WP/21/01

ATI Working Paper

Technical Efficiency of Water Boards in South Africa: A Costing and Pricing Benchmarking Exercise

Victor Ngobeni and Marthinus C. Breitenbach

AFRICAN TAX INSTITUTE

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Economic and Management Sciences
Fakulteit Ekonomiese en Bestuurswetenskappe
Lefapha la Disaense tša Ekonomi le Taolo

Technical Efficiency of Water Boards in South Africa:
A Costing and Pricing Benchmarking Exercise

Victor Ngobeni[1] *and Marthinus C. Breitenbach*[2]

ABSTRACT

South Africa is a water-scarce country with deteriorating water-resource quality, security, infrastructure investment and management. Although 89 per cent of households have access to water supply, only 64 per cent or 10.3 million households are estimated to have reliable water supply. The sector faces weakening financial viability due to inefficient operations coupled with inadequate investment, financing and under-pricing. As a result, cost recovery is not achieved.

In this paper, we use Data Envelopment Analysis (DEA) to investigate the technical efficiency of the nine water boards. We achieve this objective by using expenditure, water losses, sales volumes and tariffs to model the industry's efficiency frontiers; the four models produce mean technical efficiency scores of 73.2, 83.7, 85.8 and 92.3 per cent, respectively. The study also determines the average bulk water tariffs that should be charged in the sector, thereby establishing the basis for economic regulation.

JEL Classification: C14, C6, D24, H32, Q25

Keywords: Water Boards, Water Losses, Data Envelopment Analysis, Volumes, Tariffs, Expenditure, Technical Efficiency

---

[1] Victor Ngobeni is a PhD student in the field of public economics and an economist by profession practising in the public sector in South Africa.

[2] Prof. Marthinus Breytenbach is an associate professor at the Department of Economics, University of Pretoria.

1. Introduction

The value chain in the water sector comprises water resources, bulk and retail water, and sanitation services. According to Masindi and Duncker (2016), the Department of Water and Sanitation (DWS) is the custodian of water resources; it leads policy development and regulates the water and sanitation sector in South Africa. The DWS manages water resources by planning and implementing large infrastructure projects, issuing water use licenses, allocating water, performing catchment management functions, river systems management, water storage and abstraction, and return-flow management. Masindi and Duncker (2016) report that South Africa is a water scarce country. The DWS (2019) points out that this is not only caused by insufficient water resources, but also by poor infrastructure maintenance and low levels of investment. This has a significant impact on the socio-economic objectives of the country; it is therefore critical that water resources are managed efficiently.

According to the DWS (2019), the national annual runoff is approximately 49 000 million m^3 giving a reliable yield of surface water, at an acceptable assurance of annual supply at 98 per cent of 10 200 million m^3. There are more than 5 511 registered dams in South Africa; the water boards, DWS, municipalities and other state departments own about 854 dams, mostly with high storage capacity and the private sector owns about 4 657 dams (DWS 2018). The mines, industries and businesses own approximately 335 dams and agriculture has 4 322 dams, most of which have small storage capacity. The total gross storage capacity of registered dams is approximately 33 292 million m^3 (i.e. 33 292 gigalitres). Ground water potential is 7 500 million m^3/a, with only 50 per cent currently in use. The quality of rivers and ground water remains poor, signalling weaknesses in the management of water resources. In terms of water use, the DWS (2019) reports that agriculture uses 61 per cent of allocated water while municipalities use 27 per cent. The remainder is attributable to other sectors, such as energy, industries, mining, livestock and forestry.

According to Masindi and Duncker (2016), there are nine water boards mainly responsible for bulk water purification and distribution; some municipalities and the DWS however also perform this function. The National Treasury (2019) states that water boards are mandated by the Water Services Act to provide bulk industrial and potable water services to municipalities and industries within their legislated areas of supply. The water boards vary in size, activities, customer mix, revenue base and operational capacity. The National Treasury (2020, 2019, 2018) indicates that over the five-year period from 2015 to 2019, the consolidated water boards’ bulk potable water supply volumes were 2 528 million m^3 or 2.528 gigalitres per annum on average, charged at varying levels of bulk water tariffs. Rand Water accounted for 65 per cent of total volumes and Umgeni Water accounted for 17 per cent.

According to National Treasury (2020, 2019, 2018), the relative revenue and expenditure of the water boards are commensurate with the variations in volume, with Rand Water accounting for 62 per cent of the total average expenditure of R16.2 billion and Umgeni Water for 12 per cent over the five-year period. To improve reliable and clean water supply, the water boards invested on average R5 billion on bulk water and sanitation infrastructure over the same period. The water boards purchased most of their raw water from the DWS. These entities treat the raw water at their water treatment plants (WTWs) for distribution to their customers (largely the 143 municipalities).

In terms of the Constitution, municipalities have the sole powers to reticulate water to households. Where there is no capacity to deliver, however, they appoint other service providers to perform the function on their behalf. The bulk distribution networks of water boards are generally in good condition, with acceptable levels of water losses, showing good management of infrastructure. However, water losses are higher for some water boards relative to peers, needing immediate attention. The DWS (2019) indicates that approximately 56 per cent of over 1 150 municipal wastewater treatment works (WWTWs) and approximately 44 per cent of 962 WTWs in the country are in a poor or critical condition, and 11 per cent of this infrastructure is completely dysfunctional. Despite this, 89 per cent of households have access to water supply infrastructure; only 10.3 million people (64 per cent of households) however are estimated to have a reliable water supply service. Therefore, most challenges in the water sector are prevalent in the water resources and retail space.

Masindi and Duncker (2016) and DWS (2019) indicate that some challenges facing water boards, municipalities and the DWS include weak governance and lack of adequate funding coupled with inefficient operations to meet and sustain investment requirements, inappropriate financing and pricing arrangements, and lack of accountability. Moreover, water is severely under-priced and cost recovery is not being achieved. This results in ineffective operations and maintenance of water supply infrastructure. Gupta et al. (2012) advise that if the revenue generated from user charges falls short of the expenditure made for the supply of water, the consequence is deteriorating assets and weak financial sustainability of services. According to the DWS (2019), to achieve water security an estimated capital funding gap of around R33 billion per annum is needed for the next ten years. This must be achieved through a combination of improved revenue generation and a significant reduction in costs.

Restating the aforementioned problems is not helpful; a solution is needed. The aim of the study is to benchmark the production technologies of the water boards in South Africa to determine potential technical efficiency improvements. There are many water sector technical efficiency benchmarking studies across the globe, including on municipalities in South Africa. However, we did not find any study that examined the efficiency of South African water boards from a technical efficiency perspective (in particular costing and pricing). This paper fills this gap in the literature by applying a non-parametric benchmarking tool known as Data Envelopment Analysis (DEA) to compare the efficiency of productive units (nine water boards in this case). This is achieved by scientifically analysing data related to the resources used by the water boards and the outcomes they achieve during the study period. DEA enables us to analyse the technical efficiencies of water boards with respect to water loss management, bulk water costing and pricing, using data from 2014/15 to 2018/19. This provides an opportunity for policy makers to determine how well a particular water board is performing relative to its peers, to identify good and bad practices, and finally find more efficient approaches to achieve financial sustainability and reliable water supply.

In scenario 1, we find that the average technical efficiency score of the nine water boards is 73.2 per cent. The score is 83.7 per cent in scenario 2, 85.8 per cent in scenario 3 and 92.3 per cent in scenario 4. This reflects that not all water boards were operating on the efficiency frontiers. The inefficient water boards needed to improve technical efficiency by 26.8, 16.3, 14.2 and 7.7 per cent respectively in the four scenarios. Specifically, in Model 1, only three water boards were efficient, while four boards were efficient in Models 2, 3 and 4 respectively. That is, in Models 1 and 2, the efficient water boards use optimal levels of personnel, expenditure while maintaining appropriate levels of water losses at prevailing output levels (volumes sold). In Models 3 and 4, the efficient water boards are maximising water sales volumes and charging bulk water tariffs at prevailing levels of expenditure.

The rest of the paper is organised as follows: Section 2 discusses the relevant literature, Section 3 presents the methodological specification, Section 4 explains the data, Section 5 presents the results and Section 6 concludes the study.

2. Literature review

DEA has been extensively used globally to analyse technical efficiency in the water sector. To the best of our knowledge, this is the first study using DEA or any other modelling technique to analyse the efficiency of water boards in South Africa. In their paper regarding water sector efficiency, Ali et al. (2018) use the constant returns to scale (CRS) along with an input-minimisation DEA to analyse the performance of four water supply units in Pakistan over a three-year period (from 2013 to 2015). The study adopts a six-variable production technology consisting of two outputs (number of consumers served and revenue) and four inputs (management, maintenance, operations and energy costs). The authors find that only three units were efficient. The average technical efficiency scores of 89, 92 and 97 per cent are respectively observed for the three years. Lannier and Porcher (2014) use an input-minimisation DEA based on the variable returns to scale (VRS) in stage one and a Stochastic Frontier Analysis (SFA) in stages two and three. They assess the relative technical efficiency of 177 water-supply decision making units (DMUs) in France. Revenue is used as a proxy for costs, while the volume of billed water, number of customers and length of water pipes are used as outputs. Network performance is included as a quality output. Lannier and Porcher find that private utilities are on average slightly less efficient than public utilities due to differences in resource management.

The first-stage DEA yields an average technical efficiency score of 75.4 per cent and 84.1 per cent. After factoring the environmental variables, the public management scores are on average 0.88 while the private management scores are 0.82. The third-stage DEA yields average technical efficiency scores of 90 per cent.

Kulshresthaa and Vishwakarma (2013) use a DEA model to determine the water supply efficiency of 20 urban municipalities in the state of Madhya Pradesh in India. Three input-oriented DEA models are used in efficiency evaluation. Each model has three outputs (number of connections, length of distribution network and average daily water production), while the number of inputs vary from one to three (staff per 1000 connections, operating expenditure and non-revenue water) consecutively in each model. The results of the analysis indicate significant inefficiencies amongst various municipalities that supply water. It is found that larger cities exhibit better efficiencies than the smaller ones. The average technical efficiency score in Model 1 is 49 per cent with the highest score of 83 per cent observed in Model 3. Alsharif et al. (2008) use DEA to measure the technical efficiency of 33 Palestinian municipalities for the years 1999 to 2002. They find that the Gaza Strip efficiency scores are considerably lower than those of the West Bank. Water losses are the major source of the inefficiency, indicated by the large slacks on this input. Another study by Gupta et al. (2012) applies an output-oriented DEA to assess the productive efficiency of urban water supply systems in 27 selected Indian cities. The study uses expenditure as an input and total water served by a water utility as a function of revenue, expenditure and water production capacity. Two cities are efficient under the CRS while six reach the efficiency frontier under the VRS. The efficiency results have implications for urban domestic water pricing. Most water utilities are operating under decreasing returns to scale (DRS), implying that water should be priced at a marginal cost of supply.

Singh et al. (2014) apply DEA to determine the relative efficiency of 12 selected Indian urban water utilities (municipal bodies) of Maharashtra state/province. They use an input-oriented CRS DEA model with total expenditure and staff size as two inputs and water supplied and the number of connections as two outputs. Only a third of the DMUs are efficient. Marques et al. (2014) apply DEA to 5,538 observations of 1,144 utilities that supplied drinking water between 2004 and 2007 in Japan. The models consider three inputs and two outputs. The inputs include capital, staff and other operational expenditures. For outputs, the volume of water and the number of customers are used. They find that the average level of inefficiency (weighted by volume) is 57 per cent in the CRS model, but only 24 per cent for the VRS model. Lombardi et al. (2019) use DEA to determine the efficiency of a selected sample of 68 Italian water utility companies from 2011 to 2013. The study uses water distributed percentage of the water delivery network length as an output. The costs of material, services, leases and capital are used as inputs. Under the output-oriented models, the mean technical efficiency score is 0.85 under the VRS and 0.65 under the CRS. From an input-minimisation perspective, the scores are 0.74 and 0.63 respectively for the VRS and the CRS.

Turning to South Africa, Brettenny and Sharp (2016) study the efficiency of 88 authorised water services of local and metropolitan municipalities. The paper uses an input-oriented DEA with operating costs and system input volume as sole input and output variables. Of the 44 urban water services authorities, ten are efficient under the VRS and four under the CRS. Of the rural water services authorities, 5 are efficient under the VRS and only one under the CRS. The performances yield an average technical efficiency of 63.6 per cent for urban municipalities and 52.6 per cent for rural municipalities. This indicates that, on average, 36.4 per cent less expenditure could be used in urban municipalities and 47.4 per cent less expenditure in rural municipalities to achieve the given levels of water service delivery nationwide.

Murwirapachena et al. (2019) adopt DEA, SFA and stochastic non-parametric envelopment of data (StoNED) methods to analyse efficiency, based on cross-sectional data from 102 South African water utilities in the period 2013/14. They obtain varying results under the different methods. The study uses total cost as a single input and water output, total connections and the length of mains as outputs, while population serves as an environmental output variable. The study estimates an input-oriented DEA, which assumes VRS to deal with size variability. The maximum average efficiency scores under each method are as follows: StoNED (MM): 68.1 per cent, SFA: 66.2 per cent and DEA: 44.7 per cent for all utilities, 58.7 per cent for the big ones and 46.1 per cent for the small utilities.

In another study, Monkam (2014) uses DEA and SFA to analyse the efficiency of 231 local municipalities in South Africa. The study uses municipal operating expenditure as an input and five output variables: the number of consumer units receiving water, sewerage and sanitation, solid waste management and electricity and the total population per municipality. The results show that on average, B1 and B3 category municipalities could have theoretically achieved the same level of basic services with about 16 and 80 per cent fewer resources respectively.

Mahabir (2014) uses the Free Disposable Hull (FDH) technique to measure the technical efficiency of 129 municipalities in the provision of water from 2005 to 2009. The selected input is municipal expenditure per capita; the selected outputs are access to piped water, grid electricity connections, a ventilated pit latrine, a flushable toilet and removal of solid waste at least one a week. The study concludes that over the period, four municipalities remains constantly efficient: Thembisile in Mpumalanga, Polokwane in Limpopo, Mangaung in the Free State and eThekwini in Kwazulu-Natal. The average technical efficiency score is 0.3 in 2005/06, peaking at 0.39 in 2007/08, and declining to 0.35 in 2008/09. This suggested that on average, municipalities in the sample could obtain the same level of output with at least 60 to 70 per cent less inputs (resources).

Dollery and Van der Westhuizen (2009) use DEA to determine the productive efficiency of 231 local municipalities and 46 district municipalities in the delivery of basic services covering the period 2006/2007. The study uses two inputs: operating income and staff costs and five outputs, number of households, water, sanitation, refuse and electricity. The study determines the efficiency estimates under the CRS and the VRS; embracing output-orientated and input-orientated approaches. Under the output-orientated approach, the district municipalities are on average only 30.5 per cent efficient under the CRS, 58 per cent efficient under the VRS and 48 per cent scale efficient. Two municipalities are operating at DRS — they are operating at a too large scale in efficiency terms. Under the input-orientated approach, the district municipalities are on average 47 per cent technically efficient in the case of the VRS and 64.1 per cent scale efficient. With regard to the returns to scale, 32 municipalities are operating under IRS, implying they are operating on a scale that is too small in efficiency terms. Only two district municipalities are operating at the optimal scale. The remaining district municipalities are operating at DRS. In terms of local municipalities, those with the highest average technical efficiency scores under the output-maximisation and input-minimisation measures for both the CRS and VRS are in Gauteng, with respective average technical efficiency scores of 67.7, 79.4, 67.7 and 76.7 per cent.

3. Modelling setup

Gupta et al. (2012) recommend the use of DEA for determining the technical efficiency of DMUs. They argue that despite other techniques such as the ordinary least square (OLS) and SFA being used in analysing the technical efficiency of the water industry, DEA is the most appropriate. The OLS technique is easy to use and simple to interpret; it does however suffer from the problem of specifying the functional form for the production technology and is unable to provide information on frontier performance. The SFA, although able to solve the latter problem by specifying a composed error term and splitting the error into two different parts as a data noise term and error due to the inefficiency, also suffers from the problem of specifying the functional form and requires specification of the distribution patterns of the inherent error terms.

Gupta et al. (2012) states that a DEA technique does not require the specification of either the functional form and/or the distributional form of the error term. Its major disadvantage is its failure to accommodate the effects of data noise, which OLS and SFA do. DEA basically erects a production frontier consisting of the most technically efficient DMUs in the sample. This process generates technical efficiency measures for each unit in the sample by comparing observed values to optimal values of outputs and inputs. A score of 1 represents the best performing unit in the sample and a score of less than 1 implies that the unit is not performing as well as its efficient peers. DEA determines how much input could have been saved and the extent of output that could have been improved by inefficient DMUs by emulating the production processes of efficient DMUs.

In this paper, we use the VRS approach reported by Gavurova et al. (2017) that was developed in 1984 by Banker, Charnes and Cooper, to allow for consideration of scale efficiency analysis, this approach is referred to as the Banker, Charnes and Cooper (BCC) model. The terminology "envelopment" in DEA refers to the ability of the efficiency production frontier to tightly enclose the production technology (that is, the input and output variables). Cooper et al. (2007) and McWilliams et al. (2005) state that DEA was developed in a microeconomic setting and applied to firms to convert inputs into output. However, in efficiency determination, the term “firm” is often replaced by the more encompassing DMU. DEA is an appropriate method of computing the efficiency of institutions employing multivariate production technologies. Aristovnik (2012) and Martić et al. (2009) state that there are input-minimisation and output-maximisation DEA models. The former determines the quantity of inputs that could be curtailed without reducing the prevailing level of outputs. The latter expands the outputs of DMUs to reach the production possibility frontier while holding inputs constant. However, the selection of each orientation is study-specific.

According to Taylor and Harris (2004), DEA is a comparative efficiency measurement tool that evaluates the efficiency of homogeneous DMUs operating in similar environmental conditions, for example, DMUs dealing with bulk water supply and where the relationship between inputs and outputs is unknown. Wang and Alvi (2011) report that DEA only uses the information used in a particular study to determine efficiency and does not consider exogenous factors. DEA measures the distance of production functions by determining the radial extent of DMUs to the efficiency frontiers. It does so by categorising the DMUs into extremely efficient and inefficient performers. In terms of the DEA methodology, the current study uses the BCC model with the ratio of DMUs complying with the norms of being at least two to three times the combined number of inputs and outputs. Before explaining the BCC model, it is prudent to first describe the CRS model developed by Farrell in 1957 and enhanced in 1978 by Charnes, Cooper and Rhodes (also called the CCR model). They converted the fractional linear efficiency estimates into linear mathematical efficiency programmes under the CRS. These models are described in the following paragraphs.

Under the CCR model, suppose there are C different number of inputs and D different number of outputs for N DMUs. These quantities are represented by column vectors xij (i = 1, 2, 3, …C, j = 1,2,3 …N) and qrj (r = 1, 2, 3, …D, j = 1,2,3 …N) The $C \times N$ input matrix (X) and $D \times N$ output matrix (Q) represent the production technology for all N of the DMUs. For each DMU, the ratio of all the output variables over all the input variables is represented by $u'qrj/v'xi$ where $u = D \times 1$ vector output weights and $v = C \times 1$ vector input weights. The optimal weights or the efficiency estimates are obtained by solving a mathematical problem. In the context of the CRS, an efficient DMU operates at technically optimal production scale (TOPS). Hence the optimal weights or efficiency estimates are obtained by solving a mathematical problem that is reflected in equation 1.

$$\text{Tops} = \max_{u,v} (u'qrj/v'xij)$$

$$St.$$

$$u'qrj/v'xij \leq 1 \qquad (1)$$

$$u, v \geq 0$$

Equation 1 shows the original linear programme, called the primal. It aims to maximise the efficiency score, which is represented by the ratio of all the weights of outputs to inputs, subject to the efficiency score not exceeding 1, with all inputs and outputs being positive. Equation 1 has an infinite number of solutions, if (u,v) is a solution, so is αv,αv. To avoid this, one can impose a constraint v'xij =1, which produces equation 2.

maxu,v (u'qrj)

$St.$

v'xij =1 (2)

u'qrj - v'x$ij \leq 0$

u, v ≥ 0

An equivalent envelopment problem can be developed for the problem in equation 2, using duality in linear programming. The dual for $\max_{u,v}$ (u'qrj) is $min\theta, \lambda\theta$. The value of θ is the efficiency score; it satisfies the condition $\theta \leq 1$; it is the scalar measure. Lauro et al. (2016) report that λ is an $N \times 1$ vector of all constants representing intensity variables indicating necessary combinations of efficient entities or reference units (peers) for every inefficient DMU, it limits the efficiency of each DMU to be greater than 1. This results in equation 3, which represents the CCR-CRS model with an input minimisation orientation.

$Min\theta, \lambda\theta$

$St.$

-qrj + $Q\lambda \geq 0$ (3)

θxi - $X\lambda \geq 0$

$\lambda \geq 0$

Avkiran (2001) states that the CRS postulates no significant relationship between DMUs' operational size and their efficiency. That is, under the CRS assumption, the large DMUs are deemed to attain the same levels of efficiency as small DMUs in transforming inputs to outputs. Therefore, the CRS assumption implies that the size of a DMU is not relevant when assessing technical efficiency. However, in most cases DMUs have varying sizes and this becomes a factor when determining their efficiency. As a result, Gavurova et al. (2017) mention that in 1984, the CCR formulation was generalised to allow for the VRS. Aristovnik (2012) adds that if one cannot assume the existence of the CRS, then a VRS type of DEA is an appropriate choice for computing efficiency. Gannon (2005) advises that the VRS should be used if it is likely that the size of a DMU will have a bearing on efficiency. As such, Yawe (2014) cautions that the use of the CRS specification when the DMUs are not operating at an optimal scale results in a measure of technical efficiency that is confounded by scale effects. The solution is to use the VRS as it permits for the calculation of scale inefficiency. The VRS is comprehensive as it also captures the CRS performance results. The CRS linear programming problem can be modified to account for the VRS by adding the convexity constraint: $N1'\lambda = 1$ to equation 3, where $N1$ is a $N \times 1$ vector of ones to formulate equation 4. Therefore, equations 1 to 3 represent the CRS models while equations 4 to 5 represent the VRS models with an input-minimisation orientation. The data for Models 1 and 2 of this study are fitted through equations 4 and 5.

$Min\theta, \lambda\theta$

$St.$

$$-qrj + Q\lambda \geq 0 \quad (4)$$

$\theta xij - X\lambda \geq 0$

$N1'\lambda = 1$

$\lambda \geq 0$

Lauro et al. (2016) and Yuan and Shan (2016) report that the CCR and the BCC models only differ in the manner the latter includes convexity constraints. Since the current model considers the VRS, the restriction $\sum_{i=1}^{n} \lambda n = 1$ is introduced. Ramírez Hassan (2008) cautions that if this restriction is not there, it would imply the application of the CRS model. The same analogy applies to all the inefficient DMUs in the sample. That is, the slacks and the radial movements are calculated for all inefficient DMUs using equation 5. The BCC is able to calculate pure technical efficiency and inefficiency, and when applied with the CCR model, it also measures scale inefficiency. Where $\sum_{i=1}^{I} \lambda I = 1$, a DMU is on a CRS frontier. If $\sum_{i=1}^{I} \lambda I < 1$, the DMU is located on the IRS frontier and if $\sum_{i=1}^{I} \lambda I > 1$, there is DRS given that this study has adopted both the CCR and the VRS with an input-minimisation orientation. The DEA models used in this study also consider the slack movements for the inefficient DMUs. As a result, the models account for the slacks in equation 5.

Min $\theta, \lambda j, Sr^{+}, Si^{-}$

$$\theta - \varepsilon \left[\sum_{i=1}^{C} Si^{-} + \sum_{r=1}^{D} Si^{+} \right]$$

$St.$

$$\theta xi_0 - \sum_{j=1}^{N} xij\,\lambda j - Si^{-} = 0, \quad (5)$$

$\theta qr_0 = \sum_{j=1}^{N} qrj\,\lambda j - Sr^{+} = 0,$

$$\sum_{j=1}^{N} \lambda j = 1.$$

Models 3 and 4 of this paper adopt a slack-based VRS model with an output-maximisation orientation. Therefore, the model is expanded to account for this in Equation 6, which represents the VRS output-maximisation orientation with no slacks while equation 7 includes them. The improved input and output variables (X_j', Y_j') in equation 8 are considered fully BCC efficient.

$Max\theta, \lambda\theta$

St.

$-qrj + Q\lambda \geq 0$ (6)

$\theta xij - X\lambda \geq 0$

$N1'\lambda = 1$

$\lambda \geq 0$

Max $\theta, \lambda j, Sr^+, Si^-$

$$\theta + \varepsilon \left[\sum_{i=1}^{C} Si^- + \sum_{r=1}^{D} Si^+ \right]$$

$St.$

$\theta xi_0 + \sum_{j=1}^{N} xij\, \lambda j + Si^- = 0,$ (7)

$\theta qr_0 = \sum_{j=1}^{N} qrj\, \lambda j - Sr^+ = 0,$

$$\sum_{j=1}^{N} \lambda j = 1$$

$\lambda j, Sr^+, Si^- > 0$

$X'j = Xj - s-$ (8)

$Y'j = \theta Yj + sr^+.$

Coelli et al. (2005) define slacks as input excesses and output shortfalls that are required over and above the initial radial movements to push DMUs to efficiency levels. Both the slack and radial movements are associated only with the inefficient DMUs. The radial movements are initial input contractions or output expansions that are required for a firm to become efficient. Si^{+} and Si^{-} in equation 5 are the output and input slacks respectively to be calculated with $\theta,$ while $\lambda n.$ ε is the non-Archimedean constant. Gavurova et al. (2017) suggest that if the slack variables of a DMU are not equal to zero and the technical efficiency score is lower than one, it is necessary to perform a non-radial shift that is expressed by the slack variables to achieve technical efficiency. In equation 5, the slack variables determine the optimum level of inputs that DMUs would have to utilise and the outputs that they would have to produce to become efficient, provided that these DMUs are inefficient. Therefore, the slacks depict the underproduced outputs or overused inputs.

4. Data

The sample of the study consists of nine water boards for Models 1 to 3 and seven DMUs for Model 4. The study measures the technical efficiency of water boards using sales in bulk water volumes, personnel, water losses, total expenditure and tariffs across the four models (Table 1). There is a 99 per cent positive correlation between all input and output variables, except for tariffs (as a proxy of revenue) and total expenditure, where the correlation coefficient is 30 per cent and for volumes sold and water losses (a proxy of cost incurred and not recovered) is -48 per cent. In this study, we follow Kulshresthaa and Vishwakarma (2013) and Alsharif et al. (2008) in using water losses as an input; Picazo-Tadeo et. al (2007) advise that omitting quality variables such as water losses may produce a biased picture of performance.

Table 1: Analytical variables and data

	Model 1		Model 2			Models 3 and 4		
Water Boards	**Volumes sold (ML/pa)**	**Personnel numbers**	**Water losses (%)**	**Volumes sold (ML/pa)**	**Total expenditure (R'000)**	**Volumes sold (ML/pa)**	**Tariffs (R/kl)**	**Total expenditure (R'000)**
Amatola	32 733	458	12	32 733	417 805	31 820	11	459 773
Bloem	81 141	357	9	81 141	639 829	79 528	8	764 629
Lepelle	90 054	464	5	90 054	626 799	91 627	6	689 588
Magalies	86 027	293	6	86 027	484 741	91 458	7	574 320
Mhlathuze	45 208	264	3	45 208	590 534	44 229	4	549 716
Overberg	3 872	68	7	3 872	44 988	3 355	7	50 075
Rand	1 635 630	3 403	3	1 635 630	10 078 781	1 624 584	9	11 429 180
Sedibeng	114 074	852	9	114 074	1 389 795	120 425	9	1 544 882
Umgeni	439 706	1 106	3	439 706	1 934 871	453 185	7	2 161 570

Sources: National Treasury (2020, 2019, 2018), Amatola Water (2019, 2018, 2017, 2016, 2015), Bloem Water (2019, 2018, 2017, 2016), Lepelle Northern Water (2015), Magalies Water (2019, 2018, 2017, 2016, 2015), Mhlathuze Water (2019, 2018, 2017, 2016, 2015), Overberg Water (2019, 2019, 2017), Sedibeng Water (2019, 2017, 2016, 2015), Rand Water (2019, 2018, 2017, 2016, 2015), Umgeni Water (2019, 2018, 2017, 2016).

Data for Models 1 and 2 are based on a five-year average from 2014/15 to 2018/19. Data for Models 3 and 4 are based on a two-year average from 2017/18 to 2018/19 due to missing values in earlier years for the bulk water tariffs for some water boards. The data for Model 4 are similar to Model 3, except that Rand and Umgeni water boards are excluded from Model 4. Our study uses an input-minimisation VRS DEA for Models 1 and 2 and the output-maximisation DEA for Models 3 and 4.

5. Results

The results of the efficiency analysis are reported in Table 2 and Figure 1. The mean technical efficiency score of the nine entities is 73.2 per cent in Model 1. Only Overberg, Rand and Umgeni water boards are efficient in using the current staff levels and keeping water losses low, at prevailing levels of water volumes sold. The Sedibeng, Amatola and Mhlathuze water boards are the most inefficient in this model. On average, all six inefficient water boards could improve the use of resources by 26.8 per cent. Appendix 1 shows that these water boards could reach the efficiency benchmark with 1 299 fewer personnel and could realise expenditure savings of R1.9 billion at prevailing levels of water sales volumes per annum. Appendix 1, also shows the efficient peers from which the inefficient water boards could draw some lessons. The average technical scale efficiency score in this model is 83.7 per cent. Only Rand and Umgeni water boards operate at an optimal scale while others were on IRS (too low scale).

The mean technical efficiency rate of water boards in Model 2 is 83.7 per cent. In this scenario, Mhlathuze, Overberg, Rand and Umgeni water boards are efficient. Five water boards are inefficient and could improve on the use of resources by 16.3 per cent. Appendix 1 shows that these entities could be fully technically efficient by realising consolidated expenditure savings of R1.2 billion, with Sedibeng Water accounting for 59 per cent. Amatola, Bloem and Sedibeng water boards have to reduce water losses by 6, 3 and 5 per cent respectively.

Table 2: Technical and scale efficiency benchmarks

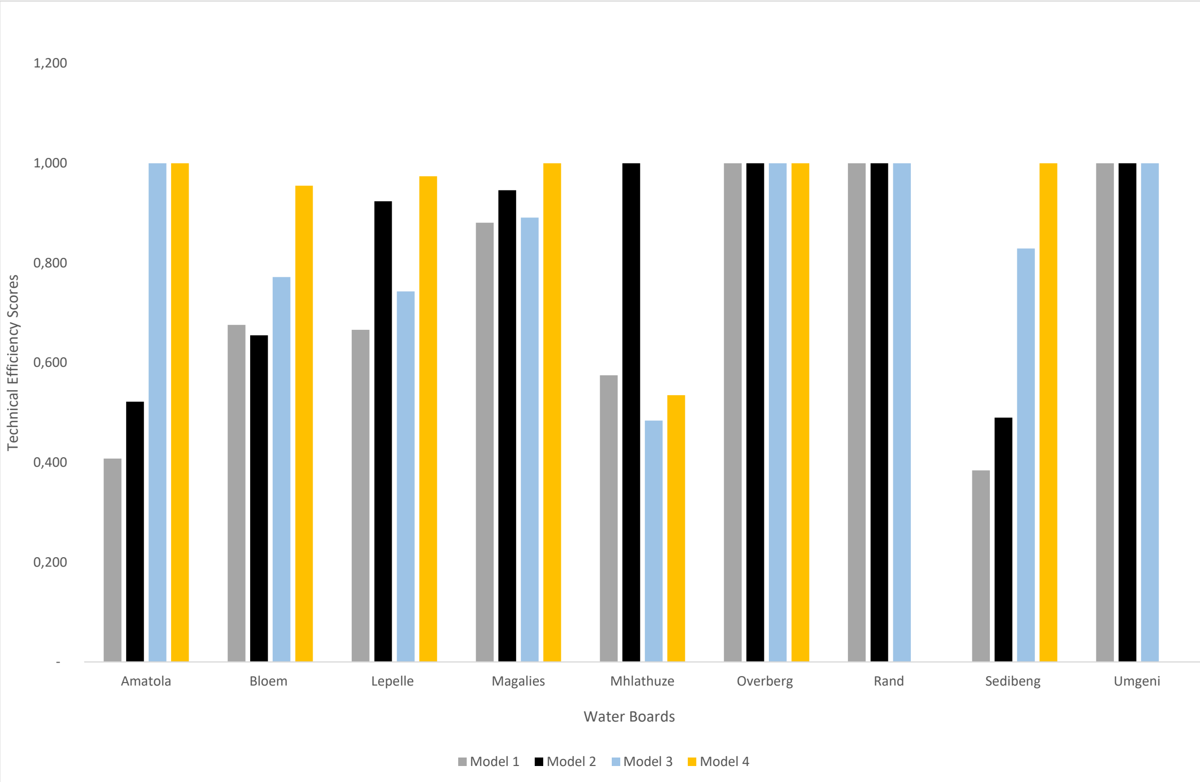
	Technical Efficiency				Scale efficiency							
Water boards	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 1**		**Model 2**		**Model 3**		**Model 4**	
Amatola	0,408	0,522	1,000	1,000	0,850	IRS	0,665	IRS	0,449	DRS	0,524	DRS
Bloem	0,676	0,655	0,772	0,955	0,838	IRS	0,850	IRS	0,705	DRS	0,702	DRS
Lepelle	0,666	0,924	0,743	0,974	0,947	IRS	0,683	IRS	0,902	DRS	0,864	DRS
Magalies	0,881	0,946	0,891	1,000	0,885	IRS	0,825	IRS	0,905	DRS	1,000	
Mhlathuze	0,575	1,000	0,484	0,535	0,688	IRS	0,335	IRS	0,854	DRS	0,953	DRS
Overberg	1,000	1,000	1,000	1,000	0,391	IRS	0,391	IRS	1,000		1,000	
Rand	1,000	1,000	1,000		1,000		1,000		0,679	DRS		
Sedibeng	0,384	0,490	0,829	1,000	0,938	IRS	0,735	IRS	0,476	DRS	0,490	
Umgeni	1,000	1,000	1,000		1,000		1,000		1,000			
Mean	0,732	0,837	0,858	0,923	0,837		0,720		0,774		0,790	

Sources: DEA efficiency results.

In this model, only Umgeni and Rand water boards are operating on the most optimal scale compared to the rest. The seven water boards on IRS have room to improve their operational scale to reach scale efficiency.

The mean technical efficiency score of the nine DMUs in Model 3 is 85.8 per cent. In this model, most water boards are close to the efficiency frontier. Four (or 44.4 per cent) of the studied water boards are efficient while five (or 55.6 per cent) are inefficient. Amatola water joined Overberg, Rand and Umgeni water boards in the most optimal technical efficiency frontier. Therefore, the current expenditure, volumes supplied and tariffs charged by these water boards are at efficient levels. The other five water boards have to improve productive efficiency by maximising the outputs (tariffs and volumes) at prevailing levels of expenditure.

Figure 1: Technical efficiency benchmarks



Sources: Authors' graph based on efficiency results

Appendix 1 reflects the necessary technical efficiency improvements. Bloem water could reach the best practice frontier by selling an additional 23 639 million m^3 per annum while increasing tariffs from R8 to R10 per kilolitre. The Lepelle Northern Water need to increase the volumes sold by 31 747 million m^3 per annum and tariffs to R8 per kilolitre. To reach the efficiency frontier, Magalies water board should increase volumes sold by 102 143 million m^3 per annum and bulk water tariffs by R1 to R8 per kilolitre. Comparatively, the Mhlathuze Water needs to increase its volumes by more than 100 per cent and tariffs by R4 to R8 per kilolitre to be technically efficient. The Sedibeng water board has to increase volumes sold by 24 779 million m^3 per annum at prevailing levels of expenditure while increasing bulk water tariffs to R11 per kilolitre. Only Umgeni and Overberg water are operating at optimal scale; the other water boards are on a DRS.

In Model 4, the average technical efficiency score of the seven small to medium-sized water boards (excluding Rand and Umgeni) is 92.3 per cent. In this model, Bloem, Lepelle Northern and Mhlathuze water boards are inefficient. Bloem water needed to improve bulk water sales by 3 779 million m^3 per annum and bulk water tariffs by R8 per kilolitre. Lepelle Northen Water could reach the efficiency frontier by selling 2 464 million m^3 per annum and increasing tariffs by R1 to R7 per kilolitre. Mhlathuze water has potential to be technically efficient by increasing sales volumes by 38 231 million m^3 per annum and bulk water tariffs by R3 to R7 per kilolitre. Amatola, Magalies, Overberg and Sedibeng water boards are at the most productive optimal scale in this model, they serve as best-practice benchmarks for the inefficient water boards.

6. Conclusion

The study analyses the technical efficiency of water boards using the input-oriented and output-oriented DEA methodologies. Model 1 recommends that the six inefficient water boards should review their staff composition to realise technical efficiency. They could operate with 1 299 fewer personnel and still be efficient while also finding spending efficiency savings of R1.8 billion, at prevailing output levels. Model 2 determines that on average, the five inefficient water boards should be spending R15 billion instead of R16.2 billion while Amatola, Bloem and Sedibeng water boards have to reduce water losses by 6, 3 and 5 per cent respectively. These resources could be redirected for capital outlays and expansion to address backlogs within their areas of supply.

Given the pricing and operational sustainability challenges facing water boards, the results of Models 3 and 4 are extremely important. They carry a significant weight in influencing bulk water pricing reforms. In Model 3, it is observed that on average, water boards should charge an average bulk water tariff of R9 per kilolitre and R7 per kilolitre in Model 4. Therefore, the study provides a basis for pricing or economic regulation – a policy imperative that has eluded the sector for decades.

In Model 3, we show that Bloem, Lepelle, Magalies, Mhlathuze and Sedibeng water boards are not charging optimal bulk water tariffs and selling optimal water volumes relative to efficient peers. The average technical efficiency score in this production technology is 85.8 per cent, with these five water boards needing to improve efficiency by 14.2 per cent. Amatola, Overberg, Rand and Umgeni water boards are however on the best practice frontier. They manage to reach the frontier by optimising the combination of tariffs and volumes sold, at prevailing levels of expenditure. In Model 4, we show that when sampling only the small and medium-sized water boards, only Bloem, Lepelle Northern and Mhlathuze water boards are inefficient, needing to improve relative technical efficiency by 7.7 per cent. Amatola, Magalies, Overberg and Sedibeng water boards are efficient. The study ascertains the relative and optimal average national bulk water tariffs that could be charged by the water boards' industry. The findings of the study also scientifically quantify the necessary input and output adjustments for optimal productive efficiency in the sector. Moreover, water losses are the major source of inefficiency as indicated by the large improvements in efficiency scores between Models 1 and 2. Therefore, decision makers operating in inefficient water boards should also focus on maintaining, refurbishing and rebuilding the water infrastructure networks to minimise water losses. Moreover, all the inefficient water boards identified in the study could be assisted through state or private financing to expand operations and maintain their assets, with repayment channelled through future generated efficiencies and increased tariff revenue predicted by the study. It is advised however that the recommendations of the study should be implemented subject to the feasibility and affordability of the proposed reforms. The study is constrained in several ways. It does not take into consideration other external environmental factors that could affect the efficiency of water boards, such as non-payment for water services. Also, the selection of the indicators affects the outcomes of the model; a different set of indicators may therefore lead to a different collection of results and analyses.

References

Ali, A. Bashir, M. Munib, M. Saqib, S. and Sami, A. 2018. "Assessing the Efficiency of Water and Sanitation Agencies of Punjab, Pakistan: A Benchmarking Approach." *Journal of Managerial Sciences*, XI (3), pp. 245-254.

Alsharif, K. Feroz, E.H. Klemer, A. and Raab, R. 2008. "Governance of Water Supply Systems in the Palestinian Territories: A Data Envelopment Analysis Approach to the Management of Water Resources." *Journal of Environmental Management*, 87(1), pp.80-94.

Amatola Water. 2019. *Integrated Annual Report. 2018/19.* Accessed, 18 June 2020 https://www.amatolawater.co.za/files/documents/000/000/032/1579774887_lXyLS_Amatola-Water-AR--2018-19--29.pdf

Amatola Water. 2018. *Integrated Annual Report. 2017/18.* Accessed, 18 June 2020 https://www.amatolawater.co.za/files/documents/000/000/031/1579774544_hjGqI_Amatola-Water-AR-2018-Dec-2019-february.pdf

Amatola Water. 2017. *Integrated Annual Report. 2016/17.* Accessed, 18 June 2020 https://www.amatolawater.co.za/files/documents/000/000/030/1592131003_ltnWk_Integrated20Annual20Report20Version2017.pdf

Amatola Water. 2016. *Integrated Annual Report. 2015/16.* Accessed, 18 June 2020 https://www.amatolawater.co.za/files/documents/000/000/029/1579770404_Dvjeb_9718-16-Amatola-AR-WS228-MR.pdf

Amatola Water. 2015. *Integrated Annual Report. 2014/15.* Accessed, 18 June 2020 https://www.amatolawater.co.za/files/documents/000/000/028/1579770041_JjONO_Annual-Report-Inside-Pages-v9.pdf

Avkiran, N.K. 2001. "Investigating Technical and Scale Efficiencies of Australian Universities through Data Envelopment Analysis." *Socio-Economic Planning Sciences*, 35(1), pp.57-80.

Bloem Water. 2019. *Annual Report. 2018/19.* Accessed, 18 June 2020 https://www.bloemwater.co.za/assets/annual-report-2018-2019-bloem-water.pdf

Bloem Water. 2018. *Annual Report. 2017/18.* Accessed, 18 June 2020 https://nationalgovernment.co.za/entity_annual/1605/2018-bloem-water-annual-report.pdf

Bloem Water. 2017. *Annual Report. 2016/17.* Accessed, 18 June 2020 https://nationalgovernment.co.za/entity_annual/1425/2017-bloem-water-annual-report.pdf

Bloem Water. 2016. *Annual Report. 2015/16.* Accessed, 18 June 2020 https://www.bloemwater.co.za/assets/2015--16.pdf

Brettenny, W. and Sharp, G. 2016. "Efficiency Evaluation of Urban and Rural Municipal Water Service Authorities in South Africa: A Data Envelopment Analysis Approach." *Water SA*, 42(1), pp.11-19.

Coelli, T.J. Rao, D.S.P. O'Donnell, C.J. and Battese, G.E. 2005. "An Introduction to Efficiency and Productivity Analysis." *Springer Science & Business Media*.

Cooper, W.W. Seiford. L.M. and Tone, K. 2007. *Data Envelopment Analysis: A Comprehensive Text with Models, Applications, References and DEA-Solver Software*. Springer, New York, USA.

Department of Water and Sanitation. 2019. *National Water and Sanitation Master Plan.* Accessed, 07 June 2020 https://www.gov.za/sites/default/files/gcis_document/201911/national-water-and-sanitation-master-plandf.pdf

Department of Water and Sanitation. *2018. 2017/18 Annual Report.* Accessed, 06 June 2020 https://www.gov.za/sites/default/files/gcis_document/201810/water-and-sanitation-annual-report.pdf

Dollery, B. and Van der Westhuizen, G. 2009. "Efficiency Measurement of Basic Service Delivery at South African District and Local municipalities." *The Journal for Transdisciplinary Research in Southern Africa*, 5(2), p.13.

Gannon, B. 2005. "Testing for Variation in Technical Efficiency of Hospitals in Ireland." *The Economic and Social Review*, Vol. 36 (3), pp.273-294.

Gavurova, B. Kocisova, K. Belas, L. and Krajcik, V. 2017. "Relative Efficiency of Government Expenditure on Secondary Education." *Journal of International Studies*, 10(2), pp.329-343.

Gupta, S. Kumar, S. and Sarangi, G.K. 2012. "Measuring the Performance of Water Service Providers in Urban India: Implications for Managing Water Utilities." *Water Policy*, 14(3), pp.391-408.

Kulshrestha, M. and Vishwakarma, A. 2013. "Efficiency Evaluation of Urban Water Supply Services in an Indian State." *Water Policy*, 15(1), pp.134-152.

Lannier, A.L. and Porcher, S. 2014. "Efficiency in the Public and Private French Water Utilities: Prospects for Benchmarking." *Applied Economics*, 46(5), pp.556-572.

Lauro, A. Dos Santos Figueiredo, O.H. and Wanke, P.F. 2016. "Efficiency of Municipal Schools in Rio sde Janeiro: Evidence from Two-Stage DEA." *Journal of Economics and Economic Education Research*, 17(3), p.147.

Lepelle Northern Water. 2015. *Annual Report. 2014/15.* Accessed, 18 June 2020 https://nationalgovernment.co.za/entity_annual/670/2015-lepelle-northern-water-annual-report.pdf

Lombardi, G.V. Stefani, G. Paci, A. Becagli, C. Miliacca, M. Gastaldi, M. Giannetti, B.F. and Almeida, C.M.V.B. 2019. "The sustainability of the Italian Water Sector: An Empirical Analysis by DEA." *Journal of Cleaner Production*, 227, pp.1035-1043.

Magalies Water. 2019. *Annual Report. 2018/19.* Accessed, 18 June 2020 http://www.magalieswater.co.za/wp-content/uploads/2020/01/Magalies-Annual-Report-Financial-Year-FY-2018-2019.pdf

Magalies Water. 2018. *Annual Report. 2017/18.* Accessed, 18 June 2020 http://www.magalieswater.co.za/wp-content/uploads/2019/04/Annual-Report-17-18-1.pdf

Magalies Water. 2017. *Annual Report. 2016/17.* Accessed, 18 June 2020 http://www.magalieswater.co.za/wp-content/uploads/2018/02/Annual-Report-1617.pdf

Magalies Water. 2016. *Annual Report. 2015/16.* Accessed, 18 June 2020 https://nationalgovernment.co.za/entity_annual/966/2016-magalies-water-annual-report.pdf

Magalies Water. 2015. *Annual Report. 2014/15.* Accessed, 18 June 2020 http://www.magalieswater.co.za/wp-content/uploads/2016/01/annual_report_2014-2015.pdf

Mahabir, J. 2014. "Quantifying Inefficient Expenditure in Local Government: A Free Disposable Hull Analysis of a Sample of South African Municipalities." *South African Journal of Economics*, 82(4), pp.493-517.

Marques, R.C. Berg, S. and Yane, S. 2014. "Nonparametric Benchmarking of Japanese Water Utilities: Institutional and Environmental Factors Affecting Efficiency." *Journal of Water Resources Planning and Management*, 140(5), pp.562-571.

Martić, M. Novaković, M and Baggia, A. 2009. "Data Envelopment Analysis-Basic Models and their Utilization." *Organizacija*, 42(2), pp.37-43.

Masindi, V. and Duncker, L.C. 2016. *State of Water and Sanitation in South Africa*. Council for Scientific and Industrial Research. Accessed, 07 June 2020 https://www.researchgate.net/profile/Vhahangwele_Masindi3/publication/311451788_State_of_Water_and_Sanitation_in_South_Africa/links/5846deb508ae61f75ddfdca3/State-of-Water-and-Sanitation-in-South-Africa.pdf

McWilliams, A. Siegel, D. and Van Fleet, D. D. 2005. "Scholarly Journals as Producers of Knowledge: Theory and Empirical Evidence Based on Data Envelopment Analysis." *Organisational Research Methods*, 8(2), pp.185-201.

Monkam, N.F. 2014. "Local Municipality Productive Efficiency and its Determinants in South Africa." *Development Southern Africa*, 31(2), pp.275-298.

Mhlathuze Water. 2019. *Annual Report. 2018/19.* Accessed, 18 June 2020 https://www.mhlathuze.co.za/wp-content/uploads/2019/12/Mhlathuze-Water-AR2019-Ebook.pdf

Mhlathuze Water. 2018. *Annual Report. 2017/18.* Accessed, 18 June 2020 https://www.mhlathuze.co.za/wp-content/uploads/2019/09/Annual-Report-2017_2018.pdf

Mhlathuze Water. 2017. *Annual Report. 2016/17.* Accessed, 18 June 2020 https://www.mhlathuze.co.za/wp-content/uploads/2019/09/MW-Annual-Report_2016_2017.pdf

Mhlathuze Water. 2016. *Annual Report. 2015/16.* Accessed, 18 June 2020 https://www.mhlathuze.co.za/wp-content/uploads/2019/09/MW-Annual-Report-2016.pdf

Mhlathuze Water. 2015. *Annual Report. 2014/15.* Accessed, 18 June 2020 https://www.mhlathuze.co.za/wp-content/uploads/2019/09/Annual-Report_14_15.pdf

Murwirapachena G, Mahabir J, Mulwa R, Dikgang J. 2019. *Efficiency in South African Water Utilities: A Comparison of Estimates from DEA, SFA and StoNED*. Accessed, 07 June 2020 http://www.academia.edu/download/59324507/working_paper_78020190520-23982-1t5h0qv.pdf

National Treasury. 2020. *2020 Estimates of National Expenditure*. Accessed, 07 June 2020 http://www.treasury.gov.za/documents/national%20budget/2020/enebooklets/Vote%2041%20Water%20and%20Sanitation.pdf

National Treasury. 2019. *2019 Estimates of National Expenditure*. Accessed, 07 June 2020 http://www.treasury.gov.za/documents/national%20budget/2019/enebooklets/Vote%2036%20Water%20and%20Sanitation.pdf

National Treasury. 2018. *2018 Estimates of National Expenditure*. Accessed, 07 June 2020 http://www.treasury.gov.za/documents/national%20budget/2018/booklets.aspx

Overberg Water. 2019. *Annual Report. 2018/19.* Accessed, 18 June 2020 https://www.overbergwater.co.za/documents/owb_Overberg%20Water%20Annual%20Report%202018-19.pdf

Overberg Water. 2018. *Annual Report. 2017/18.* Accessed, 18 June 2020 https://www.overbergwater.co.za/documents/owb_Overberg%20Water%20Annual%20Report%202017-18.pdf

Overberg Water. 2017. *Annual Report. 2016/17.* Accessed, 18 June 2020 https://www.overbergwater.co.za/documents/owb_Overberg%20Water%20Annual%20Report%202016-17.pdf

Picazo-Tadeo, A.J. Sáez-Fernández, F.J. and González-Gómez, F. 2007. *Does Service Quality Matter in Measuring Performance of Water Utilities?* Accessed, 18 June 2020 http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.690.2281&rep=rep1&type=pdf

Ramírez Hassan A. 2008. *Consequences of Omitting Relevant Inputs on the Quality of the Data Envelopment Analysis Under Different Input Correlation Structures.* Accessed, 31 January 2019. https://repository.eafit.edu.co/bitstream/handle/10784/556/2008-1%20Andres%20Ramirez%20Hassan.pdf?sequence=1

Rand Water. 2019. *2019 Integrated Annual Report.* Accessed, 18 June 2020 https://www.randwater.co.za/Annual%20Reports/Annual%20Reports/2018-2019%20Annual%20Report%20Final/10374%20RANDWATER%20AR%20FINAL%20Electronic%202019.pdf

Rand Water. 2018. *2018 Integrated Annual Report.* Accessed, 18 June 2020 https://www.randwater.co.za/Annual%20Reports/Annual%20Reports/2017-2018%20Annual%20Report%20Final/RAND%20WATER%20ANNUAL%20REPORT%202018.pdf

Rand Water. 2017. *2017 Integrated Annual Report.* Accessed, 18 June 2020 https://www.randwater.co.za/Annual%20Reports/Annual%20Reports/2016-2017%20Annual%20Report/Final%20Annual%20Report%2014Nov2017.pdf

Rand Water. 2016. *2016 Integrated Annual Report.* Accessed, 18 June 2020 https://www.randwater.co.za/Annual%20Reports/Annual%20Reports/2015-2016%20Annual%20Report/RW%20IAR%202015-2016.pdf

Rand Water. 2015. *2015 Integrated Annual Report.* Accessed, 18 June 2020 https://www.randwater.co.za/Annual%20Reports/Annual%20Reports/2014-2015%20Annual%20Report%20Final/RW%20IAR%202014-15%20part%205.pdf

Sedibeng Water. 2019. *Annual Report. 2018/19.* Accessed, 18 June 2020 http://new.sedibengwater.co.za/wp-content/uploads/2019/12/Final-Draft-SW-Annual-Report-2018-2019.pdf

Sedibeng Water. 2017. *Annual Report. 2017/18.* Accessed, 18 June 2020 http://new.sedibengwater.co.za/wp-content/uploads/2018/12/Annual-Report-2017-2018.pdf

Sedibeng Water. 2016. *Annual Report. 2015/16.* Accessed, 18 June 2020 https://nationalgovernment.co.za/entity_annual/1052/2016-sedibeng-water-annual-report.pdf

Sedibeng Water. 2015. *Annual Report. 2014/15.* Accessed, 18 June 2020 https://nationalgovernment.co.za/entity_annual/760/2015-sedibeng-water-annual-report.pdf

Singh, M. Mittal, A.K. and Upadhyay, V. 2014. "Efficient Water Utilities: Use of Performance Indicator System and Data Envelopment Analysis." *Water Science and Technology: Water Supply*, 14(5), pp.787-794.

Taylor, B. and Harris, G. 2004. "Relative Efficiency among South African Universities: A Data Envelopment Analysis." *Higher Education*, 47(1), pp.73-89.

Umgeni Water. 2019. *Annual Report. 2018/19.* Accessed, 18 June 2020 https://www.umgeni.co.za/wp-content/uploads/2019/12/UW-AR-2018-2019_rev-13-compressed.pdf

Umgeni Water. 2018. *Annual Report. 2017/18.* Accessed, 18 June 2020 https://www.umgeni.co.za/pdf/ar_2018/performance.pdf

Umgeni Water. 2017. *Annual Report. 2016/17.* Accessed, 18 June 2020 https://www.umgeni.co.za/pdf/ar_2017/performance.pdf

Umgeni Water. 2016. *Annual Report. 2015/16.* Accessed, 18 June 2020 https://www.umgeni.co.za/pdf/ar_2016/performance.pdf

Wang, E.C. and Alvi, E. 2011. "Relative Efficiency of Government Spending and its Determinants: Evidence from East Asian Countries." *Eurasian Economic Review*, 1(1), pp.3-28.

Yawe, B.L. 2014. *Technical efficiency and Productivity of Primary Schools in Uganda*. Accessed, 31 January 2019.
https://www.africaportal.org/documents/17554/RP277.pdf

Yuan, Y. and Shan, M. 2016. "The Educational Efficiency Evaluation Framework: By Using DEA Model and CA Method." *International Journal of Information and Education Technology*, 6(12), p. 923.

Appendix 1: Radials, slacks and efficient peers

Water Boards	1. Amatola	2. Bloem	3. Lepelle	4. Magalies	5. Mhlathuze	6. Overberg	7. Rand	8. Sedibeng	9. Umgeni	Total
Model 2: VRS										
Input 1: Total expenditure (R'000)	418 000	640 000	627 000	485 000	590 000	45 000	10 078 000	1 390 000	1 935 000	16 208 000
Input radial movement	(199 767)	(220 808)	(47 820)	(26 372)	-	-	-	(708 327)	-	(1 203 094)
Input slack movement	-	-	-	-	-	-	-	-	-	-
Input target	218 233	419 192	579 180	458 628	590 000	45 000	10 078 000	681 673	1 935 000	15 004 906
Input 2: Avoidable water losses (%)	12	9	5	6	3	7	3	9	3	
Input radial movement	(6)	(3)	-	-	-	-	-	(5)	-	
Input slack movement	-	-	-	-	-	-	-	-	-	
Input target	6	6	5	6	3	7	3	4	3	
Output 1: Volumes (ML/per year)	33 000	81 000	90 000	86 000	45 000	4 000	1 636 000	114 000	440 000	2 529 000
Input radial movement	-	-	-	-	-	-	-	-	-	-
Input slack movement	-	-	-	-	-	-	-	-	-	-
Input target	33 000	81 000	90 000	86 000	45 000	4 000	1 636 000	114 000	440 000	2 529 000
DMU peers	9;5;6	6;9;5	5;6;9	6;9;5	5	6	7	9;5;6	9	
Model 3: VRS										
Input 1: Total expenditure (R'000)	460 000	765 000	690 000	574 000	550 000	50 000	11 429 000	1 545 000	2 162 000	18 225 000
Input radial movement	-	-	-	-	-	-	-	-	-	-
Input slack movement	-	-	-	-	-	-	-	-	-	-
Input target	460 000	765 000	690 000	574 000	550 000	50 000	11 429 000	1 545 000	2 162 000	18 225 000
Output 1: Volumes (ML/per year)	33 000	80 000	92 000	91 000	44 000	3 000	1 625 000	120 000	453 000	2 541 000
Input radial movement	-	23 639	31 747	11 143	46 985	-	-	24 779	-	138 293
Input slack movement	-	-	-	-	-	-	-	-	-	-
Input target	33 000	103 639	123 747	102 143	90 985	3 000	1 625 000	144 779	453 000	2 679 293
Output 2: Bulk Water Tariffs (R/kl)	11	8	6	7	4	7	9	9	7	
Input radial movement	-	2	2	1	4	-	-	2	-	
Input slack movement	-	-	-	-	-	-	-	-	-	
Input target	11	10	8	8	8	7	9	11	7	
DMU peers	1	7;9;1	6;1;9	1;9;6	6;1;9	6	7	1;7	9	
Model 4: VRS										
Input 1: Total expenditure (R'000)	460 000	765 000	690 000	574 000	550 000	50 000		1 545 000		4 634 000
Input radial movement	-	-	-	-	-	-		-		-
Input slack movement	-	-	-	-	-	-		-		-
Input target	460 000	765 000	690 000	574 000	550 000	50 000		1 545 000		4 634 000
Output 1: Volumes (ML/per year)	33 000	80 000	92 000	91 000	44 000	3 000		120 000		463 000
Input radial movement	-	3 779	2 464	-	38 231	-		-		44 474
Input slack movement	-	-	-	-	-	-		-		-
Input target	33 000	83 779	94 464	91 000	82 231	3 000		120 000		507 474
Output 2: Bulk Water Tariffs (R/kl)	11	8	6	7	4	7		9		
Input radial movement	-	0	1	-	3	-		-		
Input slack movement	-	-	-	-	-	-		-		
Input target	11	8	7	7	7	7		9		
DMU peers	1	4;7;1	4;7	4	1;6;4	6		8		

Sources: Authors' calculations based on efficiency results.