Implications of water policy reforms on water use efficiency and quality in South Africa: The Olifants river basin

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Abstract

Water is a complex economic good. It requires optimal management to control rising scarcity and competition for use. South Africa like many other parts of the world is in the process of implementing market based water policy reforms to attain equity, efficiency, and sustainability in water use. However, these reforms have not been entirely successful and water allocation problems persist, while their economic evaluation is lacking. The current study assessed the effects of water policy on irrigation water use efficiency and quality in the Olifants basin of South Africa. The study uses Data Envelopment Analysis and regression technique approaches to ascertain the effects of water policy on water use efficiency and quality.Results from the Data Envelopment Analysis show that the average water use efficiency for irrigation water users was as low as 31 percent. Among the policy factors of interest, compulsory licensing significantly influenced water use efficiency. Water pricing, compulsory licensing and membership in WUAs on the other hand significantly influenced water use quality. These factors can act as policy indicators towards better water reform and management.

Introduction

Irrigated agriculture is a pathway into developing competitiveness in the agricultural sector and promoting rural development and inclusive growth. In many water stressed countries, irrigation farming is threatened by severe water scarcity and an increasing deterioration of water quality. For instance, with an increase in pesticides use in farming activities, return flows released through polluted runoffs deteriorate water quality, therefore requiring investment in water treatment options. Such a situation has direct economic implications through yield losses, cost of irrigation water, and environmental costs associated with water quality control policy and health effects, as shown in Dinar et al (2008).

Different analyses have shown the importance of well implemented water policy reforms in promoting the double objective of water use efficiency and water quality improvement. In South Africa, for instance, in order to fulfill this double objective, the country has introduced water policy reforms (National Water Act - 1998) that target better equity in water distribution among the different users, control of the resource's sustainability and integration of local stakeholders into the water management practices. Additional elements of the water sector reforms include removal of price subsidies, compulsory licensing, and promotion of water trade to improve efficiency in water use and allocation as well as new institutions (e.g. catchment management agencies (CMAs) and water user associations (WUAs) for decentralized and more inclusive water management. However, almost two decades after the reforms, no evaluation has been provided to account for outcomes of the policy reforms. Previous studies have rather discussed the strengths and weaknesses of these reforms, but there is no formal study that clearly evaluates the impacts of water policy reforms in the country. Therefore, the present study aims to assess the effect of water policy reforms (water rights, water pricing and WUAs) in South Africa, on water use efficiency and water quality. The study builds on the works of Thiam et al (2015) and Hassan and Thiam (2015) that investigated the implications of water policy on farmers' livelihoods and virtual water trade respectively.

Water rights, water pricing and participatory water use management here in referred to as Water User Associations, (WUAs) are policies that are highly prioritized in the policy agenda of many water-scarce countries such as South Africa. Such policies are envisioned to regulate water scarcity and eventually improve water use efficiency and quality (Yang et al., 2003; Varela-Ortega, 1998). Therefore the effects of these selected water policies remain of key importance as they translate into the competitiveness of any region. Water prices, for example, create the necessary awareness of water scarcity to stakeholders and induce the thinking of water allocation to higher value activities such as crops with higher returns (Wang, 2011; Speelman et al., 2009). Allocation of secure water rights promotes increasing water use productivity and foster rural livelihoods (Speelman et al., 2010). As such, water rights determine the real value of water and encourage investment and efficiency in use, due to improved security of ownership. Participatory water management on the other hand is seen as the appropriate organization under which water management should take place. WUAs foster effective water management because local users are seen to be in a better position to discern the local ecological, technical, economic, and social

conditions out of their indigenous knowledge, thus able to come up with well adapted rules, procedures, and sanction mechanisms easily supported by all resource users (Adhikari, 2005; Meinzen-Dick, Raju et al. 2002).

The rest of the paper is organized as follows: Section 2 provides the related literature. Section 3 discusses the case of analysis: the water sector in the Olifants river basin. The study methodology is provided in Section 4. Section 5 presents the data used, whereas Section 6 presents the study findings. Conclusion and policy recommendations are provided in section 7.

2. Relevant literature

Exploring the implications of water policy on water use efficiency and quality allows an assessment of the human aspects, physical resources and institutions that must be targeted by public investments to improve farm efficiency and guide policy intervention. Several studies have investigated the relationship between efficiency in water use and various farm or farmer characteristics (Speelman et al., 2008; Binam et al., 2004; Lilienfeld & Asmild, 2007; Frija et al., 2009; Wang, 2010; Wannasai & Shrestha, 2008; Njiraini & Guthiga, 2013; Wadud & White, 2000, Bozoğlu & Ceyhan, 2007; Binam et al., 2003; Dhungana et al., 2004). The farm and farmer characteristics previously examined include age, household size, gender, farming experience, education, involvement in WUAs, farm size, land tenure, farmer type, water costs, crop choice, income, farm location, and extension services. A few studies have assessed the effect of water pricing on water use efficiency (Wang, 2010), while others (Speelman et al., 2008; Frija et al., 2009) have recommended such assessments between water price/costs and water use. Little or no evidence exists of the relationship between water rights and irrigation water use, a gap that the current study seeks to fill. Literature also remains scanty on the factors that influence the quality of water used by irrigation farmers. The above mentioned factors however exhibit mixed effects on water use efficiency such that no standard effect can be guaranteed. Therefore, this study seeks to find out the context specific factors influencing water use efficiency and quality in the Olifants basin of South Africa. In addition to the hypothesized demographic, institutional, and socio economic factors, we include selected water policy intervention factors currently undergoing implementation in the study region; this is in attempt to assess their effects so far, amid the policy implementation process.

3. The case of analysis

South Africa, having been ranked among the 30 most water stressed countries in the world, recognizes that it is not easy to augment existing water supplies in the face of rising competition between water users, increasing populations and varying climatic changes (Rosegrant & Binswanger, 1994; Earle, Goldin & Kgomotso, 2005). The country has therefore intensified efforts to implement its very comprehensive National Water Act (NWA), which stipulates various Integrated Water Resource Management (IWRM) principles for better water management. These reforms were expected to have major impacts on water management,

welfare of water users and other aspects of the South African economy (Hassan & Thurlow, 2011; Hassan and Thiam, 2015). Specifically, the Olifants river basin ranks as the country's third most water stressed basin as well as one of the most polluted (Kloos, 2010; Walter, 2010). This is resultant from intensified demand for water from the main water use sectors such as domestic, mining, agriculture, and industry. Consequently, there are concerns of demand outstripping supply despite the construction of newer dams. For instance, the basin entails 37 major[1], 300 minor[2] and around 4000 small[3] dams constructed mainly for irrigation purposes and livestock watering. Table 1 illustrates water use by sector for the year 2011 while Table 2 shows the water balance for the Olifants catchment in the year 2010. Table 2 indicates a small surplus with the exclusion of the reserve requirement, which would bring it down to a deficit. Projection from this indicates that by the year 2035, the basin will be experiencing a negative water balance (Mallory, 2011).

Table 1: Sectoral water requirements[4] in the Olifants basin in million m^3 /annum

Sub-catchment	Power generation	Industrial	Urban	Rural	Mining	Irrigation	Total
Upper	228	9	93	4	26	249	609
Middle	0	0	56	22	28	81	187
Lower	0	0	29	3	32	156	220
Total	**228**	**9**	**178**	**29**	**86**	**486**	**1016**

Source: (Mallory, 2011)

Table 2: Water balance for the Olifants basin in the year 2010: Million m^3 /annum

Sub catchment	Water requirement	Water resource	losses	Water balance
Upper	609	630	0	21
Middle	187	185	(19)	(21)
Lower	220	248	(5)	23
Total	1016	1063	(24)	**23**

Source: (Mallory, 2011)

The Olifants river basin, in addition to being water stressed, also acts as a hotspot for policy reform implementation, since it covers three main important provinces, (Gauteng, Mpumalanga and Limpopo) and has experienced many institutional changes over the past years. The basin is divided into three management zones namely upper, middle and the lower Olifants. The region experiences a summer rainfall regime that is highly varied and this emphasizes the need for

[1] Major dams are reservoirs storing more than 2Mm3 volume of water
[2] Minor dams are reservoirs storing between 0.1 and 1Mm3 volume of water
[3] Small dams are reservoirs storing less than 0.1Mm3
[4] The water requirements are summed up over all user sectors (urban, rural, industrial, mining, irrigation, and power generation) while the water resource is the yield from major dams and diffuse resources such as farm dams, run off river abstraction, and ground water.

irrigated farming. Approximately, 5 percent of South Africa's GDP comes from the Olifants region with economic activities ranging from mining, power generation, metallurgic industries, irrigation, eco-tourism, forestry, and subsistence agriculture. Agriculture remains the largest water user for the middle and lower Olifants sub basins while power generation takes up the big part of water use in the upper Olifants. Commercial irrigation is well developed and organized with sophisticated technology and produces a wide variety of crops such as maize, soya beans, citrus, cotton, vegetables, wheat, and tobacco (Kloos, 2010; Lange et al., 2003). Almost all irrigation farming occurs in the commercial sector with majority of land owners being whites who take up about 95 percent of total irrigated area (Tsegai, Linz, & Kloos, 2009). Only a small part of the Olifants irrigated area is occupied by small holders, but most households at least derive some part of their livelihoods from the government schemes, individual, and communal vegetable gardens. Figure 1 shows the map of the Olifants basin within the bigger South Africa and Africa context.

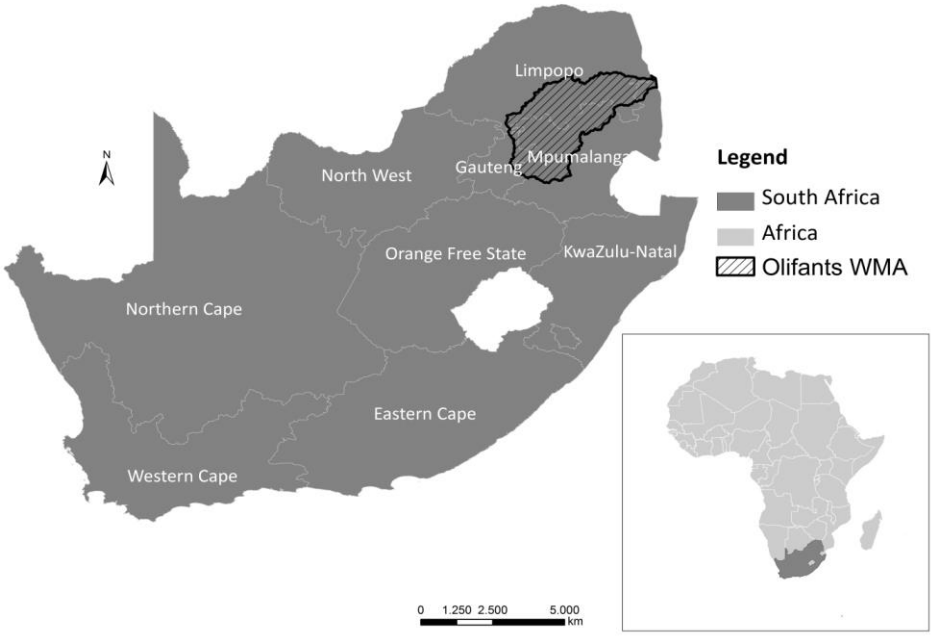

Figure 1: Map of the Olifants basin

4. Methodology

4.1 Effects of water policy on irrigation water use efficiency

We examine how water policies coupled with socio-economic factors (demographic, institutional, economic), influence water use efficiency (WUE) of irrigation farmers in the Olifants basin.

Figure 2 depicts our hypothesis that WUAs, water pricing, and compulsory licensing affect irrigation water use efficiency and quality. The policy effects on water use could either be positive thereby enhancing attainment of the desired water Act goals, have no effect yet (status quo), or the water users and water resource could be worse off (negative effects) (Figure 2). Other demographic, institutional and economic factors besides water policy also play a role in influencing water use efficiency and quality.

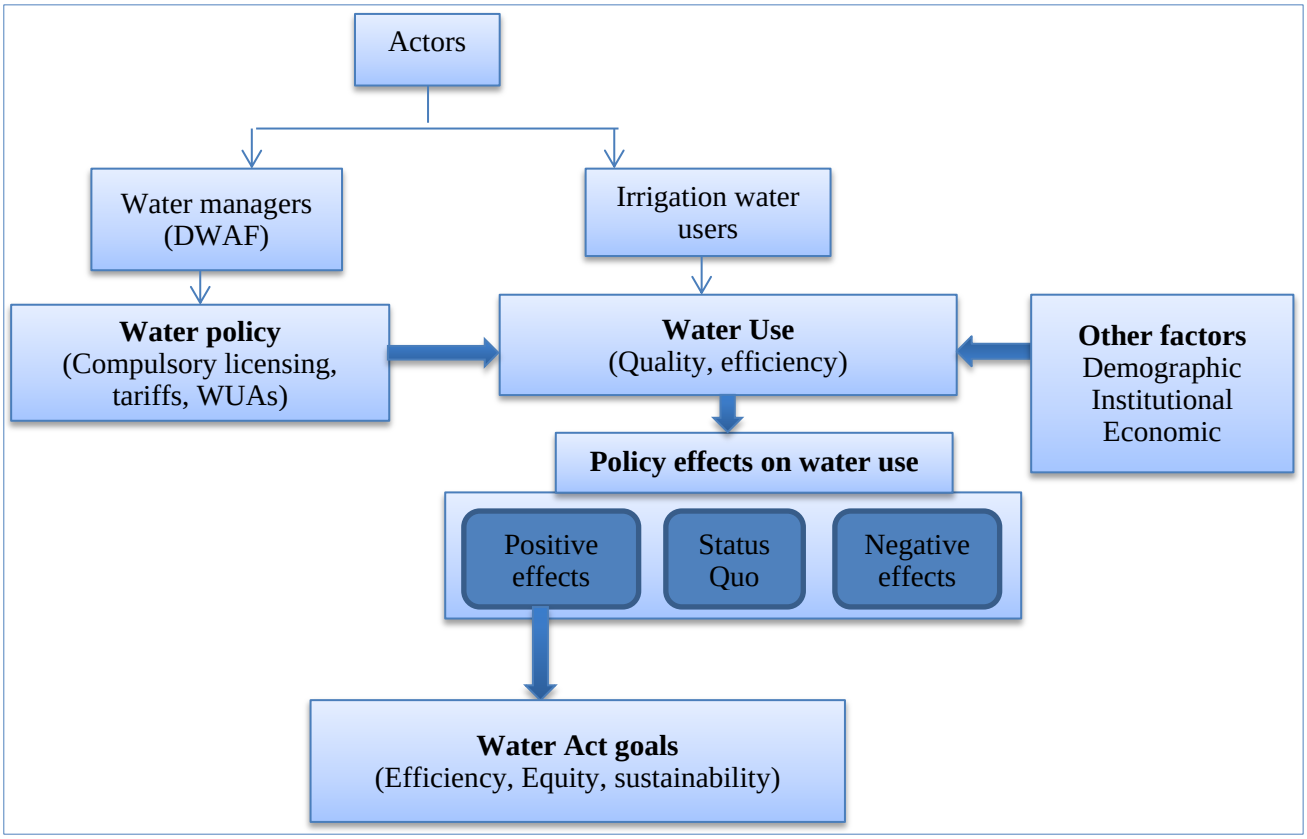

Figure 2: Conceptual framework on effects of water policies on irrigation water use
Source: Own compilation

This paper follows Dinar et al. (2007) and posits that WUE can better indicate the intended effects of water policy because it is one of the goals targetted by the South African water policy reform. Furthermore, efficiency measures indicate the relationship between all outputs and inputs in a production process, as previously described in Zilberman et al. (2003), Dinar et al. (1985) and and Díaz et al. (2004). Technical efficiency measures originate from the seminal work of Farrell (1957), in which he defines efficiency as the ability of a farm to produce the maximum feasible output from a given bundle of inputs (output-oriented measure) or to use minimum feasible amounts of inputs to produce a given level of output (input-oriented measure). Sub vector technical efficiency measures, on the other hand, generate technical efficiency measures for an individual input, in this case water. The concept of sub vector efficiency examines the possibility of reducing a subset of inputs while holding other inputs and outputs constant.

There are two main approaches in literature used for measuring technical efficiency. The parametric approach, known as the stochastic frontier analysis and the non-parametric approach referred to as Data Envelopment Analysis (DEA) (Speelman, et al., 2008; Frija et al.,2009; Wang, 2010). The parametric approach estimates a parametric production function (or its dual cost or profit function) representing the best available technology. It also provides a convenient framework for hypothesis testing and the construction of confidence intervals. The non-parametric DEA on the other hand uses linear programming methods to construct a linear envelopment frontier over the data points. The DEA is considered to have several advantages over the parametric approach because firstly, it does not need to assume a functional form such as a translog production function for the frontier technology (Speelman et al., 2008). Secondly, the constructed surface over the data allows comparing one production method with the others through a performance index. Therefore, DEA provides a straightforward approach to calculate the efficiency gap that separates each producer's behavior from best productive practices; which can be assessed from actual observations of the inputs and outputs of efficient firms (ibid). The most important advantage of DEA to this study is its flexibility, which permits the calculation of technical efficiency for an individual input in a production process (sub vector efficiency). This would otherwise be computationally problematic using the stochastic frontier approach as the production technology assumed can limit the efficiency results, as shown in Speelman et al. (2008) and Frija et al. (2009). DEA considers a farm using less inputs as more efficient than another which uses more inputs to produce the same amount of output (Speelman et al., 2008). Therefore, it simultaneously constructs a production frontier and attains the efficiency measures. The frontier surface is a result of piece wise accumulation through solving sequences of linear programming problems, one for each farm and in relation to the frontier (ibid). The frontier forms an envelop over the observed input and output data points of each farm.

Following Speelman et al. (2008), we give an example of a model where data is available on K inputs and M outputs for each of the N farms. Input and output data for the ith farm, are given by the column vectors x_i and y_i, respectively. The K by N input matrix, X, and the M by N output

matrix, Y, represent the data for all N farms in the sample. Equation 3.1 demonstrates the DEA model to calculate general technical efficiency

$$
\begin{aligned}
&\text{Min}_{\theta\lambda}\theta, \\
&\text{Subject to} \quad -y_i + Y\lambda \geq 0, && (i) \\
&\qquad \theta x_i - X\lambda \geq 0, && (ii) \qquad (3.1) \\
&\qquad N1'\lambda = 1, && (iii) \\
&\qquad \lambda \geq 0 && (iv)
\end{aligned}
$$

Where θ is a scalar, $N1$ is a vector of ones, and λ is a vector of constants. Using the variables λ and θ, the model solves once for each farm, aiming for the largest radial contraction of the input vector x_i within the given technology. The value of θ corresponding with this contraction is the technical efficiency score for the ith farm. This score always lies between zero and one, with one showing that the farm lies on the frontier and is efficient. Constraint *(i)* ensures that output produced by the ith farm is smaller than that on the frontier. Constraint *(ii)* limits the proportional decrease in input use; when θ is minimized to the input use achieved with the best-observed technology. Constraint *(iii)* is a convexity[6] constraint that creates a variable returns to scale (VRS) specification of the model; it ensures a farm is benchmarked against farms of similar size. Without the convexity constraint, Equation 3.1 makes up the constant returns to scale (CRS) specification. CRS assumes that all farms are operating at an optimal scale, which is not possible in reality due to limitations such as finances and imperfect competition (Coelli et al., 1998). Therefore, the VRS specification is more suitable especially in agriculture where increases in inputs do not proportionately result in increased outputs (ibid).

Equation 3.2 shows the programming problem used to obtain the sub vector efficiency for the variable input k (water) for each farm i

$$
\begin{aligned}
&\text{Min}_{\theta\lambda}\theta^k \\
&\text{Subject to} \quad -y_i + Y\lambda \geq 0, && (i) \\
&\qquad \theta^k x_i^k - X^k\lambda \geq 0, && (ii) \\
&\qquad x_i^{n-k} - X^{n-k}\lambda \geq 0, && (iii) \qquad (3.2) \\
&\qquad N1'\lambda = 1, && (iv) \\
&\qquad \lambda \geq 0 && (v)
\end{aligned}
$$

Where, θ^k is the input k sub-vector technical efficiency score for farm i. The terms x_i^{n-k} and X^{n-k} in the third constraint refer to x_i and X with the kth input (column) excluded, while, in the second constraint, the terms x_i^k and X^k include only the kth input. Other variables definitions remain as in Equation 3.1. Constraints *(i)*, *(iv)*, and *(v)* are the same as in model 3.1, while constraints *(ii)* and *(iii)* ascertain that a value of θ^k is found which represents a maximum reduction of the variable input k remaining within the technology set and holding outputs and all other inputs constant.

Table 3 gives the list of hypothesized factors included in the regression models and their hypothesized effects on water use efficiency and quality.

Table 3: List of the variables included in the Tobit and MNL analysis

Variable	Description	Model and Expected signs	
		Tobit	MNL
WUE	The DEA sub vector water use efficiency measure	Dependent	
Water quality	Water quality type (1=Ideal, 2=acceptable, 3=tolerable, 4=unacceptable)		Dependent
WUA	Farmer involvement in Water User Associations/groups	+	+
Compulsory licensing	Compliance to water licensing	+	+
Water cost/m^3	Natural log of total cost of irrigation water used based on current paid tariffs	+	+
Region	Farmer geographic location (upper,middle and lower Olifants)	+/-	+/-
Leadership in WUA	Leadership position held in water use groups/WUA	+	+
Race	Race of respondent (black or white)		+/-
Gender	Male or female farmer	+/-	+/-
Years of schooling	Total number of years of school attendance	+	+
Main occupation	Main activity of a respondent (1=largescale, 2=smallscale, 3=other)	+/-	+/-
Farming years	Total number of years of farming	+	+/-
Farm size	Natural log of farm size	+/-	+/-
Land claims	Proxy for tenure security	+	+
Income	Natural log of income	+/-	+/-
Technical assistance	Source of technical policy information (1=DWAF,0=other sources)	+	+
ICT tool	ICT tools used for water management purposes (1= radio,TV,phone,email 0=none)	+	+
Irrigation methods	Irrigation technology used (1= center pivot, 2= drip, 3=flood, 4=other, 5= sprinkler)	+/-	+/-
Perennial crops	Perennial crops grown (citrus, mangoes, grapes, cotton)	+/-	+/-
Cereal crops	Cereal crops grown (maize and wheat)	+/-	+/-
Vegetables and other	Vegetables and other crops (leafy vegetables, peas, potatoes, onions, beans)	+/-	+/-

Source: Own compilation

Figure 3 demonstrates the measurement of technical efficiency and sub vector efficiency using DEA. The problem takes the ith farm R and radially contracts the input vector, x_i, as much as possible, while maintaining the feasible input set. The inner boundary of this set is a piecewise linear isoquant (Y^F) determined by the frontier data points. The radial contraction of the input vector x_i produces a projected point on the frontier surface (R_0). This projected point is a linear combination of the observed data points, with the constraints in Equation 3.1, which ensure that the projected point cannot lie outside the feasible set. The overall technical efficiency measure of farm R relative to the frontier is given by the ratio $\theta = 0R_o/0R$. The sub-vector efficiency for input X_1 (water) is obtained by reducing X_1 while holding X_2 and output constant. This is a non-radial concept of input efficiency measurement and it allows for a differential reduction of the inputs used (Reinhard, 1999). Figure 3 shows that R is projected to R_1 and sub-vector efficiency is given by the ratio θ^1 = QR1/QR

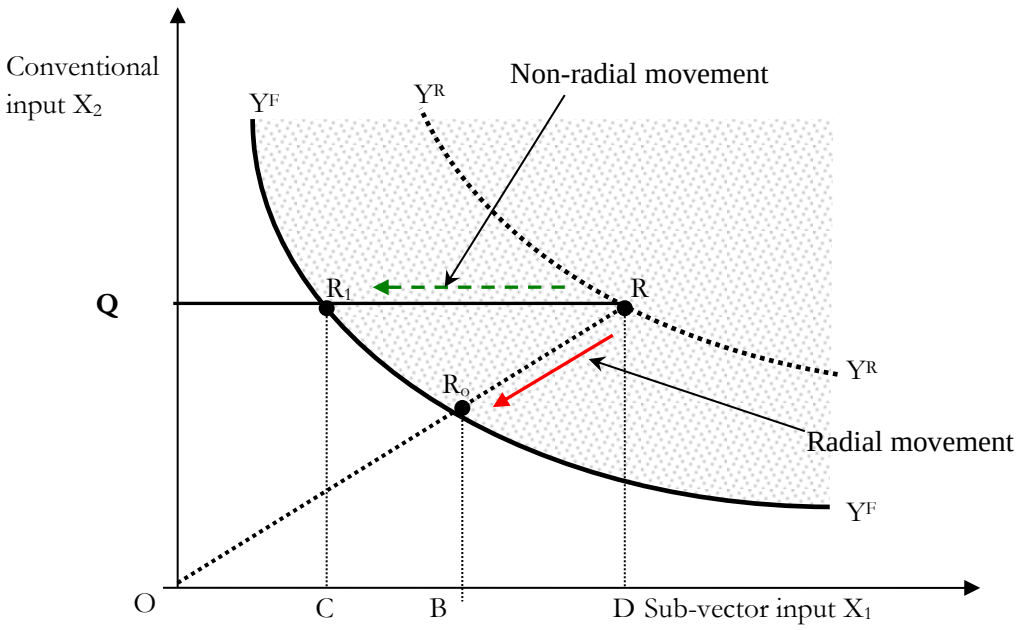

Figure 3: Measurement of technical and sub vector efficiency using DEA
Source: Mulwa 2006

After obtaining the sub-vector efficiency estimates as outlined above, the estimates were regressed on hypothesized correlates of water use efficiency through a second stage relationship using the Tobit model (Barnes, 2006; Chavas et al., 2005; Binam et al., 2003). Tobit regression, is an alternative to OLS for situations in which the dependent variable is bounded from below or above (or both) either by being censored, or by corner solutions (Frija et al., 2009). The Tobit

model was suitable because the efficiency parameters vary between zero and one thus termed as censored. The dependent variable lacks a normal distribution, since its value lies between zero and one. OLS in this case, would produce biased and inconsistent estimates even at asymptotic levels as shown Wooldridge (2002). OLS further underestimates the true effect of the parameters, and decreases the slope. Tobit analysis therefore uses the maximum likelihood estimation methods. The theoretical Tobit model takes the form:

$$y_i^* = x_i'\beta + \varepsilon_i, \quad i = 1,2, \ldots\ldots, N, \qquad (3.3)$$
$$y_i = y_i^* \quad if\ y_i^* > 0$$
$$y_i = 0 \quad if\ y_i^* \leq 0,$$

Where, y_i^* is the latent variable for the ith farm, x is the vector of independent variables hypothesized to affect efficiency. ($\beta = \beta_0, \beta_1 \ldots \beta_n$) are the unknown parameter vectors related with the independent variables for the ith farm. ε_i is the error term assumed to be normally distributed and independent of x_i (0,σ^2) with zero mean and constant variance (Verbeek, 2012). This is a censored regression model whereby all the negative values map to zeros. The model assumes that there is an underlying stochastic term equal to $+\varepsilon$. The model describes the probability that y_i= zero given x_i and the distribution of y_i given that it is positive; this is a truncated normal distribution. In this case, the efficiency values lie between zero and one hence the point of truncation is one and the dependent variable is not normally distributed. Accordingly, for the purposes of this study, the empirical model takes the form:

$$y_i^* = \beta_0 + \sum_{n=1}^{n} \beta_n x_i + \varepsilon_i \qquad (3.4)$$

Where,
$0 < y_i^* < 1$,
0 if y_i^* <0, and, 1 if $y_i^* > 1$

y_i^* is the DEA sub-vector efficiency index for water used as a dependent variable. x_i is a vector of independent variables related to attributes of the farmers and policy compliance as listed in Table 3.

4. 2 Effects of water policy on irrigation water quality

Technically, water quality is defined as the chemical, physical, biological, radiological, and aesthetic characteristics of water (UNESCO/WHO/UNEP, 1996). However, measurement and determination of water quality is relative to its intended purpose; hence, it is the ability of water to support all appropriate beneficial uses at a given point in time. In general, the parameters of measurement to describe water quality are: biological (i.e bacteria, algae), Physical (i.e temperature, turbidity and clarity, color, salinity, suspended solids, dissolved solids), Chemical (i.e pH, dissolved oxygen, biological oxygen demand, nutrients - including nitrogen and

phosphorus, organic and inorganic compounds - including toxicants), Aesthetic (i.e odors, taints, color, floating matter), Radioactive: alpha, beta, and gamma radiation emitters).

Accordingly, the Department of Water Affairs and Forestry (DWAF) of South Africa has categorized the fitness-for-use of water for various uses using six parameters, which give the discrete values that describe a specific effect due to a given set of conditions. These are namely:

i. Electrical Conductivity (EC): This indicates salinization of water resources and serves as a proxy for total dissolved solids (dissolved inorganic salts). Salinization affects domestic and irrigation water use. Aquatic life is only affected in extreme high levels
ii. Orthophosphate (PO_4-P): Phosphate indicates the nutrient levels in water resources (eutrophication). Phosphate has no direct effect on water use but indicates contamination from activities in a catchment such as fertilizer use and wastewater discharge.
iii. Sulphate (SO_4 2): Sulphate is a naturally occurring substance found in mineral salts in the soil, decaying plant and animal matter. It is generally not toxic but affects human consumption at very high levels.
iv. Chloride (Cl): It shows the nature of salinity i.e. salty taste and corrosiveness. Mainly affects aquatic life and irrigation
v. Ammonia (NH_3-N): indicates presence of ammonia, which is highly toxic to aquatic life even in low concentrations. It has no effect on human life and irrigation in the state it occurs in rivers and dams
vi. pH (pH units): It is a measure of the acid-base equilibrium of various dissolved compounds and indicates the acidity/alkalinity of water. Water pH only affects water use at the extreme levels.

Based on the above values, the DWAF has come up with water quality guidelines or criteria used in conjunction with the statistical values to determine the fitness for use. The guidelines provide a description of the effect on a user if exposed to increasing concentration or changing values of quality components. The description consists of cut off values for each category of fitness for use in relation to the specific water use. Therefore, the guidelines show fitness for use of water in consideration of its biological, chemical, and physical characteristics. The guidelines have been set into four categories as:

1. Ideal: the user of the water is not affected in any way
2. Acceptable: slight to moderate problems are encountered
3. Tolerable: moderate to severe problems are encountered
4. Unacceptable: the water cannot be used under normal circumstances

Table 4 shows the cut off values for fitness for use range in irrigation activities.

Table 4: Cut off pollution values categorizing agricultural water use

variable	units	Ideal	Acceptable	Tolerable	Unacceptable
Ec	mS/m	< 40	40-270	270-540	> 540
pH: upper range lower range	pH units	> 6.50 < 8.40			< 6.50 > 8.40
Nitrate	Mg/l N	-	-	-	-
Ammonia	Mg/l	-	-	-	-
Chloride	Mg/l	< 100	100-175	175-700	> 700
Phosphate	Mg/l P	-	-	-	-
Sulphate	Mg/l	-	-	-	-

Source (Van Veelen, 2011)

Irrigation farmers might not be aware of the exact values attached to each of the guideline categories. However, the assumption made in this study is that they are aware of the adverse effects of the water they use on their farming activities; following these effects, farmers were therefore able to categorize the water they used into the four categories, as they perceived.

Following the outlined categorization of water quality, we used the Multinomial Logit Model (MNL) for this section because it allows estimating choice probabilities for many categories (Maddala, 1983; Wooldridge, 2002). The dependent variable (water quality) is a multivariate variable with four possible categories (Ideal, acceptable, tolerable, and unacceptable). The four categories enabled collection of water quality information from farmers, based on their perceptions. The multinomial logit model assumes all errors of the alternatives to be independent (independence of irrelevant alternatives (IIA) and this ensures the parameter estimates of the model remain unbiased and consistent i.e. P_j/P_k is independent of the remaining probabilities. However, this is not always the case especially if alternatives are very similar as shown in Verbeek (2012). A test is usually relevant to compare estimates from the model with all alternatives to estimates using a subset of alternatives.
The MNL model takes the form:

$$P\left(y = {}^{j}/_{x}\right)$$

$$= \exp(x\beta_j) \;/\; [1 + \sum_{h=1}^{j} \exp(x\beta_h), \qquad j = 1,2,\ldots,J] \qquad (3.5)$$

Where y denotes a random variable taking on the values {1, 2, …, J} for a positive integer J; and x denote a set of conditioning variables. x is a 1xK vector with first element unity and β_j is a K×1 vector with j = 1,2, …, J. In this study, y denotes water quality (category) status while x signifies hypothesized factors influencing farm water quality described in Table 3. Equation 3.5 above shows the effect of changes in an element of x (holding other factors constant), on the response probabilities $P(y = j/x)$, j = 1, 2, …, J. This indicates the direction of the effect of the explanatory

variables on the dependent variable. Following Sadeghi,et al. (2012), the implicit form of the structural model linking water quality and the set of hypothesized independent varibles is as follows:

$$WatQlty_j = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \in \qquad (3.6)$$

Where;

$WatQlty_j$ = quality of water, j (j=1,2,3,4) used and ranked by an irrigation farmer in the Olifants basin

x_1 = vector of the water policy interventions (compulsory licensing, water pricing (water costs) and WUAs

x_2 = vector of economic heterogeneity factors such as income, farm size, crop choice, main occupation

x_3 = vector of household demographic characteristics such as, geographic location, gender, farming experience, race and schooling years

x_4 = vector of other institutional related factors namely, leadership positions in informal and formal water use groups, tenure security, use of ICT tools for water management purposes, and technical assistance

ε = error term

5. Data

Data was collected through a survey from a total of 183 irrigation farmers both small scale and large scale in the Olifants basin of South Africa. Data collection took place between September 2013 and April 2014. Using a data base of water users and authorization from the Department of Water Affairs, stratified random sampling and Probability Proportionate to Size sampling (PPS) were used to obtain the suitable number of survey respondents. We then used a semi-structured questionnaire to elicit information on household socio economic characteristics, farm activities, water policy compliance, quantities and costs of inputs used in production, quantities and value of outputs, the quantity of water used, involvement in WUAs and other irrigation practices. For the different outputs by farms, both quantities and corresponding prices were obtained then the total output was converted into monetary terms. The inputs considered in the efficiency analysis included land (hectares), irrigation water (m^3), labor (man days), seeds (expenses), fertilizers (expenses), and pesticides (expenses). Small-scale water use estimations were based on capacities of pumps used to draw water from the rivers and the frequency of irrigation in non-metered cases. Local experts and extension agents further verified the small-scale water use quantities.

6. Results and discussion

6.1 Effects of water policy on irrigation water use efficiency: DEA and Tobit results

Water use efficiency results

Table 5 gives a summary of the inputs and output used for the efficiency analysis. It shows a wide variation between inputs used and output produced from irrigation farming. This can be explained by the subsistence and commercial nature of small scale and large scale farmers studied.

Table 5: Summary statistics of inputs and outputs used in the efficiency analysis

	Mean	Standard Deviation	Minimum	Maximum
Land(Ha)	39,40	106,43	0,04	690
Water(m^3)	70978,14	215345,63	11,25	1408200
Seeds(ZAR)	6089,78	14462,21	0	91000
fertilizer(ZAR)	49182,68	331305,18	0	3000000
pesticides(ZAR)	4912,74	21813,64	0	201500
Labour(mandays)	93	291,40	4	2412
Crop output(ZAR)	6806472,13	32936266,52	0	299970000

Source: own compilation

Figure 4 indicates the frequency distribution, categorized in classes of water use efficiencies obtained from the DEA estimation methods. A large percentage of the farmers had low water use efficiency scores; 17 percent of farmers had efficiency scores below 1 percent, while 35 percent

of farmers had their efficiency scores between 1 and 10 percent. Twenty-one percent of the irrigation farmers were water use efficient. The average overall water use efficiency was 0.31 (31 percent) indicating large inefficiencies in irrigation water use. Accordingly these findings suggested that, if all other inputs were held constant, it would still be possible to attain the current outputs using on average 69 percent less irrigation water. This is in line with findings of Frija et al. (2011) and Speelman et al. (2009). Following Speelman et al. (2009), the results further suggested that, if efficiency was to improve, it would be possible to re-allocate the excess water used into other water demands without negatively affecting farm production. The results showed that irrigation water use efficiency was low and barely reflected efforts of the current water policy reforms. We argue that water policy implementation is still a 'work in progress' yet to attain its goals for the Olifants basin among many other basins of South Africa.

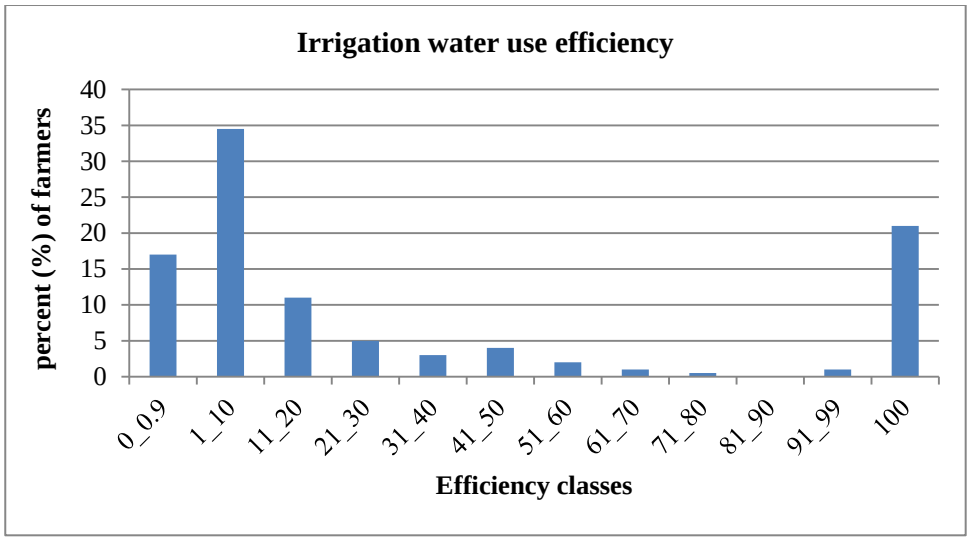

Figure 4: Sub vector water use efficiencies
Source: own compilation

Tobit regression results

The tobit regression results in Table 6 indicated that compulsory licensing positively influenced irrigation water use efficiency. This was an interesting result for water policy reform in South Africa, indicating a positive step towards attainment of the water reform objectives. This finding implies a call towards more widespread implementation of compulsory licensing in order to foster irrigation water use efficiency. The positive significance of compulsory licensing on WUE was attributable to the incentive it gives to farmers as an entitlement to water hence more efficient water use (Burness & Quirk, 1979). Compulsory licensing is a water right and just like any other property right, it fosters security of ownership and encourages farm level investments and efficiency (Wang, 2010; Frija et al., 2009; Speelman et al., 2008).

The results further show that farmers with more years of schooling were likely to be more water use efficient. This was in line with the findings of Dhungana et al. (2004), Binam et al. (2004) and Wang (2010) who found that farmers above a certain threshold of schooling were more likely to be efficient in their farming activities. Our findings thus support the Schultz (1964) hypothesis that, education improves the ability to perceive, understand, and react to new endeavors and nurtures farmers' managerial skills. Schooling improves access to information from a variety of sources such as newspapers and instruction manuals (Rosenzweig, 1995).

Technical assistance has in the past been regarded as a positive driver of water use efficiency (Frija et al., 2009; Binam et al., 2004; Bozoğlu & Ceyhan, 2007). This study examined technical assistance received by farmers and in reference to the sources of such assistance. A surprising result was that, farmers who obtained their technical assistance from the DWAF were less efficient in water use compared to farmers who obtained their technical assistance from private companies, WUAs and their fellow farmers. This could mean that DWAF is not as efficient as the private companies and WUAs in disseminating technical information to irrigation farmers. This was in line with the findings of Binam et al. (2004) who attributed it to bureaucratic inefficiency, poor program design and generic inherent weaknesses in public operated systems. More so, the top down approach used by government systems is ineffective in improving farmer knowledge and more participatory approaches are preferred.

Crop choice significantly affects water use efficiency and previous studies recommend growing crops that have higher profit returns per unit (m^3) of water used (Speelman et al., 2008; Njiraini & Guthiga, 2013). The findings from this study indicated that vegetable and cereal crop growers were less water use efficient. However, comparison of crops in terms of profit per unit (m^3) of water used was beyond the scope of this study.

Table 6: Effects of water policy on irrigation water use efficiency: Tobit results

Variable	coefficient
WUA-membership(1=yes,0=no)	$0.073_{(0.064)}$
Compulsory Licensing compliance(1=yes,0=no)	$0.389_{(0.133)}$***
Region- Middle Olifants	$0.002_{(0.118)}$
Region- Lower Olifants	$-0.116_{(0.129)}$
Leadership in WUA(1=yes, 0=no)	$0.048_{(0.164)}$
Gender(1=male, 0=female)	$-0.035_{(0.064)}$
Years of schooling	$0.011_{(0.006)}$ *
Main occupation-small scale	$0.098_{(0.131)}$
Main occupation-other	$-0.010_{(0.175)}$
Farming years	$0.002_{(0.002)}$
Farm size- ln farm size	$0.000_{(0.000)}$
Landclaims (1=yes,0=no)	$0.012_{(0.117)}$
Income- ln income	$-0.002_{(0.016)}$
Water cost- ln water cost	$-0.021_{(0.013)}$
Technical assistance (1=DWAF,0=others)	$-0.246_{(0.100)}$ **

ICT tool	0.020(0.058)
Perenial crop growers (1=yes,0=no)	0.006(0.123)
Cereal crop growers (1=yes,0=no)	-0.169(0.087) *
Vegetable crop growers (1=yes,0=no)	-0.282(0.113) **
Irrigation method- drip	-0.085(0.157)
Irrigation method-flood	-0.084(0.171)
Irrigation method-other	-0.025(0.249)
Irrigation method-sprinkler	-0.016(0.162)
_cons	0.717(0.333) **

Source: Own compilation

6.2 Effects of water policy on irrigation water quality: Multinomial Logit (MNL) results

We estimated a multinomial logit model (MNL) to assess the factors influencing water quality used in irrigation farming in the Olifants basin. Among them, we included water policy factors to assess their effectiveness on water quality status amid the Water Act implementation process. Table 7 gives the results of the MNL regression. The dependent variable (water quality) was a multivariate variable with four possible quality categories as outlined by DWAF and perceived by the farmers in this study. These are namely: (Ideal (good)- the water has no effect on the user in any way, acceptable (moderate)-slight to moderate problems are encountered, tolerable (bad)- moderate to severe problems encountered and unacceptable (very bad) - highly unusable water). The acceptable (moderate) category is used as a base category hence we describe the results for the remaining three categories. Estimation of the MNL regression model used maximum likelihood procedures. The chi statistic (p-value < 0.0000), suggests that the model fit the data well and is highly explanatory.

- ***Ideal water quality***

For the ideal water quality category, the number of farming years and farming of cereals significantly explain water quality. More farming years negatively influenced the ideal water quality while growing of cereal crops also negatively influenced ideal water quality.

- ***Tolerable water quality***

Farmer location, occupation, cereal, and perennial crop farming significantly influenced tolerable water quality use. Results indicated that, irrigators from the middle and lower Olifants were less likely to use water of tolerable quality compared to their upper Olifants counterparts. Respondents who were engaged in other nonfarm activities were more likely to use water of tolerable quality compared to the commercial irrigation farmers. Farmers growing perennial crops were less likely to use water of tolerable quality in comparison to those who did not engage in perennial crops farming. Cereal crop farmers on the other hand were more likely to use water of tolerable quality unlike none cereal growers.

- ***Bad water quality***

The results indicated that farmers compliant to compulsory licensing, those involved in WUAs/informal water use groups, and the leaders in these groups were less likely to use bad quality water. This was in line with Shah (2002) who reported positive and significant effects on water use, under cooperative irrigation management in WUAs. The study results further indicated that farmers who paid high costs for their water were less likely to use bad quality water; we suggest that given their ability to pay higher costs for higher water quantities used, these farmers could be in a position to treat their water for farming activities before use. Further, the results showed that white farmers were less likely to use bad quality water in comparison to their black counterparts. We linked this to the fact that most of the white farmers especially the exporters individually treated their water for their farming activities in the study region. The results further confirmed this, as we found that small-scale farmers and those involved in other non-farm activities were more likely to use water of bad quality compared to their commercial

scale counterparts. Additionally, the results showed that farmers with large farm sizes were less likely to use bad quality water; these were mainly the commercial scale farmers. Khalkheili & Zamani (2009) suggested that large-scale landholders have more stakes to loose hence the incentive to find alternative coping strategies.

Farmers with more schooling years and farming experience were less likely to use bad quality water probably because they had discerned ways of differentiating and coping with different water qualities for their farm activities given their knowledge and experience. We further found that farmers faced with tenure insecurities were less likely to use bad quality water and this could be due to their minimal investments in farming activities thus not much water used in agriculture. Shah (2002), and Adger & Luttrell (2000) suggest that insecure property rights limit farmers from making any major investments in their farming activities. Our results also indicated that recipients of technical assistance information about water policy from DWAF and extension agents were more likely to use water of bad quality, which was a surprising result from this study. However, this could point out to weak extension services or the fact that, the policy process has not yet attained full implementation and desirable results. Farmers in the middle and lower Olifants were more likely to use water of very bad quality compared to those in the upper Olifants region. This was attributed to their location in the downstream part of the basin; Cardenas (2009) suggested that location of water users along a river basin is a determining factor in the appropriation of the resource. Lastly, our results showed that cereal growers were less likely to use bad quality water.

Table 7: Effects of water policy on irrigation water quality: MNL results

	Ideal quality	Tolerable quality	Unacceptable quality
Variable	**Coeff**	**Coeff**	**Coeff**
Region-middle Olifants	1.141$_{(1.181)}$	-2.368 $_{(1.270)}$*	6.790$_{(2.594)}$ ***
Region-lower Olifants	0.135$_{(1.297)}$	-1.612$_{(0.958)}$ *	7.422$_{(2.732)}$ ***
WUA-membership (1=yes,0=no)	-0.807$_{(0.514)}$	-0.238$_{(0.694)}$	-4.953$_{(1.862)}$) ***
Compulsory Licensing compliance (1=yes,0=no)	0.971$_{(1.201)}$	1.795$_{(1.215)}$	-7.615$_{(1.820)}$ ***
Leadership in WUA (1=yes,0=no)	0.742$_{(0.914)}$	-0.297$_{(0.828)}$	-3.915$_{(1.554)}$ **
Race (1=white,0=black)	-1.025$_{(1.506)}$	-2.020$_{(1.505)}$	-33.517$_{(9.483)}$ ***
Gender (1=male,0=female)	0.232$_{(0.457)}$	0.896$_{(0.574)}$	-0.732$_{(1.148)}$
Years of schooling	-0.041$_{(0.045)}$	0.019$_{(0.053)}$	-0.178$_{(0.107)}$ *
Main occupation-small scale	-0.683$_{(0.819)}$	0.457$_{(1.593)}$	10.738$_{(2.936)}$ ***
Main occupation-other	-0.074$_{(1.201)}$	2.974$_{(1.645)}$ *	17.951$_{(4.428)}$ ***
Farming years	-0.050$_{(0.022)}$**	0.012$_{(0.020)}$	-0.082$_{(0.039)}$ **
Land claims (1=yes,0=no)	0.895$_{(0.836)}$	-0.465$_{(1.298)}$	-18.504$_{(1.455)}$ ***
Technical assistance (1=DWAF,0=others)	-0.096$_{(0.869)}$	1.281$_{(0.864)}$	3.245$_{(1.504)}$ **
ICT tool for water management (1=yes,0=no)	0.285$_{(0.461)}$	0.145$_{(0.589)}$	-0.530$_{(0.999)}$
Water cost-ln water cost	0.000$_{(0.000)}$	-0.000$_{(0.001)}$	-0.923$_{(0.190)}$ ***
Perennial crops grown (1=yes,0=no)	-1.013$_{(1.140)}$	-1.508$_{(0.879)}$ *	-0.226$_{(1.698)}$
Cereal crops grown (1=yes,0=no)	-0.972$_{(0.514)}$ *	1.879$_{(0.911)}$ **	-2.268$_{(1.009)}$ **
Vegetable crops grown (1=yes,0=no)	0.911$_{(0.925)}$	1.102$_{(0.844)}$	5.617$_{(3.124)}$ *
Farm size-ln farm size	0.003$_{(0.002)}$	0.001$_{(0.002)}$	-0.211$_{(0.057)}$ ***
Income-ln income	-0.022$_{(0.125)}$	-0.053$_{(0.099)}$	-0.161$_{(0.120)}$
_cons	1.228$_{(2.355)}$	-3.004$_{(2.453)}$	-23.803$_{(7.855)}$ ***
N=179	R2 =0.501	P=0.501	
N for all categories: Acceptable=60	Ideal=52	Tolerable=31	Unacceptable=36

7. Conclusions and policy recommendations

IWRM is now a popular approach to address issues of water management given rising water scarcity. However, literature lacks enough evidence of the effect of the proposed water principles on water use and its management. Some mixed outcomes exist while the effects of some of the associated policies remain unknown. The study used regression methods to examine the effects of water policies among other factors', on water use efficiency and quality in irrigation farming in the Olifants basin. Water use efficiency was assessed using DEA methods and the results indicated that irrigation farmers in the Olifants were water use inefficient; the average water use efficiency was only 31 percent suggesting major room for improvement and water re-allocation. Various demographic, socio-economic and institutional factors influenced water use efficiency, and quality. The Tobit results showed that compulsory licensing, schooling years, technical assistance, and crop choice influenced water use efficiency. The MNL results on the other hand indicated that, compulsory licensing, involvement in WUA, and water costs among other factors negatively influenced the use of bad quality water. Use of ideal water quality was explained by farming experience and cereal farming while tolerable water quality, was significantly explained by farmer location, main occupation and crop choice.

We conclude that the array of factors influencing the various aspects of irrigation water use, should guide policy towards better water management; this is especially so for the examined water policy reform factors of compulsory licensing, WUAs and water pricing. For example, the highly significant positive effect of compulsory licensing on water use efficiency highlights the importance of water rights and lays emphasis on water reforms. The water rights ensure farmers have entitlement to the water they use and promote water use efficiency. Current water prices on the other hand do not seem to encourage water saving as farmers comfortably pay the corresponding costs for higher quantities of water used. We recommend a review of the current tariffs and strict implementation of the same. Other factors such as technical assistance point to the needed improvement in extension service and alternatives of information dissemination. Schooling points to the importance of capacity building though it is a difficult target for policy in the short run. In the short term, farmers can best learn from the practices of their efficient counterparts, possibly through extension tools such as farmer field days.

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