Monetary valuation of salinity impacts and microbial pollution in the Olifants Water Management Area, South Africa

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Abstract

This paper estimates costs associated with water pollution in the Olifants River Water Management Area (WMA) in South Africa, and, more specifically, the area represented by the Loskop Dam Water User Association. We focus on the impacts of salinisation on commercial irrigated agriculture, and of microbial pollution on the general population of the WMA, many of whom do not have access to municipal water and sanitation services, leaving them vulnerable to microbial pollution in the water resource. Costs associated with salinity are estimates based on the impacts of increased salinity on the value of marginal product of certain irrigated crops. Costs associated with microbial pollution are estimated based on the direct and indirect costs of human health impacts as a result of microbial pollution in the study area. These monetary value estimates give an indication of the magnitude of the cost of water pollution to society in the WMA. It is concluded that the once-off cost required to provide some pollution prevention infrastructure will be lower than the current annual cost burden of pollution on society in the WMA, and that pollution prevention is therefore cost effective.

Keywords: water pollution, costs, agriculture, society, pollution prevention

Introduction

Polluted water impacts negatively on agriculture, industry, human health, living organisms, resource quality and property (DWAF, 1998), by rendering the resource less fit for beneficial use by downstream users. The effects of polluted water on a country's economy could be disastrous. This paper attempts to estimate the monetary value of the impact of water pollution in the Olifants Water Management Area of South Africa, focusing on salinity impacts and microbial pollution. The impact of increased salinity on commercial irrigated crops was assessed in terms of the decrease in the value of marginal product (VMP) of irrigation water as used by these crops. The impact of microbial pollution on human health was estimated using a cost of illness (COI) approach consisting of direct and indirect cost estimates. Some of the main reasons for monetary estimates of the impacts of water pollution include: (i) raising awareness in order to convince politicians, community leaders and health administrators that a pollution problem of significant magnitude exists, and to encourage them to engage in preventative strategies, (ii) serving as an input for priority setting in water pollution management decision-making, and (iii) analysing the cost-effectiveness of water pollution interventions.

This paper forms part of a solicited research study funded by the Water Research Commission of South Africa. The overall aim of the study was to inform policy and future research targeted at mitigating the challenge of water pollution in the water management area. The hypothesis that was tested focused on the notion that pollution prevention is better than cure; however, unnecessarily strict regulation could have negative consequences for the economy. The general aim of this research was therefore to compare the costs associated with a regime which controls pollution at source, thereby preventing its occurance with costs associated with a regime which focuses more on treatment before extraction, while allowing the occurance and consequences of water pollution. A suitable study area for the valuation of the cost impact of salinisation on commercial irrigated agriculture was identified in the Olifants River Water Management Area (WMA), more specifically, the area respresented by the Loskop Dam Water User Association. In addition, a significant portion of the population in this WMA does not have access to municipal water and sanitation services, leaving them vulnerable to microbial pollution in the water resource.

Pollution of water resources in the study area

The Olifants WMA (Fig. 1) corresponds with the South African portion of the Olifants River catchment and includes portions of Gauteng, Mpumalanga and Limpopo provinces (DWAF, 2004). The WMA covers an area of 54 562 km^2 and is home to approximately 3.2 million people living in urban to peri-urban areas. The economy of the area consists of mining, electricity generation, metallurgic industries, and agriculture. It generates approximately 5% of the gross domestic product (GDP) of South Africa (DWAF, 2004).

Salinisation of irrigation water is a major contributing factor to soil degradation, which affects commercial and subsistence agriculture (and hence food security) directly (Aihoon et al., 1997, Armour, 2007). Salinity is regarded as a major contributor to water pollution, not only in the study area, but throughout South Africa (DWAF, 2001). Although progress has been made towards implementing the 'polluter pays' principle among mines, industry and domestic users; the case of agriculture generally remains unresolved because of the large number of dispersed sources (non-point sources), which renders traceability difficult (Aihoon et al., 1997; Armour, 2007; Viljoen and Armour, 2002; Armour, 2002). Dilution effects add to this

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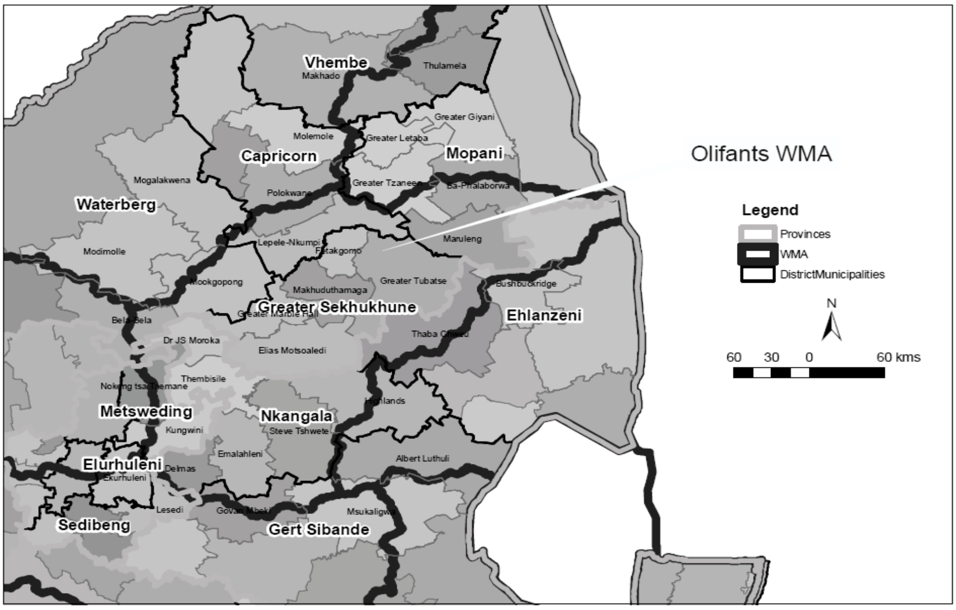

Figure 1
The Olifants Water Management Area in South Africa

problem, implying that the quantification of salinity impacts and the assessment of costs associated with salinisation is time consuming and expensive.

The microbial pollution of water resources increases the risk of contracting waterborne diseases such as diarrhoea, cholera, salmonellosis and typhoid fever (DWAF, 2001). A direct functional relationship exists between dysfunctional water and sanitation systems and a high risk of waterborne disease (Hinrichsen et al., 1997; Montgomery and Elimelech, 2007). This relationship is especially evident in the study area. Diarrhoea, in particular, is considered to be the third leading cause of death in children under the age of 5 in South Africa (Bradshaw et al., 2003). Furthermore, it is estimated that in South Africa 84% of all deaths due to diarrhoea are attributable to unsafe water, sanitation and hygiene (Lewin et al., 2007). This makes microbial water pollution an environmental risk factor of national importance, which justifies our focus on this problem.

Methods and data inputs

Different approaches were employed to estimate the monetary value of the impacts of salinisation and microbial pollution in water resources in the study area. These methods are discussed separately below.

Salinisation of irrigation water

The monetary value of the impact of increased salinity was modelled in terms of expected decreases in production value of selected crops, *ceteris paribus*. A marginal value based analysis framework was employed for the valuation, because of the diminishing marginal utility of water use in agriculture (Hassan and Farolfi, 2005; Lange and Hassan, 2006; Young, 2004). The functional relationship between water salinity and crop yield (based on field trials) was used to create crop production functions at different levels of water salinity. These crop production functions were used to derive water productivity curves and to calculate the value of marginal product (VMP) of irrigation water for different salinity levels. The VMP of water for crops can thus be defined as the loss of income based on incremental increases in salinity levels of irrigation water used by the particular crop (Nieuwoudt et al., 2004). It should be noted that plant responses to salinity cannot be predicted on an absolute basis, but rather on a relative basis, based on general salt tolerance guidelines (Maas, 1986). Most commercial crops can maintain yield up to a certain salinity threshold, beyond which a linear or exponential decrease in yield is observed. These thresholds have been thoroughly researched for different crops and regions (Urban-Econ, 2000; Viljoen and Armour, 2002; Du Preez et al., 2000), and are presented in Table 1.

Table 1
Observed thresholds (total dissolved solids (TDS) mg/ℓ) for selected commercial crops in South Africa

Crop	Salinity threshold (TDS mg/ℓ)	Crop	Salinity threshold (TDS mg/ℓ)
Strawberry	650	Cabbage	1 170
Green beans	650	Celery	1 170
Carrots	650	Lucerne	1 300
Aubergine	715	Spinach	1 300
Onions	780	Cucumber	1 625
Radish	780	Broccoli	1 820
Citrus	845	Rice	1 950
Lettuce	845	Peanuts	2 080
Plums	975	Peas	2 210
Almonds	975	Fescue	2 535
Grapes	975	Beetroot	2 600
Sweet potato	975	Asparagus	2 665
Pepper	975	Gemsquash	3 055
Clover	975	Soya	3 250
Apricots	1 040	Ryegrass	3 640
Peach	1 105	Wheat	3 900
Potatoes	1 105	Triticale	3 965
Garlic	1 105	Sorghum	4 420
Maize	1 105	Sugarbeet	4 550
Sweet corn	1 105	Cotton	5 005
Sugarcane	1 105	Barley	5 200
Tomatoes	1 105	Rye	7 410

(Source: Du Preez et al., 2000)

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Table 2 Yield responses at different salinisation pollution levels												
Crop	**Typical yield (t/ha)**	**Threshold salinity (TDS in mg/ℓ)**	**Yield responses (% of unconstrained yield) for different salinity levels (TDS in mg/ℓ)**									
			900	**1000**	**1100**	**1200**	**1300**	**1400**	**1500**	**1600**	**1700**	**1800**
Maize	7.87	1 207	100	100	100	100	98.5	97	95	93.5	92	90
Wheat	5.47	4 346	100	100	100	100	100	100	100	100	100	100
Potatoes	37.8	1 151	100	100	100	99	97	94.5	92	90	88	86
Citrus	45	975	100	96	82	67	53	38	24	9	0	0

Adapted from: Urban-Econ (2000), Viljoen and Armour (2002), Du Preez et al. (2000), and Maas (1986) for the study area

Table 3 Summary of standardised crop budget data as employed in this study				
	Maize	**Wheat**	**Potatoes**	**Citrus**
Market price (ZAR/kg)	1.53	1.89	1.95	1.65
Yield (kg/ha)	7 871	5 466	41 045	45 000
Typical farm size (ha)	25	25	25	25
Total variable cost (ZAR/ha)	9 234	6 985	48 405	35 840
Fixed cost including irrigation (ZAR/ha)	1 197	474	14 849	25 247
Volume of water used to realise the yield (cubes/ha)	5 930	7 400	5 650	10 510
Water constraint (cubes/ha)	5 930	7 400	5 650	7 700
Total water available (cubes)	148 250	185 000	141 250	262 750

Table 4 SAPWAT simulation input and output data				
	Maize	**Wheat**	**Potatoes**	**Citrus**
Weather station name	**'Loskop-Proefstas'**			
Choice options in SAPWAT	Medium grower early plant; planting in October; centre pivot irrigation	Plant 05/25; planting in may; centre pivot irrigation	Standard; planting in August; centre pivot irrigation	Average; planting in June
Climatic region	Semi-arid with warm summers			
Total water requirement (mm/hectare)	1 203	884	813	1 732
Total irrigation requirement (mm/hectare)	593	740	565	1 051

Four irrigated crops with known salinity-yield relationships (i.e. the salinity threshold and rate of decline in yield beyond the threshold has been confirmed in field trials) were selected from Table 1 and used as representative crops to estimate the impact of increased salinity on VMP of irrigation water in the study area (Aihoon et al., 1997; Maas et al., 1983; Maas, 1986; Armour, 2007; Armour and Viljoen, 2000; Viljoen and Armour, 2002). Table 2 presents a summary input table for the salinty-yield relationships as employed in the VMP estimates. Crop coverage was verified with data from Statistics South Africa (Statistics South Africa, 2002).

The average maximum allowable salinity of irrigation water for the study area is 1 700 mg/ℓ TDS, while the recommended operational salinity limit for the representative crops is considered to be a maximum of 1 000 mg/ℓ TDS (Ferreira, 2009). These specifications implied a salinity range from 900 mg/ℓ TDS (100 mg/ℓ TDS below the recommended operational salinity limit) up to 1 800 mg/ℓ TDS (100 mg/ℓ TDS above the maximum allowable water salinity); these values were used as the lower and upper thresholds for the modelling runs. Field trial data were applied to salinity levels for the study area and consequently modelled to estimate the associated loss in typical farm income per 100 mg/ℓ increment in TDS, starting from the salinity threshold for each crop. A critical assumption was that the salinity of irrigation water is directly proportional to the salinity of the saturated soil (which is not always the case). Representative crop budgets and current market prices (Western Cape Department of Agriculture, 2006; Van Zyl, 2009; Deciduous Fruit Producers Trust, 2008) were used to calculate the impact of salinity on the VMP of irrigation water for incremental increases in salinity. Table 3 summarises the crop budget input data as used in this study. Values were inflated against the producer price index (7.78%) for maize, wheat and citrus, while current prices were available for potatoes.

SAPWAT (South African procedure for estimating irrigation water requirements) (Crosby, 1996; Van Heerden et al., 2008) simulations were employed to confirm the water requirement per crop per hectare per year (Table 4). A water constraint of 7 700 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ (Ferreira, 2009) was used.

The data were used to develop an input matrix for a linear programming (LP) model (Jabeen et al., 2006), bearing an objective function and associated constraint functions. A total

Table 5 Waterborne burden of disease statistics for the Olifants WMA					
	Age groups				
	< 5	5-14	15-65	>65	TOTAL
% of population	10.74	21.20	62.88	5.16	
People **below** RDP water and sanitation standards					
Number	238 886	471 472	1 398 258	114 811	2 223 427
Diarrhoea cases per 1 000	2 515	1 001	750	1 001	
Actual diarrhoea incidence	600 798	471 943	1 048 693	114 925	2 236 359
People **above** RDP water and sanitation standards					
Number	125 087	246 875	732 164	60 118	1 164 244
Diarrhoea cases per 1 000	501	250	104	181	
Actual diarrhoea incidence	62 669	61 719	76 145	10 881	211 414
Recorded diarrhoeal deaths within the Olifants WMA	3 723	931	2 516	498	7668

(Source: Statistics South Africa, 2007; Pegram et al., 1998; Wright et al., 2006)

of 25 simulations were run to cover all the different crop and water pollution combinations for the study area. Area cultivated was not allowed to increase or decrease due to the effect of salinity. Furthermore, no allowance for leaching was made (it is a water-stressed area) while input and produce prices were assumed to remain constant for each run. The optimised solutions for the selected crops are presented in the 'results and discussion' section.

Microbial pollution of drinking water

The occurrence of water pollution related diseases is attributable to various environmental risk factors, which implies that traceability of attributable risk factors at the level of an individual is lost (Pruss-Ustun et al., 2003). However, the ability to attribute a disease to a particular environmental exposure becomes possible when individuals are grouped together in controlled experimental trials. This can be attributed to the difference in the morbidity and/or mortality impacts between the experimental and the control group, which represents the burden of disease. According to Pruss-Ustun et al. (2003), this is one of the fundamental concepts underlying burden of disease assessments, which involve the idea of attribution and causal inference by using population groups. Although such data do not distinguish between individuals who fell ill due to exposure to the factor and those who fell ill from other causes, the data can be used to deduce the fraction of the total burden of disease in the population that could have been avoided if the exposure had not occurred. This is a meaningful component of a preventative argument against the risk factor.

Although contingent valuation (Ciriacy-Wantrup, 1947; Davis, 1963) and averting behaviour (Bartik, 1988; Courant and Porter, 1981; Goudge et al., 2009) approaches have been used to value the impacts of waterborne diseases in other studies, a cost of illness (COI) approach was used in this study to facilitate more accurate cross-country comparisons. The COI approach attempts to measure benefits of pollution prevention and/or reduction by estimating the direct and indirect opportunity costs associated with an illness (Pegram et al., 1998). It was thus necessary to determine the level of access to water supply and sanitation in the study area; two categories emerged:

- Above RDP (Reconstruction and Development Programme) water and sanitation standards – a reliable supply of water and sanitation inside the house
- Below RDP water and sanitation standards – no access to safe water and sanitation within a radius of 200 m from the dwelling

The above-mentioned distinction was necessary to reflect the potential difference in diarrhoea incidence rates from varying levels of access to water supply and sanitation. Table 5 summarises water supply categories, diarrhoea incidence and death rates for the different age groups living in the study area.

Based on the incidence-to-population ratio, it was assumed that each person within the study area would have at least 1 diarrhoea episode per year. The highest incidence rate was 2.5 episodes per child for children under the age of 5 years for the population with below-RDP standards of water supply and sanitation. This is a very conservative figure since Wright et al. (2006) found that children in rural areas of Limpopo province had up to 7.2 diarrhoea episodes per year. Furthermore, only a small percentage of the total diarrhoea cases require formal treatment, as the majority of incidences are mild and can usually be treated at home, and are thus not recorded. It is estimated that 8% of all diarrhoea cases for people living with below-RDP standards for water supply and sanitation, require treatment, whereas 5% of cases for those who live with above-RDP service standards require treatment (DWAF, 2001).

The actual direct health-care costs per treatment were taken from a Department of Water Affairs and Forestry (DWAF, 2001) study, which estimated this cost at a value of ZAR1 904 per treatment for people with access to below-RDP standard services and ZAR1 692 per treatment for cases where above-RDP standard services are available (these figures were inflated to ZAR3 769 and ZAR3 349, respectively, to allow for comparison with 2010 values, see Table 6).

Indirect cost estimates were based on the monetary value of the decrease in the productivity of human capital due to the burden of disease. This was based on a composite measure of burden of disease, known as the disability-adjusted life year (DALY) (Mathers et al., 2007; WHO, 2010), and the foregone gross income as a result of the burden of disease.

Prevention and control of diseases requires information about the causes and impacts of the disease. Generating such information is sometimes hampered by the lack of common protocol and standardised methods to assess the burden of disease. However, Murray and Lopez (1996) provide a standardised approach to epidemiological assessment which employs the DALY. The DALY is an indicator of the overall burden of disease, combining a measure of both mortality (years of life lost due to premature death) and morbidity (years of 'healthy' life lost as determined by the severity and duration of illness or disability). The following presents the basic formula used to calculate the DALY:

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Table 6 Estimated direct treatment costs for diarrhoea in the WMA		
Description	**< RDP (low service level) direct health costs**	**> RDP (high service level) direct health costs**
Estimated diarrhoea incidences	2 220 151	210 636
No. of cases treated	8% or 177 612	5% or 10 532
Average treatment costs	3 769 ZAR/a	3 349 ZAR/a
Total direct health costs	669 419 628 ZAR/a	35 271 668 ZAR/a

Table 7 Method of calculating the opportunity costs		
Data	**Measure**	**Source**
DALYs (incidence rate for waterborne disease per 1 000 individuals per year)	8.1	(WHO, 2009)
Incidence of diarrhoea in the economically active population group of the Olifants WMA	1 048 693	(DWAF, 2003; Naudé et al., 2007)
Average per capita gross income per annum	ZAR11 195*12	(Statistics South Africa, 2010b)

DALY = Years of life lost (YLL) + Years lived with disability (YLD)

where YLL is determined by the West model life-table (Coale and Guo, 1989); and YLD is based on the incidence and duration of conditions resulting in non-fatal occurrences of disease, and is weighted according to the severity of the disability. In this way, YLD are rendered comparable to YLL (Schneider, 2001). The DALY employs an age-weight function to allocate a comparatively heavier weight to the middle age group (9-54 years) of the population as compared to age groups 0-8 and 55+ years (Schneider, 2001; Murray and Lopez, 1996). Some studies disagree with this concept (Anand and Hanson, 1997). However, in this study, it was argued that the middle age group constitutes the bulk of the employment and tax base within an economy and thus assumes responsibility for fending for the youth and elderly, implying that their income is distributed across the entire demographic structure of the population.
The aim of health interventions is to minimise the number of DALYs, that is, to promote a longer and healthier life for people (Bradshaw et al., 2003). The World Health Organisation country profile of environmental burden of disease for South Africa (WHO, 2009) estimates a DALY for South Africa associated with water pollution related illnesses of 8.1 per thousand people per year. This is based on comparative risk assessment, evidence synthesis and expert evaluation for regional exposure and WHO country health statistics.

The second constituent of estimating the indirect cost of the burden of disease was an estimate of the value of human capital. Similarly to a study by Le et al. (2005), gross income was used as a proxy for the value of human capital. In congruity with moral judgement, this study assumed that the human capital capacity is unaffected by employment status. The Statistics South Africa (2010b) quarterly employment statistics present the gross income (the amount of income before taxes have been paid) for employed individuals in the formal non-agricultural sector of South Africa. On this basis an average monthly gross income of ZAR11 195 per capita per month in South Africa for formal non-agricultural sectors was used (Statistics South Africa, 2010b).

It should thus be noted that the Statistics South Africa gross earnings estimates exclude the agricultural sector. However, the national income figures referred to above were used during this study based on the following arguments:

- The study area falls within the Gauteng, Mpumalanga and Limpopo provinces of South Africa, which are axiomatically expected to have different earning levels (Gauteng by far the highest). However, the country has a long history of labour migration and significant numbers of people from Limpopo and Mpumalanga will search for employment in neighbouring Gauteng, or any other province. People are therefore not confined to one province, and therefore provincial income figures would not have been representative.
- The impacts on the informal economy are most often excluded from these kinds of studies. While the cash value of trade in the informal economy (bartering) is estimated to be at least 9.5% of the value of GDP (Saunders, 2005) or 28.4% of GNP (gross national product) (Schneider, 2002), pollution will also impact on these values. Given that there is no reliable way of estimating such impacts, it is anticipated that the choice for representative gross income (ZAR11 195 per month) would account for this limitation.

The product of the burden of disease (in terms of DALYs per annum) and the potential gross annual income per capita, for the economically active group, thus provides an estimate of the opportunity costs associated with waterborne diseases in the study area. Table 7 summarises the input data for the calculation of the indirect costs due to water pollution incurred in the study area, and the sources of data used.

Results and discussion

All crops (except wheat) showed a declining VMP with incremental increases in salinity. Wheat, being salinity-tolerant, has a salinity threshold of 4 346 mg/ℓ TDS, which implies that the VMP of 0.45 ZAR/m^3 will stay constant throughout the chosen salinity range (Fig. 2). The VMP of maize was observed to decline from 0.47 ZAR/m^3 to 0.27 ZAR/m^3 of water as salinity increased from 1 200 to 1 800 mg/ℓ TDS. The gradient after the salinity threshold of maize was −0.033, which implies that for every 100 mg/ℓ increase in salinity, maize production suffers a 0.033 ZAR/m^3 loss in the VMP.

The VMP of potatoes (Fig. 3) declined from 5.60 ZAR/m^3 to 3.62 ZAR/m^3, after experiencing a salinity threshold at 1 100 mg/ℓ TDS. The gradient of potatoes was −0.29. The VMP

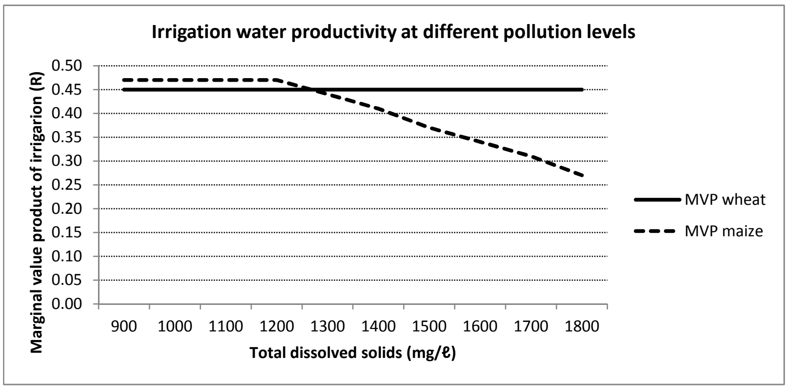

Figure 2
Irrigation water productivity at different water pollution levels: wheat and maize

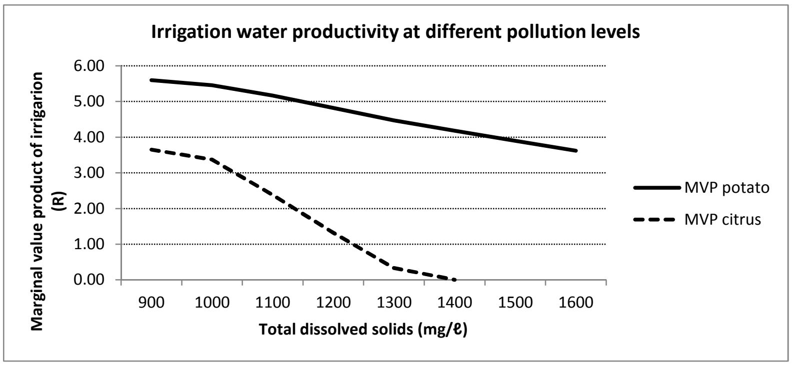

Figure 3
Irrigation water productivity at different water pollution levels: potatoes and citrus

for citrus declined from 3.65 ZAR/m^3 to zero, with a salinity increase from 900 to 1 400 mg/ℓ TDS. The gradient for citrus was −0.81 as salinity increased.

Apart from being the most sensitive to salinity, citrus production was also observed to suffer the highest total decrease in terms of the VMP (3.65 ZAR/m^3). Given that wheat experienced no decline in VMP for the modelling range, one would expect an increase in the area utilised for wheat production if the salinity problem worsens in the future.

For microbial pollution, a direct cost estimate of the burden of disease for diarrhoea of ZAR704 million per year (ZAR 669 million plus ZAR 35 million) was calculated for the study area. While the direct cost due to diarrhoea seems to be significant, a much larger economic burden results from the indirect cost estimates. The indirect cost estimate of water pollution was approximately ZAR1.14*10^9 per year for the study area (total DALYs associated with diarrhoea in the study area of 8 494 multiplied by the annual income loss of ZAR134 340 per capita). This represents at least 0.046% of national nominal GDP, estimated at ZAR2500*10^9 for 2010 (Statistics South Africa, 2010a). The indirect cost estimates are, in essence, estimates of the value (the benefit) of preventing water pollution and thus represent the upper bound of potential microbial water treatment intervention costs (interventions have to be equal to or less costly than ZAR1.141*10^9 to avoid a net social cost in terms of indirect health costs of microbial pollution). Thus, a pollution control intervention with a higher cost than this estimate will not be financially worthwhile for society, because the costs of such an intervention could exceed the benefits derived from it (*ceteris paribus*). Given that the burden of disease (BoD) is equal to the sum of mortality and morbidity impacts (Mathers et al., 2007; WHO, 2010), it was possible to infer the mortality impacts of microbial pollution by taking the difference between indirect (morbidity plus mortality) cost and the direct (morbidity) cost, resulting in a mortality cost of ZAR437*10^6. Note that the mortality impact is thus lower than morbidity impacts which could be as a result of a higher burden of disease in the economically-inactive portion of the population (young children in particular).

Conclusion

Poor water quality is a result of physical, social and institutional factors, which necessitates a thorough understanding of the cause-effect relationship between variables contributing to this problem. This study estimated the costs associated with salinisation and microbial pollution of water resources in the Olifants WMA in South Africa.

The monetary impact of salinisation of irrigation water was quantified in terms of the income lost when crops are irrigated with polluted water. The results of these estimates provide a baseline for comparisons of salinity effects on agriculture. The difference between the VMP for the different crops and the current 'raw' water tariff of 0.14 ZAR/m^3 for the area indicates that water is underpriced. It further suggests that water user charges are currently not an effective water demand management tool in South Africa, mainly because of immature water markets. Water pricing should be regarded first and foremost as a cost-recovery tool in water management, i.e., water tariffs should be set to ensure full cost recovery for infrastructure and the management of catchments, including pollution control, and should therefore be approached responsibly.

The monetary impact of microbial pollution focused on the assessment of the environmental burden of disease associated with such pollution. The DALY metric (Foege, 1994) was used in this procedure. The study area suffered direct health costs of an estimated ZAR 669 million due to diarrhoea. In addition, indirect costs of diarrhoea were estimated at ZAR 1.141 billion per year for the study area. These figures are significant when considering that 84% of all diarrheal disease in South Africa

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is attributable to water and sanitation (Levin et al., 2007). The estimates and assumptions used in the BoD assessment were conservative and stated explicitly. Although the results should be interpreted with caution, they do provide an order of magnitude indication of the extent of the cost of pollution to society and should be applied to usher a paradigm shift of environmental health policy approaches that proffer more effective and sensitive interventions.

Putting these figures in perspective, more than 2 million people in the study area are subjected to below-RDP standard water and sanitation services. If they are to be provided with 50 litres of potable water per person per day, a water purification works with 111 Mℓ/day treatment capacity will be required. The construction cost for such a facility would be in the order of ZAR 510 million (Oelofse et al., 2011), which is less than the current annual direct health cost burden (ZAR669 million) as estimated in this study (this excludes the indirect cost estimate). It is therefore evident that investments to improve service delivery for safe drinking water and sanitation will realise net savings in the study area from a social welfare perspective.

The information generated in this study provides monetary estimates for the management of water-pollution risk factors. The information should be used to monitor the impacts of the pollution burden over time, which is necessary for interventions to reduce environmental risk factors or to change behaviour.

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