

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

DE LANGE, W.J.,*¹ MAHUMANI, B.K.¹, STEYN, M.¹ and OELOFSE, S.H.H.²

1 CSIR, Natural Resources and the Environment, PO Box 320, Stellenbosch, 7599, South Africa

2 CSIR, Natural Resources and the Environment, PO Box 395, Pretoria, 0001, South Africa

*Author for correspondence:

Willem de Lange

CSIR, Po Box 320, Stellenbosch, 7599

Email: wdelange@csir.co.za;

Phone: +27 (0)21 8882462;

Fax: +27 (0)21 8866518

Abstract

This paper estimates costs associated with water pollution in the Olifants River Water Management Area (WMA) in South Africa, more specifically 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 gives an indication of the magnitude of the cost of water pollution to society in the WMA. It concludes that the once off cost required to provide some pollution prevention infrastructure will be less than the current annual cost burden of pollution on society in the WMA and that pollution prevention is therefore cost effective.

1 Introduction

Polluted water impacts negatively on agriculture, industry, human health, living organisms, resource quality and property (Department of Water Affairs and Forestry, 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: (a) 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, (b) serving as an input for priority setting in water pollution management decision-making, and (c) 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 where tested focused on the notion that pollution prevention is better than cure, but that 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 control pollution at source with a regime which focus more on treatment before extraction while allowing the 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 Loskop Dam Water User Association. In addition, a significant portion of the population in this WMA do not have access to municipal water and sanitation services, leaving them vulnerable to microbial pollution in the water resource.

2 Pollution of water resources in the study area

The Olifants WMA (Figure 1) corresponds with the South African portion of the Olifants River catchment and includes portions of Gauteng, Mpumalanga and Limpopo provinces (Department of Water Affairs and Forestry, 2004). The WMA covers an area of 54 562km² 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 (Department of Water Affairs and Forestry, 2004).

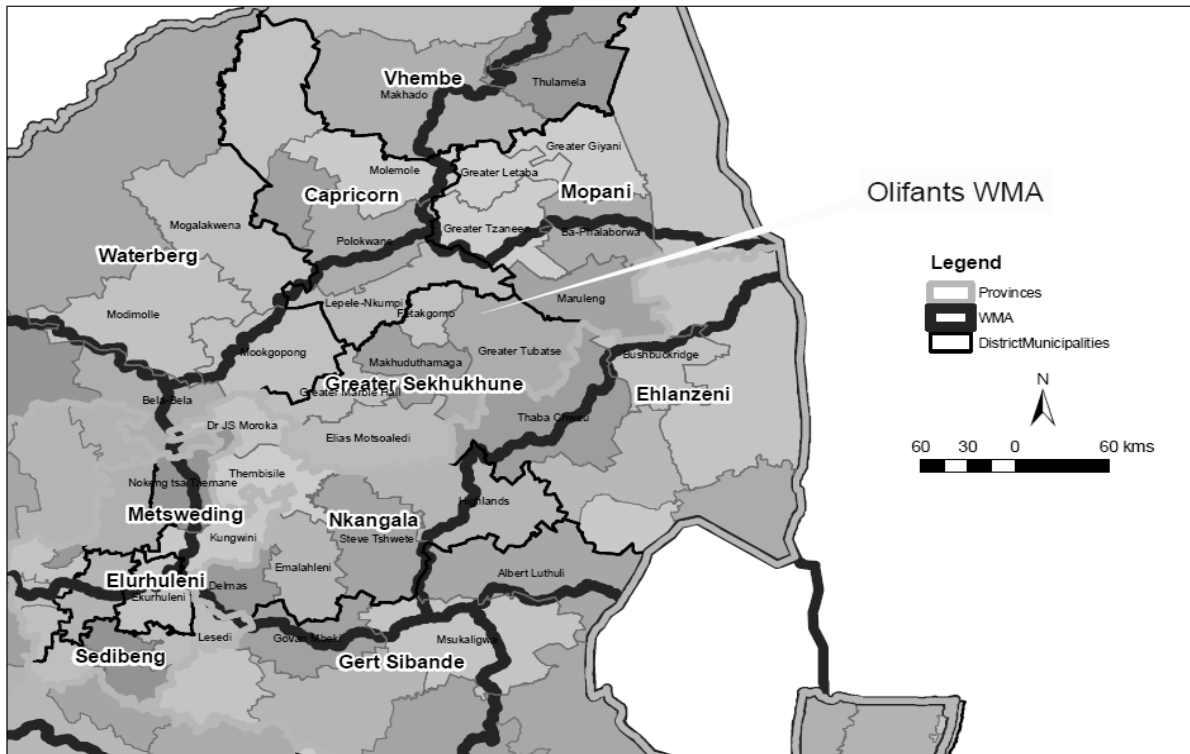


Figure 1: The Olifants Water Management Area in South Africa

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 (Department of Water Affairs and Forestry, 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 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 (Department of Water Affairs and Forestry, 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 five 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.

3 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.

3.1 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)

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 salinity-yield relationships as employed in the VMP estimates. Crop coverage was verified with data from Statistics South Africa (Statistics South Africa, 2002).

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	1207	100	100	100	100	98.5	97	95	93.5	92	90
Wheat	5.47	4346	100	100	100	100	100	100	100	100	100	100
Potatoes	37.8	1151	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.

The average maximum allowable salinity in irrigation water for the study area is 1 700mg/l TDS, while the recommended operational salinity limit for the representative crops is considered to be a maximum of 1 000mg/l TDS (Ferreira, 2009). These specifications implied a salinity range from 900mg/l TDS (100mg/l TDS below the recommended operational salinity limit) up to 1 800mg/l TDS (100mg/l TDS above the maximum allowable water salinity), which was 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 100mg/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.

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

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 7700 cubic meter per hectare per year (Ferreira, 2009) was used.

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	1051

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 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 Section 4.

3.2 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, of which two categories emerged:

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

Table 5: Waterborne burden of disease statistics for the Olifants WMA

	Age groups				TOTAL
	< 5	5-14	15-65	>65	
% of population	10.74	21.20	62.88	5.16	
Number of people below RDP water and sanitation standards	238 886	471 472	1 398 258	114 811	2 223 427
Diarrhoea cases per 1000	2 515	1 001	750	1 001	
Actual diarrhoea incidence	600 798	471 943	1 048 693	114 925	2 236 359
Number of people above RDP water and sanitation standards	125 087	246 875	732 164	60 118	1 164 244
Diarrhoea cases per 1000	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)

Based on the incidence-to-population ratio, it was assumed that each person within the study area would have at least one diarrhoea episode per year. The highest incidence rate was 2.5 episodes per child for children under the age of five 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 of people living below RDP standards for water supply and sanitation, requires treatment, whereas 5% of cases for those who live above RDP service standards requires treatment (Department of Water Affairs and Forestry, 2001).

The actual direct health care costs per treatment were taken from a Department of Water Affairs and Forestry (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 comparison with 2010 values, see Table 6).

Table 6: Estimated direct treatment costs for diarrhoea in the WMA

Description	< RDP (Low service level) Direct health costs (ZAR/annum)	> RDP (High service level) Direct health costs (ZAR/annum)
Estimated diarrhoea incidences	2 220 151	210 636
No. of cases treated	8% or 177 612	5% or 10 532
Average treatment costs	R 3 769	ZAR 3 349
Total direct health costs	ZAR 669 419 628	ZAR 35 271 668

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, World Health Organization, 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, the Murray and Lopez (1996) provides 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:

$$\text{DALY} = \text{Years of life lost (YLL)} + \text{Years lived with disability (YLD)}$$

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 funding 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 (World Health Organization, 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. Similar 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 presents 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).

Table 7: Method of calculating the opportunity costs

Data	Measure	Source
DALYs (incidence rate for waterborne disease per 1000 individuals per year)	8.1	(World Health Organization, 2009)
Incidence of diarrhoea in the economically active population group of the Olifants WMA	1 048 693	(Department of Water Affairs and Forestry, 2003, Naudé et al., 2007)
Average per capita gross income per annum	ZAR11 195*12	(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 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.

4 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 346mg/l TDS, which implies that the VMP of ZAR0.45/m³ will stay constant throughout the chosen salinity range (Figure 2). The VMP of maize was observed to decline from ZAR0.47/m³ to ZAR0.27/m³ of water as salinity increased from 1 200 to 1 800mg/l TDS. The gradient after the threshold of maize was -0.033, which implies that for every 100 mg/l increase in salinity, maize production suffers a ZAR0.033/m³ loss in the VMP.

**Insert figure 2 here

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

The VMP of potatoes (Figure 3) declined from ZAR5.60/m³ to ZAR3.62/m³, after experiencing a salinity threshold at 1 100 mg/l TDS. The gradient of potatoes was -0.29. The VMP for citrus declined from ZAR3.65/m³ to zero with a salinity increase from 900-1 400mg/l TDS. The gradient for citrus was -0.81 as salinity increased.

**Insert figure 3 here

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

Apart from being the most sensitive to salinity, citrus production was also observed to suffer the highest total decrease in terms of the VMP (ZAR3.65/m³). 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*10⁹ per year for the study area (total DALY's 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*10⁹ 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*10⁹ to avoid a net social cost in terms of indirect health costs of microbial pollution). I.e., 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, World Health Organization, 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*10⁶. 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).

5 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 ZAR0.14/m³ 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 (BoD) 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 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.

6 Acknowledgements

This research was funded by the Water Research Commission of South Africa (<http://www.wrc.org.za/>). The authors would therefore like to thank the members of the reference group of the project for continued guidance throughout the duration of this research project. We would also like to thank the reviewers of this article for their constructive criticism on an earlier draft.

4. References

- AIHOON J, GROENEWALD J and SARTORIUS VON BACH H (1997) Agricultural salinization in the Olifants river at Loskop valley, Mpumalanga. *Agrekon* **36** (3) 268-283.
- ANAND S and HANSON K (1997) Disability Adjusted Life Years - A critical review. *Journal of Health Economics* **16**: 685-702.
- ARMOUR RJ (2002) The economic effects of poor and fluctuating irrigation water salinity levels in the Vaal and Riet rivers. Department of Agricultural Economics, University of the Free State. URL: <http://etd.uovs.ac.za/ETD-db/theses/available/etd-12062007-084412/unrestricted/ArmourRJ.pdf>
- ARMOUR RJ (2007) Integrated modelling for sustainable management of salinity in the Lower Vaal and Riet river irrigation areas. Department of Agricultural Economics, University of the Free State. URL: <http://etd.uovs.ac.za/ETD-db/theses/available/etd-12102007-075814/unrestricted/ArmourRJ.pdf>
- ARMOUR RJ and VILJOEN MF (2000) Towards quantifying the economic effects of poor and fluctuating water quality on irrigation agriculture. *Agrekon* **39** (1) 99-110.
- BARTIK TJ (1988) Evaluating the benefits of non-marginal reductions in pollution using information on defensive expenditures. *Journal of Environmental Economics and Management* **15**: 111-127.
- BRADSHAW D, GROENEWALD P, LAUBSCHER R, NANNAN N, NOJILANA B, NORMAN R, PIETERSE D and SCHNEIDER M (2003) Initial burden of disease estimates for South Africa – 2000. Burden of disease research unit, Medical Research Council, Report number: ISBN: 1-919809-64-3, Cape Town.
- CIRIACY-WANTRUP SV (1947) Capital returns from soil conservation practices. *Journal of Farm Economics* **29**: 1181-1196.
- COALE A and GUO G (1989) Revised regional model life tables at very low levels of mortality. *Population Index* **55** (4) 613-643.
- COURANT PN and PORTER RC (1981) Averting expenditures and the costs of pollution. *Journal of Environmental Economics and Management* **8**:321-329.
- CROSBY CT (1996) SAPWAT - A computer program for estimating irrigation requirements in Southern Africa. Water Research Commission, Report number: 379/1/96, Pretoria.
- DAVIS RK (1963) The Value of Outdoor Recreation: An Economic Study of the Maine Woods. Department of Economics, Harvard University.
- DECIDUOUS FRUIT PRODUCERS TRUST (2008) Annual key deciduous fruit statistics., Paarl, South Africa, Compiled by the Deciduous Fruit Producers Trust (DFPT) and Optimal Agricultural Business Systems (OABS) for the South African Apple and Pear Producers' Association; Dried Fruit Technical Services; South African Stone Fruit Producers Association and the South African Table Grapes Producers' Association.
- DEPARTMENT OF WATER AFFAIRS AND FORESTRY (1998) National Water Act No. 36 of 1998, Statutes of the Republic of South Africa, Pretoria.
- DEPARTMENT OF WATER AFFAIRS AND FORESTRY (2001) Water quality management series: Managing the water quality effects of settlements. Department of Water Affairs and Forestry, Report number: Edition 2, Policy Document U 1.3
URL:<http://www.dwaf.gov.za/Projects/Dense/docs/NS%20Ed%20%20complete%20document.pdf>, Pretoria.
- DEPARTMENT OF WATER AFFAIRS AND FORESTRY (2003) Olifants Water Management Area: Water resources situation assessment. Department of Water Affairs and Forestry report number: P/04000/00/0101, Pretoria.
- DEPARTMENT OF WATER AFFAIRS AND FORESTRY (2004) Olifants River Water Management Area Internal Strategic Perspective. Department of Water Affairs and Forestry report number: P WMA 04/000/00/0304, Pretoria.
- DU PREEZ CC, STRYDOM MG, LE ROUX PAL, PRETORIUS JP, VAN RENSBURG LD and BENNIE ATP (2000) Effect of water quality on irrigation farming along the lower Vaal River: The influence on soils and crops. Water Research Commission, Report number: 740/1/00, Pretoria.
- FERREIRA D (2009) Personal communication. Manager: Loskop water user association, Groblersdal.
- FOEGE W (1994) Preventative medicine and public health. *JAMA* **271**: 1704-1705.
- GOUDGE J, GILSON L, RUSSELL S, GUMEDE T and MILLS A (2009) The household costs of health care in rural South Africa with free public primary care and hospital exemptions for the poor. *Tropical Medicine and International Health* **14**: 458-467.

- HASSAN RM and FAROLFI S (2005) Water value, resource rent recovery and economic welfare cost of environmental protection: A water-sector model for the Steelpoort sub-basin in South Africa. *Water SA* **31** (1) 9-16.
- HINRICHSEN D, ROBEY B and UPADHYAY UD (1997) Solutions for a Water-Short World. Population Reports Series M, 14, URL: <http://www.k4health.org/pr/m14/m14creds.shtml>.
- JABEEN S, ASHFAQ M and AHMAD-BAIG I (2006) Linear program modelling for determining the value of irrigation water. *Journal of Agriculture and Social sciences* **2**: 101-105.
- LANGE GM and HASSAN RM (2006) The economics of water management in Southern Africa-An environmental accounting approach. Edward Elgar press, UK. 296pp.
- LE T, Gibson JG and OXLEY L (2006) A forward looking measure of the stock of human capital in New Zealand, Department of Economics, University of Canterbury, URL: http://dea.uib.es/digitalAssets/123/123222_loxley.pdf
- LEWIN S, NORMAN R, NANNAN N, THOMAS E, BRADSHAW D and SOUTH AFRICAN COMPARATIVE RISK ASSESSMENT COLLABORATING GROUP (2007) Estimating the burden of disease attributable to unsafe water and lack of sanitation and hygiene in South Africa in 2000. *South African Medical Journal* **97**: 755-762.
- MAAS EV (1986) Salt tolerance of plants. *Applied Agricultural Research* **1**: 12-26.
- MAAS EV, HOFFMAN GJ, CHABA GD, POSS JA and SHANNON MC (1983) Salt sensitivity of corn at various growth stages. *Irrigation Science* **4**: 45-57.
- MATHERS CD, EZZATI M and LOPEZ AD (2007) Measuring the burden of neglected tropical diseases-The global burden of disease framework. *PLoS Neglected Tropical Diseases* **1**: e114-e129.
- MONTGOMERY MA and ELIMELECH M (2007) Water and sanitation in developing countries including health in the equation. *American Chemical Society*. URL: http://www.yale.edu/env/elimelech/publication-pdf/ES&T_Feature_Montgomery_Elimelech_January_2007.pdf
- MURRAY CJL and LOPEZ AD (1996) The Global Burden of Disease: a comprehensive assessment of mortality and disability from diseases, injuries and risk factors in 1990 and projected to 2020. World Health Organization, Harvard School of Public Health and World Bank, Geneva. URL: http://www.who.int/mip/2003/other_documents/en/globalburdenofdisease.pdf
- NAUDÉ AH, BADENHORST W, ZIETSMAN HL, VAN HUYSSSTEEN E and MARITZ J (2007) Technical overview of the mesoframe methodology and South African Geospatial Analysis Platform. CSIR, Report number: CSIR/BE/PSS/IR/2007/0104/B, Pretoria.
- NIEUWOUDT WL, BACKEBERG GR and DU PLESSIS HM (2004) The value of water in the South African economy: Some implications. *Agrekon* **43** (2) 162-183.
- OELOFSE SHH, ROUX S, DE LANGE WJ, MAHUMANI BK, LE ROUX W, DU PREEZ M, GREBEN HA and STEYN M (2011) A comparison of the cost associated with pollution prevention measures to that required to treat polluted water resources., Council for Scientific and Industrial Research, Report number: CSIR/NRE/PW/ER/2011/0006/A, Pretoria.
- PEGRAM GC, ROLLINS N and ESPEY Q (1998) Estimating the costs of diarrhoea and epidemic dysentery in KZN and SA. *Water SA* **24** (1) 11-20.
- PRUSS-USTUN A, MATHERS C, CORVALAN C and WOODWARD A (2003) Introduction and methods-Assessing the environmental burden of disease at national and local levels. Geneva, Environmental Burden of Disease Series No.1. URL: http://www.who.int/quantifying_ehimpacts/publications/9241546204/en/index.html
- SAUNDERS GH (2005) Estimates of the informal economy in South Africa: Some macroeconomic policy implications. Department of Economics, University of Johannesburg. URL: <https://ujdigispace.uj.ac.za/handle/10210/653?show=full>
- SCHNEIDER F (2002) Size and measurement of the informal economy in 110 countries around the world. Canberra, Australia, Paper presented at an Workshop of the Australian National Tax Centre. URL: http://www.amnet.co.il/attachments/informal_economy110.pdf
- SCHNEIDER M (2001) The setting of health research priorities in South Africa. Burden of Disease Research Unit, Medical Research Council, Report number: ISBN: 1-919809-15-5, Cape Town.
- STATISTICS SOUTH AFRICA (2002) Census of agriculture provincial statistics 2002: Eastern Cape financial and production statistics. Statistics South Africa, Report number: 11-02-09, Pretoria.
- STATISTICS SOUTH AFRICA (2007) Community Survey, 2007 (revised version). Statistics South Africa, Report number: P 0301, Pretoria.
- STATISTICS SOUTH AFRICA (2010a) Gross Domestic Product: Second Quarter 2010. Pretoria.
- STATISTICS SOUTH AFRICA (2010b) Quarterly employment statistics March 2010, Statistics South Africa, Report number: P0277, Pretoria.

- URBAN-ECON (2000) The economic cost effects of salinity: Water quality analysis, feeder systems and natural environment. Water Research Commission, Report number: 634/6/00, Pretoria.
- VAN HEERDEN, P. S., CROSBY, C. T., GROVE, B., BENADE, N., THERON, E., SCHULZE, R. E. and TEWOLDE, M. H. (2008) Integrating and upgrading of SAPWAT and PLANWAT to create a powerful and user-friendly irrigation water planning tool. Water Research Commission, Report number: TT391/08, Pretoria.
- VAN ZYL P (2009) Personal communication. Potatoes South Africa, URL: <http://www.potatoes.co.za/>
- VILJOEN MF and ARMOUR RJ (2002) The economic impact of changing water quality on irrigated agriculture in the lower Vaal and Riet rivers. Water Research Commission, Report number: 947/1/02, Pretoria.
- WESTERN CAPE DEPARTMENT OF AGRICULTURE (2006) Computerised budgeting system (COMBUD). Agricultural Economics services, Western Cape Department of Agriculture, Elsenburg.
- WORLD HEALTH ORGANIZATION (2009) Country profile of environmental burden of disease - South Africa. URL: http://www.who.int/entity/quantifying_ehimpacts/national/countryprofile/southafrica.pdf
- WORLD HEALTH ORGANIZATION (2010) World Health Organization Metrics - Disability Adjusted Life Year (DALY). URL: http://www.who.int/healthinfo/global_burden_disease/metrics_daly/en/index.html
- WRIGHT JA, GUNDRY SW, CONROY R, WOOD D, DU PREEZ M, FERRO-LUZZI A, GENTHE B, KIRIMI M, MOYO S, MUTISI C, NDAMBA J and POTGIETER N (2006) Defining episodes of diarrhoea: Results from a three-country study in Sub-Saharan Africa. *Journal of Health population and Nutrition* **24**: 8-16.
- YOUNG RA (2004) *Determining the economic value of water: Concepts and methods*. RFF press, Washington. 357 pp.

