11.28 4.1875E11 0.27 5.025E10 7.22E-4 5.8625E11		<b>Potential Total VAD: Irrigated C...</b> 0.00 0 - 8.375 0.00 8.375E9 0.00 1.675E10 0.00 2.5125E11 0.00 3.35E10 0.00 4.1875E11 14.63 5.025E10 85.37 5.8625E11	
<b>Total VAD: Irrigated C...</b>  16.16 0 - 8.375 14.19 8.375E9 7.36 1.675E10 17.59 2.5125E11 32.68 3.35E10 11.85 4.1875E11 0.17 5.025E10 7.79E-4 5.8625E11		<b>Total VAD: Irrigated C...</b>  16.01 0 - 8.375 14.27 8.375E9 6.94 1.675E10 12.02 2.5125E11 17.90 3.35E10 16.56 4.1875E11 9.60 5.025E10 6.70 5.8625E11	

### **4.3 Mitigation strategies**

This section explains the possible mitigation strategies to attain a higher total VAD given the climate change projections.

- **Scenario 6:** Increase in temperature, decrease rainfall and a higher Total VAD. The model shows that, in order to achieve a higher Total VAD (in this case:  $5.8265E10 - 6.7E10$ ) given an increase in temperature by  $3^{\circ}\text{C}$  and a decrease of rainfall by  $100\text{mm/a}$ , the following are the measures to be embark on as shown in Table 3:
  - Reduce the inter-basin transfers slightly
  - Store more water in dams ( from  $5\text{-}10\text{km}^3/\text{a}$  to  $10\text{-}15\text{ km}^3/\text{a}$ )
  - Increase the area under fruit and nuts to 160% of its current value
  - The area under wheat, grain and sugarcane should however, remain at its current value.

**Table 3: Mitigation strategies**

Initial states	Scenario 6
<p>Temperature range (de...)</p> <p>2.04 15 - 17 2.57 17 - 19 9.92 19 - 21 63.86 21 - 23 6.22 23 - 25 5.70 25 - 27 4.01 27 - 29 2.42 29 - 31 1.82 31 - 33 1.44 33 - 35</p>	<p>Temperature range (de...)</p> <p>0.00 15 - 17 0.00 17 - 19 0.00 19 - 21 0.00 21 - 23 100.00 23 - 25 0.00 25 - 27 0.00 27 - 29 0.00 29 - 31 0.00 31 - 33 0.00 33 - 35</p>
<p>Rainfall mm/a</p> <p>0.66 0 - 150 0.71 150 - 300 1.07 300 - 450 48.13 450 - 500 46.51 500 - 550 0.62 550 - 600 0.44 600 - 750 0.56 750 - 900 0.66 900 - 1050 0.66 1050 - 1100</p>	<p>Rainfall mm/a</p> <p>0.00 0 - 150 0.00 150 - 300 0.00 300 - 450 0.00 450 - 500 100.00 500 - 550 0.00 550 - 600 0.00 600 - 750 0.00 750 - 900 0.00 900 - 1050 0.00 1050 - 1100</p>
<p>Interbasin transfer (lm3)</p> <p>1.20 0 - 0.5 1.90 0.5 - 1 2.17 1 - 1.5 3.30 1.5 - 2 4.75 2 - 2.5 10.47 2.5 - 3 19.85 3 - 3.5 56.36 3.5 - 4</p>	<p>Interbasin transfer (lm3)</p> <p>2.14 0 - 0.5 2.89 0.5 - 1 3.04 1 - 1.5 4.30 1.5 - 2 5.72 2 - 2.5 11.53 2.5 - 3 19.83 3 - 3.5 50.56 3.5 - 4</p>
<p>Stored water in dams (...)</p> <p>0.00 -60 - 45 0.00 -45 - 30 0.00 -30 - 15 9.07 -15 - 0 20.37 0 - 5 31.90 5 - 10 24.68 10 - 15 11.36 15 - 20 2.61 20 - 30 0.01 30 - 45 5.83E-7 45 - 60</p>	<p>Stored water in dams (...)</p> <p>0.00 -60 - 45 0.00 -45 - 30 0.00 -30 - 15 0.39 -15 - 0 4.91 0 - 5 15.49 5 - 10 38.00 10 - 15 23.61 15 - 20 17.52 20 - 30 0.09 30 - 45 5.75E-6 45 - 60</p>
<p>Area: Fruits &amp; nuts (ha)</p> <p>0.39 0 - 81580 0.52 81580 - 163160 0.78 163160 - 244740 8.09 244740 - 326320 14.48 326320 - 407900 0.58 407900 - 489480 0.80 489480 - 571060</p>	<p>Area: Fruits &amp; nuts (ha)</p> <p>0.00 0 - 81580 0.00 81580 - 163160 0.00 163160 - 244740 0.00 244740 - 326320 0.18 326320 - 407900 4.40 407900 - 489480 9.50 489480 - 571060</p>
<p>Area: Sugarcane (ha)</p> <p>0.53 0 - 18000 0.59 18000 - 36000 0.93 36000 - 54000 1.07 54000 - 72000 83.92 72000 - 90000 12.04 90000 - 108000 0.52 108000 - 126000 0.39 126000 - 144000</p>	<p>Area: Sugarcane (ha)</p> <p>0.00 0 - 18000 8.35E-4 18000 - 36000 7.38E-3 36000 - 54000 0.02 54000 - 72000 3.48 72000 - 90000 20.72 90000 - 108000 2.08 108000 - 126000 3.69 126000 - 144000</p>
<p>Area: grain (ha)</p> <p>0.84 0 - 25760 0.98 25760 - 51520 1.04 51520 - 77280 10.63 77280 - 103040 11.69 103040 - 128800 13.28 128800 - 154560 0.83 154560 - 180320 0.72 180320 - 206080</p>	<p>Area: grain (ha)</p> <p>5.3E-3 0 - 25760 0.04 25760 - 51520 0.15 51520 - 77280 4.72 77280 - 103040 67.44 103040 - 128800 21.86 128800 - 154560 2.37 154560 - 180320 3.43 180320 - 206080</p>
<p>Area: wheat (ha)</p> <p>0.44 0 - 43320 0.55 43320 - 86640 0.56 86640 - 129960 9.05 129960 - 173280 5.52 173280 - 216600 12.62 216600 - 259920 0.69 259920 - 303240 0.57 303240 - 346560</p>	<p>Area: wheat (ha)</p> <p>0.00 0 - 43320 0.00 43320 - 86640 3.63E-3 86640 - 129960 1.47 129960 - 173280 62.93 173280 - 216600 25.49 216600 - 259920 3.19 259920 - 303240 6.92 303240 - 346560</p>
<p>Total VAD: Irrigated C...</p> <p>16.16 0 - 8.375 14.19 8.375E9 7.36 1.675E10 17.59 2.5125E1 32.68 3.35E10 11.85 4.1875E1 0.17 5.025E10 7.79E-4 5.8625E1</p>	<p>Total VAD: Irrigated C...</p> <p>0.00 0 - 8.375 0.00 8.375E9 0.00 1.675E10 0.00 2.5125E1 0.00 3.35E10 0.00 4.1875E1 0.00 5.025E10 100.00 5.8625E1</p>

## 5. Conclusions

This research demonstrates how Bayesian networks may be used to derive key thresholds and sensitivities reflecting how agricultural activities are affected by climate change. It also demonstrates how alternative adaptation measures may be conceived using the Bayesian network to test alternative combinations of agricultural activities. In this way, adaptation options that maintain economic benefits and ecological flow requirements may be tabled and presented with complete sensitivities and uncertainties, enabling more focused, rigorous inter-disciplinary consideration of proposed adaptation measures. The Bayesian model offers an adaptable analytical framework where different values for economic multipliers may be considered.

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