Households' welfare analyses of the impact of global change on water resources in South Africa

JS Juana[1], KM Strzepek[2] and JF Kirsten[3]

Abstract

Most of the climate change models for South Africa predict a reduction in freshwater availability by 2050. Population growth is projected at 3% per annum, implying increased domestic water use. In addition to these factors, the concern for ecological sustainability and increased water pollution due to increased industrial, mining and agricultural activities, water availability for sectoral production activities is expected to decline. This decline has an impact on sectoral output, value added and households' welfare. Using a computable general equilibrium approach, this study investigates the possible impact of global change on households' welfare. The simulation results show that water scarcity due to global change can potentially lead to a general deterioration in households' welfare. The poor households, whose incomes are adversely impacted, are the most vulnerable to the consequences of the impact of global change on water resources in South Africa. This vulnerability can only be reduced if welfare policies that maintain food consumption levels for the least and low-income households are implemented.

Keywords: Sectoral output; factor remuneration; households' income/consumption; welfare analysis; food stamps

1. Introduction

The need for sustainable economic growth in South Africa, coupled with increased domestic water use due to population growth, urbanisation and concerns about environmental sustainability has increased the competition for water between agricultural and the non-agricultural production activities. Generally, freshwater availability is projected to decline in the future as a result of climate change, increased industrial activities and wasteful use of the resource (Rosegrant *et al.,* 2002). Climate change models predict an increase in temperature of between 2.5°C and 3°C in South Africa. While some models

[1] *Lecturer, Department of Economics and Economic History, Rhodes University, Grahamstown 6140, South Africa, and PhD Candidate, University of Pretoria; jamessjuana@yahoo.com.*

[2] *Professor, Department of Civil, Environmental and Architectural Engineering, University of Colorado, Boulder, USA.*

[3] *Professor and Head, Department of Agricultural Economics, Extension and Rural Development, Faculty of Agriculture and Natural Sciences, University of Pretoria, Pretoria 0002, South Africa; Johann.Kirsten@up.ac.za.*

predict a catastrophic reduction of 70% in mean annual runoff (MAR), others predict reduction in MAR between 10 and 30% by 2050 (Turpie *et al.,* 2002). Because of the concern for environmental sustainability, 10% of the renewable water resources should be reserved for ecological services in South Africa (DWAF, 2005). The ecological reserve requirement can change in response to changes in freshwater availability in the country.

The above changes can lead to a reduction in water availability for sectoral production activities, and competition among the production sectors for the use of the scarce resource. This has consequences for the production of food and non-food items in the country; hence, it has welfare implications for the people, and especially poor households. The need to investigate the possible consequences of water scarcity and recommend policies that can minimise those consequences in South Africa requires an analysis of households' welfare implications of the impact of global change on water resources. Therefore, this study uses a computable general equilibrium approach to analyse the possible changes in households' welfare as a result of the impact of global change on water resources in South Africa

Generally, climate change has a direct impact on human health, water resources, livestock, agricultural productivity and the economy. These consequences vary from one agro-climatic region to the other. However, this study focuses on the socio-economic consequences of the impact of global change on water resources in South Africa. Specifically, it investigates the impact of global change on sectoral output, factor remuneration and households' welfare through its impact on water availability for sectoral production activities.

2. Data, theoretical framework and modelling procedure

This section discusses the data and model used in the study. Particular attention is given to the standard computable general equilibrium conditions and the specific model closures assumed for the study.

2.1 Description and sources of data

The study uses an updated version of 1998 social accounting matrix (SAM) for South Africa which was developed by Thurlow and Van Seventer (2002). The 43 activities and 43 commodities are consistent with the time series data compiled by South Africa's Trade and Industrial Policy Strategies (TIPS, 2004). The 1998 entries for activities and commodities were updated by using the figures of 2003 supply-use tables extracted from the TIPS data set. The information on household income and expenditure patterns were extracted from Statistics South Africa 2001 census figures. The original SAM has four factors of production; capital, unskilled, medium skilled and highly skilled labour. There are fourteen household categories, which are formed by grouping households into income deciles and then disaggregating the tenth (richest) group into four further groups. Other institutions are firms and government accounts. The remaining accounts are the net savings-investment and the rest of the world accounts.

2.2 Water

As a key factor in this study, the use of water requires a detailed description of the water data source and adjustments made to the SAM to properly account for sectoral water allocation and use in the economy. The water supply information from the municipalities' billing records grossly understates the actual water used by the different sectors, because most sectors use self-supplied water. These entries were therefore replaced by the information published in Statistics South Africa (STATSSA, 2004) water accounts for the nineteen water management areas. Using the municipal water tariff schedule the monetary value of the physical quantities of water used by each production sector was computed.

In Thurlow and Van Seventer (2002), water is treated as a production sector, with the row accounts showing water used as a fixed intermediate input by each of the other production sectors and as a final good by households. It also shows payments by these sectors and institutions to the water sector. The column entries show payments by the water sector to the other sectors for the use of other intermediate inputs and factors services. A key objective in this study is to investigate the welfare implications of the impact of global change on sectoral water availability and use. Consequently, treating water as a fixed intermediate input (as is usually the approach in standard CGE models) is not suitable. Therefore, water enters into the production process as a fifth factor of production (value added function) and not as a fixed intermediate input.

As a factor of production, the row accounts represent distribution of water among the production sectors and the respective payments by these production sectors for the use of this factor. Households initially used water as a final good and made payments to the water sector for this good. These payments are removed from the water accounts and transferred to government which provides the service via its municipal water supply networks. The initial account payments from the other production sectors to the water sector are maintained in the adjusted SAM as payments for the use of this factor. Water no longer pays for factor services as well as for fixed intermediate inputs. To balance the SAM again the study assumes that all factor payments to water accrue to government as recorded as part government receipts. This increases government revenue. In its expenditure accounts, government's net investments as well as payments to the services sector increases. This is followed by a corresponding increase in investments in water delivery infrastructure and services payments to the factors of production. The increased factor payments are finally redistributed among the various household categories. Government also pays the rest of world for the use of water from sources outside South Africa. The adjusted SAM is presented in the appendix.

2.2.1 The SAM aggregations

For the purpose of this study the updated SAM was aggregated to 13 activities/commodities. The agriculture sector, consisting of agriculture (crop production and animal husbandry), forestry and fishing accounts, were aggregated to agriculture; while coal, gold, uranium and other mining were aggregated to mining activities/commodities. Using the three-digit ISIC codes the other production sectors, consisting of 41 activities and 41 commodities were aggregated to 11 activities/commodities accounts comprising agro-based industries (food, beverage and tobacco manufacturing); textile and wearing apparel (textile, wearing apparel, leather and leather products and footwear); wood, paper and paper products (wood and wood products, paper, paper products, printing, recording and recorded media); petroleum products; chemicals (basic and other chemicals); heavy manufacturing (non-metallic minerals, basic iron and steel, basic non-ferrous metals and metal products excluding machinery); machinery and equipments (machinery and equipment, electrical machinery and apparatus, TV, radio and communication equipments, motor vehicles and spare parts and professional and scientific equipments); and other manufacturing. While the electricity account was maintained, building, civil engineering and other construction were aggregated to construction, and wholesale and retail trade, catering and accommodation, transport and storage, communication, business, medical, dental and veterinary, other professional and general government services aggregated to services These aggregations reflect the structure of water use by these sectors or sub-sectors.

The adjusted SAM has five factors of production (water, capital, unskilled, medium-skilled and high-skilled labour). There are also five household accounts (the first to the fifth quintile). Each quintile represents 20% of the households. Ranked from first to fifth, the quintiles represent the least-income, low-income, middle-income, high-income and highest-income households respectively.

Households receive income from wages and from both local (government and inter-personal) and international transfers. Their disposable income is allocated to consumption and savings. Households' consumption is divided into food and non-food consumption. Food consumption is determined by households' expenditure on agriculture and food, beverages and tobacco manufacturing sectors. Non-food consumption expenditures are those incurred on the other sectors, which are further divided into durables and non durables. These divisions are the basis for welfare policy investigations. Sectoral output is sold to the production sectors as intermediate input, consumed domestically, or exported. Government accounts, which were broken down into expenditure and income accounts in the original SAM are maintained.

2.3 The theoretical framework

A Computable General Equilibrium (CGE) model is used to present a counterfactual picture of the impact of reductions in sectoral water availability on households' welfare in South Africa. The study adopts the CGE framework developed by Strzepek and Carbone (2007) and used by Juana (2007). This framework uses the mathematical programming for general equilibrium (MPSGE), which is a GAMS extension developed by Rutherford (1998), with the MCP GAMS solver. The model uses multi-level nested production functions to determine the level of production. Sectoral outputs are represented by a Leontief's combination of fixed intermediate consumption and value added. The model also specifies a constant elasticity of substitution (CES) function to establish the relationship between inputs and output. However, the use of capital is modelled by a Leontief's functions, because the short-run use of this input is assumed to be fixed and sector specific. Conversely, water and the three labour categories are freely mobile across sectors except where specified. Therefore, the use of these inputs is modelled by the CES function. This allows the functioning of a competitive market to efficiently allocate the mobile factors. Therefore, these mobile factors move to sectors where factor returns are highest. The free movement of these factors of production enhances the adjustment of wages for each of the three labour categories and water tariffs to achieve equilibrium in the factor markets.

The model uses the constant elasticity of transformation (CET) function to formulate the imperfect substitution between domestic consumption of sectoral output and export. The constant elasticity of substitution function is also used to model the imperfect substitution of domestically produced goods and imported goods. The imperfect substitutability modelled above enhances the importation and exportation of the same goods.

The factor market for water is closed by assuming that the quantity of water used is fixed and that total sectoral water use is equal to the total sectoral water supply; hence there are no reserves except under the experimental simulations. The capital and labour markets are closed by assuming that the demand for each of these factors is equal to their supply. These assumptions imply full employment of the factors. The saving-investment closure assumes that savings equal investment and that government income (receipts) is equal to the government spending (payments).

2.4 The experimental simulations

The situation documented in the adjusted SAM is the base situation which reflects the current sectoral water allocation in South Africa. All input and output prices including water are normalised in this base period. This situation represents water market inefficiency because the price paid by the production sectors does not reflect the competitive market price of water. To achieve the efficient level of water allocation the study uses the sectoral marginal values of water estimated by Juana (2007) as shadow prices to calibrate the SAM. This is referred to as market allocation scenario. Sectoral water use, output, value added at factor cost, and household consumption under the market allocation scenario are compared to the base scenario.

Water reduction scenarios: After running the market allocation scenario, the study simulates the impact of 10%, 20% and 30% reductions in total sectoral water availability on sectoral output, value added and households' welfare. Total sectoral water availability/use is reduced by the given percentages and the remaining water is allocated among the sectors by the market mechanism, using the estimated sectoral marginal values of water as shadow water prices. These experiments assume that households' consumption of both food and non-food items change with changes in income. The experiments are re-run by assuming that food consumption for the least and low-income households are maintained at base consumption levels. Food consumption is maintained by the institution of food stamps to the least and low-income households who are the most vulnerable to global change impacts. The food stamps in these experiments are equivalent to the loss in consumption. Food stamps are recorded as a government transfer to the targeted households. In this scenario, government's inter-departmental expenditure is reduced by an equivalent amount of the reduction in consumption expenditures of the least and low-income households. Food vouchers equivalent to the loss in consumption expenditures are distributed among the low and least-income households. This paper investigates the impact of such a programme on general households' welfare and on the importation and exportation of agricultural commodities. All the changes in output, value added and households' welfare

are relative to the base indices. These changes show the impact of water scarcity on output and general households' welfare.

2.5 Households' welfare analysis

The study uses the concept of equivalent variation (EV) discussed in Chitiga and Mabugu (2006) to analyse the impact of the different global change on households' welfare. EV compares the level of households' consumption at the given price and income in the base scenario to the levels of consumption in both the market allocation and water reduction scenarios. In principle, equivalent variation can be interpreted as the minimum amount of money that has to be given to the households to renounce a utility increasing project or the maximum amount of money that households are willing to pay to prevent a utility decreasing change. As used in this study, equivalent variation (EV) is defined as the maximum amount households are willing to pay to prevent a decline in consumption levels due to water shortages. Alternatively, it is the minimum amount they are willing to accept to forgo an increase in consumption levels such that the same level of utility is maintained after the reduction in sectoral water use.

Functionally, equivalent variation is denoted as:

$$EV = \left(\frac{P_1^0}{P_1^1}\right)^{\gamma} \left(\frac{P_2^0}{P_2^1}\right)^{1-\gamma} Y^1 - Y^0 \qquad (6.1)$$

Where P_1^0 is the price of good 1 in the base model,
P_1^1 is the price of good 1 after the simulation,
P_2^0 is the price of good 2 in the base model
P_2^1 is the price of good 2 after the simulation
Y^0 is the income in the base model and
Y^1 is households' income after the simulation

A positive EV implies welfare improvement, while a negative EV implies welfare deterioration (loss). An increase in households' expenditures or income implies welfare improvement, while a decrease implies welfare deterioration.

3. Presentation of the simulation results

Section 3.1 discusses changes in sectoral water use due to percentage changes in water availability and Section 3.2 analyses the impact of water scarcity due to global change on sectoral output. Section 3.3 presents the impact of changes in sectoral water availability on factor remuneration, and section 3.4 discusses changes in households' consumption levels, agricultural output, imports and exports under the different scenarios.

3.1 Sectoral water allocation under the different scenarios

Table 1 shows the quantity of water available to each sector after the various simulations. Column 2 of Table1 shows the base distribution of water among the various production sectors in South Africa.

Table 1: Sectoral water allocation under different global change scenarios

Sectors	**Base allocation**	**Market allocation**	**Water reduction scenarios**		
(1)	**(2)**	**(3)**	**M30 (4)**	**M20 (5)**	**M10 (6)**
Agriculture	12.34	12.07 *-2.12*	8.17	9.48	10.72
Mining	0.43	0.87 *102.33*	0.73	0.82	0.88
Agro-industry	0.22	0.21 *-4.55*	0.16	0.18	0.19
Leather & wearing apparel	0.06	0.06 *0.00*	0.04	0.05	0.05
Paper, pulp &printing	0.09	0.08 *-11.11*	0.07	0.06	0.07
Petroleum	0.02	0.01 *-50.00*	0.01	0.01	0.01
Basic chemicals	0.07	0.09 *28.57*	0.06	0.07	0.08
Heavy manufacturing	0.12	0.15 *25.00*	0.11	0.12	0.14
Machinery & Equipment	0.02	0.02 *0.00*	0.01	0.02	0.02
Other manufacturing	0.03	0.03 *0.00*	0.02	0.02	0.03
Electricity	0.12	0.09 *-25.00*	0.08	0.11	0.12
Construction	0.09	0.05 *-44.44*	0.04	0.04	0.05
Services	2.08	1.95 *-6.25*	1.48	1.56	1.76
Total	**15.69**	**15.69**	**10.98** ***(30.00)***	**12.54** ***(20.00)***	**14.12** ***(10.00)***

Column 3 presents the sectoral water use under the market allocation scenario. Columns 4, 5 and 6 show the sectoral water use under the various water reduction experiments. The captions m30, m20, and m10 imply 30%, 20% and 10% reduction in total sectoral water availability in South Africa and allowing the market to re-allocate the residual sectoral water, by using the marginal values computed in Juana (2007). With the market allocation of sectoral water, some sectors gain while others loss water, but the base quantity of water is maintained. The figures in italics are the percentage changes in sectoral water availability from the base allocation. For example, while water use in the agriculture declines by 2.12 the mining sector's water use increases by 102.3%.

In the water reduction scenarios, sectoral water use reduces by a specified percentage (m30, m20 and m10) and the market allocates the residual water among the production sectors. These simulations have consequences for sectoral output and households' income and consumption expenditures, and implications for agricultural exports and imports, which will be discussed under the household welfare and different policy scenarios.

3.2 Changes in sectoral output under the different scenarios

Changes in water availability for sectoral production activities can potentially lead to significant changes in sectoral output.

Table 2 presents the potential impact of water scarcity on sectoral output. Column 2 shows the changes in sectoral output when the market allocates water among the production sectors, while columns 3, 4 and 5 show the percentage changes in sectoral output levels after the specified water reduction experiment. Column 2 of Table 2 shows that with the market allocation of water in South Africa agricultural output falls by 4.78%. The services sector also shows a significant decline in sectoral output by 2.49%. On the contrary, the mining sector records an increase of 22% in output. Heavy metal and basic chemical manufacturing industries also record percentage increases in output. Overall, sectoral output increases by about 6.79%. This implies that market allocation of available water resources generally leads to increased sectoral output in South Africa, although some sectors experience output decline.

Table 2: Changes in sectoral output under different global change scenarios

Sectors (1)	Market Allocation (2)	m30 (3)	m20 (4)	m10 (5)
Agriculture	-4.78	-15.96	-12.37	-8.43
Mining	22. 03	-23.27	-14.45	-9.40
Agro-industry	-2.75	-17.38	-9.28	-3.72
Leather & wearing apparel	0.01	-1.79	-0.16	-0.09
Paper and pulp	-1.36	6.35	3.16	2.44
Petroleum	-2.19	-1.93	-1.64	-0.30
Basic chemicals	2.85	-10.46	-9.33	-0.17
Heavy metal manufacturing	1.98	9.76	3.42	1.13
Machinery & equipment	0.17	3.88	2.02	2.20
Other manufacturing	0.44	7.54	4.20	4.88
Electricity	1.05	-11.72	-8.53	-4.05
Construction	-3.57	2.72	1.34	0.48
Services	-2.49	-8.96	-7.96	-1.75
Total	**6..79**	**-16.39**	**-7.58**	**-4.39**

Therefore, market allocation of water resources leads to efficient use of the resource. With this allocation mechanism sectors pay the competitive market price of water, which reflects the marginal value of the resource. This impacts on sectoral output, but the overall impact shows increased output and indicates efficient use of water.

Generally, under `the water reduction scenarios, total sectoral output declines by 16.39%, 7.56% and 4.39% with 30%, 20% and 10% reduction in sectoral water availability respectively. However, while the simulation results record significant decreases in output for certain sectors, others sectors show significant increase in sectoral output. For example, under all the global change scenarios, the agriculture, mining, food, beverages and tobacco manufacturing, clothing and textile, petroleum, basic chemical manufacturing, electricity and services sectors show significant output decline, while the pulp and paper, heavy metal manufacturing, machinery and equipment and construction sectors show output growth. Columns 3, 4 and 5 of Table 2 present the potential impact of water reduction/scarcity on sectoral output.

3.3 Changes in factor remuneration under the global change scenarios

Changes in sectoral outputs due to water reduction under the different global change scenarios have a direct impact on factor payments. While some sectors substitute water with other factors, other sectors cannot. Therefore, changes in sectoral water allocation and scarcity have varying impact on factor remuneration. Table 3 presents the possible impact of water reduction on factor payments.

Firstly, the market allocation scenario shows an overall increase of factor remuneration by 9.73%. Specifically, the wages of both unskilled and medium skilled labourers increase by 13.57% and 11.95% respectively. Similarly, the wages of high skilled labourers and the returns on capital and water significantly increase. This implies that the market allocation of water among the production sectors enhances growth in both sectoral output and factor remuneration.

Reductions in water availability under the adverse global change conditions result in a decrease in overall factor remuneration. Column 3 of Table 3 shows that with a 30% reduction in sectoral water availability, overall factor remuneration falls by 16.58%. Columns 4 and 5 also record percentage decreases in total factor payments due to 20% and 10% reduction in sectoral water availability. Although factor payments decline under the water reduction scenarios, returns on capital increase. The possible economic reason is that reduction in sectoral water availability may increase the demand for capital by some sectors.

Table 3: Changes in factor remuneration under the different scenarios

Primary factors	Market allocation	Water reduction scenarios		
(1)	(2)	m30 (3)	m20 (4)	m10 (5)
Capital	4.69	6.27	3.91	2.58
Water	8.93	-18.26	-12.65	-8.47
Unskilled labour	13.57	-23.05	-15.76	-9.82
Medium skilled labour	11.95	-3.92	-1.75	-0.65
High skilled labour	7.26	0.93	0.78	0.00
Total impact on factor remuneration	**9.73**	**-16.58**	**-9.47**	**-3.93**

Since capital is fixed within the short run, the price of capital increases to clear the excess demand for the factor. Hence, returns on capital increases on the average, while payments to the other factors fall.

3.4 Changes in households' welfare

Changes in water availability for sectoral production activities have consequences for households' welfare. Welfare measurements in this study consider changes in households' income and consumption expenditures. Changes in households' welfare are based on the two assumption made during the experiments.

3.4.1 Household's welfare analysis without maintaining food consumption

Table 4 shows the percentage changes in households' consumption expenditures or income under the different simulations.

Table 4: Percentage changes in households' consumption under the different scenarios

Household Category (1)	Market allocation (2)	Water reduction scenarios M30 (3)	M20 (4)	M10 (5)
Least-income	9.73	-16.52	-10.32	-3.18
Low-income	8.97	-17.58	-11.31	-4.39
Middle-income	4.18	-5.22	-7.43	-1.77
High-income	2.63	4.36	1.38	0.97
Highest-income	1.04	2.71	0.57	0.09
Total	4.39	-6.7	-2.16	-1.73

The table shows that total households' consumption increases with the market allocation of water among the production sectors. Under this experiment the income/consumption of all the household categories increases. This implies a general welfare improvement. On the contrary, the experimental results indicate that reductions in sectoral water use lead to a general deterioration in households' welfare. Specifically, the results show that while the income/consumption expenditures of the least, low and middle income households decline, those of the high and highest-income households increase. These results imply that only the poor and middle-income households are adversely impacted by water scarcity due to global change. The possible interpretation of these results is that reductions in sectoral water use lead to a decline in output, hence, an increase in output prices. It also leads to a decline in the wages of unskilled and medium-skilled labourers. This generally leads to decline in the incomes of the least, low and middle-income households, because the derive most of their income from wages and transfer payments. Therefore, they reduce their consumption of basic items, including food.

The above results have consequences for agriculture supply, exports and imports of agricultural commodities. Table 5 illustrates the impact of a reduction in sectoral water use on agricultural supply, exports and imports of agricultural commodities.

The results of the market allocation simulation show that both agricultural exports and imports increase by 13.29% and 7.59% respectively, with a 28.42% increase in agricultural supplies. On the contrary, a 30% reduction in total sectoral water use leads to a 29.37% decline agricultural exports and a corresponding 21.93% increase in agricultural imports, while domestic supply of agricultural commodities falls by 25.48%. The same trend of changes in agricultural exports, imports and domestic agricultural supply are recorded for 20% and 10% reduction in sectoral water use.

Table 5: Agricultural supply, exports and imports under the different scenarios

	Market allocation (2)	Water reduction scenarios M30 (3)	M20 (4)	M10 (5)
Agricultural export	13.29	-29.37	-17.21	-12.57
Agricultural import	7.59	21.93	9.08	1.38
Agricultural supply	28.42	-25.48	-10.23	-3.54

In general, these results show that any reduction in sectoral water availability and use due to global change leads to a decline in agricultural output, which results in a decline in agricultural exports and an increase in agricultural imports.

3.4.2 Changes in households' welfare under the food stamp policy

This section discusses the possible impact of global change on households' consumption if the level of food consumption is maintained. According to the simulation results reported on Table 6, only the middle-income households are adversely affected by the reduction in sectoral water use if food consumption by the least and low-income households is maintained at base levels.

Overall, the results show a general improvement in households' welfare, if a programme that maintains food consumption levels for the poor households is implemented. These results have consequences for domestic agricultural supplies, and the exportation and importation of agricultural commodities as shown on Table 7. The table shows how domestic agricultural supplies, exports and imports change in response to the various sectoral water reduction scenarios.

Table 6: Households, welfare analyses under the different scenarios with food stamp

Household categories (1)	Market allocation (2)	Water reduction scenarios M30 (3)	M20 (4)	M10 (5)
Least-income	9.73	23.47	11.70	6.81
Low-income	8.97	20.29	13.79	8.04
Middle-income	4.18	-28.63	-10.83	-8.45
High-income	2.63	16.76	11.38	9.62
Highest-income	1.04	7.73	6.92	8.68
Total	4.39	12.04	10.57	7.84

According to Table 7 a 30% reduction in sectoral water availability leads to 45.82% decline in agricultural exports, while the importation of agricultural commodities increases by 36.35% and domestic supply of these commodities declines by 17.28%. The same trend of percentage changes is observed for 20% and 10% reductions in sectoral water use.

Table 7: Changes in agricultural exports, imports and domestic supply under the food stamp policy

	Market allocation	Global change scenarios		
		M30 (3)	M20 (4)	M10 (5)
	(2)			
Agricultural export	13.29	(45.82)	(27.52)	(20.15)
Agricultural imports	7.59	36.35	24.01	12.07
Agricultural supply	28.42	(17.28)	(12.47)	(8.37)

As shown in Table 1, a reduction in sectoral water use leads to decline in the output of the agriculture and mining sectors. A decline in agricultural output leads to a corresponding decline in both domestic agricultural supplies and exports. Hence, to maintain domestic food consumption, the importation of agricultural commodities must increase. Furthermore, most welfare programmes target poor households and exclude the middle income-households. Therefore, with the institution of food stamps to maintain food consumption by the poor households, middle-income households' welfare deteriorates since they are excluded from such programmes, but pay the same market price for food and other commodities.

4. Discussion of main research findings and conclusions

The simulation results show that market allocation of water among the production sectors generally leads to a growth in sectoral output although the output of some sectors decline. Factor payments increase, which leads to a general improvement in households' welfare, since it increases their income and their consumption expenditures.

The experimental results of the global change scenarios show that generally, households' welfare deteriorates with reductions in sectoral water availability and use. The poor and the middle-income households are adversely impacted by global change, while the rich households' welfare improves. As sectoral water use reduces, agricultural output significantly declines, resulting in increased food prices. Households' expenditure on food increases. Therefore, total expenditure on non-food items declines, leading to a general decline in welfare. However, the least, low and middle-income households are more adversely impacted by global change impact than the high and highest-income households. Secondly, the reduction in water mostly impacts the sectors that employ most of the unskilled and semi-skilled labourers. When the output of these sectors decline, wages of labourers in these sectors decrease and so does the income of the least, low and middle-income households. However, the improvement in the welfare of the rich households is not strong enough to compensate the loss in welfare of the poor and middle-income households.

With reduction in sectoral water availability and the subsequent decline in agricultural output, exportation of agricultural commodities falls, while the importation of these commodities increase to meet the domestic demand for food. Generally, domestic agricultural supplies fall.

To minimise the adverse impact of global change on poor-households an appropriate welfare programme such as food stamps should be implemented. When policies that maintain food consumption levels are implemented, it is only the middle-income households that experience the adverse impact. The reason is that welfare programmes generally target the poor households. The expenditure of middle-income households on food increases dramatically at the expense of the non-food items, which leads to a deterioration in their welfare.

These results have consequences for agricultural output, exportation and importation of agricultural commodities. The distribution of food stamps among the least and low-income households increases the demand for food. While agricultural output declines, exportation of agricultural products consequently declines. Therefore, to meet the increased demand for food, importation of agricultural commodities should increase. Hence, policies that favour the importation of food commodities at affordable prices by households should be implemented to mitigate the adverse consequences of global change. These findings imply that appropriate food security policies should be designed and implemented to dampen the potential adverse consequences of future global change.

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Appendix 1: Aggregated 2003 Social Accounting Matrix for South Africa

	AGR	MIN	AGI	TEX	PPP	PET	CHM	HEV	MAC	OHM	ELE	CON	SER	WAT
AGR	51179.44	39	31236.81	614.55	1257.44	1.34	441.12	83.39	206.14	2292.17	9.71	713.2413	973.9	0
MIN	174.49	84078.39	117.13	23.89	216.72	11935.15	2368.04	9466.06	156.37	1669.464	3952.16	4173.316	858.4019	0
AGI	4917.889	60.46	99823.11	1178.62	134.75	0	1103.543	16.90133	8.93	41.36907	29.74	0	12610.38	0
TEX	536.25	450.43	109.4447	33442.74	38.12039	0	240.5841	44.69	770.6393	1304.204	6.35	523.99	2935.821	0
PPP	322.98	153.46	2824.19	353.0498	41966.02	1.58	1332.618	281.6255	383.1449	905.4129	28.89	490.88	21555.07	0
PET	2907.73	1256.07	523.55	110.1	270.22	23328.16	5421.384	1399.62	526.35	287.05	103.72	1987.12	19221.59	0
CHM	4544.83	3254.82	967.39	2557.774	2313.88	362.9285	68996.97	2654.39	2799.127	6677.15	64.87	853	14098.83	0
HEV	585.69	2808.21	2070.35	295.7044	139.56	81.68237	1526.521	94345.85	15303.41	1923.57	180.92	12595.27	7760.594	0
MAC	2005.96	5118.48	517.84	528.7002	779.6	288.96	831.0025	3708.045	115517.9	733.3131	1163.26	6059.42	31216.8	0
OHM	430.75	2304.21	2465.59	819.4579	1292.191	30.15	3426.252	766.0711	4075.272	39579.01	55.75	3261.68	10958.55	0
ELE	452.27	3733.23	624.92	279.17	512.28	257.92	1125.73	4665.73	647.06	474.72	28993.26	1067.536	6477.404	0
CON	206.05	841.63	0	0	0	0	0	0	0	0	1250.87	86746.12	8350.898	0
SER	9847.098	22060.78	45002.11	22173.53	11432.47	15179.26	26264.49	22238.34	48440.81	20095.73	1377.614	6128.277	1115810	0
WAT	225.71	426.54	217.04	59.88	87.27	21.6	66.96	117.37	23.56	30.45	121.37	91.59	4143.958	0
CAP	16839.68	23460.27	14246.86	1415.704	5228.822	8134.283	8438.903	12188.8	7562.646	3027.285	11465.5	8281.711	240701.9	0
LABLO	7101.787	16898.2	4972.932	5265.065	1895.607	542.8917	2170.905	7221.988	6627.511	5307.775	3329.165	8740.542	71440.1	0
LABMED	1040.271	4365.496	3456.139	922.7977	2733.825	501.1002	2003.79	3996.142	4507.312	2379.858	1476.14	2711.795	138977.2	0
LABHI	238.2006	2348.441	2859.657	822.2685	2327.55	855.98	3422.877	2990.921	4937.438	1832.052	2314.796	2317.645	59270.73	0
HH1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HH2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HH3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HH4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HH5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FIRMS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GOV	572.413	854.7123	15482.47	2803.183	1174.737	16660.98	2428.248	1102.039	11935.55	2582.164	1111.735	3099.811	29088.56	18147.24
INV	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ROW	3419.824	11962.82	10878.17	6646.451	5705.463	4011.269	17012.52	8669.843	70792.9	9071.414	276.1526	591.8585	34922.44	70.87598
TOTAL	**107549.3**	**186475.6**	**238395.7**	**80312.64**	**79506.52**	**82195.24**	**148622.5**	**175957.8**	**295222.1**	**100214.2**	**57311.97**	**150434.8**	**1831373**	**18218.11**

	CAP	**LABLO**	**LABMED**	**LABHI**	**HH1**	**HH2**	**HH3**	**HH4**	**HH5**	**FIRMS**	**GOV**	**INV**	**ROW**	**Total**
AGR	0	0	0	0	1161.373	1873.908	8861.837	2372.792	1606.611	0	0	-5771.77	8396.309	107549.3
MIN	0	0	0	0	14.68648	18.1452	105.3415	47.31159	20.97652	0	0	1470.733	65608.87	186475.6
AGI	0	0	0	0	10440.25	16852.28	79871.43	21517.39	14586.28	0	0	-37041.8	12244.17	238395.7
TEX	0	0	0	0	1175.996	2700.606	19080.48	5965.266	3396.541	0	0	3057.809	4532.683	80312.64
PPP	0	0	0	0	15.05778	85.67436	2087.359	1853.211	1768.568	0	0	-1406.75	4504.488	79506.52
PET	0	0	0	0	159.8663	265.381	7150.867	6102.661	4701.724	0	0	2648.263	3823.803	82195.24
CHM	0	0	0	0	671.6051	1222.933	10502.69	5452.788	3588.556	0	0	4327.503	12710.43	148622.5
HEV	0	0	0	0	11.5771	36.82683	498.1534	302.6131	233.0671	0	0	6926.326	28331.93	175957.8
MAC	0	0	0	0	94.77138	341.6139	10846.41	10860.44	10720.69	0	0	73883.72	20005.14	295222.1
OHM	0	0	0	0	175.1699	600.6077	8687.129	4629.741	3366.27	0	0	1478.518	11811.79	100214.2
ELE	0	0	0	0	727.8532	899.2652	5220.66	2344.734	1039.584	0	0	-3274.91	1043.556	57311.97
CON	0	0	0	0	0	0	0	0	0	0	0	52922.5	116.7313	150434.8
SER	0	0	0	0	2687.07	6969.896	88084.79	57292.87	49661.34	0	199164.8	28750.64	32711.16	1831373
WAT	0	0	0	0	0	0	0	0	0	0	0	12542.89	41.92777	18218.11
CAP	0	0	0	0	0	0	0	0	0	0	0	0	9424	370416.4
LABLO	0	0	0	0	0	0	0	0	0	0	0	0	0	141514.5
LABMED	0	0	0	0	0	0	0	0	0	0	0	0	0	169071.9
LABHI	0	0	0	0	0	0	0	0	0	0	0	0	0	86538.55
HH1	0	6549.209	2482.516	208.9023	0	0	0	0	0	1399.727	7014.094	0	20.44769	17674.9
HH2	0	13335.19	6193.585	457.8611	0	0	0	0	0	3725.615	9796.266	0	45.43085	33553.95
HH3	0	85838.35	94717.09	31087.69	0	0	0	0	0	56383.88	13826.76	0	142.6527	281996.4
HH4	0	25429.51	49466.65	37397.79	0	0	0	0	0	33236.89	1287.388	0	17.55192	146835.8
HH5	0	10362.2	15211.24	16681.09	0	0	0	0	0	71667	360.4957	0	4.916807	114287
FIRMS	343111.4	0	0	0	0	0	0	0	0	0	0	0	0	343111.4
GOV	0	0	0	0	330.4448	1665.002	40236.15	27310.71	18997.12	35767.22	210036.8	0	173	441560.3
INV	0	0	0	0	9.104741	21.42932	739.6052	725.4737	555.3871	140842	-5777.36	3248.039	3398	143761.7
ROW	27305	0	1000.783	705.217	0.074399	0.380314	23.52336	57.78476	44.23717	89	5851	0	0	219109
TOTAL	**370416.4**	**141514.5**	**169071.9**	**86538.55**	**17674.9**	**33553.95**	**281996.4**	**146835.8**	**114287**	**343111.4**	**441560.3**	**143761.7**	**219109**	**6061221**