BENCHMARKING THE TECHNICAL EFFICIENCY OF SOUTH AFRICAN MUNICIPAL WATER UTILITIES: A DOUBLE-BOOTSTRAP DEA APPROACH

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Declaration about plagiarism

I certify that this research report, which is submitted in partial fulfilment of the Degree of Master of Commerce (Economics) at the University of the Witwatersrand is my own unbiased work. It has not been previously submitted for any degree at any other university.

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Abstract

Efficiency enhancement in the water sector can help to optimise the use of available resources and mitigate the impact of climate change on water resources, while promoting sustainable water usage. Ultimately, this can lead to cost savings that may be channelled into enhancing service delivery and expanding access to water. Benchmarking is considered a useful method for improving water sector efficiency. The production frontier approach is the most commonly used technique for benchmarking, which can be computed using either non-parametric techniques, including data envelopment analysis (DEA), or parametric methods, including stochastic frontier analysis (SFA).

A review of the literature reveals that DEA has become the most frequently used method for efficiency analysis in the water sector. Though a predictable approach, the DEA method may be influenced by measurement errors and anomalies, and it cannot be used to draw statistical conclusions. To address this problem, the double-bootstrap DEA technique was introduced, which permits statistical inference in DEA models. This technique helps the researcher to estimate efficiency scores that have been corrected for bias, and also identifies the factors that influence efficiency. For these reasons, this research employs double-bootstrap DEA to evaluate the efficiency scores of municipal water utilities in the South African water sector.

The truncated double-bootstrap regression outcomes show that water consumer debt, consuming units receiving free water, and the effects of climate change (such as temperature variation and altered rainfall patterns) all impact the relative efficiencies of municipal water utilities. The results indicate notable distinctions in rankings and efficiency scores between the double-bootstrap DEA model and the traditional DEA model for both urban and rural municipal water utilities. Using the regression model, this research discovered that water consumer debt and consuming units receiving free water are significant factors influencing the efficiency of urban and rural municipal water utilities. These findings raise concerns about the prospects of South African municipal water utilities, particularly their ability to strike a balance between supporting indigent households and securing revenue for maintenance and future water infrastructure development, as well as efficiently managing water consumer debt and addressing the effects of climate change to deliver desired results consistently and sustainably.

Keywords: benchmarking, efficiency, municipal water utilities, data envelopment analysis, double-bootstrap, bias correction

Chapter One
Introduction and Background

1.1 Introduction

Water sustainability has become increasingly important in light of climate change. Climate change modifies global hydrologic cycles due to shifts in temperature and rainfall patterns, worsening global and regional water shortages (Du et al., 2021). According to the World Economic Forum (2022), if current practices persist, the disparity between global water provision and demand could reach 40 percent by 2030. Ablanedo-Rosas et al. (2020) argue that water is an essential resource for the survival of humanity. In many countries, water is supplied by municipalities (i.e. water utilities). Considering the negative impacts of climate change, it is vital that water utilities operate more efficiently.

However, as government-regulated entities, water utilities generally have no incentives for efficiency. Benchmarking is deemed to be a useful tool to enhance efficiency because it evaluates the performance of firms comparatively, thus supporting effective regulation (Walker et al., 2019). In developed countries like Canada and England, benchmarking has been adopted as a common practice in regulated water utilities (Dikgang et al., 2020). Benchmarking has also proven to be successful in developing countries' water utilities (Samkange et al., 2019).

In the last few years benchmarking has gained attention in academia, with regular attempts to improve water sector benchmarking methodologies (Walker et al., 2019). The production frontier approach is the most widely utilised methodology for benchmarking, which can be executed using either non-parametric approaches, including data envelopment analysis (DEA); or parametric approaches, including stochastic frontier analysis (SFA) (Molinos-Senante et al., 2018; Worthington, 2014). The DEA approach is favoured for its mathematical properties in handling multiple inputs and outputs, and it places lower importance on the configuration of the efficiency frontier; conversely, SFA can break down anomalies from the frontier into two components: random noise and inefficiency (Murwirapachena, Dikgang, Mulwa & Mahabir, 2019). For this reason, DEA is the most widely utilised method for analysing water utilities' efficiency (Ablanedo-Rosas et al., 2020).

A number of South African studies utilised the DEA method to measure water utilities' efficiency (see Brettenny & Sharp, 2016; Van der Westhuizen & Dollery, 2009). However, DEA is a deterministic method that can be affected by measurement errors and outliers, and it cannot be used for statistical inferences (Ananda & Pawsey, 2019; Molinos-Senante et al., 2018). To transcend this constraint, Simar and Wilson (2007) suggested a double-bootstrap approach, which allows statistical inferences and correction of bias in DEA models, as well as identification of factors that influence efficiency. A few studies in the water sector in South Africa have utilised this methodological approach to estimate water utilities' efficiency (see Nithammer, Dikgang & Mahabir, 2022; Samkange et al., 2019). This study joins those in applying the more recent analytical method (double-bootstrap DEA) to analyse the efficiency scores of South African municipal water utilities.

1.2 Problem statement

Water accessibility is vital for sustaining livelihoods and for economic growth. Therefore, it is important that countries manage their water resources carefully and sustainably (Mutamba, 2019). This is crucial given that global climate change may worsen water shortages by reducing precipitation in many parts of the world (Du et al., 2021). According to Ngobeni and Breitenbach (2021), there is evidence of declining water resources and precipitation and increasing temperature changes for the African continent for the next 70 years. South Africa is one of the world's driest countries, with an average annual rainfall of 450mm compared to the global average of 860mm (Trans-Caledon Tunnel Authority, 2020). In this context, efficient management of South Africa's limited water resources is crucial to guarantee sustainable water security. According to Mutamba (2019), the management of water delivery and ensuring the security of a country's water resources is determined by the infrastructure, organisations, and regulatory frameworks employed.

The delivery of safe and affordable water in South Africa is constitutionally mandated to local government in the form of Water Services Authorities[1] (WSAs). At present, WSAs are faced with systemic challenges that negatively impact the efficient delivery of water to the country's citizens. According to the Government Communication Information System (GCIS) (2021), these challenges are caused by (among other reasons): poor water infrastructure management and investment; climate change; deteriorating water quality; non-payment by water users; and capacity constraints. Climate change, water supply variability and dwindling water quality could constrain the country's economic growth. Moreover, failure to efficiently manage water

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[1] In terms of the Water Services Act (Act No.108 of 1997) a Water Service Authority is a municipality responsible for ensuring access to water service to end users.

infrastructure, and to collect, treat and reuse water efficiently, may exacerbate water shortages in South Africa.

Municipal surveys are showing a decline in customer satisfaction with water provision in South Africa. Dissatisfaction with the quality of water services provision is prevalent, with water quality being one of the major concerns and a proxy for the operational efficiency of water treatment plants (Department of Cooperative Governance - DCOG, 2021). The percentage of households rating service provision quality ‘average’ or ‘poor’ increased from 24 percent in 2005 to 39 percent in 2008, while reports of frequent water interruptions increased from 19.3 percent in 2002 to 31.4 percent in 2008 (DCOG, 2021). An assessment of social protest pathways indicated that water services delivery is an integral part of a mix of social services that have been linked to social protests (Water Research Commission, 2015). According to Mamokhere (2020), dissatisfaction with delivery of clean running water is the leading reason behind the countrywide service delivery protests. Masiangoako et al. (2022) affirm that water is generally the main focus of service delivery protests in South Africa. The Auditor General South Africa (AGSA) (2020) reported that service delivery failures and technical inefficiency are prevalent in municipal service delivery, and these problems include poor-quality water services.

There has been a decline in access to services, particularly water facilities, despite the increase in government expenditure on essential services (United Nations South Africa, 2020). Considering there are only seven years left to 2030, it is unlikely that South Africa as a United Nations member state will by 2030 realise universal and fair access to safe and reasonably priced drinking water for all, as set out in Sustainable Development Goal (SDG) 6.

Over the years, South African legislation has created a climate that encourages benchmarking. The Department of Water and Sanitation (DWS) developed benchmarking programmes that are aimed at improving the quality and delivery of water services. These initiatives consist of the Blue Drop and Green Drop certification programmes, among others. The former is intended to protect South African citizens from the dangers and risks associated with polluted drinking water, and the latter is intended to protect the environment from the dangers and risks related to polluted wastewater/sewage (DWS, 2014).

These benchmark initiatives are about comparing service standards between WASs, and do not consider the productive efficiency of water provision in the achievement of the set standards; they are more about effectiveness than efficiency. Technical or productive efficiency is a crucial evaluation element when measuring the functioning of water utilities. As such, it is imperative to adopt scientific technical-efficiency benchmarking frameworks that employ strong mathematical and econometric methods to ensure accurate performance interpretation, instead of simply describing the results (Nithammer et al., 2022).

Given this background, the aim of this study is to utilise the double-bootstrap DEA approach suggested by Simar and Wilson (2007) to calculate the efficiency scores of South African municipal water utilities while correcting for bias, and identify the factors that influence their efficiency. A review of previous literature suggests the importance of accounting for exogenous variables in water utility efficiency (see Salazar-Adams, 2021; Villegas et al., 2019; Molinos-Senante et al., 2018). As previously stated, South African municipal water utilities are faced with challenges that impact their productivity. Some of these challenges are within the control of management, and others are not. In essence, the utilisation of the bootstrap-based algorithm in this study will help to evaluate the influence of external factors and generate efficiency estimates that are more reliable and accurate (Samkange, 2019).

1.3 Research objectives

The objectives of the research are based on the problem statement which paints a dire picture of inefficient water provision by South African municipal water utilities. Thus, this study addresses the following main objectives:

i. To use the double-bootstrap DEA technique to estimate unbiased efficiency scores of municipal water utilities in South African, and then compare the scores with those obtained through the traditional DEA approach;

ii. To determine the exogenous factors that influence the efficiency of South African municipal water utilities, while considering the utilities' location; and

iii. To provide policy recommendations to improve the efficiency of the sampled water utilities, based on empirical findings.

1.4 Contributions and significance of the research

In the last few years, efficiency analysis in the water sector has been an important research objective. To the best of this researcher's knowledge, there is a limited number of studies that have employed the methodology suggested by Simar and Wilson (2007) (i.e. double-bootstrap DEA) to assess the efficiency of water utilities and the factors that influence it (see Nithammer et al., 2022; Molinos-Senante et al., 2018; Ananda, 2014). However, a review of the literature reveals that none of these previous studies examined the influence of water consumer debt, consuming units receiving free water and climate change effects (i.e. temperature and rainfall patterns) on water utility efficiency. These issues are currently prevalent in South Africa's water sector. The level of consumer debt of South African municipalities has raised concerns. Municipalities are struggling to collect payments from residents who are in arrears or have defaulted, leading to an increase in consumer debt and a decline in the quality of services delivered; for example, water (Enwereji & Uwizeyimana, 2020).

Additionally, South Africa has a policy of providing free basic municipal services, where the government provides essential services to indigent households, without any charges. The introduction of the free basic water policy is a significant step towards promoting equal access throughout the country. However, this approach presents financial constraints for municipalities because supplying these complimentary services puts extra strain on their budgets, as the beneficiaries of these services do not make any financial contributions towards them (Monkam, 2014).

Moreover, South Africa is prone to and at risk of suffering from the destructive impacts of climate change, especially the consequences of extended periods of drought (Mutamba, 2019). Regulators and policymakers cannot rely solely on past determinants of efficiency and expect different results; they must consider the changing environment. Thus this study considers recent potential environmental factors for regulators and policymakers to target, in order to enhance the efficiency of their support and intervention. It extends the 2022 study by Nithammer et al. by including additional political-institutional and climate change explanatory variables, which provides a more comprehensive operating context for water utilities in South Africa.

1.5 Structure of thesis

The remainder of this study is structured in the following manner: Chapter Two reviews the water sector in South Africa and Chapter Three reviews and critically discusses the existing literature. Chapter Four provides an explanation of the data and methods utilised in this research. Chapter Five provides the empirical findings, the concluding remarks regarding this study are provided in Chapter Six.

Chapter Two
Overview of the South African Water Sector

2.1 Introduction

The main objective of the water sector is to guarantee that all individuals have access to fundamental water and sanitation services, as mandated by the constitution's requirement for water access for every citizen. Since 1994, South Africa has made considerable strides in extending water services to underserved communities and rural areas, with a particular focus on vulnerable populations. However, despite these advances, the water sector operates with limited resources. Moreover, it is experiencing the effects of climate change, including prolonged drought, increased temperatures and erratic rainfall patterns. With this context in mind, the purpose of this section is to provide a brief overview of South Africa's water sector.

2.2 Water sector composition

2.2.1 Water resource management

The water sector in South Africa comprises water resource management, which follows the guidelines set by the National Water Act (1998), and water services provision, which follows the guidelines set by the Water Services Act (1997). 'Water resource management' involves overseeing catchment functions, water storage and abstraction, river systems, and return flow; 'water services' involves the provision of both clean water and sanitation facilities, which include both regional and local water schemes, as well as the collection and treatment of wastewater, and on-site sanitation (National Treasury, 2011). Notably, water resource management and water services are interdependent and mutually beneficial. Efficient water resource management is crucial for ensuring sustainable water services. Insufficient management of water resources could lead to a situation where the demand for water services cannot be met due to a shortage of water.

The primary source for water in South Africa has been the utilisation of surface water. According to Mutamba (2019), the country's water supply comes mainly from surface water (77 percent), while the remaining water supply is sourced from groundwater (9 percent) and return flows (14 percent). The reliable amount of surface water that the country produces annually is approximately 14.2 billion cubic meters, and there is an estimated usable groundwater supply of an additional 3.5 billion cubic meters per year (Mutamba, 2019).

The usage of the available water resources is mostly for agricultural purposes, which account for 60 percent of total demand; domestic demand accounts for 27 percent of total demand: 24 percent of domestic usage is for urban areas, while the remaining 3 percent is for rural areas (National Treasury, 2011). The demand for water is projected to increase to 17 billion cubic meters per year by 2025, versus a reliable yield of 15 billion cubic meters (National Treasury, 2011). Considering these statistics, South Africa must manage its water resources prudently and efficiently. This is particularly important given that it is considered one of the driest countries globally. The DWS suggests plans to diversify water sources to ensure water security, by using groundwater, managing water demand, and conserving water (Ngobeni & Breitenbach, 2021).

2.2.2 Water services

Since 1994, government has significantly improved access to basic water supply in South Africa compared to other countries, when measured on progress in achieving SDG 6 (Ngobeni & Breitenbach, 2021). According to Statistics South Africa (StatsSA) (2016), there are close to 17 million households in South Africa, and a total population of approximately 60 million. Almost 90 percent of households receive water through pipe infrastructure traversing into their yards. On the other hand, only 14 million households (83 percent) receive safe potable water, and there is reliable water supply for only 10.8 million households (64 percent). Notwithstanding the significant improvement in water access, the overall status of water supply systems in the country is deteriorating (DWS, 2022). Poor management of drinking water services poses a significant threat to human health. As such, proper management, maintenance and operation of drinking water purification systems is critical for ensuring that water services are reliable, safe, and sustainable in the long run.

2.3 Water sector institutional arrangements and role players

The water sector is integrated, but various role players can be identified. The DWS is the owner of major water resources such as large dams and rivers. The department is assigned the responsibility of developing and regulating water resources policy by the National Water Act (1997). The DWS's main tasks include the planning and execution of significant water resource infrastructure initiatives, granting water-use licenses, water allocation, management of river systems and return flows, water abstraction, and water storage (Nithammer et al., 2022). The DWS also monitors other institutions involved in water management, including water boards, catchment management agencies, municipalities, and other water providers.

Ngobeni and Breitenbach (2021) list nine government-owned water boards that are tasked with the responsibility of purifying and distributing bulk water; but some municipalities and the DWS also carry out this function. According to the National Business Initiative (NBI) (2019), local government is constitutionally mandated to provide water services to communities at a local level. South Africa has 257 municipalities, but only 144 of these are legally authorised WSAs allowed to provide water services to communities. Nithammer et al. (2022) and DWS (2014) have argued that in certain instances, a WSA could designate a Water Services Provider (WSP) to deliver water services to customers within a particular geographic region; these may include water boards, other municipalities and private companies.

2.4 The water sector's challenges

The water sector in South Africa is facing several noteworthy challenges related to water, including issues with the availability of the resource itself, as well as problems with the delivery of water services by municipalities. Mutamba (2019) states that the notable issues impacting South Africa's water resources include water scarcity, negative water balance (most river basins and water management areas are in deficit), water resources pollution, and aging water infrastructure (resulting in extensive water losses). The Trans-Caledon Tunnel Authority (TCTA) (2020) associated water services challenges in municipalities with poor technical and leadership capacity. Additionally, municipalities pay limited attention to sound operation and maintenance; consequently leading to high non-revenue water, estimated at 35 percent (TCTA, 2020). Coupled with high levels of non-payment by water users, this negatively affects the sustainability of the entire water value chain. GCIS (2021) pointed out that municipalities are also faced with capacity constraints (lack of skilled personnel) and deteriorating water quality.

These challenges slow the rollout of water infrastructure, impacting negatively on water supply and access, and thus increasing the number of interruptions to water delivery. Studying the technical efficiency of municipalities and the factors that influence it is highly important in South Africa. This is especially true when it comes to providing basic water services efficiently, which is a pressing matter that requires thorough scientific inquiry.

2.5 Benchmarking in the water sector

Over the past 15 years there have been numerous performance benchmarking initiatives developed in the water services sub-sector of South Africa. According to Brettenny and Sharp (2018), these include the National Benchmarking Initiative (NBI); the Blue Drop and Green Drop certification programmes; and the Municipal Benchmarking Initiative (MBI). Brettenny and Sharp (2018) explained that the NBI and MBI have the objective of using benchmarking as a solution to tackle the significant issues in South Africa’s water sector, whereas the Blue and Green Drop initiatives prioritise the improvement of service quality.

These benchmarking initiatives undertaken in the South African water sector illustrate the magnitude of the maintenance-related difficulties in this sector. Nonetheless, it is worth noting that these initiatives focus mainly on comparing the service standards of the different municipalities, rather than assessing their productive efficiency in delivering water to meet these standards. Although it is crucial to assess the effectiveness of water utilities, evaluating their technical or productive efficiency is equally important. As Nithammer et al. (2022) pointed out, to achieve this, it is necessary to use scientific technical efficiency benchmarking methods that employ rigorous mathematical and econometric techniques for accurate performance interpretation, rather than relying on a descriptive analysis of results.

2.6 Conclusion

South Africa’s ability to ensure long-term water security and drinking water quality is not completely guaranteed. To guarantee water sustainability and drinking-water quality, municipalities need to overcome various challenges related to both resources and the actual provision of water services. Despite efforts to address these challenges, the country’s current approach is not optimal, particularly regarding water services management. This is evidenced by municipalities not adhering to legislation regarding the management, maintenance and operation of their drinking-water purification systems. It is worth emphasising that water security relies not only on availability but also on quality. Therefore, to enhance the country’s water security and drinking water services management, regulators and policymakers must take the lead in embracing non-traditional water sources, and improve the benchmarking of service standards among different municipalities by adopting benchmarking methods that employ rigorous mathematical and econometric techniques for accurate performance interpretation.

Chapter Three
Literature Review

3.1 Introduction

In the past few years, there has been considerable expansion in the analysis of efficiency within the water sector. Scholars in the fields of economics and management science have shown wide interest in both mathematical programming and econometric approaches (Hosseinzadeh, 2019). As stated previously, SFA and DEA are the most two popular parametric and non-parametric efficiency analysis techniques for measuring efficiency. The DEA approach ascribes less importance on the form of the efficiency frontier, and is preferred due to its mathematical characteristics for dealing with various inputs and outputs; in contrast, the SFA method can break down deviations from the frontier into two components: random errors and inefficiency (Murwirapachena et al., 2019). These techniques have been widely used in empirical studies across various economic activities and sectors. However, in water-efficiency studies, the DEA method is the most commonly used approach (Ablanedo-Rosas et al., 2020).

In the water sector arena there have been several research studies that have utilised the non-parametric DEA approach to analyse the technical efficiency of water utilities. However, as mentioned previously, the traditional DEA method is vulnerable to measurement errors and outliers because it is deterministic, and statistical conclusions cannot be drawn from this method (Ananda & Pawsey, 2019; Molinos-Senante et al., 2018). Simar and Wilson (2007) came up with a method called double bootstrap to overcome this restriction in DEA models, which permits statistical inferences to be made. This methodology enables the calculation of efficiency scores that have been adjusted for bias, and also enables the identification of factors that influence efficiency (Villegas et al., 2019; Molinos-Senante et al., 2018). Therefore, this section will provide a brief overview of international and South African studies that have applied the traditional DEA method and/or the double-bootstrapping procedure to calculate water utilities' efficiency scores.

3.2 International studies

The efficiency scores of three Spanish water utilities were estimated using the traditional DEA model by García-Valiñas and Muñiz (2007) during the period 1985 and 2007. The study considered operational costs as an input. The outputs considered were water delivered, population served with water, and length of mains. Additionally, the authors included the non-controllable variable rainfall in the DEA estimation. The study found that adding rainfall led to efficiency scores that were similar to those observed globally. The importance of this study in the efficiency literature is due to its attempt to include a non-controllable variable (rainfall) in the DEA estimation. Despite this novelty, the use of traditional DEA limited the study in evaluating whether or not the non-controllable variable (rainfall) significantly influenced efficiency. To address this shortcoming, the current study evaluated the significance of the non-controllable variable (rainfall) in influencing efficiency results.

Romano and Guerrini (2011) analysed the efficiency scores of 43 Italian water companies that operate as the sole provider for their respective regions for the 2007 period. They utilised cross-sectional data and classified the water utilities into different categories based on their ownership structure, size, and geographic location. The study employed the traditional DEA model for determining efficiency scores, and found that the efficiency scores of water utilities were influenced by their size, ownership structure, and geographic location. Regarding the ownership structure, public utilities achieved greater efficiency scores compared to private utilities. In terms of geographical location, the water utilities of central and southern Italy were found to be most efficient. In terms of size, smaller utilities had higher efficiency scores than medium-sized ones. This knowledge advises policymakers and water utility managers in the water sector to avoid using a one-size-fits-all strategy when dealing with the factors that contribute to operational inefficiency. They must consider efficiency determinants such as ownership, size and location. The study was constrained in its ability to evaluate the significance of ownership, size, and location on efficiency results due to the utilisation of the traditional DEA method. The approach of the current study would help water utility managers and policymakers to target specific areas influencing efficiency.

Using a double-bootstrap DEA method, Walker et al. (2019) evaluated explanatory factors alongside bias-corrected economic and environmental efficiency scores for 13 water and sewage companies in the United Kingdom and Ireland. The study utilised operational and capital expenditure, operational greenhouse gas emissions, length of mains, and length of sewage pipes as inputs. The outputs used in the study were water supplied and wastewater treated, drinking water quality, and discharge permit compliance. The authors listed four prospective environmental elements that were considered to impact efficiency: consumption per capita, leakage, population density, and surface water. The study found the application of the double-bootstrap technique rectified biases in the conventional DEA estimations, changing the company rankings. The significant factors influencing efficiency were found to be surface water and population density.

The significance of Walker et al. (2019) in the field of efficiency studies lies in its attempt to identify the drivers of efficiency. The study used a robust method to determine the performance of water utilities, and showed the specific areas that required improvement to enhance efficiency. This nuanced approach is more effective in attaining the intended result. Moreover, the study showed the importance of truncating the initial efficiency scores for bias-correctness, as this has a considerable effect on the rankings of technical efficiency among water utilities.

3.3 South African studies

Regarding South African research, Dollery and Van der Westhuizen (2009) conducted a study to assess the effectiveness of basic service delivery in 231 local municipalities and 46 district municipalities during 2006/2007. They used traditional DEA methodology to determine the efficiency estimates, using operational efficiency and labour costs as inputs, while the total numbers of households receiving water, sanitation, electricity and refuse removal through the Reconstruction and Development Programme (RDP) were used as outputs. Dollery and Van der Westhuizen (2009) observed that the level of efficiency differs between provinces. Municipalities situated in Gauteng had the greatest mean technical efficiency scores among the local municipalities.

This is a useful study because it examines how well basic services are being provided in South Africa. However, it would have been beneficial to evaluate the efficiency of basic service delivery over a longer period, as it would indicate the progress or decline of individual municipalities over time. This would enable more focused efforts to improve and intervene in those specific areas. Moreover, the study used traditional DEA, thus there was no evaluation of the factors that influence efficiency. This is particularly important, since is it commonly known that various external factors impact the efficiency of water utilities.

Brettenny and Sharp (2016) utilised the traditional DEA model to calculate the efficiency scores of 88 authorised water services. The study utilised operating expenses as its input, while its outputs included the number of connections served, length of mains, the amount of water delivered to customers (both metered and non-metered), the measured volume of water delivered, the estimated volume of water remaining, and the expenses associated with repairs for pipe bursts. The study found that water utilities functioning in urban areas performed more efficiently compared to those in rural areas. This was advantageous, as it provided insights into how location (whether urban or rural) impacts the efficiency outcomes. The distinction between municipalities maintains homogeneity in the sample, and avoids the application of a one-size-fits-all method of efficiency measurement. Even so, although the water utilities were split between urban and rural, the use of traditional DEA in the study restricted the practical application of the findings. As a result, the study did not evaluate the influence of location (urban or rural) on efficiency results. Furthermore, the outcomes of the study only showed which municipalities were performing poorly, without providing any understanding of the specific areas that required improvement to enhance efficiency.

Nithammer et al. (2022) utilised a double-bootstrap DEA approach to assess bias-corrected efficiency scores and the factors influencing efficiency for water utilities in urban and rural areas, covering the period 2010-2012, as well as 2014. The study utilised length of mains and operating cost as inputs, while authorised consumption and water quality were used as outputs. The authors included nine environmental factors believed to impact efficiency: location, number of consumer units, WSA status, ratio of metered to unmetered connections, own bulk water or is sourced from a water board, outsourcing of water delivery to a non-municipal third-party WSP, proportion of votes obtained by the majority party, and the impact of the election cycle on local government spending choices. The findings showed substantial disparities in the rankings and efficiency scores produced by the traditional DEA model in comparison with the double-bootstrap DEA model, for urban and rural water utilities. The study also discovered factors such as location and the proportion of metered to unmetered connections had a significant impact on the effectiveness of water utilities in both urban and rural areas.

The study above showed the major drawbacks of using traditional DEA, and emphasised the significance of employing robust efficiency assessments to identify unusual or abnormal occurrences. Moreover, it provided estimations regarding the factors that influence efficiency scores, as well as insights into what external factors policymakers and water utility managers should target to improve efficiency. It can be seen from these that there is a need to expand on the operational environment and look at other factors that could potentially affect water utility efficiency. Policymakers and water utility managers cannot rely solely on past determinants of efficiency and expect different results. They must consider the changing environment in order to make their support and intervention more effective.

3.4 Conclusion

In summary, this literature review highlights the significance of employing reliable methods to assess the technical efficiency of water utilities. Additionally, it shows that there is a rich body of knowledge that can be utilised to assess the technical efficiency of water utilities, both internationally and in South Africa. Furthermore, it emphasises the limitations of traditional DEA when compared to double-bootstrap DEA. In essence, the literature review bolsters the assertion that the double-bootstrap DEA approach is a more credible methodology to use, as it calculates efficiency scores that have been corrected for bias and also reveals the factors that influence efficiency. This is particularly important, since is it commonly known that water utilities are impacted by various external factors. Therefore, there is an obvious gap in the existing literature, particularly in South Africa, in terms of expanding on the operational environment and looking at other factors that could potentially affect water utility efficiency. This study addresses this shortcoming by considering recent environmental occurrences that could potentially impact the technical efficiency of South African municipal water utilities.

Chapter Four
Methodology and Data

4.1 DEA approach

This study utilised traditional DEA to extrapolate the efficiency scores affected by biases of municipal water utilities in South Africa.

Charnes et al. (1978) developed the DEA approach, which has been extensively used to evaluate the efficiency of water utilities (Molinos-Senante et al., 2018). DEA is a tool for benchmarking efficiency that allows for a comparison of decision-making units (DMUs) that are similar in nature and operate in similar environments (in this case, South African municipal water utilities). The most efficient frontier (with a score of 100 percent) is established by utilising sector-specific inputs and outputs for production technology. Simar and Wilson (2007) stated that the type of DEA models, either input- or output-orientated, depends on the nature of the industry being analysed and on the purpose of the research. The input-orientated model focuses on maintaining the existing level of outputs though determining the maximum number of inputs that can be saved; on the other hand, the output-oriented model aims to enhance the outputs of DMUs so that they can achieve the production possibility frontier while keeping the inputs constant (Ngobeni & Breitenbach, 2021).

Generally, when it comes to measuring efficiency in the water sector, an input-oriented model is considered better than an output-oriented model, this is because water utilities aim to minimise their input usage while producing a specific amount of output (Salazar-Adams, 2021). This research has utilised an input-orientated model, which aligns with previous studies in the field that has used the traditional DEA methodology to calculate initial efficiency scores (see Nithammer et al., 2022; Güngör-Demirci et al., 2018). Furthermore, the DEA benchmarking tool adjusts for variances in size in the selected Variable Returns to Scale (VRS) orientation. Water utilities differ in many aspects besides size; they are also likely to have different levels of productive capacity and efficiency. As a result, this research adopts a VRS input-minimisation orientation model, which according to Cetrulo et al. (2019) is a credible dispensation when applied to the measurement of water. As such, given $j = 1, 2 \ldots, N$ units (which in this case are the urban and rural South African municipal water utilities), each municipal water utility uses M inputs $xj = (x1j, x2j, \ldots, xMj)$ in the production process to produce S outputs $yj = (y1j, y2j, \ldots, ySj)$. The linear programme that minimises the use of inputs while maintaining constant outputs for each DMUj is depicted as follows (Walker et al., 2019):

$$Min\ \theta_j$$

subject to

$$\begin{aligned} &\sum_{j=1}^{N} \lambda_j x\, i_j \leq \theta x_{i0} && 1 \leq i \leq M \\ &\sum_{j=1}^{N} \lambda_j y_{r_j} \geq y_{r0} && 1 \leq r \leq S \\ &\qquad \lambda_j \geq 0 && 1 \leq j \leq N \end{aligned} \tag{1}$$

The efficiency of the water utility being evaluated is determined by θ_j, which is efficient when $\theta_j = 1$ and inefficient when $\theta_j > 1$. It is important to note that the DEA efficiency scores are greater than 1 because of the use of inverted Farrell efficiency scores. As indicated above, this study used a VRS model; which means that inverting the efficiency scores has an impact on the resulting efficiency scores (Nithammer et al., 2022). In this context, M represents the total inputs utilised by the water utility, while S represents the number of outputs generated, N is the total number of water utilities evaluated, and λ_j refers to a set of variables that indicate the relative importance of each water utility in the composition of the efficient frontier.

4.2 Double-bootstrap DEA approach

Additionally to the traditional DEA methodology described earlier, this study applied a revised form of the double-bootstrap DEA technique suggested by Simar and Wilson (2007) to calculate technical efficiency without bias, and also evaluate the influence of explanatory factors. This method outputs accurate measures of technical efficiency, and is more robust and stable than traditional one-stage DEA-derived efficiency scores. Two-stage DEA produces new data drawn from the initial set, which is then used to re-estimate the DEA model in equation 1 (Molinos-Senante et al., 2018). Therefore, like previous studies (see Nithammer et al., 2022; Molinos-Senante et al., 2018), this research applies Simar and Wilson's (2007) Algorithm 2 double-bootstrap procedure, summarised below:

After obtaining θ from the traditional DEA model (equation 1), the maximum-likelihood method is employed to calculate the estimates of $\hat{\beta}$ of β and $\hat{\sigma}_\varepsilon$ of σ_ε, which represent the beta and standard deviation of the error term ε_j, respectively. This is achieved by performing a truncated regression of θ against independent variables, as indicated by the subsequent equation:

$$z_j, \theta_j = z_j \beta + \varepsilon_j \tag{2}$$

For each water utility, then once more repeat the following four steps (1.1 – 1.4) B_1 times, to obtain a set of B_1 bootstrap estimates $\hat{\theta}_{jb}$ for $b = 1, \dots, B_1$ (Simar & Wilson 2007; Nithammer et al., 2022):

1.1 Generate the residual error ε_j from the normal distribution $N(0, \sigma_\varepsilon^2)$.

1.2 Compute $\theta_j^* = z_j \hat{\beta} + \varepsilon_j$.

1.3 Generate a pseudo-data set (x_j^*, y_j^*) where $x_j^* = x_j$ and $(y_j^* = y_j \left(\frac{\theta_j}{\theta_j^*}\right)$.

1.4 Using the pseudo-data set (x_j^*, y_j^*) and equation 1, estimate the pseudo-efficiency estimates θ_j^*. Then calculate the bias-corrected estimator θ_j for each utility j $(j = 1,2, \dots, N)$ using the bootstrap estimation or the bias $\hat{b}_j$, where $\hat{\theta}_j = \theta_j - \hat{b}_j$ and $\hat{b}_j = \left(\frac{1}{B} \sum_{b=1}^{B_1} \hat{\theta}_{jb}^*\right) - \theta_j$. Use a truncated maximum-likelihood estimation to regress $\hat{\theta}_j$ on the explanatory variables z_j and provide an estimation for $\hat{\beta}^*$ of β and an estimation for $\hat{\sigma}^*$ of σ_ε. Repeat the subsequent three steps (2.1 – 2.3) B_2 times to obtain a set of B_2 pairs of bootstrap estimates $(\hat{\beta}_j^{**}, \hat{\sigma}_j^{**})$ for $b = 1, \dots, B_2$ (Nithammer et al., 2022; Simar & Wilson 2007):

2.1 Generate the residual error ε_j from the normal distribution $N(0, \hat{\sigma}^{*2})$.

2.2 Calculate $\theta_j^{**} = z_j \beta^* + \varepsilon_j$.

2.3 Use maximum likelihood estimation to run a truncated regression $\hat{\sigma}_j^{**}$on the explanatory variables z_j and provide an estimate $\hat{\beta}^{**}$ for β and $\hat{\sigma}^{**}$ for σ_ε.

4.3 Description of data

4.3.1 The study sample

In South Africa, there exists a governance structure that comprises of three tiers: national, provincial, and local government (Goto et al., 2020). Municipalities are constitutionally mandated to provide public services; among others these include water services to communities. As shown in Table 1, there are 278 municipalities in the country. However, out of the 278 municipalities, only 144 have the legal authority to offer water services within their area of jurisdiction; as previously mentioned, these authorised municipalities are referred to as WSAs (NBI, 2019).

Table 1: Classification of South African municipalities

Category	Description	Number of municipalities
A	Metropolitan municipalities	8
B1	Secondary cities	19
B2	Municipalities with a large town as a core	27
B3	Municipalities characterised by small towns	108
B4	Municipalities that are mainly rural	72
C1	District municipalities not authorised to provide water services	23
C2	District municipalities authorised to provide water services	21

Source: StatsSA, 2016

The system of categorisation of municipalities was established to reflect significant differences within and across municipalities. They vary with regard to the operating and institutional challenges they face in fulfilling their service delivery mandates. The Department of Cooperative Governance and Traditional Affairs (COGTA) (2009) argue that municipalities within the same category tend to share homogenous challenges pertaining to (for instance) revenue collection. Combining similar units is a reasonable approach to facilitating the benchmarking of technical efficiency (Brettenny & Sharp, 2016).

In order to simplify the comparison and interpretation of the technical efficiency results, this study has adopted the approach of Nithammer et al. (2022) by grouping the water utilities into two categories, namely - urban and rural - to maintain homogeneity. Metropolitan municipalities, secondary cities, and large municipalities (i.e. A, B1, B2) are considered urban utilities; whereas smaller local municipalities, rural municipalities, and district municipalities authorised to provide water services (i.e. B3, B4 and C2) are considered rural utilities (Nithammer et al., 2022). Although there are currently 278 municipalities, the sample reflects the 144 municipalities who are legally authorised to provide water services within their geographic area. However, as a result of the unavailability of climatic data for 90 of the municipal water utilities, this study only evaluates 54 municipal water utilities: 27 urban municipal water utilities and 27 rural municipal water utilities.

4.3.2 Variables for efficiency estimation

It is essential to choose appropriate variables to be used in the measurement and assessment of productive efficiency. Accuracy in selection is crucial in public sector efficiency measurement. Benito et al. (2019) maintained that input and output selection is cumbersome, as these parameters are difficult to establish. Data availability is another material consideration. The literature review conducted was used to buttress the rationale for and selection of the production technology (inputs and outputs) for this research. The inputs that are commonly used in the literature regarding water utility efficiency are operating and labour costs, length of mains and number of workers/staff (see Nithammer et al., 2022; Ablanedo-Rosas et al., 2020; Villegas et al., 2019; Benito et al., 2019; Molinos-Senante et al., 2018). The most recommended approach for water utilities responsible for meeting the water needs of the community, is to adopt the input-minimisation orientation commonly utilised in mainstream studies (Brettenny & Sharp, 2016).

In terms of output variables, the ones commonly found in the literature are water quality (%), water losses or non-revenue water (%), and volumes of water delivered (see Nithammer et al., 2022; Molinos-Senante et al., 2018; Ananda, 2018; Brettenny & Sharp, 2016). Therefore, the input variables utilised in this study are operating expenditure (R) and length of mains (km), while the default output variables are authorised consumption volumes (kl) and water quality (%). It is crucial to note that municipal operating expenditure reinforce the link between spending and selected indicators of municipal outputs, and they also lead to the prompt delivery of those outputs (Financial and Fiscal Commission, 2011).

Table 2: Efficiency analysis variables

Variable	**Model Specification**
Total operating expenditure (R)	Input
Authorised consumption volumes (kl)	Output
Length of mains (km)	Input
Water quality (%)	Output

4.3.3 Explanatory variables

This study evaluates seven potential determinants of efficiency performance, namely the number of consuming units, number of consuming units receiving free water, water consumer debt (R), average daily maximum temperature (°C), average daily minimum temperature (°C), average monthly rain (mm), and location (urban or rural). ‘Number of consuming units’ in this study is used as a substitute for the potential cost savings that could be achieved by offering water services to a larger customer base, which is expected to improve the effectiveness of the delivery of water service (Monkam, 2014). To put it simply, Samkange (2019) suggests that if economies of scale are present, bigger utilities that serve more consumers are more likely to deliver water services at a reduced cost and with greater efficiency than smaller utilities. Moreover, as highlighted by Nithammer et al. (2022), the consuming units served by municipal water utilities in South Africa vary greatly, with the smallest utility catering to around 2 000 consumer units and the largest catering to nearly a million consumer units; this stark difference in size emphasises the cruciality of examining whether the water sector in South Africa enjoys economies of scale, which could potentially put the smaller rural utilities at a significant disadvantage.

South Africa has a free basic municipal services policy, wherein the government provides services at no cost to indigent households. The primary goal of this policy is to ensure that all citizens, particularly those living in low-income and vulnerable communities, have access to essential services, irrespective of their ability to pay. These services encompass a minimum amount of electricity, water, and sanitation, which are deemed sufficient to meet the basic needs of poor households. As part of this policy, households receiving free water are allocated a monthly amount of 6 000 litres (6 kl) of water per household. The allocation is managed and monitored using technological devices, such as prepaid meters, water management devices, and water restrictors (Water Alternatives Forum, 2022). The implementation of the free basic water policy represents a positive stride towards achieving equality of access across the country. However, it also poses financial challenges for municipalities, as the provision of free services places additional pressure on their budgets, given that those benefiting from these services do not contribute financially towards them (Monkam, 2014). As such, this study evaluated how ‘the number of consuming units receiving free water’ impact the efficiency of municipal water utilities in South Africa.

The culture of non-payment by water users has a consequential impact on basic service delivery. It results in decreasing or stagnant water utilities’ own revenues, which in turn forces them to rely more heavily on grant transfers from national government, possibly overburdening the fiscus (DCOG, 2021). Moreover, unrecovered municipal consumer debt reduces the funding that is accessible for infrastructure delivery, maintenance, and improvement. The issue of citizens in South Africa not paying for municipal services has been extensively discussed, as the amount of consumer debt in most municipalities continues to increase (Enwereji & Uwizeyimana, 2020). Therefore, it is generally believed that municipalities would be able to offer satisfactory services if they could collect payments from all customers who utilise their services. In this study, ‘water consumer debt’ is the total amount owed by water users/customers over a time period of over 90 days. It is essential to note that the amount of consumer debt assessed in the study is considered realistically collectable, as it has not been written off yet.

As previously mentioned, South Africa is the 29th-driest country globally and experiences an average annual precipitation of 450mm, which is lower than the global average of 860mm (TCTA, 2020). South Africa gets its water supply predominantly (77 percent) from surface water (Mutamba, 2019). This means the country is open to and at risk from the destructive effects of climate change. Therefore it is important to assess the effects of climatic factors such as precipitation and temperature on the efficiency of South African municipal water utilities. Climate change aggravates both water scarcity and water-related dangers such as flooding and drought, because higher temperatures cause disruption to precipitation patterns and thus to the entire water cycle. Consequently, according to Mutamba (2019), South Africa is susceptible to long-term droughts. Therefore, given that it is crucial to tackle climate change to guarantee a sustainable water supply in the future, this study assessed ‘average daily maximum temperature’ (°C), ‘average daily minimum temperature’ (°C), and ‘average monthly rainfall’ (mm) as potential determinants of efficiency in water service provision in South Africa.

Significant variations exist in economic and political circumstances, as well as location, performance and capacity (encompassing human resources, finances, and institutions), both within and between municipalities in South Africa (Monkam, 2014). Considering these differences, this study includes ‘location’, to assess whether efficiency is influenced by being in an urban or rural region (Nithammer et al., 2022). For instance, municipal water utilities in the same location (whether urban or rural) tend to share similar characteristics (COGTA, 2009). As such, it is necessary to compare rural and urban municipal water utilities separately to provide a comparison that is more accurate (Brettenny & Sharp, 2016).

4.3.4 Data sources

Since this study extends the 2022 study by Nithammer et al., the dataset covers the same period used in that particular study, which is 2010 to 2012 and 2014. Considering the use of ‘water quality’ as an output variable, this study also excluded the year 2013 from the analyses mainly because the DWS did not conduct the 2013 Blue Drop assessment, resulting in the unavailability of water quality data for that specific year.

The input, output and explanatory variables data is not accessible from a single source in South Africa; the data for this study was obtained from different sources. The data for operating cost and non-payment by water users was sourced from the National Treasury website, in accordance with 'Section 71 information (In-year Management, Monitoring and Reporting)'. Length of mains and authorised consumption was obtained from the DWS National Water Services Knowledge System, specifically the 'Water conservation and demand management' section. The study obtained water quality data from the Blue Drop report (DWS, 2014). The StatsSA website was the source of data for the number of consuming units, specifically the 'P9115 Non-financial census of municipalities', while the data on rainfall and temperature was acquired from the South African Weather Service (SAWS).

4.4 Descriptive statistics

This study made use of panel data to conduct an efficiency analysis of water utilities in South Africa. By using panel data, the study was able to recognise possible trends and control for time-varying variables that may differ across different entities (individuals, groups, or units), thus taking into account the unique differences between entities.

Table 3: Summary statistics of municipal data

Variables	**Measurements**	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Inputs	Operating costs (R/year in millions)	347	902	0.556	5 100
	Length of mains (km in thousands)	1.945	3.307	0.046	12.479
Outputs	Authorised consumption (kl/year in millions)	32.1	72.1	0.221	350
	Water quality (%)	70	25	5	99
Continuous explanatory variables	Consuming units (in thousands)	117.895	229.070	2.065	965.975
	Consuming units receiving free water (in thousands)	50.259	125.290	0.420	745.810
	Water consumer debt (R/ year in millions)	267	679	1.131	4 450

Continuous explanatory variables	Average daily maximum temperature (C)	24.789	2.387	19.775	32.642
	Average daily minimum temperature (C)	11.335	2.654	5.667	18.758
	Average monthly daily rain (mm)	42.617	22.598	0.533	114.583
Categorical explanatory variable	Location: Urban = 1	0.5	0.5	0	1

Table 3 provides summary statistics of the sample data utilised in this study to calculate the efficiency scores of municipal water utilities in South Africa. Based on the provided summary statistics, many of the variables appear to not follow a normal distribution. This is evident from the significant standard deviation for all variables apart from ‘water quality’, ‘average daily maximum temperature’, ‘average daily minimum temperature’, and ‘average monthly rain’. These variables have relatively smaller standard deviations, indicating potential closer adherence to a normal distribution. The data exhibits considerable variations in values across all factors, as seen in the difference between the smallest and largest values for each variable.

The ratio between the municipal water utility with the highest operating costs and the one with the lowest operating costs is approximately 9 107:1, indicating a significant difference in spending. The ratio of consuming units between the municipal water utility with the most and the fewest units is approximately 468:1, highlighting a substantial difference in the number of consumers served. The municipal water utility with the highest water consumer debt has approximately 4 449 times more debt than the municipal water utility with the smallest water consumer debt, indicating a significant disparity in debt levels. The difference in average monthly rain between the municipal water utility with the most and the one with the minimum rain is approximately 114.050 mm.

Based on the data presented in Table 3, we can infer that the municipal water utilities are not homogeneous, as there are substantial differences within and across the utilities. These variations in factors such as operating costs, consuming units, water quality, and water consumer debt suggest diverse conditions and management practices among the utilities.

Generally, in South Africa, larger municipalities, such as metropolitan municipalities (Category A), are predominantly located in urban areas. Urban areas have higher population densities, increased access to job opportunities, infrastructure, and services. As a result, there is an increased demand for and affordability to pay for these services. Consequently, municipal water utilities with a large number of consuming units located in urban areas may have a higher overall debt load due to the sheer number of consumers. However, they are more likely to collect the debt given the consumers' ability to afford payment for their services. In contrast, municipalities in rural areas often face higher unemployment rates, which can lead to consumers being less likely to pay for services. These variations in economic conditions point to the likelihood that 'water consumer debt' will likely be a significant factor influencing the efficiency of South African municipal water utilities.

4.5 Conclusion

Due to the unavailability of climatic data for 90 municipal water utilities, this study assessed the efficiency of only 54 South African municipal water utilities (27 urban and 27 rural municipal water utilities) during the periods 2010 to 2012 and 2014. The study employed both the traditional DEA approach and the double-bootstrap DEA approach to estimate the efficiency scores. The variables utilised as inputs in this research were 'operating expenditure' and 'length of mains', and the default output variables were 'authorised consumption volumes' and 'water quality'.

This study considered seven potential determinants of efficiency performance: 'number of consuming units', 'number of consuming units receiving free water', 'water consumer debt', 'average daily maximum temperature', 'average daily minimum temperature', 'average monthly rain', and 'location'.

Chapter Five

Empirical Results: Presentation and Discussion

5.1 Results: full urban and rural regression

This study evaluated the efficiency of South African municipal water utilities in three stages. In the first stage, all 54 municipal water utilities were assessed to identify the efficiency scores, corrected for biases, and the external factors that influence efficiency. The second stage entailed calculating the efficiency scores and the variables that drive efficiency for the 27 urban municipal water utilities; and the third stage involved computing the efficiency scores and drivers of efficiency of the 27 rural municipal water utilities. As indicated previously, it was necessary to compare rural and urban municipal water utilities separately, to compare 'like with like' and provide a more accurate comparison (Brettenny & Sharp, 2016).

This study selected seven potential determinants of efficiency, namely 'number of consuming units', 'number of consuming units receiving free water' 'water consumer debt', 'average daily maximum temperature', 'average daily minimum temperature', 'average monthly rain', and 'location'. The regression analysis presented in Table 4 considers the inefficiency of utilities as the dependent variable. A municipal water utility is considered efficient if its bias-corrected efficiency score is 1; on the other hand, if its score is greater than 1, it is considered inefficient. Provided that Shepard's efficiency scores are used (which are the opposite of Farrell efficiency scores), a negative estimated coefficient means an improvement in efficiency for the water utility, while a positive coefficient suggests that the estimated parameter reduces efficiency (Nithammer et al., 2022). The regression results for the complete set of 54 municipal water utilities is displayed in Table 4.

Table 4: Results of urban and rural truncated regression

Dependent	**Inefficiency**
Independent	**Coefficients**
Consuming units	0.0145* (0.0082)
Consuming units receiving free water	- 0.0115***(0.0039)
Water consumer debt	- 0.0299*** (0.0060)
Average daily maximum temperature	0.1225* (0.0650)
Average daily minimum temperature	0.0241 (0.0245)
Average monthly daily rain	- 0.0082 (0.0088)
Location	- 0.0369** (0.0175)
Cons	1.1698*** (0.2464)
Observation	54

Note: Standard errors in parentheses

*p < 0.10; **p < 0.05; ***p < 0.01

In the first stage analysis, the primary explanatory variables are ‘water consumer debt’ and ‘number of consuming units receiving free water’. The coefficient value associated with water consumer debt is negative (- 0.0299), implying that water consumer debt has a positive influence on efficiency. It has a p-value of 0.0000 and is significant at 1%, indicating its strong significance in the analysis of efficiency for municipal water utilities in South Africa. The results do not align with the preconceived assumptions that consumer debt has adverse effects on municipal efficiency. In this study, water consumer debt refers to the total amount owed by water users over a 90-day period and is not yet written off, making the debt considered realistically collectible. Therefore, water consumer debt can be considered to have a short-term positive impact on efficiency. If municipal water utilities could successfully collect the outstanding debt in the short term before it becomes written off and realistically uncollectable, municipal revenues would potentially increase. Consequently, if the recovered outstanding debt is used wisely, it will assist water utilities in financing the maintenance and upgrading of water infrastructure. Managers and policymakers should aim to develop and implement efficient water consumer debt strategies to effectively manage the debt.

The number of consuming units receiving free water has a positive impact on efficiency, as shown by the negative sign of its coefficient, with a p-value of 0.0040, signifying significance at 1%. The number of consuming units receiving free water significantly and positively impacts the efficiency of municipal water utilities by reducing non-revenue water through decreased illegal connections and tampering, leading to water conservation. It can increase revenue collection by avoiding billing costs for indigent households while ensuring access to a basic necessity, promoting social equity and poverty alleviation. Additionally, it contributes to improved public health and sanitation, reducing waterborne diseases. Furthermore, political and social stability are fostered by addressing water access grievances. While providing free water can have significant positive impacts, it should be done in a balanced and sustainable manner to ensure the financial viability of municipal water utilities.

The ‘location’ coefficient has a p-value of 0.0350, indicating its significance at a 5% level. The negative sign of its coefficient suggests that location has a positive impact on efficiency. These results are expected, considering the significant differences in location between municipalities in South Africa (Monkam, 2014). Municipal water utilities in the same type of location (urban or rural) tend to share similar characteristics, such as unemployment and capacity constraints (COGTA, 2009). Therefore, it is crucial to compare rural and urban municipal water utilities separately to provide a more accurate and comparable comparison (Brettenny & Sharp, 2016). As such, the study determined the influence of the above determinants of efficiency on the efficiency scores of urban and rural municipal water utilities, respectively.

The study determined that ‘average daily maximum temperature’ is significant at a 10% level of significance. It has a positively signed coefficient, indicating a negative impact on efficiency. These findings suggest that the efficiency scores of South African municipal water utilities are adversely affected by high temperatures. This finding aligns with preconceived assumptions, as high temperatures can cause increased evaporation of surface water, leading to reduced water availability (Department of Water Affairs, 2013). This is particularly problematic in South Africa, considering the country is water stressed and relies on surface water (Mutamba, 2019). Additionally, high temperatures exacerbate the effects of drought, negatively impacting water storage (Department of Water Affairs, 2013). Moreover, high temperatures can potentially affect water quality: as water levels in reservoirs and other water sources decrease, the concentration of pollutants and minerals in the remaining water may increase, making it more challenging to treat and deliver safe drinking water to consumers (Department of Water Affairs, 2013).

On the other hand, ‘average monthly rain’ has a positive impact on efficiency, as shown by the negative sign of its coefficient; however, the effect is negligible. Given that South Africa, according to TCTA (2020), has an average annual rainfall of 450mm, which is lower than the world average of 860mm and ranks as the 29th-driest country globally, the result was expected. While rain can positively impact the efficiency of municipal water utilities by replenishing water sources and reservoirs, increasing water availability, its overall efficiency benefit may be negligible due to insufficient rainfall during droughts, challenges in water management practices, distribution issues, aging infrastructure, and the strain of rapid population growth and urbanisation on water resources.

‘Number of consuming units’ has a positive coefficient and a p-value of 0.0780, indicating its significance at a 10% level and its negative effect on efficiency. Based on the findings, the efficiency scores of municipal water utilities essentially decrease as the number of households or businesses that use their services increase. This means the preconceived idea that larger municipal water utilities in urban areas enjoy economies of scale is incorrect. In essence, they are not more efficient than smaller water utilities serving rural areas.

5.2 Results: urban municipal water utilities

5.2.1 Traditional DEA results

The 27 urban municipal water biased efficiency scores were calculated in this study using the traditional DEA model. However, the dataset used in this study includes four sets of data for each of the municipal water utilities because panel data was used. This means that the study covered a total of 108 DMUs for the urban analysis. Table 5 displays the biased efficiency scores of the 20 best efficient scores, while **Appendix 1** comprise the results of the complete sample.

Table 5: Top 20-urban biased efficiency scores

ID	Municipal Category	Year	Biased efficiency score	Rank
31	B1	2012	1.0000	1
87	B1	2012	1.0000	1
51	B2	2012	1.0000	1
71	B1	2012	1.0000	1
67	B2	2012	1.0000	1
20	A	2014	1.0000	1
27	B1	2012	1.0000	1
19	A	2012	1.0000	1
8	A	2014	1.0000	1
38	B2	2011	1.0000	1
15	B2	2012	1.0000	1
11	A	2012	1.0000	1
39	B2	2012	1.0000	1
35	B2	2012	1.0000	1
23	B2	2012	1.0015	15
2	A	2011	1.0017	16
25	B1	2010	1.0022	17
37	B2	2010	1.0027	18
17	A	2010	1.0034	19
5	A	2010	1.0035	20

The ‘Biased efficiency score’ column in Table 5 lists the traditional DEA efficiency scores. Out of the 27 urban municipal water utilities analysed over a four-year period, the top 20 performers consisted of seven from category A, five from category B1, and eight from category B2. The results indicate that the urban municipal biased efficiency scores are not significantly influenced by their category or size. The urban sample had an average efficiency score of 1.0318 and a standard deviation of 0.0258. This indicates that an urban utility could achieve the same level of output while reducing its inputs by approximately 3.18% to match the benchmark utility’s efficiency.

5.2.2 Double-bootstrap DEA results

This study utilised the double-bootstrap DEA model to calculate the bias-corrected efficiency scores of the 27 urban municipal water utilities. The top 20 most efficient utilities’ scores corrected for bias are shown in Table 6. **Appendix 1** comprise the complete sample.

Table 6: Top 20-urban bias-corrected efficiency scores

ID	Municipal Category	Year	Biased efficiency score	Rank	Bias	Bias-corrected efficiency score	Rank
2	A	2011	1.0017	16	-0.0049	1.0066	1
5	A	2010	1.0035	20	-0.0087	1.0122	2
35	B2	2012	1.0000	8	-0.0123	1.0123	3
1	A	2010	1.0071	26	-0.0057	1.0128	4
31	B1	2012	1.0000	8	-0.0147	1.0147	5
9	A	2010	1.0096	28	-0.0059	1.0154	6
29	B1	2010	1.0092	27	-0.0069	1.0161	7
25	B1	2010	1.0022	17	-0.0148	1.0170	8
27	B1	2012	1.0000	8	-0.0175	1.0175	9
23	B2	2012	1.0015	15	-0.0163	1.0178	10
30	B1	2011	1.0063	23	-0.0118	1.0181	11
17	A	2010	1.0034	19	-0.0151	1.0185	12
37	B2	2010	1.0027	18	-0.0161	1.0188	13
8	A	2014	1.0000	8	-0.0198	1.0198	14
10	A	2011	1.0147	36	-0.0059	1.0206	15
26	B1	2011	1.0047	22	-0.0159	1.0207	16
3	A	2012	1.0117	29	-0.0095	1.0212	17
39	B2	2012	1.0000	8	-0.0216	1.0216	18
43	B1	2012	1.0188	41	-0.0030	1.0218	19
6	A	2011	1.0122	30	-0.0097	1.0218	20

Table 6 includes a column labelled ‘Bias’, which displays the traditional DEA model’s estimated bias efficiency scores. The double-bootstrap approach used in this study found a negative bias, which is consistent with the findings of previous studies that also employed this method (see Nithammer et al., 2022; Molinos-Senante et al., 2018). The column named ‘Bias-corrected efficiency score’ in Table 6 displays the efficiency scores of municipal water utilities that have been corrected for bias. On average, the bias-corrected efficiency score is 1.0433, which is significantly higher than the biased efficiency score of 1.0318. This suggests that a typical water utility could lower its inputs by 4.33% to achieve the same level of efficiency as the benchmark municipal water utility although preserving the same output level. If biased efficiency scores were used, potential input savings would be underestimated by an average of 1.15%.

When bias-corrected efficiency scores are employed, there is a significant alteration in the ranking of municipal water utilities. Despite 14 urban municipal water utilities being recognised as efficient with biased efficiency scores (i.e., scoring 1), only four out of these are among the 20 most efficient water utilities for any of the four years analysed. When adjusting for bias, the City of Tshwane was ranked as the top performer for its efficiency scores in 2011. However, it was only ranked 16th when using the traditional DEA model. Breede Valley was ranked 14th for its performance in 2012 using the traditional DEA model, but was ranked 3rd in the top 20 most efficient double-bootstrap efficiency scores for its performances in 2012. Drakenstein was ranked the top performer in terms of the traditional DEA scores for its 2012 performance, but was ranked 5th in the bias-corrected efficiency scores . The City of Cape Town, identified as ID 5, ranked second in the bias-corrected efficiency scores but only 20th in the biased efficiency scores. Additionally, the City of Cape Town was found to be the utility that performed the best in all four years based on the double-bootstrap efficiency scores. According to the efficiency scores corrected for bias, the City of Ekurhuleni (identified as ID 9 and ID 10) ranked 6th and 15th, respectively. However, when using the traditional DEA model, it was ranked 28th and 36th, respectively.

Table 6 shows that the rankings of certain municipal water utilities undergo notable changes when taking into account the bias-corrected efficiency scores. These variations can have momentous consequences for policymakers and regulators. As a result, in countries where efficiency analysis outcomes are utilised to regulate the water sector, it is crucial to accurately reward or penalise utility companies based on the dependable efficiency scores generated by the double-bootstrap model (Nithammer et al., 2022).

5.2.3 Determinant results

In the second phase of the double-bootstrap DEA approach, it becomes possible to identify external factors that impact the initial efficiency results obtained in the first stage. Therefore, this study examined the subsequent explanatory variables: ‘number of consuming units’, ‘number of consuming units receiving free water’, ‘water consumer debt’, ‘average daily maximum temperature’, “average daily minimum temperature’, and ‘average monthly rain’. The results of the regression analysis for the urban sample, comprising 27 municipal water utilities, are presented in Table 7.

Table 7: Results of urban truncated regression

Dependent	**Inefficiency**
Independent	**Coefficients**
Consuming units	0.0009 (0.0033)
Consuming units receiving free water	- 0.0109*** (0.0033)
Water consumer debt	- 0.0000 (0.0023)
Average daily maximum temperature	0.0315 (0.0293)
Average daily minimum temperature	0.0075 (0.0112)
Average monthly rain	0.0074 (0.0056)
Cons	0.9851*** (0.1013)
Observation	27

Note: Standard errors in parentheses

*p < 0.10; **p < 0.05; ***p < 0.01

In this study, the ‘Number of consuming units’ is an approximation for the economies of scale that water utilities may achieve by catering to a greater number of units that consume water services. The number of consuming units was found to have a negative but insignificant impact on urban municipal water utilities. This indicates that urban municipal water utilities do not benefit from economies of scale. These findings are supported by the bias-corrected efficiency scores. In the classification of municipalities in South Africa, Category A municipalities are regarded as the largest and are located in urban areas. However, not all of these municipalities are included in the top 20 most efficient municipal water utilities based on the bias-corrected efficiency scores. For instance, Mangaung (ID 64) is a Category A municipality but is ranked 80th in efficiency. Municipal water utilities in urban areas may not always benefit from economies of scale due to factors such as aging infrastructure with increased maintenance costs, distributed demand requiring multiple facilities, and higher operating expenses.

‘Number of consuming units receiving free water’ is negative and significant at 1%, and the p-value is 0.000. This implies that consuming units receiving free water positively impacts the efficiency of urban municipal water utilities. The outcome is consistent with the one discovered in the complete sample, implying that the same argument put forth in the complete sample applies here as well. Providing free water to indigent households in urban areas significantly positively impacts the efficiency of municipal water utilities by encouraging legal connections, fostering gradual payment habits, reducing disconnection rates, and supporting economic activity. Free water provision to poor households incentivises legal connections, by leading more residents to register with the utility and transition to paying customers beyond the free allocation.

‘Water consumer debt’ insignificantly positively impacts efficiency. Efficient management of water consumer debt can have a favourable but not so significant impact on the efficiency of urban municipal water utilities. Municipal water utilities located in urban areas are likely to have more effective water consumer debt collection due to higher population density and better accessibility. Urban areas are concentrated with educated and skilled individuals, leading to improved debt management practices and lower unemployment rates, ensuring more regular income for timely bill payments. Additionally, urban areas offer better access to financial services and information, and greater resources for enforcement and monitoring of debt collection policies. Therefore, consumer debt is likely to be collected successfully in urban areas. It is essential for water utility managers and policymakers to implement policies and processes that enable positive collection and recovery of outstanding water consumer debt to ensure it has a significant impact on efficiency. As water is a constitutional right in South Africa, municipal water utilities should consider implementing strategies that do not completely terminate water service to non-paying customers but instead foster a culture of paying for the service.

‘Average daily maximum temperature’ negatively influences the efficiency of municipal water utilities in South Africa. These results are not consistent with those obtained in the complete sample, which indicated that the average daily maximum temperature is a significant variable despite negatively impacting efficiency. Municipal water utilities in South Africa are constitutionally obligated to provide secure drinking water to communities. Persistently high temperatures can have an adverse effect on the ability of water utilities to deliver safe drinking water to communities, as the maintenance required for the operation of drinking water purification systems will be compromised by the increasing concentration of pollutants and minerals in remaining water sources. Moreover, poor water quality exacerbates water quality-related diseases, thus affecting human health.

The second-last explanatory variable is ‘average daily minimum temperature’. For urban municipal water utilities, this variable has a negative impact on efficiency but is insignificant. This implies that average minimum temperatures negatively influence efficiency, but not significantly. However, it is important for water suppliers to monitor and manage temperature-related issues to ensure safe and reliable water for their customers. The last factor affecting efficiency considered in this study is ‘average monthly rainfall’. It also negatively impacts efficiency but not significantly. South Africa’s water resources are impacted by aging water infrastructure (resulting in extensive water losses) (Mutamba, 2019). Considering the limited technical and leadership capacity in municipalities, which impacts effective operation and maintenance, heavy rainfall could potentially harm water infrastructure, such as storage reservoirs and treatment plants. As such, it is important for urban municipal water utilities to continually monitor and assess their systems to adapt to changing climatic conditions and ensure long-term water sustainability.

5.3 Results: rural municipal water utilities

5.3.1 Traditional DEA results

The 27 rural municipal water utilities’ biased efficiency scores were computed using the traditional DEA model. The analysis of rural municipal water utilities in the study was based on panel data, covering a total of 108 DMUs. The top 20 biased efficiency scores for rural municipalities are presented in Table 8. **Appendix 2** comprise the complete results.

Table 8: Top 20-rural biased-efficiency scores

ID	Municipal Category	Year	Biased efficiency score	Rank
111	B3	2012	1.0000	1
126	B3	2011	1.0000	1
125	B3	2010	1.0000	1
120	B3	2014	1.0000	1
119	B3	2012	1.0000	1
128	B3	2014	1.0000	1
157	B3	2010	1.0000	1
159	B3	2012	1.0000	1
141	B3	2010	1.0000	1
140	B3	2014	1.0000	1

124	B3	2014	1.0000	1
155	B3	2012	1.0000	1
122	B3	2011	1.0000	1
151	B3	2012	1.0000	1
123	B3	2012	1.0000	1
150	B3	2011	1.0002	16
118	B3	2011	1.0011	17
117	B3	2010	1.0011	18
113	B3	2010	1.0047	19
134	B4	2011	1.0114	20

The ‘Biased efficiency score’ column in Table 8 represents the traditional DEA efficiency scores. The 20 most efficient rural municipal water utilities over four years include 19 from category B3 and one from category B4. These results suggest that the biased efficiency scores may be impacted by the category and size of a utility in the rural sector. The rural sample as a whole had an efficiency score of 1.1007 on average, with a standard deviation of 0.0799. This indicates that, on average, a rural utility could operate with about 10.07% less input and still achieve the same output level as the benchmark utility while maintaining efficiency.

5.3.2 Double-bootstrap DEA results

This study employed a double-bootstrap DEA method to compute the 27 rural water utilities’ bias-corrected efficiency scores. Table 9 displays the top 20 most efficient bias-corrected efficiency scores of the 108 rural DMUs included in the study.

Table 9: Top 20-rural bias-corrected efficiency scores

ID	**Municipal Category**	**Year**	**Biased efficiency score**	**Rank**	**Bias**	**Bias-corrected efficiency score**	**Rank**
111	B3	2012	1.0000	8	-0.0169	1.0169	1
113	B3	2010	1.0047	19	-0.0144	1.0191	2
118	B3	2011	1.0011	18	-0.0186	1.0197	3
117	B3	2010	1.0011	18	-0.0212	1.0222	4
126	B3	2011	1.0000	8	-0.0241	1.0241	5
125	B3	2010	1.0000	8	-0.0266	1.0266	6
120	B3	2014	1.0000	8	-0.0277	1.0277	7
119	B3	2012	1.0000	8	-0.0281	1.0281	8
115	B3	2012	1.0163	24	-0.0147	1.0311	9

130	B3	2011	1.0134	22	-0.0191	1.0325	10
116	B3	2014	1.0212	26	-0.0166	1.0378	11
128	B3	2014	1.0000	8	-0.0442	1.0442	12
142	B3	2011	1.0276	28	-0.0229	1.0506	13
114	B3	2011	1.0336	34	-0.0186	1.0522	14
133	B4	2010	1.0161	23	-0.0379	1.0540	15
134	B4	2011	1.0114	20	-0.0428	1.0542	16
136	B4	2014	1.0122	21	-0.0421	1.0543	17
146	B3	2011	1.0418	38	-0.0142	1.0560	18
110	B3	2011	1.0291	30	-0.0280	1.0571	19
112	B3	2014	1.0312	33	-0.0267	1.0580	20

The column labelled ‘Bias’ in Table 9 indicates the bias estimates of the efficiency scores calculated using the traditional DEA model. The negative bias corresponds to the findings in the urban sample. The average bias-corrected efficiency score of the rural utilities is 1.1398, which is significantly higher than the average biased efficiency score of 1.1007. This suggests that an average utility can reduce its inputs by 13.98% to operate at the same efficiency level as the benchmark utility without reducing output. Furthermore, utilising the biased efficiency scores will lead to an average underestimation of possible input savings by 3.91%.

The municipal water utilities rankings differ considerably when utilising bias-corrected efficiency scores. Although 15 rural municipal water utilities were initially identified as efficient using biased-efficiency scores (i.e., scores of 1), only six of these utilities appear in the 20 most efficient utilities in any of the four years examined. Karoo Hoogland (ID 110, ID 111, ID 112) was ranked first for its 2012 performance, 19th for its 2011 performance, and 20th for its 2014 performance in terms of the double-bootstrap efficiency scores. The traditional DEA model also identified Karoo Hoogland as efficient in 2012, but most of the rankings of other municipal water utilities underwent significant changes. The utilisation of bias-corrected efficiency scores resulted in a significant change in the ranking of Siyathemba (ID 118). It moved up from 17th place, as per the traditional DEA, to the third spot when utilising the bias-corrected efficiency scores for its 2011 performance. The municipal water utility Mafube (ID 130) moved from its 22nd ranking in the traditional DEA model to the 10th ranking when the bias-corrected efficiency scores were used for its 2011 performance.

The variances in the rankings and scores found from the traditional DEA and the double-bootstrap model have considerable consequences for policymakers and regulators operating in rural areas. Essentially, the analysis of rural water utilities showed a similar scenario to the urban utility analysis, where some municipal water utilities' rankings changed considerably when the bias-corrected efficiency scores were taken into account.

5.3.3 Determinant results

Similar to the analysis conducted on urban municipal water utilities, the study also used the second stage of the double-bootstrap DEA model to determine the factors that affect the bias-corrected efficiency scores of rural water utilities. The same set of explanatory variables that were used in the urban analysis were also used in this rural analysis.

Table 10: Results of rural truncated regression

Dependent	**Inefficiency**
Independent	**Coefficients**
Consuming units	0.0914*** (0.0147)
Consuming units receiving free water	- 0.0019 (0.0050)
Water consumer debt	- 0.0297*** (0.0104)
Average daily maximum temperature	0.1965** (0.0960)
Average daily minimum temperature	0.0258 (0.0348)
Average monthly daily rain	0.0004 (0.0109)
Cons	0.0934 (0.4253)
Observation	27

Note: Standard errors in parentheses

*p < 0.10; **p < 0.05; ***p < 0.01

'Number of consuming units' is significant at 1% for rural municipal water utilities, and is discovered to have a detrimental effect on efficiency. The results are consistent with those of the complete sample, indicating that rural municipal water utilities in South Africa do not receive any advantages in terms of economies of scale. The findings depict the reality of rural water utilities. According to National Treasury (2011), in numerous rural areas, networked services like piped water and waterborne sewerage are frequently too expensive to establish and sustain, resulting in them being financially inaccessible.

The 'number of consuming units receiving free water' has a positive but insignificant impact on efficiency. Although providing free water to poor households in rural areas can lead to positive social and health outcomes, the overall effect on the efficiency of municipal water utilities may be minor due to challenges such as limited access to services, high unemployment rates, financial constraints, and infrastructure limitations in rural regions. To achieve a more substantial impact, a comprehensive approach is required, addressing not only free water provision but also broader issues like poverty, access to opportunities, and sustainable water management.

For rural water utilities ‘water consumer debt’ has a negative coefficient and is significant at 1%. This suggests that it has a positive impact on the efficiency of rural municipal water utilities. These results align with those obtained from the full sample. If managed well and successfully collected, consumer debt could significantly boost municipal own revenues and enable rural municipalities to fund their capital programmes.

‘Average daily maximum temperature’ is significant at 5%. High temperatures have a negative impact on the efficiency of rural water utilities, as evidenced by the positive coefficient. On the other hand, ‘average daily minimum temperature’ and ‘average monthly daily rain’ have no significance on the efficiency scores of rural municipal water utilities. These results are consistent with those obtained from the urban analysis. Notwithstanding this finding, it is important for municipal water utilities to mitigate against the effects of climate change. Policymakers and regulators must develop plans that will establish sufficient resources and expertise in the water sector and in the country to monitor and detect any issues promptly, as well as being able to adapt to protect water resources and ensure a sustainable supply of water in the future.

5.4 Conclusion

The results imply that the efficiency rankings and scores of municipal water utilities differ considerably depending on whether the traditional or double-bootstrap DEA model is employed. Moreover, these findings suggest that the drivers of efficiency in urban and rural municipal water utilities in South Africa vary. For municipal water utilities located in urban areas, the number of consuming units receiving free water is an important determinant of water utility efficiency. Surprisingly, water consumer debt has a positive effect on efficiency, even though its impact is insignificant, given that it might not be fully recovered. On the other hand, the climatic variables, i.e., average daily maximum temperature, average daily minimum temperature, and average monthly daily rain, negatively impact efficiency, aligning with previously held assumptions.

For municipal water utilities geographically located in rural areas, the number of consuming units is significant which is not the case in urban municipal water utilities. Water consumer debt is also significant, as well as average daily maximum temperature. Both number of consuming units and average daily maximum temperature negatively impact efficiency. Conversely, water consumer debt positively impacts efficiency, which goes against theoretical expectations.

Chapter Six

Conclusions and Policy Recommendations

6.1 Summary and conclusions

Improving efficiency and benchmarking are important for ensuring water sustainability, for managing the effects of climate change, and for improving water service delivery. The efficiency of South African municipal water utilities was evaluated using the modified double-bootstrap DEA model. Initially, this study employed traditional DEA to estimate the biased-efficiency scores of South African municipal water utilities during 2010-2012 and 2014. Subsequently, the double-bootstrap DEA approach was utilised to produce the bias-corrected efficiency scores, as well as to assess the impact of external factors. The findings suggest that the rankings of water utilities based on biased efficiency scores are not reliable. Regarding the biased-efficiency scores obtained from traditional DEA, certain municipal water utilities were deemed 100% efficient, whereas the bias-corrected scores reveal that none of them are entirely efficient. The results emphasise the significance of employing dependable methods to determine efficiency scores, as biased-efficiency scores can be deceptive, particularly in areas where they are employed to govern water utilities.

Given that the double-bootstrap DEA method permits the detection of external factors that impact the initial efficiency estimates, the study analysed seven possible factors that could affect efficiency in municipal water utilities in South Africa. These included ‘number of consuming units’, ‘number of consuming units receiving free water’, ‘water consumer debt’, ‘average daily maximum temperature’, ‘average daily minimum temperature’, ‘average monthly rain’, and ‘location’. To provide a more accurate comparison, the study compared rural and urban municipal water utilities separately.

The variable ‘consuming units’ had a significant negative impact on efficiency in the rural sample. This suggests that rural municipal water utilities in South Africa do not benefit from economies of scale. In the urban sample, the variable ‘consuming units’ also had a negative impact on efficiency but was deemed insignificant. The study revealed that the ‘number of consuming units receiving free water’ had a significant positive impact on municipal water efficiency in the urban sample. Additionally, ‘water consumer debt’ had a significant positive effect on efficiency in the rural sample. This seems contrary to what we would expect based on intuition. However, considering that water consumer debt represents the total amount owed by water users within a period of over 90 days and has not been written off yet, the debt is considered realistically collectible. Therefore, it may be considered to have a short-term positive influence on efficiency, depending on whether it is successfully collected.

‘Average daily maximum temperature’ had a negative effect on efficiency scores in both the urban and rural samples, but its effect was significant only in the rural sample. This was expected, given that high temperatures can potentially affect water quality. On the other hand, the study determined that the ‘average daily minimum temperature’ was not a significant factor for either the urban or rural sample. To ensure customers receive safe and dependable water, it is important for water providers to monitor and address temperature-related concerns. The study also investigated the influence of ‘average monthly rainfall’ as an explanatory variable. In both the urban and rural sample, the variable was found to negatively impact efficiency but insignificantly. To avoid the challenges that variations in rainfall can present to municipal water utilities, it is crucial to implement efficient measures and preventive actions.

The disparity in efficiency rankings between the traditional and double-bootstrap DEA models indicate the need for careful consideration when comparing and interpreting the results. Additionally, the distinct drivers of efficiency for urban and rural utilities highlight the importance of tailoring management strategies to the specific challenges faced in each context. Policymakers and regulators must recognise the influence of factors such as free water allocation and water consumer debt on efficiency and explore methods to optimise these variables effectively. Furthermore, the negative impact of climatic variables on efficiency underscores the urgency of developing adaptive measures to address the challenges posed by climate change and protect water resources for sustainable supply in the future.

Due to unavailability of data, this study computed bias-corrected efficiency scores for only 54 metropolitan and local municipalities in South Africa, of which all are categorised as WSAs. The availability and reliability of data is a serious concern in terms of the efficiency analysis of South African municipal water utilities. According to Brettenny and Sharp (2018), the information provided by the South African municipal water utilities may not always be trustworthy or precise, which means that the outcomes reported may have significant discrepancies. Even though the benchmarking systems among municipalities have enhanced the quality of data management, further efforts are needed to address the issue (Brettenny & Sharp, 2016). For this reason, future studies should confirm these results, also taking into account other exogenous factors such as fiscal autonomy and institutional capacity, and socio-economic factors such as citizens’ income levels. Moreover, given that some municipal water utilities struggle to recover all outstanding consumer debt, resulting in the debt being written off, the effect of written off bad debt on the efficiency of municipal water utilities should be determined.

6.2 Policy recommendations

The findings emphasise the significance of utilising credible methodologies to assess the technical efficiency of water utilities, as biased scores produced by the traditional DEA model differed significantly from the bias-corrected scores, as demonstrated in both the urban and rural samples.

Location was discovered to positively influence efficiency. Municipal water utilities in the same type of location (urban or rural) tend to share similar characteristics. Therefore, it is necessary to analyse rural and urban municipal water utilities separately to assess comparable systems and produce a more accurate comparison. The understanding of location-specific factors can inform policymakers and utility managers in adjusting their funding models for water to better reflect these differences. Additionally, considering the impact of location on efficiency may lead to targeted interventions and resource allocation strategies, ultimately enhancing the overall performance and sustainability of water services across urban and rural areas.

The finding that providing free water to consuming units significantly and positively impacts the efficiency of municipal water utilities has important policy implications. Offering free water to indigent households not only improves access to water services but also promotes social equity. The policy reduces the financial burden on poor households and enhances their overall well-being, contributing to poverty alleviation efforts. Through the implementation of the free basic water policy, the municipal water supply system’s overall performance can be enhanced with improved management practices and operational effectiveness. Policymakers must carefully manage the policy’s implementation to ensure the long-term financial sustainability of water utilities, balancing support for disadvantaged households with securing revenue for maintenance and future infrastructure development.

The negative impact of temperature and rainfall patterns on efficiency has significant policy implications for the operating context of municipal water utilities. Currently, South Africa is not experiencing a shortage of water; however, if serious measures are not promptly implemented, the country may face a water crisis in the future. Moreover, the anticipated impacts of climate change on precipitation and temperature are expected to further exacerbate the water security challenges in the country. It is of utmost importance for the government to take prompt action to prevent a situation where water demand exceeds supply. Therefore, building sufficient capacity within the sector and the country to effectively monitor and detect climate change is imperative to adapt accordingly. This proactive approach is necessary to safeguard water resources and ensure a sustainable water supply for the future, considering the potential challenges posed by climate change.

The study identified water consumer debt as a significant factor in determining efficiency. This has serious policy implications, as consumer debt is one of the major obstacles facing South African municipalities. It is important for water utilities to manage consumer debt and ensure the successful collection thereof. Water consumer debt can boost water utilities' revenue if collected successfully. Therefore, to improve the chances of successfully collecting consumer debt for water services, regulators and policymakers should ensure the following:

- Water utilities should develop and implement debt management strategies that include regular communication with customers who are in arrears, as well as the implementation of payment plans and the use of debt collection agencies;

- Water utilities should provide customers with multiple payment options, such as online payment, automatic debit, and payment at local banks or post offices. This will make it easier for customers to pay their bills and reduce the likelihood of missed payments;

- Water utilities should develop and implement education and awareness campaigns to educate customers about the importance of paying their water bills on time, and the consequences of non-payment; and

- Water utilities should regularly monitor and evaluate their debt collection approaches to determine what is working and what is not, and make changes to those tactics that are not working.

In conclusion, the scientific evidence presented in this study can be utilised by policymakers and regulators to tackle the inefficient management of drinking water services. Therefore, this study contributes to the conversation surrounding fiscal policy in South Africa. As such, the study has successfully accomplished its primary objectives of benchmarking the technical efficiency of municipal water utilities in South Africa.

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Appendix 1: Full Sample: Urban Results

Table 1.1: Full sample: urban biased and bias-corrected efficiency scores

ID	Municipal Category	Water Utility	Year	Biased efficiency score	Rank	Bias	Bias-corrected efficiency score	Rank
2	A	City of Tshwane	2011	1.0017	16	-0.0049	1.0066	1
5	A	City of Cape Town	2010	1.0035	20	-0.0087	1.0122	2
35	B2	Breede Valley	2012	1.0000	8	-0.0123	1.0123	3
1	A	City of Tshwane	2010	1.0071	26	-0.0057	1.0128	4
31	B1	Drakenstein	2012	1.0000	8	-0.0147	1.0147	5
9	A	City of Ekurhuleni	2010	1.0096	28	-0.0059	1.0154	6
29	B1	Drakenstein	2010	1.0092	27	-0.0069	1.0161	7
25	B1	Stellenbosch	2010	1.0022	17	-0.0148	1.0170	8
27	B1	Stellenbosch	2012	1.0000	8	-0.0175	1.0175	9
23	B2	Mossel Bay	2012	1.0015	15	-0.0163	1.0178	10
30	B1	Drakenstein	2011	1.0063	23	-0.0118	1.0181	11
17	A	City of Johannesburg	2010	1.0034	19	-0.0151	1.0185	12
37	B2	Dihlabeng	2010	1.0027	18	-0.0161	1.0188	13
8	A	City of Cape Town	2014	1.0000	7.5	-0.0198	1.0198	14
10	A	City of Ekurhuleni	2011	1.0147	36	-0.0059	1.0206	15
26	B1	Stellenbosch	2011	1.0047	22	-0.0159	1.0207	16
3	A	City of Tshwane	2012	1.0117	29	-0.0095	1.0212	17
39	B2	Dihlabeng	2012	1.0000	7.5	-0.0216	1.0216	18
43	B1	Emalahleni	2012	1.0188	41	-0.0030	1.0218	19
6	A	City of Cape Town	2011	1.0122	30	-0.0097	1.0218	20
34	B2	Breede Valley	2011	1.0146	35	-0.0074	1.0220	21
7	A	City of Cape Town	2012	1.0136	33	-0.0087	1.0223	22
11	A	City of Ekurhuleni	2012	1.0000	8	-0.0223	1.0223	23
41	B1	Emalahleni	2010	1.0197	42	-0.0031	1.0228	24
71	B1	George	2012	1.0000	8	-0.0229	1.0229	25
47	A	eThekwini	2012	1.0045	21	-0.0185	1.0231	26

36	B2	Breede Valley	2014	1.0136	34	-0.0103	1.0240	27
12	A	City of Ekurhuleni	2014	1.0181	40	-0.0059	1.0241	28
15	B2	Overstrand	2012	1.0000	8	-0.0247	1.0247	29
54	A	Nelson Mandela Bay	2011	1.0211	43	-0.0040	1.0251	30
40	B2	Dihlabeng	2014	1.0063	24	-0.0196	1.0259	31
4	A	City of Tshwane	2014	1.0181	39	-0.0082	1.0263	32
18	A	City of Johannesburg	2011	1.0065	25	-0.0198	1.0263	33
20	A	City of Johannesburg	2014	1.0000	8	-0.0269	1.0269	34
33	B2	Breede Valley	2010	1.0179	38	-0.0091	1.0270	35
69	B1	George	2010	1.0127	32	-0.0144	1.0271	36
62	A	Mangaung	2011	1.0240	47	-0.0035	1.0276	37
57	B1	uMhlathuze	2010	1.0225	45	-0.0053	1.0278	38
38	B2	Dihlabeng	2011	1.0000	8	-0.0283	1.0283	39
55	A	Nelson Mandela Bay	2012	1.0248	48	-0.0039	1.0287	40
56	A	Nelson Mandela Bay	2014	1.0252	49	-0.0035	1.0287	41
73	A	Buffalo City	2010	1.0237	46	-0.0058	1.0296	42
67	B2	Knysna	2012	1.0000	8	-0.0296	1.0296	43
32	B1	Drakenstein	2014	1.0261	50	-0.0041	1.0302	44
90	B1	City of Mbombela	2011	1.0284	52	-0.0044	1.0328	45
83	B1	Emfuleni	2012	1.0220	44	-0.0111	1.0331	46
63	A	Mangaung	2012	1.0298	58	-0.0034	1.0332	47
66	B2	Knysna	2011	1.0147	37	-0.0202	1.0348	48
53	A	Nelson Mandela Bay	2010	1.0296	57	-0.0054	1.0350	49
51	B2	Saldanha Bay	2012	1.0000	8	-0.0351	1.0351	50
44	B1	Emalahleni	2014	1.0320	60	-0.0032	1.0352	51
79	B2	Mogalakwena	2012	1.0125	31	-0.0252	1.0377	52
19	A	City of Johannesburg	2012	1.0000	8	-0.0378	1.0378	53
42	B1	Emalahleni	2011	1.0358	67	-0.0033	1.0391	54
46	A	eThekwini	2011	1.0337	62	-0.0068	1.0405	55
65	B2	Knysna	2010	1.0293	54	-0.0113	1.0407	56
98	B1	Matjhabeng	2011	1.0369	69	-0.0039	1.0408	57
45	A	eThekwini	2010	1.0335	61	-0.0073	1.0408	58

95	B2	Makana	2012	1.0308	59	-0.0103	1.0411	59
68	B2	Knysna	2014	1.0289	53	-0.0129	1.0418	60
50	B2	Saldanha Bay	2011	1.0296	56	-0.0127	1.0422	61
75	A	Buffalo City	2012	1.0383	71	-0.0048	1.0431	62
22	B2	Mossel Bay	2011	1.0295	55	-0.0140	1.0435	63
87	B1	Sol Plaatje	2012	1.0000	8	-0.0440	1.0440	64
49	B2	Saldanha Bay	2010	1.0337	63	-0.0105	1.0442	65
61	A	Mangaung	2010	1.0378	70	-0.0068	1.0446	66
96	B2	Makana	2014	1.0339	64	-0.0108	1.0447	67
93	B2	Makana	2010	1.0264	51	-0.0193	1.0457	68
89	B1	City of Mbombela	2010	1.0426	75	-0.0051	1.0478	69
81	B1	Emfuleni	2010	1.0421	73	-0.0057	1.0478	70
94	B2	Makana	2011	1.0366	68	-0.0137	1.0503	71
48	A	eThekwini	2014	1.0431	77	-0.0074	1.0506	72
14	B2	Overstrand	2011	1.0352	65	-0.0155	1.0507	73
78	B2	Mogalakwena	2011	1.0352	66	-0.0159	1.0510	74
99	B1	Matjhabeng	2012	1.0425	74	-0.0104	1.0529	75
86	B1	Sol Plaatje	2011	1.0478	82	-0.0058	1.0537	76
101	B1	Polokwane	2010	1.0493	83	-0.0044	1.0537	77
82	B1	Emfuleni	2011	1.0448	78	-0.0091	1.0539	78
13	B2	Overstrand	2010	1.0477	81	-0.0102	1.0579	79
64	A	Mangaung	2014	1.0556	87	-0.0040	1.0596	80
16	B2	Overstrand	2014	1.0429	76	-0.0169	1.0598	81
91	B1	City of Mbombela	2012	1.0529	86	-0.0068	1.0598	82
97	B1	Matjhabeng	2010	1.0558	88	-0.0041	1.0599	83
70	B1	George	2011	1.0457	79	-0.0148	1.0605	84
52	B2	Saldanha Bay	2014	1.0495	84	-0.0110	1.0605	85
92	B1	City of Mbombela	2014	1.0529	86	-0.0079	1.0608	86
59	B1	uMhlathuze	2012	1.0468	80	-0.0151	1.0619	87
77	B2	Mogalakwena	2010	1.0411	72	-0.0216	1.0627	88
74	A	Buffalo City	2011	1.0579	89	-0.0051	1.0630	89
85	B1	Sol Plaatje	2010	1.0586	90	-0.0065	1.0651	90
84	B1	Emfuleni	2014	1.0645	94	-0.0038	1.0684	91

102	B1	Polokwane	2011	1.0606	92	-0.0092	1.0699	92
76	A	Buffalo City	2014	1.0670	96	-0.0033	1.0703	93
100	B1	Matjhabeng	2014	1.0603	91	-0.0109	1.0712	94
60	B1	uMhlathuze	2014	1.0622	93	-0.0097	1.0718	95
58	B1	uMhlathuze	2011	1.0662	95	-0.0079	1.0741	96
103	B1	Polokwane	2012	1.0734	100	-0.0054	1.0788	97
104	B1	Polokwane	2014	1.0701	98	-0.0090	1.0790	98
28	B1	Stellenbosch	2014	1.0693	97	-0.0110	1.0804	99
106	B1	Rustenburg	2011	1.0775	101	-0.0063	1.0838	100
88	B1	Sol Plaatje	2014	1.0811	104	-0.0079	1.0890	101
72	B1	George	2014	1.0777	102	-0.0117	1.0894	102
107	B1	Rustenburg	2012	1.0840	105	-0.0058	1.0899	103
80	B2	Mogalakwena	2014	1.0718	99	-0.0203	1.0921	104
24	B2	Mossel Bay	2014	1.0796	103	-0.0155	1.0951	105
105	B1	Rustenburg	2010	1.0895	106	-0.0101	1.0996	106
108	B1	Rustenburg	2014	1.1018	108	-0.0045	1.1063	107
21	B2	Mossel Bay	2010	1.0968	107	-0.0116	1.1084	108
		Average		**1.0318**			**1.0433**	
		Standard Deviation		**0.0258**			**0.0236**	

Appendix 2: Full Sample: Rural Results

Table 2.1: Full sample: rural biased and bias-corrected efficiency scores

ID	Municipal Category	Water Utility	Year	Biased efficiency score	Rank	Bias	Bias-corrected efficiency score	Rank
111	B3	Karoo Hoogland	2012	1.0000	8	-0.0169	1.0169	1
113	B3	Richtersveld	2010	1.0047	19	-0.0144	1.0191	2
118	B3	Siyathemba	2011	1.0011	18	-0.0186	1.0197	3
117	B3	Siyathemba	2010	1.0011	18	-0.0212	1.0222	4
126	B3	Khâi-Ma	2011	1.0000	8	-0.0241	1.0241	5
125	B3	Khâi-Ma	2010	1.0000	8	-0.0266	1.0266	6
120	B3	Siyathemba	2014	1.0000	8	-0.0277	1.0277	7
119	B3	Siyathemba	2012	1.0000	8	-0.0281	1.0281	8
115	B3	Richtersveld	2012	1.0163	24	-0.0147	1.0311	9
130	B3	Mafube	2011	1.0134	22	-0.0191	1.0325	10
116	B3	Richtersveld	2014	1.0212	26	-0.0166	1.0378	11
128	B3	Khâi-Ma	2014	1.0000	8	-0.0442	1.0442	12
142	B3	Tsantsabane	2011	1.0276	28	-0.0229	1.0506	13
114	B3	Richtersveld	2011	1.0336	34	-0.0186	1.0522	14
133	B4	Gamagara	2010	1.0161	23	-0.0379	1.0540	15
134	B4	Gamagara	2011	1.0114	20	-0.0428	1.0542	16
136	B4	Gamagara	2014	1.0122	21	-0.0421	1.0543	17
146	B3	Kou-Kamma	2011	1.0418	38	-0.0142	1.0560	18
110	B3	Karoo Hoogland	2011	1.0291	30	-0.0280	1.0571	19
112	B3	Karoo Hoogland	2014	1.0312	33	-0.0267	1.0580	20
109	B3	Karoo Hoogland	2010	1.0417	37	-0.0169	1.0587	21
157	B3	Bitou	2010	1.0000	8	-0.0600	1.0600	22
135	B4	Gamagara	2012	1.0279	29	-0.0325	1.0603	23
150	B3	Witzenberg	2011	1.0002	16	-0.0608	1.0610	24
159	B3	Bitou	2012	1.0000	8	-0.0645	1.0645	25
143	B3	Tsantsabane	2012	1.0346	36	-0.0341	1.0687	26
149	B3	Witzenberg	2010	1.0301	31	-0.0406	1.0707	27
154	B3	Beaufort West	2011	1.0171	25	-0.0551	1.0721	28
152	B3	Witzenberg	2014	1.0254	27	-0.0477	1.0731	29

141	B3	Tsantsabane	2010	1.0000	8	-0.0734	1.0734	30
144	B3	Tsantsabane	2014	1.0346	35	-0.0403	1.0749	31
127	B3	Khâi-Ma	2012	1.0538	42	-0.0224	1.0762	32
163	B3	Bergrivier	2012	1.0461	40	-0.0306	1.0768	33
167	B3	Hantam	2012	1.0530	41	-0.0275	1.0805	34
140	B3	Lephalale	2014	1.0000	8	-0.0816	1.0816	35
158	B3	Bitou	2011	1.0311	32	-0.0511	1.0822	36
124	B3	Setsoto	2014	1.0000	8	-0.0855	1.0855	37
155	B3	Beaufort West	2012	1.0000	8	-0.0858	1.0858	38
122	B3	Setsoto	2011	1.0000	8	-0.0920	1.0920	39
151	B3	Witzenberg	2012	1.0000	8	-0.0940	1.0940	40
171	B3	Swartland	2012	1.0452	39	-0.0526	1.0978	41
173	B3	Umsobomvu	2010	1.0772	44	-0.0301	1.1073	42
123	B3	Setsoto	2012	1.0000	8	-0.1113	1.1113	43
168	B3	Hantam	2014	1.0875	48	-0.0347	1.1222	44
121	B3	Setsoto	2010	1.0809	45	-0.0415	1.1224	45
156	B3	Beaufort West	2014	1.0632	43	-0.0640	1.1272	46
184	B3	Cederberg	2014	1.1130	56	-0.0153	1.1282	47
178	B3	Emthanjeni	2011	1.1080	52	-0.0219	1.1300	48
179	B3	Emthanjeni	2012	1.1095	54	-0.0213	1.1308	49
160	B3	Bitou	2014	1.0949	49	-0.0405	1.1354	50
189	B3	Sundays River Valley	2010	1.1173	60	-0.0217	1.1390	51
185	B3	Matzikama	2010	1.1170	59	-0.0227	1.1396	52
131	B3	Mafube	2012	1.1188	61	-0.0218	1.1406	53
162	B3	Bergrivier	2011	1.1061	51	-0.0356	1.1417	54
174	B3	Umsobomvu	2011	1.1133	57	-0.0304	1.1437	55
170	B3	Swartland	2011	1.0841	46	-0.0598	1.1439	56
139	B3	Lephalale	2012	1.0845	47	-0.0628	1.1473	57
175	B3	Umsobomvu	2012	1.1193	62	-0.0284	1.1477	58
177	B3	Emthanjeni	2010	1.1209	63	-0.0293	1.1502	59
187	B3	Matzikama	2012	1.1155	58	-0.0358	1.1513	60
153	B3	Beaufort West	2010	1.1047	50	-0.0486	1.1533	61
199	B3	Blue Crane Route	2012	1.1280	64	-0.0276	1.1556	62

190	B3	Sundays River Valley	2011	1.1352	67	-0.0252	1.1603	63
186	B3	Matzikama	2011	1.1408	71.5	-0.0211	1.1619	64
188	B3	Matzikama	2014	1.1408	71.5	-0.0230	1.1638	65
176	B3	Umsobomvu	2014	1.1382	68	-0.0298	1.1680	66
195	B3	Theewaterskloof	2012	1.1125	55	-0.0567	1.1692	67
198	B3	Blue Crane Route	2011	1.1391	69	-0.0304	1.1695	68
200	B3	Blue Crane Route	2014	1.1412	73	-0.0287	1.1699	69
191	B3	Sundays River Valley	2012	1.1443	74	-0.0275	1.1718	70
180	B3	Emthanjeni	2014	1.1303	65	-0.0447	1.1750	71
129	B3	Mafube	2010	1.1541	78	-0.0222	1.1764	72
181	B3	Cederberg	2010	1.1547	79	-0.0238	1.1785	73
197	B3	Blue Crane Route	2010	1.1598	83	-0.0241	1.1839	74
161	B3	Bergrivier	2010	1.1610	86	-0.0240	1.1850	75
138	B3	Lephalale	2011	1.1089	53	-0.0774	1.1863	76
193	B3	Theewaterskloof	2010	1.1494	76	-0.0396	1.1890	77
137	B3	Lephalale	2010	1.1339	66	-0.0571	1.1910	78
205	B3	Ndlambe	2010	1.1606	84	-0.0330	1.1936	79
165	B3	Hantam	2010	1.1563	80	-0.0375	1.1938	80
183	B3	Cederberg	2012	1.1498	77	-0.0447	1.1945	81
169	B3	Swartland	2010	1.1408	70	-0.0549	1.1957	82
192	B3	Sundays River Valley	2014	1.1626	87	-0.0361	1.1987	83
206	B3	Ndlambe	2011	1.1660	89	-0.0336	1.1996	84
201	B3	Kouga	2010	1.1465	75	-0.0540	1.2005	85
145	B3	Kou-Kamma	2010	1.1751	91	-0.0274	1.2025	86
132	B3	Mafube	2014	1.1810	94	-0.0249	1.2059	87
166	B3	Hantam	2011	1.1580	82	-0.0485	1.2065	88
207	B3	Ndlambe	2012	1.1798	92	-0.0271	1.2069	89
202	B3	Kouga	2011	1.1574	81	-0.0502	1.2075	90
164	B3	Bergrivier	2014	1.1809	93	-0.0274	1.2083	91
203	B3	Kouga	2012	1.1699	90	-0.0398	1.2097	92
194	B3	Theewaterskloof	2011	1.1607	85	-0.0510	1.2117	93
182	B3	Cederberg	2011	1.1913	97	-0.0253	1.2166	94
204	B3	Kouga	2014	1.1866	96	-0.0389	1.2256	95

196	B3	Theewaterskloof	2014	1.1851	95	-0.0406	1.2256	96
172	B3	Swartland	2014	1.1651	88	-0.0623	1.2274	97
147	B3	Kou-Kamma	2012	1.1946	98	-0.0344	1.2290	98
148	B3	Kou-Kamma	2014	1.1973	99	-0.0360	1.2333	99
208	B3	Ndlambe	2014	1.2002	101	-0.0366	1.2368	100
211	B3	Nama Khoi	2012	1.1991	100	-0.0377	1.2368	101
209	B3	Nama Khoi	2010	1.2238	102	-0.0342	1.2580	102
210	B3	Nama Khoi	2011	1.2285	103	-0.0413	1.2699	103
212	B3	Nama Khoi	2014	1.2475	104	-0.0552	1.3027	104
214	B3	Kopanong	2011	1.2878	106	-0.0283	1.3161	105
213	B3	Kopanong	2010	1.2841	105	-0.0393	1.3235	106
216	B3	Kopanong	2014	1.2904	107	-0.0449	1.3353	107
215	B3	Kopanong	2012	1.3398	108	-0.0576	1.3974	108
		Average		**1.1007**			**1.1398**	
		Standard Deviation		**0.0799**			**0.0794**	