Efficiency Measurement of the Urban Water and Sewerage Authorities (UWSAs) in Tanzania: A Data Envelopment Analysis

Tobias A. Swai, University of Dar es Salaam, Tanzania
tobias@udsm.ac.tz

This paper attempts to measure the efficiency of the Urban Water and Sewerage Authorities (UWSAs) in Tanzania for the years 2005/06 and 2006/07 using input oriented Data Envelopment Analysis (DEA) as well as Malmquist Productivity Index (MPI). The data was collected for the 19 UWSAs taking two inputs (total own operating expenditure and amount of water produced) and outputs (revenues generated and percentage of population served) measures. The results indicate that category A authorities which are self sufficient are the least efficient as compared to others which receive government support to run their activities. The findings indicate also that the increase in the performance of the UWSAs is not resulted from technological advancement rather than operational efficiency. The study calls for application of more comprehensive techniques to monitor the efficiency of the UWSAs in Tanzania.

INTRODUCTION

Background Information

Tanzania's National Water Policy (2006) creates a new direction for utilization of the nation's water resources, the availability of water supply, sewerage and sanitation services. It also incorporates the principles of decentralization and subsidiary of water supply management whereby this should be devolved to the lowest appropriate level (GoT, 2006). The policy repeals the one formulated in 2002 after a failure of various governmental plans for water supply. The history of water supply in Tanzania and the need for efficiency measures can be traced in decades. In 1971 the government launched a 20-year Rural Water Supply Programme (RWSP) that aimed at providing access to adequate, safe, dependable water supply within a walking distance of 400 meters from each household by the year 1991. Under this programme, water was provided free of charge by the Government. In 1985 it was revealed that only 46% of the rural population had access to water supply service. Various reasons were outlined including non involvement of the beneficiaries, use of inappropriate technologies and lack of decentralization as a result of abolishment of local government authorities in 1972.

For the past two decades, the ministry responsible for water supply in Tanzania has been publishing annual reports to measure the technical and operational efficiencies using core indicators such as labor productivity and water losses. Berg and Corton (2007), suggests that there is a move from the water authorities to measure core indicators to the application of statistical reports and the use of Data Envelopment Analysis (DEA).

This paper analyses the efficiency of the UWSAs for the years 2005/06 to 2006/07 using DEA. DEA has received numerous applications for performance measurement in various sectors such as banking, universities, hospitals, water supply and transport. In Tanzania, very few application of DEA has been employed. According to Bhattacharyya (1995), DEA application in water sector has not received much attention in academics as compared to others. This study perhaps is the first one attempting to analyze the performance of the utility companies using this technique in Tanzania. The analysis of the efficiency of UWSAs is important not only to welfare of the citizens but also for businesses. Water is among the basic infrastructure needed by businesses. Benchmarking the performance of water authorities is important for both managerial and policy decision (Berg *et al* 2008).

Status of Water Supply in Tanzania

The provision of water in Tanzania is divided in two parts. The first part is operation of the community water supply which is aimed at providing water in the rural areas and monitoring the implementation and performance of rural water supply programmes. Second part is through the commercial water supply and sewerage which aimed at provision of water in the cities, municipals and other urban areas through water authorities. UWSAs operate as independent institutions with proper governance structures. The authorities are regulated by the Energy and Water Utilities Regulatory Authority (EWURA) which was established in 2001.

According to the Household Budget Survey 2002 (WaterAid Tanzania, 2003), it was recorded that 46% of rural households in the year 2000 were using water from improved sources (up 11% from 1991). The National Strategy for Poverty Reduction (MKUKUTA) indicates various issues related to water supply in Tanzania. Under MKUKUTA framework, the government intends to increase proportion of rural population with access to clean and safe water from 54% in 2003 to 65% in 2010. It also intends to increase proportion of urban population with access to clean and safe water from 73% in 2003 to 90% by 2010 with improved sewerage facilities from 17% in 2003 to 30% in 2010. It is estimated that in order to reach the Millennium Development Goals (MDGs) related to water supply and sanitation, Tanzania Mainland needs investment of US $ 2 billion (De Vaal *et al* 2005). The World Bank in 2007 financed the water sector by providing US $200mil to support the UWSAs in reaching the MDGs. A survey of public opinion done in Tanzania in 2007 indicated that access to water services is still a problem to many. Currently the water supply coverage in urban centers is 74% while the sewerage service in towns and cities, coverage is 17% (www.maji.go.tz).

This study focuses more on the operations of the UWSAs. There have been numerous reports on the performance improvement of UWSAs following the benchmarking of the activities of the authorities done by the Ministry of Water (MoW) on annual basis. The recent report of 2006/07 show that there is improvement in water supply, population served with water as well as operation and technical efficiency of the UWSAs has improved over time (MoW, 2008). The report also categorizes the authorities in three major categories. Category A consists of 9 authorities that meet all annual costs for operation and maintenance of water supply and sewerage systems, including staff wages, costs for electricity and some contribution to investment. Category B consists of 8 authorities that meet operation and maintenance costs including costs for electricity. Category C consists of 2 authorities that meet partially their operation and maintenance costs. The Government meets part of cost for electricity and pays the salaries for the permanent employees.

MODEL DESCRIPTION

Data Envelopment Analysis

Data Envelopment Analysis (DEA) is a technique for measuring the relative efficiency of organizational units (Charnes *et al* 1994). The methodology's main strength lies in its ability to capture the interplay between multiple inputs and outputs, a process that cannot be satisfactorily probed through traditional ratio analysis (Gattoufi *et al* 2004). It can also be referred to as a tool to measure total factor productivity (Ramanathan, 2003). DEA has gained popularity in its application from the past one decade more than 1000 papers has been published.

DEA has been successfully employed to measure relative performance of firms operating in the same industry which can be referred as Decision Making Units (DMUs) which use identical inputs to produce variety of identical outputs. In comparing DMUs, the objective of DEA is to identify DMUs that produce the largest amount of outputs by consuming least amounts of inputs subject to the same input and output measures by the rest of the DMUs.

In order to understand DEA operations Ramanathan (2007) outlined the process. Assume that there are *N* DMUs where by any of them convert *I* inputs to *J* outputs. Taking one of the DMUs, say *M*, which produces outputs y_{mj} using x_{mi} inputs. DEA analysis seeks to identify DMUs that produce largest output by consuming less inputs subject to limits imposed by the performance of peer DMUs. A model for calculating the efficiency of *m*th DMU is given as:

$$\text{Max } \frac{\sum_{j=1}^{J} v_{mj} y_{mj}}{\sum_{i=1}^{I} u_{mi} x_{mi}} \quad (1)$$

such that

$$0 \leq \frac{\sum_{j=1}^{J} v_{mj} y_{nj}}{\sum_{i=1}^{I} u_{mi} x_{ni}} \leq 1; \text{ for } n = 1,2,..,N \quad (2)$$

$$v_{mj}, u_{mi} \geq 0 \,;\, i = 1, 2, \ldots, I \text{ and } j = 1, 2, \ldots, J$$

Subscript *i* stands for inputs and *j* stands for outputs also *n* stands for number of DMUs.
Variable v_{mj} and u_{mi} represents weights to be determined by solving the above model by the *m*th DMU.

This study assumes that the DMUs are minimizing the inputs to attain effectively various levels of output produced. Hence the model below applies for the *m*th DMU.

$$\text{Min } \theta_m$$

$$\sum_{n=1}^{N} y_{nj} \lambda_n \geq y_{mj};\, j = 1, 2, \ldots, J \quad (3)$$

$$\sum_{n=1}^{N} x_{ni} \lambda_n \leq \theta_m x_{mi};\, j = 1, 2, \ldots, I$$

$$\lambda_n \geq 0; n = 1, 2, \ldots, N; \theta_m \text{ free} \quad (4)$$

In computing the DEA efficiency score, two assumptions can be made. One is consideration for the Constant Returns to Scale (CRS) and the other is Variable Return to Scale (VRS). The discussions of the returns to scale are discussed extensively by Banker *et al* 2004. Under constant returns to scale, from equation (3) and (4) the following condition must hold;

$$\sum_{n=1}^{N} \lambda_n = 1$$

When the above condition does not prevail, then the assumption is that the DMU operate on VRS. It is assumed as to many related studies, that the UWSAs operate under VRS due to the differences in the DMUs.

Malmquist Productive Index

This study also took into consideration a two year period for the DMUs. For this matter the authors were interested in measuring the performance of the DMUs over the two years. In measuring this, the paper utilizes the Malmquist Productive Index (MPI) approach. The approach is based on the works done by Malmquist 1953 and further developed by Cavers *et al* 1982 as outlined in Ramanathan 2007. The MPI output is defined as:

$$M^{t+1}(x^{t+1}, y^{t+1}, x, y) = \left[\frac{D^t(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} X \frac{D^{t+1}(x^{t+1}, y^{t+1}}{D^{t+1}(x^t, y^t} \right]^{1/2} \quad (5)$$

Where D^t is a distance function measuring efficiency of conversion of inputs x^t to outputs y^t in period (year) *t*. The comparison takes into consideration the changes in technological measurement, such that should there be a technological change in period *t+1*, then $D^{t+1}(x^t, y^t) \neq D^t(x^t, y^t)$.

DATA AND METHODS

Data used in this study was obtained from the report on the performance of the UWSAs for the years 2005/06 and 2006/07 published by the Ministry of Water in Tanzania. These reports provide various extensive data and efficiency measures using financial ratios. The data utilized include those of 19 UWSAs, excluding the Dar es Salaam based water supply company. In the past four years the operation of water services in Dar es Salam has been disputed following the privatization of Dar es Salaam Water and Sewerage Authority (DAWASA) to City water and currently under the ownership of a government parastatal. Also it was revealed from the report that for three years consecutively, the audit reports for DAWASA and its successors have been qualified and hence another reason for exclusion of the data from our analysis. This paper uses multi-input and multi product analysis using DEA to analyze the efficiency of the UWSAs and assess the technological efficiency change for the two years.

There have been many studies elsewhere in the world suggesting various input and output measures in the water sector. A study by Kirkpatrick *et al* 2004 treated output measures as water distributed which was represented the volume of output produced and percentage of water loss as outputs taking. Based on the statistical indicators and the DEA, the study confirms that privatization can lead to performance gains. Coelli and Walding (2005) used two output measures (number of properties connected and volume of water delivered) as well as two input measures (operating expenditure and capital) to study the efficiency of local water authorities in Germany.

For the case of this study, the input measures which were selected are total own operating expenditure and volume of water produced while the output measures are revenue generated and percentage of population served with water. The multi stage DEA with consideration of CRTS and VRTS was applied as well as MPI. The study has utilized a DEA programme developed by the Centre for Efficiency and Productivity Analysis (CEPA), at the University of Queensland in Australia. The software can be downloaded freely for academic uses from http://www.uq.edu.au/economics/cepa/deap.htm. The author downloaded the programme on 10th December 2008 and consulted the programme developer Prof. Timothy Coelli on clarification and updates of the software since its development in 1996.

RESULTS AND DISCUSSIONS

DEA results are presented in two folds, related to the individual and per category of the UWSAs for the efficiency measurements and technical efficiency for the years 2005/06 and 2006/07. Summary of results is presented in Appendix A.

Performance of UWSAs 2005/06 and 2006/07

The results for the performance of the 19 UWSAs but also the analysis can be presented across the categories of the UWSAs for the two years of analysis. For category A, shows that the performance of the institutions differs significantly and are comparable to performances of in categories as shown in Table 1 below.

Table 1: Summary of DEA Results by Category of the UWSAs

Category	Number	CRSTE	VRTSE	SCALE	Remark
A	9	0.271	0.440	0.495	2 experience DRS, 7 IRS
B	8	0.688	0.846	0.798	3 very efficient, 6 IRS
C	2	0.857	0.933	0.913	1 efficient, 1 IRS
Average Total	19	0.508	0.663	0.667	

Note: CRSTE = technical efficiency from CRS DEA
VRSTE = technical efficiency from VRS DEA
SCALE = scale efficiency = CRSTE/VRSTE
DRS = decreasing returns to scale
IRS = increasing returns to scale

It can be noted that category A UWSAs which are regarded as self sustaining are less efficient as compared to the others which are partially supported by the government. Category A authorities have been attaining high scores of the core indicators set by the Ministry of Water as opposed to others. On average, the performance of the authorities is only 66.3% based on the inputs and output measures used in this study. In general category B and C experience decreasing returns to scale as opposed to category A authorities. In any case, they can be defined as weakly efficient. Further analysis of the peering of the authorities indicated that only 3 peered to others. Babati in category C peered only once. Singida and Shinyanga from category B peered 10 and 13 times respectively. All the named three UWSAs record a CRSTE and VRSTE of 1.000, meaning they are the most efficient. This shows great disparity of the performance of the authorities and their categorization based on core indicators. The result confirms to what Berg and Corton (2007) argued; that the core efficiencies alone cannot be used to measure the efficiencies of the water authorities and that more comprehensive analysis techniques should be employed.

Patterns of Changes in Efficiency Score

These were calculated by the DEAP software using the relationship presented in equation 4 above. The results for the firms are as presented in the table below based on the categories.

Table 2: Average Malmquist Productivity Index Summary of Authorities Means

Category	Authority	EFFCH	TECHCH	PECH	SECH	TFPCH
A	9	17.876	0.341	6.373	2.246	3.697
B	8	1.030	1.007	1.042	1.031	1.009
C	2	1.152	1.016	1.047	1.097	1.196
Total	19	2.219	0.467	1.901	1.167	1.037

Note:
EFFCH = Technical efficiency change (Relative to CRTS technology)
TECHCH = Technology change
PECH = Pure technical efficiency change (Relative to VRTS technology)
SECH = Scale efficiency change
TFPCH = Total Factor Productivity change

It should be noted from the results that there is dominance on the efficiency changes as opposed with the changes in technology for the year 2005/06 and 2006/07 under consideration. This means that the performance of the UWSAs is much contributed to operational rather than technical capabilities. Category A records highs of efficiency changes, pure technical efficiency change, scale efficiency and total factor productivity changes as opposed to others. The results calls for the emphasis in increase technological application by the water authorities which can aid in improving the efficiency of the inputs used to generate output as indicated in this study.

Study Weaknesses and Future studies

The study utilizes financial data of which three of the UWSAs have Qualified audit report opinion, 2 for three years consecutively which affect the quality of financial data used. Also the study utilizes only mathematical model without taking review of the various problems which affects the authorities in meeting their maximum productivity, managerial competencies, etc. Further, there has been switching of the authorities from one category to another from year to year depending on the performance of previous years. For instance in 2005/06 report, category A authorities has remained the same as in 2006/07 while category B contained only 4 authorities. In this study, the analysis thus took into consideration that UWSAs were in the same category classification for the two years as presented by the raw data.

Future studies can focus on the long term horizon say for a period of 5 years and utilize another set of input-output measures. The future studies may also utilize information from Dar es Salaam Water Supply Company (DAWASCO) as Dar es Salaam is largest city in Tanzania with population of over 3 mil people. A similar study can be done using other techniques, such as ordinary least squares (OLS) regression, stochastic frontier analysis (SFA) and other measures. Also it may consider undertaking case studies to study various qualitative factors affecting efficiency of the UWSAs such as management competencies. One can also consider undertaking a study on the efficiency of sewerage services offered by the authorities.

CONCLUSIONS AND IMPLICATIONS

The results from the study calls for application of more comprehensive techniques in measuring the efficiency of the UWSAs in the future. Core indicators do not provide an insightful analysis of the performance of the authorities. The regulator of the authorities should also put in place mechanisms to ensure that category A authorities which are self sustaining are well monitored to deliver. The results indicated that the Category A UWSAs are the least efficient although they are self sustaining. The MPI results calls for more improvement of technical efficiency of the UWSAs and thus a challenge to the authorities and the regulatory bodies in the Water and Utilities sector.

REFERENCES

Banker, R. D, Cooper, W.W; Seiford, L. M; Thrall, R.M; and Zhu, J. (2004), *"Returns to scale in different DEA models"*. European Journal of Operational Research 154 345–362

Berg, S. V. and Corton, M. L. (2007); "*Water Utility Benchmarking for Managerial and Policy Decisions: Lessons from Developing Countries".* Public Utility Research Centre, University of Florida. Downloaded from www.cba.ufl.edu/purc/purcdoc on 10th Dec 2008.

Berg, S. V. and Padowski, J. C. (2008), *"Overview of Water Utility Benchmarking Methodologies: From Indicators to Incentives"*. Public Utility Research Center. Downloaded from the Site www.cba.ufl.edu/purc/purcdoc on 26th Jan. 2008

Bhattacharyya, A., T.R. Harris, R. Narayanan, and K. Raffie (1995*), "Technical Efficiency of Rural Water Utilities"* Journal of Agricultural and Resource Economics, 20, 373-91.

Charnes, A.; Cooper, W. W.; Lewin, A. Y.; Seidford, L. M. (1994): Data Envelopment Analysis – Theory, Methodology and Applications. Boston.

Coelli, T. (1996), *"A Guide to DEAP Version 2.1: A Data Envelopment (Computer) Programme"*. Centre for Efficiency and Productivity Analysis Working Paper Series No. 08.

Coelli, T. and Walding, S. (2005), *"Performance Measurement in the Australian Water Supply Industry"*. Centre for Efficiency and Productivity Analysis Working Paper Series No. 01.

De Vaal, D. and Nkongo, D. (2005), *US$ 2 Billion – The Cost of Water and Sanitation for the Millennium Development Goals.* Water Aid.

Gattoufi, S., Oral, M. and Reisman, A. (2004), *"A taxonomy for data envelopment analysis"*. Socio-Economic Planning Sciences Volume 38, Issues 2-3, pp 141-158.

Government of Tanzania (GoT) 2006, National Water Policy

Haug, P. (2007), *"Local Government Control and Efficiency of the Water Industry: An Empirical Analysis of Water Suppliers in East Germany"*. IWH-Discussion Papers No.3

Kirkpatrick, C.; Parker, D. and Zhang, Y. (2004); *State versus Private Sector Provision of Water Services in Africa: An Empirical Analysis*. A paper presented at Centre on Regulation and Competition 3rd International Conference, Pro-Poor Regulation and Competition: Issues, Policies and Practices, Cape Town, South Africa, 7-9 September.

Ministry of Water (MoW) – Tanzania (2008), Performance of Urban Water and Sewerage Authorities for the Year 2006/07.

Ramanathan, R. (2003), An Introduction to Data Envelopment Analysis, Sage, New Delhi.

Ramanathan, R. (2007), *"Performance of Banks in Countries of the Gulf Cooperation Council, International Journal of Productivity and Performance Management"*. Vol.56 No.2. pp 137-154.

WaterAid Tanzania (2003). *Water and Sanitation in Tanzania: Poverty monitoring for the sector using national Surveys.* WaterAid, Dar es Salaam.

Appendix A
DEA and Malmquist Index Summary Results for Individual UWSAs

Category	Authority	CRSTE	VRSTE	Scale	Remarks	EFFCH	TECHCH	PECH	SECH	TFPCH
A	Arusha	0.855	1.000	0.855	drs	0.426	0.292	0.844	0.504	0.124
	Dodoma	0.015	0.066	0.227	irs	66.435	0.165	15.049	4.414	10.939
	Mbeya	0.807	0.837	0.963	irs	0.883	0.347	1.183	0.746	0.306
	Morogoro	0.012	0.110	0.105	irs	41.851	0.205	9.067	4.615	8.564
	Moshi	0.125	1.000	0.125	drs	3.286	0.178	0.846	3.885	0.584
	Mtwara	0.453	0.600	0.755	irs	1.186	1.019	1.107	1.071	1.209
	Mwanza	0.083	0.187	0.444	irs	12.056	0.339	5.352	2.252	4.082
	Tabora	0.065	0.100	0.654	irs	8.171	0.350	9.985	0.818	2.857
	Tanga	0.020	0.060	0.329	irs	26.587	0.173	13.921	1.910	4.610
B	Bukoba	0.525	0.769	0.683	irs	1.672	1.334	1.300	1.286	2.230
	Iringa	1.000	1.000	1.000	-	0.085	0.162	1.000	0.085	0.014
	Kigoma	0.574	0.632	0.908	irs	1.274	1.204	1.169	1.090	1.534
	Musoma	0.601	0.740	0.812	irs	0.908	1.259	1.107	0.820	1.143
	Shinyanga	1.000	1.000	1.000	-	1.000	0.082	1.000	1.000	0.082
	Singida	1.000	1.000	1.000	-	1.000	1.289	1.000	1.000	1.289
	Songea	0.354	0.806	0.439	irs	1.460	1.342	1.075	1.358	1.959
	Sumbawanga	0.449	0.823	0.545	irs	1.121	0.900	1.066	1.052	1.009
C	Babati	1.000	1.000	1.000	-	1.000	0.848	1.000	1.000	0.848
	Lindi	0.714	0.865	0.826	irs	1.304	1.183	1.093	1.193	1.543
Mean		0.508	0.663	0.667		2.219	0.467	1.901	1.167	1.037