Hydrology and Earth System Sciences Discussions

Analysis of virtual water flows associated with the trade of maize in the SADC region: importance of scale

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HESSD

5, 2727–2757, 2008

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Abstract

The concept of virtual water encourages a country to view agricultural crops in terms of the amount of water required to produce those crops, with a view to implementing trading policies that promote the saving of scarce water resources. Recently, increased attention has focussed on partitioning the virtual water content of crops into green and blue water (derived from rainfall and irrigation, respectively) as the latter has higher opportunity costs associated with its use and therefore impacts directly on scarcity. Maize is the most important crop traded within the SADC region. South Africa is the largest producer and exporter of maize, with the majority of its exports destined for other SADC countries. In comparison to other SADC countries, South Africa produces maize relatively efficiently, with a low virtual water content and a high green ($868\,m^3\,tonne^{-1}$) to blue ($117\,m^3\,tonne^{-1}$) water ratio. The blue water content is however higher than for maize produced in all other SADC countries, with the exception of Namibia ($211\,m^3\,tonne^{-1}$). Current trade patterns therefore result in a net expenditure of blue water ($66\times10^6\,m^3$), almost all of which is exported by South Africa ($65\times10^6\,m^3$). South Africa is one of the most water scarce countries in the region and analysis of virtual water flows indicates that current SADC maize trading patterns are influenced by national productivity as opposed to water scarcity. The virtual water content of maize was estimated for each of South Africa's nineteen Water Management Area's (WMA) and used as a proxy to represent water use efficiency for maize production. The virtual water content varied widely across all of the WMAs, ranging from $360\,m^3\,tonne^{-1}$ in the Ustutu Mhlatuze to $1000\,m^3\,tonne^{-1}$ in the Limpopo. A comparison of the virtual water content and production of maize (expressed as a percentage of the total national production) identified those WMAs where maize production is highly water inefficient (e.g. Lower Orange and Limpopo WMAs). Results suggest that, while a national estimate of the virtual water content of a crop may indicate a relatively efficient use of water, an analysis of the virtual water content at smaller scales can reveal inefficient use of water for the same crop. Therefore, analysis of the virtual water content of crops

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and trading of agricultural products at different spatial scales (i.e. regional, national and WMA) could be an important consideration within the context of water allocation, water use efficiency and alleviation of water scarcity.

1   Introduction

South Africa is a water scarce country and the water resources available in many of its 19 Water Management Areas (WMAs) have already been over allocated (DWAF, 2004), with irrigated agriculture accounting for approximately 60% of national water use (FAO, 2005). Within the Southern African Development Community (SADC), maize is the most important staple food source and South Africa is the largest producer (producing 11 749 000 tonnes on a total area of 3 233 000 ha; DoA, 2007) and exporter of maize in the region (Maasdorp, 1998). Production of one metric tonne of maize in South Africa requires approximately 1609 m^3 of water (Chapagain and Hoekstra, 2004); approximately 9% of South Africa's maize is irrigated while the balance is rain-fed (FAO, 2005). Given the water requirements of maize and the large quantities produced each year, current production and trade trends in SADC are likely placing increased pressure on South Africa's scarce water resources.

The concept of virtual water trading advocates the idea that water-scarce countries should increasingly meet their food requirements by importing crops from water-rich countries (Horlemann and Neubert, 2007), thereby saving the amount of water that would have been required to produce the crop locally. The most positive effect generated by virtual water trade is the water savings that that are generated in the countries that import agricultural products (Chapagain et al., 2006). South Africa has gradually shifted from being self sufficient in terms of crop production and has reduced the production of low value crops such as maize, wheat and other cereals, while increasing production of higher value crops, such as citrus (Earle, 2001). This has a positive impact through efficient use of scare water resources, by generating more monetary value per unit of water used. Given that maize is the most important agricultural crop traded

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in the SADC region, there are likely to be large volumes of virtual water associated with maize trade. Analysis of virtual water flows in the region is relevant in that the SADC region is characterized by four countries (Botswana, Namibia, South Africa and Zimbabwe) that are regarded as severely water deficient (Falkenmark, 1989; WRI, 2008)
5 and which could therefore benefit from the implementation of a virtual water trading policy.

This study investigates those flows of virtual water into and out of South Africa that are associated with the trade of maize. The study highlights the importance of maize trade at a national scale and focuses on the significance of maize to agricultural trade
10 in the SADC region. Through an analysis of virtual water flows, we examine the impact of the maize trade on water resources in the region, with a particular focus on South Africa. The concept of virtual water is used to analyse water flows at a regional level, as well as to determine the water-use efficiency of maize production within each of South Africa's 19 WMAs. Particular attention is paid to the partitioning of green and blue
15 water and their respective impacts on regional (SADC) water savings and production efficiencies at the WMA level.

2 Methodology

2.1 South African virtual water trade

A detailed analysis of virtual water flows associated with imports to and exports from
20 South Africa was performed. Agricultural crops used in the analysis included those included in the Department of Agriculture statistical outlook (DoA, 2007). For each crop, data on the production (tonnes), crop area (ha), crop yield (tonne ha^{-1}) and the quantity (tonnes) and value ($ tonne^{-1}) of exports and imports were obtained from the FAOSTATS database (FAO, 2007). Using the virtual water content value of each
25 crop (Chapagain and Hoekstra, 2004), the total virtual water export and import were calculated for each crop. In this approach, the virtual water content of a crop was taken

to be the amount of water used to produce that crop under local conditions. Therefore, imported crops result in a virtual water import, which is considered to be the amount of water that would have been required to produce that crop locally. Virtual water export is the amount of water required to produce the crop locally, and which leaves the country as a result of trade.

Virtual water export (VW_{ex}) is the amount of water associated with exported crops, representing a water flow out of the producing country, and was calculated as follows:

$$VW_{ex} = Q_{ex} \times VW \tag{1}$$

where Q_{ex} is the quantity (in metric tonnes) of an exported crop and VW is the virtual water content (m^3 tonne^{-1}) of the crop, in the country which it is produced (i.e. South Africa). Virtual water import (VW_{im}) is the amount of water that virtually flows into the country in an imported crop, and is equivalent to the amount of water that would have been required to produce that particular crop in the importing country in question. WW_{im} was determined according to the following equation:

$$VW_{im} = Q_{im} \times VW \tag{2}$$

where Q_{im} is the quantity (in metric tonnes) of the imported crop and VW is the virtual water content of that crop in the importing country (e.g. South Africa). For each crop, a net virtual water (Net VW) trade (i.e. the sum of virtual water imports or exports associated with a specific crop) was determined according to Eq. (3):

$$NetVW = VW_{im} - VW_{ex} \tag{3}$$

where a negative (−) value represents a net export of water (i.e. for a given crop more virtual water leaves the country than enters it, and therefore represents water expenditure), and a positive (+) value represents a net import of virtual water (i.e. for a given crop, more virtual water enters the country than leaves it, thereby representing a water saving). This saving is based on the volume of water that the exporting country used to produce the crop and the amount of water that would have been used by the importing

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country to grow the crop internally. The total net virtual water trade was determined by summing the Net VW trade for each crop. Again a negative value represents an overall export of virtual water, while a positive value represents an overall import of virtual water.

2.2 Importance of maize in the SADC region

Our analysis included all of the countries comprising the Southern African development Community (SADC; Angola, Botswana, Democratic Republic of Congo, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe). For each country a detailed trade matrix (for the year 2003) for export and import of maize was constructed using FAOSTAT data (FAO, 2007). The matrix provided information on the quantity of maize that was exported from and/or imported into a country (including the specific countries which maize is exported to and imported from). Using these matrices it was possible to calculate, for each SADC country, the percentage of maize trade (import and export) that was confined to other SADC countries only, and that that was confined to countries from the rest of the world. These matrices were combined to construct a single matrix showing only the quantity of maize imported into and exported out of other SADC members, for each country included in the analysis.

2.3 Virtual water flows associated with maize in the SADC region

2.3.1 Virtual water calculations

The blue, green and total virtual water content of maize was calculated for each SADC country, based on data collected for important maize growing areas in each country (Hartkamp et al., 2000). For each country, an average crop water and irrigation requirement was calculated using the FAO CROPWAT model (FAO, 2003). Effective rainfall was estimated to be the difference between the crop water and irrigation requirement.

The blue virtual water content (BVW) was calculated as follows:

$$BVW = \frac{10 \times CIR \times CA_{irr}}{CP_{total}} \qquad (4)$$

where CIR is the crop irrigation requirement (mm), CA_{irr} is the area (ha) of crop under irrigation and CP_{total} is the total amount of maize (tonnes) produced. Estimates of the area of maize under irrigation for each SADC country were obtained from the FAO Aquastat survey (FAO, 2005). Green virtual water content (GVW) was calculated as follows:

$$GVW = \frac{10 \times (CWR - CIR) \times CA_{total}}{CP_{total}} \qquad (5)$$

where CWR is the crop water requirement (mm) and CA_{total} is the total area under maize (ha). The total virtual water content is equal to the sum of the green and blue virtual water content for maize in the country. Using the trade matrix, the volumes of total virtual water exported and imported in maize was calculated for each SADC country according to Eqs. (1) and (2), respectively. For each exporting country, an overall saving was calculated by summing the net water savings associated with maize export to each of the corresponding importing countries. This figure gives an indication of the water savings associated with the export of maize from a particular country to other SADC nations. Similarly, for each importing country, an overall saving was calculated by summing the net water savings associated with maize imports from each of the corresponding exporting countries. The total water saving in the SADC region was calculated by summing the net savings for each exporting country. A trade matrix was constructed to detail the net virtual water flows associated with maize trade between countries.

2.3.2 Blue water flows associated with maize in the SADC region

The use of irrigation water (blue water) for agriculture constitutes a high opportunity cost, because it can be used in many alternative uses (i.e. industry, domestic use, and

maintenance of the integrity of aquatic ecosystems). In contrast, the use of rainfall by dryland agriculture (green water use) does not significantly impact on the quantity of scarce surface or groundwater resources in a country. Therefore, an analysis of the virtual water trade in terms of blue water may give a more accurate representation of real water savings that accrue to a particular country. Accordingly an identical trade matrix was drawn up, as described above, to detail flows of blue water. The virtual blue water savings were calculated according to the following equation:

$$NetVW_{Blue} = Q \times (BVW_{ex} - BVW_{im}) \tag{6}$$

where Q is the quantity (in metric tonnes) of maize traded, BVW_{ex} is the blue virtual blue water content of maize produced in the exporting country, and BVW_{im} is the virtual blue water content of irrigated maize in the importing country.

2.4 Impact of maize production at WMA scale

Data on the area, production and proportion of irrigated and dryland maize in each of South Africa's WMAs were obtained from Statistics South Africa (STATSSA, 2002). Major maize production areas were identified for each WMA (Fig. 1) and crop water and irrigation requirements and effective rainfall were determined for each of these areas using the SAPWAT (Crosby and Crosby, 1999) computer software programme. SAP-WAT is a programme designed to estimate crop irrigation requirements for the planning of water requirements for Water User Associations in South Africa. The programme is designed as a planning and management aid and relies on an extensive South African crop and climate database and contains data from over 350 weather stations located throughout the country. In order for the programme to calculate water requirements for a particular crop, it is necessary for the user to provide input in the form of a) selecting a weather station that is representative of the area in which the crop is grown; and b) crop information (crop type, month of planting). Collected data were used to calculate blue, green and total virtual water content for maize in each of the WMAs using Eqs. (4)

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and (5). The SAPWAT weather stations used for the derivation of water requirements are indicated on Fig. 1.

3 Results

3.1 Net virtual water flows for South Africa

South Africa is a net exporter of agricultural crops, exporting almost 6 million tonnes of produce and importing approximately 1.7 million tonnes. Important import crops are cereals and grains, including wheat, barley, maize and oats, while maize, fruits and sugar cane are important export crops (Table 1). Apart from maize, major export crops generate far greater value per m^3 of water used than crops that are imported. All export crops generate at least three times more value per m^3 of water used, in comparison to maize. As a result of current agricultural trade activities, South Africa is a net exporter of virtual water, with maize accounting for almost 68% of the total volume of virtual export water (Table 1).

3.2 Trade analysis of maize

In 2003, countries within the SADC region collectively exported 1 018 507 tonnes of maize, of which 79% was exported to other SADC countries. South Africa is the largest exporter of maize in the SADC region, accounting for 75% of the total maize exports, of which 80% is destined for other SADC countries (Table 2), and, together with Tanzania accounts for 90% of the total quantity of maize exported from all SADC countries. Zimbabwe and Zambia are the largest importers of maize (accounting for almost 60% of the total), almost all of which originates from other SADC countries (Table 2). Most SADC countries import maize from other SADC countries. The exceptions are Mauritius, Tanzania and South Africa which, together, account for less than 10% of imported maize, the majority of which originates from countries outside of the SADC region.

3.3 Virtual water content

The average water requirements for maize grown in important maize production areas in each of the SADC countries vary from 413 mm in the DRC to 620 mm in Namibia (Table 3). The effective rainfall is relatively high in most SADC countries, resulting in relatively low irrigation requirements, particularly for countries such as Angola, DRC, Malawi, Mauritius and Zambia, which receive high annual rainfalls. In contrast, countries with lower effective rainfalls such as Zimbabwe, South Africa, Namibia, Lesotho and Botswana, have comparatively high irrigation requirements for maize. Maize yields vary from 0.2 (Botswana) to as high as 6.6 (Mauritius) tonnes ha^{-1}. South Africa, with an average of 2.7 tonnes ha^{-1} produces higher yields than all SADC countries (with the exception of Mauritius). The virtual water content for maize across all SADC countries varies widely, from 748 m^3 tonne^{-1} in Mauritius to as much as 12 703 m^3 tonne^{-1} in Botswana (Table 4). With the exception of Mauritius, South African maize has the lowest virtual water content, despite the fact that maize produced in South Africa has comparatively higher crop water requirements than other SADC countries. Of all the SADC countries, irrigation of maize only takes place in Namibia, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe, with South Africa containing the highest proportion of irrigated area. Of these countries that irrigate maize, the maize produced in South Africa and Namibia has the highest blue water content. The majority of maize production in SADC is attributable to green water. Even in South Africa and Namibia, the blue water content is low in comparison to green water content.

3.4 Net water savings at the SADC level

3.4.1 Total virtual water

When the total virtual water content of the maize produced in all SADC countries is taken into account, maize trade within the SADC region results in a net virtual water saving for the region of 3126×10^6 m^3 (Table 5). The largest proportion of these sav-

ings is achieved as a result of South Africa exporting maize to other SADC countries, with the export of maize to Botswana and Zimbabwe resulting in the largest net water savings. The largest virtual water expenditure occurs as a result of the importation of maize by South Africa. Given South Africa's low virtual water content in comparison to other SADC countries, imports into South Africa result in a net water loss, though this is insignificant in comparison to the water savings generated by the import of maize into other countries.

3.4.2 Blue virtual water

In contrast to the trade of total virtual water, an analysis of the quantity of blue water associated with maize that is traded between SADC countries shows a net expenditure of 66×10^6 m^3 (Table 6). This is largely as a result of countries importing maize from South Africa, resulting in a net expenditure of 65×10^6 m^3 for this country. Net virtual blue water expenditure occurs as a result of the export of maize from countries that irrigate (e.g. South Africa) to countries that do not irrigate maize. Savings occur as a result of countries with high blue water content importing maize from countries with a lower blue water content (e.g. Namibia importing maize from South Africa). Net savings are also achieved by those countries that do not irrigate maize (e.g. Mozambique) exporting maize to countries that do irrigate.

3.5 South African maize production analysis

While maize is produced in all of South Africa's WMAs, the majority is produced in the Upper, Middle and Lower Vaal WMAs (Fig. 2); together, these WMAs account for almost 70% of the total national maize production. Other relatively important maize production areas include the Olifants (12%) and Upper Orange (6%) WMAs. In total, almost 90% of South Africa's maize is produced within these five WMAs. Irrigation of maize takes place in all of South Africa's WMAs, with the Gouritz, Fish and Tsit-sikamma, Limpopo, Lower Orange and Luvuvhu and Letaba WMAs having particularly

large proportions of area under irrigation (over 40%) (Fig. 3). The lowest percentage of irrigated maize occurs in the Inkomati and Upper, Middle and Lower Vaal WMAs (less than 10%). At a national level, approximately 91% of South Africa's maize is produced under dryland conditions, while 9% is irrigated.

The total virtual water content of maize varies widely amongst the different WMAs, from as high as 1000 m^3 tonne^{-1} in the Limpopo WMA to less than 400 m^3 tonne^{-1} in the Usuthu and Mhlatuze WMA (Fig. 4). At a national scale, the virtual water content of maize is 733 m^3 tonne^{-1}, with the virtual water content of maize produced in the Upper, Middle and Lower Vaal (major production areas) approximately equal to the national average. More importantly, due to the low irrigation of maize in these WMAs, the blue water content of maize is relatively low, indicating an efficient use of water (i.e. high yields and production with relatively low irrigation input per tonne of crop produced). In contrast, the Fish to Tsitsikamma, Limpopo, Lower Orange and Olifants Doring WMAs all have very high ratios of blue to green water content. This results in a relatively high total blue water use in comparison to total production (Fig. 2). The Limpopo and Lower and Upper Orange WMAs in particular use high percentages of the total national blue water use in relation to their percentage of national maize production, representing a relatively inefficient use of water. In total these WMAs result in only 9% of the national production, yet use 31% of the total blue water used in maize irrigation. In contrast, the Vaal WMAs are responsible for 70% of the national production, using 45% of the total blue water used for maize irrigation.

4 Discussion

4.1 SADC maize trade

Maize is clearly the most important crop with regards to virtual water trade in South Africa (Table 1) and the entire SADC region. Studies have shown that South Africa has increasingly exported high value crops and imported low value (high mass crops)

(Earle, 2001). With the exception of maize, data presented in this study supports the study of Earle (2001), showing that the value of exported crops is higher than those that are imported (Table 1). The example of maize, however, illustrates how virtual water trading can be used to highlight the water implications of trade policies, revealing
5　inefficient use or loss of water, and emphasizing the need for a detailed assessment of water use efficiency across the entire agricultural sector. The majority of maize grown in the SADC region is traded within the region, with South Africa being the largest producer and exporter (Table 2). Most of the South African-grown maize is destined for use in other SADC countries that produce maize with a comparatively higher virtual
10　water content (Tables 2 and 4). Even though crop water requirements for maize are lower in most other SADC countries than in South Africa, the maize productivity in these countries is low (Table 3), resulting in a comparatively high total virtual water content (Table 4). An improvement in yields would result in a lower virtual water content for maize in these countries. Current trade patterns therefore result in a total net saving of
15　water (3126×10^6 m^3) as a large proportion of maize is exported from countries with a low virtual water content (predominantly South Africa and to a lesser extent Tanzania) to countries where the virtual water content of maize is higher (Tables 4 and 5). In particular, trade from South Africa to Zimbabwe, where the virtual water content of maize is amongst the highest in the SADC region, results in large savings of virtual
20　water (Table 5). The largest virtual water expenditure occurs as a result of South Africa importing maize from SADC countries where the virtual water content for maize is comparatively higher.

The concept of virtual water trading is essentially an analysis of the trade of agricultural products based on their water content, with the emphasis on encouraging
25　water saving in countries that are water scarce (Hoekstra and Hung, 2005). In the SADC context, South Africa, Botswana, Malawi and Zimbabwe are highly water scarce (Table 4). Therefore, from a virtual water trading perspective, these countries would benefit through importing, rather than exporting, "water-rich" crops, allowing the internal water savings to be used for more beneficial uses (e.g. production of higher value

crops, economic development, industry etc.). Currently, based on the quantity of maize traded in the region, South Africa is clearly not a beneficiary of such a strategy. South Africa and Zimbabwe both experience chronic water stress with an annual per capita water availability below 1000 m^3 (WRI, 2008). Maize trade is therefore highly beneficial to Zimbabwe as this country experiences greatest water savings through its current trade policy. In contrast, South Africa experiences the greatest water expenditure, in spite of the fact that it is one of the most water scarce countries in the region. Care is therefore needed when interpreting the values for net, total water savings as presented in this study. The net water savings achieved in the SADC region are primarily as a result of South African maize production being more water efficient than the major importing countries. Even though South Africa produces more "crop per drop" than major importers, most importing countries have more abundant water resources and can therefore potentially afford to use more water for maize production. Water savings therefore do not occur where they are needed most and current trade and virtual water savings in the SADC region are driven by crop productivity rather than water scarcity.

Presently, less than a quarter of the global cereal trade occurs from water-rich to water-scarce countries (de Fraiture et al., 2004). Many other factors determine trade decisions, such as crop productivity (as illustrated in this study), food security, loss of employment (in the case of reducing agricultural output) and the reluctance of states to be dependent on importing food from other countries (Wichelns, 2001; Qadir et al., 2003). South Africa is an important producer and exporter of maize in the region and the implementation of a virtual water strategy aimed at saving water and the resulting reduction in maize productivity would likely place the food security of neighbouring nations at risk. From a regional perspective, a strategy to increase the productivity of maize production in major importing countries (many of which are suited to maize production based on abundant blue water resources and high effective rainfalls) and a shift towards greater South Africa reliance on maize imports, could also result in a net saving of water resources in the SADC region, particularly in countries where it is needed most (i.e. South Africa, Botswana and Zimbabwe). With the exception of

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Zimbabwe, South Africa and Botswana have the strongest economies in the region and could therefore essentially afford to import maize from poorer, water rich neighbouring countries.

Real water savings occur when irrigation (or blue water) water is saved as a result of trade. The green water component (i.e. water for crop growth derived from rainfall) cannot be saved as it is difficult for it to be allocated to other (non-agricultural) essential uses (Guan and Hubacek, 2006). In fact, the use of green water for agricultural production represents a highly beneficial and sustainable use in comparison to blue water (Aldaya et al., 2008). Water used for irrigation has many possible alternative uses (i.e., domestic use, industry, mining etc.) and therefore represents a high opportunity cost (Yang et al., 2006). Analysis of blue water trade via agricultural products therefore provides a more realistic indication of real water savings (de Fraiture et al., 2004). This feature is becoming more prominent in virtual water studies and many workers have sought to partition the relative contribution of green and blue water to virtual water savings (e.g. Chapagain et al., 2006; Yang et al., 2006; Schreier et al., 2007). Our study supports the views expressed by these authors and shows that trade analysis using total virtual water content (i.e. the sum of green and blue water content for a crop) can provide a misleading picture of the actual water savings that have been achieved. The analysis of the trade in blue water flows (Table 6) contradicts the findings of an evaluation of total virtual water flows (Table 5) and shows that current trade policies within the SADC region actually result in a net water expenditure. Although the total virtual water content of maize produced in South Africa is amongst the lowest in the SADC region, the blue water content is amongst the highest (Table 4), resulting in comparatively large volumes of blue water leaving the country. Furthermore, many of the countries to which South Africa exports maize do not irrigate maize at all. Therefore blue water savings are not achieved by the importing country because that country would not have used blue water resources to produce the crop. Results of this study therefore highlight the importance of partitioning the virtual water content of a crop into green and blue water when analysing water savings associated with international crop trade.

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4.2 Impact of maize production at WMA scale

Given the limitations of implementing a national virtual water trading strategy and the reliance of other SADC countries on exports from South Africa, it is difficult to envisage a national reduction in maize output aimed at alleviating water scarcity. However, considering that only 8% of South Africa's total maize production is exported to SADC, a strategy aimed at decreasing production in WMAs that are both highly water stressed and produce maize inefficiently, together with a slight increase in imports to account for the shortfall could be an option to alleviate localised water scarcity at a sub-national scale, whilst ensuring food security both in South Africa and the rest of SADC. In this respect calculating the virtual water content of crops at the WMA scale provides useful information on the water use efficiency of crop production. This in turn can identify those areas that would benefit from a virtual water trading strategy.

The majority of research relating to virtual water trade in agricultural crops has taken place at an international scale and have focussed on the import and export of crops between countries and the virtual water flows associated with such trade strategies. In countries having heterogeneous climatic and natural areas, virtual water can also be traded nationally or locally (Horlemann and Neubert, 2007). A number of studies have investigated the application of virtual water trading at a smaller provincial or catchment scale, within a country (i.e. between provinces or catchment basins within a country) (Guan and Hubacek, 2006; Ma et al., 2006). Schreier et al. (2007) analysed the virtual water content of different crops within catchments as an indicator of the relative efficiency of water use for those crops. For South Africa as a whole (where there is a heterogenous distribution of water resources) and for many WMAs, the current demand for water exceeds supply, with agriculture being the largest user of water resources (DWAF, 2004). Clearly, in the case of these WMAs, an analysis of the virtual water content of crops at the WMA scale may provide valuable inputs into decision making with regards to sustainable allocation of limited resources.

This argument is supported when national irrigation statistics and virtual water con-

tent of maize is compared to that of the individual WMAs. At the national scale the total virtual water content is relatively low. Whilst the blue water content is amongst the highest in the SADC region, this is still a relatively small component of the total virtual water content, with the majority being comprised of green water (Table 4). Analysis

5 of maize production at the scale of WMA shows the Upper, Middle and Lower Vaal WMAs to be the most important production areas, producing maize with a relatively high total virtual water content, but more importantly, with a low ratio of blue to green water content (Fig. 4). As a result of the high production the total blue water use is high, however, a comparison of percentage of national maize production to percentage

10 of national blue water use for irrigation of maize in these WMAs (Fig. 2) indicates a relatively efficient use of blue water. Nationally therefore, maize production in South Africa would appear to be relatively water efficient.

In contrast, for some WMAs, in comparison to the national estimate, maize has a high blue water content, is irrigated extensively and may therefore be impacting significantly

15 on available water resources at this localised scale. The percentage of total blue water use for maize irrigation in the Limpopo, Lower and Upper Orange WMAs is higher than would be expected, based on maize production in these WMAs (Fig. 2). In the case of the Limpopo and Lower Orange WMAs, this is as a result of the high blue water content of the maize that is produced and, given the very low proportion of national

20 maize production (1.7 and 1.1%, respectively), represents an inefficient use of blue water resources. The Limpopo and Lower Orange WMAs are both over allocated by approximately 23 and 8×10^6 m^3, respectively (DWAF, 2004). Based on results from this study, current blue water use for irrigation of maize in these WMAs is 337 and 674% (for the Limpopo and Lower Orange, respectively) higher than the quantity by which the

25 WMAs are over allocated. In addition, the blue water content of maize produced in the Fish to Tsitsikamma and Olifants Doring WMAs is also high, yet accounts for a small proportion of the total (national) maize production. With the exception of the Fish to Tsitiskamma, these WMAs are highly stressed (DWAF, 2004) and maize production is clearly inefficient and contributes little to national production while using large quantities

of a scarce water resource. An overall water saving could result via a shift to the production of more water efficient crops in these WMAs, with the shortfall in maize being produced by expanded maize production in other more water efficient WMAs (i.e. the Vaal WMAs) that rely predominantly on rainfall, or through increased imports. Therefore, an analysis of the viability of maize production in a water scarce country is highly dependent on the scale at which virtual water content of crops is calculated.

The scale at which virtual water trading is implemented is therefore an important factor and an analysis of virtual water content of crops at the WMA scale can be highly beneficial in ensuring efficient allocation of water and informing trade decisions at a national level. This study emphasises the need for analysing the virtual water content of crops at different scales so as to ensure that water is allocated as efficiently as possible within South Africa, especially given its current high agricultural production. Integrated Water Resource Management (IWRM) approaches in combination with an analysis of virtual water content of crops at the WMA or catchment scale should therefore take priority as opposed to a blanket national virtual water trading policy. Horlemann and Neubert (2007) suggest that IWRM should be a priority in tackling water scarcity and virtual water trading used as a complementary strategy. The virtual water content values represent a useful means to determine the water use of crops in different areas of the country and allow decision makers or managers to effect changes in the production of crops at the WMA scale, with the emphasis on increasing water use efficiency and alleviating water scarcity.

5 Conclusions

Blue water contributes directly to water scarcity whilst use of green water in agriculture is a relatively beneficial use of water. Analysis of virtual water associated with crop trade should therefore focus on blue water so as to determine actual water savings within the context of prevailing water scarcity. Furthermore, while a national estimate of the virtual water content of a crop may indicate a relatively efficient use of water (i.e.

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maize production in South Africa), an analysis of the virtual water content at smaller scales (i.e. WMAs in South Africa) can reveal inefficient use of water for the same crop (i.e. high blue water use in relation to productivity). At these smaller, localised scales, the implementation of a virtual water trading policy may potentially significantly contribute to alleviating water scarcity. Therefore, analysis of the virtual water content of crops and trading of agricultural products at different scales (i.e. regional, national and WMA) is an important consideration within the context of alleviating water scarcity and encouraging improved water use efficiency.

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Table 1. Net virtual water flows and value of water (expressed as US Dollars generated per m^3 of water used) associated with important export and import crops in South Africa.

Net Export Crops			Net Import Crops		
Crop	Net Virtual Water Export ($m^3 \times 10^6$)	Value ($\$\,m^3$)	Crop	Net Virtual Water Import ($m^3 \times 10^6$)	Value ($\$\,m^3$)
Apples	−130	1.19	Barley	210	0.13
Avocados	−140	0.25	Green Beans	9	0.26
Grapefruit	−230	0.43	Maize	130	0.07
Grapes	−120	2.51	Oats	100	0.30
Maize	−3400	0.07	Rye	18	0.26
Oranges	−540	0.50	Soybeans	17	0.08
Pears	−84	1.05	Wheat	1700	0.13
Sugar Cane	−170	1.19	Other	6	
Other	−200				
Total	−5014		Total	2 140	
Total Net Trade			−2829		

Table 2. Quantity of maize exported out of and imported into each of the SADC countries (expressed as tonnes and as a percentage of the total).

	Export				Import			
	Quantity		Destination		Quantity		Origin	
	Tonnes	(%)	SADC	Other	Tonnes	(%)	SADC	Other
Angola	0	(0.0)	–	–	26 486	(2.3)	100	0
Botswana	986	(0.1)	88	12	60 369	(5.2)	100	0
DRC	113	(<0.1)	100	0	6951	(0.6)	100	0
Lesotho	0	(0.0)	–	–	150	(<0.1)	100	0
Madagascar	0	(0.0)	–	–	6316	(0.5)	63	37
Malawi	54 604	(5.0)	36	64	54 436	(4.7)	59	41
Mauritius	0	(0.0)	–	–	7291	(6.3)	0	100
Mozambique	18 776	(1.7)	100	0	80 471	(7.0)	100	0
Namibia	8899	(0.8)	100	0	42 103	(3.6)	100	0
South Africa	815 013	(75.1)	80	20	13 386	(1.2)	0	100
Swaziland	640	(0.1)	100	0	354	(<0.1)	100	0
Tanzania	156 193	(14.4)	71	29	77 990	(6.8)	38	62
Zambia	28 080	(2.6)	100	0	191 043	(16.5)	95	5
Zimbabwe	1382	(0.1)	100	0	521 687	(45.2)	100	0

Table 3. Average water requirements and rainfall (total and effective) for maize production in each of the SADC countries.

Country	Crop Water Requirements	Rainfall	Effective Rainfall	Irrigation Requirements
	(mm)			
Angola	448	740	403	46
Botswana	638	312	265	373
DRC	414	843	397	17
Lesotho	548	422	246	302
Madagascar	545	683	351	194
Malawi	475	881	427	48
Mauritius	494	961	449	45
Mozambique	544	786	447	97
Namibia	620	276	114	506
South Africa	591	426	231	360
Swaziland	551	664	377	174
Tanzania	476	564	297	178
Zambia	451	900	428	23
Zimbabwe	553	548	298	254

Table 4. Yields, irrigated area and virtual water content (blue, green and total) of maize produced in each of the SADC countries.

Country	Crop Yield	Area Irrigated	Virtual Water Content			Water Availability[1]
			Blue	Green	Total	
	(tonnes ha^{-1})	(%)	(m^3 tonne^{-1})			m^3 capita^{-1} y^{-1}
Angola	0.8	0	0	5329	5329	8775
Botswana	0.2	0	0	12 402	12 402	1369
DRC	0.8	0	0	5090	5090	14 712
Lesotho	0	0	0	3692	3692	2930
Madagascar	1.6	0	0	2157	2157	17 186
Malawi	1.3	0	0	3337	3337	1200
Mauritius	6.6	0	0	748	748	2171
Mozambique	1.0	0	0	4652	4652	4887
Namibia	1.2	5.1	211	927	1137	2973
South Africa	2.7	8.7	117	868	986	939
Swaziland	1.0	0.8	14	3688	3701	2576
Tanzania	1.5	2.1	25	2022	2047	2115
Zambia	1.5	0.3	0	2761	2761	6652
Zimbabwe	0.7	1.2	46	4451	4497	932

[1] WRI (2008)

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Table 5. Trade matrix illustrating net virtual water savings (positive numbers) and expenditure (negative figures) associated with the import and export of maize between SADC countries[1] (all values in millions of cubic metres of water).

Exporting country	Importing country														
	ANG	BOT	DRC	LES	MAD	MAL	MAU	MOZ	NAM	RSA	SWZ	TNZ	ZAM	ZIM	NET
ANG	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
BOT	−0.81	–	–	–	–	−0.04	−0.01	−0.16	−0.02	−7.71	−0.01	–	−0.49	–	−9.3
DRC	–	–	–	–	–	–	–	–	–	−0.25	–	−0.14	−0.01	–	−0.40
LES	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
MAD	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
MAL	–	0.28	–	–	–	–	–	0.02	–	−1.13	–	−4.89	−0.09	22.04	16
MAU	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
MOZ	–	–	–	–	–	−9.38	–	–	–	−0.26	–	−7.73	−16.28	–	−34
NAM	4.32	0.66	–	–	–	–	–	–	–	−1.18	–	–	–	–	3.8
RSA	107.63	688.29	14.06	–	7.11	17.45	−0.001	291.19	6.38	–	–	24.55	169.72	1659.76	2986
SWZ	–	–	–	–	–	−0.53	–	–	–	–	–	–	–	–	−0.23
TNZ	–	–	6.17	–	–	20.00	–	2.65	–	−0.44	–	–	61.26	40.45	130
ZAM	1.43	9.46	3.49	0.14	–	4.37	–	–	–	−5.93	0.33	−0.11	–	23.36	37
ZIM	–	–	6.17	–	–	20.00	–	2.65	–	−0.44	–	–	61.26	40.45	130
NET	112.58	698.69	23.72	0.14	7.11	32.14	−0.02	293.70	6.36	−18.76	0.32	11.68	212.67	1745.61	–

[1] ANG (Angola), BOT (Botswana), DRC (Congo), LES (Lesotho), MAD (Madagascar), MAL (Malawi), MAU (Mauritius), MOZ (Mozambique), NAM (Namibia), RSA (South Africa), SWZ (Swaziland), TNZ (Tanzania), ZAM (Zambia), ZIM (Zimbabwe).

Table 6. Trade matrix illustrating net virtual blue water savings (positive numbers) and expenditure (negative figures) associated with the import and export of maize between SADC countries[1] (all values in millions of cubic metres of water).

Exporting country	Importing country														
	ANG	BOT	DRC	LES	MAD	MAL	MAU	MOZ	NAM	RSA	SWZ	TNZ	ZAM	ZIM	NET
ANG	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
BOT	–	–	–	–	–	–	–	–	–	0.08	–	–	–	–	0.08
DRC	–	–	–	–	–	–	–	–	–	0.007	–	0.001	–	–	0.01
LES	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
MAD	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
MAL	–	–	–	–	–	–	–	–	–	0.06	–	0.10	–	0.87	1.02
MAU	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
MOZ	–	–	–	–	–	–	–	–	–	0.008	–	0.08	0.003	–	0.09
NAM	−0.22	−0.01	–	–	–	–	–	–	–	−0.72	–	–	–	–	−0.96
RSA	−2.9	−7.08	−0.40	–	−0.71	−0.87	–	−9.33	3.92	–	–	−2.13	−11.20	−34.00	−65
SWZ	–	–	–	–	–	−0.01	–	–	–	–	–	–	–	–	−0.01
TNZ	–	–	−0.05	–	–	−0.39	–	−0.03	–	0.04	–	–	−2.13	−0.34	−2.23
ZAM	–	–	–	–	−0.003	–	–	–	–	0.39	0.005	0.004	–	0.61	1.00
ZIM	–	–	–	–	–	−0.001	–	–	–	0.04	–	–	−0.04	–	–
NET	−3.13	−7.10	−0.45	–	−0.71	−1.28	–	−9.36	3.92	−0.11	0.005	−1.96	−13.36	−32.19	–

[1] ANG (Angola), BOT (Botswana), DRC (Congo), LES (Lesotho), MAD (Madagascar), MAL (Malawi), MAU (Mauritius), MOZ (Mozambique), NAM (Namibia), RSA (South Africa), SWZ (Swaziland), TNZ (Tanzania), ZAM (Zambia), ZIM (Zimbabwe).
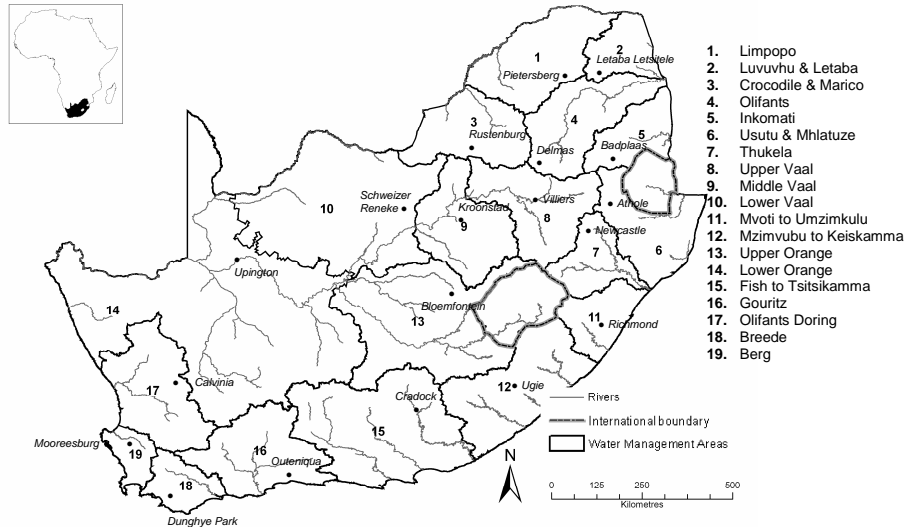
Fig. 1. Map showing South African Water Management Areas (WMAs) and the SAPWAT weather stations used to derive water requirements for maize in each of the WMAs.

1. Limpopo
2. Luvuvhu & Letaba
3. Crocodile & Marico
4. Olifants
5. Inkomati
6. Usutu & Mhlatuze
7. Thukela
8. Upper Vaal
9. Middle Vaal
10. Lower Vaal
11. Mvoti to Umzimkulu
12. Mzimvubu to Keiskamma
13. Upper Orange
14. Lower Orange
15. Fish to Tsitsikamma
16. Gouritz
17. Olifants Doring
18. Breede
19. Berg
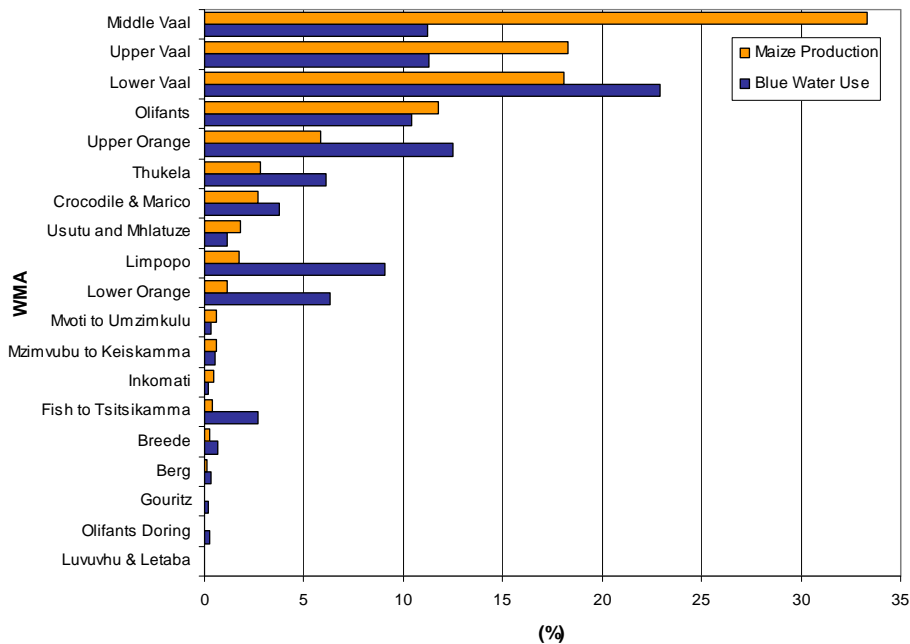
Fig. 2. Percentage of production and blue water use per Water Management Area (WMA) for national maize production in South Africa.
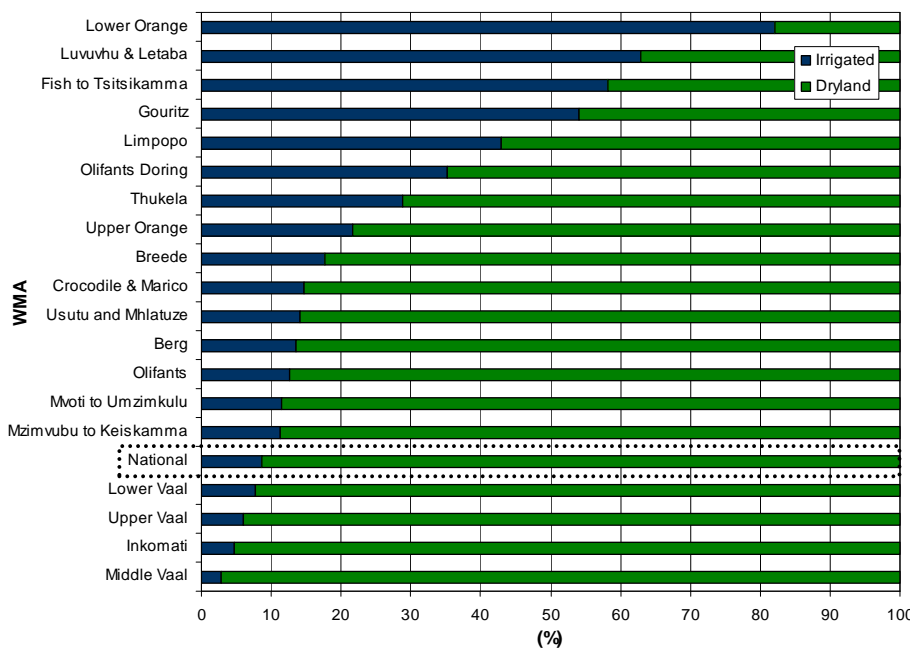
Fig. 3. Percentage of maize grown under irrigation (blue bars) and dryland (green bars) for all of South Africa's WMAs and summarized for the whole country (National; in dotted box).
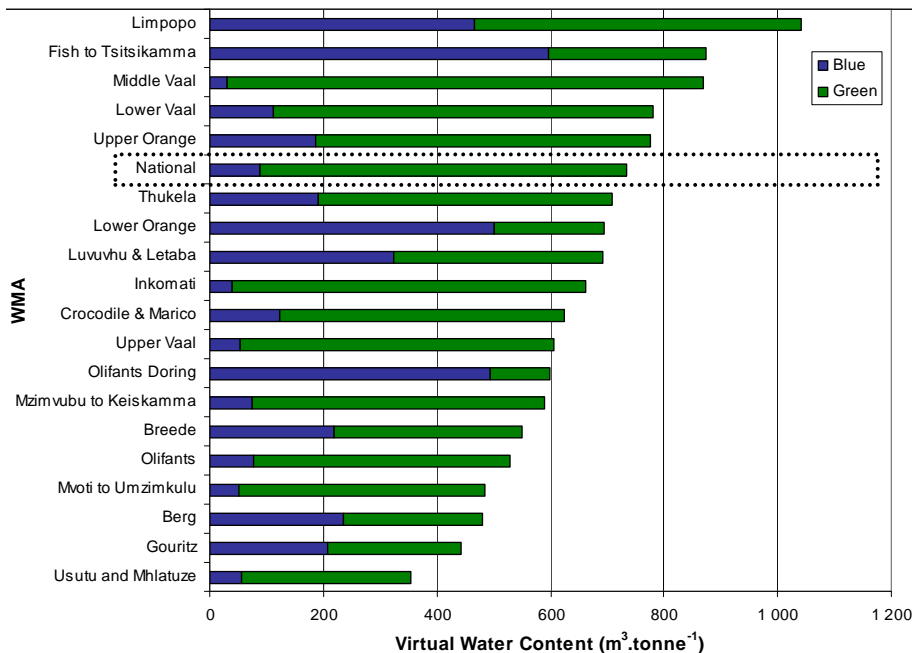
Fig. 4. Virtual water content of maize produced in all of South Africa's WMAs, and at the national scale (in dotted box). Blue bars represent blue water content (derived from irrigation) and green bars represent green water content (derived from rainfall).