International Journal of Scientific Research in Science and Technology
Print ISSN: 2395-6011 | Online ISSN: 2395-602X (www.ijsrst.com)
doi : https://doi.org/10.32628/IJSRST20766

Assessment of Water Use Efficiency in Sub-Sahara Africa : Application of The Malmquist Productivity Index

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Article Info
Volume 7, Issue 6
Page Number: 66-78
Publication Issue :
November-December-2020

Article History
Accepted : 01 Nov 2020
Published : 10 Nov 2020

ABSTRACT

This paper presents the assessment of improvement in water use efficiency in sub-Sahara Africa based on the Malmquist Productivity Index (MPI). The study was conducted in 28 countries in sub-Sahara Africa from 2007 to 2017. Two test cases comprising data with water stress as undesired output, and without water stress as undesired output were analyzed to determine their level of impact on the improvement of water use efficiency. Again the technical efficiency as well as technological efficiency change were examined. The overall mean outcome of the results regarding the test case of the MPI with the inclusion of water stress was 0.969 which is higher than the values recorded from 2012-2016. Comparing the two results, it was observed that the mean MPI estimates without water stress are much higher than that of the average MPI with the inclusion of water stress. This means that without the inclusion of undesirable factors such as water stress, the MPI scores could be overestimated. In terms of the catch-up effect, all sampled countries were technically efficient except Angola, Burundi, Chad, Madagascar, Mauritania, Mozambique, Sierra Leone and Togo which could not meet the efficiency frontier of 1.00. With the technological efficiency change, the results indicated that none of the sampled countries was able to reach the efficiency frontier. Policy recommendations based on the results are provided.

Keywords : Water Use Efficiency, Water Stress, Improvement, Malmquist Productivity Index, Data Envelopment Analysis, Sub-Sahara Africa

I. INTRODUCTION

One of the essential natural resources which is also an economic good is water. It is substantial to human survival, for environmental balance and also for socio-economic development. However, water resources are not evenly distributed in time and space and this, coupled with excess withdrawal of water for various production purposes often result in water scarcity (UN Water 2018). According to Wang et al. (2019), enhancing water use efficiency is an effective way to address water scarcity and ensure sustainable water resources management. Water use efficiency has become a hot issue for policymakers, researchers, governments and international organizations. Grounded on the studies of Pan et al. (2020) water use efficiency is a social, economic, or ecological benefit for a unit of water. Efficiency of water can be in the form of urban water use efficiency (Shi et al. 2015; Chen et al. 2016), agricultural water use efficiency (Speelman et al. 2008, Wu et al. 2014), and industrial water use efficiency (Xu et al. 2019; Zhang 2019). However, studies like (Wang et al. 2018; Zheng et al. 2018) have investigated total water use efficiency which is the combination of agricultural, industrial and urban water use efficiency.

Data envelopment analysis (DEA) is a linear programming and mathematical model that aims to measure how efficiently selected inputs from decision making units (DMUs) are able to generate both desired and undesired outputs (Charnes et al. 1978). This model has recently been used to evaluate environmental performance. The efficiency scores in most traditional DEA models such as the CCR and BCC cannot be analyzed intensely in different periods. However, Fare and Grosskopf (1997) DEA Malmquist productivity index model is effective for exploring the improvement in efficiency of DMUs in different years.

This study was conducted across 28 countries in sub-Sahara Africa (SSA) from 2007 to 2016 using labor, capital stock and total water abstracted as the desired inputs, GDP as the desired output and water stress as the undesired output. Sub-Sahara Africa was purposely selected for this study because it has been reported to be one of the fastest urbanizing regions in the world, yet it is also one of the continents that experience water-scarcity the more. Unlike other studies which investigated irrigation water use efficiency and water utilities efficiency on city levels in Africa, the main contribution of this study is that it examines the improvement of total water use efficiency in SSA countries over a decade which is enough to inform policymakers of policies that need to be implemented to ensure water use efficiency and sustainable water resources management.

II. METHODOLOGY

Data source and selection of variables

In order to represent the DMUs, five variables were chosen, which are the input and output variables. Total water use (W), Capital Stock (C), and Labor (L) were the inputs. Economic growth (E) is the desired output, while water stress (S) is the unexpected output. Past research (Zheng et al. 2018) integrated the use of residential, commercial, agricultural, and ecological water to reflect the overall use of water. Capital stock and total labor are used as inputs because they are the two most important factors of production. Gross domestic product (GDP) was used as economic growth in terms of outputs because labor, capital and water use in every production are expected to contribute to a rise in GDP. Intense abstraction of water resources, however, put pressure on the available water resources and consequently contribute to water stress, which is the unwanted output in this analysis. All variables employed in this research were derived from the database of World Bank development indicators (WDI 2019) and the duration was 2007-2016. The total number of sampled countries and duration for the study were due to data availability. Table 1 is a summary of the source of information and the elements employed.

Table 1: Items for Evaluating Water Use Efficiency

Index	Variable	Units	Data Source
Input	Capita Stock	Millions of US Dollars	WDI
Input	Labor	Total Employment	WDI
Input	Water withdrawal	Billions of cubic meters	WDI
Desired Output	GDP	Millions of US Dollars	WDI
Undesired Output	Water Stress	US$ GDP per cubic meter of Total Freshwater	WDI

Please note: WDI indicates World Development Indicators

Model Specification for the Malmquist Productivity Index

In the quest to derive the level of improvement of water use efficiency in sub-Sahara Africa, it is of utmost importance to outline the desired model for this particular study. To achieve the expected level of efficiency of water consumption over time for the selected countries in Sub-Sahara Africa, the Malmquist Productivity Index (MPI) proposed by Malmquist (1953) and further developed by Fare et al. (1992) was employed. The goal is to extend the understanding of the interpretation of the mechanisms at play and it is perceived to be a major approach to comprehend the changes that could occur in the efficiency of water consumption in the coming years (Luo et al. 2018). For example, take t and t+1 to be separate years, $D_0^t(x_0^{t+1}, y_0^{t+1})$ and $D_0^{t+1}(x_0^{t+1}, y_0^{t+1})$ to denote the distance functions of the involvements and outcomes for this study at period t and t+1 for high-tech and technical water use efficiency respectively. Accordingly, the MPI function can be written as;

$$MPI_t^{t+1} = \left[\frac{D_0^t(x_0^{t+1}, y_0^{t+1})}{D_0^t(x_0^t, y_0^t)} \times \frac{D_0^t(x_0^{t+1}, y_0^{t+1})}{D_0^{t+1}(x_0^t, y_0^t)} \right]^{0.5} \quad (1)$$

where, MPI_t^{t+1} calculates the efficiency dynamics amid the two separate periods in successive mode (t and t+1). The outcome of MPI_t^{t+1} >1 implies that the efficiency has been upgraded. However, MPI_t^{t+1} <1 indicates a drop in the efficiency ratings. To extrapolate the MPI efficiency change and technical change, the subsequent process shown in equation 2 is inferred:

$$MPI_t^{t+1} = \left(\frac{D_0^{t+1}(x_0^{t+1}, y_0^{t+1})}{D_0^t(x_0^t, y_0^t)} \right) \left[\frac{D_0^t(x_0^{t+1}, y_0^{t+1})}{D_0^t(x_0^t, y_0^t)} \times \frac{D_0^{t+1}(x_0^{t+1}, y_0^{t+1})}{D_0^{t+1}(x_0^t, y_0^t)} \right]^{0.5} \quad (2)$$

MPI_t^{t+1} = Technical Change $\times$ Efficiency Change (3)

where the technical adjustment tests the border shift effect, the systematic shift of the efficiency border relative to the two separate years is demonstrated. In other words, > 1 and < 1 indicate an increase and a decline in technical results, respectively. Efficiency change explores the catch-up effect and it either increases or degrades the efficiency of water consumption in the countries. For effective comprehension, the efficiency change is characterized to be improved, has no change, or decreased when >1, =, or <1. A further explanation of this model is that MPI is >1, =, or <1 indicates that there is an upsurge, constant, decline in productivity. Therefore, this research aims to evaluate the enhancement of water use efficiency in 28 selected economies in sub-Sahara Africa from 2007 to 2016 by matching the assessed outcomes of the technical change and the efficiency change series correspondingly. Table 2 displays the descriptive statistics of the elements used.

Table 2: Descriptive statistics of the water use efficiency in sub-Sahara African

Variable	Mean	SD	Minimum	Maximum
Capital	240585.5	462658.3	7136.864	2315612
Labor	10524281	12210423	4427780	57352456
Water	3.551411	4.248437	0.152000	15.50000
GDP	2074.711	2593.656	170.8152	10716.20
Water Stress	19.82199	21.81435	0.915604	97.68462

Please note: GDP and SD indicate gross domestic product and standard deviation

III. RESULTS AND DISCUSSION

Estimates of Water Use Efficiency Improvement in sub-Sahara Africa

The research surveyed the improvement of water use efficiency of 28 states in sub-Sahara Africa between 2007 and 2016 using the DEA Malmquist Productivity Index with the DEAP2 software. Research have shown a tremendous contribution to dynamic data analysis when there exist available data for the study. This is because scholars and their readers can comprehend the dynamics in the efficiency of water use for a given time and help to accurately predict how variations in the efficiency of water consumption will be in some years ahead (Zhang et al. 2019). To get a vivid understanding of the improvement in water use efficiency in sub-Sahara Africa, the analysis of this study is structured as follows: a) evaluation of water use efficiency with the addition of water stress as an unwanted output, and b) evaluation of water use efficiency without the addition of water stress.

Test Case 1: Malmquist Productivity Index (MPI) with water stress

The obtained results after the inclusion of water stress in the efficiency of water use analysis is shown in Table 3. For the 28 countries sampled in sub-Sahara Africa, the average mean value of water use efficiency with water stress included was 0.969. This value is greater than the 2012 to 2016 values reported. Evidently, the assessed mean scores recorded for 2008, 2009, 2010, 2011, were 0.989, 0.981, 1.002, and 0.993 while 0.948, 0.959, 0.962, and 0.963 were recorded in 2012, 2013, 2014, 2015, and 2016 respectively. These results suggest a decrease in the improvement of water use efficiency from 2012-2016 and this could be attributed to water stress. The economic implication of these results is that certain developmental activities might have occurred, while environmental regulations were not implemented. These findings agree with Pan et al. (2020), and Luo et al. (2018) whose studies proved that effluents such as wastewater harm the improvement of water use efficiency.

Table 3. Efficiency change scores for water use improvement with water stress in SSA

	MPI (TFPCH)									
COUNTRY	2008	2009	2010	2011	2012	2013	2014	2015	2016	Mean
ANGOLA	0.983	0.964	0.964	0.975	0.900	0.932	0.942	0.957	0.923	0.949
BENIN	1.014	0.941	0.958	0.95	0.884	0.912	1.018	0.970	0.980	0.958
BOTSWANA	0.975	0.926	1.095	1.059	0.929	0.998	0.992	0.913	1.015	0.987
BURKINA FASO	0.937	1.083	1.011	0.911	0.979	0.973	0.912	0.998	0.934	0.970
BURUNDI	0.982	0.959	0.956	0.951	0.949	0.956	0.942	0.95	0.945	0.955
CAMEROON	1.069	0.965	0.966	0.966	0.968	0.969	0.968	0.966	0.972	0.978
CHAD	1.027	0.844	1.029	0.984	0.904	0.931	0.962	0.782	0.866	0.922
CONGO DEM. REP.	0.935	0.971	0.987	0.947	0.979	0.924	1.017	1.012	1.000	0.974
COTE D'IVORE	1.033	1.010	0.988	1.012	1.022	0.997	0.979	0.988	0.987	1.002
ETHIOPIA	0.894	1.044	0.859	0.903	0.939	0.916	0.966	1.011	0.987	0.945
GABON	0.943	0.787	0.97	1.013	0.89	0.927	0.965	0.881	0.959	0.924
GHANA	0.938	0.968	0.959	0.939	0.933	1.041	0.935	0.952	0.979	0.960
KENYA	0.965	0.970	0.942	0.947	0.945	0.920	1.031	0.929	1.031	0.963
LIBERIA	0.930	0.988	0.960	0.975	0.975	0.967	0.957	0.889	0.921	0.951
MADAGASCAR	1.116	0.835	0.955	1.054	0.932	1.000	0.945	0.862	0.910	0.953
MALAWI	0.998	1.102	1.070	1.116	0.909	1.019	1.018	0.98	1.012	1.023
MALI	1.117	0.965	0.969	1.123	0.92	1.002	1.005	0.914	1.021	1.002
MAURITANIA	1.087	0.841	1.054	1.021	0.841	0.968	0.829	0.802	0.876	0.919
MAURITIUS	1.159	0.861	1.038	1.108	0.984	1.013	1.034	0.912	1.042	1.013
MOZAMBIQUE	0.925	0.952	0.978	0.966	0.891	0.800	0.874	0.894	0.895	0.907
NAMIBIA	0.917	0.978	1.186	1.041	0.972	0.895	0.925	0.865	0.916	0.962
NIGER	0.960	0.959	0.962	0.962	0.957	0.967	0.981	0.878	1.026	0.961
NIGERIA	1.004	0.989	1.040	0.985	0.987	0.964	0.964	0.962	0.969	0.985
SIERRA LEONE	0.989	0.984	0.878	0.849	0.953	0.976	0.972	0.959	0.970	0.947
SOUTH AFRICA	0.913	0.998	1.225	1.068	0.917	0.891	0.935	0.891	0.922	0.968
TANZANIA	1.137	0.934	0.993	0.953	1.017	1.028	0.99	0.901	0.974	0.990
TOGO	0.983	0.968	0.964	0.962	0.937	0.941	0.942	0.956	0.957	0.957
ZIMBABWE	0.833	2.158	1.194	1.126	1.180	1.073	0.977	0.994	1.004	1.129
MEAN	0.989	0.981	1.002	0.993	0.948	0.959	0.962	0.926	0.963	0.969

Please note: MPI (TFPCH) indicates Malmquist productivity index total factor productivity changes

The twenty-eight selected countries as a whole experienced a substantial drop in the efficiency of water usage by an average mark of 0.969 over the entire sample period, however a growth rate of about 0.2 percent was reported in 2010. Zimbabwe, Malawi, Mauritius, Cote d'Ivoire, and Mali showed a substantial improvement in the average water efficiency value of 1.129, 1.023, 1.013, 1.002, and 1.002 respectively in the 2007-2016 sample. That being said, the findings further revealed that with an efficiency mark of 0.907, Mozambique performed very poor. In figure 1, a pictorial view of this outcome is shown.

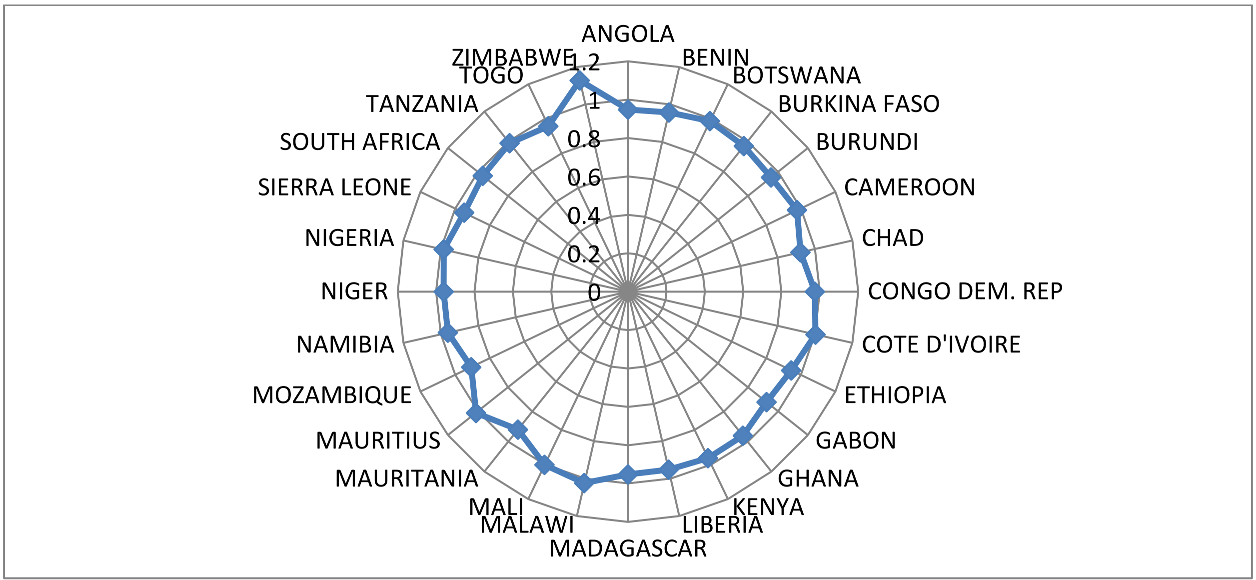

Figure 1 : Estimated MPI mean values with the inclusion of water stress

Test Case 2: Malmquist Productivity Index (MPI) without water stress

Table 4 displays the effects of the efficiency of water usage without the addition of water stress as an unnecessary outcome. In 2008, the results showed a significant productivity of 1.095. While, there was a slight reduction to 1.021 in 2010, it rose to 1.058 in 2011, after which the level of productivity in the successive periods declined (below 1.00).

Table 4. Efficiency changes scores for water use improvement without water stress in SSA

	MPI (TFPCH)									
COUNTRY	2008	2009	2010	2011	2012	2013	2014	2015	2016	Mean
ANGOLA	1.283	0.736	1.107	1.253	1.079	0.955	0.965	0.716	0.763	0.984
BENIN	1.163	0.917	0.908	1.040	0.970	1.004	0.992	0.804	0.962	0.973
BOTSWANA	0.973	0.904	1.199	1.145	0.895	1.003	1.029	0.854	1.047	1.005
BURKINA FASO	1.129	0.905	0.956	1.052	0.903	0.93	0.914	0.755	0.936	0.942
BURUNDI	1.123	1.024	1.040	1.005	0.956	0.949	1.003	1.052	0.872	1.003
CAMEROON	1.204	0.919	0.937	1.044	0.926	1.037	1.005	0.828	0.988	0.988
CHAD	1.077	0.805	1.029	1.012	0.901	0.931	0.963	0.706	0.829	0.917
CONGO DEM. REP.	1.124	0.875	1.066	1.094	1.07	1.048	1.035	0.985	0.914	1.023
COTE D'IVOIRE	1.151	0.967	0.979	0.998	1.013	1.110	1.066	1.074	0.855	1.024
ETHIOPIA	1.256	1.091	0.830	0.923	1.136	0.916	0.965	1.028	0.999	1.016
GABON	1.052	0.684	1.058	1.134	0.859	0.946	0.960	0.740	0.922	0.928
GHANA	1.014	0.843	1.127	1.105	0.947	1.372	0.787	0.845	1.031	1.008
KENYA	1.042	0.958	0.994	0.946	1.092	1.001	1.021	0.962	1.022	1.004
LIBERIA	1.107	0.968	1.030	1.110	1.051	1.044	0.952	0.944	0.959	1.018
MADAGASCAR	1.116	0.835	0.955	1.054	0.932	1.000	0.943	0.845	0.957	0.960
MALAWI	1.123	1.106	1.070	1.139	0.735	0.883	1.057	1.019	0.827	0.995

MALI	1.117	0.965	0.969	1.123	0.920	1.002	1.005	0.907	1.026	1.004
MAURITANIA	1.087	0.841	1.054	0.021	0.841	0.968	0.829	0.797	0.863	0.811
MAURITIUS	1.159	0.861	1.038	1.108	0.984	1.013	1.035	0.912	1.044	1.017
MOZAMBIQUE	1.081	0.840	0.817	1.127	0.89	0.840	0.887	0.751	0.637	0.874
NAMIBIA	0.917	0.978	1.186	1.041	0.974	0.893	0.930	0.850	0.910	0.964
NIGER	1.153	0.917	0.971	1.028	0.997	1.015	0.982	0.806	0.959	0.981
NIGERIA	1.141	0.805	1.168	1.067	1.062	1.028	1.016	0.822	0.767	0.986
SIERRA LEONE	1.119	0.943	0.886	0.931	1.165	1.206	0.952	0.774	0.771	0.972
SOUTH AFRICA	0.913	0.998	1.225	1.068	0.916	0.885	0.932	0.876	0.907	0.969
TANZANIA	1.137	0.934	0.993	0.953	1.017	1.026	0.979	0.852	0.944	0.982
TOGO	1.184	0.956	0.952	1.054	0.909	1.018	0.965	0.848	0.987	0.986
ZIMBABWE	0.833	2.158	1.194	1.126	1.18	1.073	0.976	0.991	0.993	1.169
MEAN	1.095	0.934	1.021	1.058	0.97	0.999	0.967	0.863	0.912	0.980

From Table 4, the average MPI value for the total sample is 0.980, which indicates a 2 percent decrease in efficiency. In 2009, 2012, 2013, 2014, 2015 and 2016, efficiency declined by 6.6 percent, 0.3 percent, 0.1 percent, 3.3 percent, 14.7 percent, and 8.8 percent , respectively. This decrease may be attributed to exogenous factors, such as climate change, or political interference. This finding coincides with the analysis of (Singh et al. 2014; Okello et al. 2015) who reported that high concentrations and unpredictable rainfall patterns are expected to intensify the hazards of intense rains and prolonged drought cycles in many areas which eventually affect productivity. These results imply that sectors in sub-Sahara Africa that rely on water resources as a primary input will be affected by this decline. This corresponds with the study of Ngoran et al. (2016) who cited that the economic development of SSA states depends on water use and labour. However, in 2008, 2010, and 2011, respectively, a significant increase in productivity of 1.095, 1.021 and 1.058 was reported.

Figure 2 shows the total average efficiency of water use for all selected countries in sub-Saharan Africa. A mean value of 1.169 was recorded by Zimbabwe from the estimated results. With an improvement of around 17 percent, this is perceived to be the most effective efficiency for water use improvement. Cote d'Ivoire (2.4 percent), Democratic Republic of Congo (2.3 percent), Liberia (1.8 percent), Ethiopia (1.6 percent), Ghana (0.8 percent), Kenya (0.4 percent) and Burundi (0.3 percent) are among the next countries to have reported an increase in water use productivity, while Mauritania reported the worst mean value of 0.811, reflecting a decrease in productivity of around 19 percent. It should be noted that, as in the scenario of Mauritania, as well as the other states which fall below the efficiency threshold, the decrease in water use efficiency could be due to political instability, corruption, population growth, high rates of illiteracy, increased exports of industrial and agricultural products, among others (Sharma 2017; Jenkins 2017). On the contrary, in their study, Wang et al. (2018) argued that factors such as technological development enhance water resources management and decision-making adequately thereby promoting education increase the level of knowledge, skills and creativity in all facets of the workforce and, thus, minimize the waste of water resources and improve water use efficiency. Figure 2 shows the mean efficiency scores of water use efficiency improvement in SSA without water stress.

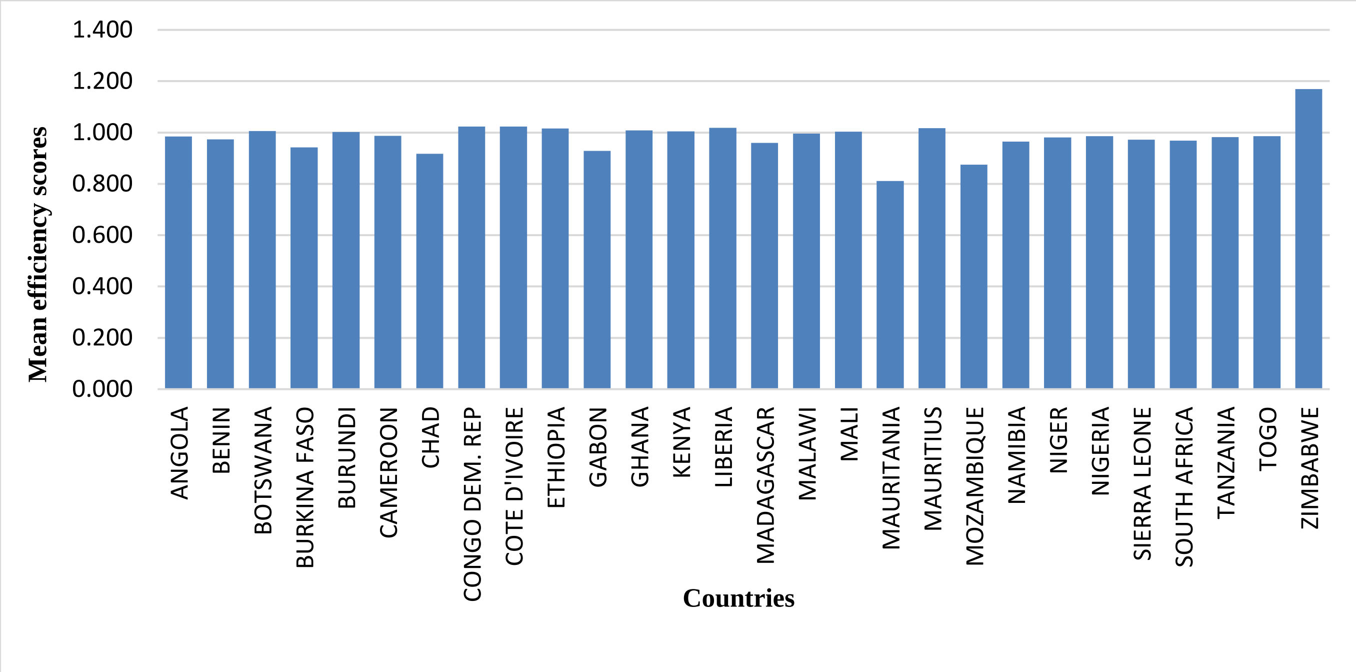

Figure 2: Estimated MPI mean values without the inclusion of water stress

Comparison of the mean MPI water use efficiency

Figure 3 provides a comparison of the average MPI water use performance outcomes with and without the inclusion of water stress. From the findings, it can be noticed that the mean MPI estimates without the inclusion of water stress are much higher than that of the average MPI values with the inclusion of water stress. This implies that without undesirable output factors such as water stress, the MPI efficiency scores could have been overestimated. Therefore, undesirable output factors should be included in studies of this nature as cited in Huang and Li (2013), and Bongo et al. (2018).

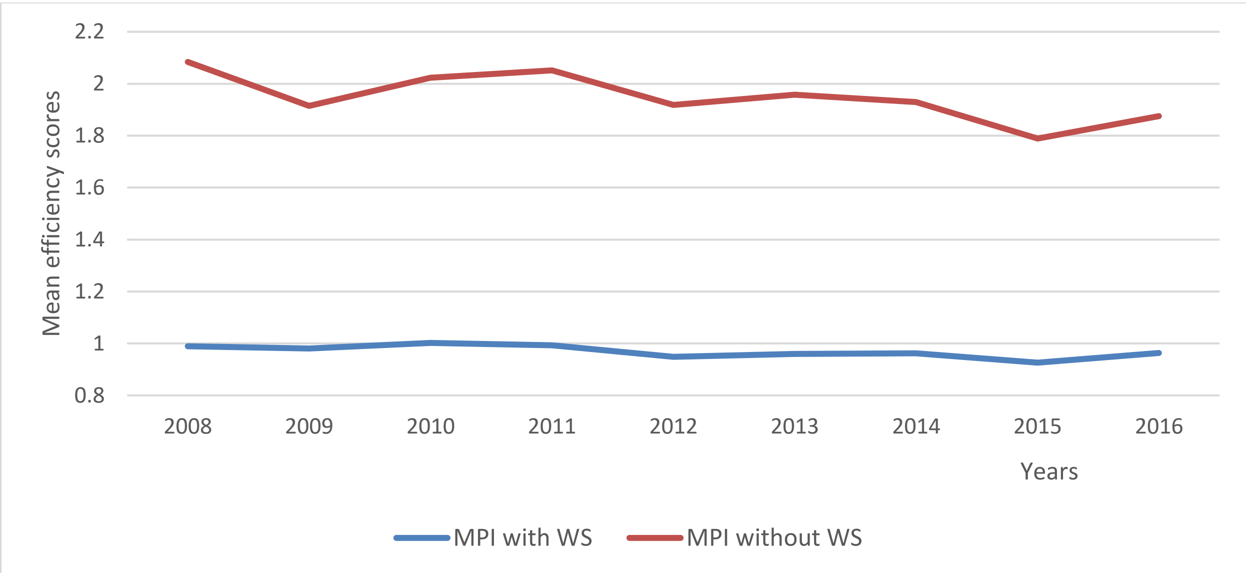

Figure 3. Comparison of water use efficiency estimates with and without water stress in SSA

Catchup Effect of the improvement in water use efficiency change in sub-Sahara Africa

In order to obtain a further understanding of the findings, the test case 1 was used to assess whether improvements in the quality of water usage in SSA were clearly the product of technical developments or technological advancement. Through this, the researchers examined water use output with water stress to test the catch-up effect. Table 5 displays the effects of the catch-up impact of the efficiency of water consumption assessments in sub-Sahara Africa.

Table 5: Efficiency change improvement in water use efficiency in SSA (Catchup)

	Efficiency change (Catchup Effect)									
COUNTRY	2008	2009	2010	2011	2012	2013	2014	2015	2016	Mean
ANGOLA	0.979	0.982	0.951	0.971	0.891	0.954	1.012	1.009	0.969	0.968
BENIN	1.311	1.122	1.096	1.064	0.986	0.999	1.014	1	1	1.062
BOTSWANA	1	1	1	1	1	1	1	1	1	1.000
BURKINA FASO	0.983	1.113	1.055	0.95	1.026	1.02	0.952	1.056	0.973	1.013
BURUNDI	1.032	0.986	0.997	0.991	0.996	1.003	0.984	1.006	0.985	0.998
CAMEROON	1.331	1.125	1.084	1.07	1.069	1.052	0.993	1.004	1	1.077
CHAD	0.919	1.096	0.929	0.859	1.036	0.984	0.996	0.947	0.925	0.963
CONGO DR	0.975	1	1.029	0.987	1.027	0.969	1.062	1.077	1.044	1.018
COTE D'IVOIRE	1.076	1.04	1.029	1.055	1.074	1.045	1.021	1.039	1.027	1.045
ETHIOPIA	0.916	1.232	0.803	0.925	1.031	0.968	0.998	1.244	1.017	1.006
GABON	1	1	1	1	1	1	1	1	1	1.000
GHANA	0.991	1.056	1.12	1.066	1.044	1.133	0.96	0.999	1.001	1.040
KENYA	1.004	0.999	0.981	1.014	1.031	0.993	1.075	1.116	1.09	1.033
LIBERIA	1	1	1	1	1	1	1	1	1	1.000
MADAGASCAR	0.953	1.137	0.862	0.895	1.071	1.057	0.963	1.044	0.935	0.987
MALAWI	0.95	1.458	0.966	0.967	0.999	1.068	1.063	1.052	1.07	1.057
MALI	0.953	1.314	0.875	0.953	1.057	1.059	1.004	1.026	1.011	1.022
MAURITANIA	0.928	1.144	0.952	0.867	0.967	1.023	0.827	0.896	0.868	0.937
MAURITIUS	0.99	1.172	0.937	0.997	1.1	1	1	1	1	1.020
MOZAMBIQUE	0.976	0.978	1.021	1.007	0.934	0.838	0.912	0.939	0.929	0.947
NAMIBIA	0.813	1.462	1.128	0.947	1.12	0.937	0.933	1.012	0.93	1.032
NIGER	1.001	0.998	1.002	1.002	1.005	1.028	1.01	0.964	1.077	1.009
NIGERIA	1.031	1.219	1.206	1.113	1.102	1.057	0.996	1.007	0.993	1.077
SIERRA LEONE	1.046	1.008	0.919	0.885	0.993	1.021	1.019	1.082	1.027	0.998
SOUTH AFRICA	0.845	1.49	1.167	0.972	1.04	0.911	0.93	1.021	0.924	1.019
TANZANIA	0.97	1.271	0.896	0.809	1.168	1.088	1.006	1.064	0.994	1.021
TOGO	1.026	0.996	1.005	1.003	0.983	0.987	0.983	1.005	0.996	0.998
ZIMBABWE	0.711	2.938	1.077	0.956	1.357	1.134	0.976	1.114	0.995	1.152
MEAN	0.983	1.155	0.999	0.973	1.037	1.010	0.988	1.024	0.991	1.018

As shown in Table 5, the overall mean value for the efficiency change for the whole years is 1.018 which reveals about a 1.8% upsurge in the productivity level of water use efficiency. Optimum output was achieved in 2009, 2012, 2013, and 2015 by 15%, 0.37%, 0.1%, and 0.24% respectively. On the country level, Angola, Burundi, Chad, Madagascar, Mauritania, Mozambique, Sierra Leone, and Togo were technically inefficient because they could not obtain the required efficiency score of 1.00 overtime. However, the remaining countries experienced a positive technical efficiency change of 1.00 in continuous years. The economic implication of this result could be that the latter countries that were recorded to be technically efficient have good managerial systems such as professionals with expertise in water resources management, and strategic development plans. This result aligns with Pan et al. (2020) who recorded a significant increase in efficiency change when they made a research on the improvement of water use efficiency of 17 capitals in the Shandong province of China.

Improvement in Technology water use efficiency change in sub-Sahara Africa

The results of the increase in technology-influenced water use efficiency in the 28 selected African countries are found in Table 6. The findings showed that technology performance scores have not increased in the sampled countries. This is because none of the states reported an average technical efficiency of 1.00 or more, indicating that the countries selected were inefficient in terms of technological progress on the frontier of water efficiency. The explanation may be that certain SSA countries do not have sufficient financial resources to purchase the required infrastructure and, or do not have adequate staff to enforce the technology transition. This is in line with the work of Chen et al. (2019), but contrary to the results of Luo et al. (2018) who said that technological progress has improved water use quality.

Table 6. Technical changes score for water use improvement in SSA with water stress

	Technology change (techch)									
COUNTRY	2008	2009	2010	2011	2012	2013	2014	2015	2016	MEAN
ANGOLA	1.004	0.982	1.013	1.004	1.010	0.977	0.931	0.949	0.953	0.980
BENIN	0.774	0.838	0.874	0.893	0.896	0.913	1.004	0.970	0.980	0.902
BOTSWANA	0.975	0.926	1.095	1.059	0.929	0.998	0.992	0.913	1.015	0.987
BURKINA FASO	0.954	0.973	0.959	0.960	0.954	0.954	0.958	0.944	0.960	0.957
BURUNDI	0.951	0.973	0.958	0.960	0.954	0.954	0.958	0.945	0.960	0.957
CAMEROON	0.803	0.858	0.892	0.902	0.905	0.921	0.974	0.962	0.973	0.909
CHAD	0.804	0.770	1.108	1.147	0.873	0.946	0.966	0.826	0.937	0.957
CONGO DEM. REP.	0.959	0.972	0.959	0.960	0.953	0.954	0.958	0.940	0.959	0.957
COTE D'IVOIRE	0.906	0.971	0.960	0.960	0.952	0.953	0.959	0.951	0.961	0.959
ETHIOPIA	0.976	0.847	1.070	0.976	0.911	0.946	0.967	0.812	0.970	0.939
GABON	0.943	0.787	0.97	1.013	0.890	0.927	0.965	0.881	0.959	0.924
GHANA	0.947	0.917	0.856	0.881	0.893	0.919	0.974	0.953	0.978	0.923
KENYA	0.961	0.971	0.960	0.934	0.916	0.926	0.959	0.832	0.946	0.933
LIBERIA	0.930	0.988	0.960	0.975	0.975	0.967	0.957	0.889	0.921	0.951
MADAGASCAR	1.172	0.735	1.108	1.178	0.870	0.946	0.981	0.825	0.974	0.965
MALAWI	1.051	0.756	1.108	1.154	0.911	0.954	0.958	0.932	0.945	0.968

MALI	1.172	0.735	1.108	1.178	0.870	0.946	1.000	0.891	1.009	0.980
MAURITANIA	1.172	0.735	1.108	1.178	0.87	0.946	1.003	0.895	1.009	0.980
MAURITIUS	1.172	0.735	1.108	1.111	0.895	1.013	1.034	0.912	1.042	0.994
MOZAMBIQUE	0.948	0.973	0.958	0.959	0.954	0.954	0.958	0.952	0.963	0.958
NAMIBIA	1.127	0.669	1.051	1.100	0.868	0.954	0.992	0.854	0.984	0.945
NIGER	0.959	0.961	0.96	0.960	0.952	0.941	0.972	0.911	0.953	0.952
NIGERIA	0.975	0.811	0.862	0.885	0.896	0.912	0.968	0.955	0.975	0.914
SIERRA LEONE	0.946	0.976	0.955	0.959	0.960	0.956	0.954	0.887	0.945	0.948
SOUTH AFRICA	1.08	0.670	1.05	1.100	0.881	0.978	1.005	0.873	0.997	0.950
TANZANIA	1.172	0.735	1.108	1.178	0.870	0.945	0.985	0.847	0.98	0.969
TOGO	0.958	0.971	0.959	0.960	0.952	0.954	0.958	0.951	0.961	0.958
ZIMBABWE	1.172	0.735	1.108	1.178	0.870	0.946	1.001	0.892	1.009	0.980
MEAN	1.006	0.849	1.003	1.02	0.915	0.95	0.974	0.904	0.972	0.955

IV. CONCLUSION AND RECOMMENDATION

Water scarcity has been a global challenge over the past decades that both governments and international organizations are battling with how to reduce the situation and manage the available water resources amid rapid globalization. This shows that both developed and developing countries need to institute global mitigation strategies to avert the continuous pressure exerted on the available water resources. This has called for researches into water resources management in the developed countries and in recent times, the developing economies too. This research, therefore, investigated the improvement of water use efficiency in sub-Sahara Africa. From the perspective of input and output, this paper has selected labour, capita stock and total water consumption as the input indicators, GDP as the desired input and water stress as the undesired output. The study was conducted in 28 countries from sub-Sahara Africa between 2007 and 2016.

Regarding the test case of the Malmquist Productivity Index (MPI) with the inclusion of water stress, the overall recorded mean value was 0.969 which is higher than the values recorded from 2012-2016. The highest MPI value without the inclusion water stress was 1.095 and the lowest was 0.862. Comparing the two results, it is observed that the mean MPI estimates without water stress are much higher than that of the average MPI with the inclusion of water stress. This means that without the inclusion of undesirable factors such as water stress, the MPI scores could be overestimated. In terms of the catch-up effect (technical efficiency change), all sampled countries were technically efficient except Angola, Burundi, Chad, Madagascar, Mauritania, Mozambique, Sierra Leone and Togo that could not meet the efficiency frontier of 1.00. With the technological efficiency change, the results indicated that none of the sampled was able to reach the efficiency frontier which means that technological improvement is very vital in the management and use of water resources in SSA. Based on the results, the following recommendations are made:

1. To ensure efficient use of water resources, various countries within sub-Sahara Africa should consider seeking for both technical and professional guidance from countries such as China, Japan, United States of America, and Israel among others who are endowed with much knowledge and innovative technologies for managing water resources and have been able to achieve the efficiency frontier in most parts of their states and

provinces. This can be done through yearly exchange programs with these developed countries. Authorities in sub-Sahara Africa can also employ experts from these countries to be part of their water resources management sectors for a period and learn from them.

2. To ensure a continuous positive effect of economic growth on water use efficiency, authorities in the water sector should adopt economic mechanisms to increase the funding for water and water-related infrastructures in terms of supplies for drinking water, rehabilitation and modern irrigation systems.
3. Also, authorities in charge of water management and water supply should frequently change old pipe tubes, monitor and repair pipe connections with leakages and faults. This will help to distribute quality water in desired quantities to the residents.
4. This study recommends that decision-makers in the water sector should empower associations of water users as structures for the management of water at the appropriate levels, taking into account the financial, legal and technological support that would be necessary for such groups to function on their own. Also, define efficient mechanisms and systems to include them in the governance and management of water supplies in neighborhoods where water users are not coordinated. Annual awards can be given to community water associates who can meet the criteria of water quality and protection set for them. This will make them feel that they have a form of responsibility towards the protection of the water resources.

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Cite this article as:

Addae E. A. and Amowini N. Assessment of Water Use Efficiency in sub-Sahara Africa: Application of The Malmquist Productivity Index, International Journal of Scientific Research in Science and Technology (IJSRST), Online ISSN: 2395-602X, Print ISSN: 2395-6011, Volume 7 Issue 6, pp. 66-78, November-December 2020. Available at doi: https://doi.org/10.32628/IJSRST20766
Journal URL: http://ijsrst.com/IJSRST20766